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Drainage and Support Considerations for Concrete Pavements

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ACPA

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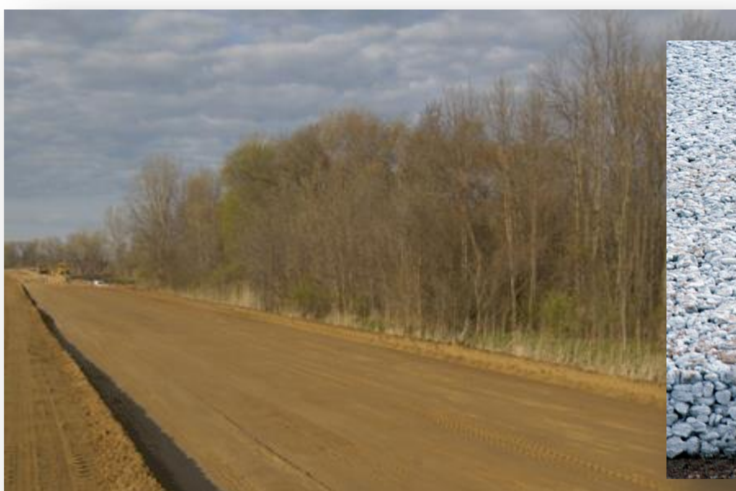
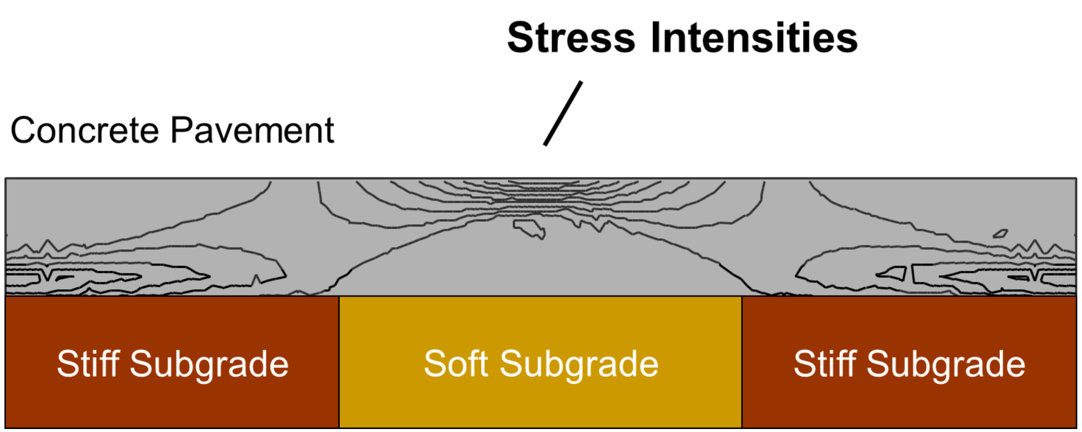
It Starts from the Ground Up

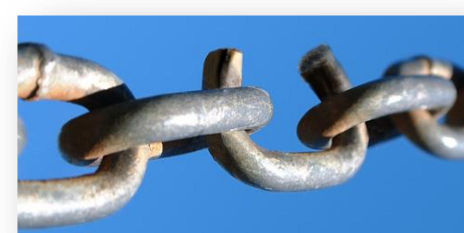
- Support design and construction are key to:
  - Long-term performance (cracking and faulting)
  - Smoothness (initial and long-term)




How do We Get Good Support?

- The support system should:
  - **Be free from abrupt changes in character of the materials –** that is to say, it should be uniform upon construction and perform as uniformly as possible during service
  - Resist erosion
  - Be engineered to control subgrade soil expansion/frost heave

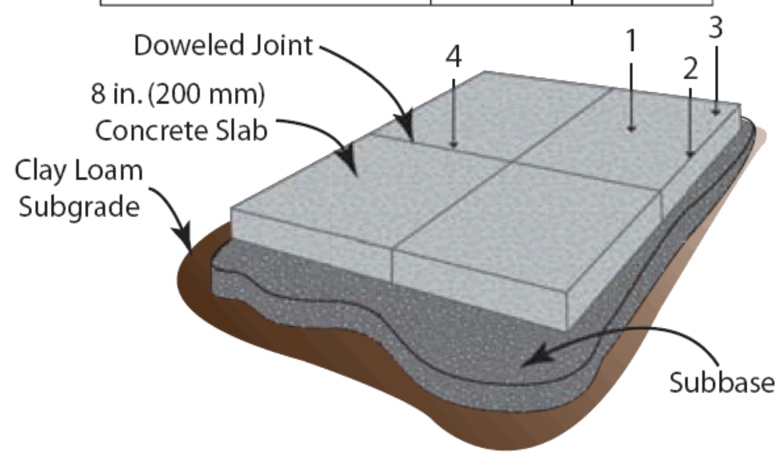




Support Strength is NOT Critical!

- Concrete is very rigid
- Loads get distributed over relatively large areas
- Stresses on the support system are relatively low
- Thus, concrete pavements do not necessarily require exceptionally strong support systems

Loading Position	Maximum Subgrade Pressure psi	Maximum Subgrade Pressure MPa
1. Slab Interior	3	0.02
2. Outside Edge	6	0.04
3. Outside Corner	7	0.05
4. Transverse Joint Edge	4	0.03

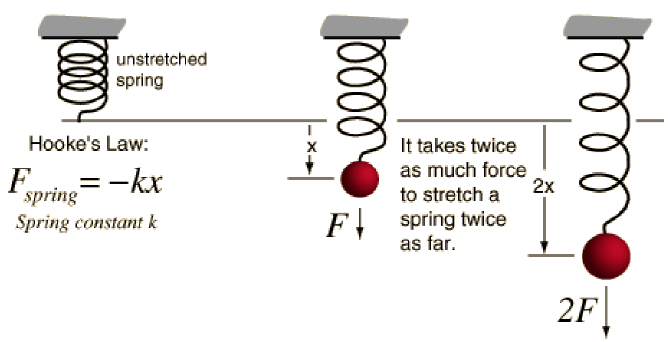


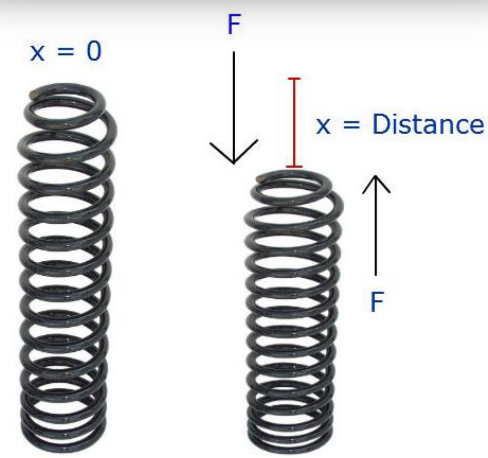
A 12,000 lb (5,400 kg) load is placed on a 12 in. (380 mm) plate. This yields a pressure of 106 psi (0.73 MPa) on the pavement surface and the resultant subgrade pressures listed above.

UNIFORMITY >> STRENGTH

Support Stiffness Used in Design

- Layered elastic theory inappropriate because stiffness differential
- Plate theory combines all support (modulus + thickness of each layer) into a composite known as modulus of subgrade reaction (k-value)
  - Essentially a spring constant (Hooke's)





Composite k-value is Iterative

Concrete

Asphalt | 6" (150 mm) | 350 ksi (2.4 GPa)

Aggregate | 6" (150 mm) | 30 ksi (207 MPa)

Soil | CBR = 3

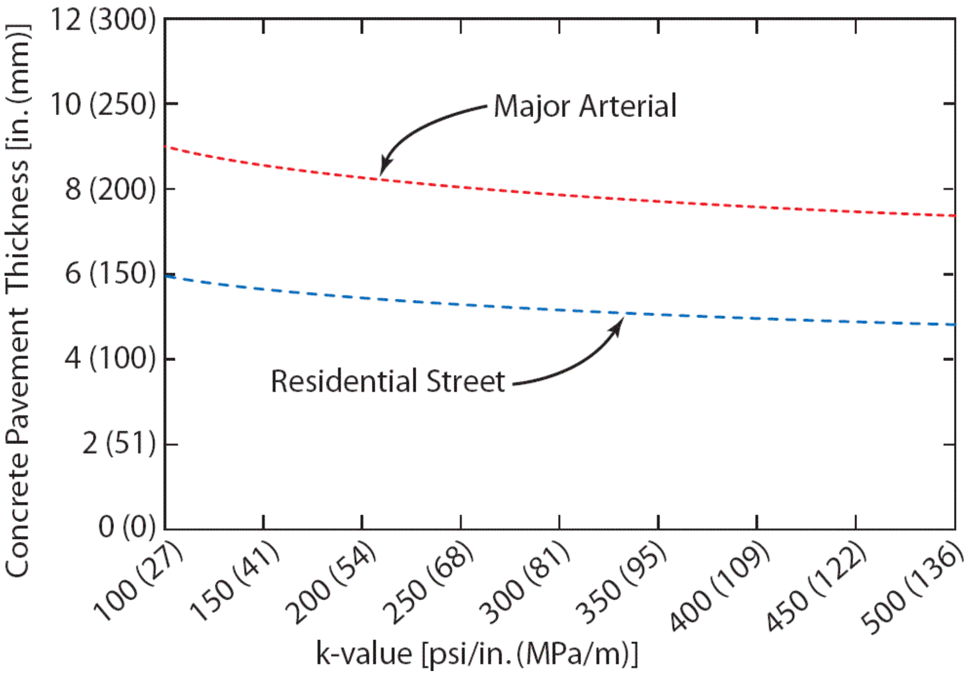
Add a layer at a time until the composite k-value immediately beneath the concrete is determined

Soil | M_{RSG} = 4,118 psi (28 MPa) + Aggregate | 6" | 30ksi / **100 psi/in. (27 MPa/m)** = **244 psi/in. (66 MPa/m)**

244 psi/in. (66 MPa/m) + Asphalt | 6" | 150 ksi / **244 psi/in. (66 MPa/m)** = **388 psi/in. (105 MPa/m)**

Stiffer Support Not of Huge Benefit

- **Proof of the point:** Traffic drives thickness; support stiffness has relatively little impact on thickness

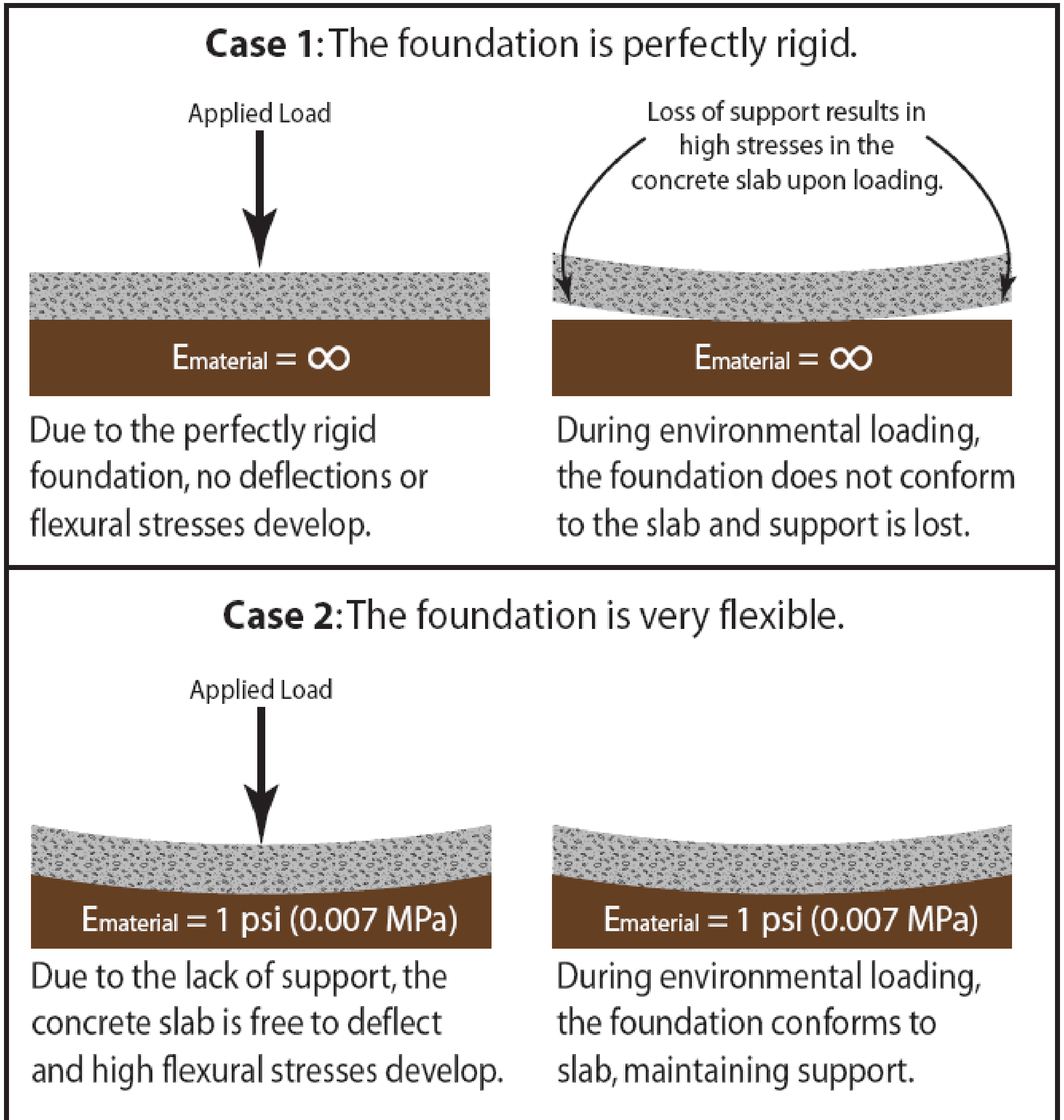


Analyses conducted in ACPA's StreetPave

- *Do not attempt to make the support system stronger/ thicker to try to decrease concrete pavement thickness*

There is an Optimal Stiffness

FOCUS HERE IS MITIGATING CRACKING



… but the optimal k-value depends on how much curl the slabs have, how much ambient conditions cycle, and other factors

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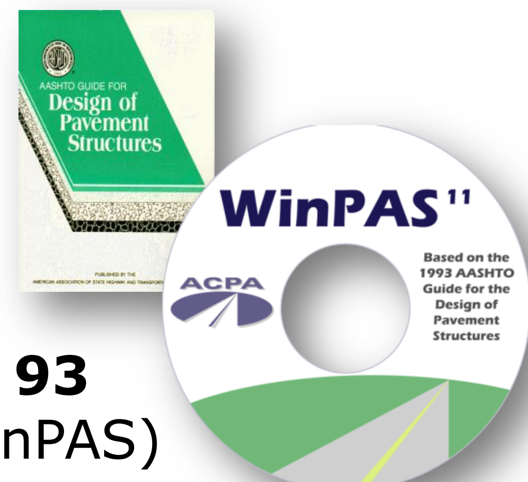
Designers should consider available materials (including recycled), stabilized vs. unstabilized support layers, drainability and other details

Common Design Methods in U.S.

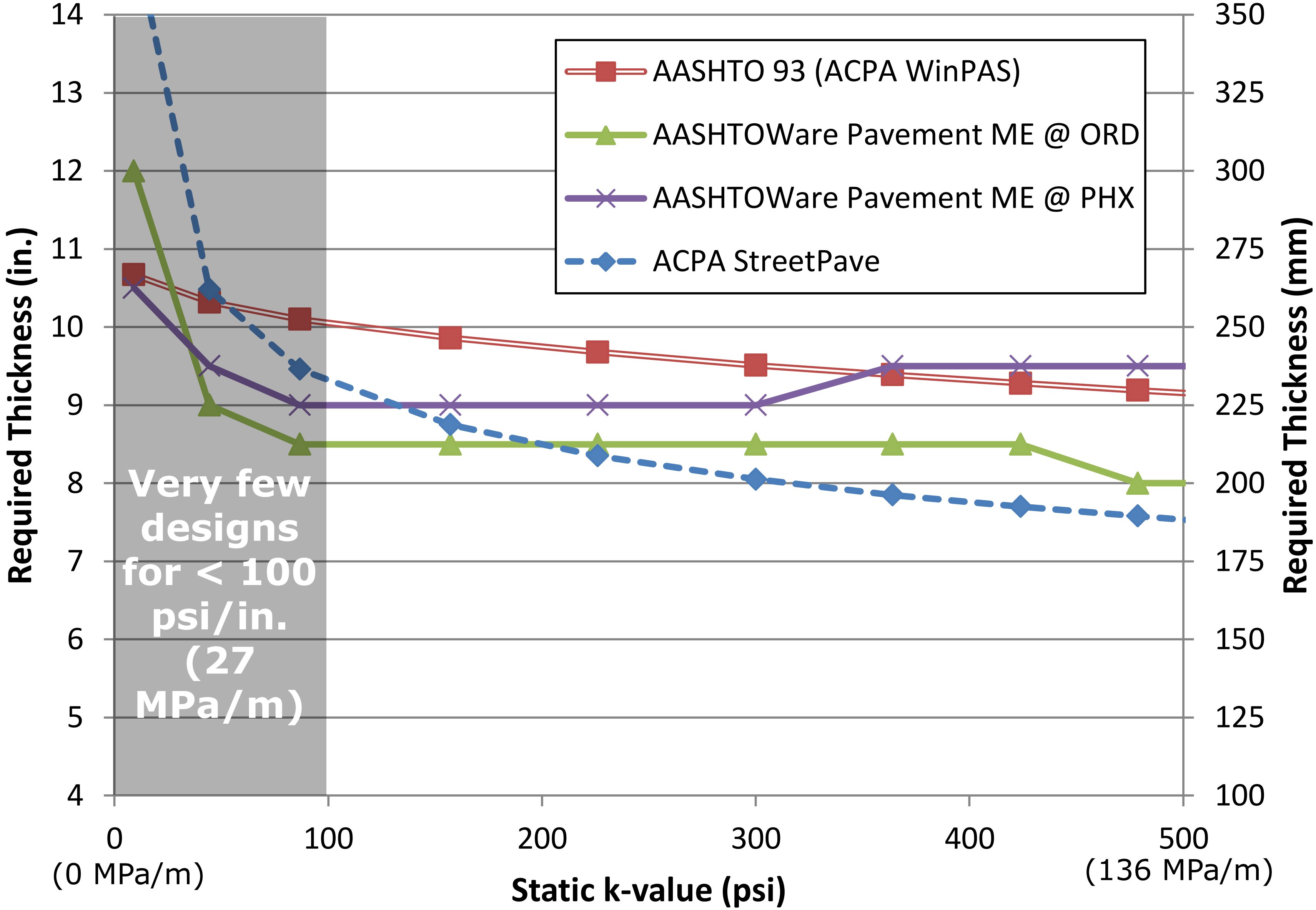
AASHTOWare Pavement ME
(previously known as DARWin-ME and MEPDG)



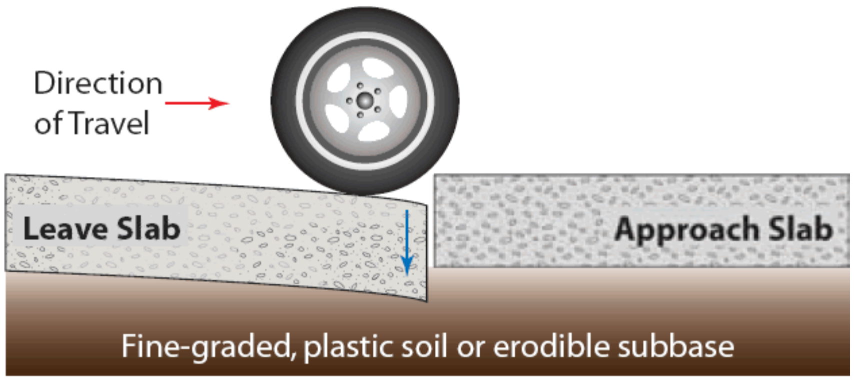
AASHTO 93
(ACPA WinPAS)

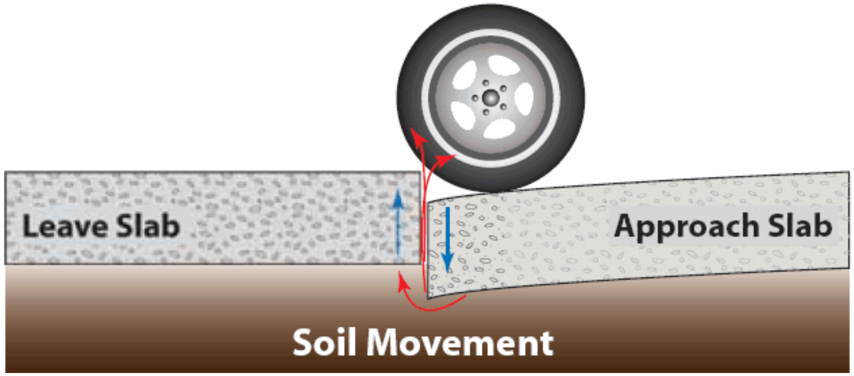
ACPA StreetPave

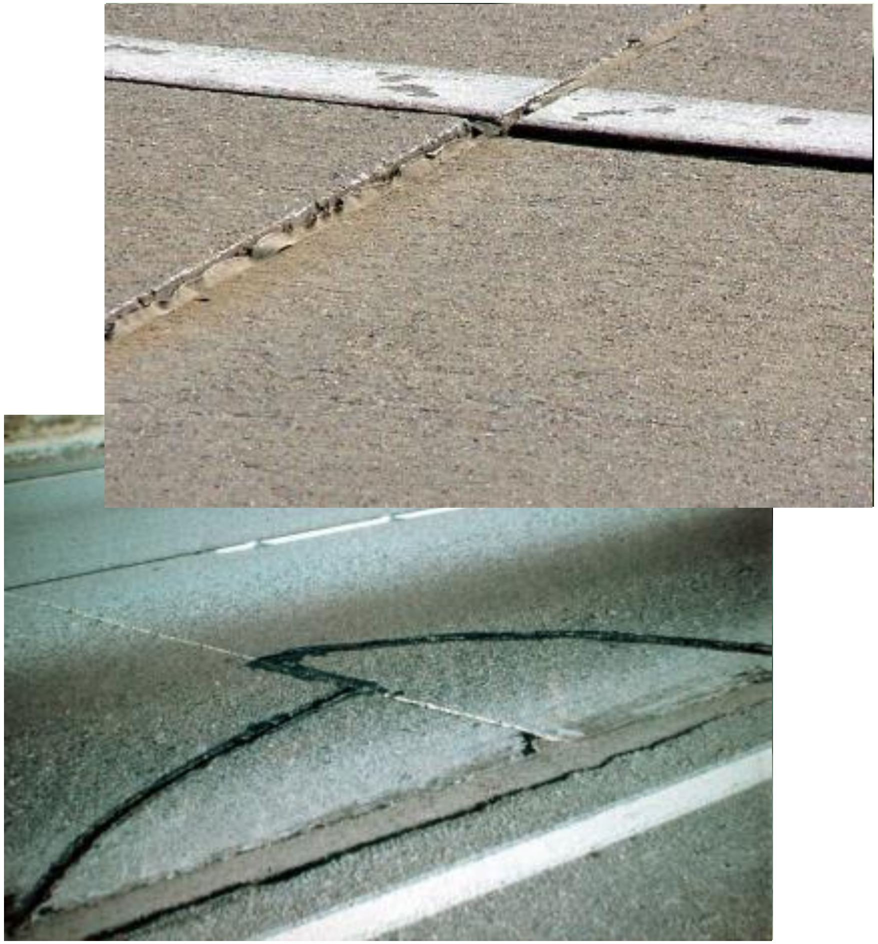
k-value Impact on Thickness



Also Concerned w/Pumping & Faulting

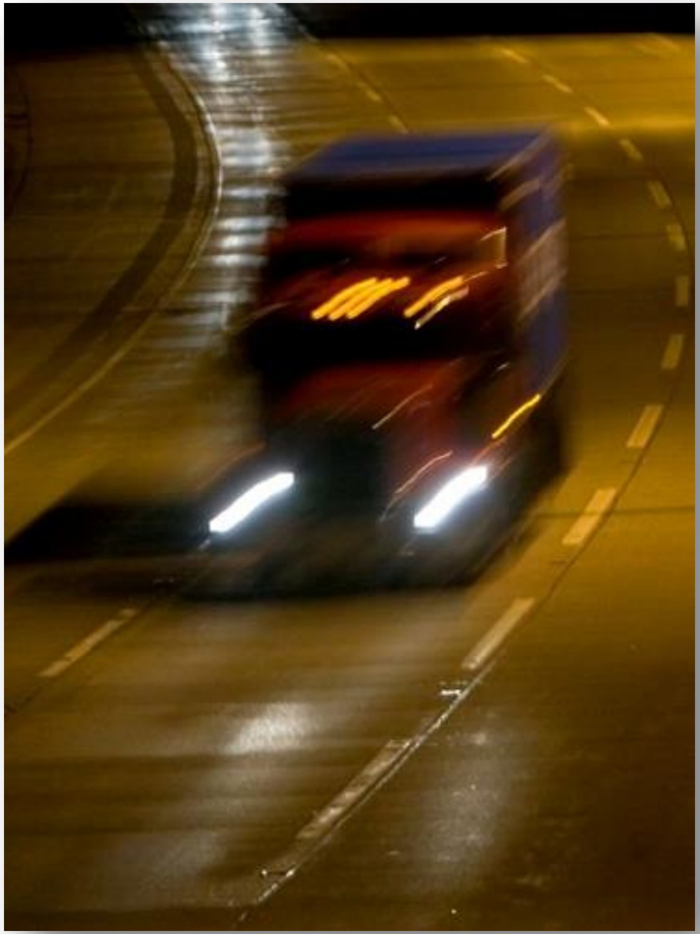






Preventing Pumping/Faulting

- Pumping of subgrade/subbase requires:
  1. Undoweled joints or joints w/ poor load transfer
  2. Water
  3. Fast moving, heavy loads
  4. Fine-grained material in subgrade or the subbase must be an erodible material
- Eliminate casual factor(s) to mitigate pumping

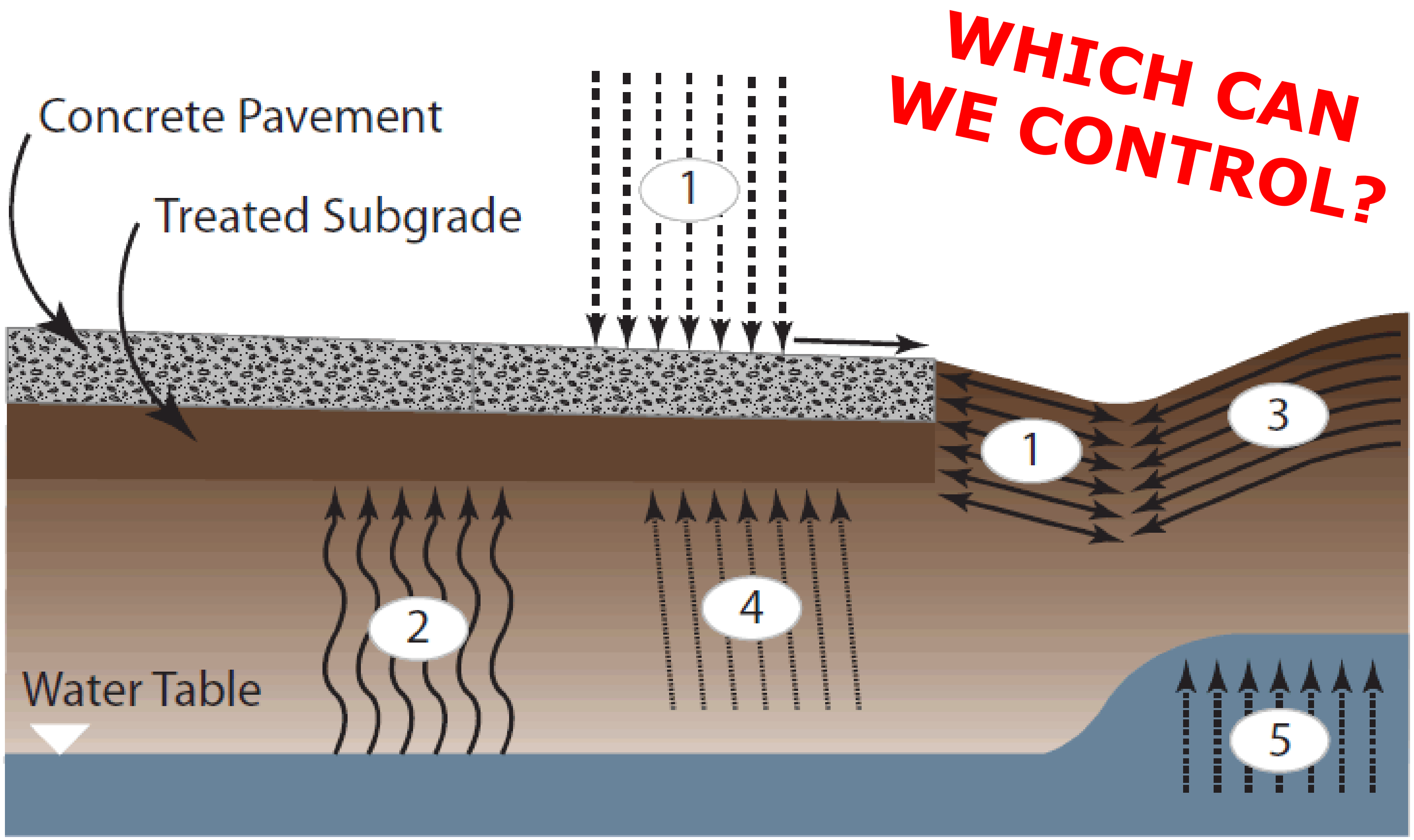


… we'll get back to this issue…



SUBSURFACE DRAINAGE

Sources of Moisture



1. Precipitation and entry from the pavement edge
2. Capillary suction from the water table
3. Drainage from natural high ground
4. Vapor movement through the soil
5. Water table rise in elevation

Purpose of Subsurface Drainage

- **Problem:**
  - Water in the pavement feeds certain types of distress (e.g., pumping/faulting, ASR, etc.)
- **Solutions:**
  - Surface water is primarily removed through proper geometric design
  - Water that infiltrates the pavement structure might be removed through subsurface drainage

Stability versus Drainability

- Concrete pavement requires long-term stability
  - Though highly drainable, low fines gradations generally don't meet this criterion
  - Potential benefits of extreme drainage are offset by added cost, constructability issues and limited data supporting enhanced performance…

Too High a Permeability is Problematic

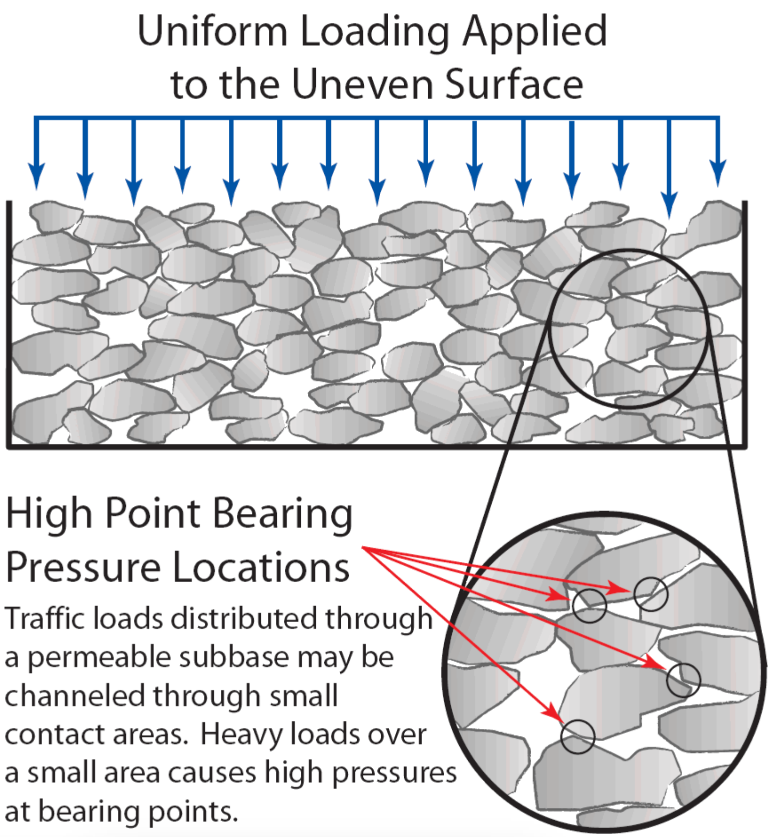
- Permeable subbases have a permeability of 350+ ft/day (107+ m/day) in laboratory tests, though value up to 20,000 ft/day (6,100 m/day) have been specified
- Crushed stone (may be stabilized with cement or asphalt) with reduced fines to create a mixture with many large voids to easily drain water
- Became popular in U.S. in the 1990s… a 2005 survey showed that 60%+ of state DOTs used them then, but many problems occurred…

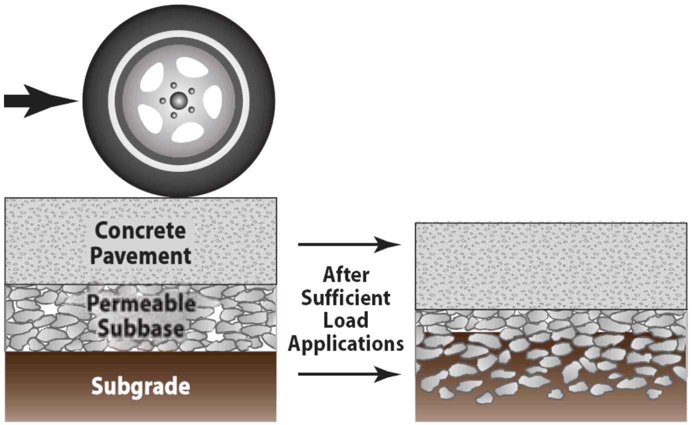
Problems Started in Construction

- Rutting while hauling concrete
- Unstable trackline; roughness
- Problems anchoring dowel baskets and/or tie bar chairs
- If stabilized, high friction with irregular, open-graded surface impacted sawing window

Problems Continued in Service

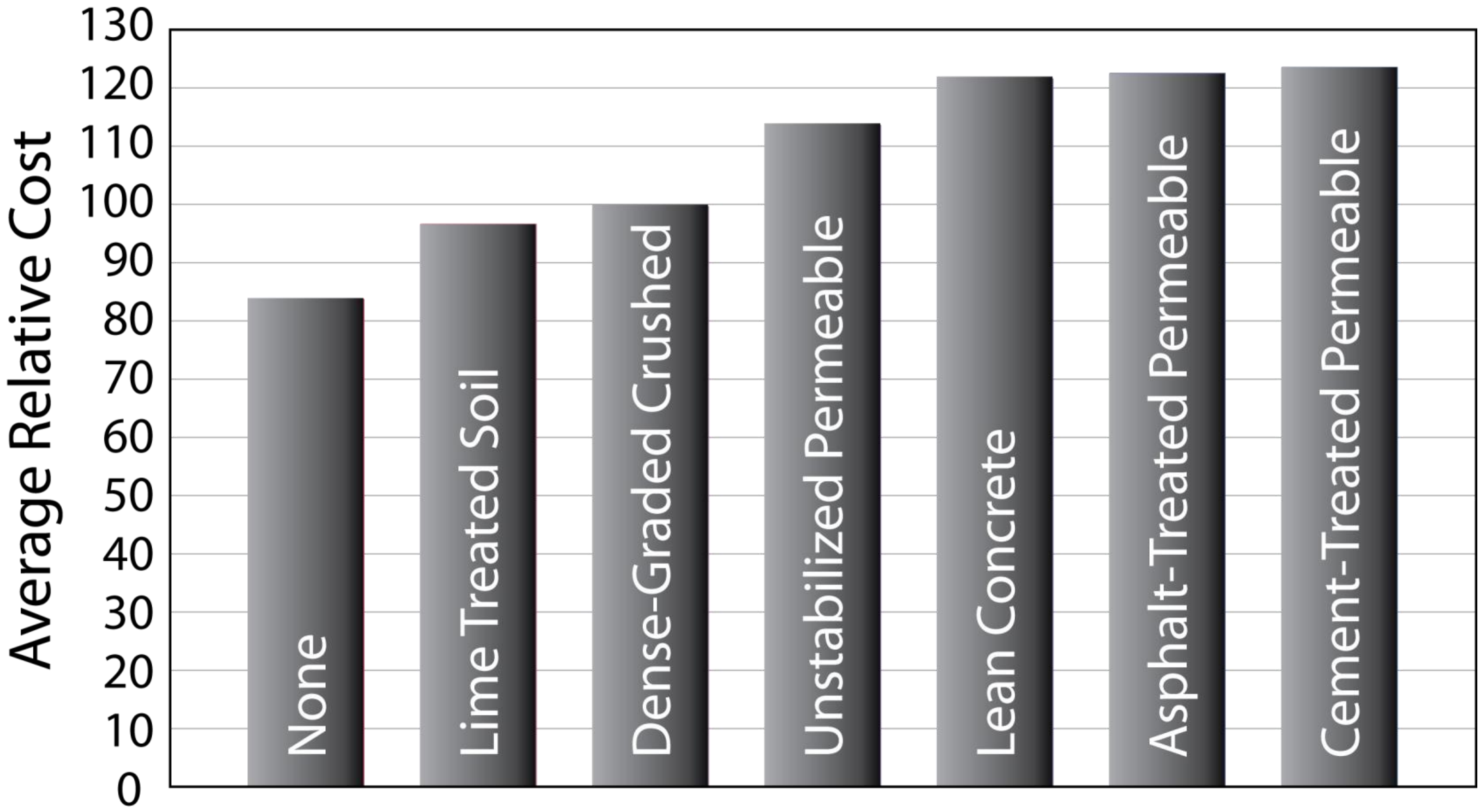
- Aggregates break down from high point bearing pressures
- Fines in subgrade can migrate into a permeable subbase





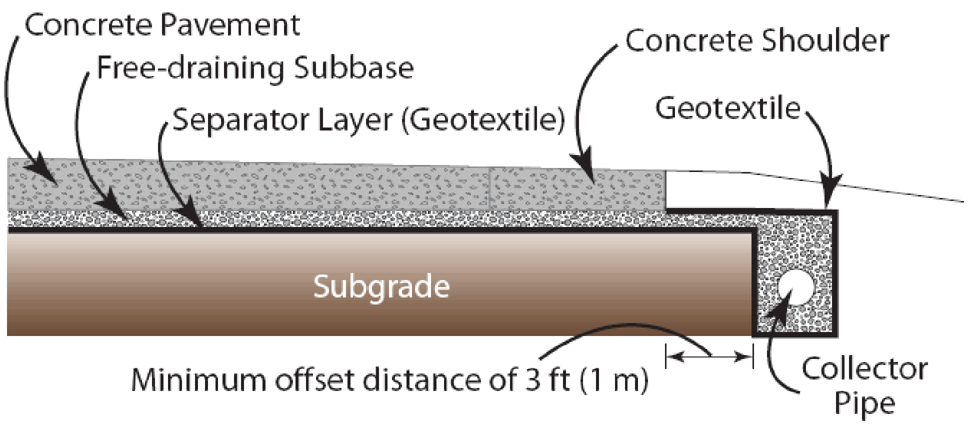
Permeable Subbase without a Separator Layer

...and Proven Not Cost Effective



Permeable subbases ***must*** extend pavement life by between **8 and 15 years** to be cost effective!!

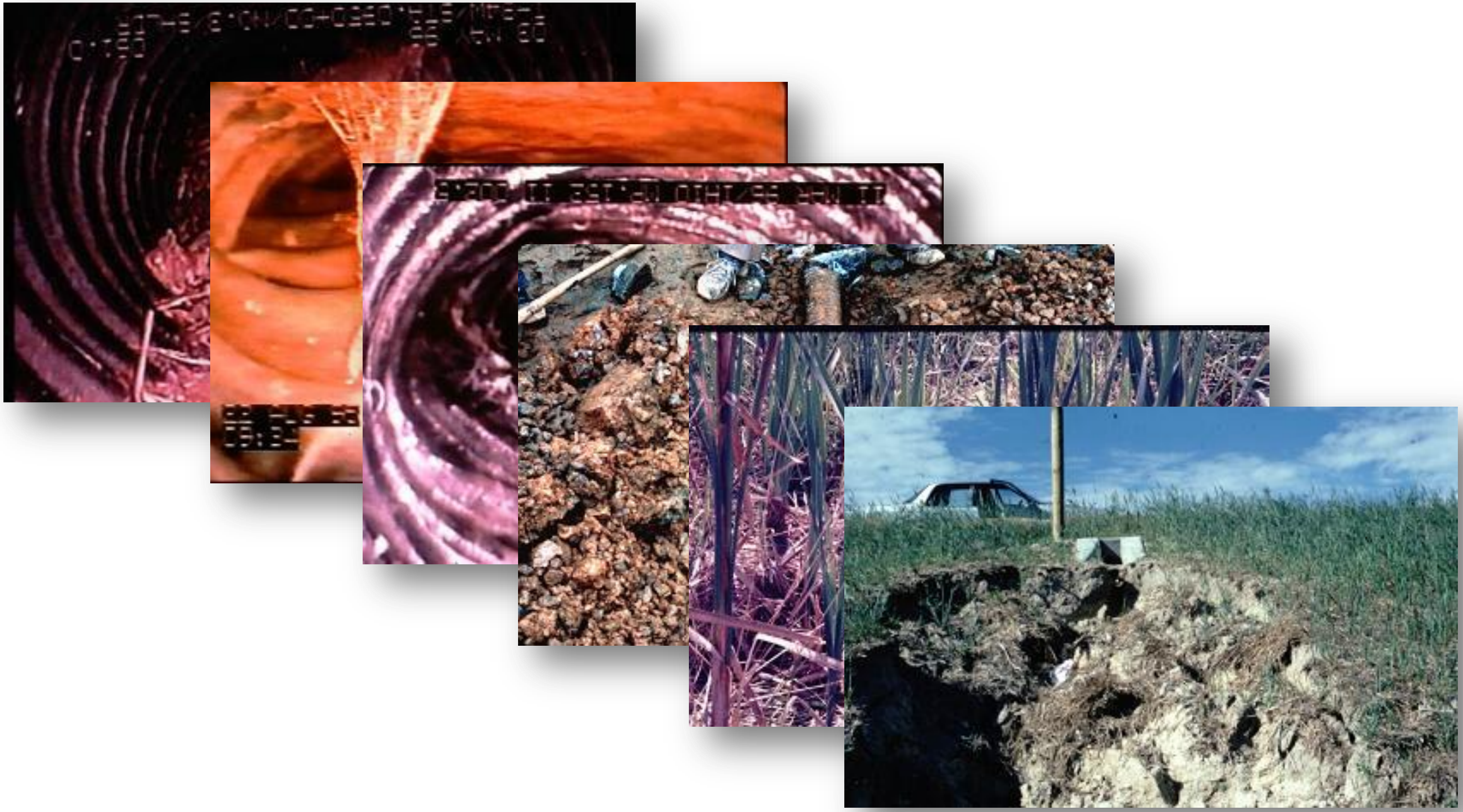
Problems with Edge Drains Too!



- Permeable subbases often used with an edge drain
- Settling, crushing, and plugging of both newly constructed and retrofitted edge drain pipes was common during installation and service
- ***FHWA:*** "If a state highway association does not have a commitment to maintenance, permeable subbases should not be provided."

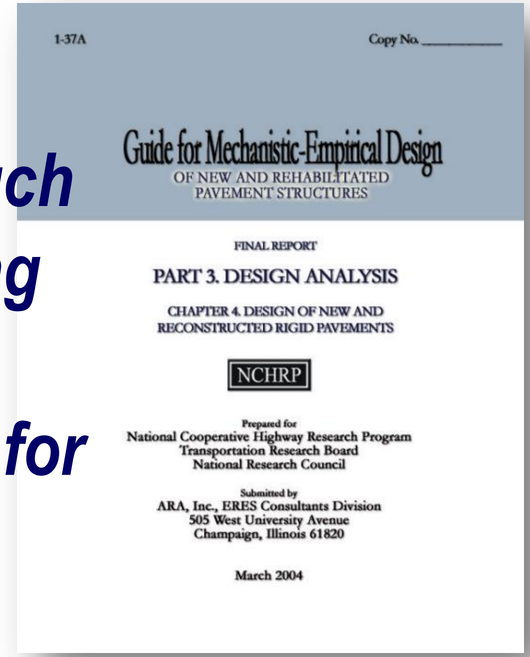
Problems with Edge Drains Too!

- FHWA 2002, "Maintenance of Highway Edge Drains"



How Much Permeability is Needed?

- The AASHTO MEPDG says:
  - *"The current state of the art is such that conclusive remarks regarding the effectiveness of pavement subsurface drainage or the need for subsurface drainage are not possible."*



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Guide for Mechanistic-Empirical Design
OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

PART 3. DESIGN ANALYSIS

CHAPTER 4. DESIGN OF NEW AND RECONSTRUCTED RIGID PAVEMENTS

NCHRP

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

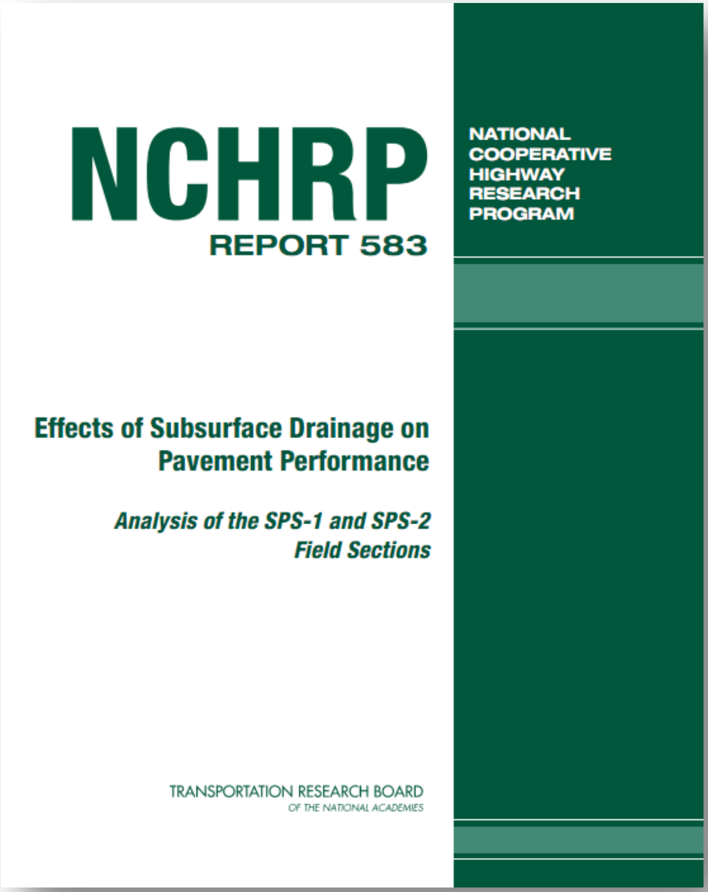
Submitted by
ARA, Inc., ERES Consultants Division
505 West University Avenue
Champaign, Illinois 61820

March 2004

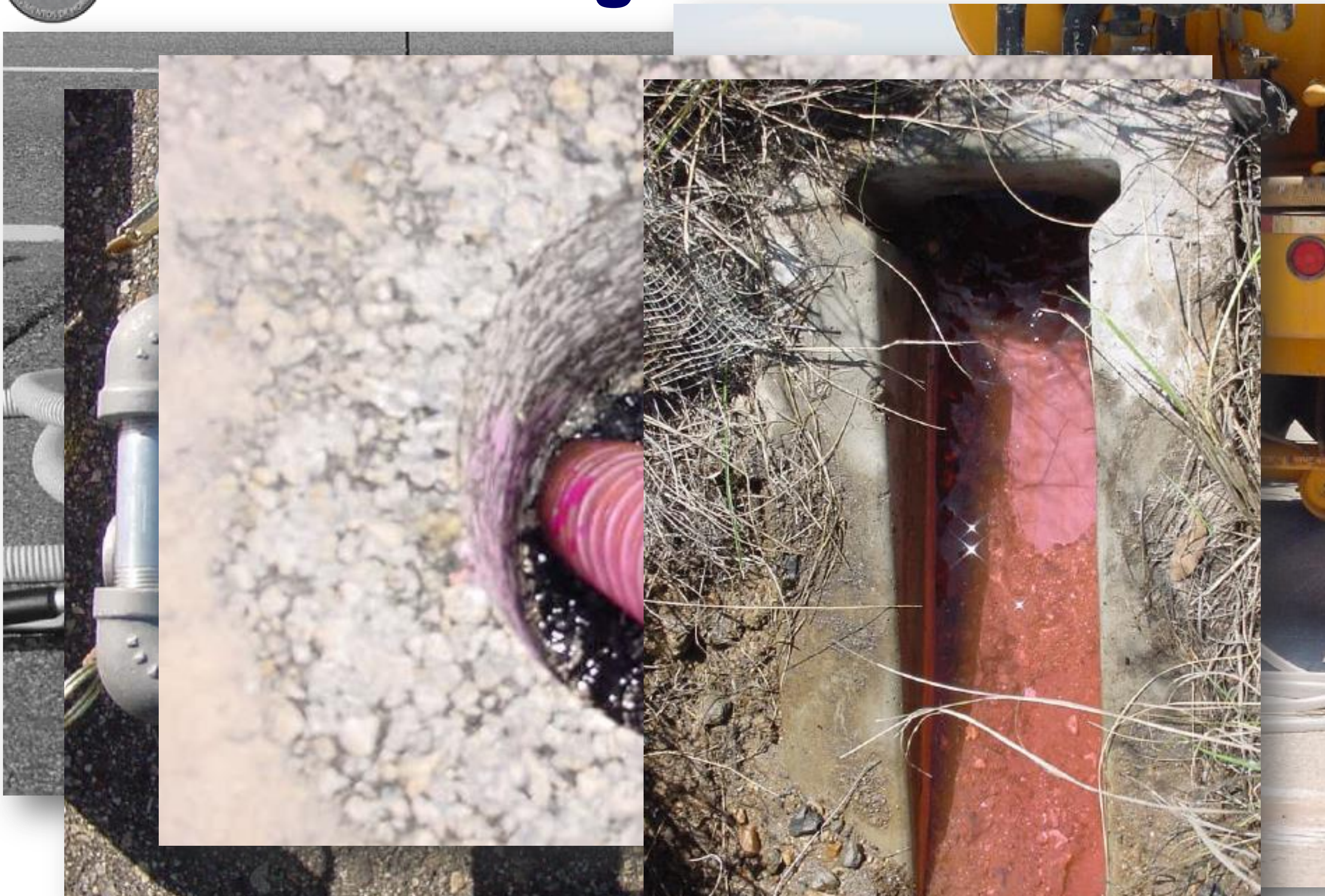
… so we must augment our understanding of the issue with field performance…

Effects of Drainage on Performance

- NCHRP 1-34D investigated long-term performance of subbases using LTPP sections across the U.S. with varying:
  - Pavement structures,
  - Environments,
  - Levels of traffic,
  - Soil types,
  - Etc.

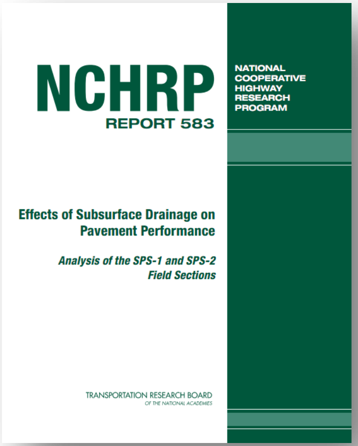


Field Testing for NCHRP 1-34D



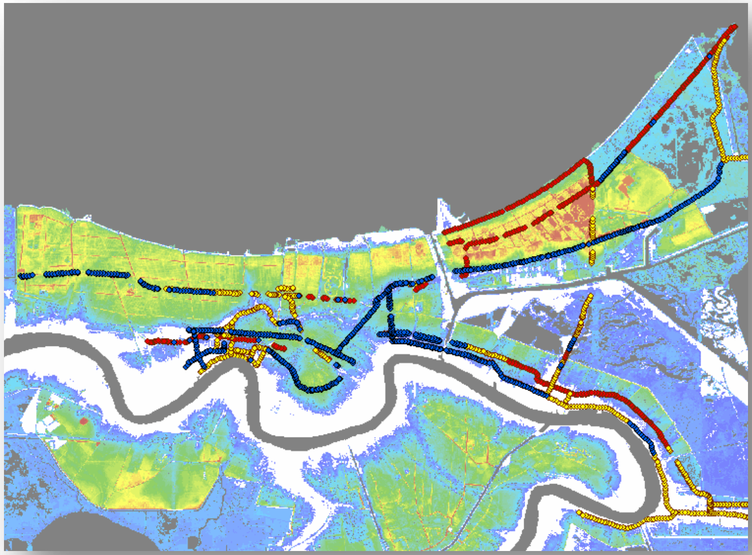
Conclusions from NCHRP 1-34D

- **Subbase stiffness matters more than drainage for concrete pavement performance**
- There is an optimal stiffness for subbases (not too stiff, not too flexible)
- Although excess moisture and poor drainage has been shown to be detrimental to pavement performance in the past, **current designs are less susceptible to moisture damage** (improved materials, **widespread use of dowels**, etc.)



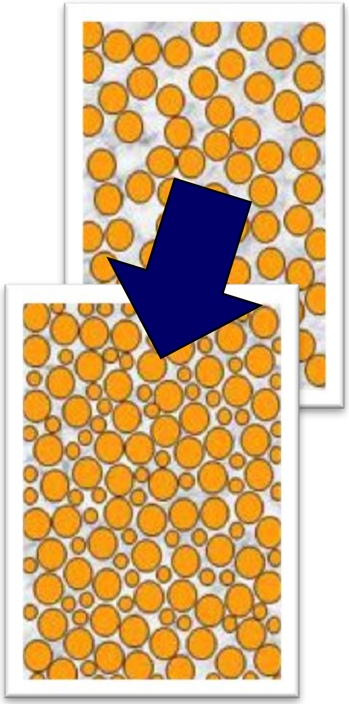
Impact of Hurricane Katrina in N.O.

- Louisiana DOT used FWD, GPR, DCP, coring, etc. to assess structural impact of flooding and overloads from relief efforts
- "…asphalt pavements had strength loss equivalent to about two inches of new asphalt concrete… Very little relative damage was detected for the PCC pavements."
- Concrete shown to be relatively insensitive to the presence of moisture!



So We Tweaked the System

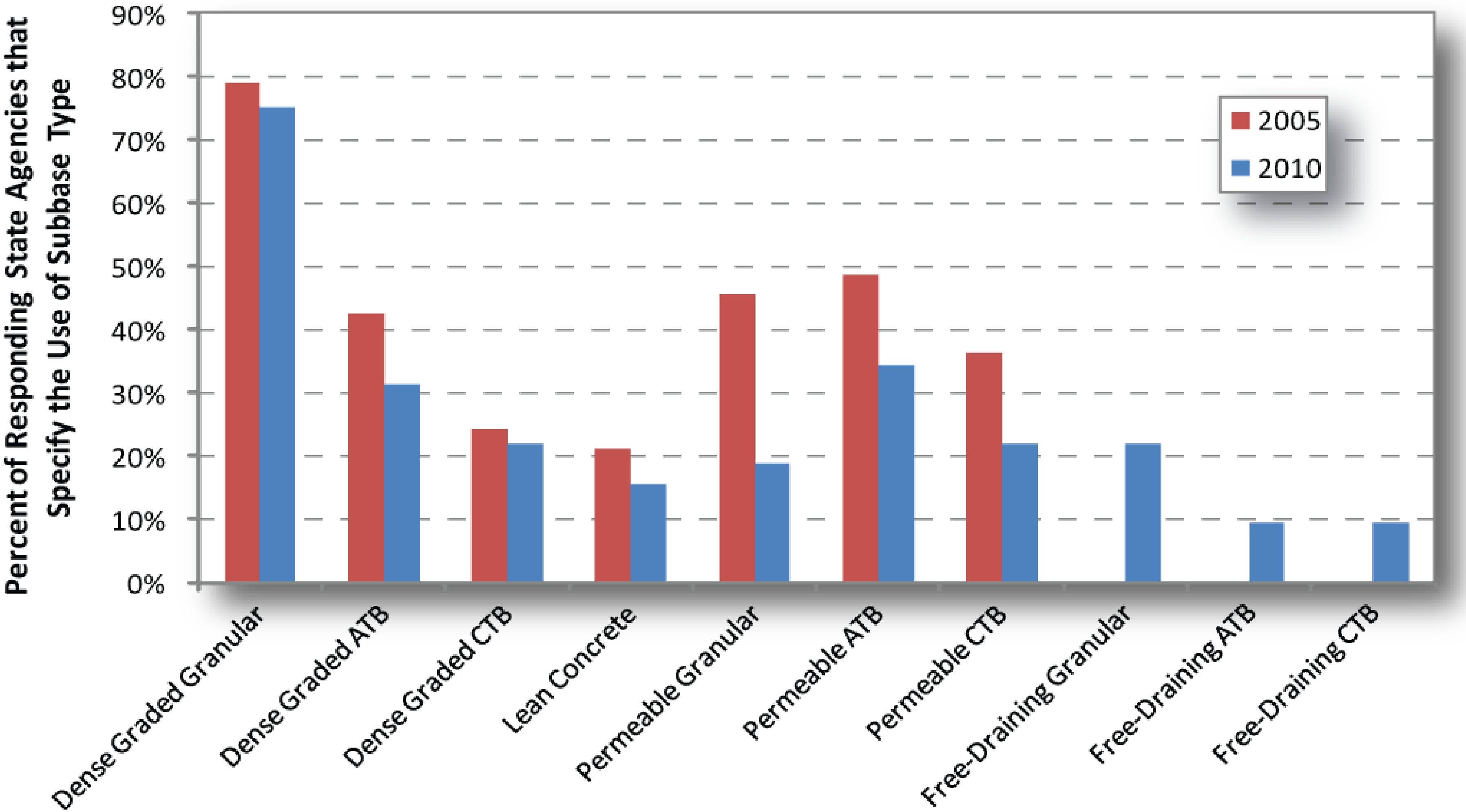
- If drainability is required, use a **free-draining subbase**:
  - Permeability of 50-150 ft/day (15-46 m/day) in laboratory tests; note a max value added!
  - Increased sand/fines content
  - Can be unstabilized or stabilized
  - Better balance of permeability and stability
  - Mitigates the distresses associated with permeable subbases



Sample Gradations

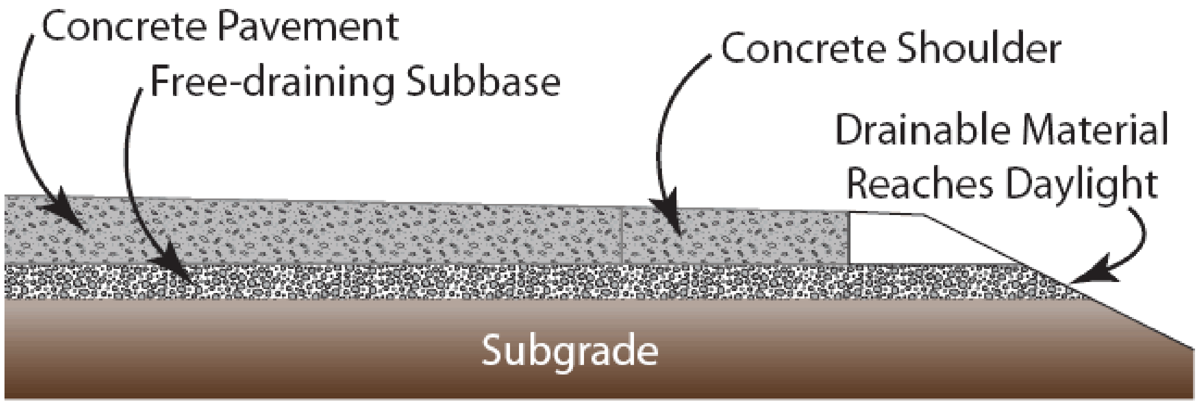
	Percent Passing						
Sieve Size	**Free-Draining**	**Unstabilized Permeable**				**Stabilized Permeable**	
2 in.	-	-	100	-	-	-	-
1 1/2 in.	-	-	-	100	-	-	100
1 in.	100	100	-	95-100	100	100	95-100
3/4 in.	-	-	52-100	-	90-100	90-100	-
1/2 in.	60-90	-	-	60-80	-	35-65	25-60
3/8 in.	-	-	35-65	-	20-55	20-45	-
No. 4	**35-60**	**-**	**8-40**	**40-55**	**20-55**	**0-10**	**0-10**
No. 8	-	10-35	-	5-25	0-5	0-5	0-5
No. 10	-	-	-	-	-	-	-
No. 16	-	-	0-12	0-8	-	-	-
No. 30	10-35	-	0-8	-	-	-	-
No. 40	-	-	-	-	-	-	-
No. 50	-	0-15	-	0-5	-	-	-
No. 200	**0-15**	**0-6**	**0-5**	**-**	**-**	**0-2**	**0-2**
Permeability (feet/day)	*150*	*500*	*1,000*	*2,000*	*18,000*	*15,000*	*20,000*

U.S. State Agencies are Changing



NOTE: Dense graded granular is still the most commonly specified!

Daylighting Subbase More Common



- Water and any free material that finds its way into the free-draining subbase will have many paths to follow that could potentially lead out of the pavement structure
- No regular scheduled maintenance is required for a daylighted subbase

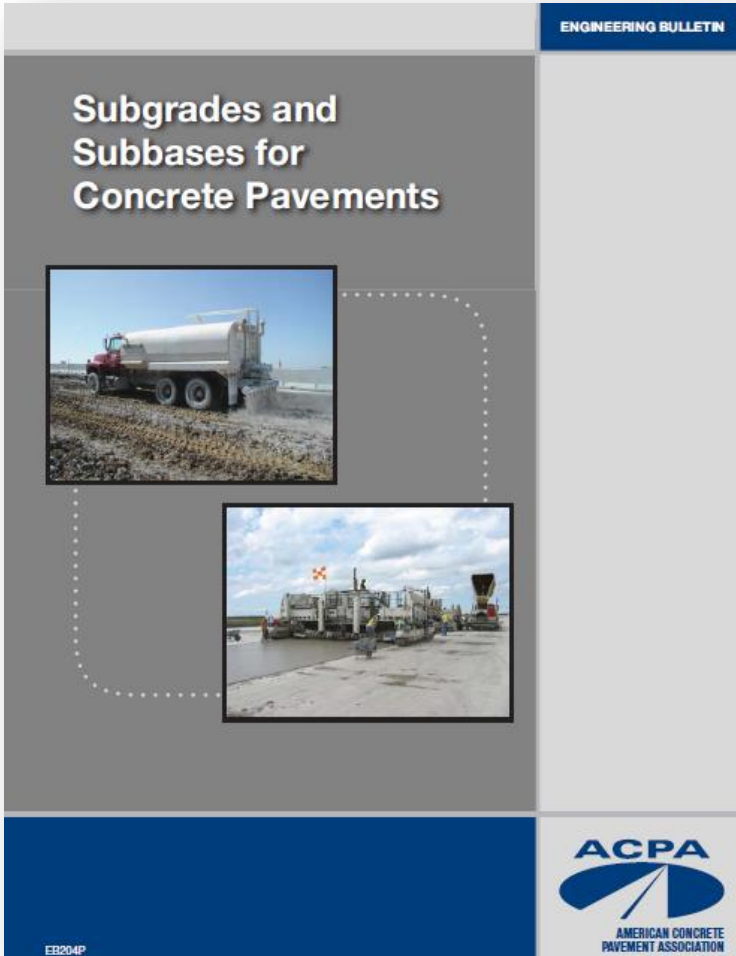
ACPA's Recommendations

- **Permeable subbases** with edge drains are **no longer recommended** for concrete pavement structures because of their many performance issues and lack of cost-effectiveness
- **Free-draining, daylighted subbases** are a reasonable alternative to rapidly draining permeable subbases with edge drainage systems

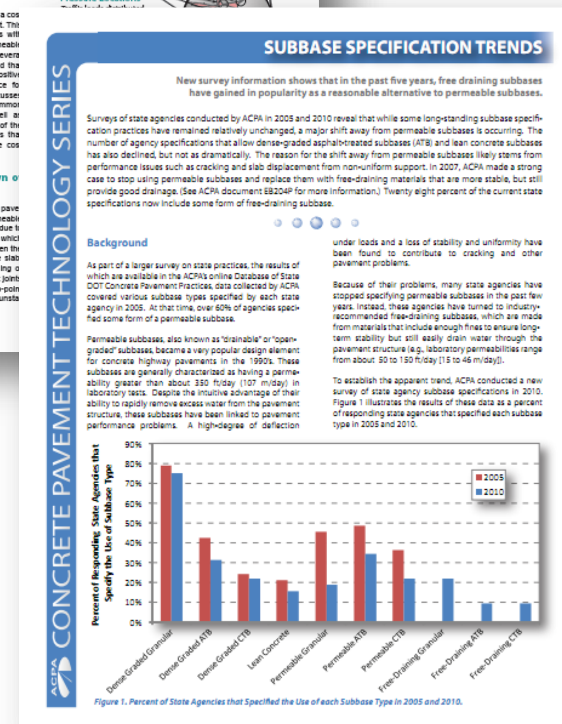
... and Remember

- Subsurface drainage is not required for every newly constructed concrete pavement!
  - There may be instances where drainage is required but this must be established on a case by case basis
- If a drainage system is put in place, a long-term commitment to maintain it must be made up front

Resources


ENGINEERING BULLETIN
Subgrades and Subbases for Concrete Pavements
ACPA
AMERICAN CONCRETE PAVEMENT ASSOCIATION
EB204P


CONCRETE PAVEMENT TECHNOLOGY SERIES
Permeable Subbases: Reasons to Avoid Their Use
The inclusion of permeable (open-graded) subbases in concrete pavement structures is no longer recommended for many of the reasons discussed herein.
The use of highly open-graded and permeable subbase layers (stabilized or unstabilized) with a permeability coefficient of more than about 350 ft/day (107 m/day) in laboratory tests are no longer recommended as a design element in concrete pavement structures. This conclusion was reached through experiences in the field and it is supported by a national performance evaluation study. Furthermore, concrete pavement structures that include permeable systems can cost as much as twenty-five percent more than conventional concrete pavement structures, substantially increasing project costs without a proportionate increase in performance. This publication details these and several other reasons to avoid the use of permeable subbases. More on the topic of permeable subbases is available in ACPA's EB204P, "Subgrades and Subbases for Concrete Pavements."
Permeable Subbases Background
Permeable subbases, also known as "drainable" or "open-graded" subbases, became a very popular design element for concrete highway pavements in the 1990's. These subbase are generally characterized as a crushed aggregate (often stabilized with cement or asphalt) with a reduced amount of fines to increase the permeability of the subbase to greater than about 350 ft/day (107 m/day) in laboratory tests. Despite the intuitive advantage of an ability of the permeable subbase to remove excess water from the pavement rapidly, permeable subbases have had a problematic history.
Uniform Loading Applied to an Uneven Surface
High Point Bearing Pressure Locations
Loss of Support Due to Breakdown of the Aggregate


CONCRETE PAVEMENT TECHNOLOGY SERIES
SUBBASE SPECIFICATION TRENDS
New survey information shows that in the past five years, free draining subbases have gained in popularity as a reasonable alternative to permeable subbases.
Surveys of state agencies conducted by ACPA in 2005 and 2010 reveal that while some long-standing subbase specification practices have remained relatively unchanged, a major shift away from permeable subbases is occurring. The number of agency specifications that allow dense-graded asphalt-treated subbases (ATB) and lean concrete subbases has also declined, but not as dramatically. The reason for the shift away from permeable subbases likely stems from performance issues such as cracking and slab displacement from non-uniform support. In 2007, ACPA made a strong case to stop using permeable subbases and replace them with free-draining materials that are more stable, but still provide good drainage. (See ACPA document EB204P for more information.) Twenty eight percent of the current state specifications now include some form of free-draining subbase.
Background
2005
2010
Dense Graded Granular
Dense Graded ATB
Dense Graded CTB
Lean Concrete
Permeable Granular
Permeable ATB
Permeable CTB
Free-Draining Granular
Free-Draining ATB
Free-Draining CTB
Figure 1. Percent of State Agencies that Specified the Use of each Subbase Type in 2005 and 2010.

Thank You! Questions?

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