Canadian Airfield Pavement Technical Group Workshop

Concrete Pavement Materials

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Cement Association of Canada

Cement Association of Canada | Association Canadienne du Ciment

le béton...génial![MC] | CONCRETE even smarter than you think™

OUTLINE

- Concrete Mixtures
- Supplementary Cementing Materials
- Aggregates
- Admixtures
- Portland-limestone Cement
- Stabilized base/subbase

CONCRETE MIXTURES

BASIC INGREDIENTS

- **Concrete**
  - Water
  - Cementitious Materials (cement, supplementary cementing materials such as slag and flyash)
  - Fine aggregates-Sand
  - Coarse Aggregates-Stone

CEMENT FACTOR

Characteristics

- More Cement Means Higher Strength
- Finely ground Cement Means Earlier Strength
- Low W/C Means Higher Strength
- High Cement Factor for Higher-Early

Offsets

- Higher Water Demand
- Needs More Water (?)
- More Mixing Time
- Smaller Aggregates and More Air

SUPPLEMENTARY CEMENTING MATERIALS

FLY ASH, SLAG, SILICA FUME, AND NATURAL POZZOLANS

Also known as —

Supplementary Cementing Materials (SCMs)

CSA A3001-13

A material or materials that, when used in conjunction with the portland cement component of hydraulic cement, contributes to the properties of the hardened concrete through hydraulic or pozzolanic activity, or both.

SUPPLEMENTARY CEMENTING MATERIALS (SCMS)

From left to right:

- Fly ash (Type CI/CH)
- Metakaolin (calcined clay) (Type N)
- Silica fume (Type SF/SFI)
- Fly ash (Class F)
- Slag (Type S)
- Calcined shale (Type N)

SCM - FLY ASH

- Fly Ash — the finely divided residue that results from the combustion of pulverized coal or a combination of pulverized coal blended with up to 30% by mass of petroleum coke and is carried from the combustion chamber of a furnace by exhaust gases
- Fly ash is classified as Type CI (8-20%), or CH (>20%) and F (<8%)based on by its calcium oxide (CaO) content

SCM - GRANULATED SLAG

- Type S —GGBFS, product obtained by grinding granulated blast-furnace slag, to which the various forms of calcium sulphate, water, and processing additions may be added at the option of the manufacturer

SCM — SILICA FUME

- Silica Fume — the finely divided residue, resulting from the production of silicon, ferro-silicon, or other silicon-containing alloys, that is carried from the burning area of a furnace by exhaust gases
- Silica Fume is classified as Type SF ($\geq$ 85% or SFI ($\geq$ 75%) by its silica (SiO_2) content

AGGREGATES FOR CONCRETE

FINE AGGREGATE (F.A.)

- Sand and/or crushed stone
- < 5 mm
- F.A. content usually 35% to 45% by mass or volume of total aggregate

COARSE AGGREGATE (C.A.)

- Gravel and crushed stone
- most particles $\geq$ 5 mm
- typically between 10 mm and 40mm

AGGREGATE CHARACTERISTICS AND TESTS (1)

Characteristic	Test
Abrasion resistance	CSA A23.2-16A, A23.2-17A, A23.2 - 23A
Freeze-thaw resistance	CSA A23.2-24A
Sulphate resistance	CSA A23.2-9A
Particle shape and surface texture	CSA A23.2-13A
Grading	CSA A23.2-2A, A23.2-5A
Void content	ASTM C 1252
Bulk Density	CSA A23.2-10A

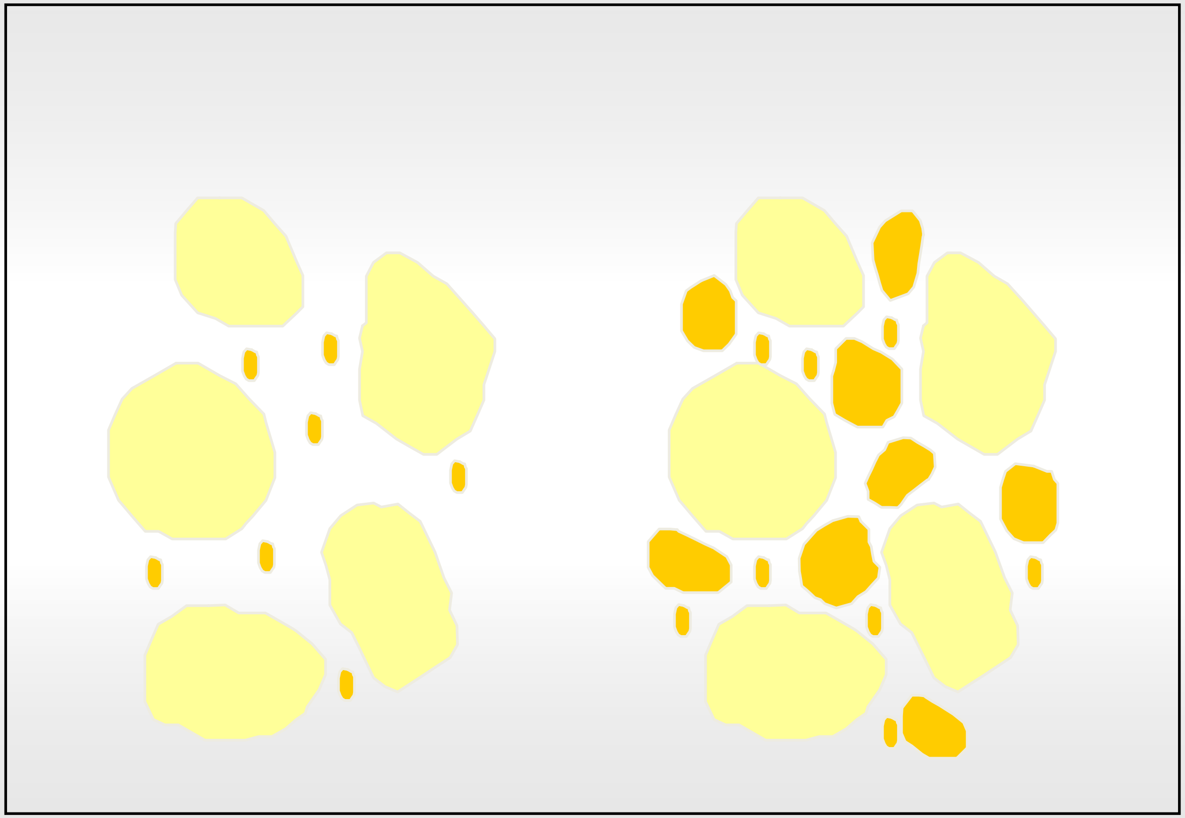
AGGREGATE CHARACTERISTICS AND TESTS (2)

Characteristic	Test
Relative density	CSA A23.2-6A — fine aggregate CSA A23.2-12A—coarse aggregate
Absorption and surface moisture	CSA A23.2-6A, A23.2-11A, A23.2-12A
Strength	CSA A23.2-8C, A23.2-9C
Def. of constituents	ASTM C 125, ASTM C 294
Aggregate constituents	CSA A23.2-3A, A23.2-4A, A23.2-5A, A23.2-7A, A23.2-8A
Alkali Resistance	CSA A23.2-14A, A23.2-25A, A23.2-26A, 27A, ASTM C 227, ASTM C 289, ASTM C 295, ASTM C 586

AGGREGATE VARIABLES

- Stone
  - **Gap Graded**
  - **Maximum Size**
  - **Nominal Maximum Size**
  - **Quality**
  - **Blends**
  - **Coarseness Factor**
- Sand
  - **Fineness Modulus**
  - **Gap Grading**
- Binder
  - **Cement and SCMs**

AGGREGATE GRADING (OPTIMIZE)



Gap-graded

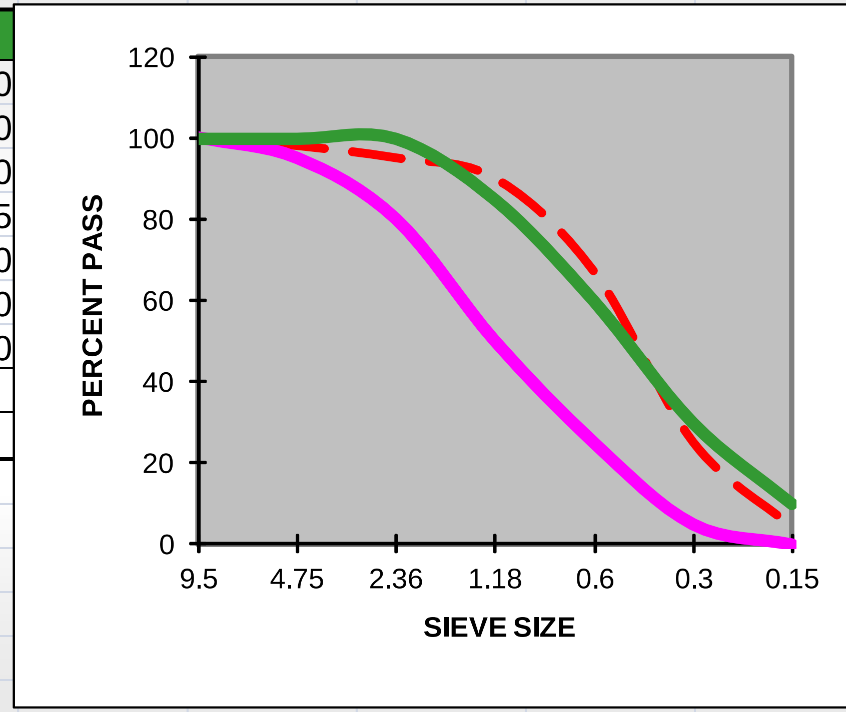
Well-graded

Sand For Masonry Mortar

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	98	95	100
NO. 8 2.36 MM	2.4	95	80	100
NO. 16 1.18 MM	1.2	90	50	85
NO. 30 600 mm	0.6	67	25	60
NO. 50 300 mm	0.3	25	5	30
NO.100 150 mm	0.2	4	0	10
TOTAL		479		
FINENESS MODULAS		2.21		



ASTM C-33 LIMITS

Standard Specification for Concrete Aggregates

FM 2.3 TO 3.5

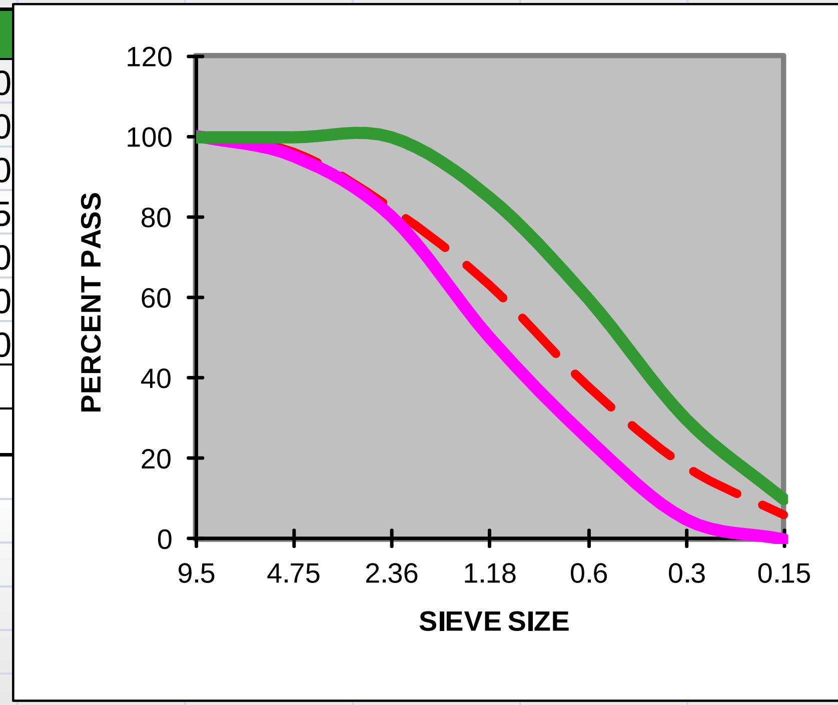
Fineness Modulus: is calculated by adding the total percentages of material in the fine aggregate sample that is retained in each designated sieve, and dividing the number by 100.

Sand That Works

FINENESS MODULAS CALCULATION

MODIFIED LOWER LIMITS FOR HIGH CEMENT FACTOR 400 lbs

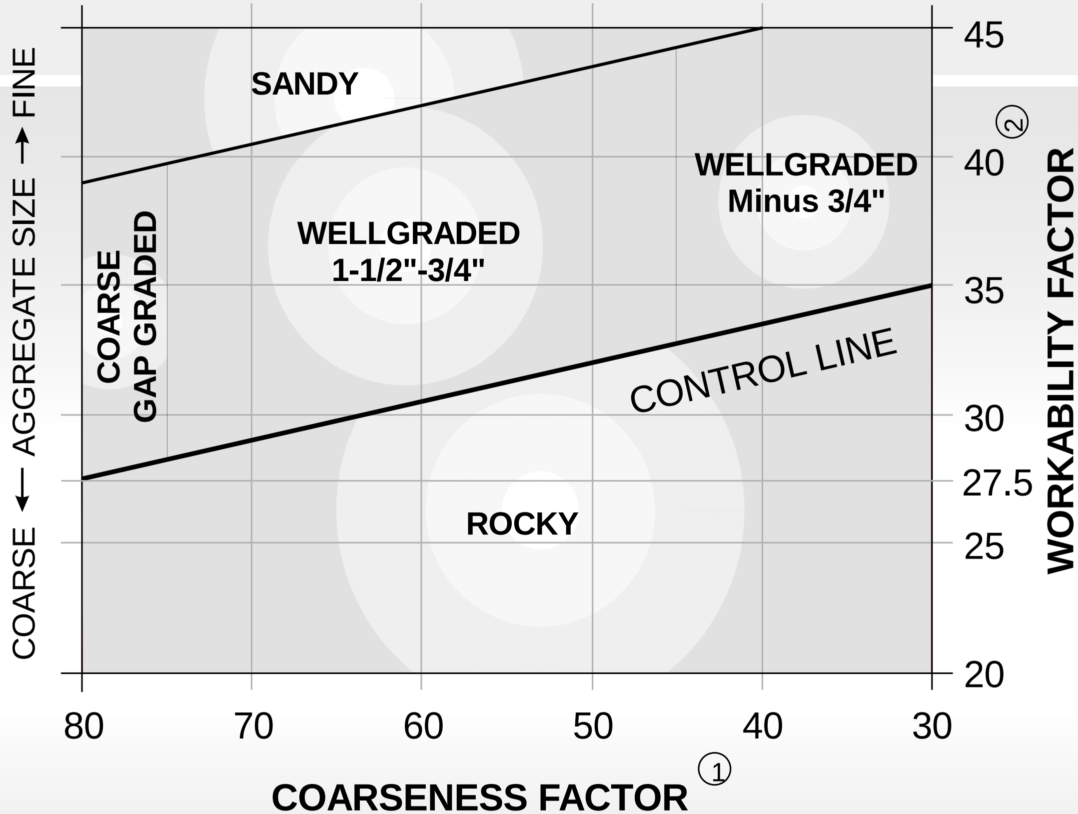
SIEVE SIZE		% PASSING		
3/8 9.5 MM	9.5	100	100	100
NO. 4 4.75 MM	4.8	96	95	100
NO. 8 2.36 MM	2.4	82	80	100
NO. 16 1.18 MM	1.2	63	50	85
NO. 30 600 mm	0.6	38	25	60
NO. 50 300 mm	0.3	18	5	30
NO.100 150 mm	0.2	6	0	10
TOTAL		403		
FINENESS MODULAS		2.97		



ASTM C-33 LIMITS

FM 2.3 TO 3.5

USAF Constructability Chart



NOTES:

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

② **WORKABILITY FACTOR =** % PASSING #8 (2.36 mm)

PROPERTIES OF CONCRETE MIXES

- Adequate durability/workability
- Adequate flexural strength
- Skid resistant

SUMMARY OF THE ISSUE

- Amount of Water per Cubic Metres single most critical factor
  - Cementing Materials Content Low
  - avoid high fines
  - use largest size coarse possible
- Water Reducers
- Extreme Elements
  - Shorten Panel Size
  - Reduce Bond with base material
  - Reduce Temperature

ADMIXTURES FOR CONCRETE

ADMIXTURES

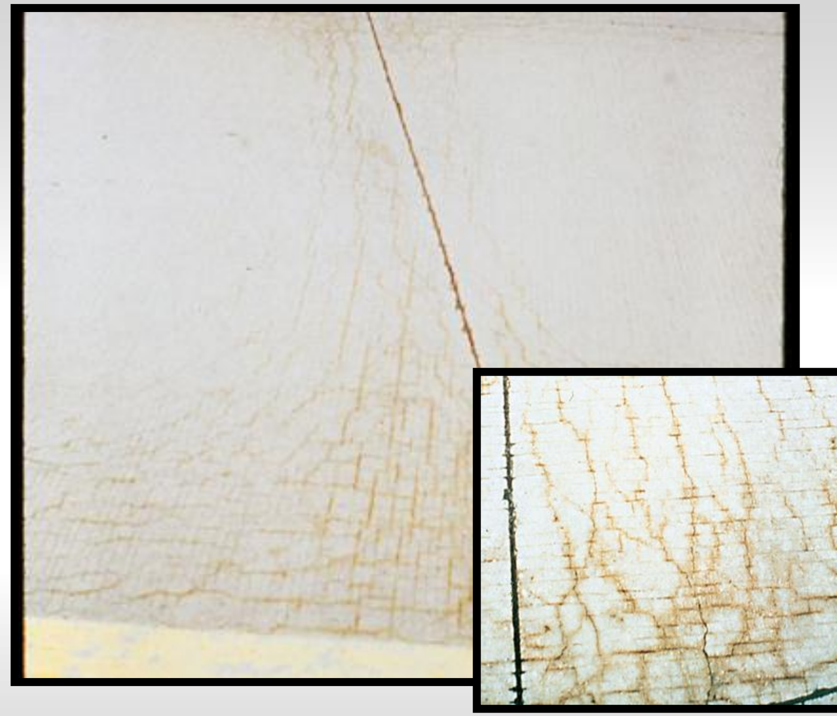
- Air-entraining admixtures
- Water-reducing admixtures
- Plasticizers
- Accelerating admixtures
- Retarding admixtures
- Hydration-control admixtures
- Corrosion inhibitors
- Shrinkage reducers
- ASR inhibitors
- Coloring admixtures
- Miscellaneous admixtures

AIR-ENTRAINING ADMIXTURES – ASTM C260

- Improve durability in concrete exposed to:
  - Freeze-thaw
  - Deicers
  - Sulphates
  - Alkali-reactive environments
- Improve workability
- Reduce risks of segregation and bleeding

FROST DAMAGE

CRUMBLING AT JOINT



FROST INDUCED CRACKING NEAR JOINT

SCALED CONCRETE SURFACE

WATER-REDUCING ADMIXTURES

Water-reducing admixtures are primarily used to:

- Reduce mixing water required to produce a certain slump
- Reduce water-cementing materials ratio
- Reduce cement content
- Increase slump

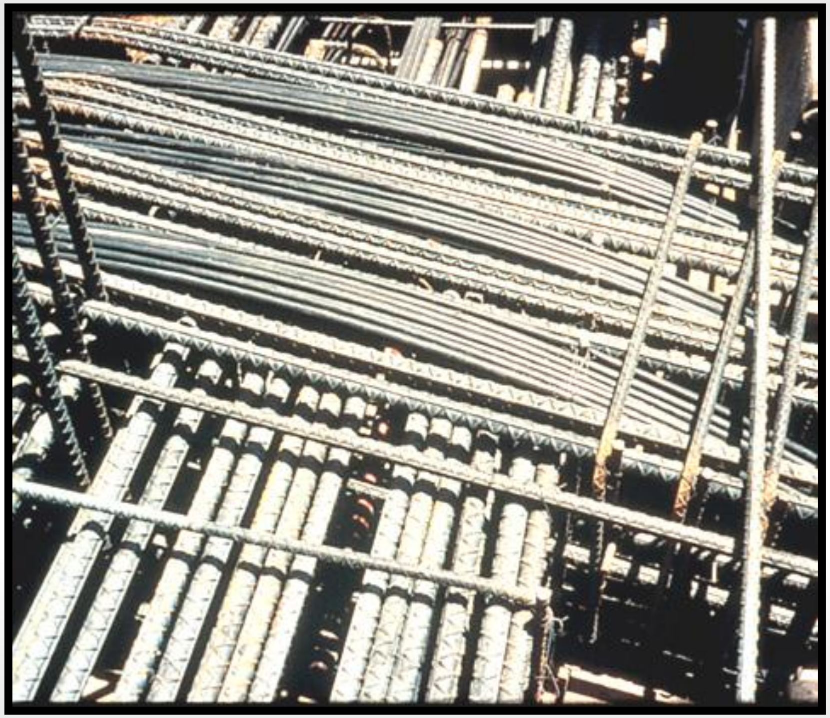
LOW WATER TO CEMENTING MATERIALS RATIO CONCRETE WITH LOW CHLORIDE PERMEABILITY

PLASTICIZERS FOR FLOWING CONCRETE

- Also known as Superplasticizers – ASTM C1017
  - Type 1- plasticizing
  - Type 2- plasticizing and retarding
- Essentially high-range water reducer
- Produce flowing concrete with high slump (≥ 190 mm)
- Reduce bleeding

FLOWING CONCRETE APPLICATIONS

FLOWABLE CONCRETE IS PLACED



AREA OF HEAVY REINFORCING STEEL CONGESTION

RETARDING ADMIXTURES ASTM C494 - TYPE B

- Delay setting or hardening rate for:
  - Hot-weather concreting
  - Difficult placements
  - Special finishing processes

ACCELERATING ADMIXTURES (ASTM C 494 – TYPE C)

- Accelerate the rate of:
  - Hydration (setting)
  - Strength gain (early-age strength gain)
- Calcium chloride accelerators
  - Increase drying shrinkage, potential reinforcement corrosion, potential scaling
  - Darken concrete

MAXIMUM CHLORIDE-ION CONTENT

Type of member	Maximum water soluble chloride-ion (Cl^-) in concrete, percent by mass of cement
Prestressed concrete	0.06
Reinforced concrete exposed to a moist environment or chlorides or both	0.15
Reinforced concrete exposed to neither a moist environment nor chlorides	1.00

CORROSION INHIBITORS

- Control corrosion of steel reinforcement
- Dosage dependent on anticipated chloride level
- Example, calcium nitrite

S413-2007 Parking Structures: Corrosion inhibitor — a chemical that is added to concrete to delay the onset of corrosion of reinforcement in the presence of chlorides.
Note: *A corrosion inhibitor provides protection to embedded reinforcement by chemically influencing the electrochemical corrosion reaction at the reinforcement surface, and not primarily by influencing the concrete matrix, rheology, or permeability.*

SHRINKAGE-REDUCING ADMIXTURES

PORTLAND-LIMESTONE CEMENT
SAVING ENERGY AND REDUCING EMISSIONS

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le béton...génial![MC] | CONCRETE even smarter than you think™

WHAT IS PORTLAND-LIMESTONE CEMENT ?

- Current Portland cements allow up to 5% interground limestone.
- Portland-limestone cement (PLC) includes a maximum of 15% interground limestone.
  - CSA A3000-08 – Portland-limestone Cement Types
    - GUL General Use Cement
    - MHL Moderate Heat of Hydration Cement
    - HEL High Early-Strength Cement
    - LHL Low Heat of Hydration Cement
- PLC cements produced in Canada have equivalent performance to the current portland cement types.
- ***PLC is not currently permitted to be used in sulphate environments (MS and HS classes) in the current CSA Standards, but has been approved in May, 2014 meeting for the next editions of CSA Standards***

PLC IS NOT NEW

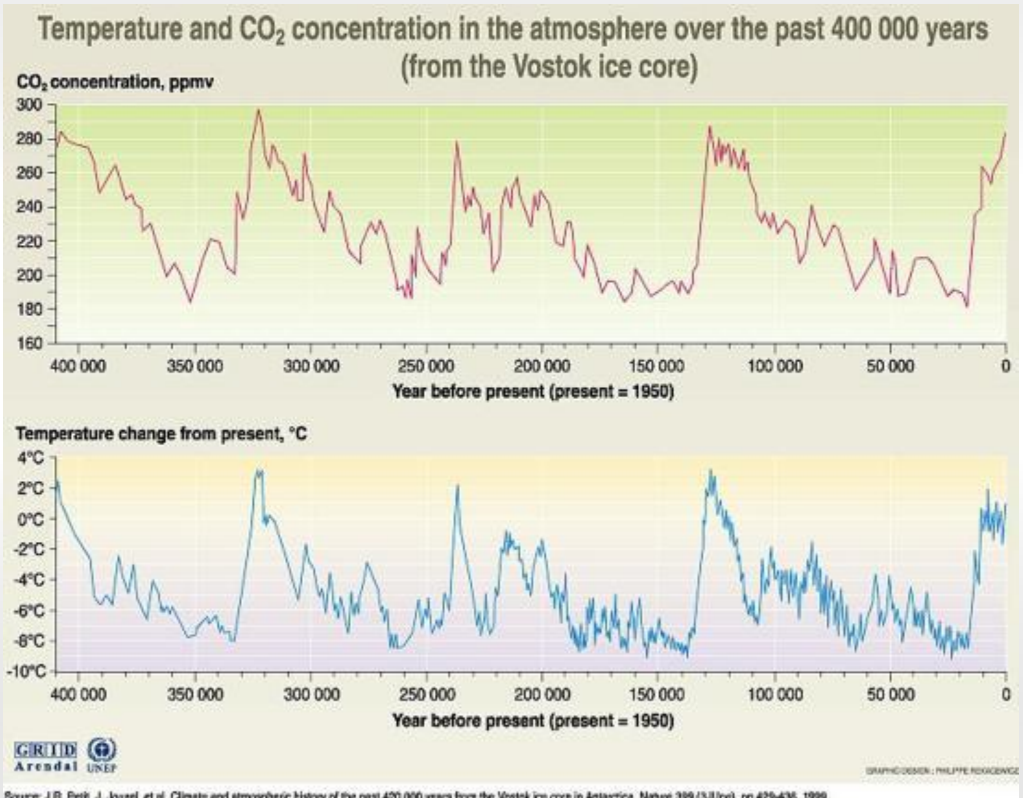
- Used successfully in Europe for over 25 years in a variety of applications and exposure conditions
- New in the specifications in Canada

HISTORY OF LIMESTONE CEMENTS

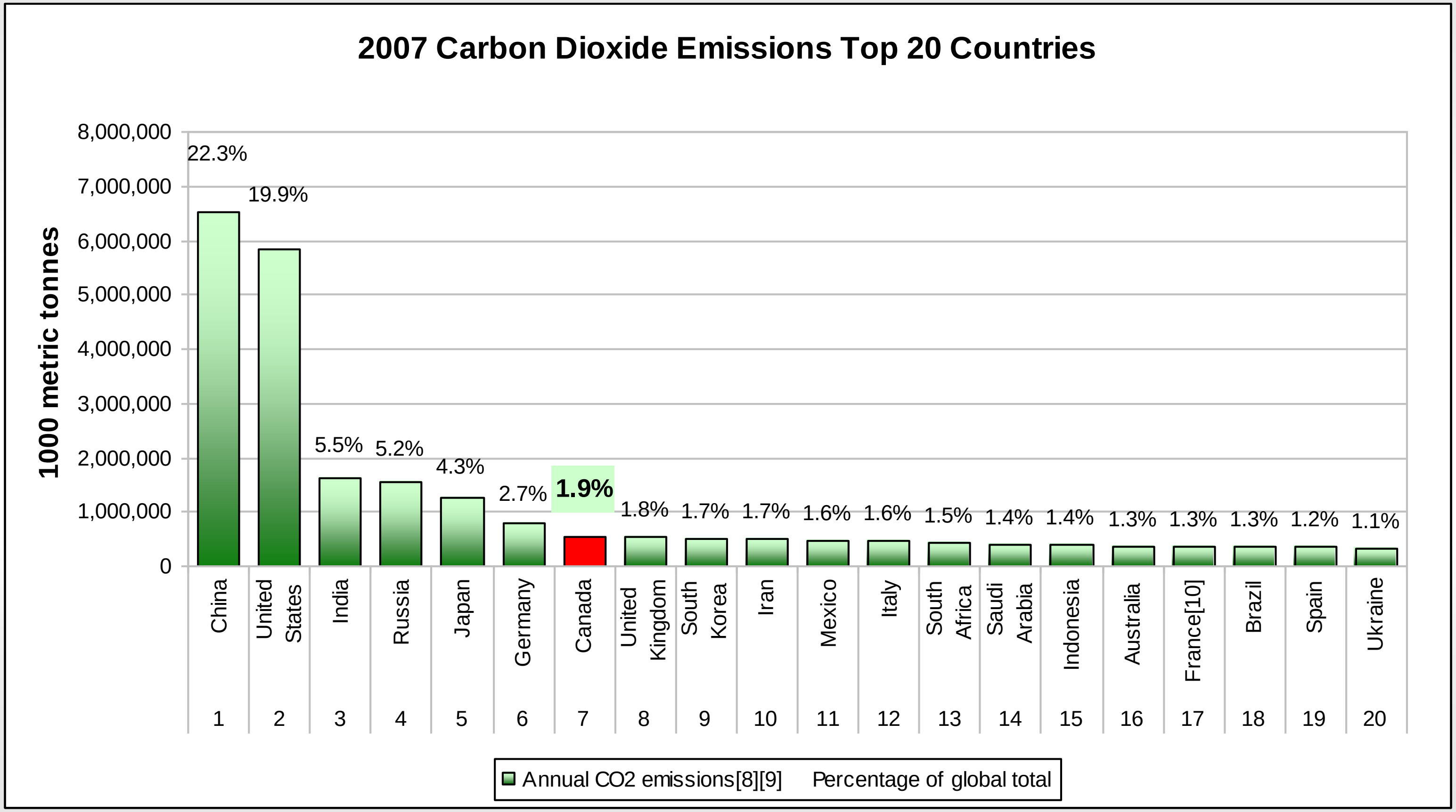
- 1965 Heidelberger produces 20% limestone cement in Germany for specialty applications (Schmidt 1992)
- 1979 French Cement Standards allow limestone additions.
- ***1983 CSA A5 allows 5% in Type 10 (now GU) cement***
- 1990, 15+/-5% limestone blended cements being used in Germany
- 1992, in UK, BS 7583 allows up to 20% in Limestone Cement
- 2000 EN 197-1 allows 5% Limestone) in all 27 common cements,
- 2000 EN 197-1 creates CEM II/A-L (6-20%) and CEM II/B-L (21-35%)
- ***2006 CSA A3001 allows 5% in all other cement types***
- 2004 ASTM C 150 allows 5% in Types I-V
- 2007 AASHTO M85 allows 5% in Types I-V

WHY BRING PLC TO CANADA NOW?

- The Global consensus is that Climate Change is real, and serious.

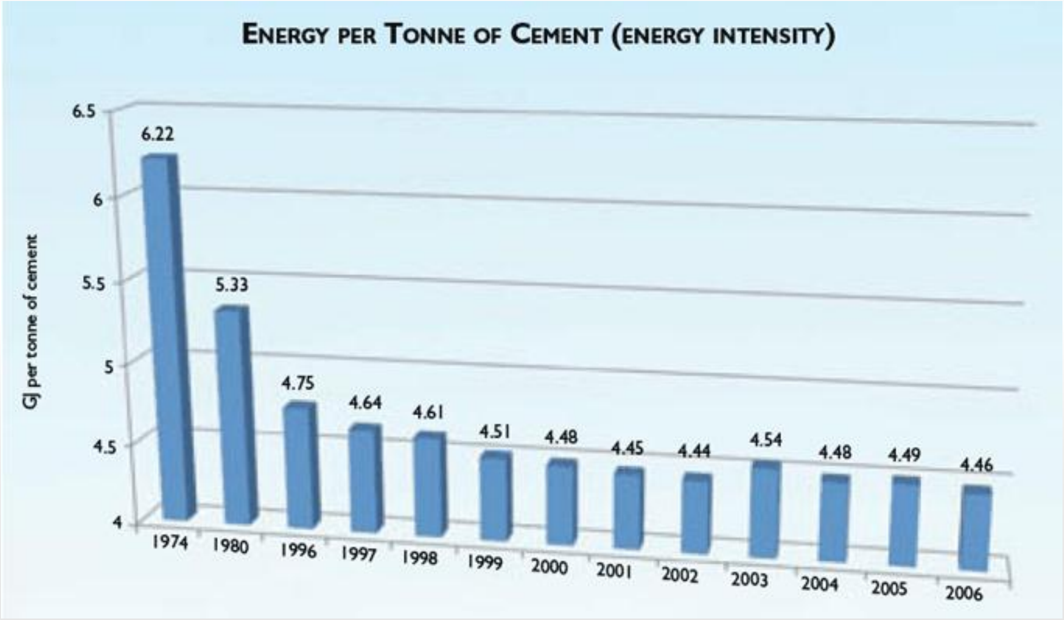


CANADA IS PART OF THE PROBLEM



THE CEMENT INDUSTRY IS IMPROVING ITS EFFICIENCY

- The Cement Industry has made significant progress in reducing the energy intensity of cement.
  - Further improvements will be incrementally more difficult.

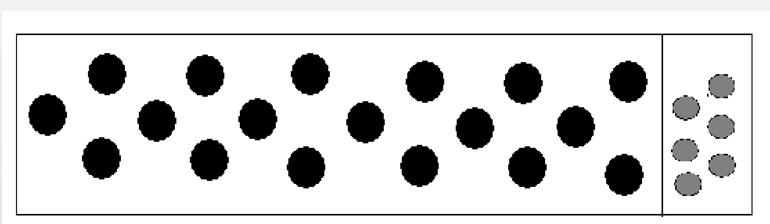


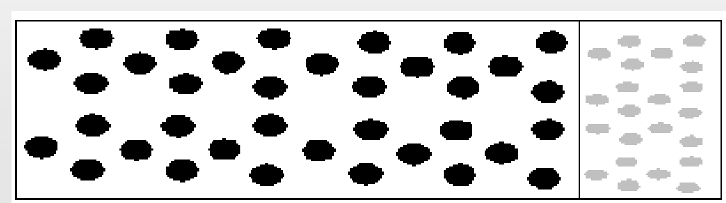
THE CEMENT INDUSTRY HAS A PLAN

- The cement industry has a comprehensive, global strategy to deliver our Clean Air objectives and remain competitive, through:
  - Energy efficiency
    - 9% improvement in energy intensity in last 15 years
    - Limited incremental opportunities remain with existing plant
  - Renewable and alternative energies
    - Biomass, municipal sludge, recovered plastics, recovered tires, etc.
  - Supplementary cementing materials
    - Fly ash, slag, silica fumes, etc.
  - Promoting life-cycle benefits of concrete
    - Roads, buildings, housing, etc.
  - Global, North American, and Canadian R&D

EQUIVALENT PERFORMANCE

- PLC cements produced in Canada have equivalent performance to the current portland cement types
  - Equivalent strengths can be achieved with a finer particle size and proper particle size distribution
- Limestone is not a completely inert filler.
  - Due to improved particle packing and the high compatibility of limestone and clinker, there is a set time, strength and rheology benefit.





PLC TRIAL POUR IN GATINEAU OCT. 6, 2008

Objective:

- Field test performance of PLC concrete with various levels of SCM in an exterior flatwork application.
- Control sections with Type GU + SCM

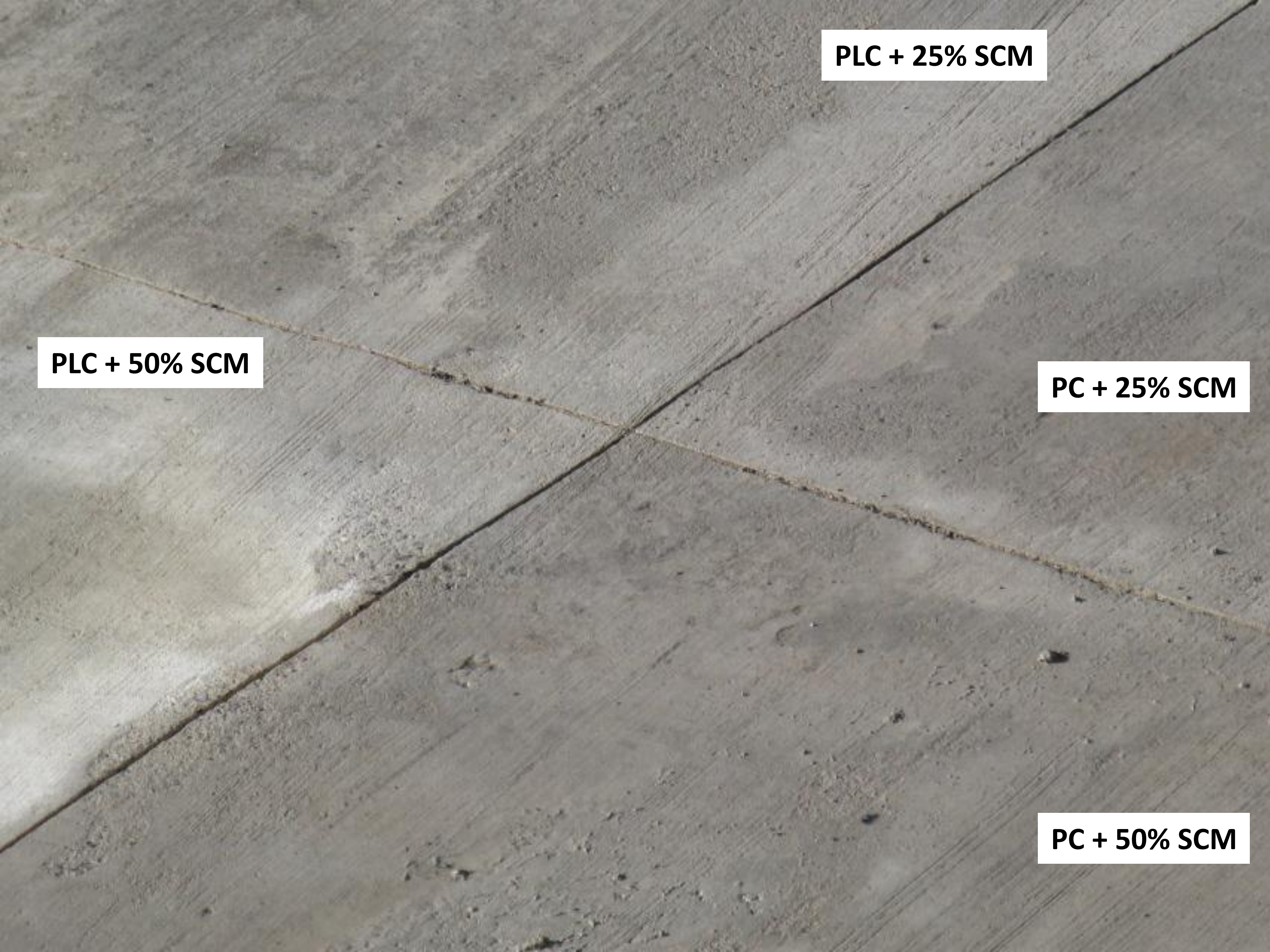
Eight Concrete Mixes:

Cement	SCM Replacement Level (%)			
	0	25	40	50
Type GU	X	X	X	X
Type GUL	X	X	X	X

Cementing Materials:

- Type GU with 3.5% limestone (PC)
- Type GUL with 12% Limestone (PLC)
- Blended SCM = 2/3 Slag + 1/3 Fly Ash


Close up photo taken here


PLC + 25% SCM
PLC + 50% SCM
PC + 25% SCM
PC + 50% SCM

QEW BARRIER WALL GUL TRIAL

- First GUL use for a public wall section in Canada in 2009
- Various durability tests will be carried out at UofT
- Initial strength test results show comparable performance of GU and GUL
- GU & GUL AVS results similar
- RCPT similar in cylinder but GUL higher in core samples (@ 62d 1600 vs. 1400 C)
- Similar scaling test results

Concrete performance

	GU	GUL
1 d [MPa]	9.5	10.3
3 d [MPa]	19.3	19.4
7 d [MPa]	25.6/25.8	26.8/24.9
28 d [MPa]	36.9/36.0	37.9/34.7
56 d [MPa]	38.9	38.0
Slump [mm]	95	100
Air (P) [%]	7.8	6.4
AVS	0.104	0.103
Air (H) [%]	6.6	6.1

CSA A23.1-09 INCLUDES CONCRETE MADE WITH PLC

Table 6
Types of hydraulic cement
(See Clauses 4.2.1.1.2 and 4.2.1.4.1.)

Name	Portland Cement	Portland-limestone cement	Application
General use hydraulic cement	GU	GUL	For use in general concrete construction when the special properties of the other types are not required.
High-early-strength hydraulic cement	HE	HEL	For use when high-early-strength is required.
Moderate sulphate-resistant hydraulic cement	MS	-	For use in general concrete construction exposed to moderate sulphate action.
High sulphate-resistant hydraulic cement	HS	-	For use when high sulphate resistance is required.
Moderate heat of hydration hydraulic cement	MH	MHL	For use in general concrete construction when moderate heat of hydration is required.
Low heat of hydration hydraulic cement	LH	LHL	For use when low heat of hydration is required.

Note:

(1) A detailed guideline to the naming practice is provided in Annex C of CSA A3001.

(2) There is no type of sulphate resisting limestone cement because Portland limestone cement shall not be used in sulphate environments such as described in Table 3.

ADOPTION OF PLC IN CANADA

- Included in CSA A3001 and A23.1 standards, now referenced in the 2010 National Building Code of Canada, under the name Portland-limestone cement
- Approved for use in British Columbia, Manitoba, Ontario, Quebec and Nova Scotia
- Will be approved for use in other provincial jurisdictions once they adopt the 2010 NBCC or update their references to the current standards
- Has just been permitted for use in sulphate exposure environments in May CSA A23.1 meeting in Victoria

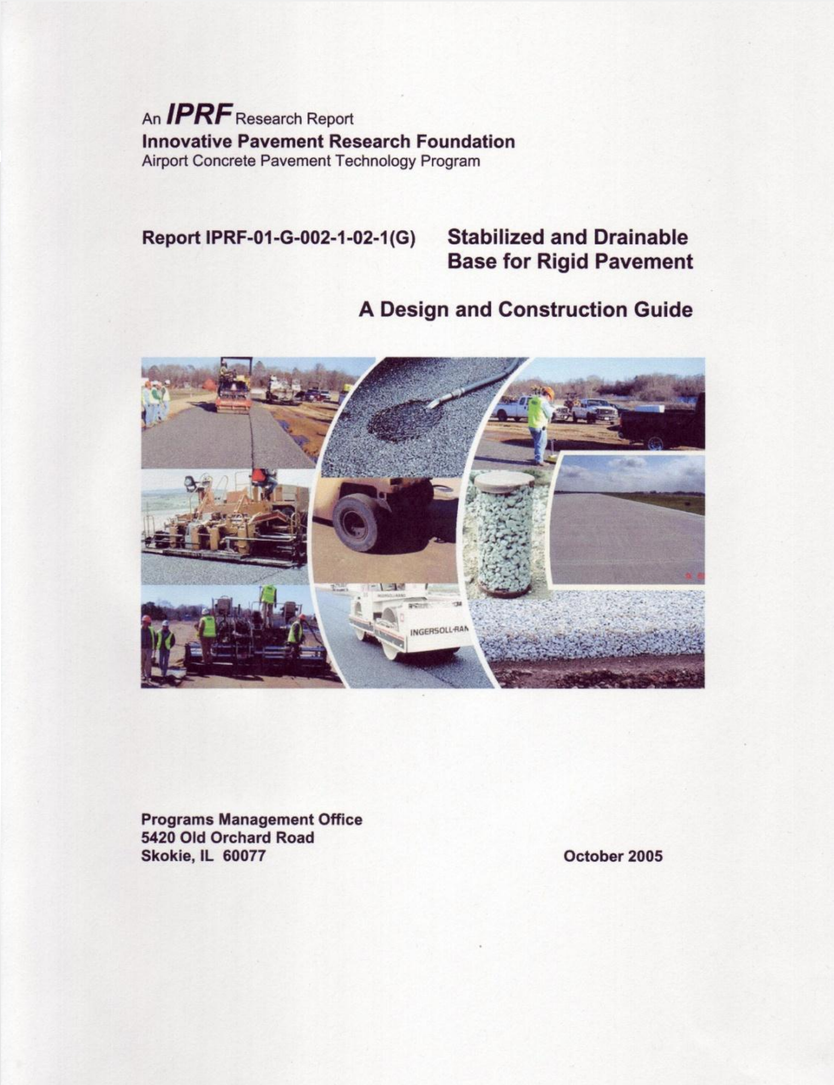
PLC IN SULFATE EXPOSURE

- PLC has been cleared for use in sulphate exposure environments in CSA A23.1-14 in a recent CSA committee meeting in May, 2015, to be referenced in NBCC 2015
- All Sulphate Resistant PLC mix designs to use w/c = 0.40 for all sulphate exposures

SUMMARY

- Is approved for use in most provincial jurisdictions – including British Columbia, Manitoba, Saskatchewan, Ontario, Quebec and Nova Scotia
- MTO has approved the use PLC in bridge and pavement structures
- Is widely available from cement manufacturers across Canada
- Please include PLC in your cement and concrete specifications

STABILIZED BASE/SUBBASE FOR RIGID PAVEMENT



An IPRF Research Report
Innovative Pavement Research Foundation
Airport Concrete Pavement Technology Program

Report IPRF-01-G-002-1-02-1(G)

Stabilized and Drainable Base for Rigid Pavement

A Design and Construction Guide

Programs Management Office
5420 Old Orchard Road
Skokie, IL 60077

October 2005

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BACKGROUND

- Advisory Circular 150/5320-6D (Airport Pavement Design and Evaluation) provides guidance
- Stabilized base for Aircraft > 100,000 lbs. (45,250 kg)
- Various forms of stabilized bases
  - Asphalt-treated (ATB)
  - Cement-treated (CTB)
  - Lean Concrete Base (LCB or Econocrete)

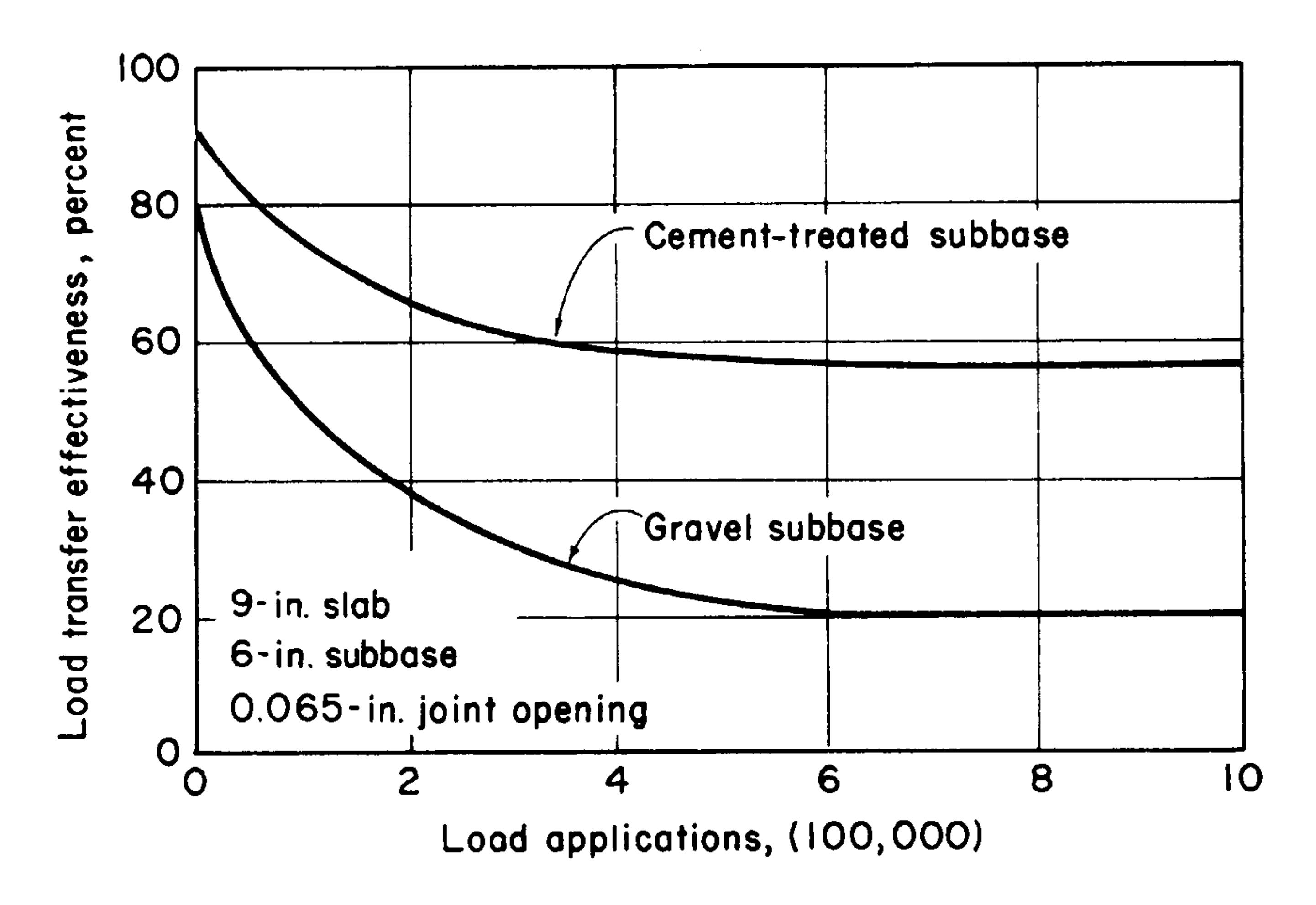
DESIGN AND CONSTRUCTION GUIDE PURPOSE

- Evidence indicating early-aged cracking
- Early-aged cracks occurring within 90 days
- Pavements constructed on stabilized bases
- Design, materials, and construction factors
- Document intent is to provide engineer or contractor understanding
- Purpose to supplement FAA150/5320-6D

THE RESEARCH

- ARA, Inc.
- 885 different pavement types at 119 different airports
- certain trigger conditions + certain construction variants = early-aged cracking.
- limit the variants ➡ probability for early cracking is reduced.

LOAD TRANSFER EFFICIENCY

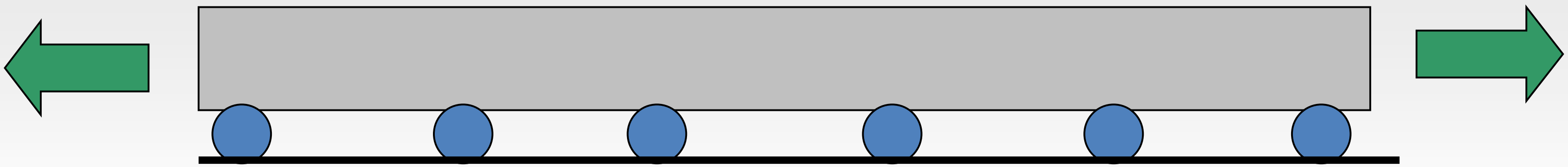


FAA GUIDANCE

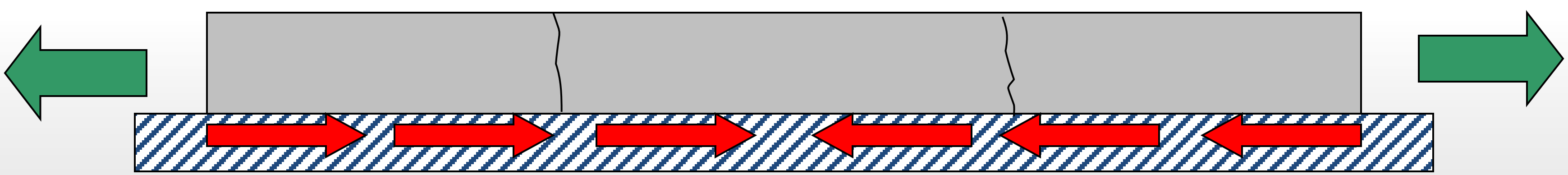
- Stabilized Base for Aircraft > 100,000 Lb (45, 250 kg)
- Better Load Transfer
- Reduced/eliminate subgrade “pumping”
- Generally longer pavement life

So Where is the problem?

EFFECTS OF SUBBASE RESTRAINT



Construction Variants
Design Variants + Trigger = Early-aged Cracks
Material Variants



VARIANTS

- Late or Shallow Saw Cutting (Const.)
- Inadequate Curing (Const.)
- Rigid Stabilized Base Material (Design)
  - Excessive 7-day Compressive Strength (>1000psi/6.9 MPa)
  - Excess Thickness (>6 in/150 mm)
  - Shrinkage Cracks
- Excessive Panel Sizes (Design)
  - Large Length to Width (>1.25)
  - Panel Size too Large (>5*l*)

l= Radius of Relative Stiffness

- Materials Prone to High Shrinkage
  - High Cement Factor (>400 lbs)
  - High Paste Volume
  - Gap Graded with Fine Sand

VARIANTS IN DECREASING ORDER OF IMPORTANCE

- Base strength/stiffness
- Sawing
- Panel sizes and aspect ratios
- PCC/base interface friction
- PCC cement factor
- Presence or absence of bond-breaker
- PCC curing
- Shrinkage susceptibility of PCC mixtures
- Base thickness
- Presence of shrinkage cracking in base
- Internal slab restraint (dowel bars, tie bars, etc)

EARLY CRACKING TRIGGERS

- A drop in Ambient Temperature (Δ = 25°F/14°C) shortly after initial set of concrete
- Hot Weather Paving (AT>90º F/32°C)
- High Surface Evaporation Rate (Cool and Low Humidity) without proper curing/protection

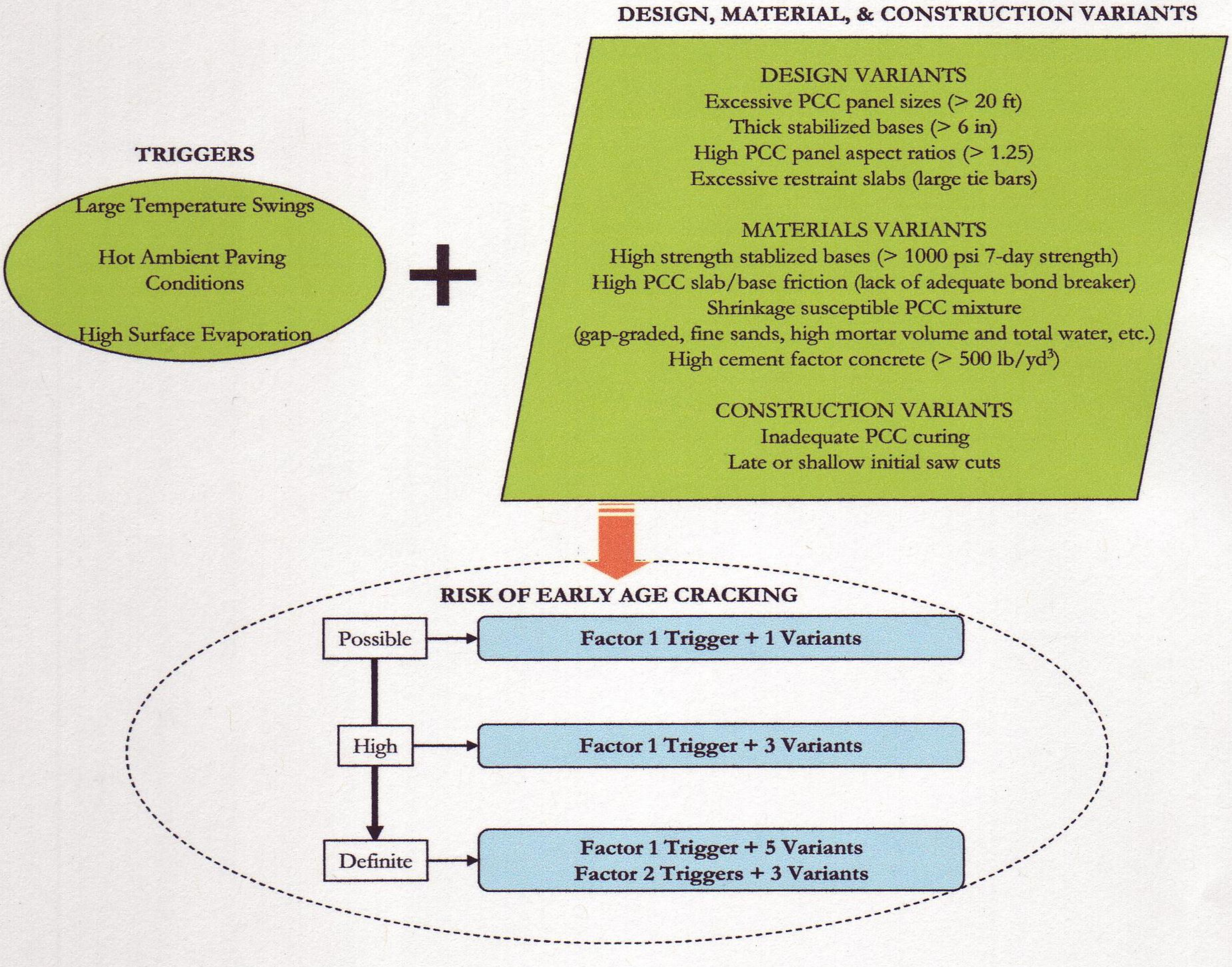
LARGE ΔT THERMAL SHOCK

- Effect
  - Negative thermal gradient (top cooler than bottom)
  - Sufficiently hardened slab = tensile stress at top w/top-down cracking

- Aggravating Variants
  - Late sawing (depth)
  - Aspect ratio (>1.25)
  - Excessive panel size
  - Thick or stiff base
  - PCC placement timing (i.e. heat vs. steep ΔT)
  - Slab/base interface restraint
  - Cold weather paving plan execution

HOT WEATHER PAVING

- Effect
  - Excessive drying shrinkage (warping and axial deformations)
  - Negative thermal gradient
  - Axial deformation/stress buildup at restraints (e.g. slab/base interface, tie bars)
- Aggravating variants
  - Hot PCC temp (>85ºF)
  - Inadequate curing
  - Late sawing/depth
  - Excessive restraint
  - High cement factor
  - Shrinkage susceptible PCC
  - Certain admixtures (HRW)
  - PCC placement timing
  - Hot base
  - Hot weather paving plan


DESIGN, MATERIAL, & CONSTRUCTION VARIANTS
TRIGGERS
Large Temperature Swings
Hot Ambient Paving Conditions
High Surface Evaporation
+
DESIGN VARIANTS
Excessive PCC panel sizes (> 20 ft)
Thick stabilized bases (> 6 in)
High PCC panel aspect ratios (> 1.25)
Excessive restraint slabs (large tie bars)
MATERIALS VARIANTS
High strength stablized bases (> 1000 psi 7-day strength)
High PCC slab/base friction (lack of adequate bond breaker)
Shrinkage susceptible PCC mixture
(gap-graded, fine sands, high mortar volume and total water, etc.)
High cement factor concrete (> 500 lb/yd³)
CONSTRUCTION VARIANTS
Inadequate PCC curing
Late or shallow initial saw cuts
RISK OF EARLY AGE CRACKING
Possible
Factor 1 Trigger + 1 Variants
High
Factor 1 Trigger + 3 Variants
Definite
Factor 1 Trigger + 5 Variants
Factor 2 Triggers + 3 Variants

WHAT ARE THE ISSUES?

- Strength
  - Controlled by what factors?
  - Frost or Construction Traffic
  - Regional Modifications
- What happens when it is too strong?
  - Remove and replace?
  - Notch?

GUIDANCE

- Existing
  - 7-day Strength - 750 psi
  - Thickness – None
- P-304
- P-306
  - Limits Strength

- Proposed
  - Compressive Strength
    - 500 psi
    - Regional Dependence
  - Thickness
    - 6-inches
  - Surface Friction – Bond Breaker

QUESTIONS?

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