Design Factors For Using RAP In Hot Mix Asphalt

Greater Iowa Asphalt Conference

March 2006

What is RAP ?

Recycled Asphalt Pavement

Asphalt pavement removed from the roadway, typically by milling.

Why Use RAP in HMA ?

Economics

Components of RAP have value

- High quality aggregate
- Asphalt binder
- No (or low) hauling cost

20% RAP = 20% Savings in new asphalt binder
(at $250/ton and 5% binder = $2.50/ton mix)

RAP in HMA

Material Factors

Variability in the pavement materials

- multiple layers
- different mix designs

Age of the hot mix asphalt

Storage & management of RAP

- Classified RAP (known materials)
- Unclassified RAP (unknown materials from multiple projects stored in same stockpile)

RAP in HMA

Binder Grade Selection

>> Iowa Specification <<

ACTION	Percent RAP
No Change in Binder Grade	20% or less
One Grade Lower	>20 - 30%
Use Blending Charts	>30%

RAP in HMA

Critical RAP Properties

Low RAP (up to 30% RAP)

- Asphalt Content of RAP
- Aggregate Gradation of RAP
- RAP Specific Gravity
- Consensus Aggregate Properties

High RAP (more than 30% RAP)

- All of the above – PLUS >>
- Asphalt binder physical properties

Extraction and Recovery Procedures

- Extraction
  - Determine asphalt content of RAP
  - Determine RAP aggregate gradation
  - Necessary for mix design
- Recovery
  - Determine asphalt binder physical properties
  - Necessary for blending charts
  - Reqiured for RAP content greater than 30%

RAP in HMA

The Black Rock Question

Does RAP act like a black rock in the mixture?

When a chunk of RAP is added to the mix does the asphalt binder in the RAP interact (blend) with the virgin AC ?

Black Rock Research

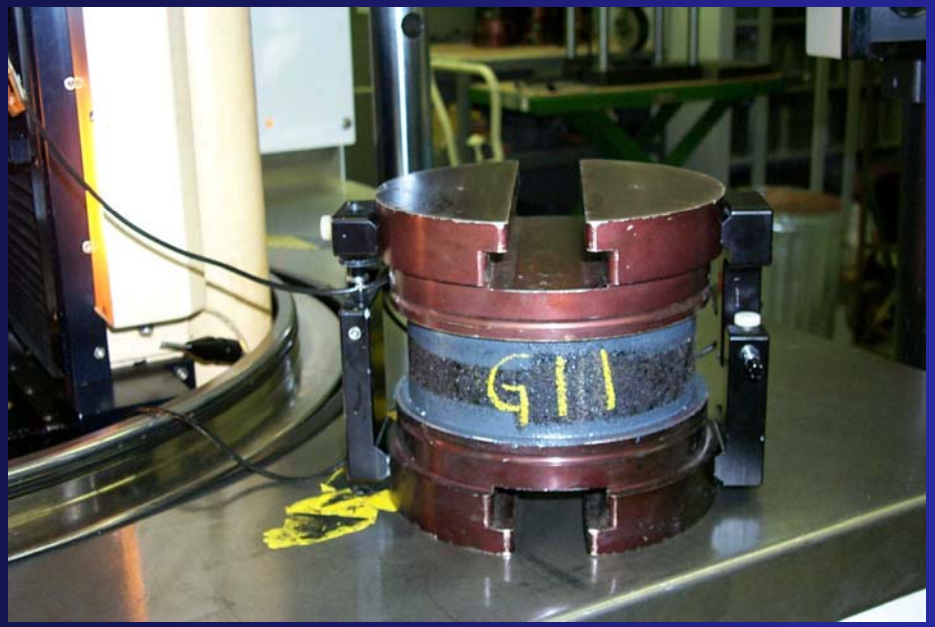
- Case A = black rock = virgin binder with virgin aggregate plus extracted RAP aggregate.
- Case B = standard practice = virgin binder with virgin aggregate plus RAP
- Case C = total blending = virgin binder physically blended with recovered RAP binder, then added to aggregate.

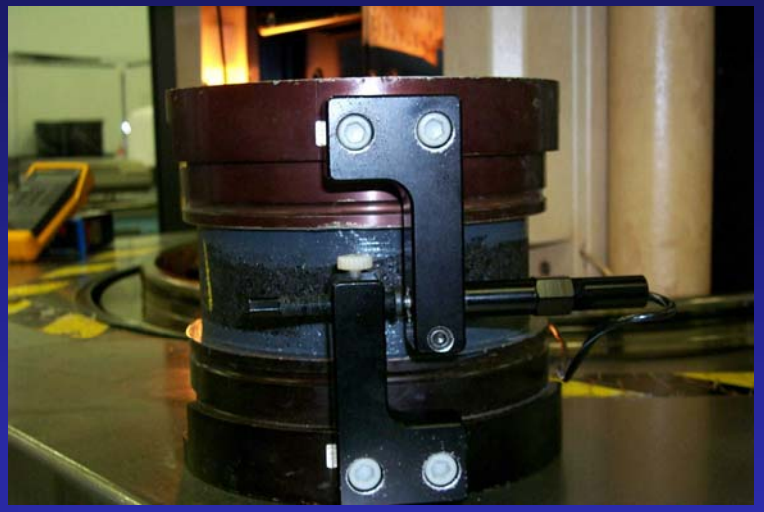
If no blending: Case A = Case B

If partial blending: Case A < Case B < Case C

Black Rock Research

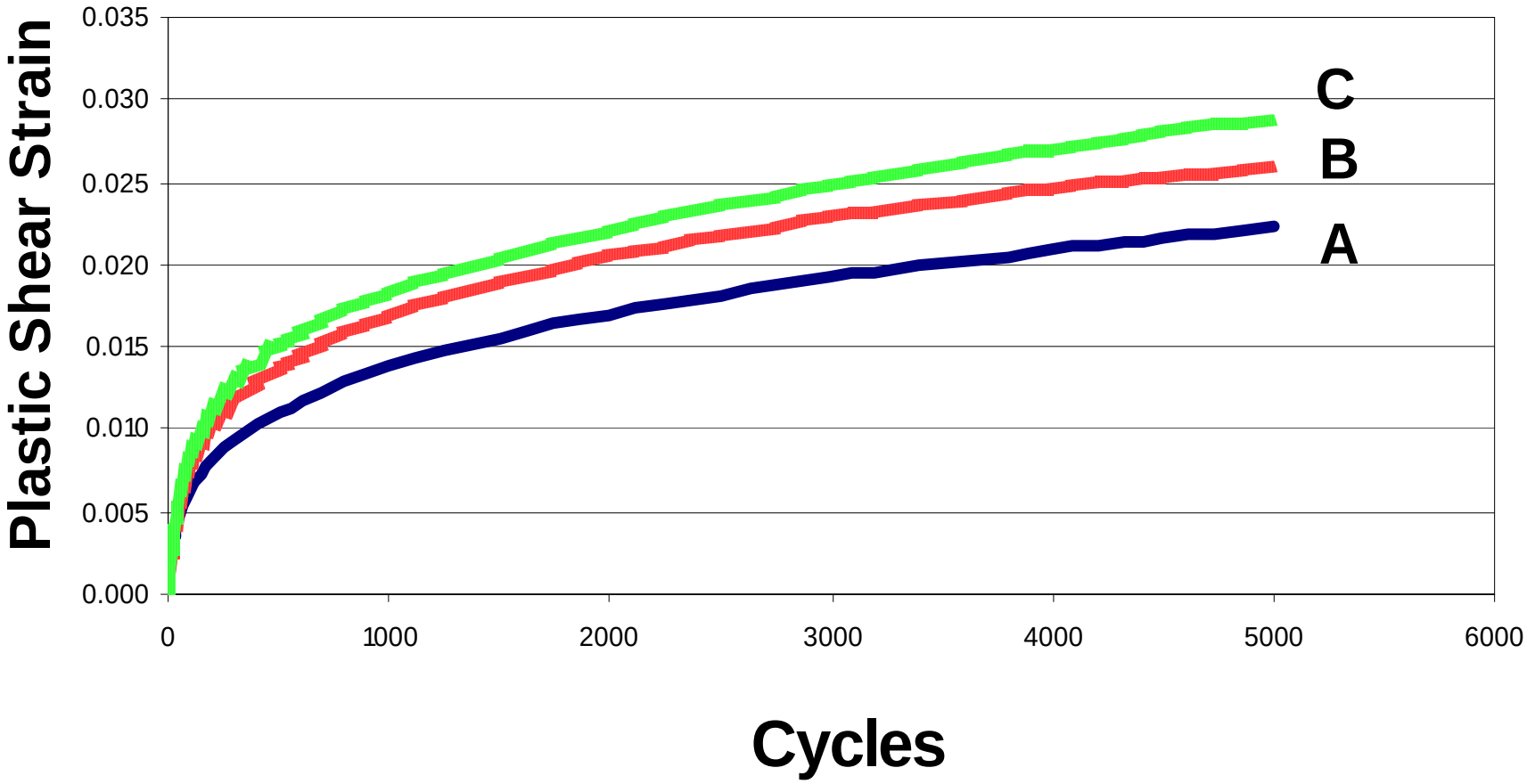
Shear Testing



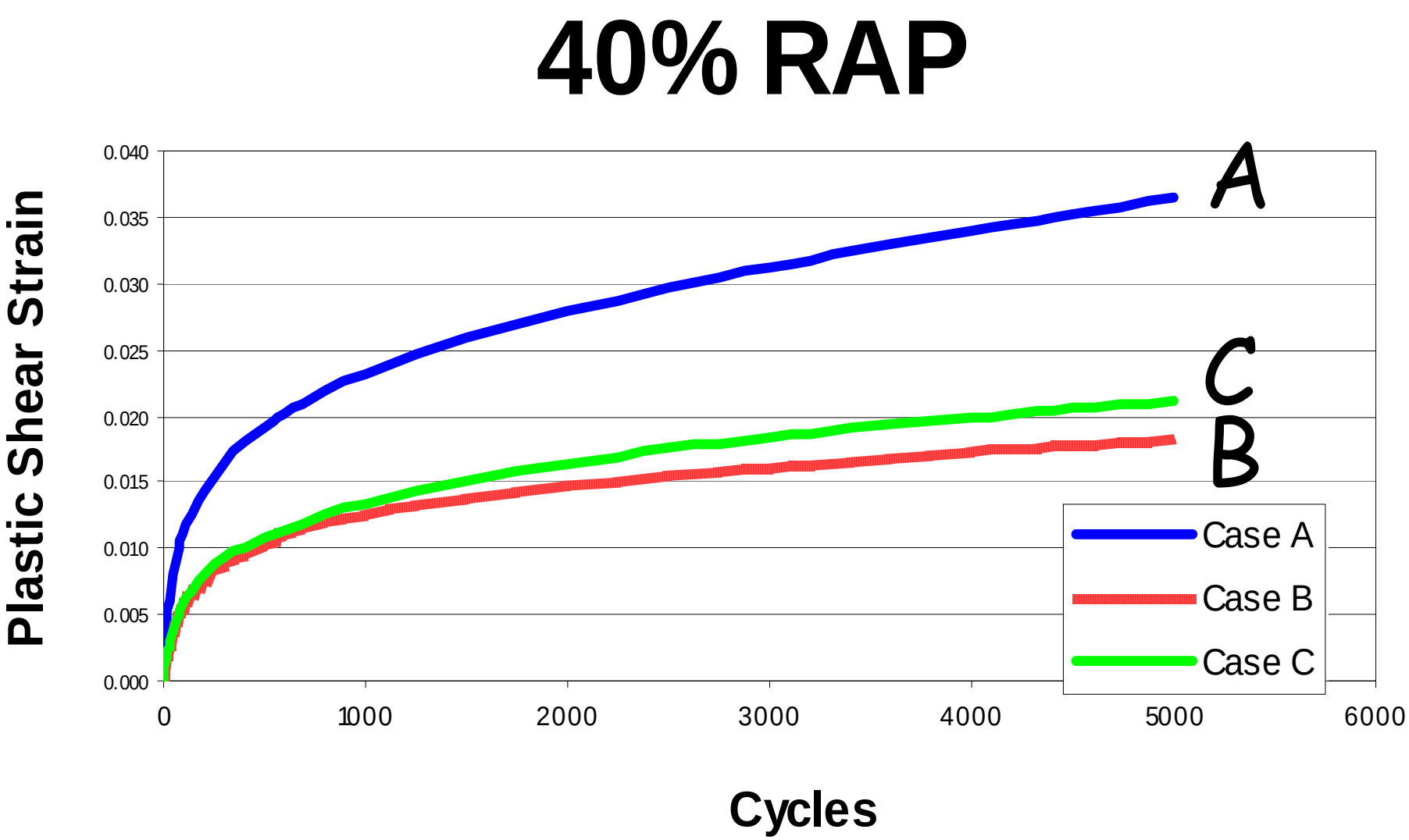


Black Rock Research

10% RAP



Black Rock Research

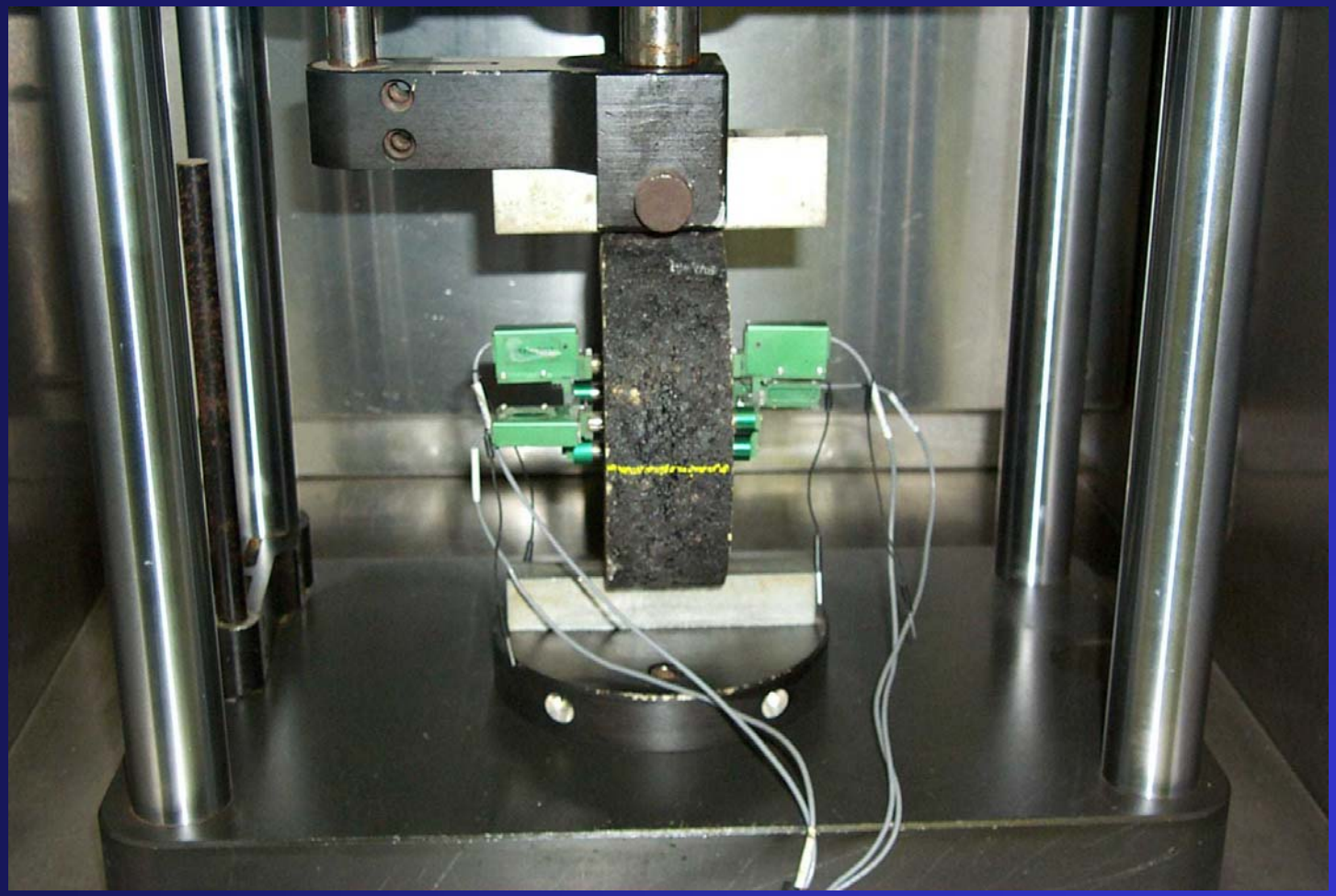


Black Rock Research

Indirect Tensile Testing

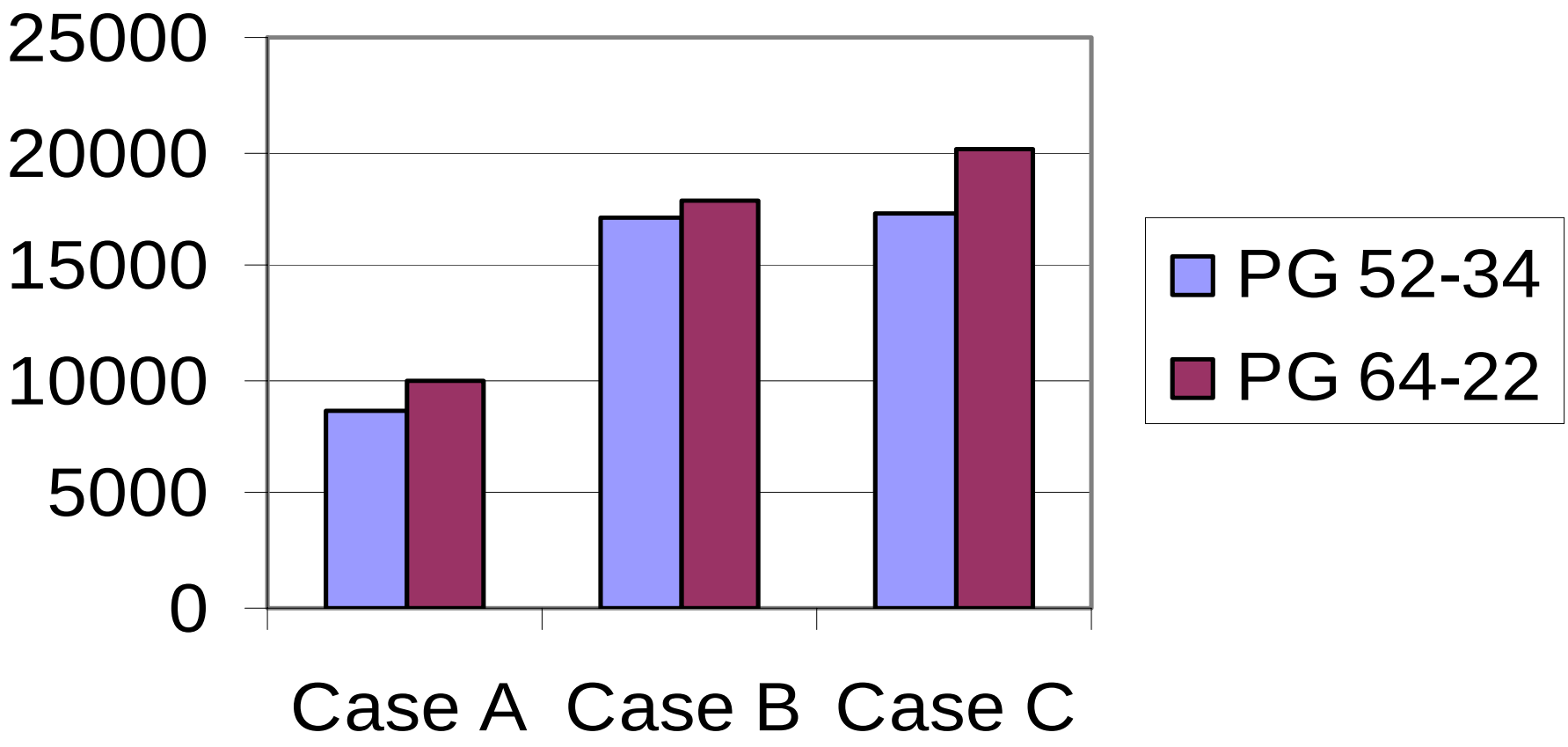
Black Rock Research

Indirect Tensile Testing



Black Rock Research

Creep Stiffness at -20°C



Black Rock Research

NCHRP 9-12 Results

- Blending occurs at higher RAP contents. At low RAP contents, effects are not significant.
- Results from all phases support concept of a tiered system.

Black Rock Research

NCHRP 9-12 Recommendations

- RAP mixtures should be able to perform at least as well as virgin mixes.
- RAP aggregates need to be included in consensus properties and gradations. Watch changes in aggregates due to extraction.
  - Exception: sand equivalent value.

Extraction and Recovery

- **Solvent Extraction**
  - ASTM D2172 -- Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
    - Method A (Centrifuge) - most common
    - Method B (Reflux) - completely contained
    - Method E (Vacuum)
- **Ignition Oven**

Reflux Extraction

Obtain mix sample, determine weight, and place into two conical containers (with filters)

Reflux Extraction

- Place conical containers in cylinder
- Place cylinder with solvent on hot plate
- Seal top of cylinder with condenser unit
- Begin reflux extraction and continue until the effluent from the lower cone is a light straw color

Component Analysis of RAP

- After Extraction Procedure…
  - Determine the final mass of the sample and the amount of asphalt binder extracted

Asphalt Content

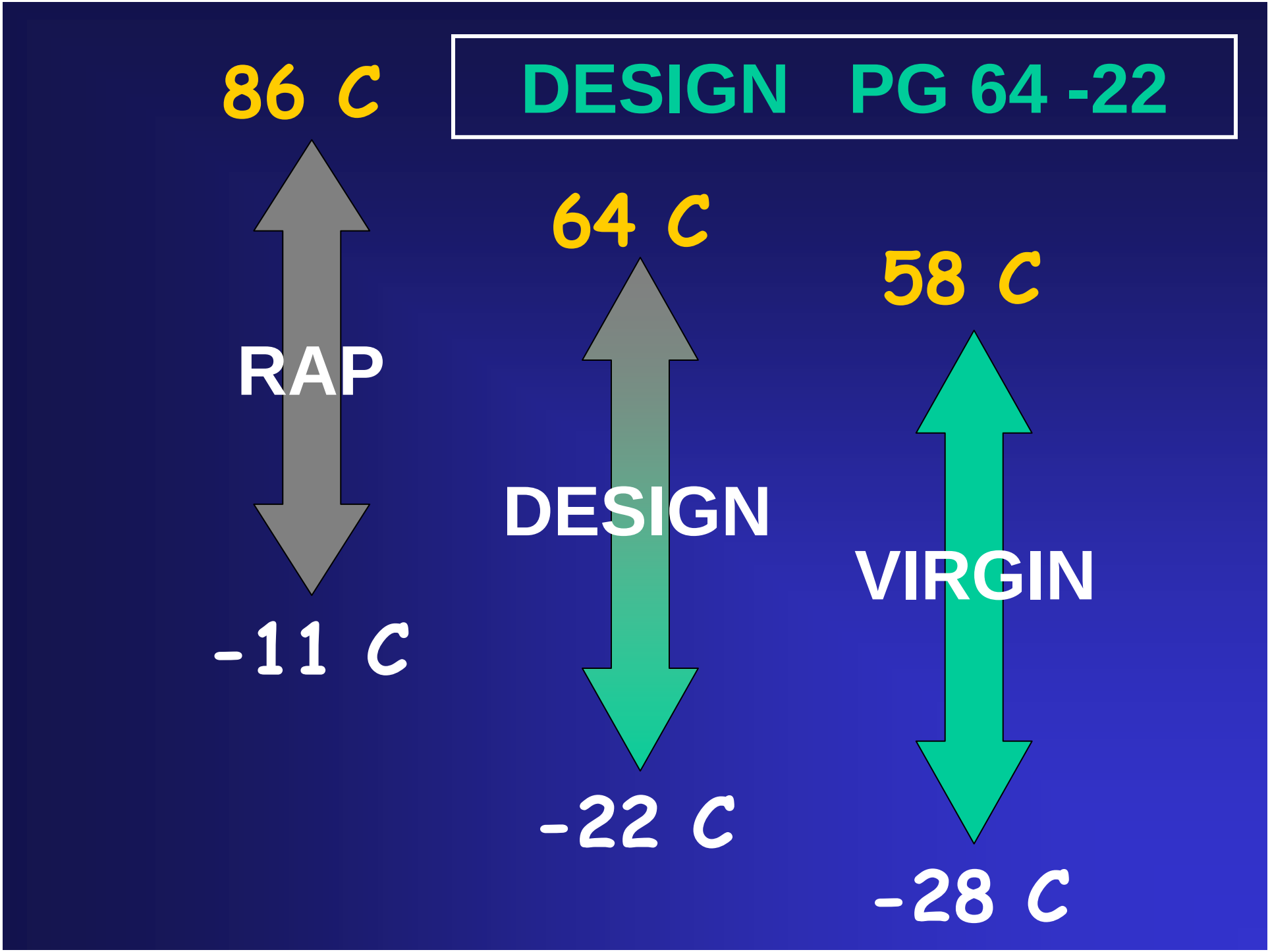
  - Use extracted aggregate for further testing

Gradation

Recovery

To Determine the Physical Properties of RAP Binder

- Conducted after extraction procedure
- ASTM 1856 - Recovery of Asphalt from Solution by Abson Method
- ASTM D5404 - Recovery of Asphalt from Solution Using the Rotavapor Apparatus
- AASHTO TP2 - Quantitative Extraction and Recovery of Asphalt Binder from Hot Mix Asphalt (HMA)


DESIGN PG 64 -22
86 C
RAP
-11 C
64 C
DESIGN
-22 C
58 C
VIRGIN
-28 C

RAP in HMA
Binder Grade Selection

Blending Method	A	B
Binder Grade Required by the Project	✓	✓
Recovered RAP Binder Properties	✓	✓
Percentage of RAP in Mixture	✓	?
Virgin Binder Properties/Grade	?	✓

RAP in HMA

Blending -- Method A

Blending at a Known RAP Percentage
(Virgin Binder Grade Unknown)

$$T_{virgin} = \frac{T_{blend} - (\%RAP \times T_{RAP})}{1 - \%RAP}$$

T(virgin) = Tc of virgin binder

T(blend) = Tc of blended binder (desired)

T(RAP) = Tc of recovered RAP binder

%RAP = percentage of RAP (expressed as a decimal)

RAP in HMA

Blending - Method A

Example

Desired Final Binder Grade: PG 64-22

RAP Percentage: 30%

RAP Binder Properties:

Aging	Property	Critical Temperature, C	
Original	DSR G*/sind	High	86.6
RTFO	DSR G*/sind	High	88.7
	DSR G*sind	Intermediate	30.5
	BBR S	Low	- 4.5
	BBR m-value	Low	- 1.7
	PG	Actual	PG 86-11
		MP1	PG 82-10

RAP in HMA

Blending Method - A

Example

Desired Final Binder Grade: PG 64-22

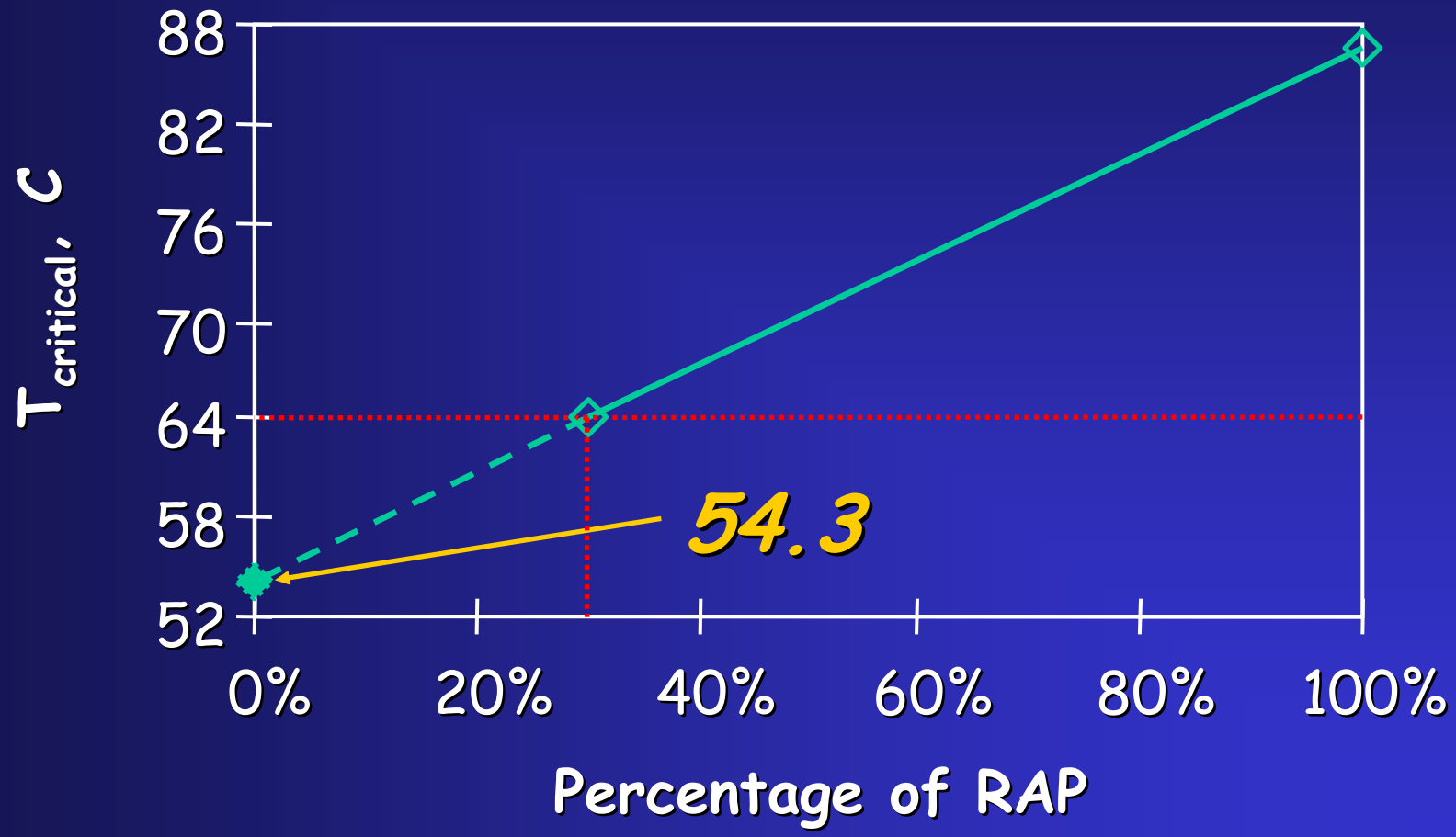
RAP Percentage: 30%

$$T_{virgin} = \frac{T_{blend} - (\%RAP \times T_{RAP})}{1 - \%RAP}$$

$$T_{virgin}\ (High) = \frac{64.0 - (0.30 \times 86.6)}{(1 - 0.30)} = 54.3$$

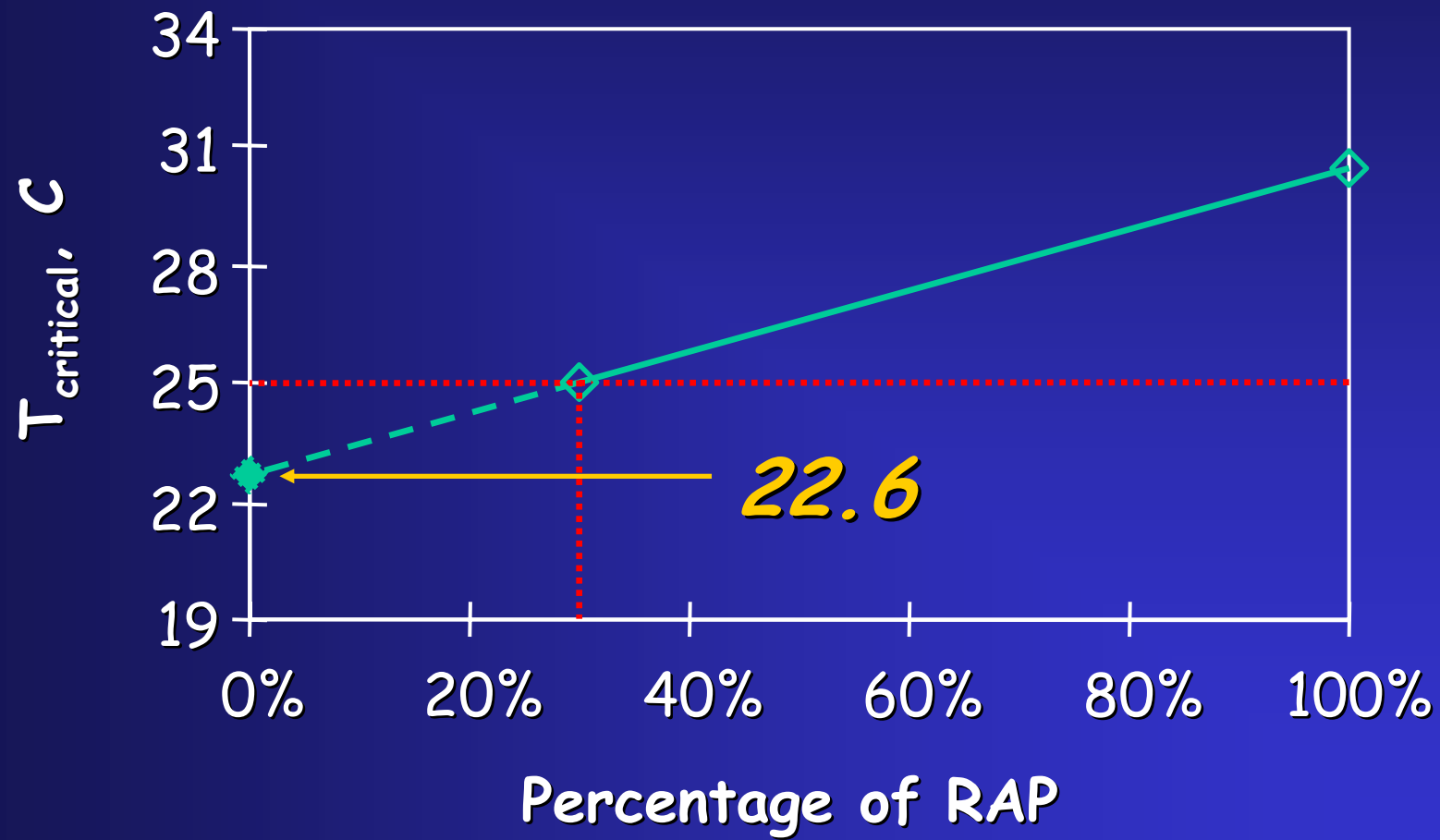
RAP in HMA

Blending Charts - Method A



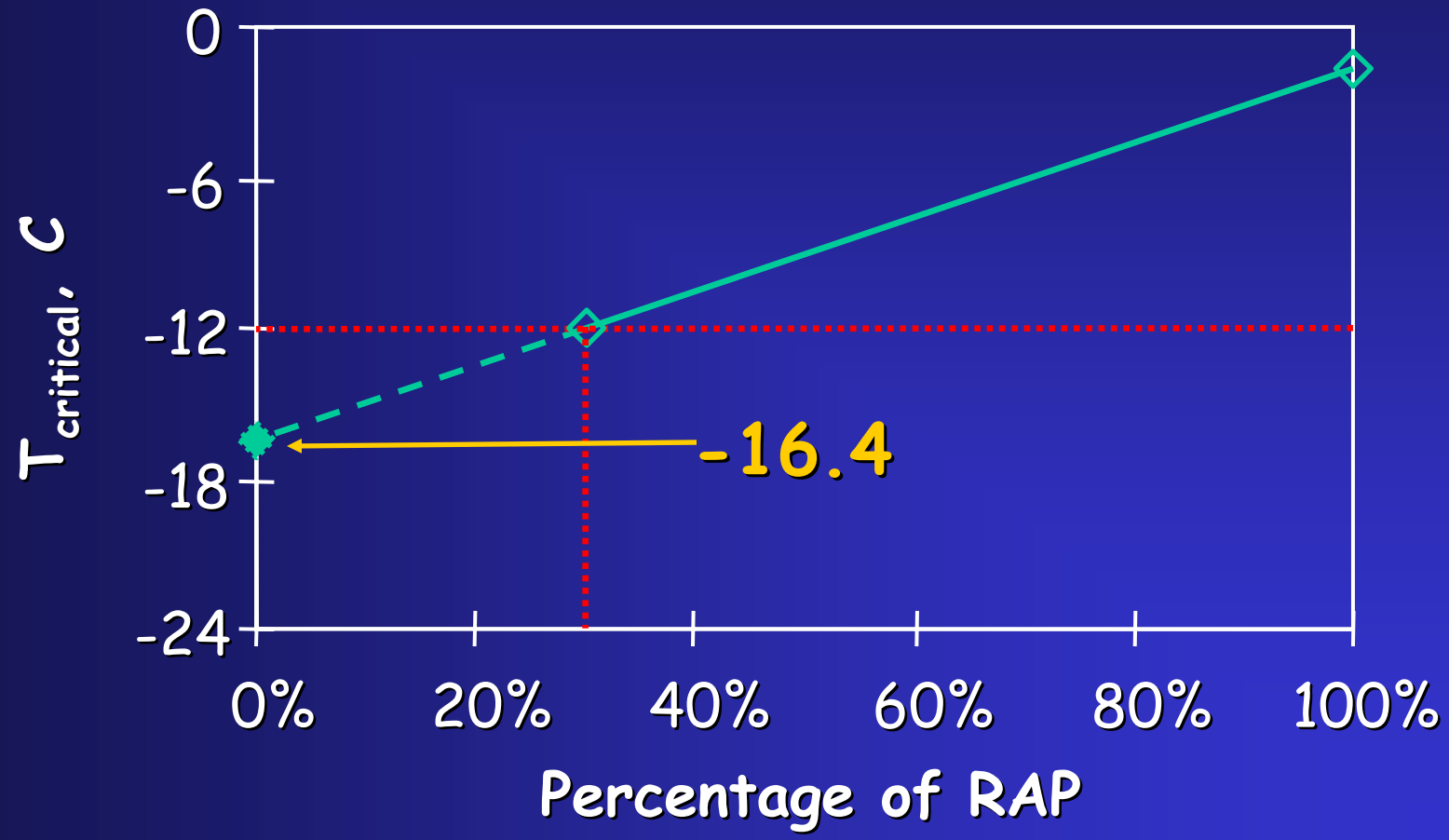
RAP in HMA

Blending Chart - Method A



RAP in HMA

Blending Chart - Method A



RAP in HMA

Blending - Method A

Virgin Binder Properties Required:

Aging	Property		Critical Temperature, C
Original	DSR G*/sinδ	High	**54.3**
RTFO	DSR G*/sinδ	High	53.4
PAV	DSR G*sinδ	Intermediate	**22.6**
	BBR s	Low	-15.2
	BBR mvalue	Low	**-16.4**

Actual Grade PG 54-26

MP1 Grade PG 58-28

RAP in HMA
Blending - Method A

- From the Example:
  - To achieve a final asphalt binder grade of **PG 64-22**…
    - Recovered RAP Binder Grade = PG 82-10
    - 30% RAP used in mixture
  - …the virgin asphalt binder needs to be PG 54-26 (**PG 58-28**)

RAP in HMA

Blending – Method B

Blending with a Known Virgin Binder Grade
(RAP Percentage Unknown)

$$\%RAP = \frac{T_{blend} - T_{virgin}}{T_{RAP} - T_{virgin}}$$

T(virgin) = Tc of virgin binder

T(blend) = Tc of blended binder (desired)

T(RAP) = Tc of recovered RAP binder

%RAP = percentage of RAP expressed as a decimal

RAP in HMA

Blending - Method B

Example

Desired Final Binder Grade: PG 64-22

Virgin and RAP Binder Properties:

			Critical Temperature, C	
Aging	Property	Temp. Range	Virgin Binder	RAP Binder
Original	DSR $G^*/\sin\delta$	High	60.5	86.6
RTFO	DSR $G^*/\sin\delta$	High	61.0	88.7
PAV	DSR $G^*\sin\delta$	Intermediate	14.2	30.5
	BBR S	Low	-22.2	-4.5
	BBR m-value	Low	-19.0	-1.7
	PG	Actual	PG 60-29	PG 86-11
		MP1	PG 58-28	PG 82-10

RAP in HMA

Blending - Method B

Example

Desired Final Binder Grade: PG 64-22

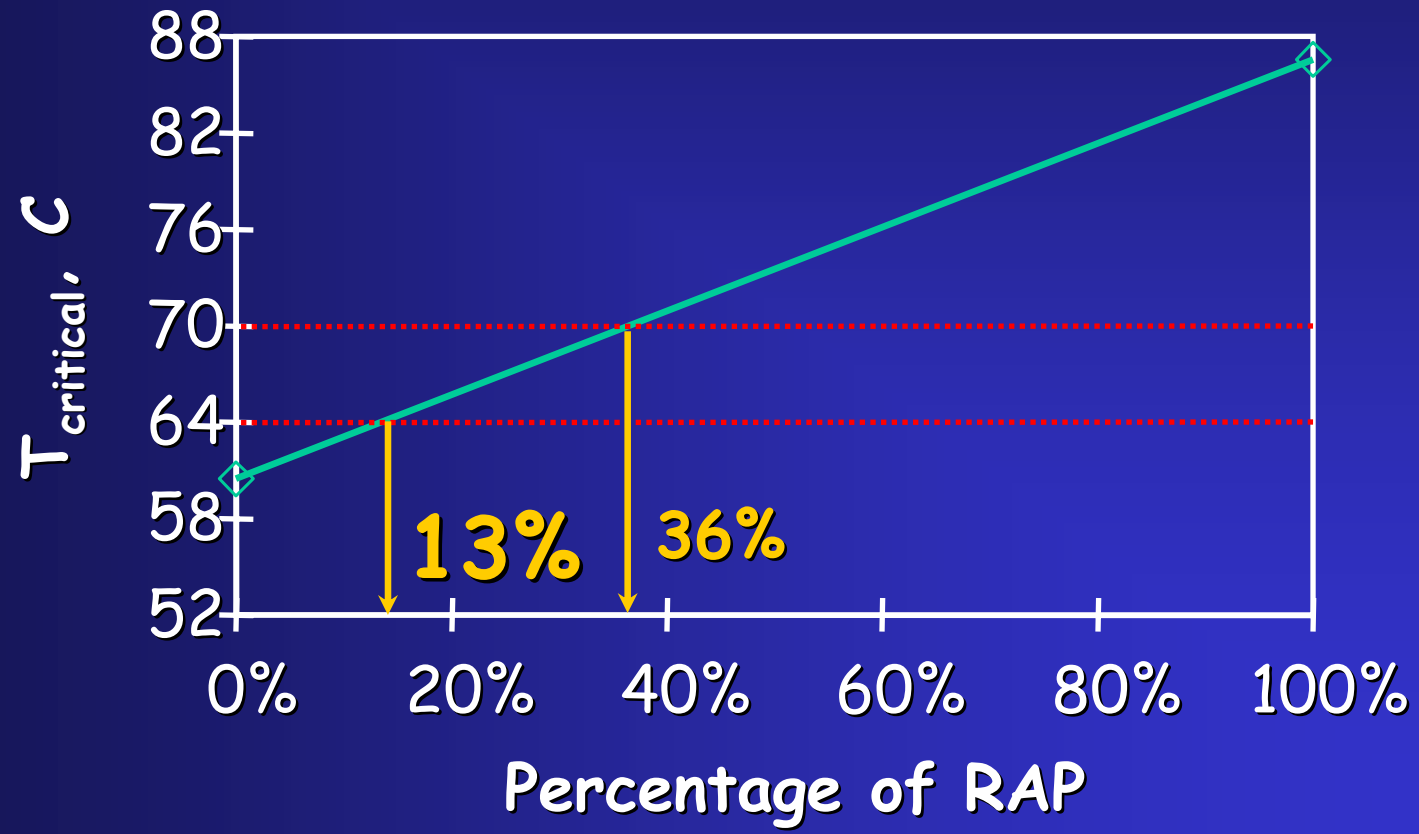
Known Virgin and RAP Binder Properties

$$\%RAP = \frac{T_{blend} - T_{virgin}}{T_{RAP} - T_{virgin}}$$

$$\%RAP\ (High) = \frac{64.0 - 60.5}{86.6 - 60.5} = 13.4\%$$

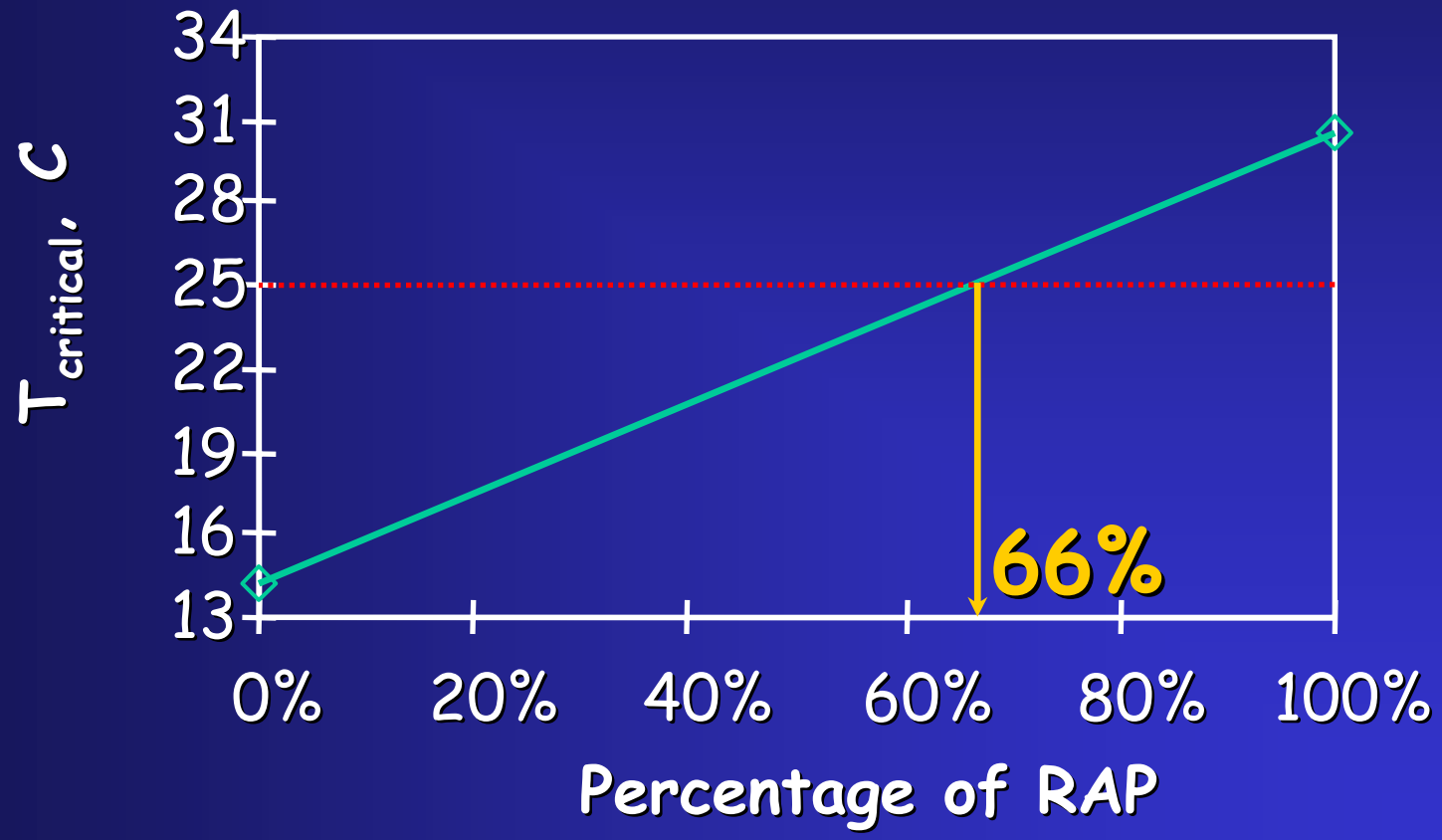
RAP in HMA

Blending - Method B



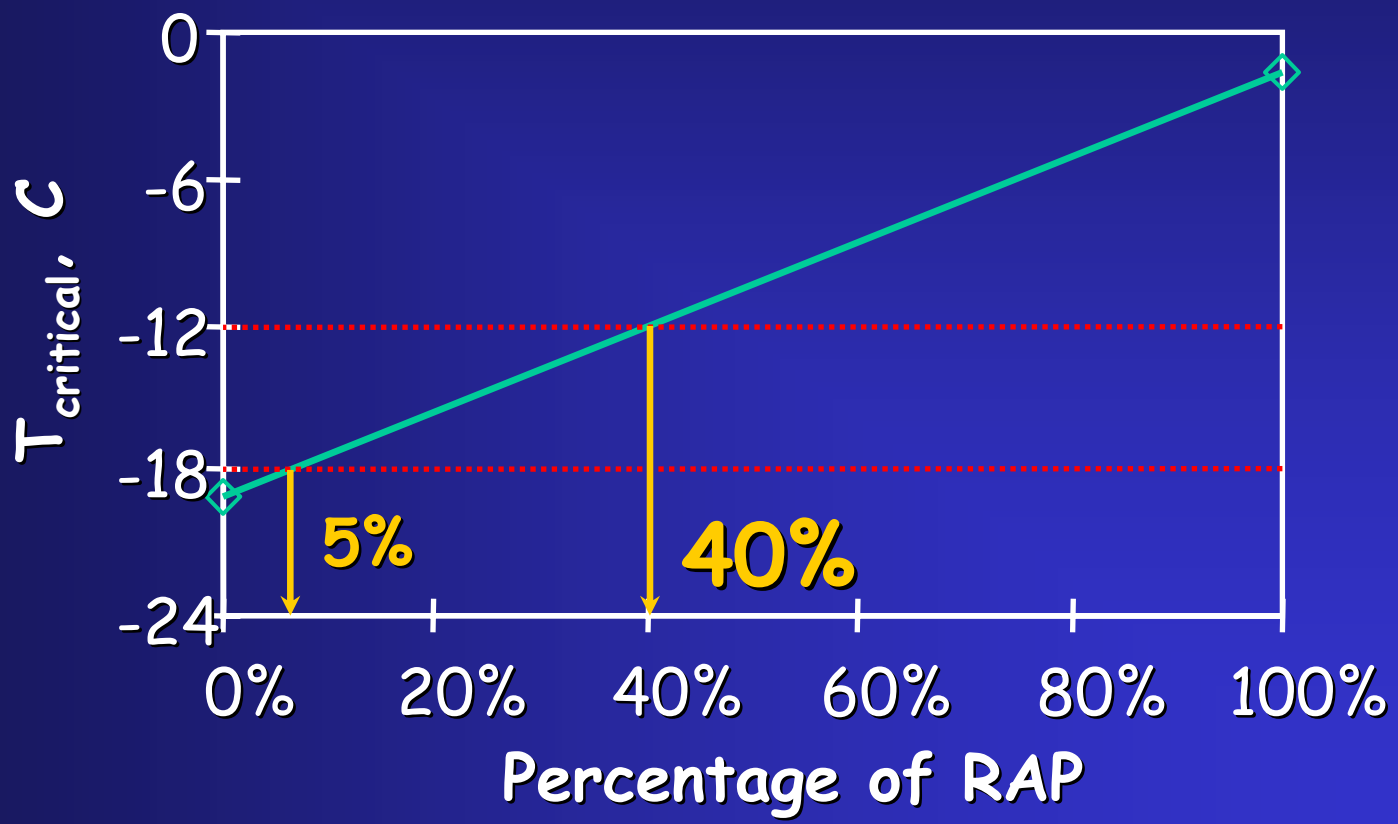
RAP in HMA

Blending - Method B



RAP in HMA

Blending - Method B



RAP in HMA

Blending - Method B

Percent RAP Required to Achieve Final Blend:

Aging	Property	Temp.	Percentage of RAP to Achieve: PG 64-22	PG 70-28
Original	DSR $G^*/\sin\delta$	High	**13.4%**	**36.4%**
RTFO	DSR $G^*/\sin\delta$	High	10.8%	32.5%
PAV	DSR $G^*\sin\delta$	Intermediate	**66.3%**	---
	BBR S	Low	57.6%	23.7%
	BBR m-value	Low	**40.5%**	**5.8%**

RAP in HMA

Blending - Method B

- From the Example:
  - To achieve a final asphalt binder grade of PG 64-22…
    - Recovered RAP Binder Grade = PG 86 -11
    - Virgin Binder Grade = PG 60-29 (PG 58 -28)
  - …the allowable RAP percentage is between 14% and 40%.

RAP in HMA

Binder Grade Selection

>> Iowa Specification <<

ACTION	Percent RAP
No Change in Binder Grade	20% or less
One Grade Lower	>20 - 30%
Use Blending Charts	>30%

Handling RAP During the Mix Design Process

- RAP Heating Procedure
  - 110 C (230 F) for 2 hours (max)
  - Suitable for 1-2 kg batches
  - Higher temperature or longer time may affect properties of some RAP
- Virgin Aggregate Heating Procedure
  - Heat to 10 C above mixing temperature

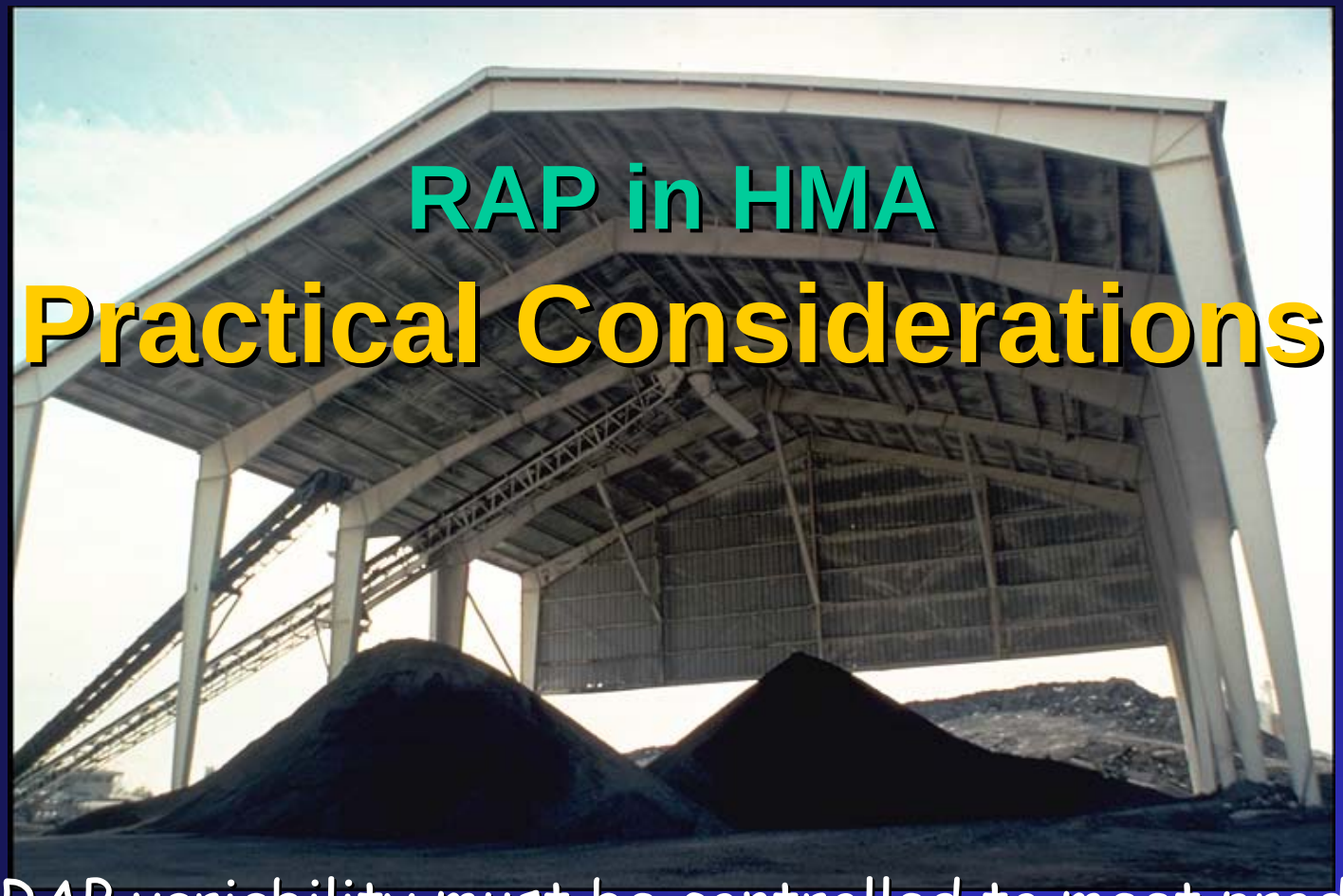
    (typically 275 + 20 = 295 F)

RAP in HMA

Practical Considerations

- Mixtures with 10 to 15% RAP may become more common.
- At high RAP contents, gradation and properties of RAP aggregate may limit amount of RAP used.
  - Processing or screening RAP ?

RAP in HMA
Practical Considerations



- RAP variability must be controlled to meet production tolerances.
- Binder blending methods are used for high RAP contents.
- Designs with modified binder require special attention.

RAP in HMA