Concrete Pavement Buckling

Dan King, P.E.
Research Engineer, CP Tech Center

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
CP Tech Center

Outline

- Introduction & History
- Re-assessing Concrete Pavement Buckling
- Areas of Investigation
- Preventative Maintenance and Repair Methods
- Design Considerations

Introduction & History

What's in a Name?

- Buckling
- Blowup, blowups
- Tenting
- Upheaval
- Shattered slab
- Pressure damage
- Crushing

Image: Indiana DOT

Description

- Localized upward movement or shattering of a slab along a transverse joint or crack
- Results from volumetric expansion that becomes restricted at the joint/crack, buildup of stresses, and release of pressure

Images: Washington State DOT; University of Pretoria

Description

- Buckling is relatively uncommon and failures are not always catastrophic, but they often require immediate attention and result in closures due to the safety hazard and need for repair

Images: Michigan DOT

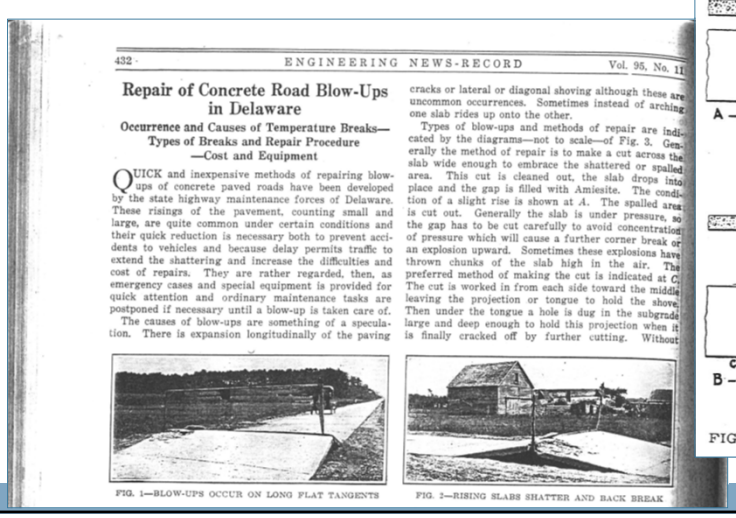
Basic Causes

Distress	Category	Description
Blowups (Material/Chemical)	Evaporation	Evaporation of original water causes drying out, induces shrinkage, and leads to blowups.
Blowups (Material/Chemical)	Aggregate Deterioration	Pavement undergoes sizable expansion when affected by aggregate freeze-thaw or alkali reactions, such as alkali aggregate reaction (AAR), alkali carbonate reaction (ACR), and alkali silica reaction (ASR).
Blowups (Material/Chemical)	Coefficient of Thermal Expansion (CTE)	The CTE defines how a material changes in length with a unit change in temperature. Amount of aggregate directly influences the CTE. Higher CTEs produce increased potential for blowups.
Blowups (Physical)	Temperature Change	Blowups are often associated with heat waves because frequency increases as temperature increases.
Blowups (Physical)	Joint Length	Long jointed pavements are more susceptible to blowups.
Blowups (Physical)	Drainage	Poor pavement drainage (especially in cold weather states) increases the risk of blowups.
Blowups (Physical)	Time of Construction	Time of year of construction has been linked to occurrence of blowups.
Blowups (Physical)	Incompressible	The filling of transverse joints with incompressible materials is the most common cause of blowups, resulting in an increase of compressive stress and blowups.

Table 11.2, *Guide for Concrete Pavement Distress Assessments and Solutions*

Buckling History

- Engineering News-Record, 1925:



432 ENGINEERING NEWS-RECORD Vol. 95, No. 11

Repair of Concrete Road Blow-Ups in Delaware

Occurrence and Causes of Temperature Breaks—Types of Breaks and Repair Procedure—Cost and Equipment

QUICK and inexpensive methods of repairing blow-ups of concrete paved roads have been developed by the state highway maintenance forces of Delaware. These risings of the pavement, counting small and large, are quite common under certain conditions and their quick reduction is necessary both to prevent accidents to vehicles and because delay permits traffic to extend the shattering and increase the difficulties and cost of repairs. They are rather regarded, then, as emergency cases and special equipment is provided for quick attention and ordinary maintenance tasks are postponed if necessary until a blow-up is taken care of.

The causes of blow-ups are something of a speculation. There is expansion longitudinally of the paving cracks or lateral or diagonal shoving although these are uncommon occurrences. Sometimes instead of arching one slab rides up onto the other.

Types of blow-ups and methods of repair are indicated by the diagrams—not to scale—of Fig. 3. Generally the method of repair is to make a cut across the slab wide enough to embrace the shattered or spalled area. This cut is cleaned out, the slab drops into place and the gap is filled with Amiesite. The condition of a slight rise is shown at *A*. The spalled area is cut out. Generally the slab is under pressure, so the gap has to be cut carefully to avoid concentration of pressure which will cause a further corner break or an explosion upward. Sometimes these explosions have thrown chunks of the slab high in the air. The preferred method of making the cut is indicated at *C*. The cut is worked in from each side toward the middle leaving the projection or tongue to hold the shove. Then under the tongue a hole is dug in the subgrade large and deep enough to hold this projection when it is finally cracked off by further cutting. Without

FIG. 1—BLOW-UPS OCCUR ON LONG FLAT TANGENTS

FIG. 2—RISING SLABS SHATTER AND BACK BREAK

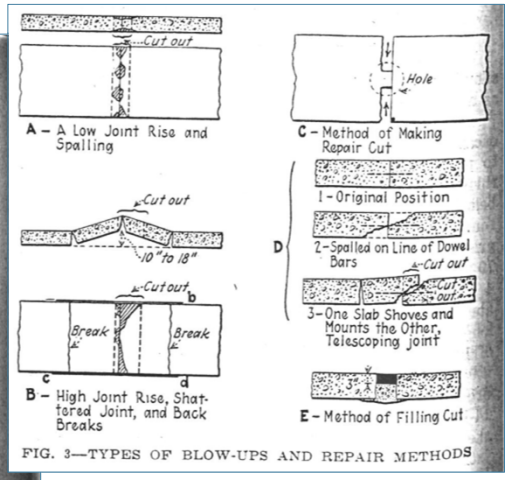
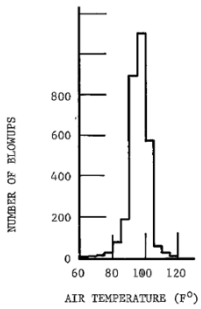
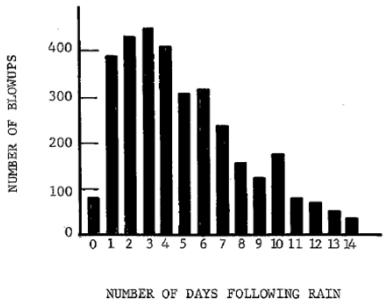


FIG. 3—TYPES OF BLOW-UPS AND REPAIR METHODS

Buckling History

- Two of the first comprehensive studies were published by Purdue University (1946) and the Illinois Division of Highways (1957)
  - Strong correlation with coarse aggregate source (IN)
  - Strong correlation with temperatures > 90°F and rain events (IL)





Images: Illinois Division of Highways (1957)

Buckling History

- Through the 1960s, many states dealt with hundreds per year
- Jointed Reinforced Concrete Pavements (JRCP) were particularly prone to buckling
  - Typical transverse joint spacing: 25 to 100 ft
- Buckling was less common in JPCP pavements with joint spacing ≤ 20 ft & in CRCP
- Blowups often continued to be an issue post-HMA overlay
- Installing pressure relief joints sometimes helped prevent future occurrences of buckling, but often did not help

Buckling History

- Buckling never disappeared, but there appeared to be a consensus by the 80s or 90s that it had largely been mitigated by modern concrete pavement design and construction practices
  - Shift away from JRCP
  - Use of better concrete materials
- Some of the advocates of leaving joints unsealed/unfilled around this time believed that joint opening and closing was no longer a significant issue

Re-assessing Concrete Pavement Buckling

Present and Future Concerns

- Buckling is still relatively rare, but changes to today's landscape have brought it back into the conversation

NEWS

Road buckle shuts down portion of Interstate 80

by: Natasha Keicher
Posted: Jul 23, 2022 / 06:08 PM CDT
Updated: Jul 23, 2022 / 07:33 PM CDT

SHARE

WEST DES MOINES, Iowa — A road buckle shut down a portion of Interstate 80 in West Des Moines on Saturday.

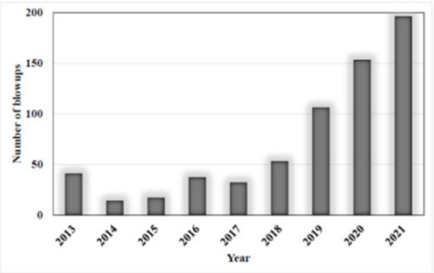
The road buckle occurred westbound on I-80 near the Jordan Creek Parkway entrance ramp. The westbound lanes were shut down for several hours while law enforcement and Iowa DOT repaired the road.

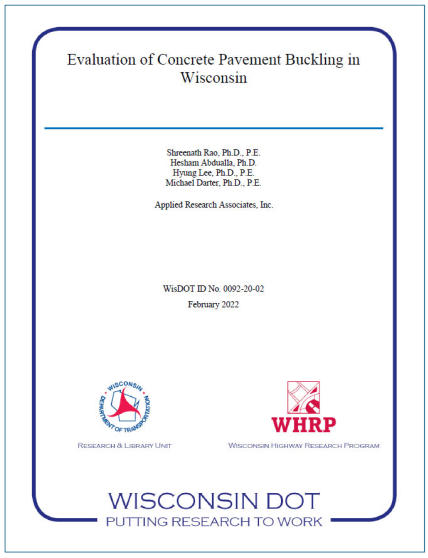
No accidents or injuries have been reported during this incident. The cause of the road buckle was due to extreme heat.

Image: WHO-TV

Wisconsin Study

- 2022 study by ARA for WisDOT
- Documents and analyzes buckling on Wisconsin concrete pavements
  - Significant increase in recent years
  - More frequent than in nearby states





Evaluation of Concrete Pavement Buckling in Wisconsin

Shreenath Rao, Ph.D., P.E.
Hesham Abdualla, Ph.D.
Hyung Lee, Ph.D., P.E.
Michael Darter, Ph.D., P.E.

Applied Research Associates, Inc.

WisDOT ID No. 0092-20-02
February 2022

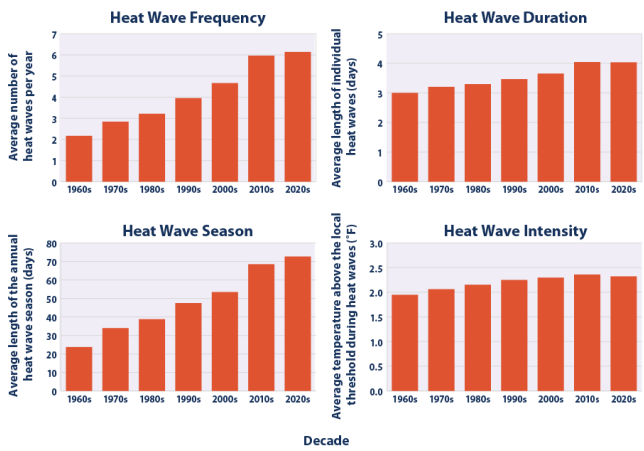
Research & Library Unit

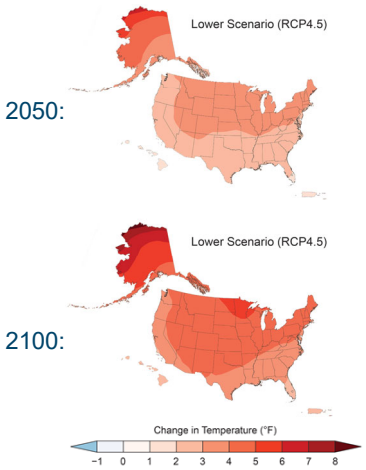
WHRP
Wisconsin Highway Research Program

WISCONSIN DOT
PUTTING RESEARCH TO WORK

Climate Change

- Increasing temperatures, more frequent heat waves:



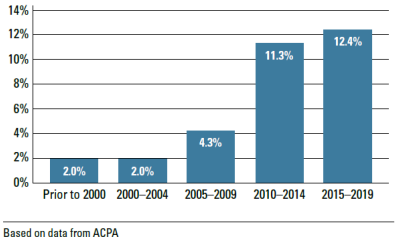


Images: US EPA; Fourth National Climate Assessment

Concrete Overlays

- Relatively new type of pavement design
- Buckling has emerged as an issue in recent years
  - Observed in COA–B and COC–U overlays

Concrete Overlays as a % of Concrete Paving



Major Questions

- Can we better understand the causes of buckling in today's environment?
- Can we predict which pavements are most susceptible to buckling, or what types of conditions are most likely to cause it?
- Is there any type of preventative or proactive maintenance/ repair that can help stop buckling or minimize its impacts?
- What design changes can we make to prevent buckling?

Areas of Investigation

Joint Sealing/Filling

- In Wisconsin, joints are generally left unsealed or unfilled
- The 2022 ARA study found more incompressible materials at sites experiencing buckling than at control sites
- Unsealed joints can also be more prone to intrusion of water and chemicals
- Likely a contributing factor to why buckling is more frequent in WI than in nearby states

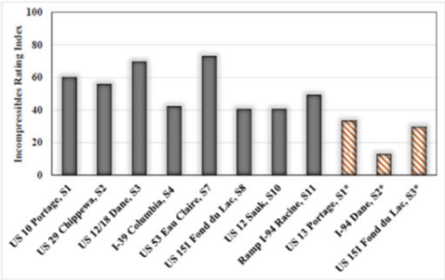


Image: ARA (2022)

Joint Sealing/Filling

- Many agencies do not fill or seal joints on thinner (≤ 6 in.) concrete overlays with shorter joint spacings (6 ft x 6 ft)
  - Opening and closing of the joints should theoretically be smaller, which should reduce potential for intrusion of incompressibles
    - This assumption may not be correct…

Joint Activation and Joint Opening

- Cracks don't always form beneath saw cut joints on these types of concrete overlays
- Some joints may never activate, while others may become dominant joints that exhibit more movement and opening
  - The working joint spacing could be significantly greater than designed
- 5 inch COA–B with 5.5 ft x 5.5 ft slabs, Worth County, IA:

Activated – wide working joint

Activated – very narrow

Not activated

Slab Migration

- Connected or correlated phenomenon of slab migration
  - More prevalent in thinner overlays with short joint spacing
  - Overlays ≤ 5 in. may not have tie bars at longitudinal joints

Image: Michigan Concrete Association

Buckling in Concrete Overlays

- Panel movement often precedes and accompanies buckling in concrete overlays

Image: Concrete Paving Association of Minnesota

Moisture Damage

- Stripping in the underlying asphalt pavement (COA) or the asphalt interlayer (COC–U) has also been found at buckled concrete overlay sections
- Potential source of incompressibles at the joint
- Does rutting in existing asphalt contribute to drainage issues?
- How well do we understand the role that moisture plays in this process in general?

Image: Indiana DOT

Preventative Maintenance and Repair Methods

Preventative Maintenance and Repair

- When failure occurs, full-depth concrete patches are best
  - Asphalt can be used for a temporary patch, but not for long-term repairs – pavements that experience buckling usually aren't finished
- Given the potential for recurrence, is there preventative maintenance that can be done on a susceptible pavement?

Image: ACPA, CO-WY Chapter

Expansion/Pressure Relief Joints

- This is probably not the way to go…
- Historically not a consistently successful method
- They can end up closing very quickly, and have not successfully mitigated buckling on concrete overlays in Iowa

Sealant squeezed out of joint just weeks after placement of expansion joints

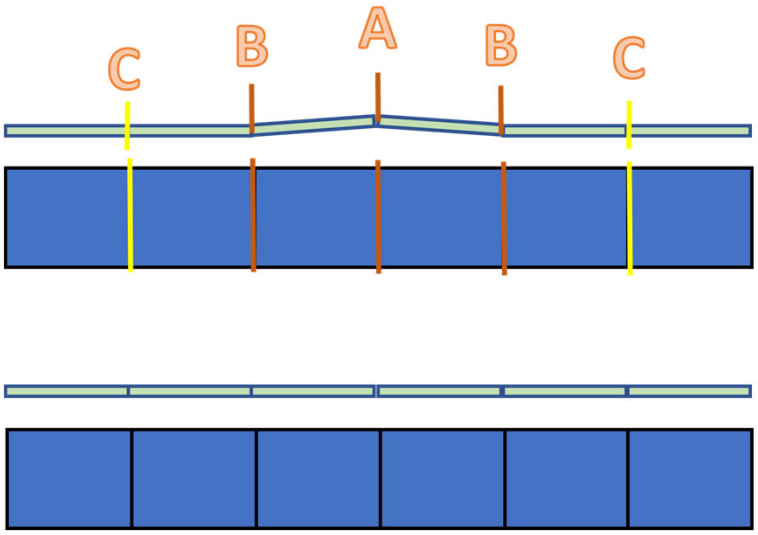
Image: ACPA, CO-WY Chapter

Relief Cuts

- If you see panels just beginning to tent up, or other signs of spalling or compression at the joint, relief cuts could help mitigate stresses and prevent a blowup
  - This technique has been used recently in IA & MN with promising results so far

Image: Iowa Concrete Paving Association

Relief Cuts



When "Tenting" is noticed
-Mark the center of the tent.
-Cut the high point "A" with full depth saw-cut. Use a steel wedge similar to a tree falling wedge to keep from panels pinching together and grabbing locking up the saw blade.
-After cutting joint "A" cut joint "B" on both ends of the tent, full depth. Wedges will most likely still be needed.

(Minnesota also makes a full depth cut on the adjacent joints "C" for additional insurance.)

Image: Iowa Concrete Paving Association

Preventative Maintenance

- The relief cut method requires ability to monitor pavement sections and prior knowledge of susceptibility
  - Future need: ability to predict what types of pavements might be most susceptible buckling
- Joint sealing/filling
  - If a pavement has had buckling and the joints are not sealed, it's not too late to clean out and seal the joints

Design Considerations

Design Factors affecting Buckling

- Joint sealing/filling to keep incompressibles out
  - Up-to-date guidance is generally in favor
  - The value proposition increases with rising temperatures
  - Should probably be a standard practice for concrete overlays with short joint spacing as well
- Use good, stable materials and durable mixes
- Ensure proper drainage design and practices
- Stabilized bases for full-depth concrete pavements should mitigate joint opening/closing

Concrete Overlay Design & Buckling

- Thinner overlays appear to be fundamentally more susceptible to buckling
  - Thinner slabs experience greater compressive stresses and may be more affected by variations in thickness
  - It's also more difficult to activate joints in thinner slabs
- Consider the potential for dominant joint behavior when designing joint spacing as well as overlay thickness
- Fiber-reinforcement generally reduces opening and closing of joints
  - Use of fibers has anecdotally correlated with reduced buckling and slab migration on a limited sample of projects
- Consider placing more emphasis on drainage characteristics of interlayers in COC–U overlays
- Joint sealing/filling…

Conclusions

- Buckling is rare, but disruptive and hazardous when it occurs
- Present and future concerns about buckling due to:
  - Changes to joint sealing practices
  - Rising temperatures due to climate change
  - New concrete pavement design types – concrete overlays
- It might be possible to alleviate buckling through proactive maintenance
  - This will require monitoring and understanding of conditions that lead to buckling

Conclusions

- There would be great value to better understanding the mechanisms causing buckling
  - Especially for concrete overlays
- How can we study this?