The Interdependence between Design, Specification and Construction

Canadian Airfield Pavement Technical Group Workshop

September 15, 2014

Vancouver, BC

Gary L. Mitchell, P.E.
Vice President
Airports and Pavement Technology

Count on Concrete PAVEMENT

INTRODUCTION

AIRFIELD PAVEMENTS—THEIR FUNCTION AND PURPOSE

Airport pavements are constructed to provide adequate support for the loads imposed by airplanes and to produce a firm, stable, smooth, all-year, all-weather surface free of debris or other particles that may be blown or picked up by propeller wash or jet blast. In order to satisfactorily fulfill these requirements, the pavement must be of such quality and thickness that it will not fail under the load imposed. In addition, it must possess sufficient inherent stability to withstand, without damage, the abrasive action of traffic, adverse weather conditions, and other deteriorating influences. To produce such pavements requires a coordination of many factors of design, construction, and inspection to assure the best possible combination of available materials and a high standard of workmanship.

FAA Advisory Circular 150/5320-6E, Airport Pavement Design and Evaluation

So…
What is the Designer's or (Engineer of Record) Role

- Creates Detailed and Executable plans and specifications (to meet owners needs)
- Reviews Shop Drawings and Submittals
- Ensures Compliance with Specs
- Manages Liability
- Makes a little profit

And…
What is the Contractor's Role

- Good Craftsmanship
- Needs Concrete that Satisfies Owner
  - Engineer (Technical)
  - Architect (Appearance)
  - Crew (Place and Finish)
- Profitable
  - Not always the Cheapest
  - Informed Purchaser

Who are the Stakeholders in a project?

- Owner
- Engineers
- Contractors
- Concrete Suppliers
- Others

✈Each wants quality

✈Durable Product

✈Reputation/Perception

✈Full Payment for work

Each Wants Quality…
But What is Quality?

- Quality is not about Strength
- Quality is not about proper air content
- Quality is not about "slump" of plastic concrete
- Quality is not about 100% Inspection
- Quality is not Obtained Through Duplicative Testing
- Quality is about:
  - Consistency
  - Trends Analysis
  - ID of Critical Variables Before They Become Statistics

Airfield Pavements

- Aircraft Loading
  - Important to remember that one aircraft wheel load can easily exceed the total gross weight of many vehicles, including semi-tractor trailers.
  - Aircraft wheel loads are approaching 65,000-lbs and tire pressures can exceed 300 psi.

Airfield Concrete Pavements

- Pavements conforming to airfield concrete specifications are generally more challenging to construct than typical state highway pavements.
- Specification has evolved over the years to keep pace with operational characteristics required to support commercial aircraft traffic.
- High quality is desired and achieving quality is the responsibility of both Contractor and Engineer.

How do we build quality?

- Consistency
- Desired Characteristics
  - workability
  - strength
  - durability

How can we insure quality?

- Design?
- Specifications?
- Can you specify quality?
- How?

Design Principals – Detailed Specs

Design Not Related to Surface Defects

Quality Cannot be Specified

Quality Is Inherent in The Specifications

SPECIFICATIONS?

Strength and Thickness

Strength and Thickness

Durability?

Are these a Measurement of Quality?

Let's look at the Specifications

- Pay Items
  - Strength
  - Thickness
- Suspension of Work
  - Slump
  - Air
- Defining Workability
  - "We know when we see it"
    - Placement and consolidation (hand verses machine)
    - Will material stand up behind the paver?
    - Will aggregate separate from the paste
    - Finishing – plastering surface is not acceptable (for pavements)

Specifications Effects on Bid Prices

- Reputation of EOR
- Reputation of Owner
- Reputation of Contractor

- Timely Payment
- Professionalism of Specifications/Tone
- Contents of Spec's

Defining Workability

(Who's Responsibility for workability?)

Component	Placement	Consolidation	Finish
Aggregates			
Coarse	**C**	**C**	**M**
Fine	**M**	**M**	**C**
Cement		**S**	**M**
Water	**C**	**C**	**C**
Admixtures			
Air Entraining	**M**	**M**	**S**
Mineral	**M**	**M**	**M**
Chemical	**C**	**C**	**S**

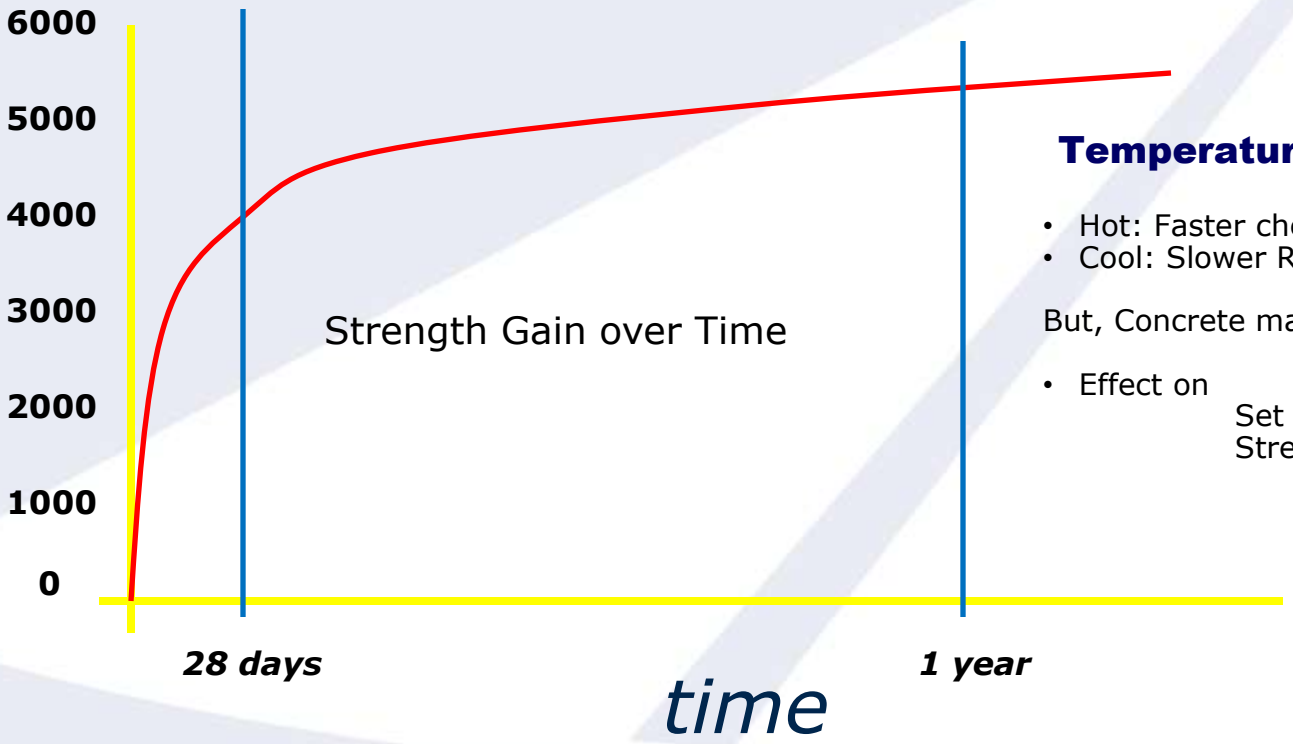
Acceptance Criteria

- Flexural strength
- Thickness
- Smoothness
- Grade
- Edge slump

How is strength related to design?

(What about thickness vs. strength)
(Should there be offsets for one vs the other)

What strength should we specify?



Temperature Effects

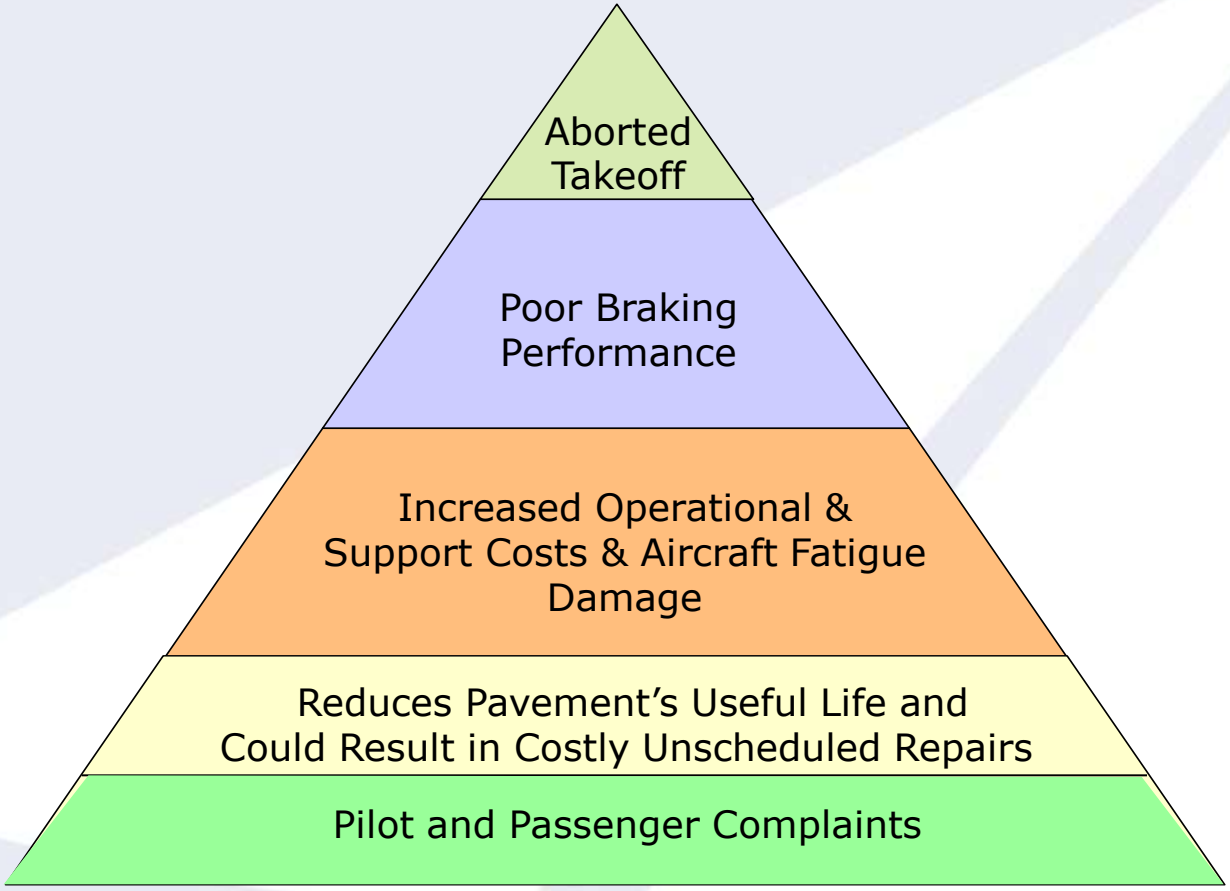
- Hot: Faster chemical reaction
- Cool: Slower Reaction

But, Concrete makes its own heat

- Effect on
  Set
  Strength gain

Smoothness Acceptance

Why Be Concerned About Runway Smoothness or Roughness?



Runway Roughness Evaluation: A Unique Problem

- Landing Gear Spacing of nearly 100 Feet
- Speeds up to 150 Knots
- Aircraft will Respond to Bumps 300 Feet Long or Longer
- Multiple Bumps in Succession; Non-Linear Effect
- Struts are Primarily Designed for Landing Impact

What is Smooth?

How smooth is smooth?

- Shock
  - Sharp Change in Elevation
  - Suspension system cannot absorb the energy
- Short Wavelengths
  - Bump (in 16 feet)
  - Suspension system can react too
- Long Wavelengths
  - Deviations from grade control or interaction with crown
  - Aircraft Responds as a whole

How do you measure smooth?

- 16 foot straightedge
- California Profilograph
- Lightweight Profilers
- Wet/Dry Profilers
- Contact Profilers

California Profilograph is old Technology—

—So what do we specify?

Evolution of the California Profilograph

- Slipform pavers became experienced with California Profilograph—highways
- Build long runs with low PI numbers
- Easier than “kicking” a 16-foot straightedge
- ACPA proposed conservative PI number for acceptance
- FAA & USACoE adopted PI
- Threshold and removal criteria began to show up
- Now leads to dispute

Problems with Profilographs

- Highway industry
- 16-foot straight vs. profilograph suggest highway criteria is much too conservative
- Profilograph doesn't consider amplification of attenuating wavelengths
- Profilograph cannot emulate the 16-foot straightedge (25 feet instead)
- Therefore the PI cannot reflect smoothness as used in P-501 critera

Misapplication and Misinterpretation of the Profilograph Specification

- Low PI = smooth
- Requiring low PI (e.g. 4”per mile)
- Low PI apron—phased project
- Short Sections
- Tying to existing pavement
- Using existing is measurements
- Effects of speed

What is the goal for smoothness?

FAA Advisory Circular 150/5380-9
(Based of Boeing Bump Criteria)

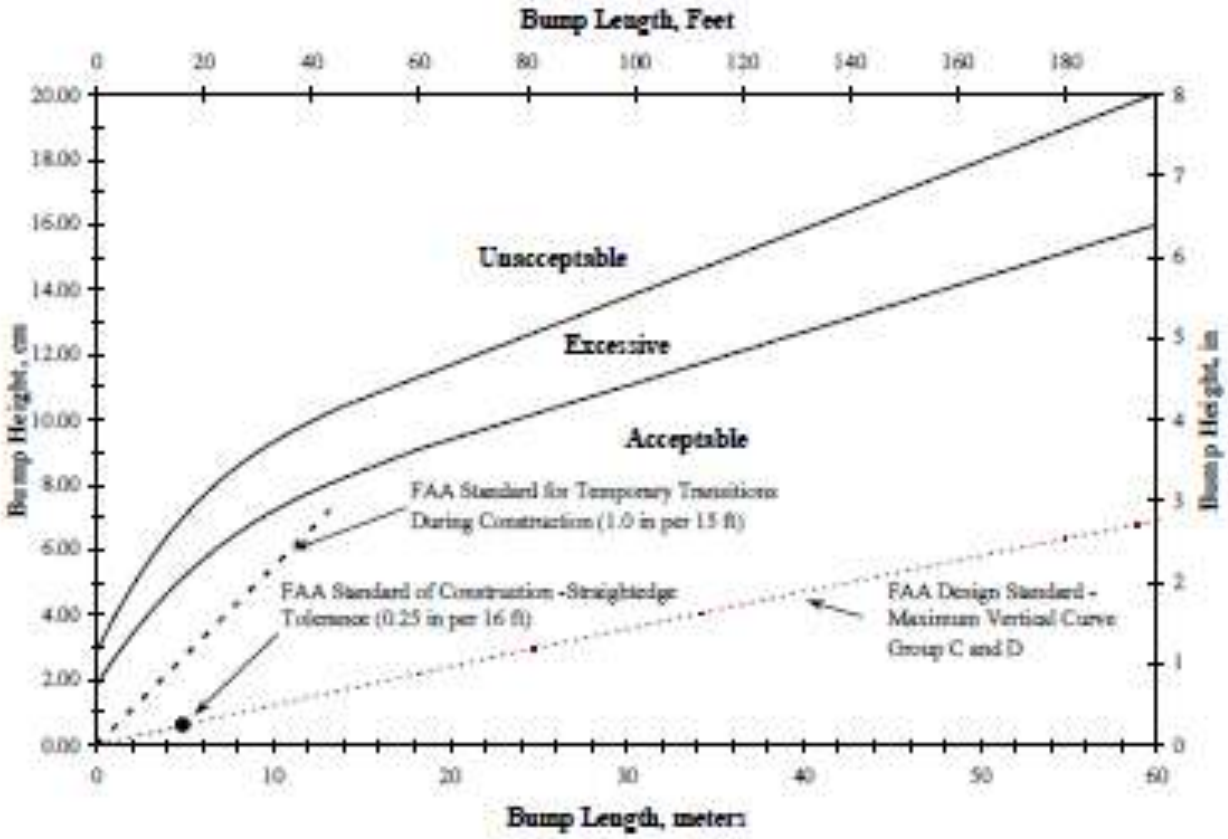


FIGURE 2-3. SINGLE EVENT BUMP - ROUGHNESS ACCEPTANCE CRITERIA

Straight Edge Methods (New Pavement Acceptance)

- FAA AC 150/5370-10F - 16-Foot Straight Edge
- California Profilograph
- These Methods Will Produce Smooth Pavement when Combined with Grade Control (.5-inch to Established Grade Elevation)

Grade Control

(4) Grade. An evaluation of the surface grade shall be made by the Engineer for compliance to the tolerances contained below. The finish grade will be determined by running levels at intervals of 50 feet (15 m) or less longitudinally and all breaks in grade transversely (not to exceed 50 feet (15 m)) to determine the elevation of the completed pavement. The Contractor shall pay the costs of surveying the level runs, and this work shall be performed by a licensed surveyor. The documentation, stamped and signed by a licensed surveyor, shall be provided by the Contractor to the Engineer.

(a) Lateral deviation. Lateral deviation from established alignment of the pavement edge shall not exceed ±0.10 feet (3 mm) in any lane.

(b) Vertical deviation. Vertical deviation from established grade shall not exceed ±0.04 feet (12 mm) at any point.

Grade Control

Pavement Grade.
.1
Acceptance of each lot for pavement grade shall be based on survey measurements of the finished surface tested in accordance with paragraph 4.5.
.2
Tolerance: The finished surfaces shall vary not more than 13 mm above or below the plan (design) grade lines or elevations indicated on the Contract Drawings.
.1
The above tolerance from the plan grade will not be permitted in areas where closer conformance with the plan grade is required for proper functioning of appurtenant structures. The finished surfaces of new abutting pavements shall coincide at their juncture.
.3
Payment will be in accordance with paragraph 5.3.

What is the goal for smoothness?

FAA Advisory Circular 150/5380-9
(Based of Boeing Bump Criteria)

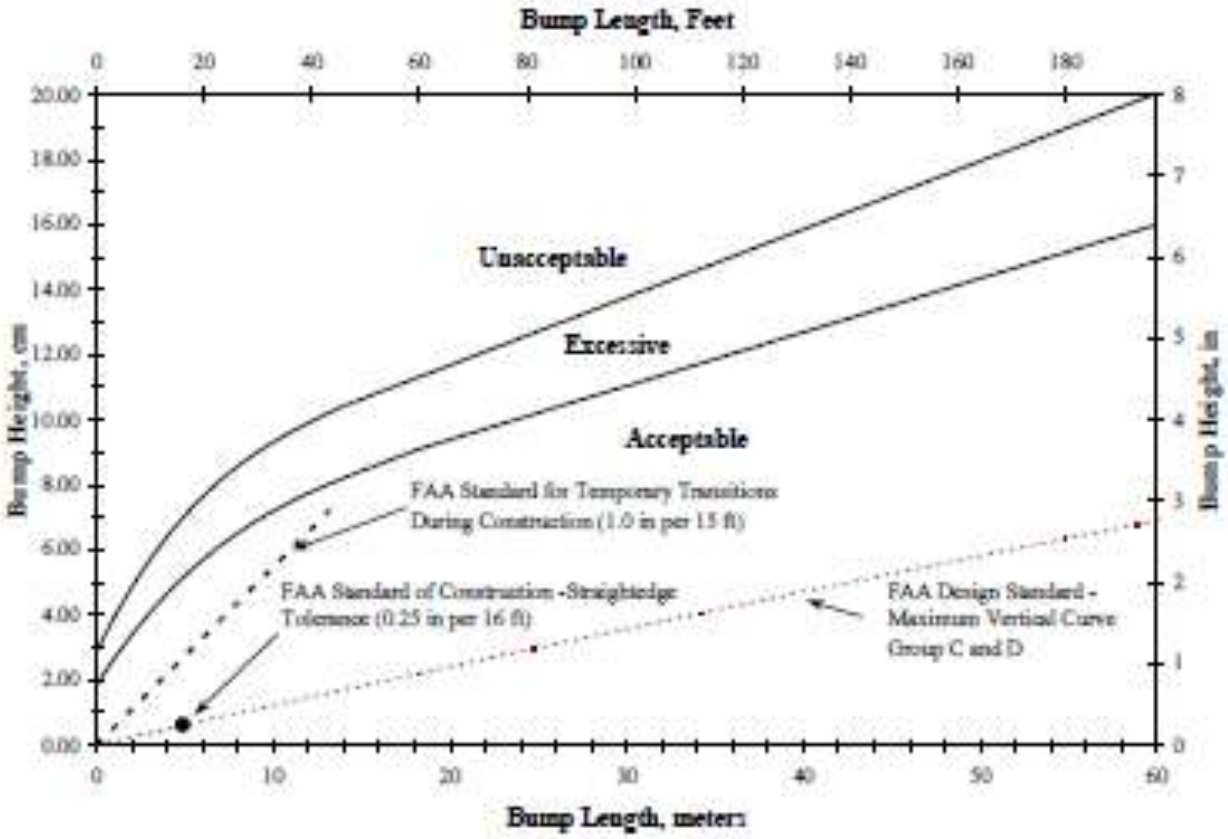


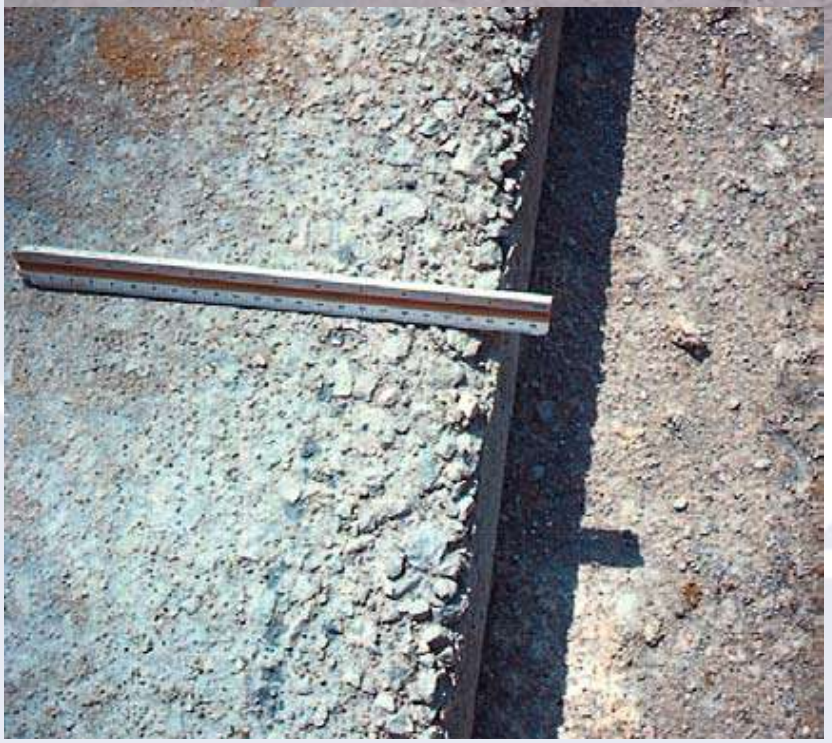
FIGURE 2-3. SINGLE EVENT BUMP - ROUGHNESS ACCEPTANCE CRITERIA

32 13 11 - 3.9.5 Repair of Weak Surfaces

Weak surfaces are defined as mortar-rich, rain-damaged, uncured, or containing exposed voids or deleterious materials. Slabs containing weak surfaces less than 1/4 inch (6 mm) thick shall be diamond ground to remove the weak surface. Diamond grinding shall be in accordance with paragraph: *Diamond Grinding of PCC Surfaces in PART 1.* All ground areas shall meet the thickness, smoothness and grade criteria of paragraph: *Acceptance Requirements in PART 1.* Slabs containing weak surfaces greater than 6 mm 1/4 inch thick shall be removed and replaced.

Diamond Grinding of PCC Surfaces in Part 1:

- **Discussed in terms of smoothness and plan grade**
- **No more that ¼ inch depth**
- **No more than 10% of any sub lot**



Aggregates

- Coarse and fine aggregate
- ASTM C33
- Reactive??
- ASTM C 1260 & 1567
- Modified ASTM C 1260 & 1567?

TABLE 2. GRADATION FOR COARSE AGGREGATE
ASTM C 33

Sieve Designations (square openings)		Percentage by Weight Passing Sieves	
in.	mm	*	*
2-1/2	63	*	*
2	50.8	*	*
1-1/2	38.1	*	*
1	25.0	*	*
3/4	19.0	*	*
1/2½	12.5	*	*
3/8	9.5	*	*
No. 4	4.75	*	*
No. 8	2.36	*	*

GRADATION FOR COARSE AGGREGATE

Sieve Designations (square openings)		Percentage by Weight Passing Sieves				
		From 2" to No. 4 (50.8 mm - 4.75 mm)		From 1-1/2" to No. 4 (38.1 mm - 4.75 mm)		From 1" to No. 4 (25.0 mm-4.75 mm)
in.	mm	#3 2"-1"	#57 1"-No.4	#4 1-1/2"-3/4"	#67 3/4"-No.4	#57 1"-No.4
2-1/2	63	100	---	---	---	---
2	50.8	90-100	---	100	---	---
1-1/2	38.1	35-70	100	90-100	---	100
1	25.0	0-15	95-100	20-55	100	95-100
3/4	19.0	---	---	0-15	90-100	---
1/2	12.5	0-5	25-60	---	---	25-60
3/8	9.5	---	---	0-5	20-55	---
No. 4	4.75	---	0-10	---	0-10	0-10
No. 8	2.36	---	0-5	---	0-5	0-5

Aggregate gradations that produce concrete mixtures with well-graded or optimized aggregate combinations may be substituted for the requirements of Tables 1 and Table 2 with prior approval of the Engineer and the FAA. The contractor shall submit complete mixture information necessary to calculate the volumetric components of the mixture.

****

Gap-Graded PCC Mixes

- Common Specifications - ACI
  - No. 57 or No. 67 Stone
  - ASTM C33 Sand
- Produce gap-graded mix
  - Large aggregate + sand
  - High paste demand to fill voids between large aggregate

Typical Sand Gradation

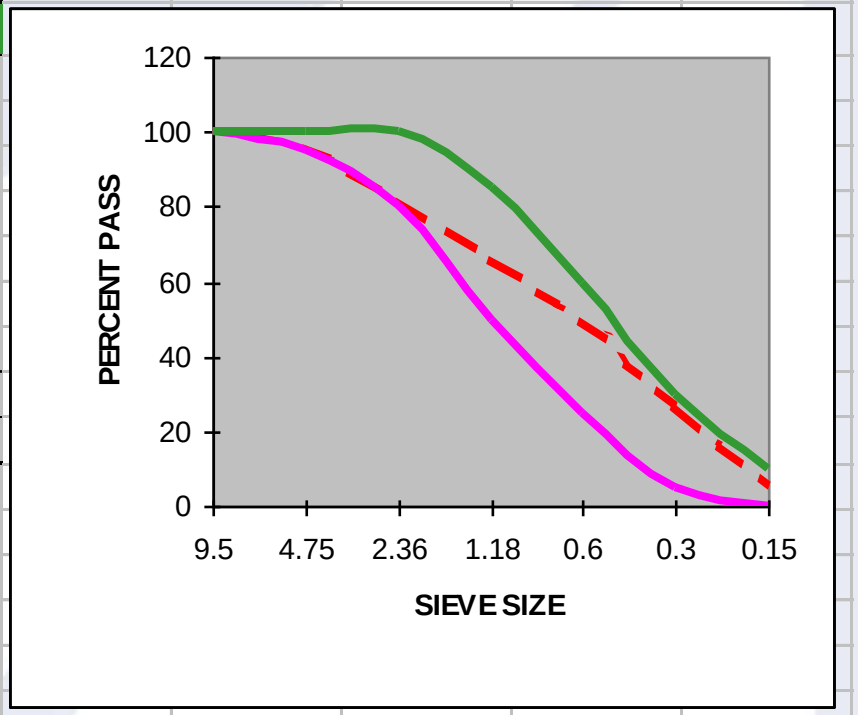
FINENESS MODULAS CALCULATION

MODIFIED LOWER LIMITS FOR HIGH CEMENT FACTOR 400 lbs

SIEVE SIZE			% PASSING		
3/8	9.5 MM	9.5	100	100	100
NO. 4	4.75 MM	4.8	96	95	100
NO. 8	2.36 MM	2.4	82	80	100
NO. 16	1.18 MM	1.2	66	50	85
NO. 30	600 mm	0.6	50	25	60
NO. 50	300 mm	0.3	27	5	30
NO.100	150 mm	0.2	6	0	10
	TOTAL		427		
FINENESS MODULAS			2.73		

ASTM C-33 LIMITS

FM 2.3 TO 3.1 45% MAX BETWEEN SIEVES



Can Coarse Sand be Specified?

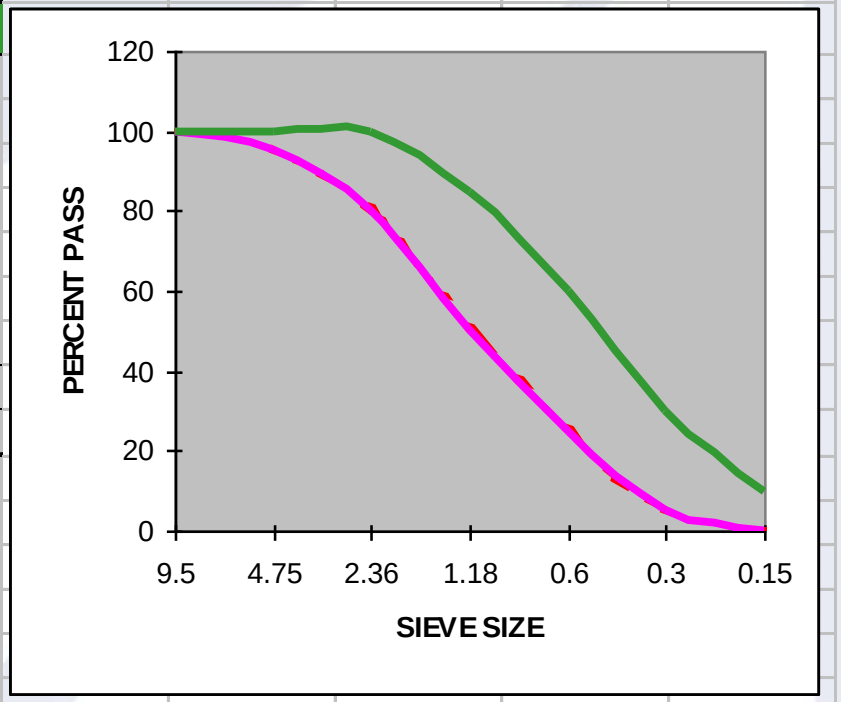
FINENESS MODULAS CALCULATION

MODIFIED LOWER LIMITS FOR HIGH CEMENT FACTOR 400 lbs

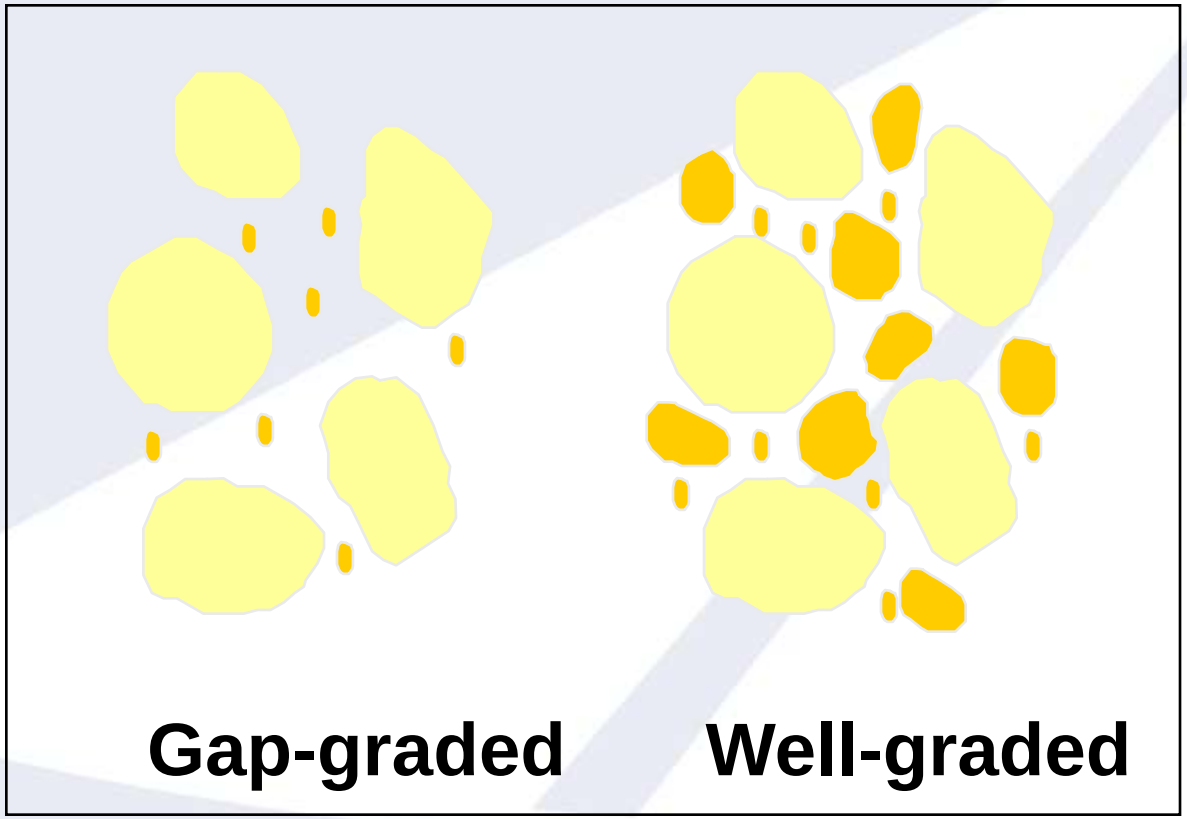
SIEVE SIZE		% PASSING			
3/8	9.5 MM	9.5	100	100	100
NO. 4	4.75 MM	4.8	95	95	100
NO. 8	2.36 MM	2.4	80	80	100
NO. 16	1.18 MM	1.2	50	50	85
NO. 30	600 mm	0.6	25	25	60
NO. 50	300 mm	0.3	5	5	30
NO.100	150 mm	0.2	0	0	10
	TOTAL		355		
FINENESS MODULAS			**3.45**		

ASTM C-33 LIMITS

FM 2.3 TO 3.1 45% MAX BETWEEN SIEVES



Aggregate Grading (Optimize)



Combined Aggregate Grading

- Proportioned for:
  - Workability
  - Finishibility
- Percent Combined Aggregate Retain

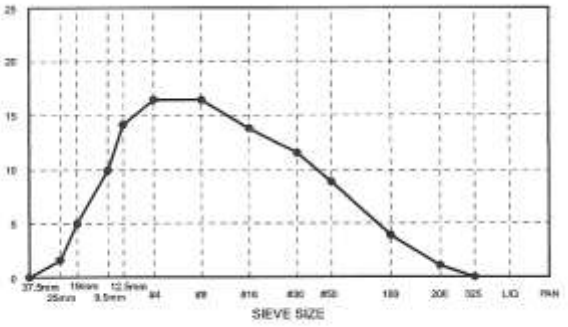


Figure 3.5 "Haystack" Particle Distribution for a Uniformly Graded Mixture

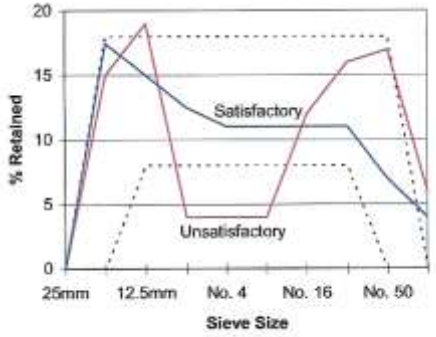
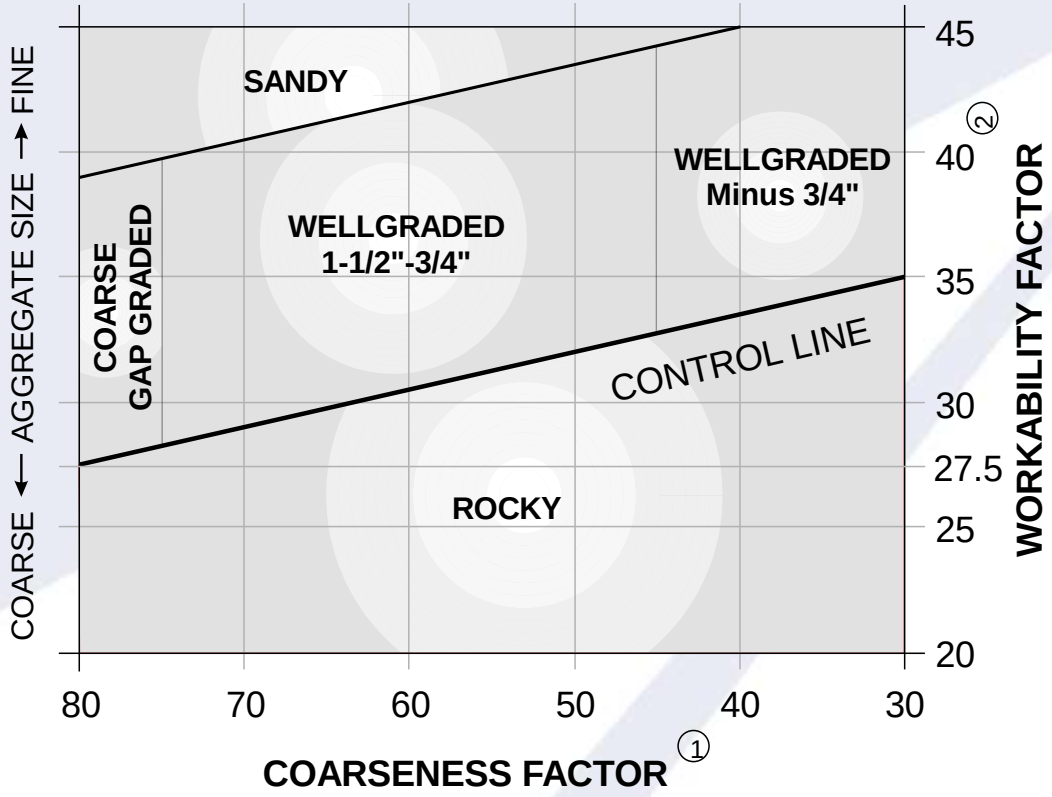


Figure 3.1 Percent Combined Aggregate Retained

USAF Constructability Chart



NOTES:

① **COARSENESS FACTOR =** $\dfrac{\text{\% RETAINED ABOVE 9.5mm SIEVE}}{\text{\% RETAINED ABOVE \#8 SIEVE}}$ X 100

② **WORKABILITY FACTOR =** % PASSING #8

Aggregate Proportioning Guide

(This is a paper analysis – starting point)

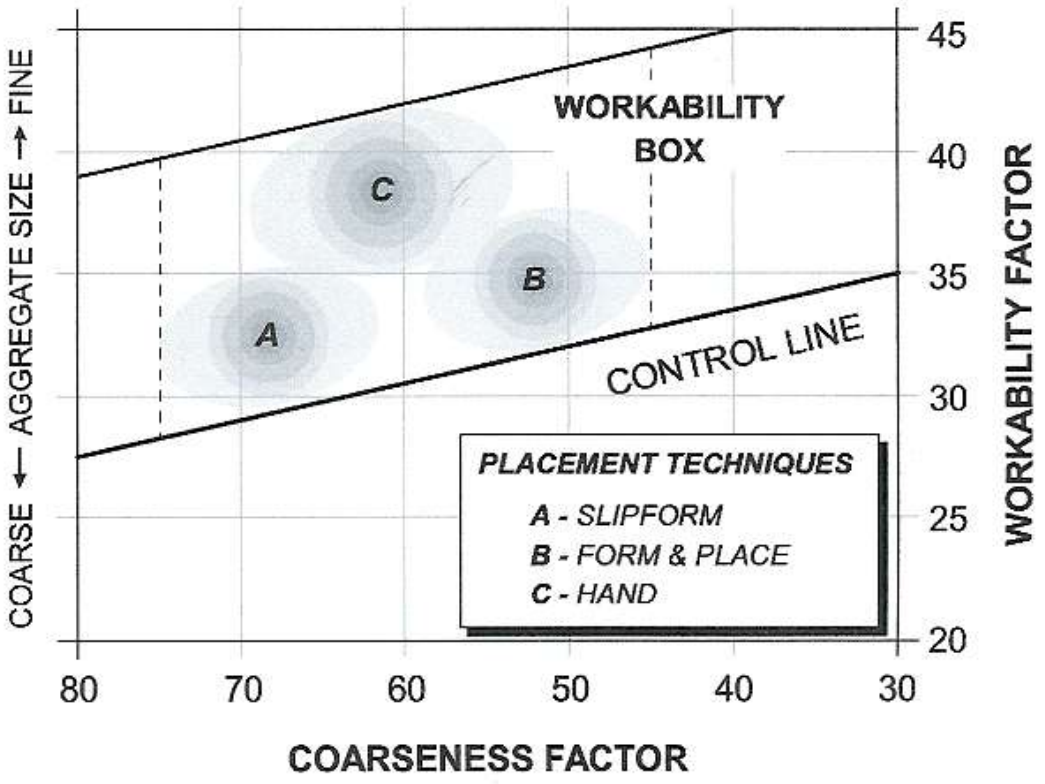


Figure 3.3 Workability Box Within Aggregate Proportioning Guide


2002 6 20

Paragraph 501-3.1 Proportions

- Minimum cementitious material content – 564 pounds
  - Is this necessary
  - Optimized mixtures man not require this much
- Maximum w/c ratio – 0.45
- Should a minimum be specified?
  - w/c < 0.38 tends to experience uncontrolled early-aged cracks

Paragraph 501-4.1 Equipment

****
The Engineer may specify the use of a central plant mixer if deemed necessary for a particular project.
****

c. Finishing Equipment. The standard method of constructing concrete pavements on FAA projects shall be with an approved slip-form paving equipment designed to spread, consolidate, screed, and float-finish the freshly placed concrete in one complete pass of the machine so a dense and homogeneous pavement is achieved with a minimum of hand finishing. The paver-finisher shall be a heavy duty, self-propelled machine designed specifically for paving and finishing high quality concrete pavements. It shall weigh at least 2200 lbs. per foot of paving lane width and powered by an engine having at least 6.0 horsepower per foot of lane width.
On projects requiring less than 500 square yards of cement concrete pavement or requiring individual placement areas of less than 500 square yards, or irregular areas at locations inaccessible to slip-form paving equipment, cement concrete pavement may be placed with approved placement and finishing equipment utilizing stationary side forms. Hand screeding and float finishing may only be utilized on small irregular areas as allowed by the Engineer.

d. Vibrators. Vibrator shall be the internal type. Operating frequency for internal vibrators shall be between 8,000 and 12,000 vibrations per minute. Average amplitude for internal vibrators shall be 0.025-0.05 inches (0.06-0.13 cm).
The number, spacing, and frequency shall be as necessary to provide a dense and homogeneous pavement and meet the recommendations of ACI 309, Guide for Consolidation of Concrete. Adequate power to operate all vibrators shall be available on the paver. The vibrators shall be automatically controlled so that they shall be stopped as forward motion ceases. The contractor shall provide an electronic or mechanical means to monitor vibrator status. The checks on vibrator status shall occur a minimum of two times per day or when requested by the Engineer.
Hand held vibrators may be used in irregular areas only, but shall meet the recommendations of ACI 309, Guide for Consolidation of Concrete.

Paragraph 501-4.1 Equipment

Problem with this provision

- What is the intent? Slip form as standard?
- Then why is side forms described in section f?
- Paragraph 501.4.8 Placing Concrete gives the option – side or slip form
  - Note to the engineer give the engineer the choice
  - Needs to be consistent with the intent in 4.1
- Leads to confusion
- Vibrators—shouldn't the mixture control the frequency

When do we get into trouble?

When we can only read and don't understand the consequences of what the written specifications say

- Example - Proper finish for application
  - Architectural
  - Industrial
  - Pavements

Clear case of specifications not being understood – nobody win a dispute

In summary

- Understand concrete basics
- Compile specs to meet projects requirements within the basics
- Avoid Surprises
- Communicate & Coordinate & inform
- Pre-paving conference
- Keep current with basics
- Be flexible when it really doesn't matter
- Stand firm when it does
- Use common sense – we are trying to build something in the real world
- Sometimes we have to do more than just "READ" the spec and enforce them

THANK YOU!

Please contact Gary L. Mitchell with questions or comments:

gmitchell@pavement.com