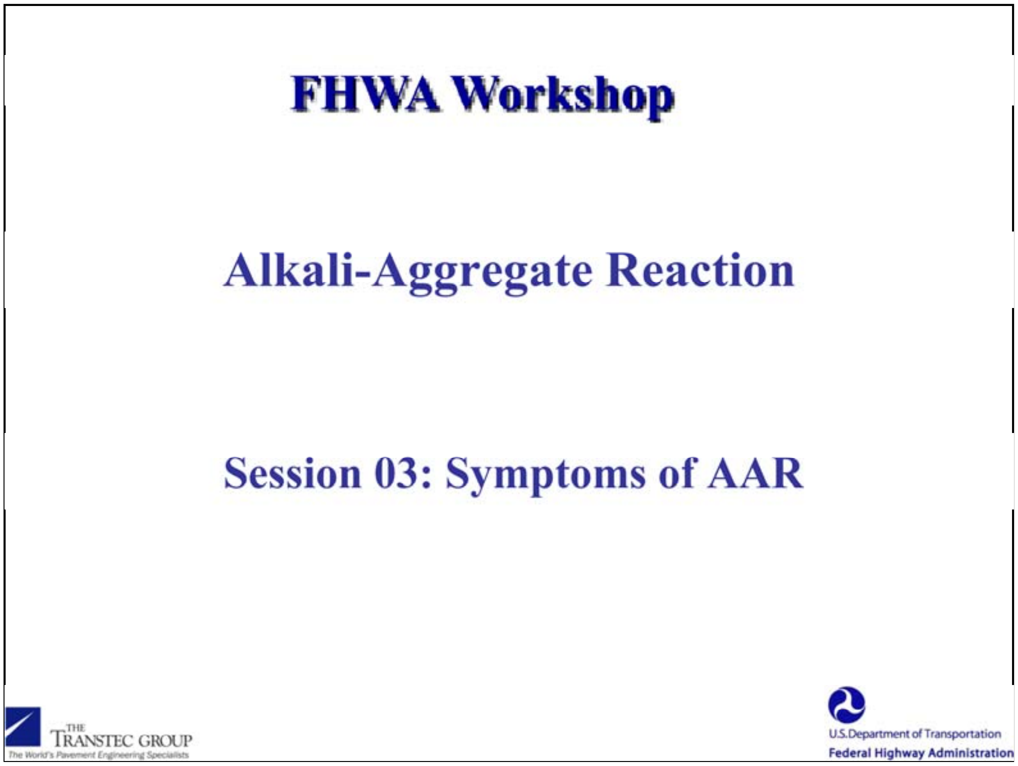
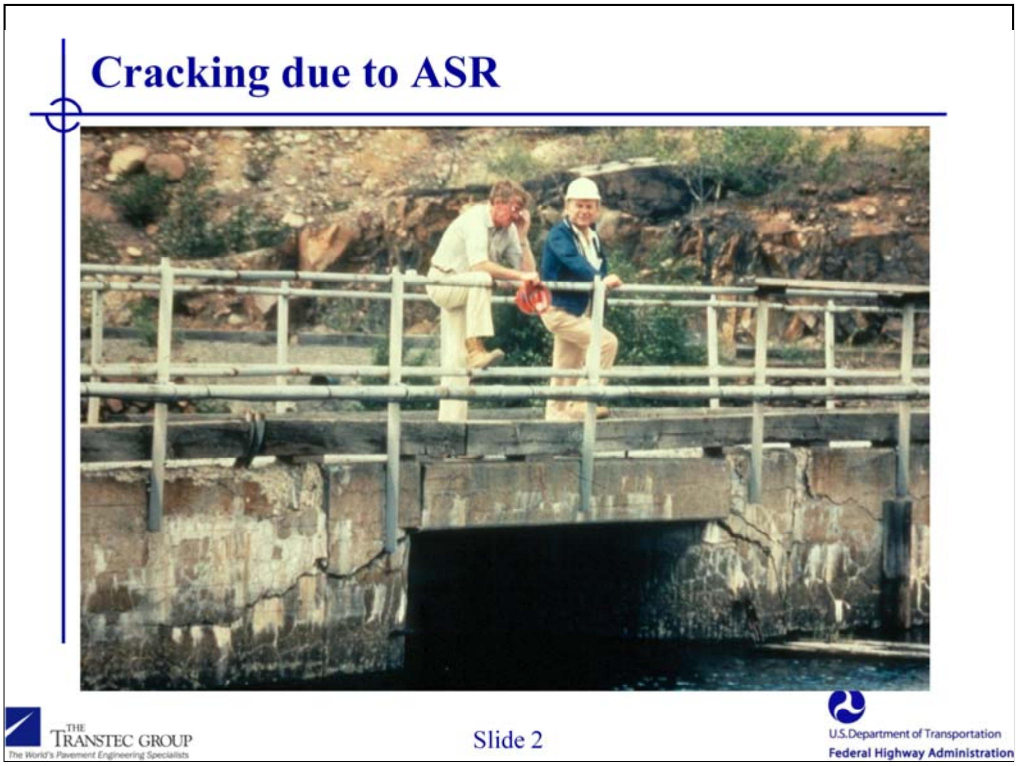


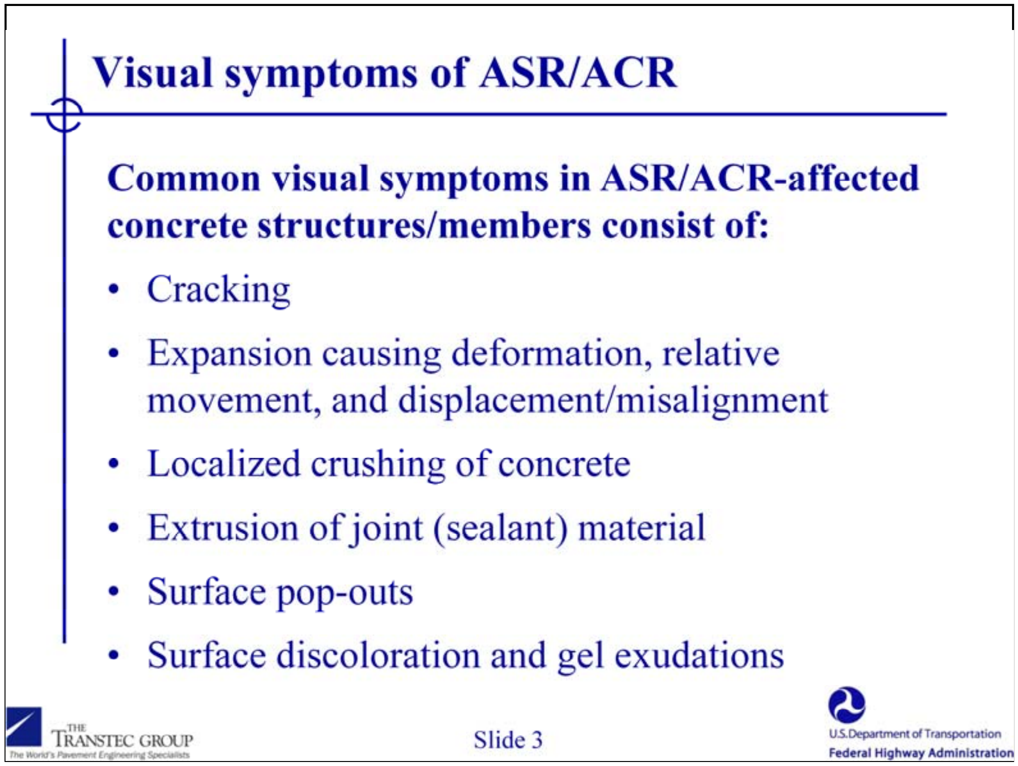
Slide 1

This presentation presents a summary of the main visual features that can be observed on AAR-affected concrete structures in the field.



Slide 2

Some of the features that will be described in this presentation are indicative of AAR, without necessarily being a definite proof that AAR is the main factor responsible for the deterioration observed. Generally, confirmation of the presence and the role (main / secondary) of AAR in the deteriorating concrete structure is required, mainly through petrographic examination of concrete cores extracted from the structures or element(s) of the structures showing features generally indicative of AAR.

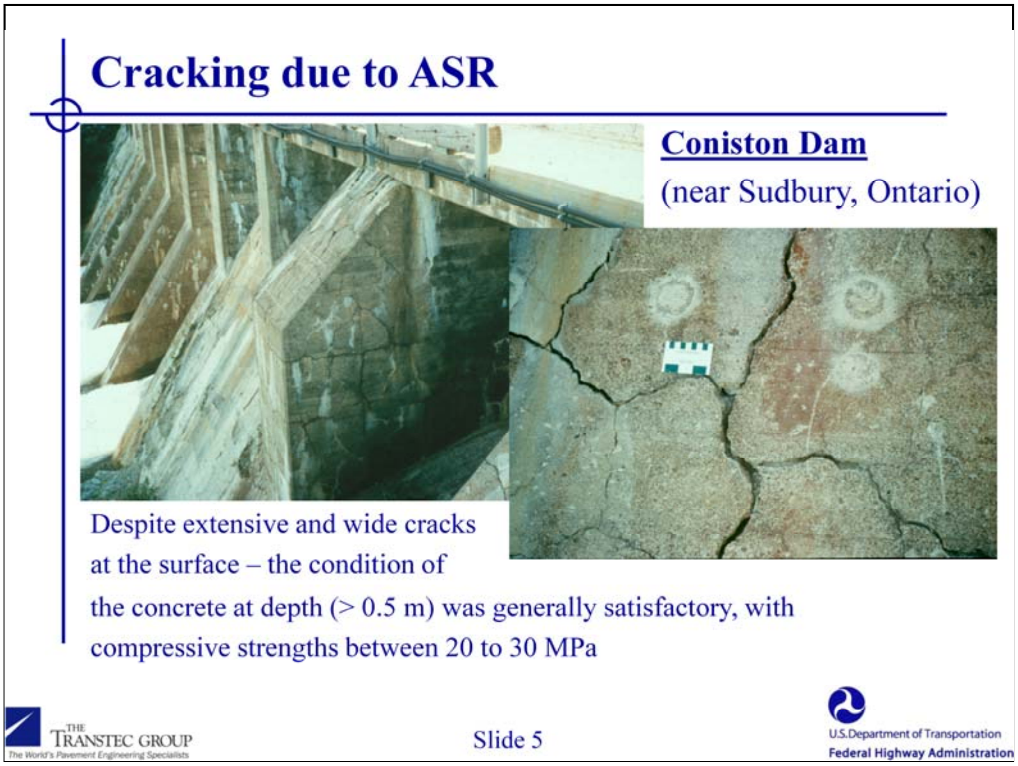


Slide 3

Common visual symptoms of ASR consist of: cracking; expansion causing deformation, relative movement, and displacement; localized crushing of concrete; extrusion of joint (sealant) material; surface pop-outs; and surface discoloration and gel exudations

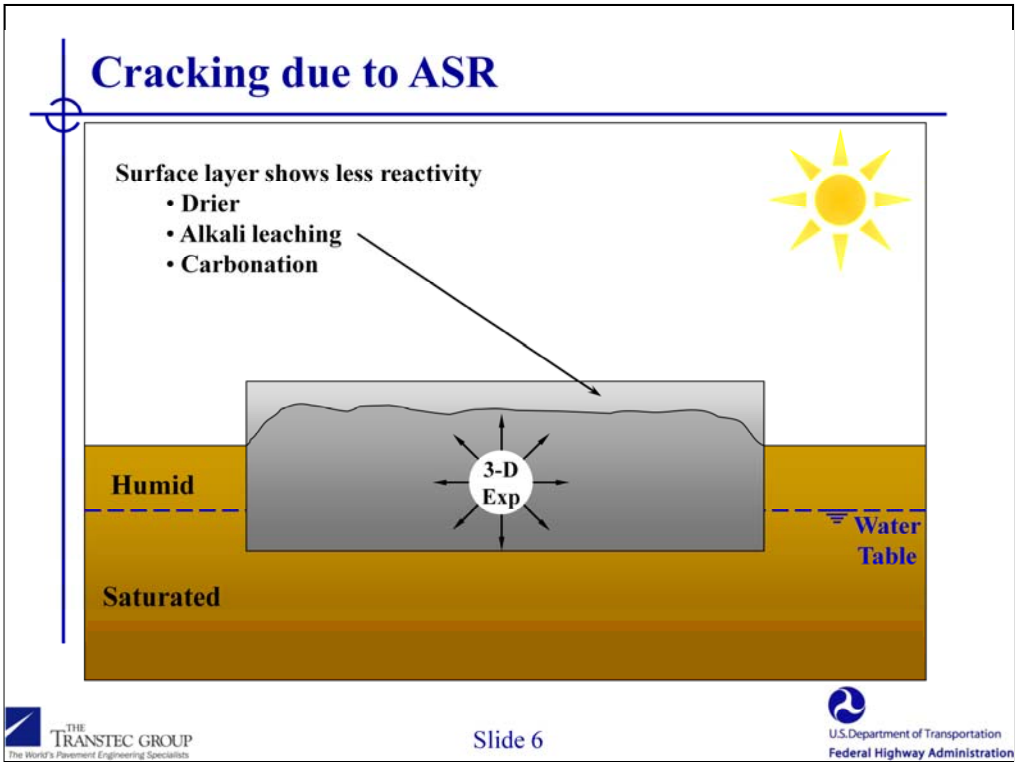
Slide 4

Cores extracted from AAR-affected concrete structures, such as in the case of the continuously reinforced concrete pavement section illustrated in this slide, will often show macrocracks penetrating only a few inches into the affected concrete, and turning into a microcracking pattern at depth.



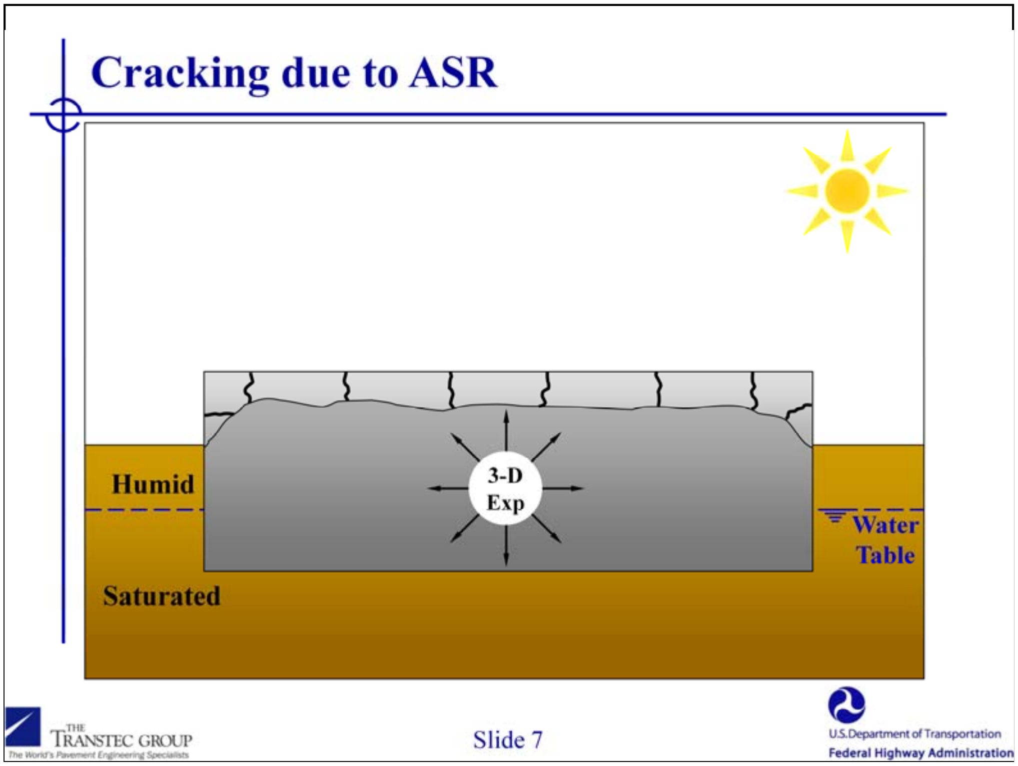
Slide 5

This would also be the case, as illustrated in the Coniston Dam illustrated in this slide, for hydraulic dams/structures where extensive and wide cracks appears at the surface of the affected concrete structure; however, such cracks would generally remain relatively superficial and the condition of the concrete at depth (greater than about 1-1.5 feet) was generally satisfactory, with compressive strengths between 20 and 30 MPa (~3000 to 4500 psi).



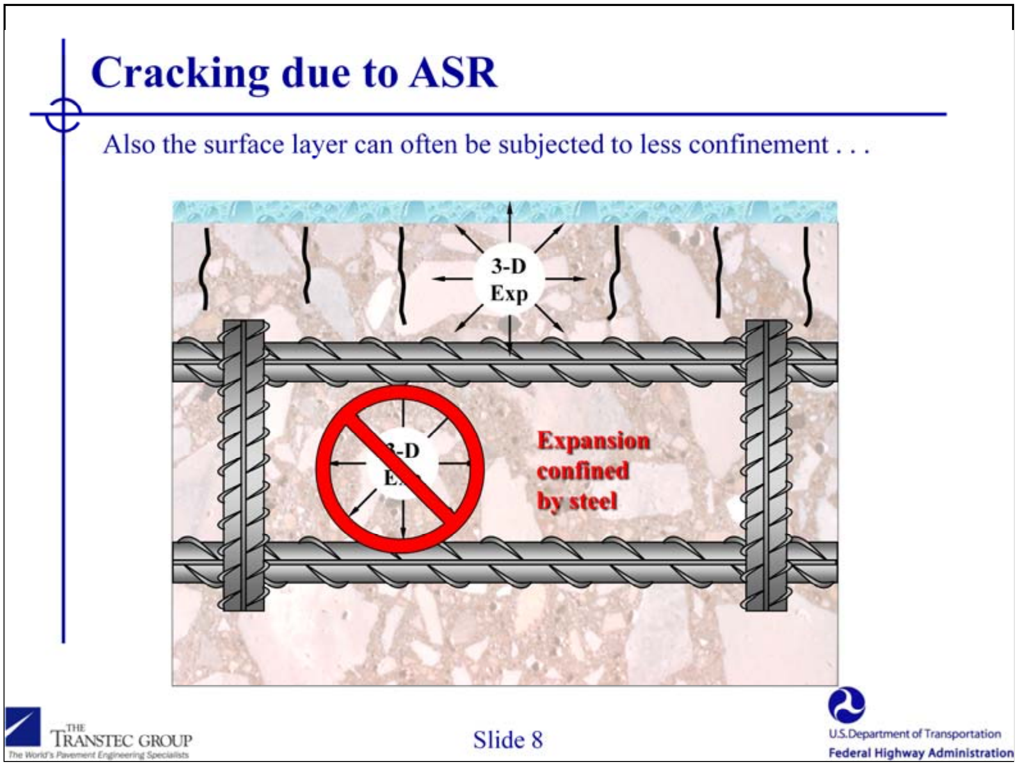
Slide 6

This "typical" cracking pattern affecting AAR-affected concrete element is explained by the following cartoons. Concrete members often experience cyclic exposure to sun, rain and wind.



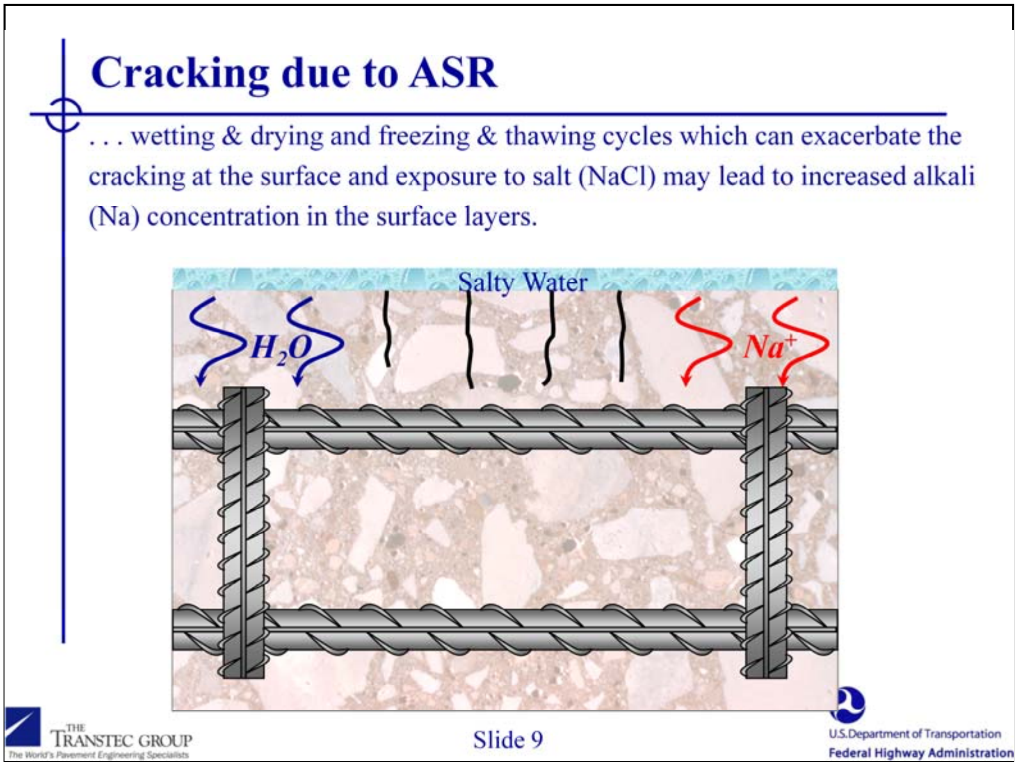
Slide 7

Surface cracking will develop as a result of the induced tensile stresses in the "less expansive" (due to alkali leaching/dilution processes, variable humidity conditions, etc.) surface layer under the expansive thrust of the inner concrete core. The surface macrocracking generally penetrates down to the reinforcement layer or the level where the internal moisture content is no longer influenced by weather effects mentioned before.



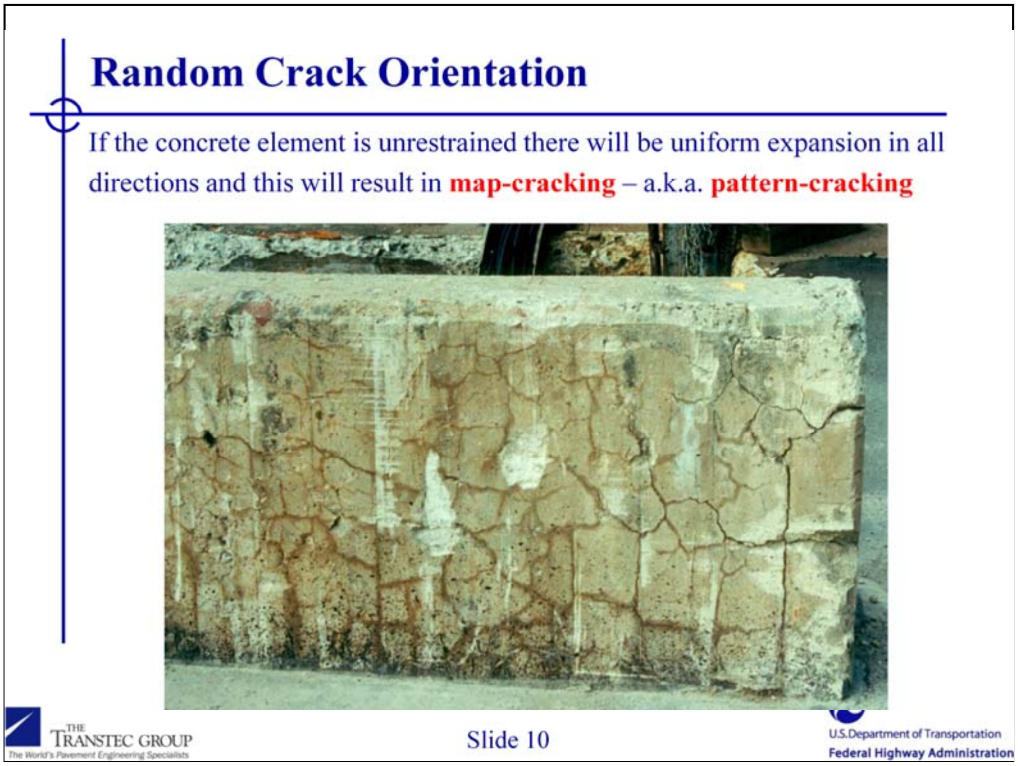
Slide 8

AAR can be prevented (or at least significantly reduced) in properly reinforced concrete members; however, expansion due to AAR can still occur in the surface of the affected concrete element when insufficient restraint is provided.



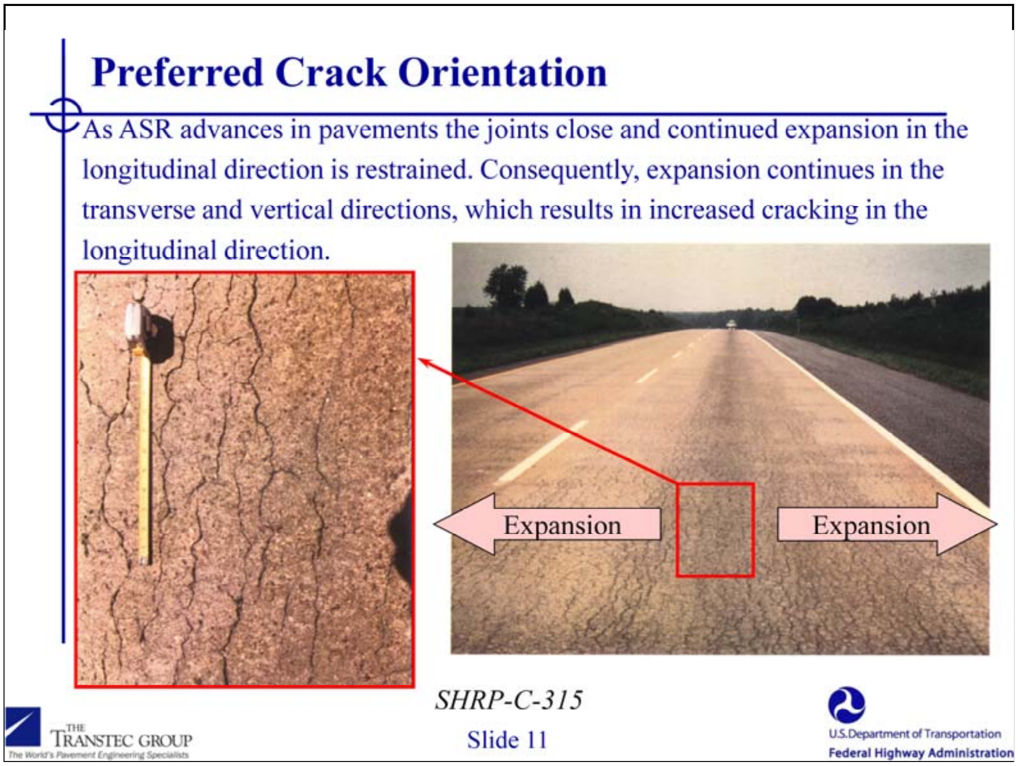
Slide 9

Cracking in the top layer of concrete elements exposed to natural environmental conditions may lead to increased alkali concentration in the surface layer, as well as moisture ingress and penetration of chloride ions (when exposed to deicing salt applications), thus increasing the risk of further deterioration (including corrosion of reinforcing steel).



Slide 10

If the concrete element is unrestrained or has limited restraint, there will be uniform expansion in all directions, thus resulting in map cracking (aka pattern cracking).



Slide 11

When expansion is restrained in one or more directions, more expansion occurs in the direction of least confinement, and the cracks become oriented in the same direction as the confining stresses. For example, with concrete pavements, the expansion being restrained in the longitudinal direction, a greater amount of expansion occurs in the transverse direction and cracks develop preferentially in the longitudinal direction. With increasing expansion, pattern cracking will likely connect the main longitudinal pattern of cracking.

Preferred Crack Orientation

Prestressed concrete – cracking aligned with the direction of principal stress (i.e. direction of main prestress tendons)

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Slide 12

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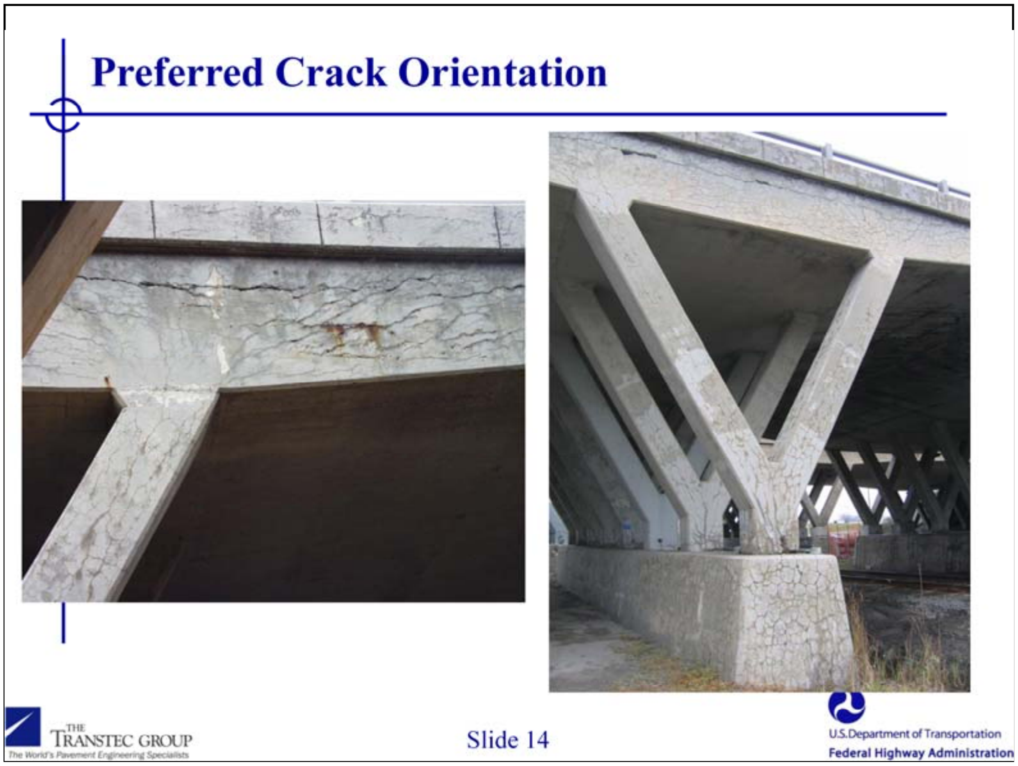
Slide 12

In the case of prestressed bridge girders, the cracks will usually be aligned horizontally due to the confinement imposed by the prestressing tendons parallel to the beam axis.

Slide 13

In the case of reinforced concrete columns, cracks tend to be aligned vertically due to the restraint imposed by the primary reinforcement and the dead load.

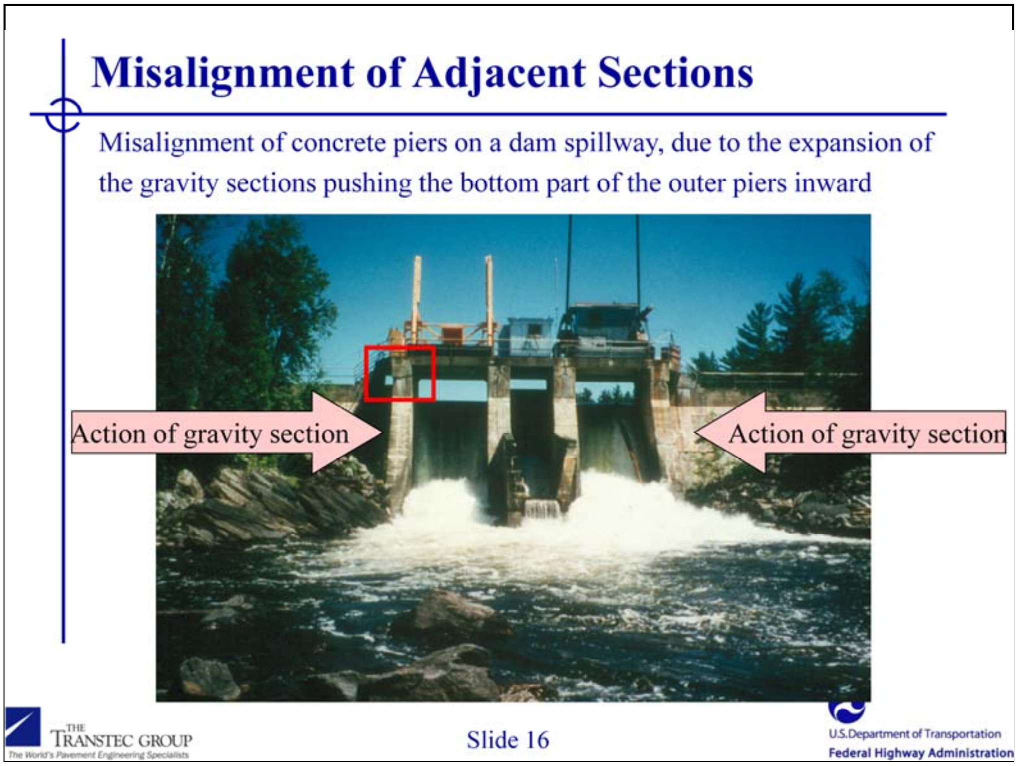


Slide 14

This photograph shows another example where cracking is aligned horizontally in the cross member and along the line of the V-shaped columns. These directions reflect the directions of the principal reinforcement in these members.

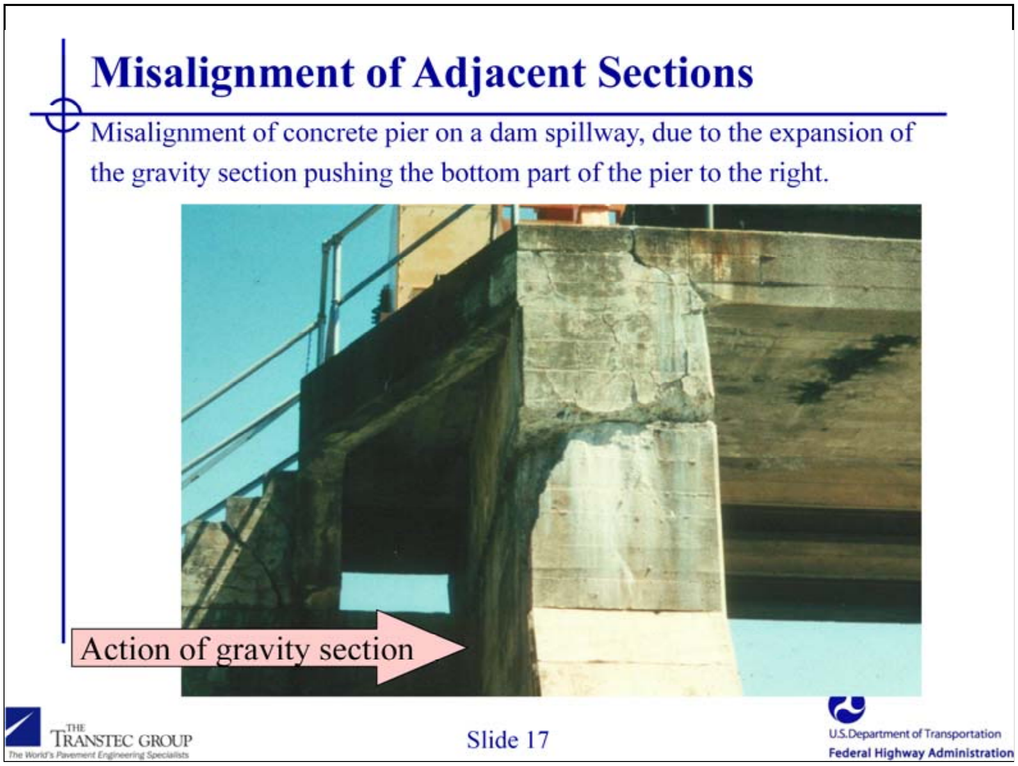
Slide 15

The extent of ASR often varies between or within the various members or components of an affected concrete structure, thus causing distresses such as the differential movement of parapet wall on a bridge.



Slides 16 and 17

Differential or restricted ASR expansion in concrete structures can result in misalignment between concrete members. For example, the gravity sections of the dam illustrated in this picture are sitting on bedrock thus resulting in an expansive action towards the spillway. The bottom part of the outer piers is being pushed inward thus causing major cracking and failure of the pier.



Slides 16 and 17

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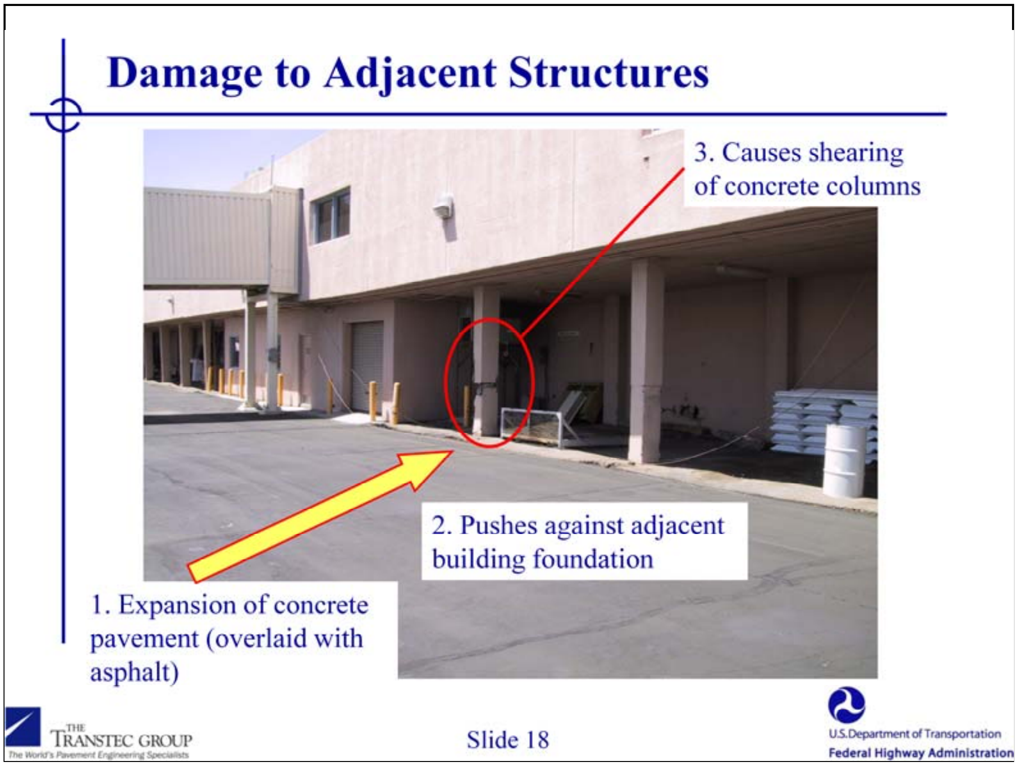

Slides 18 and 19

Another example of the effect of ASR expansion can be seen in this picture at the Albuquerque airport (New Mexico). The expansion of the ASR-affected concrete pavement (overlaid with asphalt) pushes against the adjacent building foundation, thus causing shearing and tilting (figure 18) of the concrete columns.

Slides 18 and 19

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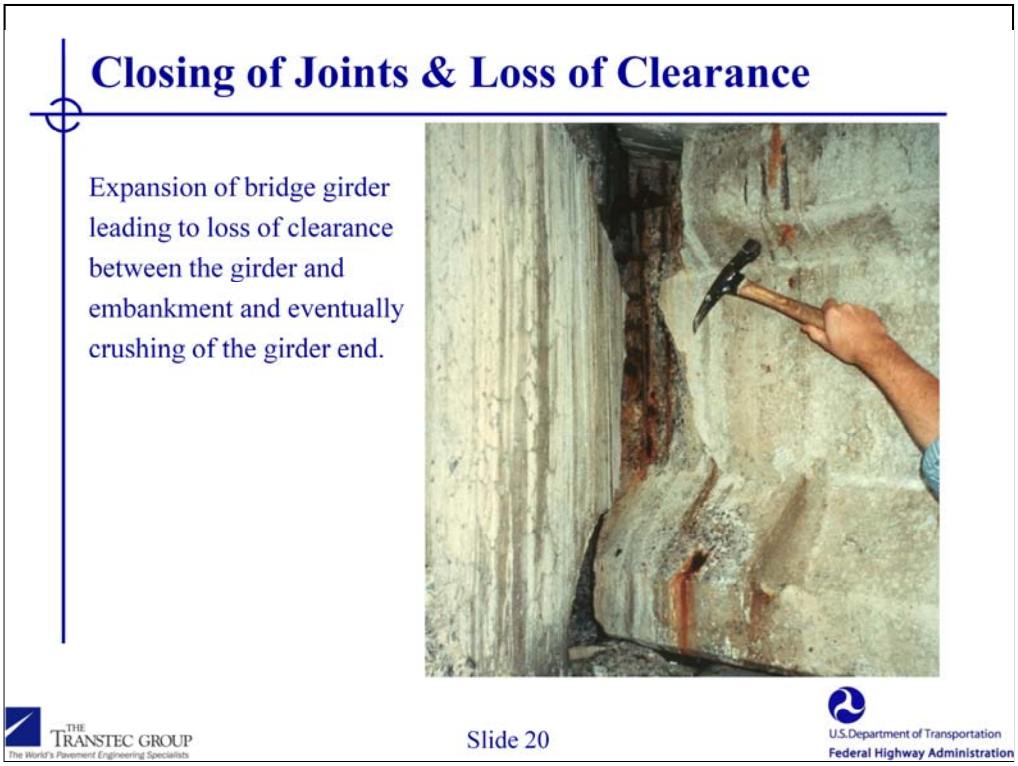
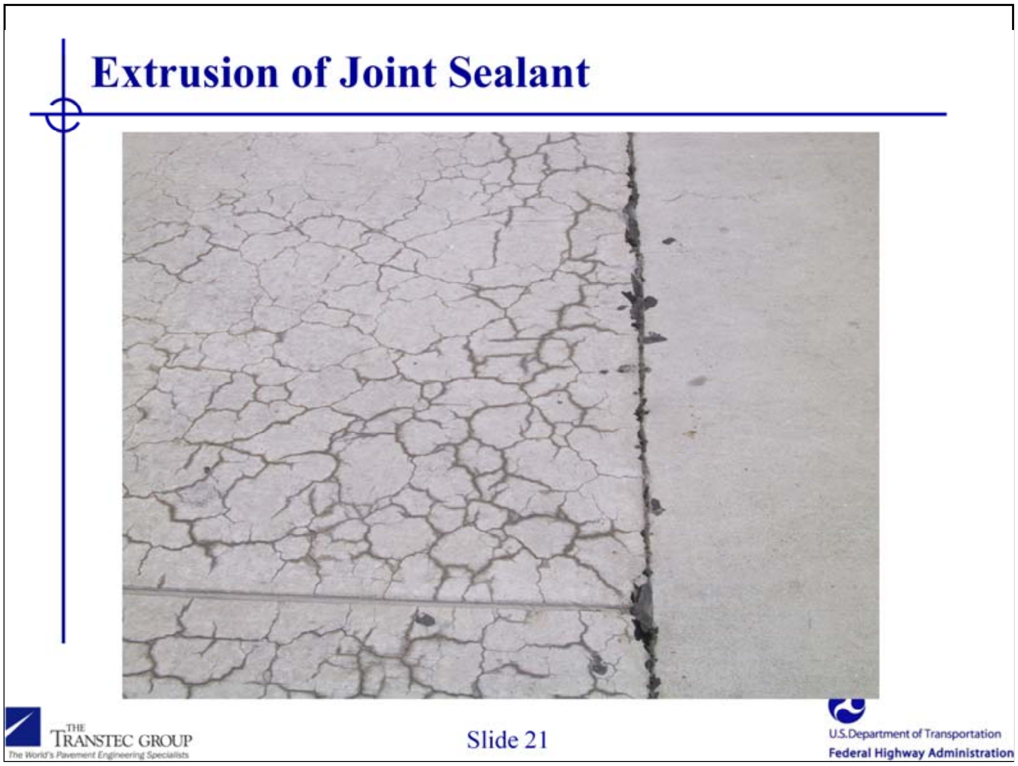


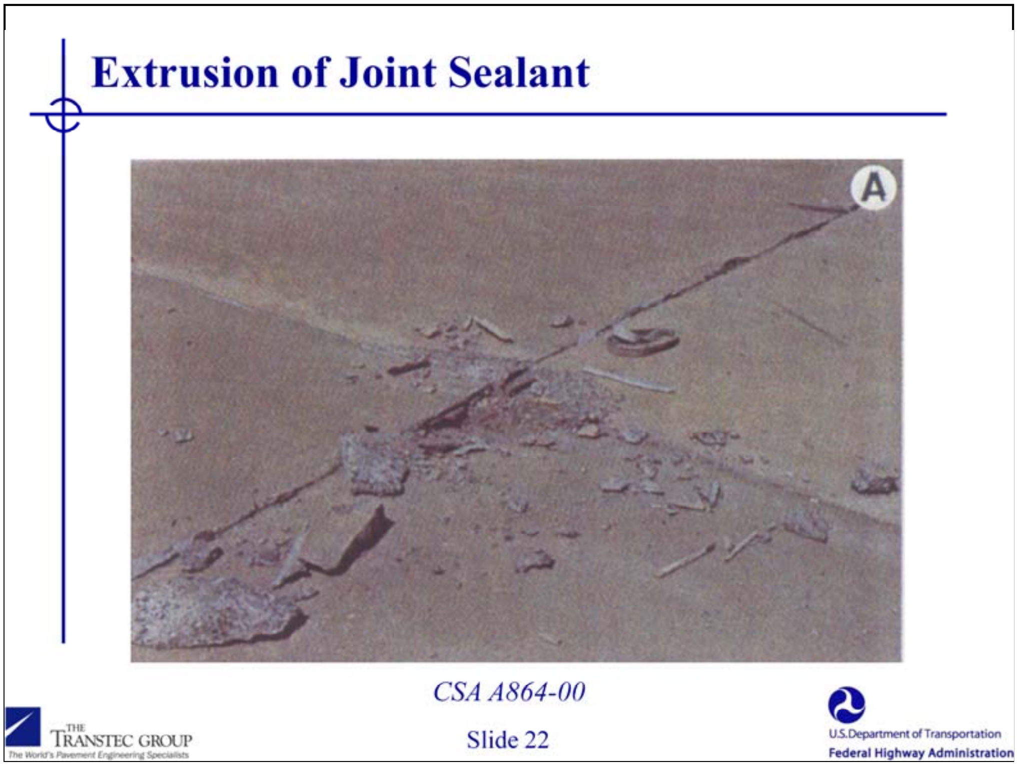
Slide 20

Similarly the desired clearance between members can be reduced – as shown here where the expansion of reinforced concrete bridge girder has led to a loss of clearance between the girder and the abutment. Continued expansion of the girder has led to a small degree of concrete crushing at the end of the girder and this has exposed some of the embedded steel, which has subsequently corroded.



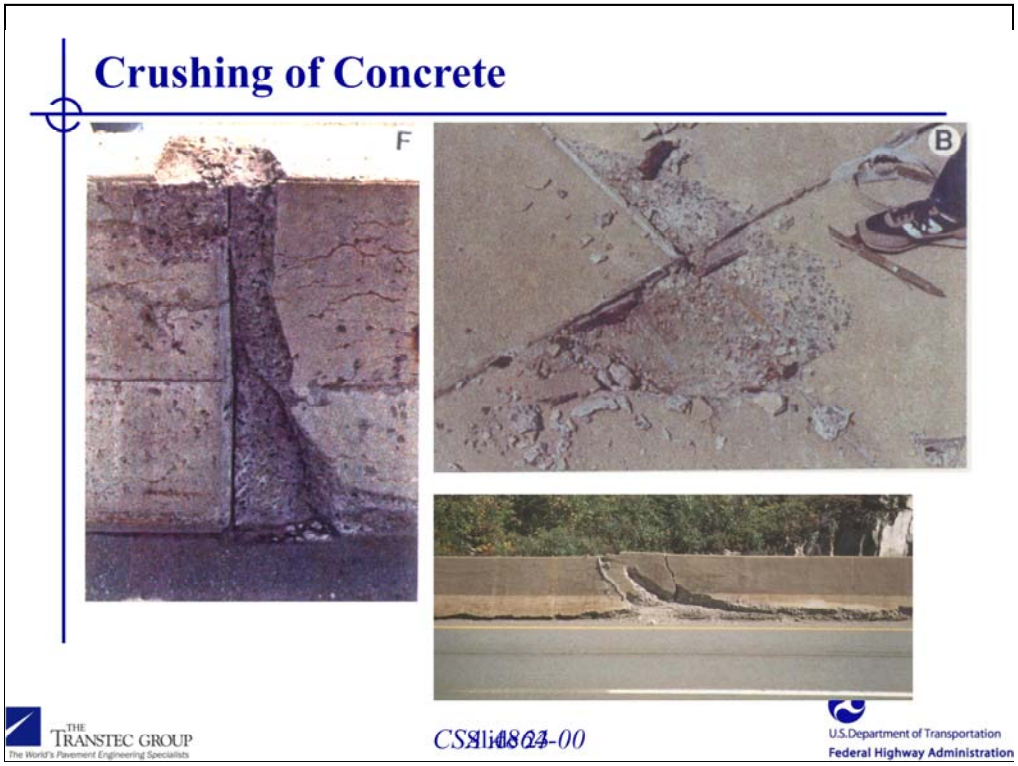
Slide 21

This photograph shows another example of ASR-affected concrete pavements where the sealant has been squeezed out of the joint as it closes due to the expansion of the concrete.



Slide 22

In this example taken from the CSA Guide A864, the expansion concrete pavement sections due to ASR has led to the closing of the joints, extrusion of the sealing material from the joint and further expansion...



Slide 23

...leading to spalling of the concrete, as in the case of barrier walls incorporating reactive siliceous limestone and greywacke aggregates.

Slide 24

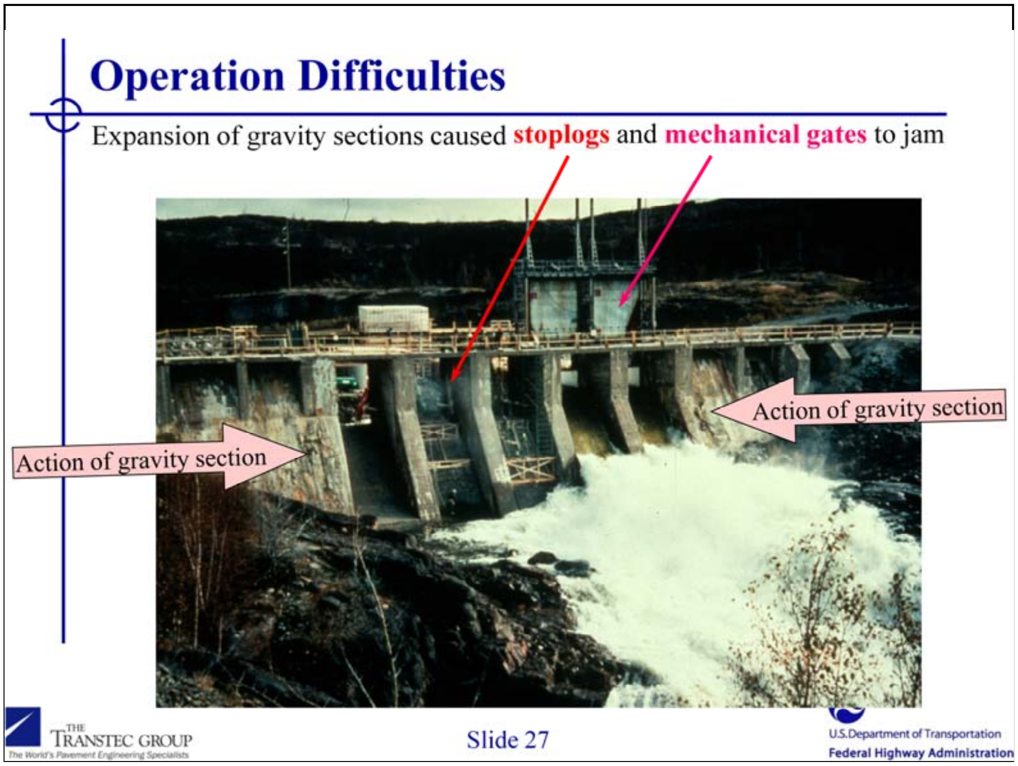
This picture illustrates moderate cracking following the perimeter of paving slabs. As ASR advances, the cracks spread around the perimeter of the slabs and there is often little or no cracking in the center of the slab. The reason that the region around the joints is more prone to cracking is because (a) there is often more moisture available in the joints, (b) there is less restraint to expansion close to the joints, and (c) mechanical stresses to vehicular loading is higher at the joints.

Slide 25

This picture shows spall and “repaired” spall at a joint in a concrete pavement. In many cases, spalling at joints is likely to continue and may require patching.

Slide 26

In severe cases of deterioration in concrete pavements, extensive patching can only delay the time until a major repair or replacement is required.



Slide 27

ASR can lead to severe operating problems in some structures. The photograph shows the view from downstream of a dam in Northern Ontario (Canada). The expansive action of the gravity sections has pushed the outside piers of the sluiceways inwards creating problems with the opening and closing of the mechanical sluice gates and with the lifting and placing of stoplogs.

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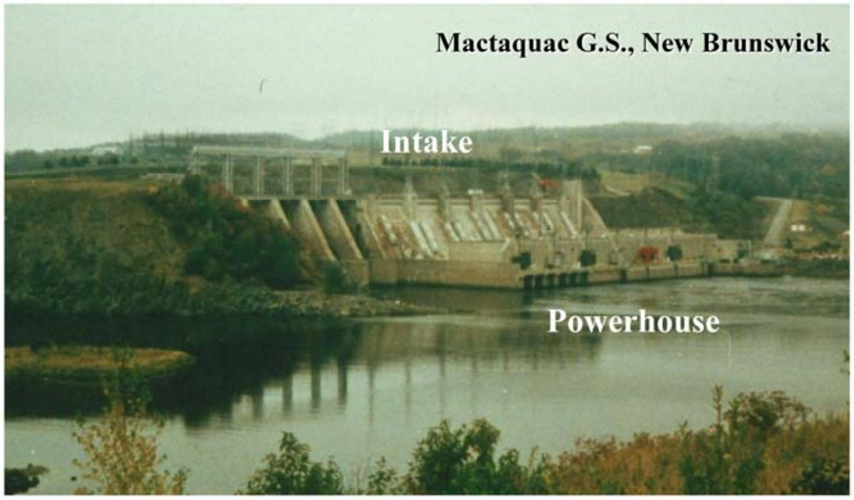
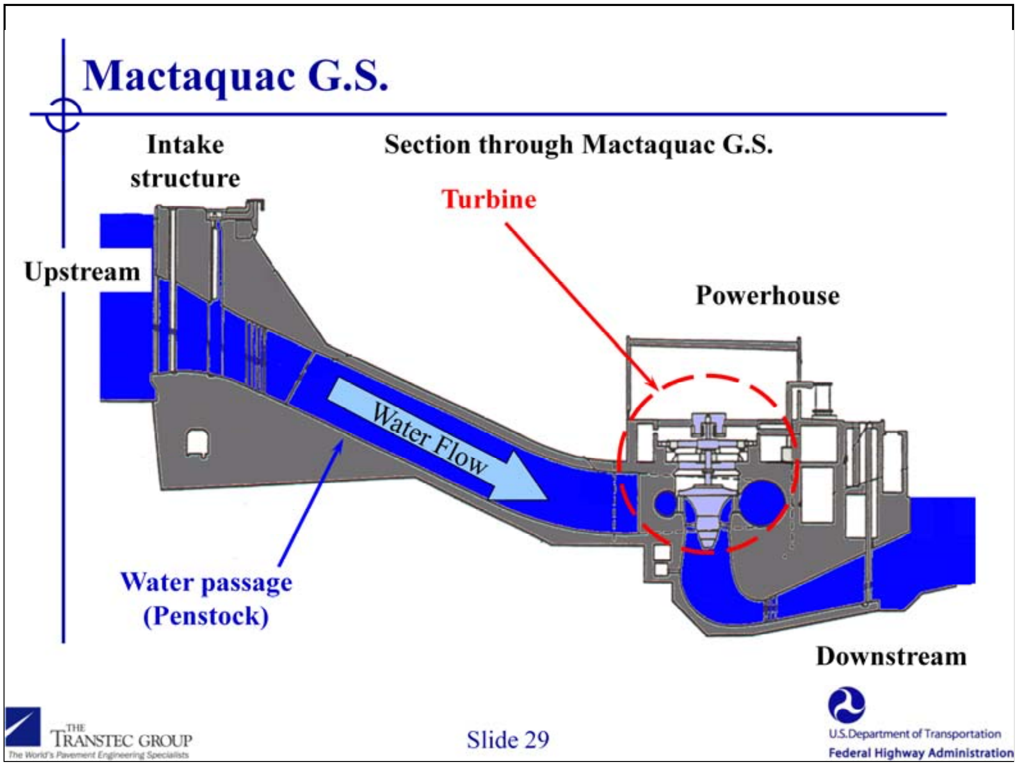


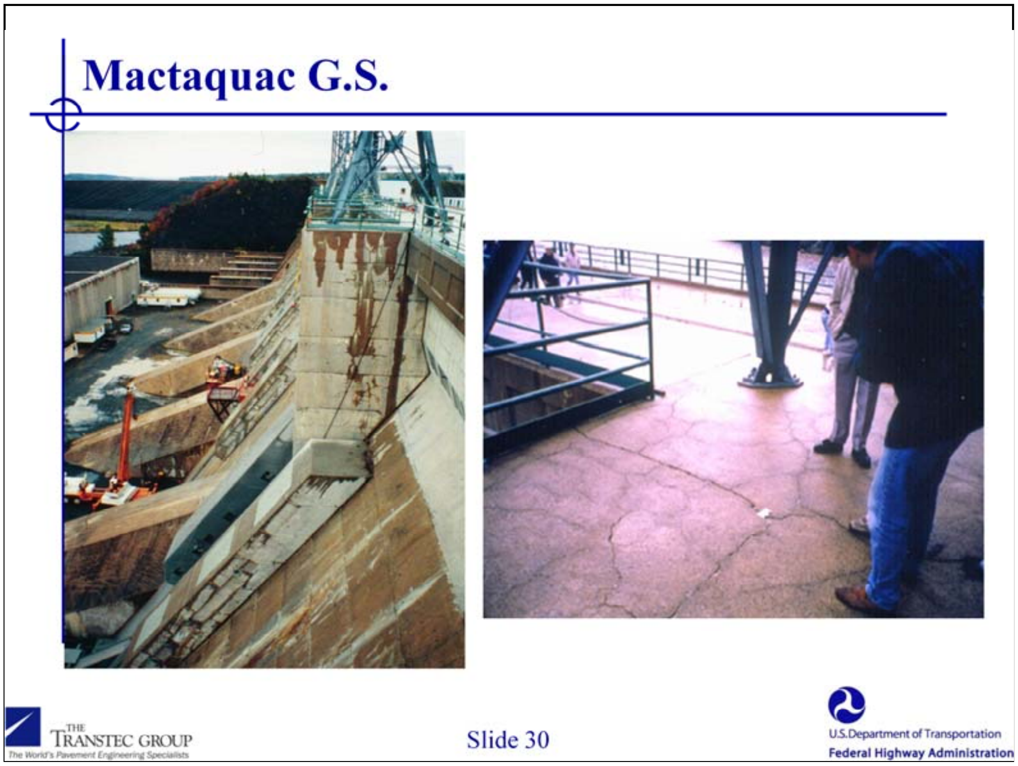
Slide 28

This slide shows another hydraulic structure from Eastern Canada. In this case, the power house – where the turbines are located – is an integral part of the structure.



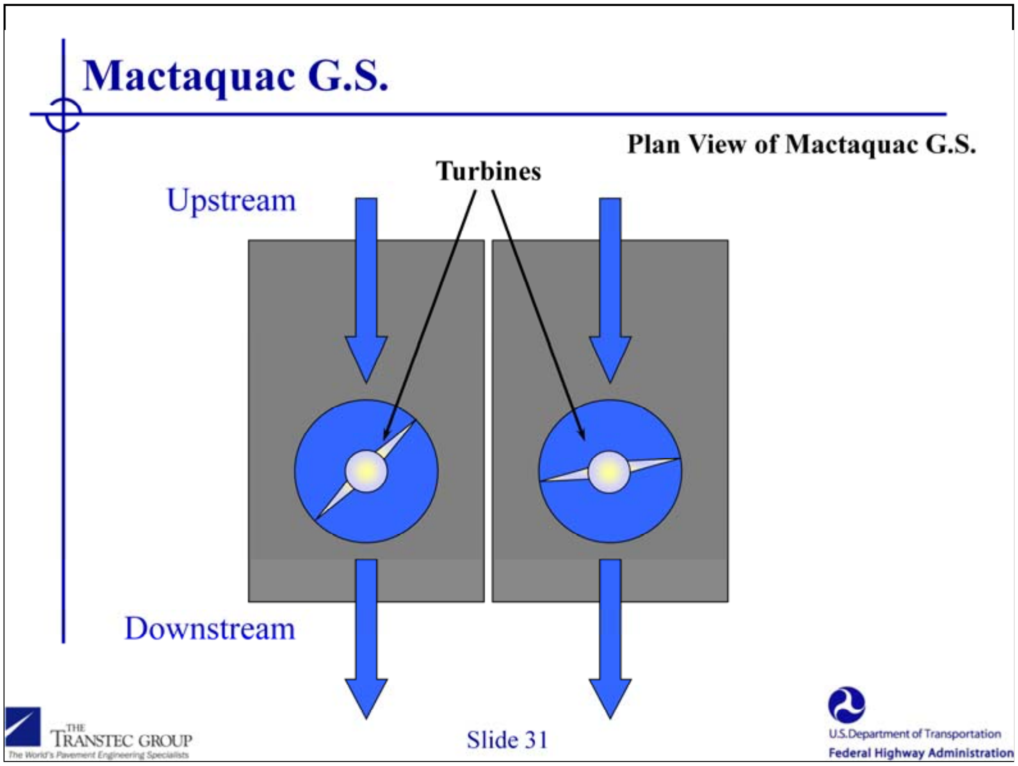
Slide 29

This section cut through the water-retaining structure shows that the water flows from upstream at the left of the photo down through the water passages - around the turbine housing – and exits downstream. The turbine is effectively embedded in the concrete structure.



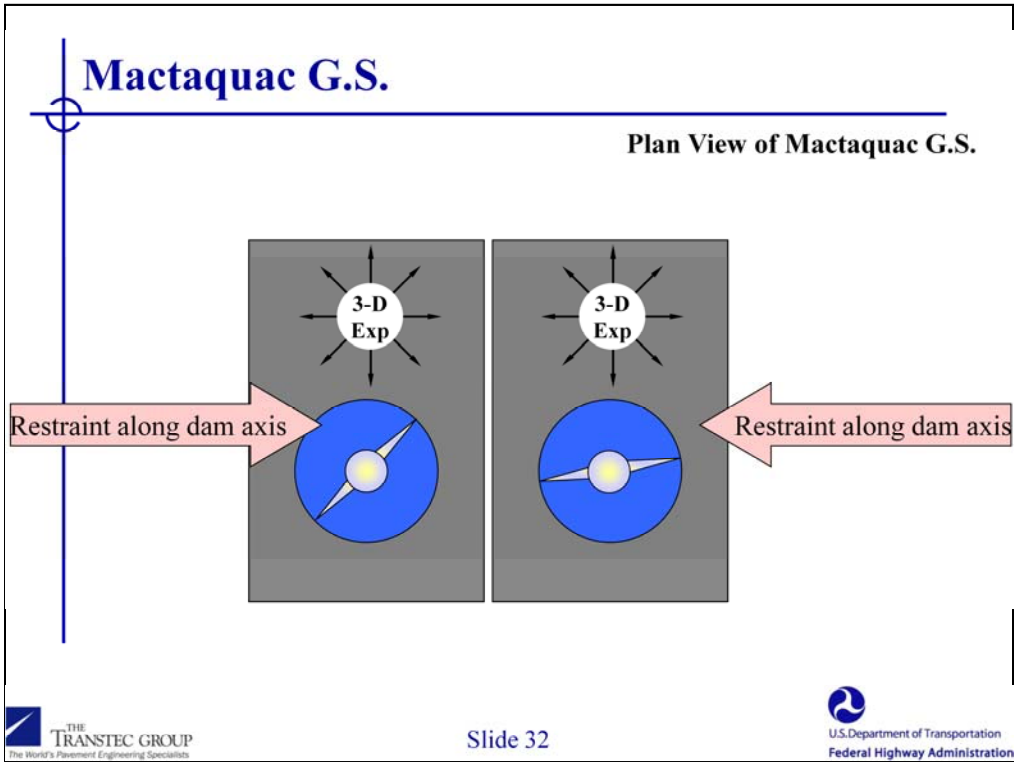
Slide 30

Symptoms of ASR can be seen as extensive cracking in the upper portion of the intake structure (picture on the right), cracking and exudations in the downstream face of the intake structure and in the penstocks (picture on the left).



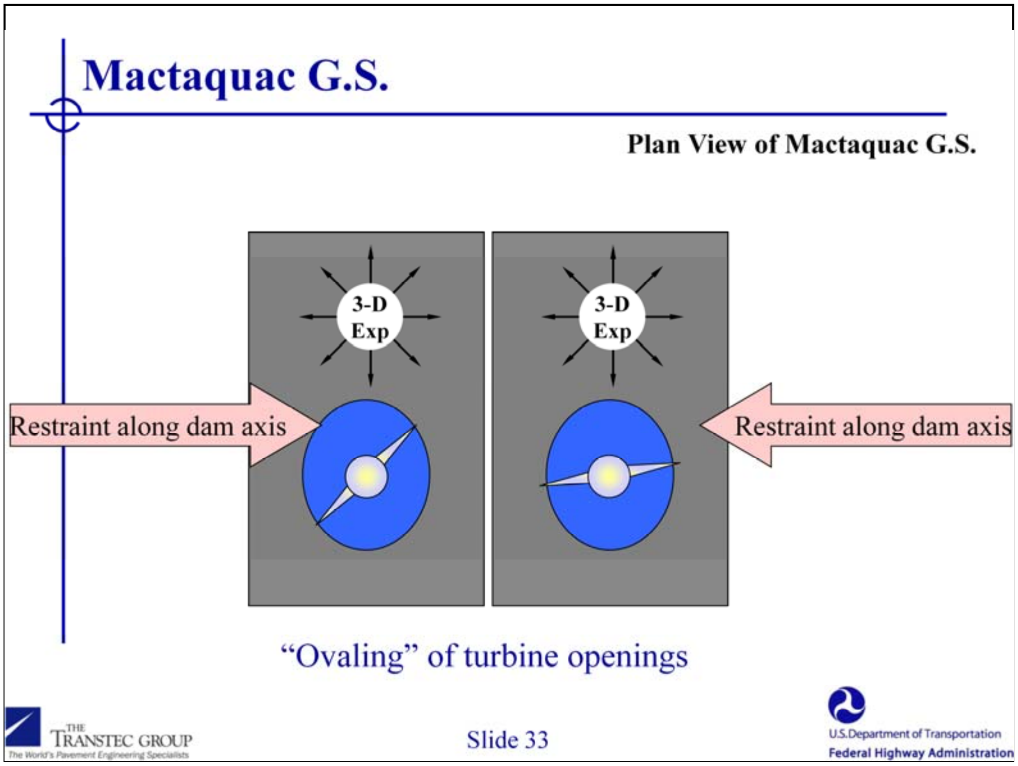
Slide 31

This shows a schematic of a plan view of a section through the powerhouse – at the level of the turbines. The openings where the turbines are located are circular.



Slide 32

ASR causes the concrete to expand initially in all 3 dimensions. However, there is restraint to the expansion along the axis of the powerhouse and after the joints between the generating units have closed up...



Slide 33

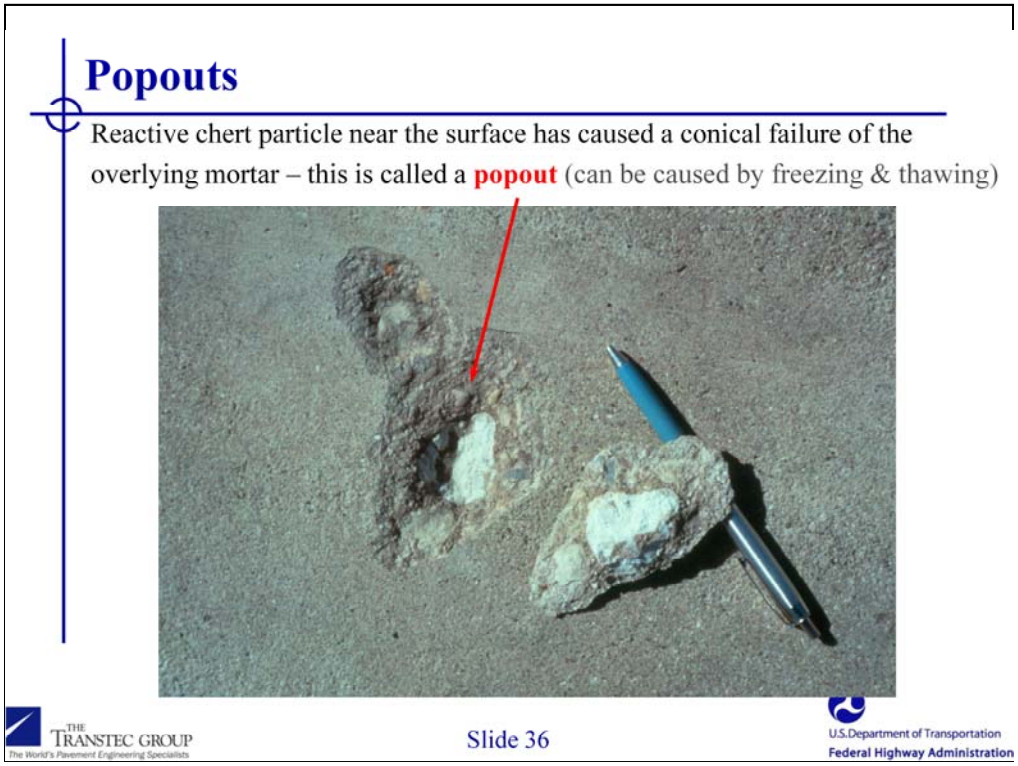
...further expansion will tend to squeeze the openings …

Slide 34

Other features are also symptomatic of ASR. These include discoloration or staining of the cracks, probably due to alkali-silica gel emanating from the cracks and carbonating on contact with the air.

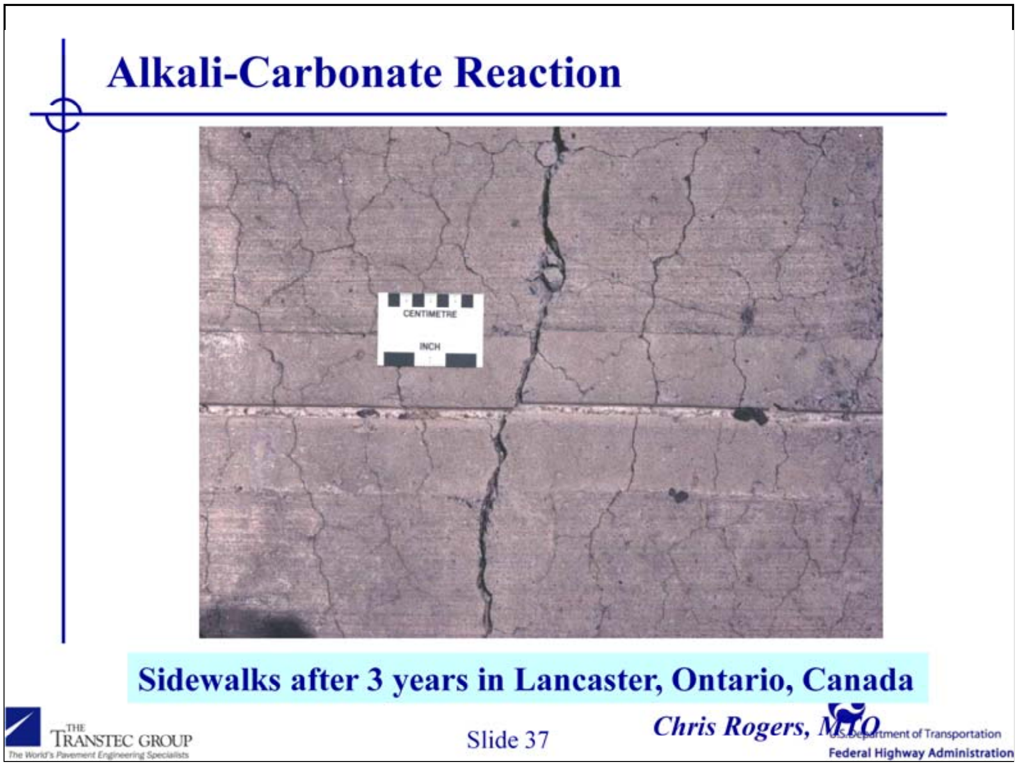
Slide 35

Here are more examples of the same phenomenon, in a bridge abutment and parapet walls.



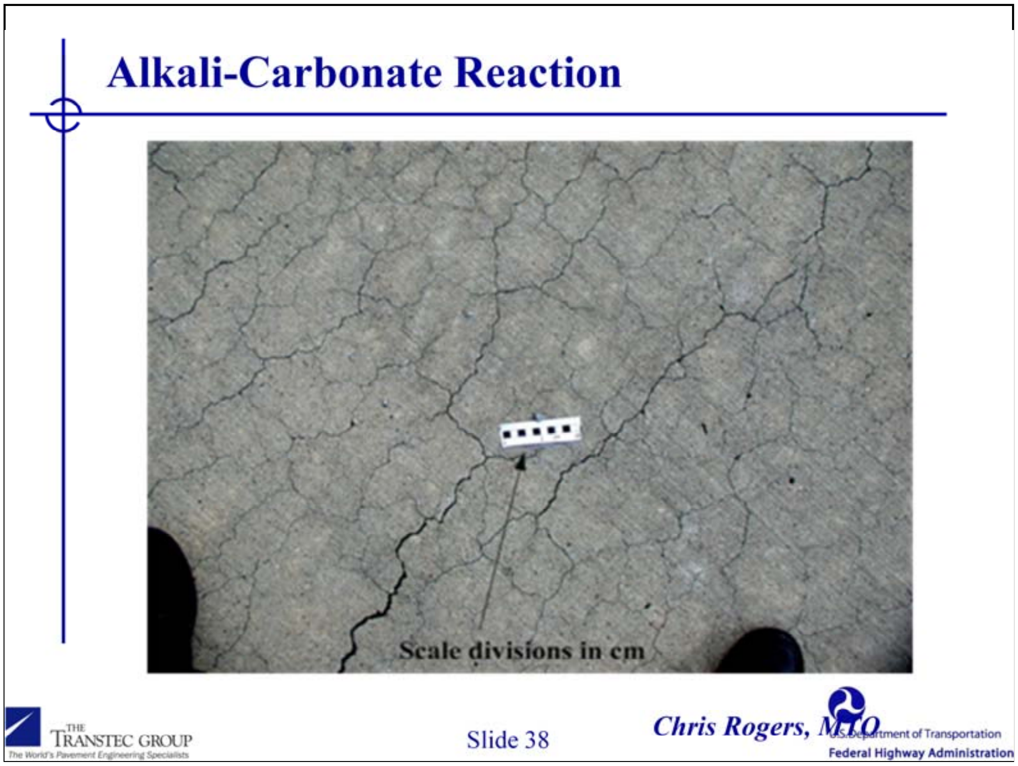
Slide 36

Popouts can sometimes be caused by ASR when the expansion of a reactive aggregate particle close to the surface of the concrete causes the overlying mortar to delaminate from the concrete surface. Popouts may also be caused by frost susceptible aggregates failing when concrete undergoes freezing.



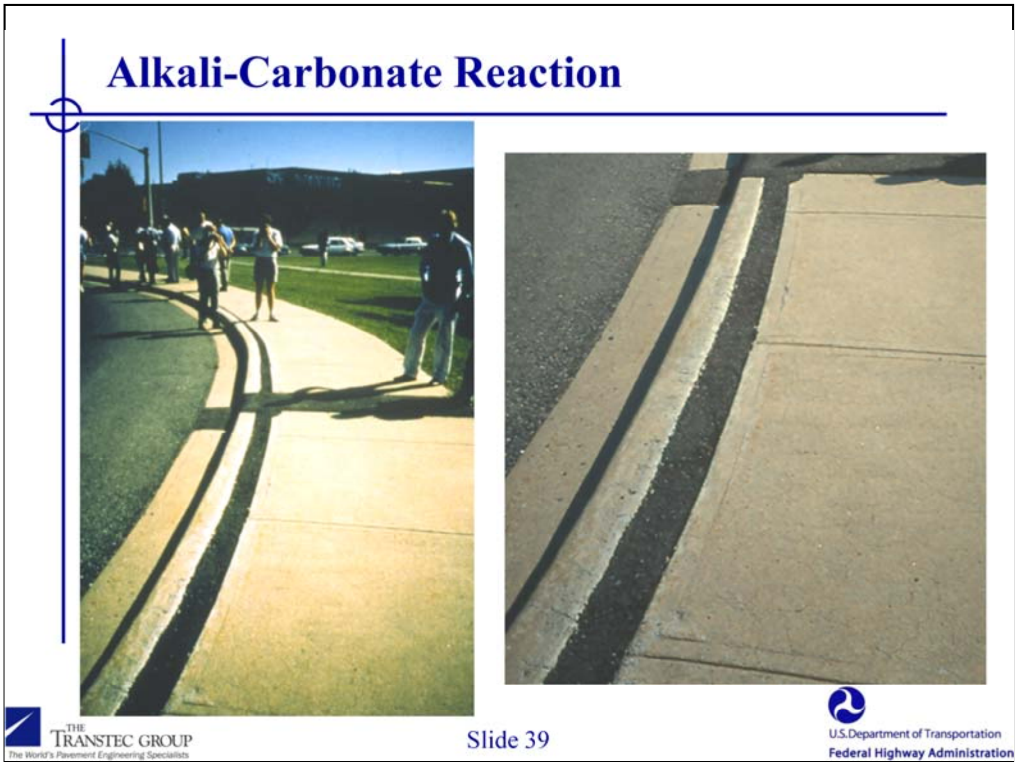
Slide 37

Symptoms of deterioration due to alkali-carbonate reaction are similar to those caused by ASR. This sidewalks from Lancaster (Ontario, Canada) showed extensive cracking only three years after construction. Relative movement can be observed along the main crack present in the middle portion of the sidewalk. Also, the cracks do not show the typical discoloration or staining indicative of ASR.



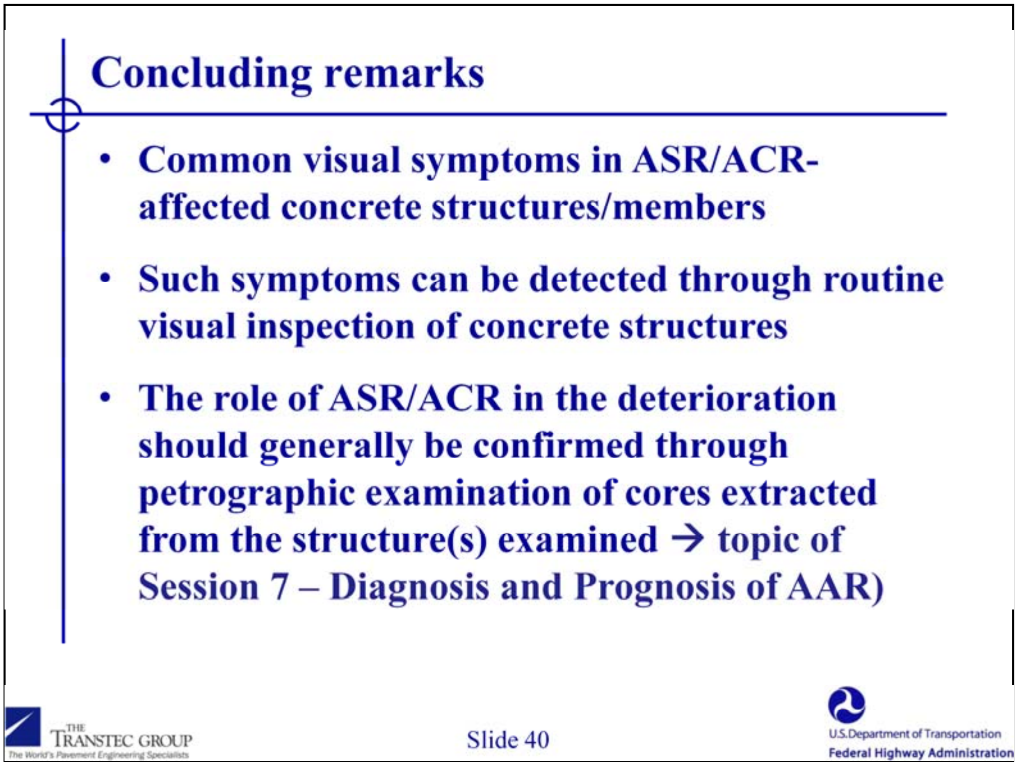
Slide 38

Map-cracking due to ACR in a sidewalk.



Slide 39

Concrete sidewalk made with ACR limestone aggregate (Cornwall, Ontario). Originally, the sidewalk and the curb were adjacent to each other; however, the expansion of the sidewalk created a gap that had to be filled with asphalt. The picture on the right shows map cracking in the sidewalk.



Slide 40

As part of this presentation, we have reviewed and illustrated the common visual symptoms in ASR/ACR-affected concrete structures/members. Such symptoms can generally be detected through routine visual inspection of concrete structures.

However, the role of ASR/ACR in the deterioration should generally be confirmed through petrographic examination of cores extracted from the structure(s) examined, which will be discussed in details in Session 7 on the Diagnosis and Prognosis of AAR.