



US Airfield Manual

Pavements for airfield aprons and taxiways

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



**MASONRY &
HARDSCAPES**

AIRFIELD PAVEMENT DESIGN WITH CONCRETE PAVERS

U.S. Version - FIFTH EDITION - 2020

by

Roy D. McQueen, P.E.
Roy D. McQueen Engineering Consultants
3112 Fox Den Lane
Oakton, VA 22124
Tel: 703-220-8038
Fax: 703-648-9475
E-mail: roy@roydmcqueen.com

John Knapton, Ph. D., Chartered Engineer
85 Monkseaton Drive
Tyne & Wear
Whitley Bay NE26 3DQ
United Kingdom
Tel/Fax: +44-191-252-8333
E-mail: john.knapton@blueyonder.co.uk

John Emery, Chartered Engineer
Bedford, United Kingdom

David R. Smith
Technical Director
Interlocking Concrete Pavement Institute
14801 Murdock Street - Suite 230
Chantilly, VA 20151
Tel: 703-657-6900
Fax: 703-657-6901
E-mail: dsmith@icpi.org

© Copyright 2003 - Interlocking Concrete Pavement Institute – Updated 2020



icpi

Interlocking Concrete
Pavement Institute

Contents

CHAPTER I: INTRODUCTION	1
1.1 Basis for Design Method.....	1
1.2 FAA Policy.....	1
1.3 Organization	1
CHAPTER II: ELEMENTS OF INTERLOCKING CONCRETE PAVEMENT.....	2
2.1 Pavers	2
2.2 Bedding Sand	2
2.3 Joint Sand	2
2.4 Sealer	2
2.5 Geotextile	3
2.6 Edge Restraints.....	3
2.7 Installation.....	3
2.8 Guide Specification	3
CHAPTER III: AIRPORT INSTALLATIONS.....	4
CHAPTER IV: ATTRIBUTES AND SELECTION CRITERIA.....	6
4.1 Operational Requirements.....	6
4.1.1 SURFACE STABILITY.	6
4.1.2 RESISTANCE TO FUELS, HYDRAULIC OILS AND DE-ICING CHEMICALS. 7	
4.1.3 RESISTANCE TO STATIC LOADING.....	8
4.1.4 SKID RESISTANCE.....	8
4.1.5 RIDEABILITY.	8
4.1.6 PAVEMENT MARKINGS.....	8
4.2 Constructability	8
4.3 Maintenance and Reinstatement.....	9
4.4 Rapid Removal of Surface Water and Snow.....	9
4.5 Climatic Considerations	10
4.5.1 FREEZE-THAW DURABILITY.	10
4.5.2 RESISTANCE TO HIGH TEMPERATURES.	10
4.5.3 RESISTANCE TO THERMAL MOVEMENTS.....	10
4.6 Use in Settlement Prone Areas.....	10
4.7 Structural Properties	10
4.8 Cost-Effectiveness.....	11
4.9 FAA Airport Eligibility.....	11
CHAPTER V: STRUCTURAL DESIGN PROCEDURE	12
5.1 Overview of Design Procedures.....	12
5.2 Basis of Design Procedure	13

5.3	Subgrade Compaction Requirements	14
5.4	Frost Requirements	14
5.5	Construction Details	14
CHAPTER VI: PAVEMENT REHABILITATION WITH CONCRETE PAVERS.....		15
6.1	Evaluation.....	15
6.2	Structural Rehabilitation	16
6.2.1	OVERLAY OF FLEXIBLE PAVEMENT.....	16
6.2.2	OVERLAY OF RIGID PAVEMENT.	16
6.3	Nonstructural Overlay	17
6.4	Typical Details	17
CHAPTER VII: LIFE CYCLE COST ANALYSIS.....		18
7.1	Initial Construction Costs	18
	TABLE 1: CONSTRUCTION COST.....	19
7.2	Maintenance Costs	19
	TABLE 2: MAINTENANCE ACTIVITIES AND COSTS.....	19
7.3	Present Worth.....	19
	TABLE 3: LIFE-CYCLE COST ANALYSIS – PAVERS.....	20
	TABLE 4: LIFE-CYCLE COST ANALYSIS – PORTLAND CEMENT CONCRETE	21
CHAPTER VIII: REFERENCES		22
APPENDIX A: GUIDE SPECIFICATION: U.S. FEDERAL AVIATION		
ADMINISTRATION ITEM P-502 INTERLOCKING CONCRETE PAVEMENT		
CONSTRUCTION FOR AIRPORT PAVEMENT		24
APPENDIX B: DETAIL DRAWINGS		41
APPENDIX C: PAVEMENT DISTRESS SURVEY AND MAINTENANCE PROCEDURES		
.....		45
APPENDIX D: FAA REVIEW LETTER.....		50

The content of the manual is intended for use only as a guideline. It is not intended for use or reliance upon as an industry standard, certification or as a specification. ICPI makes no promises, representations or warranties of any kind, express or implied, as to the content of this manual and disclaims any liability for damages resulting from its uses. Professional assistance should be sought with respect to the design, specifications and construction of each

CHAPTER I: INTRODUCTION

Concrete pavers bedded in sand have proven to provide a suitable wearing surface for both air carrier jet and general aviation aircraft. Such pavements have been used for apron and low speed taxiway pavements and have been trafficked by aircraft in U.S., Europe, and the Caribbean for several years. Pavements surfaced with concrete pavers have shown to exhibit many of the desirable properties of conventional concrete pavements (e.g. resistance to fuel spills and static indentation) at significant savings in cost and construction time.

This manual presents procedures for the structural design of airport pavements with concrete pavers. The manual is intended to augment U.S. Federal Aviation Administration (FAA) Advisory Circular 150/5320-6F, "Airport Pavement Design and Evaluation"⁽¹⁾ by modifying established FAA methods for the design of flexible pavements.

1.1 Basis for Design Method

The FAA pavement design method allows the thickness of the pavement courses to be proportioned and assumes that the pavements will be surfaced with either 4 inches or 5 inches (100 mm or 125 mm) of hot mix asphalt (HMA). By removing the HMA layer and substituting concrete pavers and sand, the resulting pavement will be at least as strong as the flexible pavement that would have been produced using the FAA design charts. This is, in fact, a conservative structural design method, since research on concrete pavers and bedding sand have shown such pavements to have load distribution characteristics greater than that of an equivalent thickness of hot mix asphalt.

1.2 FAA Policy

The FAA has concurred with the basic approach of designing the pavement as a flexible pavement and replacing the hot mix asphalt wearing surface with concrete pavers and bedding sand⁽²⁾. Current FAA policy on the eligibility of concrete pavers for federal funding is to consider case-by-case approval based on site specific merits. This manual contains selection criteria to aid the designer in evaluating the appropriateness and cost-effectiveness of pavers for specific situations.

1.3 Organization

The manual is organized to provide pavement designers with guidance in the following areas:

- Description of System and Components
- History of Use on Airports
- Attributes and Selection Criteria
- Structural Design for Aircraft over 30,000 lbs.
- Structural Design for Aircraft under 30,000 lbs.
- Pavement Rehabilitation with Pavers
- Life Cycle Cost Analysis
- References
- Specification for Concrete Paver Construction
- Typical Construction Details

CHAPTER II: ELEMENTS OF INTERLOCKING CONCRETE PAVEMENT

The components of an interlocking concrete pavement are shown in Figure 1, "Typical Components of an Interlocking Concrete Pavement". The pavers are manufactured with high strength portland cement concrete (PCC) and are nominally sized at 4 inches (100 mm) wide by 8 inches (200 mm) long by 3.125 inches (80 mm) thick. Although pavers can be produced in different shapes, rectangular shaped pavers are commonly used at airports. The pavers are bedded in approximately $\frac{3}{4}$ inch to 1 inch (20 mm to 25 mm) of high-quality bedding sand. Finer sand is then used to fill the joints between the individual pavers to provide interlock. This enables the paver/sand surface to function as a durable structural layer.

2.1 Pavers

Concrete pavers are manufactured from portland cement, and coarse and fine aggregate. The ingredients are combined to make a "no slump" concrete and molded in manufacturing equipment under vibration and extreme pressure. Admixtures may be used to increase strength, density, and to reduce the likelihood of efflorescence. The paver units are normally manufactured with 2 mm spacer bars to ensure uniform, properly spaced joints. The edges are also chamfered to resist chipping and spalling.

In the United States, pavers are manufactured to the standards contained in ASTM C 936, "Standard Specification for Solid Concrete Interlocking Concrete Paving Units." This standard requires:

- compressive strength of 8,000 psi (55 MPa)
- less than 5 percent absorption
- resistance to abrasion
- freeze-thaw durability
- close dimensional tolerances

2.2 Bedding Sand

To resist the compressive forces associated with high load and high tire pressure aircraft, a high-quality bedding sand is required. Clean (i.e. less than 1 percent passing the No. 200 sieve) hard natural or manufactured sand with a controlled gradation is normally required. For approval purposes, the sand is subjected to a discerning degradation test (Micro-Deval) and a sulfate soundness test. In many locations, locally available clean concrete sands will meet the necessary requirements for bedding sand.

2.3 Joint Sand

A finer grading (100 percent passing No. 16 sieve) is required for joint sand to fill the joints (typically 1/16-inch (2 mm) to 3/16-inch (5 mm)) between the pavers. The jointing sand is necessary to provide interlocking among the individual paver units. Aircraft loads are transmitted to surrounding pavers by shear forces through the joint sand, enabling the pavers and bedding sand to function as a distinct structural layer to allow distribution of loads in a manner similar to a hot mix asphalt layer.

2.4 Sealer

Although a sealer is 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, including elastomeric urethanes.

2.5 Geotextile

A geotextile fabric is normally not required when an aggregate base (e.g. FAA Item P-209) or hot mix asphalt base (e.g. FAA Item P-401) is used. However, a woven geotextile fabric is recommended over cement treated base (e.g. FAA Item P-304) to prevent migration of bedding sand through shrinkage cracks which normally develop as the cement treated base cures. A fabric is also recommended for overlays or inlays with pavers over existing asphalt or concrete surfaces. The fabric should be turned up against edge restraints. This prevents sand from migrating into the joint between the pavement and the restraint.

2.6 Edge Restraints

Edge restraints are needed to prevent the lateral movement of the pavers at pavement edges or at interfaces with asphalt or concrete pavements. For airport pavements, edge restraints are normally constructed with either portland cement concrete or steel angle. Typical edge restraint details are included in Appendix B.

2.7 Installation

After construction and acceptance of the pavement base, the bedding sand is spread and screeded to the proper depth (typically $\frac{3}{4}$ to 1-inch (20 mm to 25 mm)). During installation, the moisture content of the sand is kept as consistent as possible to ensure uniform compaction.

The unit pavers are then laid by hand or by mechanical means. To maximize interlock and minimize movement, the pavers are normally laid in a 90° herringbone pattern as shown on Appendix B – Construction Details. A 45° herringbone can also be applied. A single or double string (sailor) course (i.e. one to two rows of pavers) is typically placed against the edge restraint and the herringbone pattern abuts the string course. This results in a more stable surface at the edge and transition to other pavements.

The units are then vibrated with a minimum 5,000 lb (22 kN) force plate compactor to set the pavers into the sand, as well as to compact the bedding sand. Sand is swept into the joints and the pavers are re-vibrated. This process is repeated (usually twice is sufficient) until the joints are filled with sand. The surface is then final rolled with an 8 ton to 10 ton (70 KN to 90 KN) pneumatic roller to seat the pavers. The final process is application of the sealer to stabilize the joint sand. The surface is then ready for aircraft trafficking.

2.8 Guide Specification

A guide specification, Item P-502 "Interlocking Concrete Paver Construction for Airport Pavement" is included in Appendix A. The specification has been prepared in FAA format with detailed requirements for paver production and installation. This has not been published in a FAA Advisory Circular and reflects industry guidelines only. The guide specification requires review and editing to project conditions by a qualified engineer.

CHAPTER III: AIRPORT INSTALLATIONS

Concrete pavers bedded in sand^(3, 4, 5, 6) provide a suitable wearing surface for aircraft pavements. Such pavements have been in use at airports for several years. The following lists 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”²⁸.

LOCATION (m) = military	APPLICATION	APPROXIMATE AREA	
		ft ²	m ²
<u>Australia</u>			
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
<u>Bangladesh</u>			
Hazrat Shajalal Airport	Cargo Handling Area	188,370	17,500
<u>British West Indies</u>			
Cayman Brac	Aircraft Parking	9,690	900
Grand Cayman	Aircraft Apron	105,490	9,800
<u>Hong Kong, China</u>			
Chek Lap Kok International Airport	Aircraft Parking	5,382,000	500,000
<u>Israel</u>			
Ben Gurion Int'l., Israel	Aircraft Parking	430,560	40,000
Israel Aircraft Industries	Aircraft Parking	75,350	7,000
<u>Kenya</u>			
Jomo Kenyatta,	Aircraft Parking	608,812	56,650
<u>Malaysia</u>			
Subang	Aircraft Apron	731,950	68,000
Tanjong Manis	Aircraft Apron	80,730	7,500
<u>New Zealand</u>			
Christchurch	Aircraft Apron	42,195	3,920
Wellington	Aircraft Apron	16,150	1,500
<u>Norway</u>			
Kristiansand – 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
Edinburgh	Cargo Apron & Gen. Aviation Area	105,488	9,800
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
Southampton	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 AIRCRAFT PAVEMENTS 16,905,450 ft² 1,566,200 m²

Notes: There is an unspecified area of interlocking concrete pavement at Amsterdam’s Schiphol Airport in The Netherlands. And DFW Airport in Texas. There is also a military airfield with over 20,000 m² of interlocking concrete pavement. Its location cannot be published for security reasons.

CHAPTER IV: ATTRIBUTES AND SELECTION CRITERIA

The pavement designer requires a working knowledge of different pavement materials to ensure selection of an appropriate pavement system. The selection should be based on evaluation of:

- operational requirements (i.e. safety and reliability)
- 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 describes the attributes of concrete pavers, such that the pavement designer can make an informed decision on the appropriateness of concrete pavers for a particular application. Chapter VII presents detailed information on computing the life cycle cost of pavements constructed with concrete paver(s).

4.1 Operational Requirements

Airports represent a unique environment where concerns for operational safety are paramount. The pavement systems used must meet stringent requirements to ensure that safety and reliability are not compromised. In this regard, concrete pavers have demonstrated proven performance for a wide variety of airport applications.

When designing an airport pavement, particular attention must be given to:

- surface stability
- resistance to fuels, hydraulics oils, and de-icing chemicals
- resistance to static loading
- skid resistance
- rideability

4.1.1 SURFACE STABILITY.

Jet aircraft are susceptible to damage from loose material drawn into engine intakes. Damage from ingestion of materials, birds, etc. into jet engines or damage to the airframe is referred to as foreign object damage (FOD). It is essential that any surface does not produce FOD and that it remains intact. Concrete pavers with chamfered edges and uniform joint spacing will reduce the probability of this situation developing to unacceptable levels. Since the interlocking quality and stability of a concrete paver surface is also dependent on the joint sand, uptake of the joint sand is eliminated by stabilization with sealants⁽⁷⁾.

However, there are certain situations where pavers are not recommended at this time. The British Ministry of Defense, British Aerospace, PLC, and the U.S. Air Force have conducted tests on pavers exposed to high velocity jet exhaust^(8, 9, 10, and 11). Although, the results of these experiments were favorable, concrete pavers are not recommended in airport locations subject to full power or reverse thrust, such as runways or apron areas where aircraft "power-back" operations are conducted. However, based on

past performance pavers should be considered for:

- static parking positions with "tug-in/tug-out" or low engine speed "power-in/power-out" operations (excluding reverse engine thrust)
- low speed taxiways and taxi lanes

As discussed, these areas should be sealed to stabilize the joint sand and prevent its loss from occasional high levels of jet blast.

4.1.2 RESISTANCE TO FUELS, HYDRAULIC OILS AND DE-ICING CHEMICALS.

For aircraft parking positions, hot mix asphalt pavements are subject to deterioration from spilled jet fuels, aviation gas, and hydraulic oils. Although coal tar sealers can be used to protect the hot mix asphalt surface, the sealer has a finite life and typically requires re-application on a 5-year cycle. Therefore, portland cement concrete (PCC) has normally been the material of choice for aircraft parking positions and apron areas.

While PCC has generally been found to resist aviation fuels and hydraulic oils, these fluids have been found to have a deleterious effect on some joint sealant materials. This problem is averted by using concrete pavers which do not require the use of joint sealants.

Fears of concentration of aviation fuel accumulating in the sand layer under the pavers appear to be unfounded. Tests carried out at London Luton Airport under the supervision of the County Petroleum Officer indicated that no explosive vapors are present when sample pavers were removed from an area heavily contaminated with aviation fuel.⁽¹²⁾ Concrete pavers in airfields are typically sealed to help prevent intrusion of aviation fuel.

In North America urea is used as a pavement anti-icing agent, and glycol is used for aircraft de-icing purposes. These two materials have been known to have a damaging effect upon concrete, due to the very rapid cooling effect within the surface of the pavement, which can freeze any moisture present. An immediate volume increase of approximately 9 percent in the pores holding water can lead to an almost immediate disintegration of some concrete surfaces, especially if the concrete is saturated.

The Transport and Road Research Laboratory of the United Kingdom has conducted tests on air-entrained reinforced concrete comparing degradation of de-icing salts to that from urea. Urea did not adversely affect the durability of reinforced concrete in the laboratory tests. The concrete exposed to de-icing salt solutions did show lower resistance and greater loss of material.⁽¹³⁾ Tests carried out indicated that the potential for material lost with urea would not lead to the generation of debris which could cause FOD.

Based on these results, the Canadian freeze-thaw deicing test procedure found in the Canadian standard for precast concrete pavers is recommended for pavers exposed to freeze-thaw and airport deicing chemicals. The test requires that no more than 1 percent of material be lost from a paver when submerged in a 3 percent saline solution for 49 freeze-thaw cycles. The test inflicts stress and potential damage that can be greater than that of airport deicers, thereby giving the specifier an added measure of durability and safety from deteriorating concrete. The Canadian standard, including the freeze-thaw deicing salt test, is available from the Canadian Standards Association.

4.1.3 RESISTANCE TO STATIC LOADING.

Static indentation is often a problem when aircraft with high tire pressures are parked on a hot mix asphalt surface. During hot weather, the stability of the asphalt decreases and the aircraft wheels deform the surface. Over time, these depressions in the surface will collect water forming "bird baths" and localized ice patches in the winter. Therefore, PCC is often specified due to its ability to resist static indentation. Concrete pavers provide the same resistance to static indentation as conventional poured concrete pavements.

4.1.4 SKID RESISTANCE.

The frictional characteristics of airfields are typically measured by means of a wheeled machine fitted with an attachment capable of depositing water beneath the measuring wheels. For low speeds, the micro-texture of the pavement surface and the hardness of its aggregate are important to good skid resistance.

Low and high speed (5 kt and 110 kt) tests were conducted in 1992 by NASA at the Langley Research Center in Hampton, Virginia. Results have shown superior skid resistance over plain PCC. Skid resistance measured in the tests was 75 percent to 80 percent of that typically found on grooved concrete runway pavements^(14, 15) and higher than plain PCC pavement. Further, skid resistance studies on street pavements have shown pavers to have resistance equal to or better than asphalt surfaces⁽¹⁶⁾.

4.1.5 RIDEABILITY.

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 under 30 mph (50 kph). However, little is known about the performance of concrete pavers under aircraft travelling at high speeds.

4.1.6 PAVEMENT MARKINGS.

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

4.2 Constructability

When compared to conventional concrete, interlocking concrete pavements can be constructed quickly. In some situations, low speed taxiways need to be constructed adjacent to active runways, or aircraft aprons need to be rehabilitated on a gate by gate basis. Concrete pavers reduce down time of runway closures in the construction of adjacent taxiways. This can save airlines and airports interruptions in operating schedules and costs. For example, the construction of three cross taxiways with concrete pavers at Dallas/Ft. Worth Airport in 1990 saved the airlines over \$4 million in delays when compared to conventional concrete pavement, by reducing runway closure times throughout construction.

Mechanical installation of interlocking concrete pavements can accelerate construction. Knowledgeable and experienced contractors have used mechanical equipment to accurately place interlocking concrete pavements in St. Augustine, Florida, and Grand Cayman Island, BWI. High quality

construction can be maintained including conformance of surface elevations to specified tolerances and consistent paver joint widths. Daily productivity per machine and crew ranges between 4000 sf. (400 m²) and 6000 sf. (600 m²). For detailed information on mechanized installation, see the Interlocking Concrete Pavement Institute technical bulletins, Tech Spec 11, "Mechanized Installation of Interlocking Concrete Pavements"²⁶ and Tech Spec 15, A Guide for the Construction of Mechanically Installed Interlocking Concrete Pavements"²⁷.

4.3 Maintenance and Reinstatement

Pavements in busier airports may need to be repaired rapidly due to air operations limiting access time for work. When repairs to utilities or base are needed, concrete pavers can be removed and reused. They can also be rapidly reinstated in sub-freezing temperatures; however, the bedding sand and aggregate base materials should not be frozen. Once laid 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, pavements with pavers can be reinstated at approximately 25 percent less cost than concrete pavements in a fraction of the time. For further information on reinstatement, see the Interlocking Concrete Pavement Institute Tech Spec 6 technical bulletin, "Reinstatement of Interlocking Concrete Pavements". A procedure for inspection and maintaining concrete pavers is included in Appendix C.

4.4 Rapid Removal of Surface Water and Snow

Concrete pavers with chamfered edges are capable of rapid removal of surface water and are considered to be as good as, if not better than, conventional pavement in the removal of surface water. Observations have shown that after wetting, concrete pavers can dry faster than asphalt surfaces. Concrete pavers can also be colored to absorb more of the sun's radiant energy to accelerate snow and ice melting.

Concrete pavers have demonstrated a record of snow removal capability by their use in airports in the United Kingdom and Northern Europe. Snowplow blades do not catch on concrete pavers, provided that each unit has a consistent thickness and that a smooth surface is achieved when installed. Smoothness is achieved by an even surface on the base material and the bedding sand. Surface smoothness is further achieved during construction with compaction and final static proof rolling with an 8 ton to 10 ton (70 KN to 90 KN) pneumatic tired roller.

Interlocking concrete pavements are typically sealed to stabilize the sand in the joints to prevent FOD. 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 millimeter. 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 1-inch (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 $0.07 \times 0.09 \times 1\text{-inch (25 mm)} = 0.0063\text{-inch (0.16 mm)}$. 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.

4.5 Climatic Considerations

4.5.1 FREEZE-THAW DURABILITY.

Concrete pavers can be utilized under a wide variety of climatic conditions. Freeze-thaw resistant pavers typically can be achieved by cement contents of 17 percent to 19 percent, absorption less than 4 percent, densities exceeding 142 lbs. cu. ft. (2,200 kg/m³), a low water cement ratio, and durable aggregates.⁽¹⁷⁾ If concrete pavers are 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, "Precast Concrete Pavers".

4.5.2 RESISTANCE TO HIGH TEMPERATURES.

Tests carried out on concrete pavers by British Aerospace PLC during investigations for the feasibility of landing vertical take-off military aircraft (Harriers) on various surfaces have shown that concrete pavers are capable of withstanding temperatures up to 520° C (1000° F). Further, unlike thermoviscous materials such as hot mix asphalt, the structural properties 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 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.

4.5.3 RESISTANCE TO THERMAL MOVEMENTS.

Minor differential thermal movements in the underlying pavement bases do 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. Another advantage of concrete pavers is their lighter color, which reduces the amount of heat absorbed into the underlying concrete, thus reducing thermal movement.

4.6 Use in Settlement Prone Areas

The pavement designer is often required to design for difficult subsurface conditions, such as areas prone to settlement. The preferred engineering solution is to mitigate the effects of settlement using methods such as surcharging. Due to the inherent variability in subsurface conditions, differential settlement, or secondary consolidation, often results after the completion of construction. While pavers cannot prevent this condition, the pavers can be lifted, the base re-leveled, and the pavers re-instated, should post-construction differential settlement occur.

4.7 Structural Properties

Concrete pavers provide a high strength operational surface. Typically, 3.125-inch (80 mm) thick pavers can achieve a cube compressive strength of 8,000 psi to 10,000 psi (55 MPa to 69 MPa) after 28 days, compared to a cube compressive strength of 6,000 psi (35 MPa) for poured concrete.

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 from 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 450,000 psi (3082 MPa).⁽¹⁸⁾ This exceeds the hot weather (i.e. 90°F) modulus of hot mix asphalt, which is typically 150,000 psi to 300,000 psi (1370 MPa to 2055 MPa).

4.8 Cost-Effectiveness

For areas where conventional concrete pavements have been the material of choice, concrete pavers can provide a viable alternative pavement structure. Areas include aircraft parking aprons, taxi lanes, and taxiways, where resistance to fuel spills, static indentation, and rutting is required. These are areas where significant economies in initial construction and life cycle costs are achievable. Savings in initial construction cost of 10 percent to 15 percent can be realized, when an interlocking concrete pavement is compared to a conventional poured concrete pavement. Detailed information on pavement design procedures for concrete pavers, and life cycle cost analysis methods follow in subsequent chapters.

4.9 FAA Airport Eligibility

Airport pavements constructed with concrete paver surfaces are eligible for federal participation on a case by case basis. The designer should check with the FAA Airport District Office (ADO) which has jurisdiction for the particular airport project.

The construction of 260,000 sf. (26,000 sum.) of concrete pavers at Dallas/Ft. Worth International Airport has received funding (retroactively) under the FAA Airport Improvement Program (AIP). The project was determined eligible for funding in August 1992. Islip MacArthur Airport in Islip, New York, constructed rehabilitative inlay of concrete pavers over existing asphalt on two aircraft (MD-80) parking areas. The 14,000 sf. (1300 sum.) project was funded through the FAA AIP.

CHAPTER V: STRUCTURAL DESIGN PROCEDURE

5.1 Overview of Design Procedures

The structural design procedure for aircraft is modeled directly on the FAA design procedures for flexible pavements contained in FAA Advisory Circular 150/5320-6F. Application of the design procedures contained herein will provide a pavement system at least as strong as a flexible pavement designed by the FAA method. The FAA has concurred in the use of this method for airport pavements constructed with concrete pavers.

The design method for concrete pavers uses identical inputs as those used for the design of flexible pavement. These include:

- subgrade strength (e.g. CBR);
- subbase/base materials (aggregate or stabilized);
- traffic (selection of design aircraft and computation of equivalent annual departures); and
- evaluation of subgrade frost susceptibility and swelling potential.

The procedures in the Advisory Circular are then used to determine:

- total pavement thickness;
- thickness of surface plus base; and
- minimum base course thickness.

From the resulting thickness design, concrete pavers and sand are substituted for the hot mix asphalt layer, with all other layers remaining as designed for the flexible pavement. This would apply for both 4-inch (200 mm) and 5-inch (225 mm) (for wide body designs) hot mix asphalt thicknesses.

Other FAA design requirements for flexible pavements should be strictly adhered to as necessary. These include:

- use of stabilized base for aircraft with gross loads over 100,000 lbs. (45,000 kg);
- minimum subgrade compaction requirements;
- treatment of swelling soils;
- thickness adjustments for seasonal frost or permafrost conditions; and
- thickness adjustments for high departure levels.

Since the FAA is committed to continued support of their pavement design methods, changes are periodically made to the design Advisory Circular based on application of research results and field experience. Therefore, this manual will not attempt to duplicate the design requirements of the Advisory Circular. The reader is urged to obtain the latest edition of FAA Advisory Circular 150/5320-6 and use this document as the basis for pavement designs using concrete pavers.

The latest edition of the FAA design guide is Advisory Circular 150/5320-6F, with corrections. Copies of 150/5320-6 (as well as other FAA publications) are available from: www.faa.gov/airports/engineering/. A computerized version (FAARFIELD) of the flexible pavement design procedure is also available from the FAA web site.

5.2 Basis of Design Procedure

Information on the design of concrete paver pavements has been presented by Knapton,^(19,20) and Rollings,⁽²¹⁾ and Anderton.⁽²²⁾ This research established that concrete pavers and bedding sand have load spreading characteristics greater than that of an equivalent thickness of asphalt.

Knapton also developed the British Ports Association Heavy Duty Pavement Design Manual.⁽²⁰⁾ This manual allows designers to proportion pavement course thicknesses for pavements subjected to container handling equipment applying wheel loads of up to 30 tons onto concrete paver pavements. In Europe and North America, concrete pavers have been used to surface port pavements for many years. The largest container handling facility in the world, Europe Container Terminus, Rotterdam, the Netherlands, is entirely surfaced with over 11 million sf. (1 million m²) of concrete pavers.

Emery^(3,4,5,and 6) has undertaken plate bearing tests on a bituminous surfaced aircraft pavement at Luton. After removing the asphalt concrete, he undertook plate bearing tests directly on the underlying base course. He then installed concrete pavers and undertook a third set of plate bearing tests. His reported results indicate a 14 percent increase in strength when the asphalt concrete layer was replaced by concrete pavers. In this manual, this increase is ignored so that the FAA curves can be used conservatively. In view of the empirical nature of the FAA curves, it would be difficult to incorporate the additional structural benefit of pavers into the design procedure. Pavements designed in accordance with this method are intended to provide a structural life of 20 years, requiring little maintenance if no major changes in forecast traffic are encountered. Experience in heavy duty concrete paver pavements indicates that only minimal surface maintenance will be required during this period.

The application of the research referred to above allows the FAA pavement design method⁽¹⁾ to be modified to accommodate concrete pavers. The FAA pavement design method allows the thickness of the pavement courses to be proportioned and assumes that the pavements will be surfaced with either 4 inches or 5 inches (200 mm or 225 mm) of asphalt concrete. By removing the asphalt concrete and substituting concrete pavers and sand, the resulting pavement will be at least as strong as the asphalt pavement that would have been produced using the FAA design procedures.

All airport pavement designs are based on FAA's FAARFIELD computer program, which is described in detail in FAA Advisory Circular 150/5320-6F. The FAARFIELD program is available for download at www.faa.gov. The designs are based on either layered elastic (flexible pavements) or finite element (rigid pavements) methods as described in the advisory circular.

The advisory circular contains numerous design examples for flexible pavements, which the reader is encouraged to follow. The basic design procedures are based on cumulative damage concepts, whereby the damage component of each aircraft is summed over the design life. The pavement design examples are for pavements on aggregate or stabilized base depending on the gross weights of the aircraft in the design fleet mix. Stabilized base and subbase are required for pavements designed for aircraft with gross weights exceeding 100,000 lbs. Airport pavements are typically designed for 20-year design lives.

For pavement designs with pavers, the designer will use 4-inch asphalt surface, recognizing the minimum

base and subbase requirements. The pavers and bedding sand (typically approximately 4.5 inches) are then substituted for the 4-inch asphalt surface.

For example, if a design was generated as 4-inch asphalt on 8-inch aggregate base on 12-inches of granular subbase, then the resulting pavement design for pavers would be:

3.125 inches (80 mm) pavers
1.25 inches (30 mm) bedding sand
8 inches (300 mm) aggregate base (P-209)
12 inches (500 mm) aggregate subbase (P-154)

For stabilized base designs, the same design substitution of pavers and bedding sand for asphalt surface would be used. For example, if the design was for 4-inches of asphalt on 8-inches of cement treated base and 12-inches of aggregate subbase, then the resulting paver design would be:

3.125 inches (80 mm) pavers
1.25 inches (30 mm) bedding sand
8 inches (200 mm) cement treated base (P-304)
12 inches (300 mm) aggregate subbase (P-209)

5.3 SUBGRADE COMPACTION REQUIREMENTS.

The subgrade (Item P-152) for airport pavements should be compacted to the minimum densities as a percentage of modified Proctor (ASTM D1557) laboratory density for aircraft exceeding 100,000 lbs., to the depths computed by FAARFIELD. This is accomplished by checking the “Compute Compaction Requirements” check box on the FAARFIELD Options screen. The designer should note that subsequent editions of the Advisory Circular may contain different compaction depth requirements.

5.4 FROST REQUIREMENTS.

If the pavement will be constructed in a seasonal frost area, FAA requirements concerning frost protection must be followed. For this example, if the total pavement depth for the stabilized base case is approximately 25 inches (625 mm) and the frost depth exceeds this depth, the design must be modified in accordance with Advisory Circular 150/5320-6F. Frost considerations may result in a thicker subbase than that required for structural support.

5.5 Construction Details

Typical construction details for pavements to accommodate aircraft over 30,000 lbs. (13,600 kg) are included in Appendix B.

CHAPTER VI: PAVEMENT REHABILITATION WITH CONCRETE PAVERS

Most airport pavements in use today were 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. Here, the pavement may require strengthening to accommodate the forecasted traffic 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. Here, rehabilitation would be required to improve the safety and reliability of the functional surface.

Concrete pavers can be used for either structural (i.e. strengthening) or functional (i.e. non-structural) rehabilitation of airport pavements. As with new construction, the pavers are modeled as a hot mix asphalt material when performing structural overlay computations, using the procedures detailed in Chapter 4 of FAA Advisory Circular 150/5320-6D. Pavers are appropriate for rehabilitating both flexible and rigid pavements.

The computational sequence involves:

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

6.1 Evaluation

The first requirement is to evaluate the functional and structural condition of the existing pavement. FAA pavement evaluation procedures are detailed in Chapter 6 of FAA Advisory Circular 150/6320-6D. As described in the Advisory Circular, the process involves:

- **Records Research** - compilation of as-built drawings, prior reports, traffic data, and etc.
- **Site Inspection** - examination of drainage conditions and overall pavement condition, noting problem areas and planning for more detailed field investigations.
- **Conventional Testing** - field and laboratory tests to determine layer thickness, subgrade strength (i.e. CBR or k), the condition, strength, and suggested equivalencies for existing materials, and identification of special conditions (e.g. frost effects, swelling soils, reactive aggregates, etc.).
- **Nondestructive Testing** - dynamic tests to measure overall pavement stiffness, identify patterns of variability in support conditions, and evaluate the strength of pavement layers and subgrade soils. FAA Advisory Circular 150/5370-11, "Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements"⁽²³⁾ contains guidance on nondestructive testing; however, when approved by the FAA, procedures different from those contained in FAA Advisory Circular 150/5370-11 may be used.

- **Pavement Condition Survey** - visual survey to determine the Pavement Condition Index (PCI) and/or Structural Condition Index (SCI), and to generate quantities for repair of pavement distress. FAA Advisory Circular 150/5380-6A, "Guidelines and Procedures for Maintenance of Airport Pavements"⁽²⁴⁾ contains detailed information on conducting condition surveys and other information on the PCI concept.
- **Other Tools** - other methods, such as ground penetrating radar or infrared thermography may be used to identify voids, delamination, or subsurface anomalies.
- **Structural Evaluation** - determination of the structural adequacy of the existing pavement to accommodate forecasted aircraft loading, as described in Chapter 6 of FAA Advisory Circular 150/5320-6D.

The evaluation process should culminate in a detailed evaluation report which describes the analyses, test methods and results, findings, and recommendations. The report should document:

- the functional surface condition in terms of the PCI;
- the load carrying capacity with respect to the demand forecast; and
- whether rehabilitation requirements are driven by structural or functional conditions, or both.

6.2 Structural Rehabilitation

If structural rehabilitation and strengthening is required, the designer should use the flexible overlay procedures contained in Chapter 4 of FAA Advisory Circular 150/5320-6F for flexible or rigid pavements, as appropriate. Required inputs include:

- subgrade strength (CBR or k);
- existing pavement thickness;
- structural condition factor of concrete layer;
- flexural strength of concrete layer; and
- forecasted traffic.

6.2.1 OVERLAY OF FLEXIBLE PAVEMENT.

The overlay design procedure for flexible pavements is based on the structural deficiency approach. In other words, the existing pavement is compared to what is needed for a new pavement and any deficiency is made up in the overlay.

As discussed previously, pavers/sand can be conservatively substituted for hot mix asphalt (HMA) on an inch for inch (mm for mm) basis. Thus, if the overlay requirement is 4.5 inches (115 mm) or less, concrete pavers and sand can be substituted for the HMA layer. If the overlay thickness exceeds 4.5 inches (115 mm), the additional thickness can be made up with hot mix asphalt (FAA Item P-401). When needed, the minimum thickness of the HMA layer should normally be 2 inches (50 mm) or greater, depending on the maximum aggregate size of the P-401 mix.

If the surface is deteriorated, then pre-requisite distress repairs (e.g. crack sealing, full or partial depth patches, milling, etc.) should be accomplished prior to construction of the paver or paver/HMA overlay. Normally, a geotechnical fabric should be placed on the top of the asphalt layer prior to placing

bedding sand to prevent the migration of bedding sand into cracks in the asphalt layer. Steel angle or concrete edge restraints should be constructed where required.

6.2.2 OVERLAY OF RIGID PAVEMENT.

The overlay design procedure for rigid pavements is also based on a thickness deficiency approach, with the thickness of pavers/sand substituted inch for inch (mm for mm) for HMA.

As with overlays for flexible pavement, if the required thickness of HMA is greater than 4.5 inches (115 mm), the difference between the required thickness and the nominal thickness of pavers/sand can be made up with HMA. Again, a minimum HMA thickness of 2 inches (75 mm) is recommended.

The designer is cautioned that special treatments may be required when constructing a paver/sand overlay on existing concrete pavements, including:

- use of geotechnical fabric to prevent loss of bedding sand into concrete joints and cracks;
- possible jointing of the pavers over expansion joints;
- improvement of joint efficiency (i.e. load transfer), of the existing slabs using mudjacking techniques or proprietary load transfer devices, as required; and
- accomplishing prerequisite distress repair (e.g. joint resealing, crack sealing, patching, etc.).

If the condition of the existing rigid pavement is very poor, i.e., extensive structural cracking, joint faulting, "D" cracking etc. consideration should be given to using the "crack and seat" or "rubblizing" techniques. These techniques involve purposely breaking or rubblizing the existing rigid pavement and then rolling the broken pieces to firmly seat them in the foundation. A hot mix asphalt layer is then placed over the pavement. This type of section is designed as a flexible pavement treating the broken rigid pavement as base course. If concrete pavers are to be used, the thickness of the paver/sand layer is deducted from the required thickness of HMA. A geotextile fabric under the bedding sand is recommended for cracking and seating and an asphalt or aggregate levelling course is recommended for rubblized pavements.

6.3 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 may be the condition for an apron area, then, either surface reconstruction with pavers or an inlay (e.g. remove sufficient surface thickness to allow for the paver/sand layer) should be considered, depending on the thickness of the surface layer.

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

6.4 Typical Details

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

CHAPTER VII: LIFE CYCLE COST ANALYSIS

As a pre-requisite for federal funding, the FAA will normally require that various pavement construction alternatives be considered, and the life cycle cost (LCC) of each alternative computed and compared. The life cycle cost concept is a means to compare the total cost of various construction alternatives. The components of the life cycle cost typically include:

- o initial construction cost
- o periodic maintenance
- o time value of money (i.e. interest rate)

Since some of the cost components, e.g. periodic maintenance, will be incurred at a future date, these future costs must be discounted to a present value using an appropriate interest rate, and added to the initial construction cost in order to compare alternatives.

For LCC analysis, the present worth of each alternative be compared using a discount rate (i.e. interest rate) of 4 percent is typically used, but it is up to the designer to choose appropriate inputs. There are also several computer programs available for computing life cycle cost, including the Economic Analysis program included in the Data Analysis Programs portion of MICROPAVER.

Application of life cycle cost analysis can best be demonstrated by the following example.

<u>PAVERS</u>	<u>PCC</u>
3.125 inches (80 mm) Pavers	14 inches (360 mm) PCC
1.25 inches (30 mm) Bedding Sand	6 inches (150 mm) CTB
8 inches (200 mm) CTB	6 inches (150 mm) Aggregate Base
6 inches (150 mm) Aggregate Subbase	

Since the pavers are to be constructed on a cement treated base (CTB), geotextile fabric should be placed over the CTB to prevent possible loss of bedding sand through shrinkage cracks in the CTB. Further, the paver surface should be sealed to prevent the erosion of jointing sand from jet blast.

7.1 Initial Construction Costs

Using typical construction cost data (in 2002 dollars), the initial construction cost (per square yard) of each alternate is computed in Table 1, "Construction Cost". Pavement costs do not include subgrade grading and compaction, which are considered equal for each option.

The construction cost estimate for concrete pavers was taken from bid prices for concrete pavers at airports in Texas and Florida in 2003. Actual costs for pavers, as well as PCC pavement, may vary depending on geographic location, project size, and site-specific conditions. However, the costs presented are believed to be reasonable for the purpose of comparing the relative costs of the two alternatives.

TABLE 1: CONSTRUCTION COST

<u>INTERLOCKING</u> <u>CONCRETE PAVEMENTS - \$/s.y.</u>		<u>PORTLAND CEMENT</u> <u>CONCRETE----- \$/s.y.</u>	
Pavers/Bedding Sand	\$27.00	14 inches (350 mm) PCC	\$47.00
Sealer	1.50	6 inches (150 mm) CTB	9.00
Geotextile	1.50	6 inches (150 mm) AGBS	<u>6.50</u>
8 inches (200 mm) CTB	12.00		\$62.50
6 inches (150 mm) AGBS	<u>6.00</u>		
	\$48.50		

PCC = Portland Cement Concrete
 CTB = Cement Treated Base
 AGBS = Aggregate Subbase

Note: To convert \$/s.y. to \$/s.m. multiply values by 1.2

7.2 Maintenance Costs

Since pavement maintenance costs are normally included in an airports overall operations and maintenance budget, it is often difficult to identify specific annual and periodic maintenance costs for airport pavements. Therefore, some judgment is inherent in estimating these costs.

For the example presented in this section, assumptions on period maintenance activities and costs for each alternative are presented in Table 2, "Maintenance Activities and Costs".

TABLE 2: MAINTENANCE ACTIVITIES AND COSTS

<u>CONCRETE PAVERS</u>		
<u>Activity</u>	<u>Frequency</u>	<u>Costs/s.y.</u>
Reapply sealant	5 years	\$0.15
Replace pavers	5 years	\$0.45

<u>PORTLAND CEMENT CONCRETE</u>		
<u>Activity</u>	<u>Frequency</u>	<u>Costs/s.y.</u>
Reseal joints	10 years	\$0.40
Patch and crack seal	5 years	\$0.50

7.3 Present Worth

The basic equation for determining present worth is:

$$PW = C + \sum_{i=1}^m M_i \left(\frac{1}{1+r} \right)^{n_i} - S \left(\frac{1}{1+r} \right)^z \quad 20$$

Where:

- PW = Present Worth
- C = Present cost of initial construction or rehabilitation activity
- M_i = Cost of the ith maintenance or rehabilitation alternative in terms of present costs, i.e. constant dollars
- r = Discount rate (4 percent suggested)
- n_i = Number of years from the present of the ith maintenance or rehabilitation activity
- S = Salvage value at the end of the analysis period.
- z = Length of analysis period in years (20 years suggested)

The term

$$\left(\frac{1}{1+r}\right)^n$$

is commonly called the single payment present worth factor in most engineering economic textbooks. From a practical standpoint, if the difference in the present worth of costs between two designs or rehabilitation alternatives is 10 percent or less, it normally assumed to be insignificant and the present worth of the two alternatives can be assumed to be the same.

For this example, the salvage values for each alternative are assumed to be zero.

Using the input data developed above, the present worth of the two alternatives were computed to be:

Interlocking
Concrete Pavement
\$50.00/s.y.

Portland Cement Concrete
Pavement
\$64.21/s.y.

Computations are shown on Table 3, "Life Cycle Economic Analysis - Pavers" and Table 4, "Life Cycle Economic Analysis - Portland Cement Concrete."

TABLE 3: LIFE-CYCLE COST ANALYSIS – PAVERS

ACTIVITY DESCRIPTION	YEAR	COST	PRESENT VALUE
Pavers	2003	\$48.50	\$48.50
Re-apply Sealer	2008	\$0.15	\$0.12
Replace Block	2008	\$0.45	\$0.37
Re-apply Sealer	2013	\$0.15	\$0.10
Replace Block	2013	\$0.45	\$0.30
Re-apply Sealer	2018	\$0.15	\$0.08
Replace Block	2018	\$0.45	\$0.25
Re-apply Sealer	2023	\$0.15	\$0.07
Replace Block	2023	\$0.45	\$0.21

TABLE 4: LIFE-CYCLE COST ANALYSIS – PORTLAND CEMENT CONCRETE

ACTIVITY DESCRIPTION	YEAR	COST	PRESENT VALUE
Portland Cement Concrete	2003	\$62.50	\$62.50
Spall Repair & Crack Seal	2008	\$0.50	\$0.41
Spall Repair & Crack Seal	2013	\$0.50	\$0.34
Reseal Joints	2013	\$0.40	\$0.27
Spall Repair & Crack Seal	2018	\$0.50	\$0.28
Spall Repair & Crack Seal	2023	\$0.50	\$0.23
Reseal Joints	2023	\$0.40	\$0.18

Therefore, on a life cycle costs basis, the pavement constructed with concrete pavers is approximately 22 percent less expensive than Portland Cement Concrete pavement, both of which were designed to give equal performance. The same ratio applies on an initial construction costs basis.

CHAPTER VIII: REFERENCES

- (1) Airport Pavement Design and Evaluation, Department of Transportation, Federal Aviation Administration, Advisory Circular (AC) 150/5320-6F, Washington, D.C.; December 2016.
- (2) Correspondence dated March 18, 1988, from Robert Bates, Manager, Engineering and Specification Division, Office of Airport Safety and Standards, Federal Aviation Administration, Washington, D.C.
- (3) Emery, J.A., "The Use of Concrete Pavers for Aircraft Pavements" Proceedings, Institution of Civil Engineers, Part 1, Volume 77, I.C.E., Great George Street, London England, Paper No. 8841-188, 80; April 1986, pp. 451-464.
- (4) Emery, J.A., "The Design of Concrete Paver Aircraft Pavements" in Proceedings of the Third International Conference on Concrete Block Paving, Pavitalia, Rome, Italy; May 17-19, 1988, pp. 178-187.
- (5) Emery, J.A., "Concrete Pavers for Aircraft Pavement Surfaces", American Society of Civil Engineers, Journal of Transportation Engineering, Volume 112, No. 6, Paper No. 21041; November 1966.
- (6) Emery, J.A., "Concrete Paver Paving for Aircraft Hard Standings and Turning Areas", in Proceedings of the Second International Conference on Concrete Block Paving, Delft University, The Netherlands, CBP c/o KLVV, 2500 GK, The Hague; April 1984, pp. 176-182.
- (7) Emery, J.A., "Stabilization of Jointing Sand in Paver Paving", American Society of Civil Engineers, Journal of Transportation Engineering, Volume 119, No. 1, January/February 1993, Paper No. 235, pp. 142-148.
- (8) "Air Force Test Pavers with Successful Results", Pavers, Volume 3, No. 3, Concrete Paver Institute, Herndon, VA, July 1992, p. 3.
- (9) Edwards, G., "Ground Erosion Trial Element Paving (under) Shoeburgness Peagasus 2A Tethered Harrier", Military Vehicles and Engineering Establishment, UK Ministry of Defense, London, England, 1983.
- (10) Emery, J.A., "Erosion of Jointing Sand from Concrete Paver Paving", in Proceedings, Fourth International Conference on Concrete Block Paving, Auckland, New Zealand, February, 1992, Volume 2, pp. 295-299.
- (11) Knott, P., et al, "An Experimental Investigation of the Ability of Polyester Resin Based Materials to Withstand Erosion from a Heated Jet Exhaust", British Aerospace, PLC, Report No. BAe-WMT-R-RES-000-10031, Lancashire, England, 1982.
- (12) Letter from B.D. Taylor, Petroleum Officer, Association for Petroleum and Explosives Administration, Bedfordshire, England, 1989.
- (13) Sadegzadeh, M. and Page, C.L., "Effects of Urea on the Durability of Reinforced Concrete", Contractor Report No. 208, Transport and Road Research Laboratory, Berkshire, England, 1990.
- (14) Yager, T., "Friction Evaluation of Concrete Paver Pavers for Airport Applications", Society of Automotive Engineers Technical Paper series, Paper No. 922013, SAE International, Warrendale, Pennsylvania, 1992.
- (15) Yager, T., et al, "Braking, Steering, and Wear Performance of Radial Belted and Bios-Ply Aircraft Tires", Society of Automotive Engineers Technical Paper Series, Paper No. 921036, SAE International, Warrendale, Pennsylvania, 1992.
- (16) Shackel, B., "Design and Construction of Interlocking Concrete Pavements", Elsevier Applied Science, New York, N.Y., 1990, pp 67-71.

- (17) Ghafoori, N., "De-icing Salt Resistance of Concrete Paver Pavers", Research Report No. 3, Department of Civil Engineering and Mechanics, Southern Illinois University, Carbondale, Illinois, July 1992.
- (18) Rada, Gonzalo R., Stephanos, Peter J., and Tayibji, Shiraz, "Performance of Interlocking Concrete Pavements in North America", 72nd Annual Meeting of the Transportation Research Board, Paper No. 930040, Washington, D.C., 1993.
- (19) Knapton, J., "The Design of Concrete Paver Roads", Technical Report, Cement and Concrete Association, C & CA Wexham, Slough SL3 6PL, 6; 1976.
- (20) Knapton, J., "The Structural Design of Heavy Duty Pavements for Ports and other Industries", British Ports Association, London, England; 1983.
- (21) Rollings, Raymond S., Concrete Paver Pavements, Technical Report GL-83-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; 1983.
- (22) Anderton, Gary L., Concrete Paver Pavement for Airfields, Technical Report GL-91-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; 1991.
- (23) Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements, Department of Transportation, Federal Aviation Administration, Advisory Circular 150/5370-11, Washington, D.C.; June 1976.
- (24) Guidelines and Procedures for Maintenance of Airport Pavements, DOT/FAA Advisory Circular 150/5380-6, Washington, D.C.; December 1982.
- (25) Rada, G.R. and Witczak, M.W., Performance of Cracked and Seated Rigid Airport Pavements, FAA Report No. DOT/FAA/PM-87/4, NTIS, April 1987.
- (26) ICPI Tech Spec 11, Mechanical Installation of Interlocking Concrete Pavements, Interlocking Concrete Pavement Institute, Washington, DC, March 2003.
- (27) ICPI Tech Spec 15, A Guide for the Construction of Mechanically Installed Interlocking Concrete Pavements, Interlocking Concrete Pavement Institute, Washington, DC 2003.
- (28) Mujaj, L. and Smith, D.R., "Evolution of Interlocking Concrete Pavements for Airfields", in Advancing Airfield Pavements, the Proceedings of the 2001 Airfield Pavement Specialty Conference, August 2001, American Society of Civil Engineers, Reston, Virginia, pp. 253-266.

APPENDIX A: GUIDE SPECIFICATION:

ITEM P-502 INTERLOCKING CONCRETE PAVEMENT CONSTRUCTION FOR AIRPORT PAVEMENT

Note: This guide specification for the U.S. is for concrete pavers for airfields. Concrete pavers are approved for FAA- funded projects on a case-by-case basis. This guide specification is not published by FAA in their Advisory Circulars. However, it follows FAA specification format and structure as well as for quality control and quality assurance. The specification accompanies the ICPI manual, Airfield Pavement Design with Concrete Pavers. 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

502-1.1 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 paver pavers shall be manufactured for the construction of paved surfaces to be trafficked by jet or propeller driven aircraft. This item shall include paver 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 concrete paver pavements in the manner and at the locations shown on the Plans, or as directed by the Engineer.

For aircraft with gross weights in excess of 100,000 lbs. (440 KN) a stabilized base is required in accordance with FAA AC 150/5320-6C. A woven geotextile is required when a cement treated base (e.g. FAA Item P-304) is used to prevent loss of bedding sand through shrinkage cracks in the cement treated base. A woven geotextile fabric is also recommended when pavers are used as an overlay or inlay over cracked hot mix asphalt surfaces. When pavers are constructed on an aggregate base to serve aircraft with gross weights under 100,000 lbs. (440 KN), a geotextile fabric is not generally required. The use of concrete pavers is not recommended for areas subjected to full power or reverse thrust (e.g. runways or apron areas where aircraft "power-back" operations are conducted). Further guidance on design requirements and construction details for concrete pavers can be found in Interlocking Concrete Pavement Institute (ICPI) Publication, *Airfield Pavement Design with Concrete Pavers*.

2.0 Materials

502-2.1 CONCRETE PAVERS.

a. General. Concrete pavers shall be manufactured in accordance with ASTM C936, except as modified by Sections 502-4.1 and 502-4.2 of this Specification. Hard face or coated pavers with special finishes shall not be used. Pavers shall be chamfered with a beveled edge 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 width of 1/8-inch to 1/4-inch (3 mm to 6 mm) and the spacers shall have a nominal size of 1/16-inch (2 mm) in thickness. Concrete pavers shall be manufactured by a member of the ICPI.

b. Dimensions. Concrete pavers shall consist of rectangular chamfered units, 4 inches (100 mm) by 8 inches (200 mm) by 3.125 inches (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.

Dentated pavers are acceptable provided the plan aspect ratio is nominally 2:1. The minimum thickness of concrete pavers for airport application is 3.125 inches (80 mm).

c. Color. Color shall be natural grey, except where indicated on the Plans. Colored pavers shall use synthetic or natural iron oxide pigments conforming to ASTM C979, or other approved pigments with proven colorfastness.

d. Freeze-Thaw Durability. The Contractor shall submit test results and certification that the concrete pavers meet the durability requirements of ASTM C936 using the test procedure, ASTM C1645, in Appendix X1. Optional Test Method for Freeze-Thaw Durability.

Where freeze-thaw conditions are not anticipated, paragraph 502-2.1.d can be deleted.

e. Efflorescence. Concrete pavers shall be manufactured with additives to reduce efflorescence.

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

g. Acceptance. Concrete pavers shall be accepted by the Engineer at the source of manufacture in accordance with the acceptance requirements contained in Sections 502-4.1 and 502-4.2. 502-2.2 BEDDING SAND. Bedding sand shall be coarse, naturally occurring or manufactured hard sand. 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 ASTM C33, except for gradation requirements which are contained in Table 1 of this Specification. Locally available manufactured sand is acceptable, provided the sand is manufactured from rock having a Los Angeles (LA) Abrasion of 20 or less, when tested in accordance with ASTM C131, and the sand is washed to meet the grading requirements of Table 1. The sand shall contain no more than 10 percent of acid soluble material per ASTM C88. The bedding sand shall conform to the bedding sand degradation test requirements contained in paragraph 502-4.2.b.

TABLE 1
GRADING REQUIREMENTS FOR BEDDING SAND

Sieve Size	Percent Passing
3/8 in. (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100
No. 8 (2.36 mm)	80 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (0.600 mm)	25 to 60
No. 50 (0.300 mm)	10 to 30
No. 100 (0.150 mm)	2 to 10
No. 200 (0.075 mm)	0 to 2

502-2.3 JOINT SAND. All sand for joints shall conform to the grading requirements of ASTM C144, except that 100 percent by weight shall pass the No. 16 sieve (1.18 mm). 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.

502-2.4 EDGE RESTRAINTS. Edge restraints shall be fabricated and installed as shown on the Plans.

Typical details for edge restraints can be found in ICPI Publication Tech Spec 3, *Edge Restraints for Interlocking Concrete Pavements*, as well as *Airfield Design with Concrete Pavers*. The Engineer shall reference the applicable requirements and specification items for the type of edge restraint specified (e.g. galvanized steel angle or concrete) in accordance with the Guidelines contained in the ICPI publication.

502-2.5 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.

502-2.6 JOINT SEALING FILLER. When shown on the Plans, joint sealing filler used for sealing joints at edge restraint interfaces shall conform to Item P-605. No separate payment shall be made for this item, which is considered incidental to installation of edge restraints.

3.0 Initial Acceptance Requirements

502-3.1 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.

a. Certifications. The Contractor shall provide certifications that all materials to be incorporated into the work can meet the requirements of Sections 502-2.1 and 502-4.2. Certifications shall be substantiated by data from tests performed within 90 days of the planned start date for installation.

b. Samples. The Contractor shall submit the following samples for preliminary testing and evaluation by the Engineer.

(1) Pavers. Ten (10) concrete pavers, cured for a minimum of 28 days, shall be submitted to the Engineer for testing and evaluation in accordance with Sections 502-4.1 and 502-4.2 of this Specification.

(2) 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 502-4.1 and 502-4.2 of this Specification.

(3) Sealer. Manufacturer's catalogue cuts shall be submitted for sealer.

(4) 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 Item P-610.

c. Statement of Contractor Qualifications. The paver Contractor shall have installed at least 300,000 square feet (30,000 square metres) in commercial, municipal, port, or airport projects over the past twenty-four (24) months. If mechanical installation is to be used, at least 100,000 sq. ft. (10,000 sq. metres) of which shall have been mechanically installed. Submit list to the Engineer of projects completed by Installer. Include list of completed projects with project names, addresses, telephone numbers, email addresses, names of Engineers/Architects and Owners, and dates of construction.

d. ICPI Certification. The paver contractor shall provide current certificates from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program for job foremen on the project.

502-3.2 TEST STRIP. Prior to installation of unit pavers, construct a test strip at least 10-feet by 10-feet for each form and pattern of concrete paver required. Build mock-up(s) using materials, base construction, joints and special features for contiguous 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 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.

502-3.3 CONCRETE MIX DESIGN. Proportioning requirements for concrete for paver manufacturer shall be designed for a compressive strength consistent with the acceptance criteria contained in Sections 502-4.1 and 502-4.2. 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 502-4.1 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

502-4.1 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 stockpiles maintained by the Contractor at the job site for testing by the Engineer.

a. Concrete Pavers. Concrete pavers shall be sampled, tested, and accepted by the Engineer on a lot basis. A lot shall consist of [] paver units, 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 subplot in accordance with ASTM D3665. Each specimen selected shall be suitably marked so that it can be identified according to lot, subplot, and sample number at any time. The Engineer shall perform the following tests for acceptance on the number of samples indicated below.

The lot size shall consist of one-tenth (1/10) of the total area to be paved, or 50,000 concrete pavers, whichever is smaller. The minimum lot size shall be 25,000 concrete pavers.

(1) Compressive Strength. Compressive strength testing in accordance with ASTM C140 shall be performed on samples at 28 days. One (1) full paver sample from each subplot (5 total) shall be tested. This result shall represent the compressive strength for each of the five (5) individual sublots.

(2) Absorption. Five (5) full units, randomly selected from the ten (10) remaining units from each subplot, will be tested by the Engineer for absorption in accordance with Section 8 and Annex A4 of ASTM C140.

(3) Dimensions. The dimensions of the remaining five (5) units will be measured by the Engineer in accordance with Section 6 and Annex A4 of ASTM C140.

(4) Abrasion Resistance. Three (3) units shall be sampled out of every 500,000 units produced and abrasion resistance shall be measured in accordance with ASTM C418.

(5) Freeze-Thaw Durability. Three (3) units shall be sampled out of every 250,000 units produced and freeze-thaw durability shall be measured in accordance with ASTM C1645 at forty-nine (49) freeze thaw cycles. Weight loss per square metre of surface area shall be reported at twenty-five (25) and if applicable, at forty-nine (49) cycles.

The requirements for freeze-thaw durability can be deleted where freezing conditions are not anticipated.

b. Bedding Sand. Bedding sand shall be sampled, tested, and accepted by the Engineer on a lot basis. A lot shall consist of [] square feet (square metres) of sand placed for paving, except for the last lot, which shall consist of the number of square feet (metres) required for completion of paving. Each lot shall be subjected to the following tests for acceptance.

(1) Gradation. Each lot will be divided into two (2) equal sublots. One (1) sample shall be randomly located by the Engineer within the subplot in accordance with ASTM D3665. The Engineer shall test each sample for grading in accordance with ASTM C136 (Dry Sieve).

(2) Bedding Sand Degradation. One (1) 3 lbs. (1.4 kg) sample shall be randomly located within each lot in accordance with ASTM D3665. The sample shall be dried for 24 hours at 240 to 250 degrees F (115 to 121 degrees C). Obtain three (3) sub-samples each weighing 0.5 lbs. (0.2 Kg) by passing the main sample several times through a riffle box. Carry out a sieve analysis test on each sub-sample according to ASTM C136. Remix each sub-sample and place in a nominal quart/liter capacity porcelain jar with two (2) 1-inch (25 mm) diameter steel ball bearings weighing 75 +/- 5 grams each. Rotate each jar at 50 rpm for six (6) hours. Repeat the sieve analysis. Record the individual and average sieve analysis.

The lot size for bedding sand shall consist of the lesser of 20,000 square feet (2,000 square meters) or one-tenth (1/10) of the total paved area. The minimum lot size shall be 10,000 square feet (1,000 square meters).

c. Joint Sand. Joint sand shall be accepted on the lot size specified in paragraph 502-4.1.b., except that only one (1) sample will be randomly selected for each lot. The Engineer shall test the sample for grading in accordance with ASTM C136 (Dry Sieve).

502-4.2 ACCEPTANCE CRITERIA.

a. Concrete Pavers. Concrete pavers shall be evaluated on a lot basis by the Engineer for compliance with the acceptance characteristics specified in paragraphs

502-4.2.a(1) through (6), below. 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.

(1) Compressive Strength. For acceptance, the average compressive strength of the five (5) pavers tested in accordance with Paragraph 502-4.1.a(1) shall be 8,000 psi (55 MPa) with no individual test less than 7,200 psi (50 MPa).

(2) 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 502-4.1.a(3) is less than or equal to 5 percent, with no individual unit having an absorption greater than 7 percent.

(3) Dimensional Tolerances. The dimensional tolerances of each of the five (5) pavers sampled for each lot in accordance with paragraph 502-4.1.a.(3) shall not vary by more than the following amounts:

- (a) Length: + 1/16 inch (1.6 mm)
- (b) Width: + 1/16 inch (1.6 mm)
- (c) Thickness: + 1/8 inch (3.2 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 by more than 1/16 inches (1.6 mm).

(4) Abrasion Resistance. Samples tested in accordance with paragraph 502-4.1.a(4) shall not have a greater volume loss than 0.915 in.³ per 7.75 in.², (15 cm³ per 50 cm²). The average thickness loss shall not exceed 0.118 in. (3 mm).

(5) 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 sole discretion, may allow pavers with minor chipping to remain as part of the completed pavement.

(6) Freeze-Thaw Durability. The average weight loss of samples tested in accordance with paragraph 502-4.1.a(6) shall not exceed 200 g/m² of surface area after twenty-five (25) cycles or 500 g/m² after forty-nine (49) cycles.

Freeze-thaw durability requirements may be deleted where freezing conditions are mild or not applicable.

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

(1) Gradation. The two (2) samples of bedding sand tested in accordance with paragraph 502-4.1.b 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.

(2) Bedding Sand Degradation. For each sample tested in accordance with paragraph 502-4.1.b(2), the maximum increase in the percentages passing each sieve and the maximum individual percent passing shall be:

Sieve Size	Max. Increase	Max. Passing
No. 200 (0.075 mm)	2%	2%
No. 100 (0.150 mm)	5%	15%
No. 50 (0.300 mm)	5%	35%

c. Joint Sand. Joint sand sampled and tested in accordance with paragraph 502-4.1.c shall be evaluated for compliance to the requirements of Section 502-2.3.

d. Sealer. The sealer shall meet the requirements of Section 502-2.5.

e. 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:

(1) 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 Sections 502-4.1 and 502-4.2 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

502-5.1 Deliver concrete pavers to project site in steel-banded, plastic-banded, or plastic wrapped cubes capable of transfer by forklift or clamp lift. Unload pavers at project site without damage to pavers or existing construction.

502-5.2 Protect unit pavers from damage during delivery, storage and construction.

502-5.3 Sand shall be covered with waterproof coverage to prevent exposure to rainfall or removal by wind. Covering shall be secured in place.

6.0 Installation

502-6.1 PREPARATION.

a. Edge Restraints. Edge restraints shall be installed in the manner and in the locations shown on the Plans and in accordance with Section 502-2.4. The location of the edge restraints can be adjusted within +/- 2 inches (5 cm) of the Plan locations to minimize cutting of concrete pavers.

For inlays or new construction where pavers will abut hot mix asphalt surfaces, the following additional requirements are recommended.

Edge restraints shall be constructed in the following sequence:

(1) Construct P-401 courses to the bottom of the bedding sand layer, maintaining close control of grades and surface smoothness;

(2) Construct final lifts of P-401 outside the areas designated for concrete pavers, and approximately 1 foot to 2 feet (30 cm to 60 cm) inside the concrete paver areas, maintaining close control of grades and surface smoothness. Sheets of "waxed" paper or other suitable bond breaking material may be used at the edge of the hot mix asphalt to facilitate cutting back the asphalt to its final location.

(3) Saw-cut the P-401 material to neat, straight lines at the locations shown on the Plans, adjusting the saw-cut +/- 2 inches (5 cm) to facilitate concrete paver installation.

- (4) Remove the asphalt in a manner approved by the Engineer to the saw-cut lines.
- (5) Install the steel angle edge restraint by spiking and install geotextile fabric strips along the length of the angle as shown on the Plans.
- (6) After concrete paver installation, as described below, apply P-605 joint sealing filler at the hot mix asphalt/concrete paver interface as shown on the Plans.

b. Base. The base course for the pavers shall be accepted by the Engineer before the start of paver installation. The base shall be cleared of all loose or foreign material. When indicated on the Plans, a geotextile fabric shall be installed prior to the installation of bedding sand.

c. Lines and Grades. Lines and grades shown on the Plans shall be established and maintained by the Contractor during the installation of the pavers. Allowance for sand surcharge levels should be made at this time.

d. Drainage. Adequate drainage shall be provided during construction by means of temporary drains, ditches, etc. to prevent the build-up of standing water.

502-6.2 BEDDING SAND INSTALLATION.

a. Bedding sand shall comply with Section 502-2.2 and paragraph 502-4.2.b. of this Specification.

b. The finished surface of the base to receive the bedding sand shall be uniform and even, meet all smoothness and grade requirements of the base course.

c. Bedding sand shall be spread to a uniform, even thickness, such that, after compaction, it forms a uniform layer, nominally 1-1/4 inches to a maximum of 1-1/2 inches (3 cm to 4 cm), or as shown on the Plans. The Contractor shall allow for surcharge and compaction when establishing the loose thickness of bedding sand.

d. The test strip required by Section 502-3.2 shall be used to determine the true amount of surcharge required to obtain the correct levels.

e. The moisture content of the bedding sand shall remain relatively constant and within 2 percent of optimum moisture. The course shall not be subjected to any trafficking, either by mechanical equipment or pedestrian use.

f. The Contractor shall take all reasonable precautions to prevent the bedding sand from blowing to areas of the Terminal Apron or Taxiways that are open to aircraft operation. If in the opinion of the Engineer, the Contractor's controls are not adequate, the Engineer shall limit the amount of sand that can be spread at any time.

g. Spreading of the laying course sand shall stop when the Engineer considers the weather conditions to be unsuitable. If inclement weather causes deterioration of the laying course sand it shall be lifted and stored to one side to drain prior to reuse.

502-6.3 INSTALLATION OF UNIT PAVERS.

a. Do not use concrete pavers with chips, cracks, voids, or other defects which may impair functional or structural performance.

b. Use full units without cutting where possible.

c. Ensure that pavers are free of foreign materials before installation.

d. Concrete pavers shall be installed using the herringbone laying pattern shown on the Plans, matching the joint pattern of the field-constructed mock-up(s).

- e. Set concrete pavers with a consistent minimum joint width of 1/16-inch (1.5 mm) and a maximum of 1/8-inch (3 mm), being careful not to disturb the bedding sand. Ninety-five (95%) percent of the joints shall be 3/32-inch (2 mm) or less in width. Place pavers hand tight against spacer bars. Using string lines to keep straight joint lines.
- f. The pavers shall be laid away from the existing laying face or edge restraint in such a manner as to ensure squareness of pattern.
- g. Cut unit pavers with motor-driven masonry saw to provide clean, sharp, unchipped edges. Cut vertical faces and cut grind chamfers on top of cut surface to provide pattern indicated and to fit adjoining work neatly. Hammer cutting or mechanically split pavers are not acceptable. No cut segments shall be smaller than one-third (1/3) of a unit.
- h. Lay full pavers first. Lay string courses along all edge restraints and around all concrete collars and similar construction in accordance with the details shown on the Plans.
- i. If in the opinion of the Engineer weather conditions are such that the performance of the pavement may be affected, laying operations shall be discontinued and all laid pavers shall be lined and compacted prior to suspension of the works. On recommencement of laying pavers, at least two (2) edge courses of existing pavers shall be lifted and the sand re-screeded before pavers are laid.

502-6.4 COMPACTION.

- a. Initial Compaction. After the pavers have been laid on the bedding sand, and after all cut pavers have been inserted to provide a full and complete surface, and pattern lines have been straightened, vibrate concrete pavers into bedding with a low amplitude plate vibrator capable of at least 5,000 lbs. (22 KN) compaction force and at least 75 hertz. The effective compactive force from the plate should not be less than 11 pounds per square inch (75 KN per square metre).

Vibrate after edge pavers are installed, and there is a completed, restrained surface; or before surface is exposed to rain.

Before ending each day's work, vibrate installed concrete pavers more than 3 feet (1 m) of the laying face, fill joints and vibrate again. Cover remaining 3 ft with plastic sheets if rain is forecasted. Secure plastic sheets from removal by wind.

- b. Joint Sand Installation and Compaction. Immediately after vibration of the pavers to finished level, dry jointing sand shall be brushed over the surface course and the pavement shall be re-compacted until all joints are completely filled with sand. A minimum of two (2) passes shall be made, in addition to initial compaction, parallel and perpendicular to the joint pattern during joint sand installation. Additional sand shall be added until joints are filled. Care shall be taken to ensure that the joints are filled and sand shall be constantly brushed over the surface and the pavement re-compacted as necessary.

- c. Final Compaction of Units. On completion of the initial vibration and joint filling with sand, the entire area shall be compacted with an 8 to 10-ton pneumatic rubber-tired roller having a tire pressure of 90 pounds/square inch (620 KPa/sq. m.). Replace any cracked pavers with whole units and roll pavers again.

502-6.5 SURFACE TESTS.

- a. Smoothness. After completion of final compaction, the finished surface shall not vary more than 1/4-inch (6.35 mm) when tested with a 12-foot (3.6 m) straightedge in any direction.

b. Grade. After completion of final compaction, the finished surface shall deviate no more than 1/2-inch (12.7 mm) from the grade line, elevations, and cross-sections shown on the Contract Drawings. The top of the pavers shall extend approximately 1/8-inch (3 mm) higher than surrounding appurtenances and asphalt pavement.

502-6.6 SEALER APPLICATION.

a. After final compaction, remove all excess sand and debris. Ensure that there is no sand in the chamfers. Apply the sealer as soon as practical after final compaction, strictly following the sealer manufacturer's requirements regarding application methods, equipment, and rate.

b. Traffic shall not be permitted on the pavement until the sealer has cured.

502-6.7 JOINT SEALING FILLER. The joints at the interface between pavers and adjacent pavement and edge restraint shall be sealed with material conforming to Item P-605 of the Technical Specifications, as shown on the Plans, or as directed by the Engineer. No separate payment will be made for this item which shall be considered incidental to the cost of providing and installing edge restraints.

502-6.8 WEATHER LIMITATIONS. Bedding sand, pavers, and joint sand shall not be installed during periods of heavy rain or when temperatures are below 32 degrees F (0 C).

7.0 Contractor Quality Control

502-7.1 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 or procured from Subcontractors or vendors. Although guidelines are established and certain requirements are specified herein, the Contractor shall assume full responsibility for accomplishing the stated purpose.

The Contractor shall provide and maintain a Quality Control Plan, hereinafter referred to as Plan, along with all the personnel, equipment, supplies and facilities necessary to obtain samples, perform and document tests, and otherwise ensure the quality of the product.

The Plan shall be submitted to the Engineer at least 15 days prior to the start of paving. The Contractor shall be prepared to discuss and present, before the start of paving, his or her understanding of the quality control responsibilities for specific items as included in these Specifications.

The Contractor shall perform process control sampling, testing, and inspection during all phases of the work at a rate sufficient to ensure that the work conforms to the Contract requirements.

502-7.2 QUALITY CONTROL PLAN. The Plan may be operated wholly or in part by the Contractor or supplier, or by an independent organization; however, the Plan's administration, including compliance with the Plan and its modification, shall remain the responsibility of the Contractor.

a. Plan Contents. The Plan shall include as a minimum:

- (1) Quality Control organization chart.
- (2) Names and qualifications of personnel.
- (3) Area of responsibility and authority of each individual.

(4) A listing of any outside organizations such as testing laboratories that will be employed by the Contractor and a description of the services they will provide; or indicate if tests will be performed by Contractor personnel.

(5) Preparation and maintenance of a Testing Plan which shall contain a listing of all tests to be performed by the Contractor and the frequency of testing.

(6) Procedures for ensuring that tests are taken in accordance with the Testing Plan, that they are documented, and that proper corrective actions are taken when necessary. The testing procedures shall be prescribed by clear and complete instructions and shall assure quality control testing of materials as required by the Specifications, or as necessary to maintain the specified quality.

b. Plan Elements. The Plan shall address all elements which affect the quality of the concrete pavers, including but not necessarily limited to the following:

- (1) Mix Design for Paver Production
- (2) Quality of Cementitious Materials and Admixtures
- (3) Proportioning
- (4) Control of Water-Cement Ratio
- (5) Required Strength
- (6) Placement of Bedding Sand
- (7) Moisture Content and Absorption of Bedding Sand
- (8) Thickness, Smoothness, and Grade Control

c. Plan Administration. The Plan shall address management and coordination of activities of the personnel assigned to this function and shall incorporate the use of the following types of personnel.

(1) Plan Administrator. The individual administering the Plan must be a full-time employee of the Contractor or Paver Installer or a consultant employed by the Contractor or Paver Installer. In either case, the individual employed shall have full authority to institute any and all actions necessary for the successful operation of the Plan.

(2) Plant Control Technician (PCT). This person shall utilize laboratory test results and other quality control practices to ensure the quality of aggregates, cementitious materials, admixtures, and other mix components and adjust and control mix proportioning to meet the mix design(s) for paver production. The Plan shall detail the frequency of each type of test, when and how corrective actions are to be taken, and the means of documentation.

The PCT shall be responsible for periodically inspecting all equipment utilized in proportioning and mixing to ensure its proper operating condition and to ensure that proportioning and mixing is in conformance with the mix design and other Specification requirements. The Plan shall set forth how these duties and responsibilities will be accomplished and documented. The PCT may be an employee of the paver manufacturer.

(3) Field Control Technician (FCT). This person shall be responsible for periodically inspecting all equipment and processes utilized in placing to ensure that placing of pavers and bedding and joint sand is in conformance with the Specifications. The Plan shall set forth how these duties and responsibilities will be accomplished and documented.

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

- (a) Examine surfaces indicated to receive unit pavers for compliance with required installation tolerances. Verify that all surfaces to receive pavers are in proper condition, and that no conditions exist which may adversely affect progress or quality of work.
- (b) Verify that base is dry and ready to support bedding material, pavers, and imposed loads.
- (c) Verify base gradients and elevations.
- (d) Verify location, type, installation, and elevations of adjacent edge restraints, drainage inlets, grounding lugs, and other appurtenances in the pavement.
- (e) Provide adequate drainage during the entire construction phase by means of temporary drains, ditches, or other means to prevent the build-up of standing water.

502-7.3 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.

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

- (1) Batch proportioning
- (2) Aggregate gradation (evidence from quarry tickets will be acceptable).
- (3) Aggregate moisture content
- (4) Water-cement ratio
- (5) Density measurements

A minimum of two (2) tests for each shall be made for each production day. For automated plants with recordation, the Contractor can 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.

b. Bedding and Joint Sand. The Contractor shall control the gradation and moisture content of the bedding and joint sand used for installation. In addition, the Contractor shall determine the optimum moisture content for the bedding sand in accordance with ASTM D1557 and control the moisture content during construction to -2 percent and +3 percent of the optimum moisture content. A minimum of one (1) moisture content test shall be performed for each lot, as defined in accordance with paragraph 502-4.1.b. Moisture content testing shall be in accordance with ASTM C566.

8.0 Method of Measurement

502-8.1 The quantity of each element of work, installed and accepted, comprising this item, shall be in accordance with the following measurements:

- a. Concrete Pavers and Joint Sand. Per square foot (sf) [square metre (sm)], measured in-place, completed and accepted.
- b. Bedding Sand. Per ton, measured on approved truck scales, completed and accepted.
- c. Edge Restraint. Per linear foot (lf) [linear metre (lm)], measured in-place, completed and accepted.

d. Sealer. Per square foot (sf) [square metre (sm)], completed and accepted.

9.0 Basis of Payment

502-9.1 Payment for accepted quantities of concrete pavers shall be made at the full Contract unit price per square yard. The price shall be full compensation for manufacturing, furnishing, and placing all materials, including pavers, bedding sand, joint sand, edge restraints, and sealer and for all labor, equipment, tools, and incidentals necessary to complete this item.

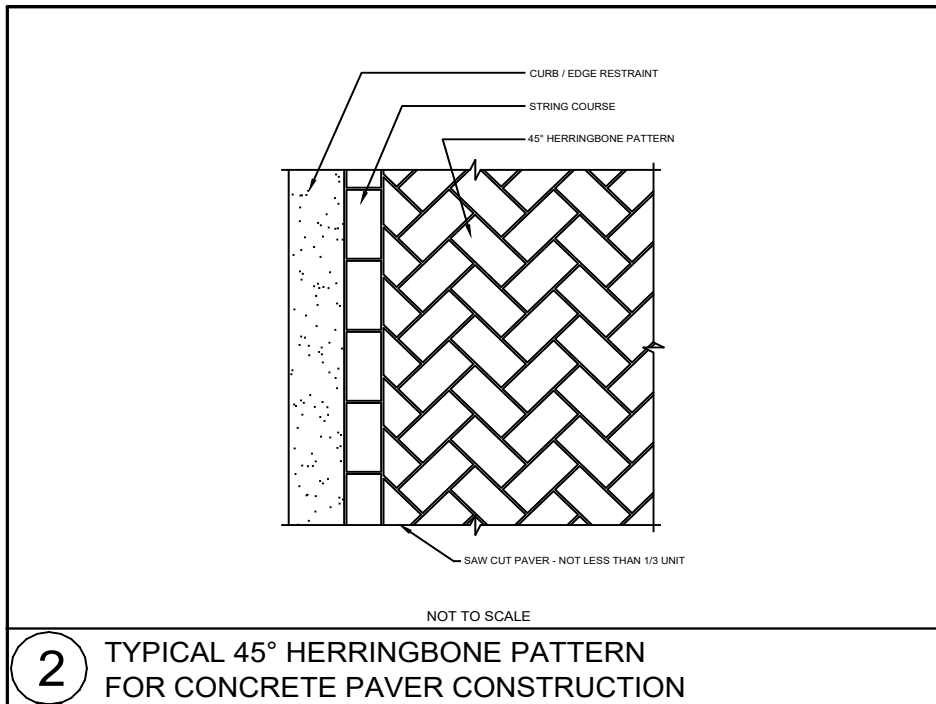
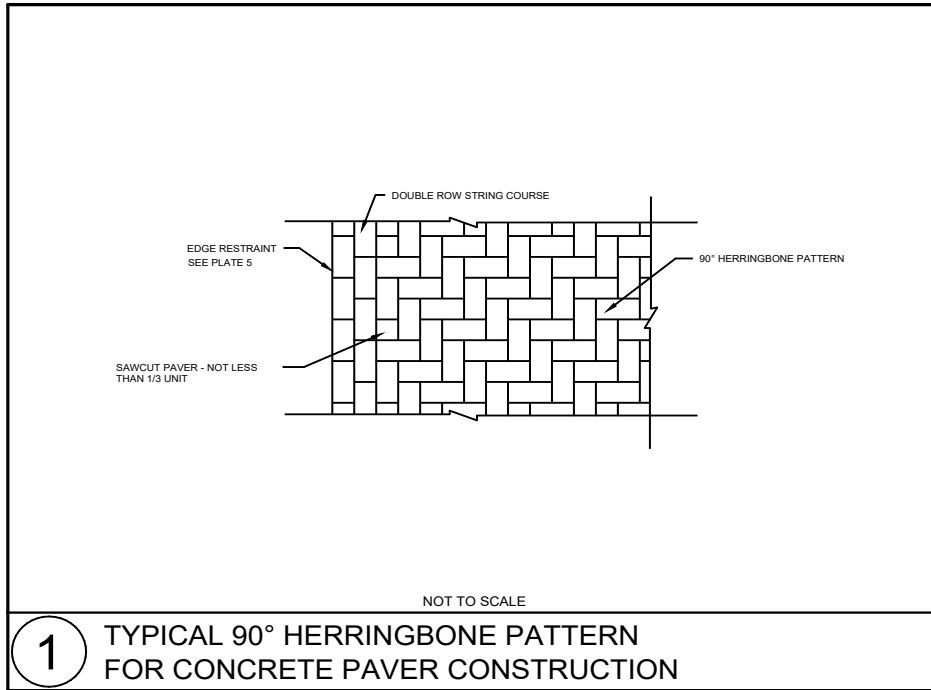
Item P-502-9.1 Concrete Pavers and Joint Sand--per square foot (square metre)
Item P-502-9.2 Bedding Sand--per ton (metric ton)
Item P-502-9.3 Edge Restraints--per linear foot (linear metre)
Item P-502-9.4 Sealer--per square foot (square metre)

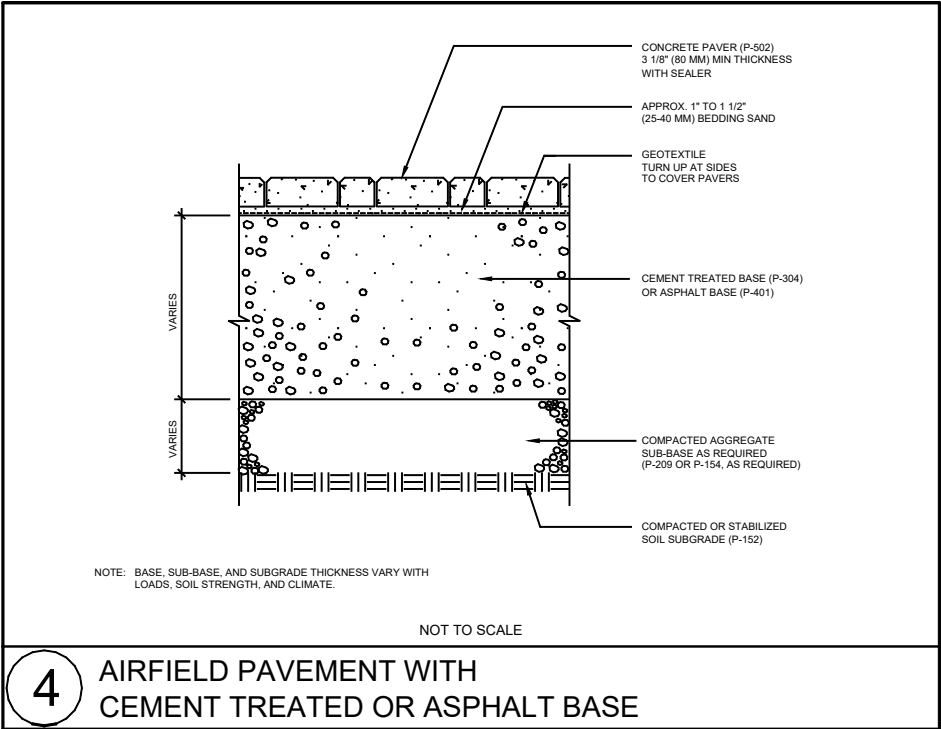
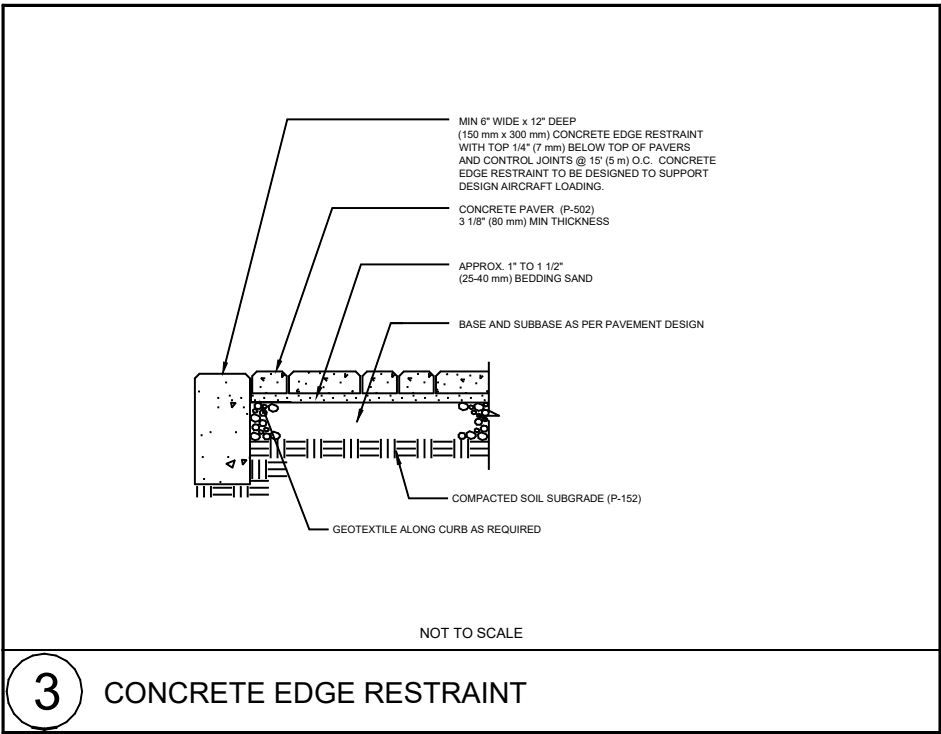
10.0 Materials and Testing Requirements

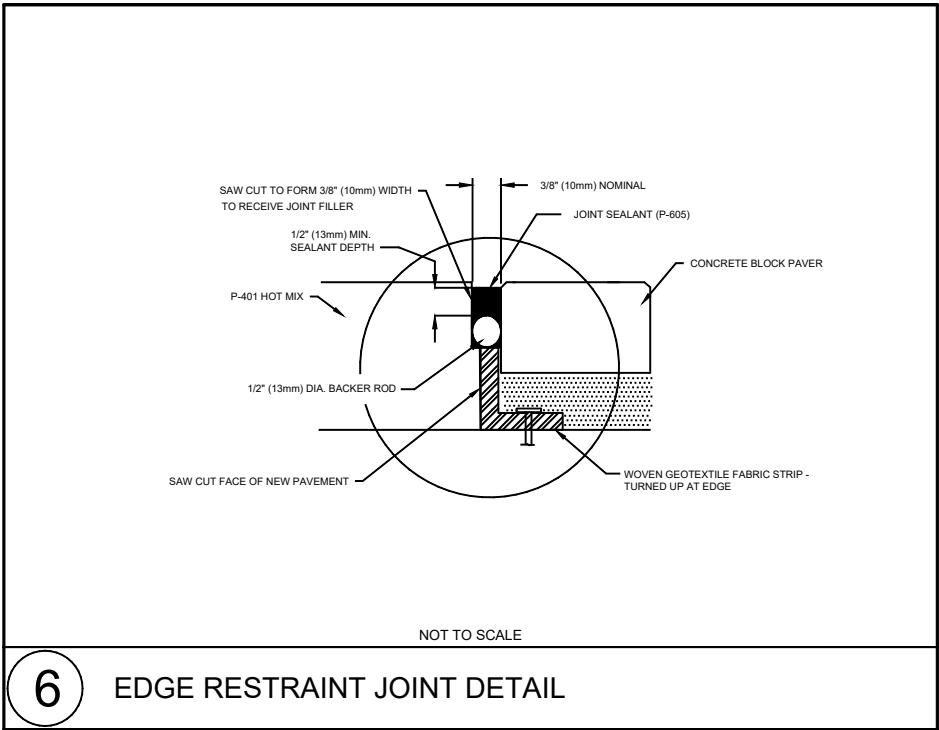
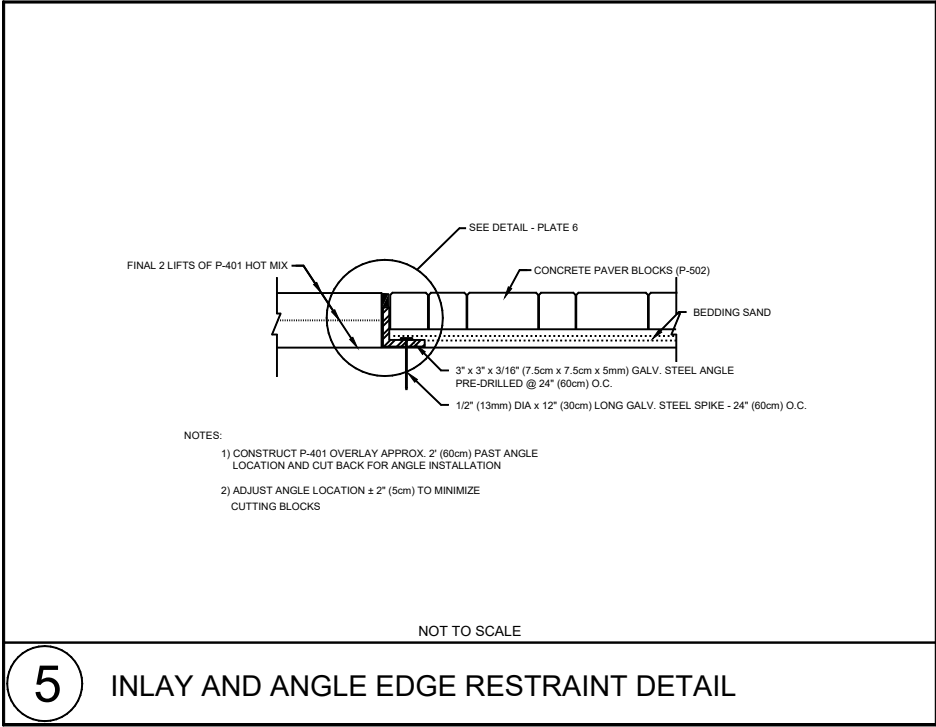
ASTM C33 Specification for Concrete Aggregates
ASTM C131 Method for Resistance to Degradation of Small Size Course Aggregate by Abrasion and Impact in the Los Angeles Machine
ASTM C136 Method for Sieve Analysis for Fine and Coarse Aggregate
ASTM C140 Method of Sampling and Testing Concrete Masonry Units
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 C1645 Standard Test Method for Freeze-thaw and De-icing Salt Durability of Solid Concrete Interlocking Paving Units
ASTM D1557 Laboratory Compaction Characteristics of Soil Using Modified Effort.
ASTM D2370 Test for Elongation and Tensile Strength of Free Films of Paint, Varnish, Lacquer, and Related Products with a Tensile Testing Apparatus
ASTM D3665 Random Sampling of Paving Materials

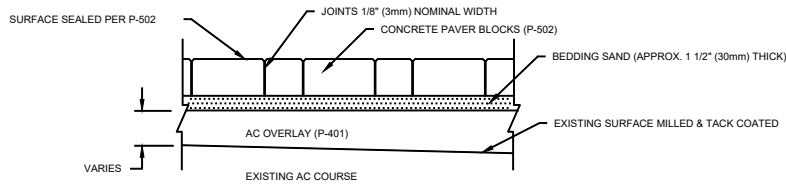
END OF ITEM P-502

APPENDIX B: DETAIL DRAWINGS



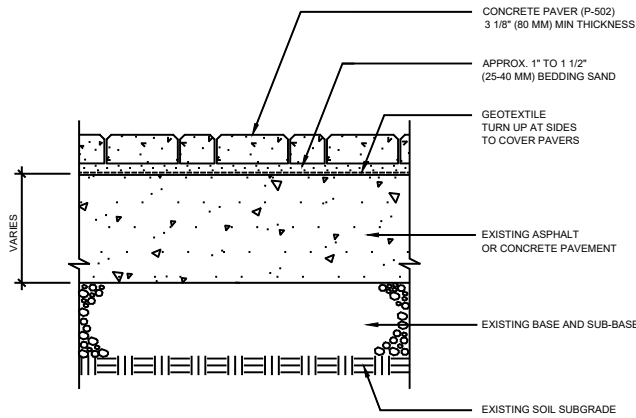






NOT TO SCALE

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 be 5,000 square feet (465 m²) ±1,000 square feet (90 m²). 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 ¼-inch (0 to 6 mm) loss
M	=	¼-inch (6 mm) to ¾-inch (19 mm) loss
H	=	Over ¾-inch (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 +1/8-inch (3 mm) or -1/16 inch (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 6 ft. (2 meters) 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 1/8-inch (3 mm) wide.
- M = Moderately spalled with some loose, in-place particles. Spalling is 1/8-inch (3 mm) to 1-inch (25 mm) wide.
- H = Spall is greater than 1-inch (25 mm) wide with loose, in-place, or missing particles. Tire damage or FOD is a risk.

Remedy: For M & H severity levels, remove damage 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 paver 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 feet (square meter) of surface area. The maximum depth determines the level of severity. Place a 10 ft. (3 meter) straightedge across the depressed area and

measure the maximum depth in inches (meters). Depressions larger than 10 ft. (3 meter) 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 ½-inch (13 mm) to 1-inch (25 mm).
- M = Depression are visible without ponding. Taxiways and aprons: depression ranges from 1-inch (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 2 inches (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: ¼-inch (3 mm) to ½-inch (13 mm) difference in elevation.
- M = Taxiways: ¼-inch (6 mm) to ½-inch (13 mm); Aprons: ½-inch (13 mm) to 1-inch (25 mm).
- H = Taxiways: greater than ½-inch (13 mm); Apron: greater than 1-inch (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 are 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	=	¼-inch (6 mm) to ½-inch (13 mm)
M	=	½-inch (13 mm) to 1-inch (25 mm)
H	=	greater than 1-inch (25 mm)

Remedy: For M & H severity, remove units and sand, repair base, install pavement materials to desired elevation. Reinstall 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	=	¼-inch (6 mm) or less deviation from reference line.
M	=	¼-inch (6 mm) to ½-inch (13 mm) deviation from reference line.
H	=	Greater than ½-inch (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 10 ft. (3 meter) straightedge would be measured as well as the area of the swell.

Severity levels:

H = Less than 3/4-inch (19 mm) height differential. Swell is barely visible.

Remedy: Remove pavers, correct base and reinstall units.