Sixth Street Viaduct
Seismic Improvement Program
Alkali Silica Reaction Workshop
8/27/08

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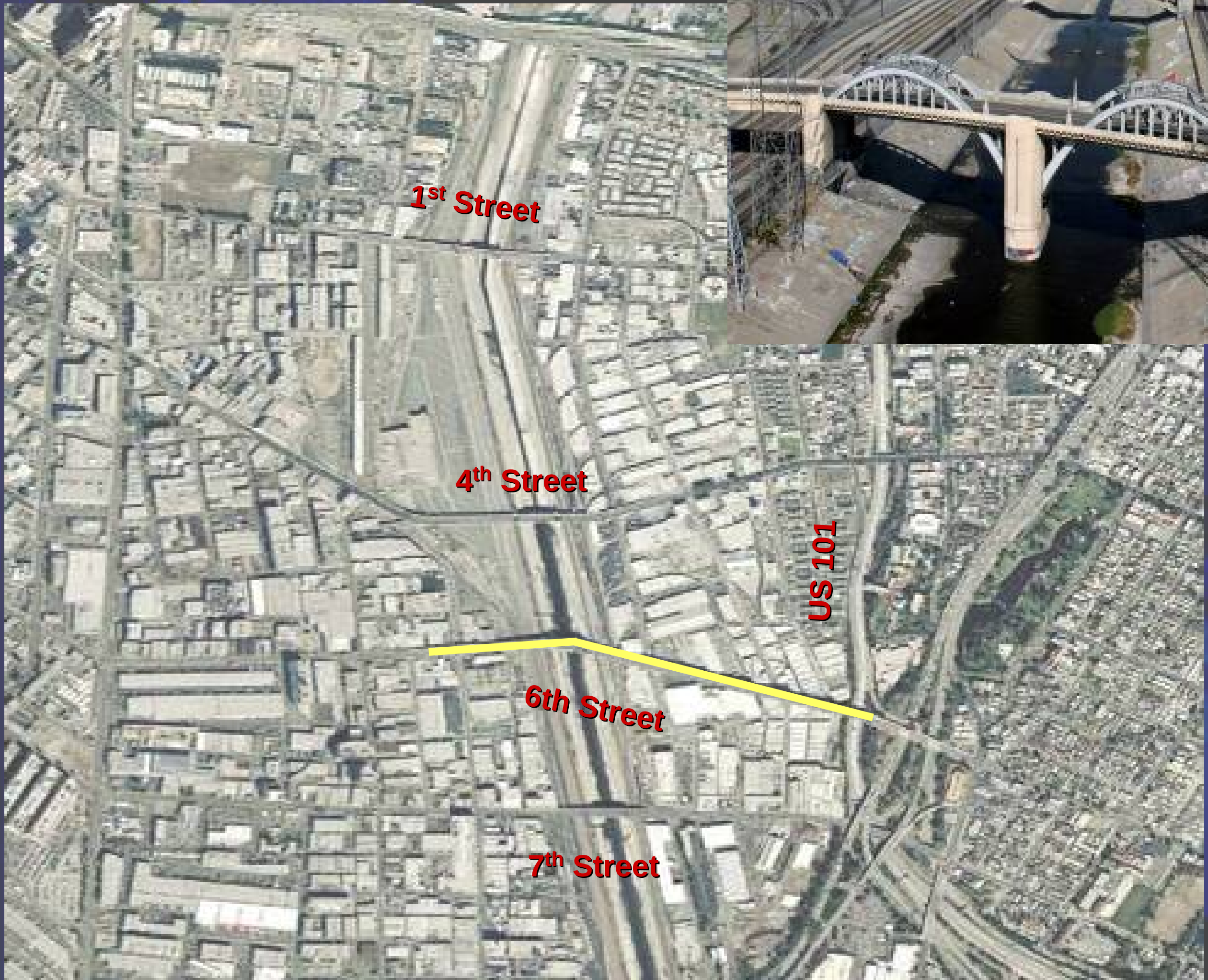
Introductions

- **Gary Lee Moore – City Engineer**
- **Clark Robins – Deputy City Engineer**
- **Phil Richardson – Program Manager, Bridge Improvement Program**
- **John Koo – Group Manager, Bridge Improvement Program**
- **Jim Wu – 6th Street Viaduct Project Manager**
- **Ken Bernstein – Head, Office of Historic Resources**
- **Eric Delony – Former Head, Historic American Engineering Record**
- **Glen Dake – Landscape Architect, Former "Green Deputy" City of LA**
- **Leo Ferroni – Retired Caltrans – Material Specialist**
- **Stephen Mikesell – Deputy State Historic Preservation Officer**
- **Kent Sasaki – Structural Engineer, Materials Testing 6th St Viaduct**
- **Don MacDonald – Architect, 6th St Viaduct**
- **Dan Weddell – Design Engineer, 6th St Viaduct Seismic Retrofit Strategy**
- **Steve Thoman – Structural Engineer, 6th St Viaduct**

Project Description

- Completed in 1932
- Total Length of 3,546 ft



Purpose & Need

- **Purpose**
  - **Reduce vulnerability of the viaduct in major earthquake**
  - **Resolve design deficiencies in the viaduct**
  - **Preserve 6th Street as a viable east-west link**
- **Need**
  - **ASR degrades the concrete, vulnerable in major earthquake**
  - **Railings damaged & cracked, not meeting crash standards**
  - **Roadway width is inadequate, roadway sight distance is inadequate**

Alkali Silica Reaction (ASR) Material Finding at the Sixth Street Viaduct

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Sixth Street Bridge Material Sampling and Testing Program as Part of the Retrofit Alternative

- **Previous Material Testing**
- **ASR Mechanisms**
- **Field Sampling and Testing**
- **Laboratory Testing**

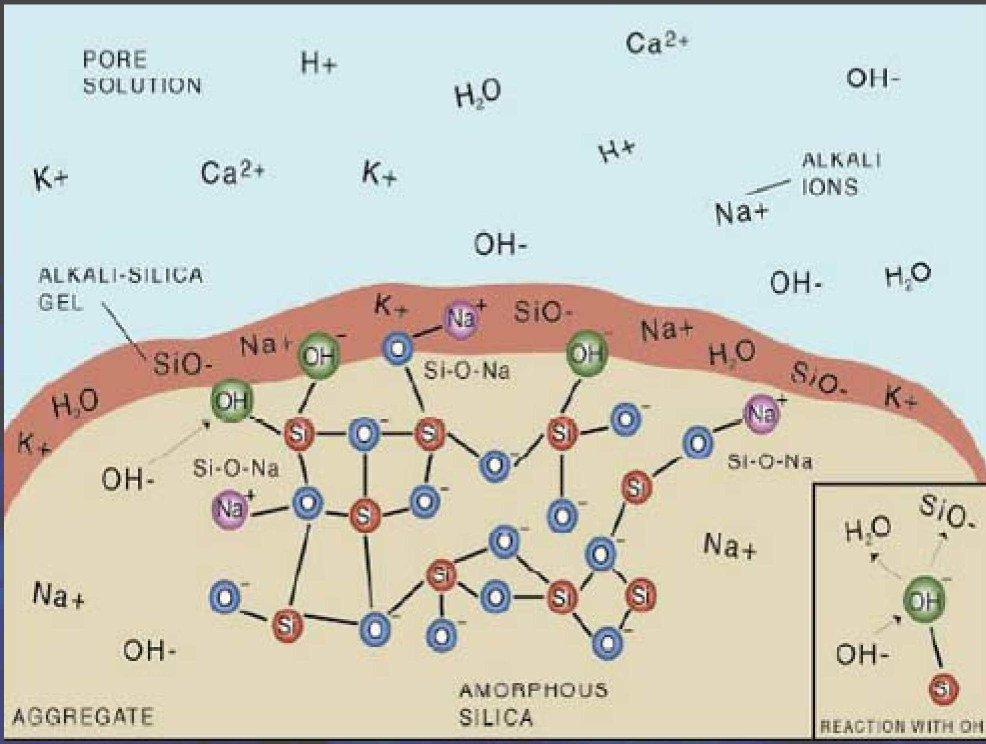
Previous Material Testing

- Two cores removed two columns in 2000
- Petrographic studies conducted
- Studies indicated that ASR was cause of distress

Alkali-Silica Reaction Mechanism

ASR is triggered by:

1. **Reactive Form of Silica in Aggregates**
2. **Sufficient Alkali (Na or K) in Cement**
3. **Sufficient Available Moisture**



Material Testing Program

- **Field Sampling and Testing**
  - **Visual survey**
  - **Core and rebar extraction**
  - **Nondestructive testing**
- **Laboratory Studies and Testing**
  - **Petrographic examinations**
  - **Compressive strength testing**
  - **Young’s Modulus testing**
  - **Rebar tensile testing**

Field Sampling and Testing

- **Performed visual condition survey of the bridge.**
- **Extracted 88 drilled concrete core samples and six rebar samples at locations throughout the structure.**
- **Performed non-destructive testing, including impact echo and pulse velocity testing, of six structural elements.**

Visual Condition Survey

- Walk-through visual survey to identify the extent, type, and level of distress.
- Rated surface distress of bridge elements.
  - Severe - major longitudinal cracks and map cracking
  - Moderate - some longitudinal cracks and map cracking
  - Light - no or little cracking
- Use to correlate surface distress with internal distress.

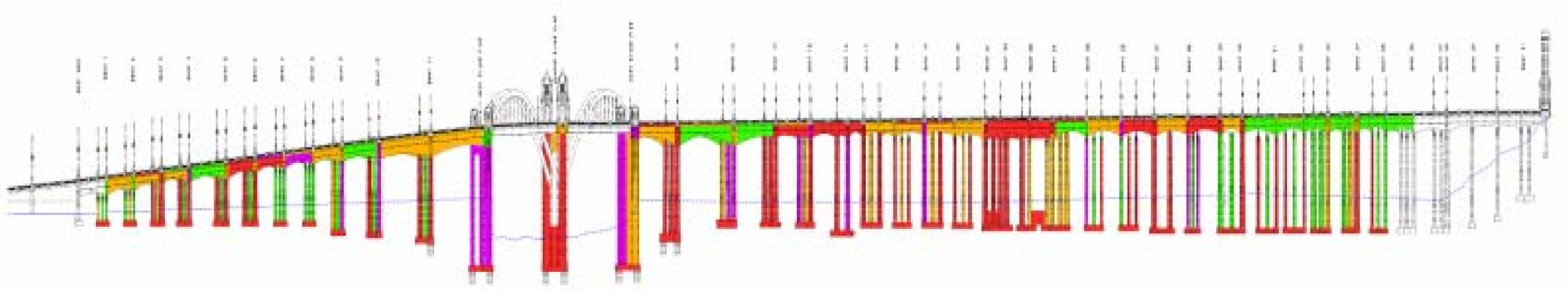
Visual Survey
Example of Severe Rating

Visual Survey
Example of Severe Rating

Visual Survey
Example of Severe Rating

Visual Survey
Example of Light Rating

Visual Survey



Light Damage

Moderate to Severe Damage

Moderate Damage

Severe Damage

- **Exterior Columns**
  - **49% moderate-severe, or severe**
  - **23% moderate**
  - **28% light**
- **Interior Columns**
  - **12% moderate-severe, or severe**
  - **32% moderate**
  - **56% light**

- **Longitudinal Girders**
  - **32% moderate-severe, or severe**
  - **35% moderate**
  - **32% light**
- **Bent Caps/Transverse Girders**
  - **46% moderate-severe, or severe**
  - **33% moderate**
  - **21% light**
- **Deck**
  - **36% moderate-severe, or severe**
  - **39% moderate**
  - **25% light**

Non-destructive Testing

- **Impact Echo & Pulse Velocity Testing**
- **Six elements tested.**
- **Impact Echo locates delaminations and honeycombing.**
- **Pulse Velocity identifies the relative condition of the concrete.**

Locations of Core Samples

- **88 cores extracted**
  - **29 cores from the West Approach**
  - **4 cores from the Center River Pier**
  - **55 cores from the East Approach**

Types of Elements Sampled

- **Cores extracted from:**
  - **25 Columns**
  - **15 Bent caps**
  - **18 Longitudinal Girders**
  - **18 Decks**
  - **12 Foundations**

Column Distress - N. Col., Bent 5

Column Distress - N. Col., Bent 5

Column Distress - S. Col., Bent 21

Column Distress - S. Col., Bent 21

Column Distress - N. Col., Bent 21

Column Distress - N. Col., Bent 21

Column Distress - N. Col., Bent 21

Column Distress - S. Col., Bent 26

Column Distress - S. Col., Bent 26

Comparison of Core Distress

Center River Pier, N. Pier

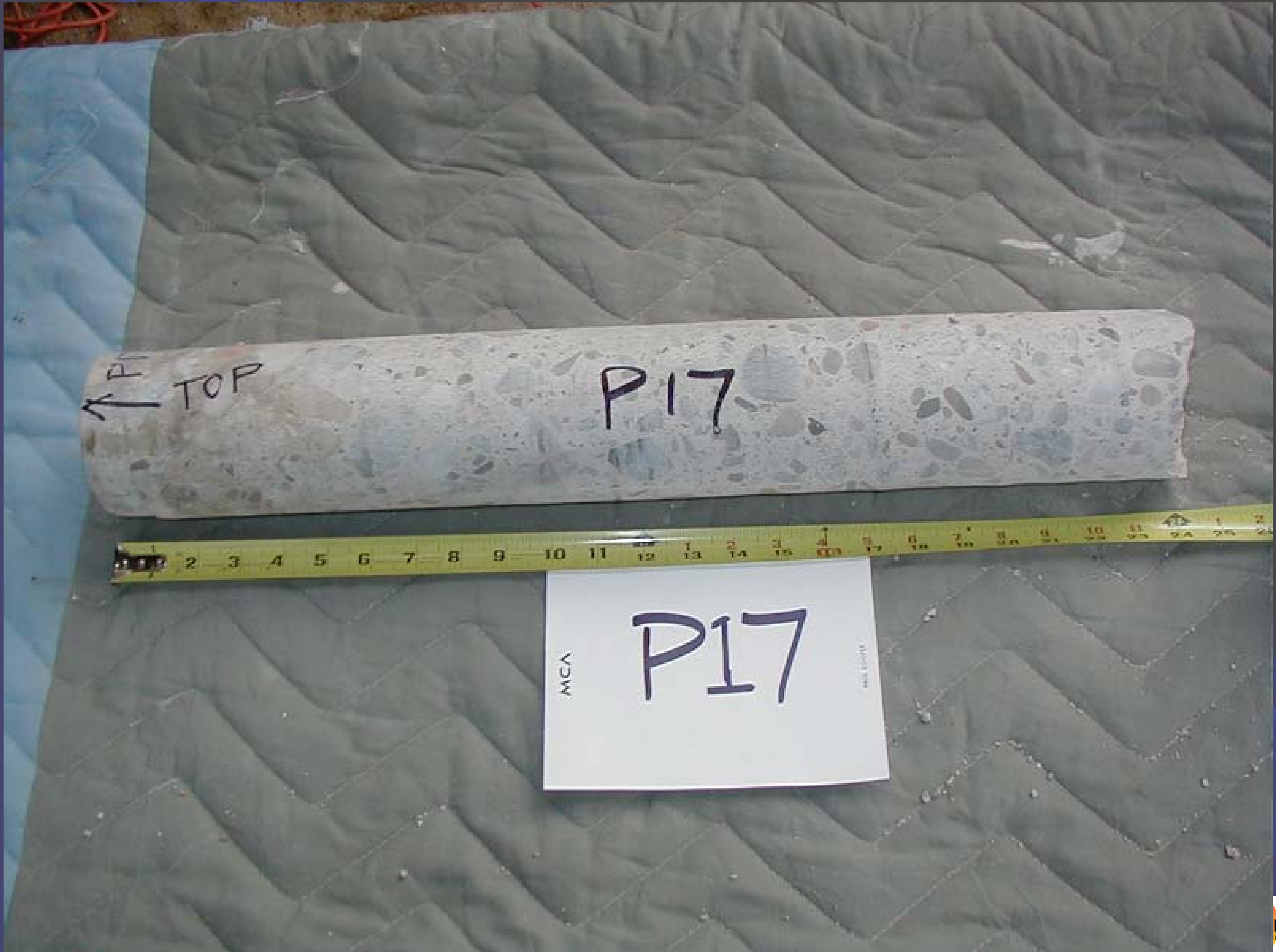
Center River Pier, N. Pier

Girder Distress, Bent 9

Girder Distress, Bent 9

Girder Distress, Bent 25

Girder Distress, Bent 25



Girder Distress, Grid 6.4

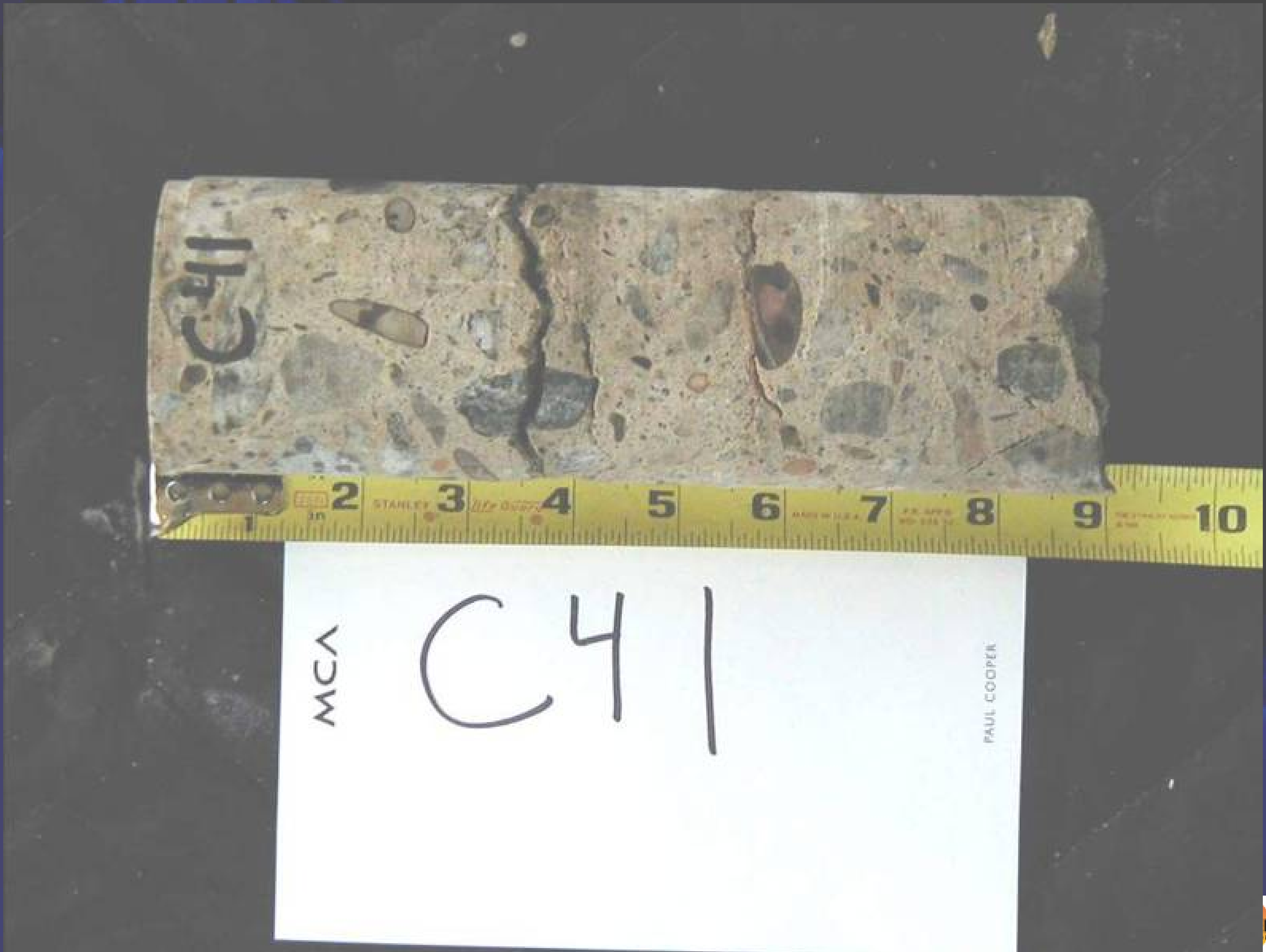
Girder Distress, Grid 6.4

Deck Distress, Grid 28.2

Deck Distress, Grid 28.2

Deck Distress, Grid 28.8

Deck Distress, Grid 28.8



RING

Foundation Distress, Bent 23

RING

Foundation Distress, Bent 23

RING

Foundation Distress, Bent 23

Foundation Distress, Bent 23

New Cracking Occurring

Low Penetration of Epoxy

Field Findings

- Evidence of extensive cracking throughout the structure
  - columns, bent caps, girders, deck, foundations
- Evidence of severely reactive aggregate
- Cracking is worse at areas exposed to moisture - expansion joints, exterior columns, base of columns, foundations
- Internal distress correlates with surface distress.

Laboratory Testing

- Petrographic examinations of core samples
- Concrete compressive strength testing
- Concrete modulus of elasticity testing
- Rebar tensile testing
- Non-destructive testing - impact echo and pulse velocity testing

Purpose of Petrographic Examinations

- To confirm the presence of ASR
- Identify reactive aggregate
- Assess potential for future ASR deterioration
- Evaluate overall quality of concrete

Petrographic Results - Presence of ASR

- Observed severe ASR deterioration in specimens
- Widespread presence of ASR gel
- Cracks empty or filled with secondary deposits
- Consumption of selective aggregates

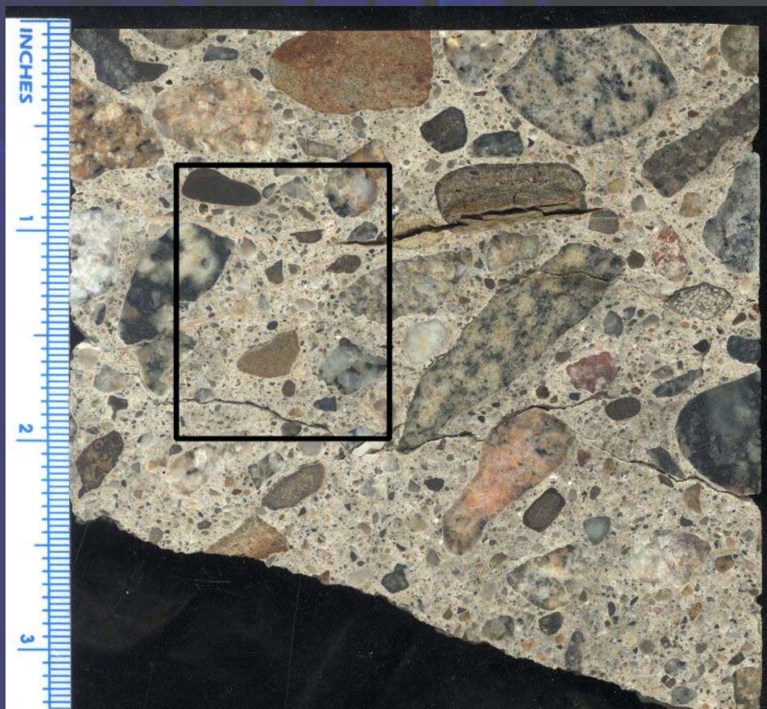
Petrographic Results - Reactive Aggregates

- Almost all aggregate present was reactive
- Ranking of reactive aggregate (most reactive listed first)
  - rhyolitic tuff
  - graywacke (including sandstone and siltstone)
  - granitic gneiss
  - quartzite
- Intermediate sized-particles most reactive for a given aggregate type

Petrographic Results - Future ASR Deterioration

- **Abundant evidence of active ASR**
  - **Fresh gel observed on saw-cut surfaces**
  - **Liquid state gel observed when aggregate broken in lab**
  - **Evidence of active expansion**
- **ASR deterioration to continue**
  - **Based on activity of ASR**
  - **Evidence of new cracks**

Presence of ASR

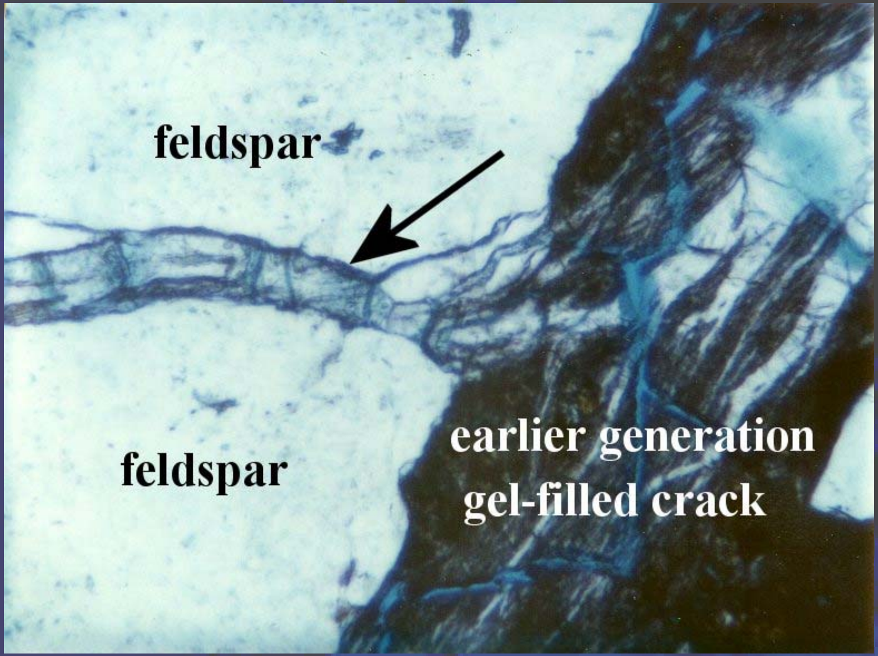


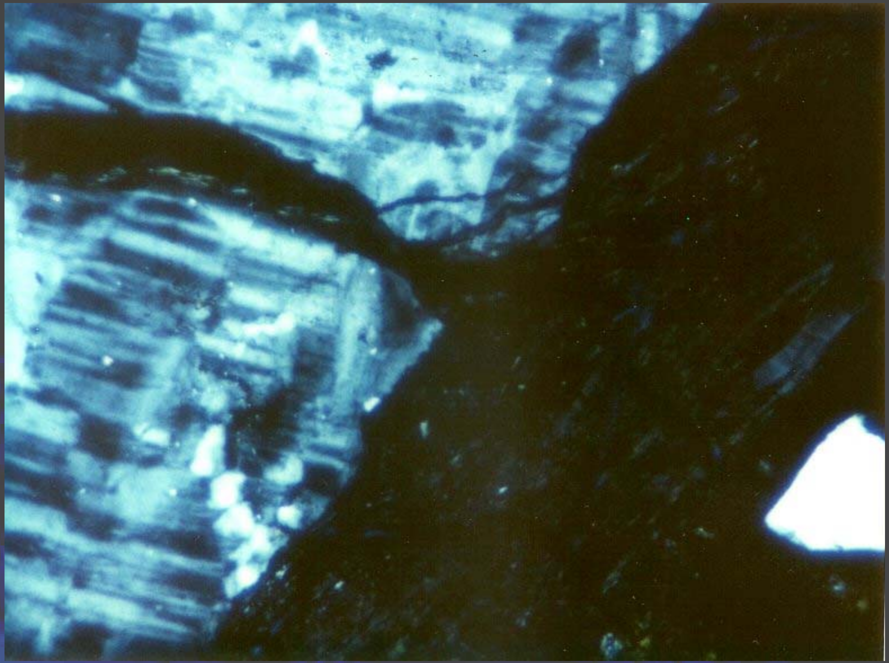
Scanned images of polished section of Core P1 showing cracks in concrete caused by ASR. Image on right is a 4X magnification of rectangular area in the left image, which shows gel-filled cracks (marked with arrows) and a gel-filled void (marked with a circle).

Presence of ASR

A photograph showing a cracked volcanic rock particle in which the original texture is still visible. The crack extended outward from aggregate into the cementitious matrix.

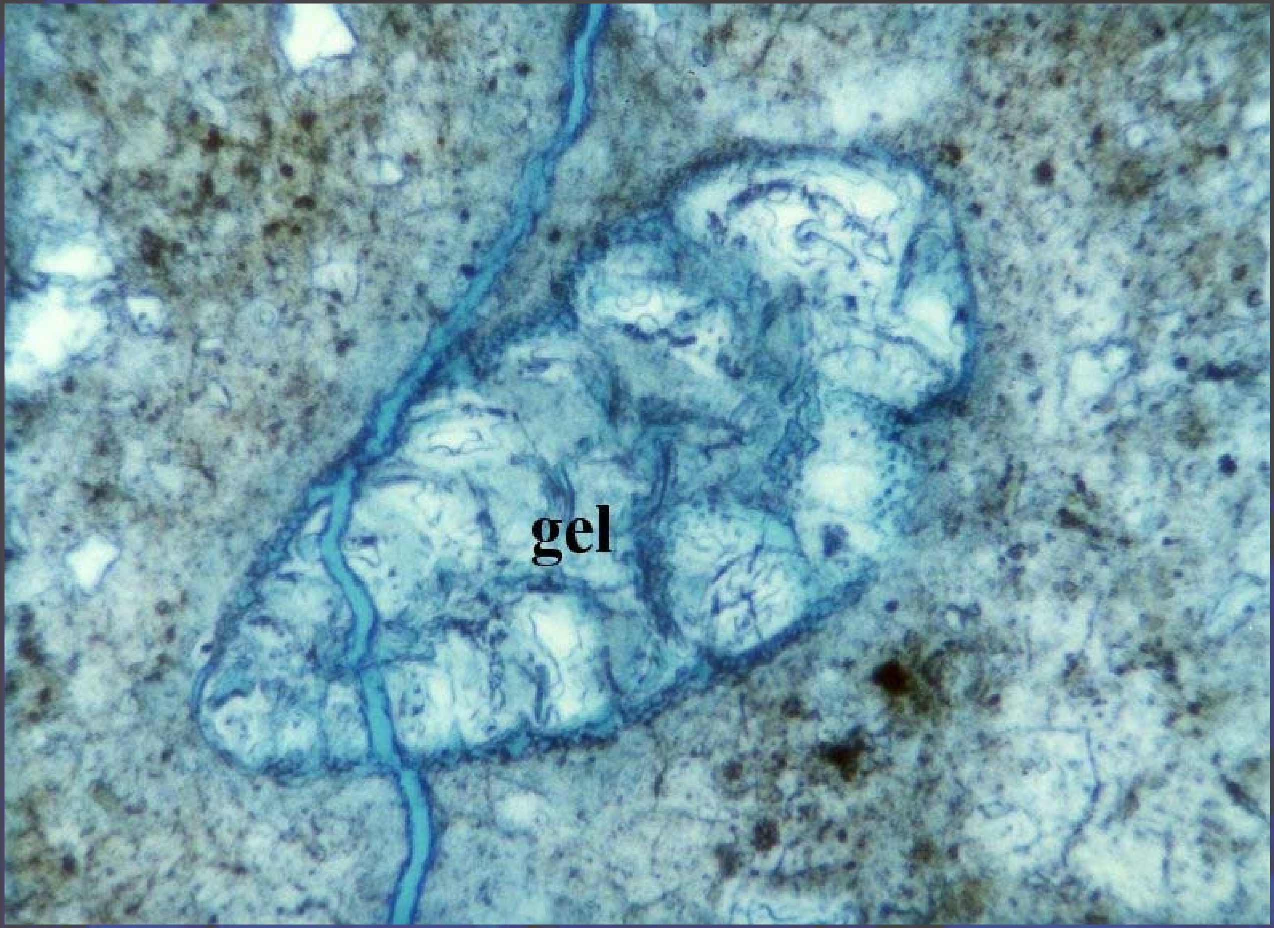
Presence of ASR





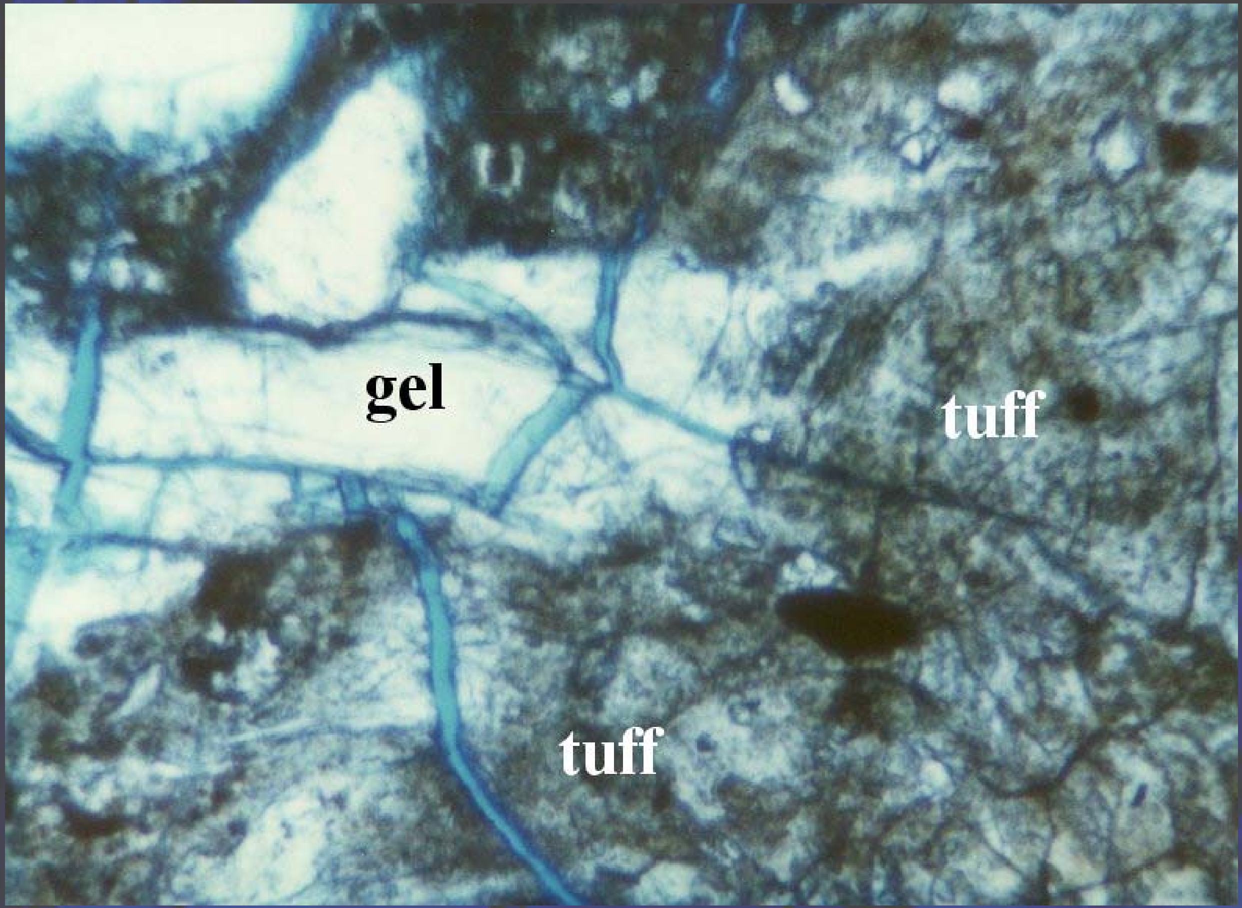
Photomicrographs showing two generations of cracks and a feldspar particle. Photo on left (plane polarized light) shows two generations of cracks. Older crack (darker-colored gel) is to the right. Newer crack (lighter colored gel and marked with arrow) likely due to the reaction of the feldspar particle. Photo on the right (crossed polars) shows alkali-silica gel as typical dark extinction of amorphous materials. (100X)

Presence of ASR



Photomicrograph taken under a petrographic microscope showing a pocket of ASR gel inside a rhyolitic tuff aggregate particle. A later generation crack propagated through the aggregate and the gel pocket. (100X, plane polarized light)

Presence of ASR



Photomicrograph taken under a petrographic microscope showing alkali-silica gel exuding out of a rhyolitic tuff aggregate particle along a crack. (100X, plane polarized light)

Variability of Cracking

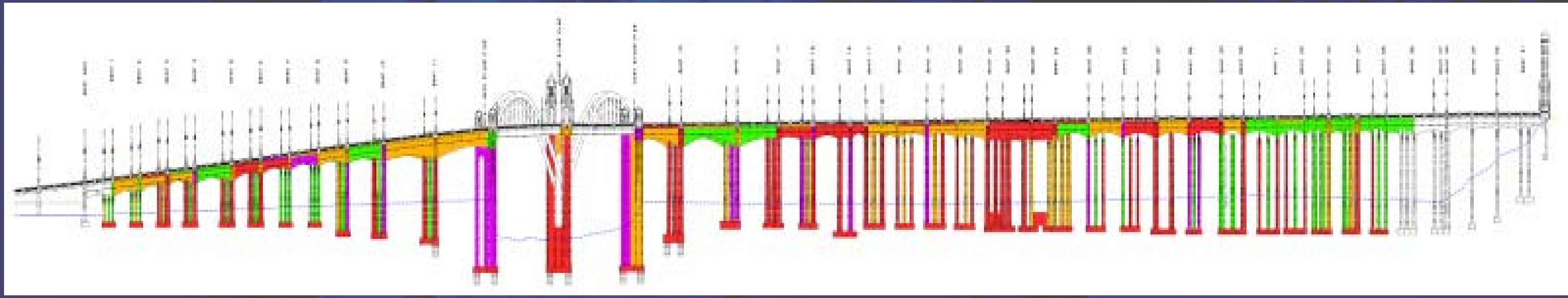
Scanned images of polished sections of Core P20 showing the difference in the degree of ASR deterioration between the top 0-5 inches (left) and the bottom 15-20 inches (right) of the core.

ASR Case Studies

- California
- U.S.
- Outside the U.S.

ASR will Stop when 1 of 3 Conditions Ceases to Exist

1. **Remove the reactive aggregate**
2. **Remove the high alkali content in the cement**
3. **Remove the available moisture from the concrete matrix**



Light Damage

Moderate to Severe Damage

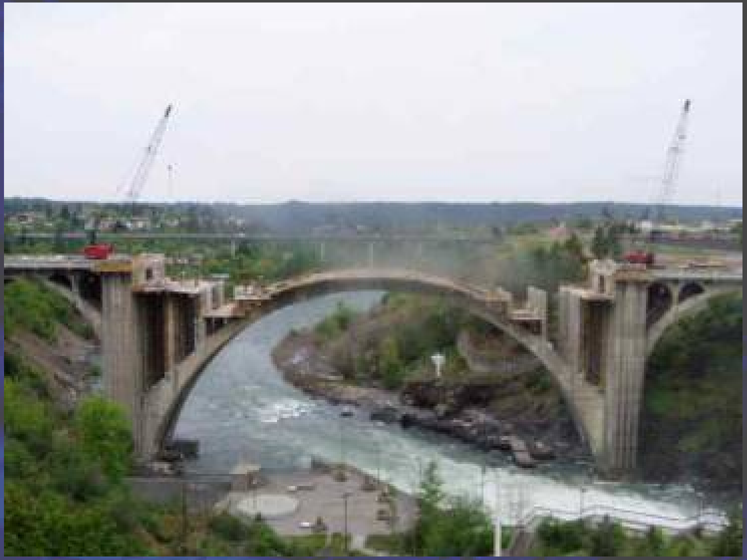
Moderate Damage

Severe Damage

Treatments for ASR In Existing Structures

- **Minimize Moisture**
  - **Epoxy Injection**
  - **Methacrylate Injection**
- **Provide 3-D Confinement Pressure**
- **Replace Most Severely Damage Members**
- **Replace Structure**

Case Studies



Identify ASR

Determine Extent of Damage

Develop Course of Action

Remove Moisture & Repair

Remove Members

Remove Structure

Monitor and Inspect

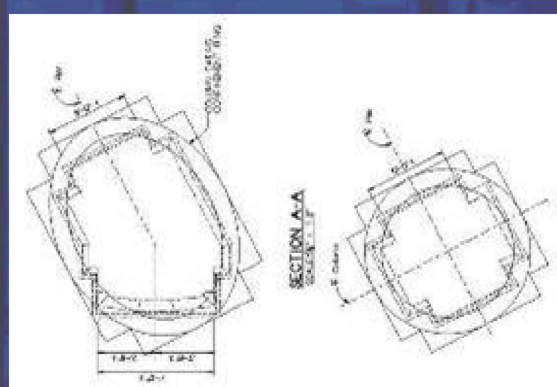
Alternative No. 2 – Rehabilitation/Retrofit

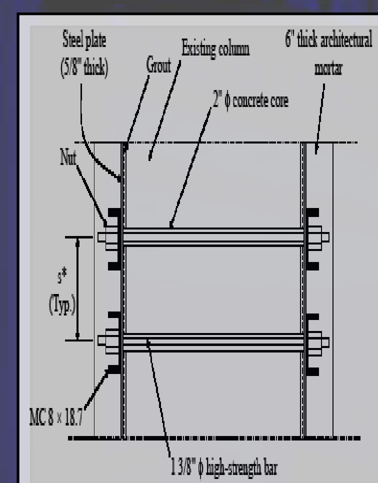
Alternative No. 2 – Retrofit
Heavy Steel Casing

Before

After

- Provides Confinement in Columns
- Strengthens Foundations





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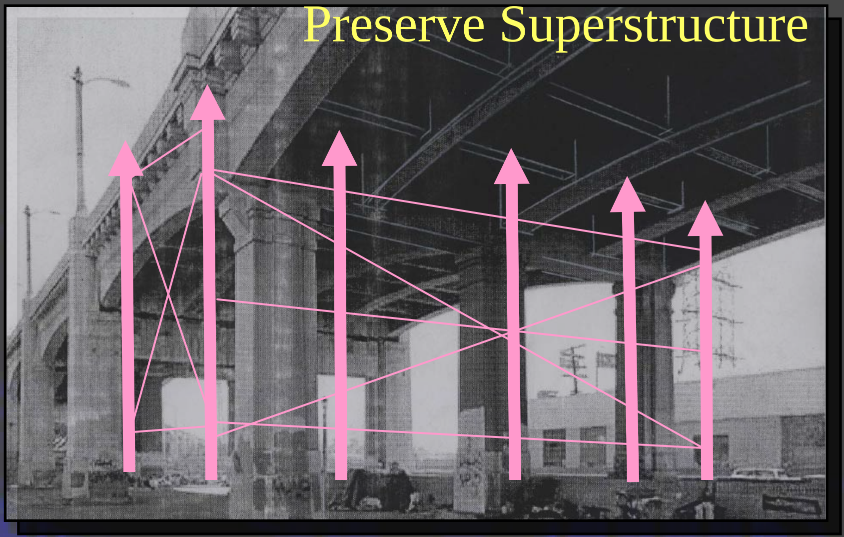
Alternative No. 2 – Retrofit Substructure Replacement

Replace All Columns



Heavy Shoring Required

Replace All Foundations

Replace All Barrier Rails

Replace All Bent Caps

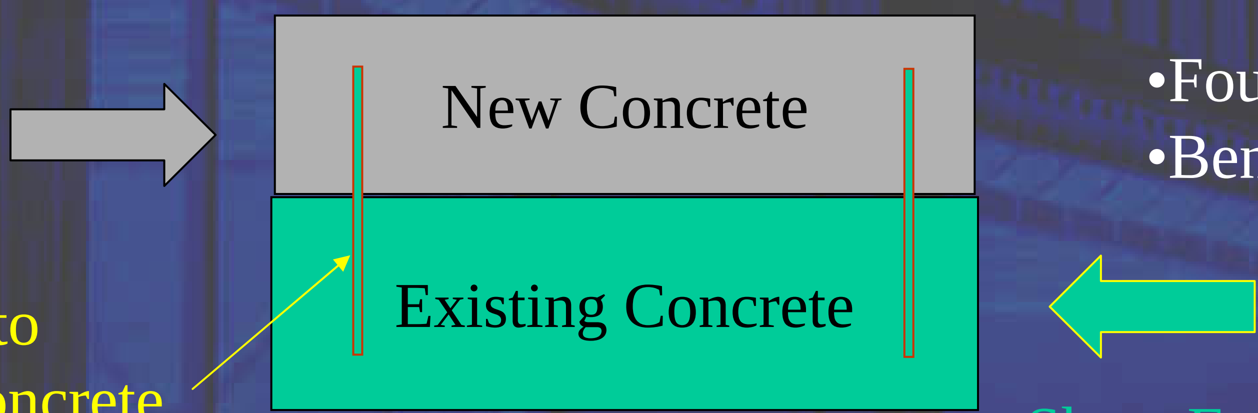
Short Term
Seismic Collapse Vulnerabilities Prevented with Steel Casing and/or Substructure Replacement

Examples

Column Flexural and Shear Failures

Alternative 2 – No Collapse Criteria

- **Seismic Reliability Concerns (Long Term)**
  - **Material deterioration from Alkali-Silica Reaction (ASR)**
  - **Structural Design**



- Foundations
- Bent Caps

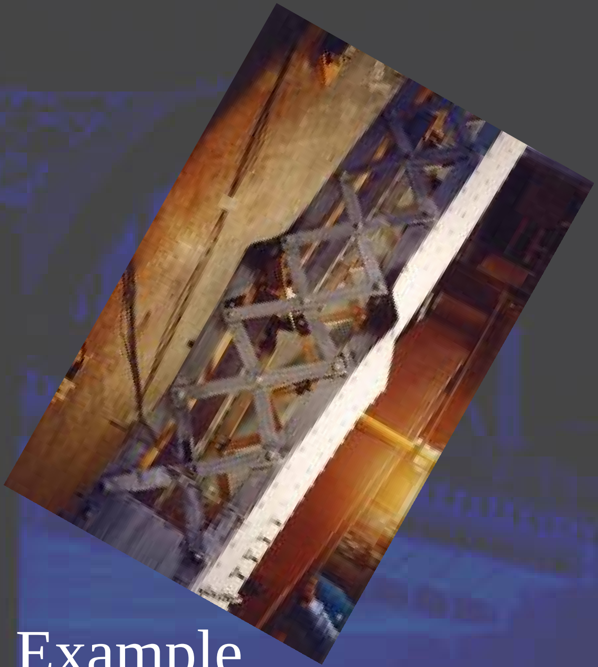
Potential Seismic Damage

Column
Reinforcing Steel
Development

Example

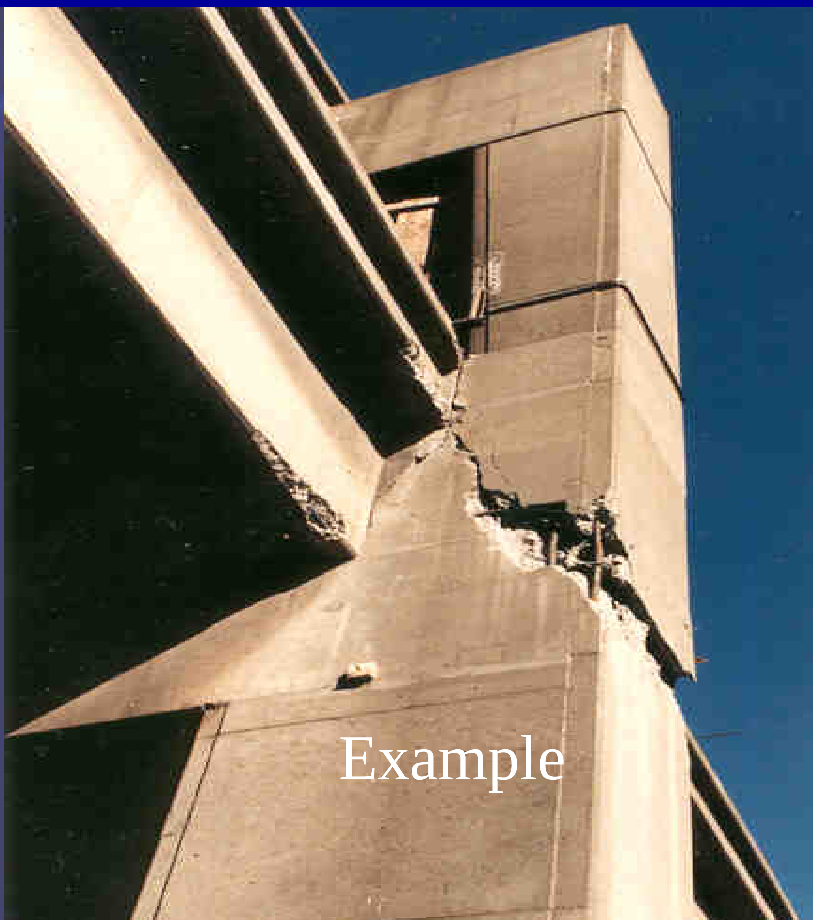
Potential Seismic Damage

Buckling of Arch Ribs Members



Example

Potential Seismic Damage



Joint Shear Failure

Alternative's Costs

	Construction ($ million)	ROW ($ million)	Eng/Admin ($ million)	TOTAL ($ million)
Retrofit - Steel Casings (30 yr life)	154.7	30.6	40.3	226
Retrofit - Substructure Replacement (75 yr life Substructure & 30 life for Superstructure)	310.7	30.6	40.3	382
Replacement – Alignment A (75 yr life)	221.2 To 279.9	53.6 To 54.4	40.3	315 To 375
Replacement – Alignment B (75 yr life)	217.5 To 280.3	81.7 To 81.8	40.3	340 To 402
Replacement – Alignment C (75 yr life)	238.4 To 290.0	43.8 To 43.9	40.3	323 To 374

Note: Costs are escalated to midyear of construction (2013)

DISCUSSIONS