Using P-501 to Specify Concrete Pavements

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Count on Concrete PAVEMENT

FAA ITEM P-501

- 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 exceed 200 psi.

FAA ITEM P-501

- Pavements conforming to Item P-501 are generally more challenging to construct than typical state highway pavements.
- The 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.

SPECIFICATIONS?

Strength and Thickness

Strength and Thickness

Durability

Measurement of Quality?

Quality Is Inherent in The Specifications

Design Not Related to Surface Defects

The Contractor Did It

Will Specifications written for this work for:

Should we have the construction method in mind during development of specifications?

Guide or boilerplate specifications?

Stakeholders

- Owner
- Engineers
- Architects
- Contractors
- Concrete Suppliers
- Others

- ✈Each wants quality
- ✈Quality finished product
- ✈Reputation/Perception
- ✈Full Payment for work

We All Intend to do GOOD!

- 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 about:
  - Consistency
  - Trends Analysis
  - ID of Critical Variables Before They Become Statistics
- Quality is not Obtained Through Duplicative Testing

How do we build quality?

- Consistency
- Desired Characteristics
  - workability
  - strength
  - durability

Engineer of Record

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

Contractor

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

Concrete Supplier Needs

- No Guesswork
- Rapid – Reasonable Decisions
- Timely Orders
- Quick Truck Turn Around
- Prompt Payment
- Arrive on time with the right concrete

Bid Price

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

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

Specifications - EOR

- 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

Defining Workability

(Who's Responsibility for workability?)

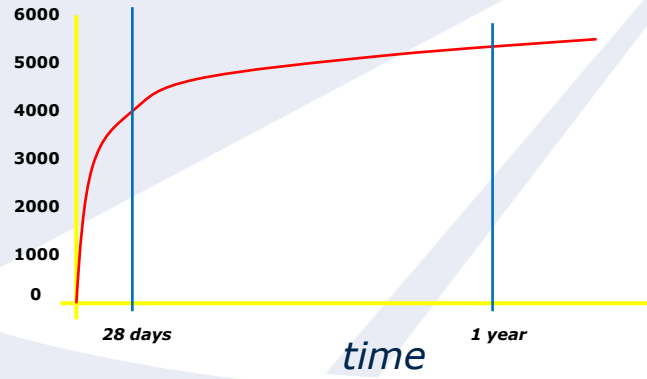
Component	Placement	Consolidation	Finish
Aggregates			
Coarse	C	C	M
Fine	M	M	C
Cement		S	M
Water	C	C	C
Admixtures			
Air Entraining	M	M	S
Mineral	M	M	M
Chemical	C	C	S

Materials

- Cement
  - C 150 Portland Cement – Type I, II, III, IV
  - C 595 Blended Cement – blended type IP, IS
  - ASTM C 1157 – High early, sulfate resistance, high sulfate resistance, low heat of hydrations
- Admixtures
  - C 618 Fly Ash, C 989 Slag, C 1240 Silica Fume
  - C 260 Air Entraining Agent
- Aggregate
  - C 33

Strength Gain over Time

What strength should we specify?



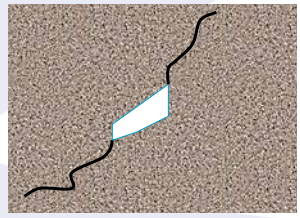
Temperature Effects

- Hot: Faster chemical reaction
- Cool: Slower Reaction
- But, Concrete makes its own heat
- Effect on
  - Set
  - Strength gain

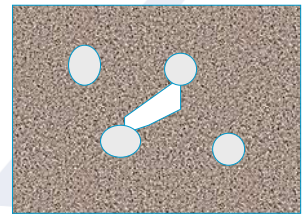
Air Entrainment

- Water expands when frozen
- Air = room to expand

Pores filled with water freezes/expands and cracks



Ice forms in entrained air voids and relieves stress



Chemical Admixtures

- Accelerators
- Retarders
- Water Reducing (High Range Water Reducers)
- Must be compatible with other components

Slump Loss over Time

- Depends on:
  - Cement content
  - Admixtures
  - Temperature
  - "Sunspots"?

Often see HRWR in concrete mixtures

Effects of HRWR

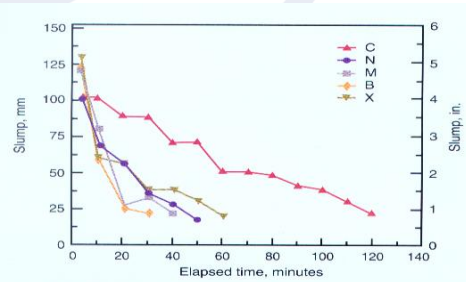


Fig. 6-7. Slump loss at 23°C (73°F) in mixtures containing high-range water reducers (N, M, B, and X) compared with control mixture (C) (Whiting and Dziedzic 1992).

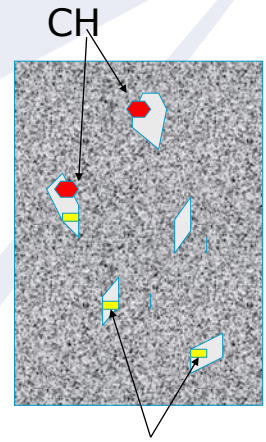
Pozzolans

- Reactive Silica from Ash, Slag, Fume
- Bonds Chemically with CH formed by cement reaction
- Slower Strength Gain
  - Takes time to get started
  - No heat early
  - Doesn't retard but does dilute
- Improves Durability
  - Fills existing pores
  - Removes reactive components

Pozzolanic Reaction

CH + S = C-S-H

- Additional Curing Time
- Lower early strengths
- Higher ultimate strengths
- Reduced permeability



Pozzolan (reactive silica)

Pozzolans

- **Fly ash**
  - Improves Durability
  - Increases Water Demand
  - Increases AEA
  - Sand Reduction
  - **Class C contains calcium**
  - Hot ↑ Cold ↓
- **GGBFS**
  - Cementitious
  - Improves Durability
  - Improves Workability
  - No Bleed Water
  - Stiff Mix
  - Sensitive to Vibration
  - Saw Cutting Critical
  - Beware of finishing issues

Pozzolans: Typical Quantities

- Fly Ash: 20 – 30 %
  - Help mitigate ASR?? (Class F low lime Ash only)
- Slag: 25 – 55 %

Aggregates

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

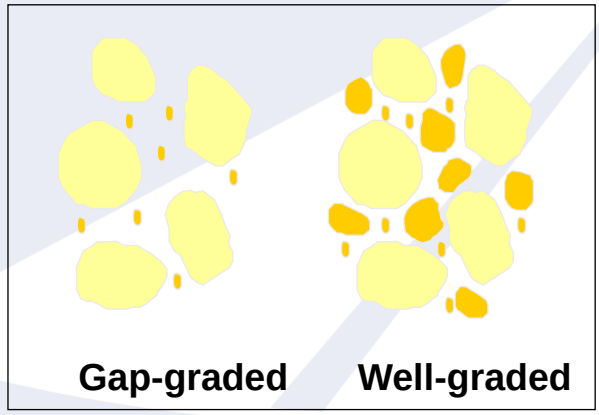
PCC Mix History

- Dense-graded prior to WWII
- After WWII began asphalt industry;
  - intermediate aggregates for aspahlt
  - PCC became gap graded
  - Admixture use increases
- Shilstone Mixes
- USAF Combined Gradation 1997

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

Aggregate Grading (Optimize)



Combined Aggregate Grading

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

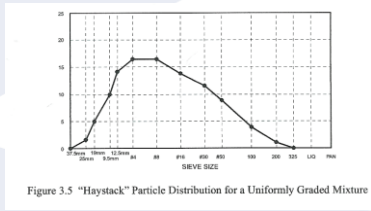


Figure 3.5 "Haystack" Particle Distribution for a Uniformly Graded Mixture

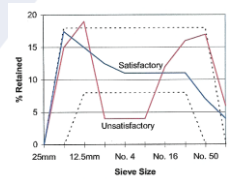
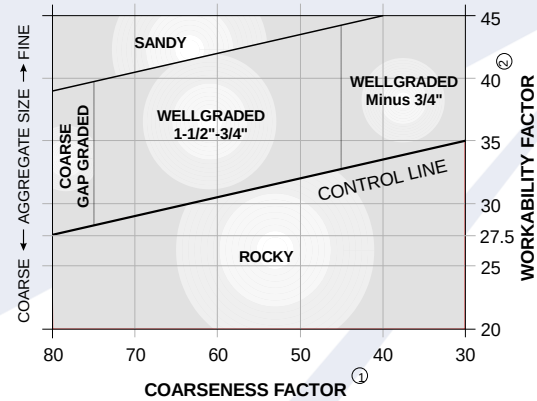


Figure 3.1 Percent Combined Aggregate Retained

USAF Constructability Chart



NOTES:

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

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

Aggregate Proportioning Guide

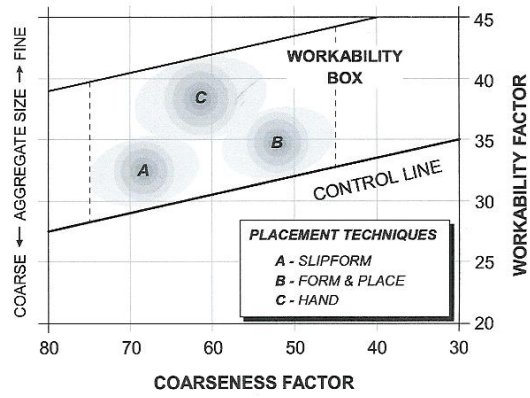


Figure 3.3 Workability Box Within Aggregate Proportioning Guide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Using P-501

- Rigid Pavement Guide Specification
- Difficult to meet
- Contradictions
- Notes to the engineer
- Need to understand the intent
- Once under contract – rule of law
  - If not well-written can create disputes

Paragraph 501-2.1 Aggregates

- Reactivity
  - Standard ASR testing on individual aggregates
  - ASTM C 1260 and ASTM C 1567
  - If deicers are used – EB # 70 applies (note)
- ASTM C 666 – Rapid Freeze/Thaw Test (note)
- Percentage of ware <40 in LA Abrasion test (note)

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.

****

Paragraph P-501-2.3 Cementitious Materials

- Delete Class C Pozzolans for area of potential ASR aggregates
- Slag Cement and other pozzolans are protected by EPA
- Hazardous material?
- Class F pozzolans appear to mitigate ASR expansion

Paragraph 501-3.1 Porportions

- 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 501-3.3 Admixtures

****

The Engineer shall specify the appropriate air content as determined from the table in this note. For warm climate areas where freezing and thawing are not a factor, non-air-entrained concrete may be used.

RECOMMENDED AIR CONTENT (PERCENT)

	Maximum Size Aggregate inches (mm)				
Exposure Level	2(51)	1.5(38)	1(25)	3/4(19)	1/2(13)
Mild	2.0	2.5	3.0	3.5	4.0
Moderate	4.0	4.5	4.5	5.0	5.5
Severe	5.0	5.5	6.0	6.0	7.0

Mild exposure - When desired for other than durability, such as to improve workability. Used where pavement will not be exposed to freezing or to deicing agents.

Moderate exposure - Service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing agents or other aggressive chemicals.

Severe exposure - Concrete which is exposed to deicing chemicals or other aggressive agents or where the concrete may become highly saturated by continual contact with moisture or free water prior to freezing.

****

If allowing the contractor to optimize the mixture, then the table should be included in the specifications

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

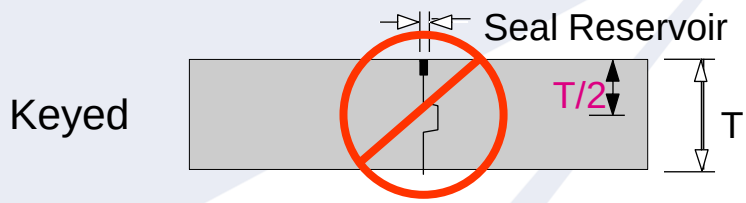
- What is the intent? Slip form as standard?
- Then why is side forms described in section f?
- Paragraph 501.4.8 Placing Concrete gives the option – side or slip form
  - Note to the engineer give the engineer the choice
  - Needs to be consistent with the intent in 4.1
- Leads to confusion

Paragraph 501-4.10 Joints

- Terminology in 6E has changed – should change "expansion joints to isolation joints"
- Eliminate reference to dowelled isolation joints
- Add terminology for Type A1 if used

Construction Joint Details

****
The Engineer should refer to Advisory Circular 150/5320-6 for guidance on the use of keyways.
****



FAA AC/150-5320-6E - Not recommended for use.

Paragraph 501-4.20 Existing Concrete Pavement Removal and Repair

****
NOTE: It is imperative that sufficient exploration be made (not just reference to as-built drawings) so that the designer knows exactly what the existing (in place) pavement is at the jointing area—dowels, keys, tie bars, etc. and its condition. Normally the joint between the new pavement and existing pavement should be made at an existing joint in the old pavement.
****

If this isn't done then expect a change order. If existing condition is different that shown on the plan, then the contractor may be due additional compensation based on actual conditions.

Paragraph 501-5.2 Acceptance Criteria, Item 3 - smoothness

****
Use of the profilograph to measure pavement smoothness is optional and will be approved on a case-by-case basis. Use of a profilometer may not be practical for all construction. However, the profilograph is useful for new construction or overlays designed to correct grade and smoothness deficiencies. If the profilograph is to be included, straightedge requirements need only apply in the transverse direction. To include profilograph requirements delete paragraph (5.2e3) and replace with the following:

(3) SMOOTHNESS. As soon as the concrete has hardened sufficiently, the pavement surface shall be tested in the transverse direction with a 16-foot straightedge or other specified device. Surface smoothness deviations shall not exceed 1/4 inch from a 16-foot straightedge at any location, including placement along and spanning any pavement joint or edge.

- The criteria is the 16 foot straight edge
- ¼ inch deviation along the entire straightedge
- California Profilograph is optional on case by case basis on approval by FAA
- Is meaningless to aircraft response
- therefore the PI cannot reflect smoothness as used in P-501

Paragraph 501-5.2 Acceptance Criteria, Item 3 - smoothness

- profilograph cannot emulate the 16-foot straightedge
- Doesn't work as a rolling profile because the straight edge is 12.5 feet and not 16 – the deviation criteria would need to be changed
- PI spec is very conservative
- Can be used to construct smooth pavement …
- … but 4 in./mile is not necessarily smoother than 8 in./mile
- Long-wave length must be considered – refer to IPRF
- Should not be used for defining remove and replace
- If not used should remove table in section 501-8.1 (c)

"When the PI exceeds the value specified, the profile as measured by the profilograph trace will be examined. Any bumps that exceed ½-inch in height are must grind with the maximum depth of grinding of ¼-inch. Bumps less than ¼-inch in height are acceptable and will remain. Bumps exceeding ¼-inch in height will be examined for approach slopes and those slopes exceeding 0.15% will be ground to a maximum of ¼-inch height. Grinding of bumps identified by the profilograph will be accomplished only within the aircraft traffic area, i.e., runway –center 75 feet, taxiway center 45 feet".

Method of Payment - PWL

- Today's requirements
- Quality vs. cost
- Boiler Plate Specs shift Risk to the Contractor
- P-501 was developed to share risk

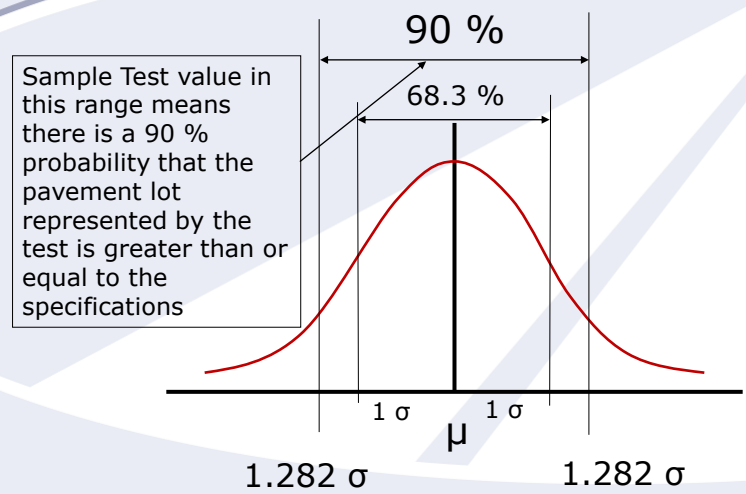
Background

- Single Representative Sample
- No provision for variability
- 1959 AASHTO Road test Results
- Method Needed that shared risk

Statistical Quality Control Concepts

- Test are estimates
- Variation expected
  - Material
  - Errors in Sampling
- Random Sampling
- Two Measures define Quality
  - Average
  - Variation (or standard deviation)

Standard Normal Probability Distribution



Acceptance Criteria and Design Relationship

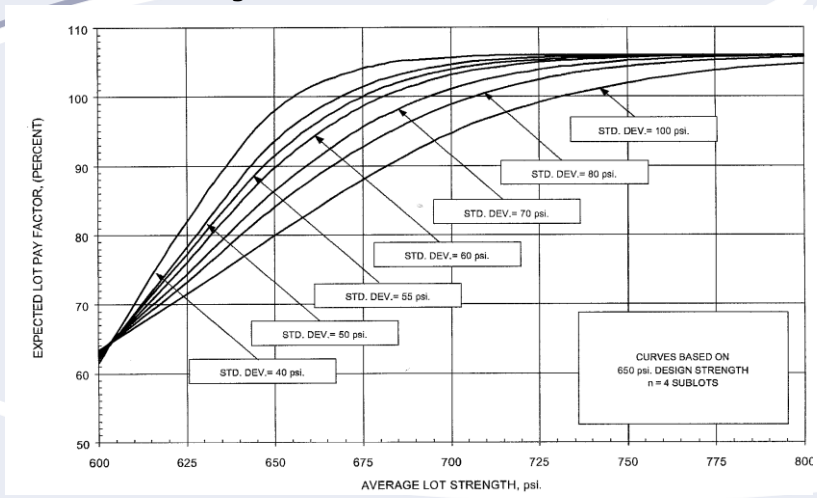
- Construction Specification purpose
- Design Intent and AQL Relationship
- Design assumes 1 Standard Deviation
- AQL is established at 90 PWL
- RQL=AQL-1 Standard Deviation

RQL = AQL – 34.1 %
= 90 – 34.1
= 55 PWL
Design intent is met

Acceptable vs. Unacceptable

- Acceptable Quality Level (AQL)
  - Minimum requirement for full pay
- Rejectable Quality Level (RQL)
  - Minimum requirement at reduced pay
- AQL and RQL can be related to total area under the normal probability density curve
- Quality Index
- 1.282 standard deviation = 90 PWL
- Lower tolerance limit = 93% of the design strength

Figure 1: Expected Pay Factor versus Average Lot Strength



Source: FAA Engineering Brief 56

FAA Pay Adjustment Schedule Helps Balance Risk Levels between the contractor and owner

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96-100	106
90 - 95	PWL + 10
75 - 90	0.5 PWL + 55
55 - 74	1.4 PWL - 12
Below 55	Reject

PWL

- Contractor strive to earn the incentive
- Production at 90 % - expect full pay
- Increased parameter test values doesn't equate to quality
- Consistency should be rewarded – less risk to owner

PWL

- Incentive incorporated to offset risk and increased production cost
- Reward the contractor with tight process control
- Consistency means higher quality pavement – increased pavement life

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:
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