MICHIGAN CONCRETE ASSOCIATION

Concrete Pavement Thickness Design

presented by Steve Waalkes, P.E., MCA's Director of Engineering – W. Mich.

Tuesday, April 14, 2020 10:00 to 11:00 am Eastern

Topics Covered Today

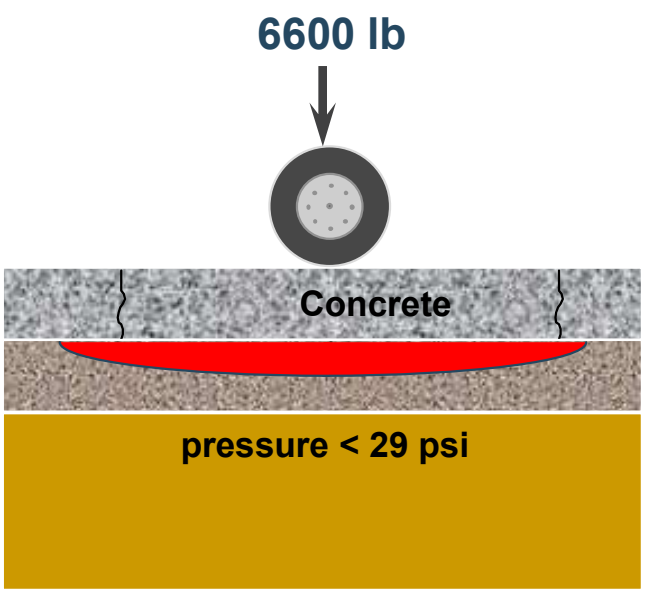
Basic Principles of Concrete Pavement Thickness Design for:

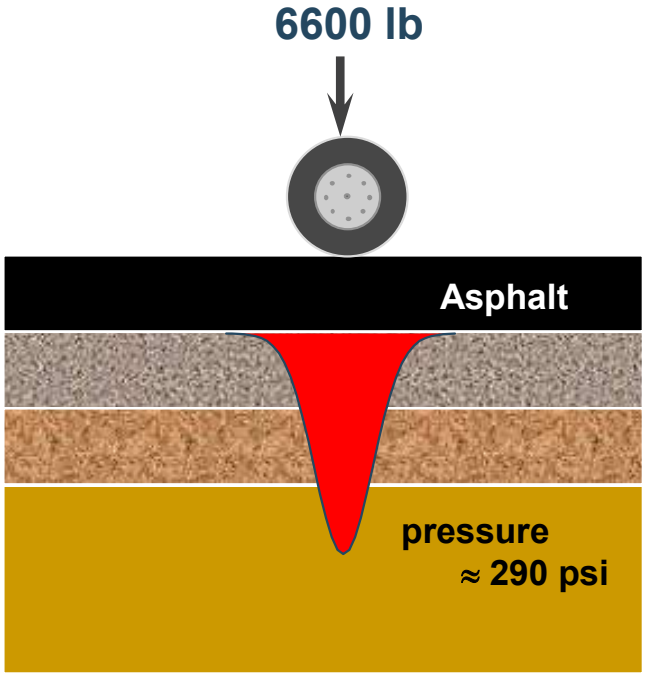
- Highways
- Streets
- Parking Lots
- Industrial / Trucking Facilities

Available guidance documents / software

Design Examples

Differences in How Pavements Carry Loads

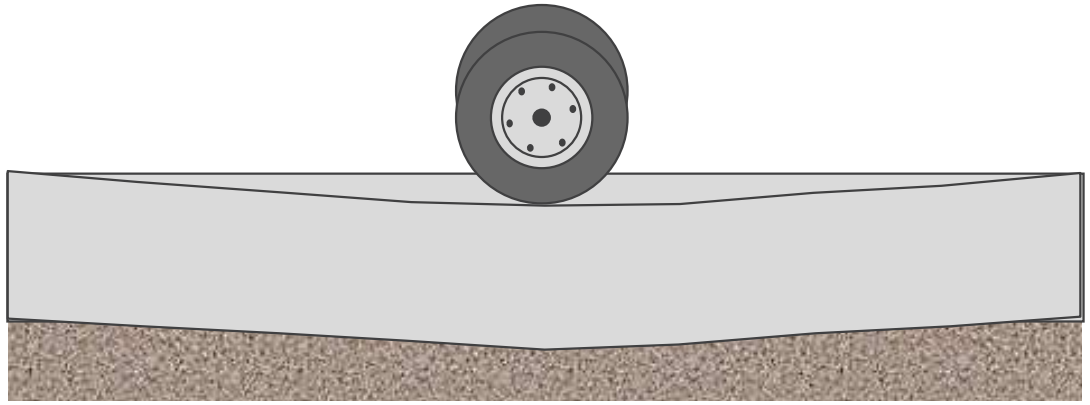


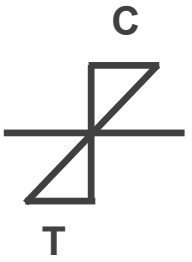


Concrete's rigidity spreads the load over a large area and keeps pressures on the subgrade low.

Pavement Design Principle #1:

Stress / Fatigue

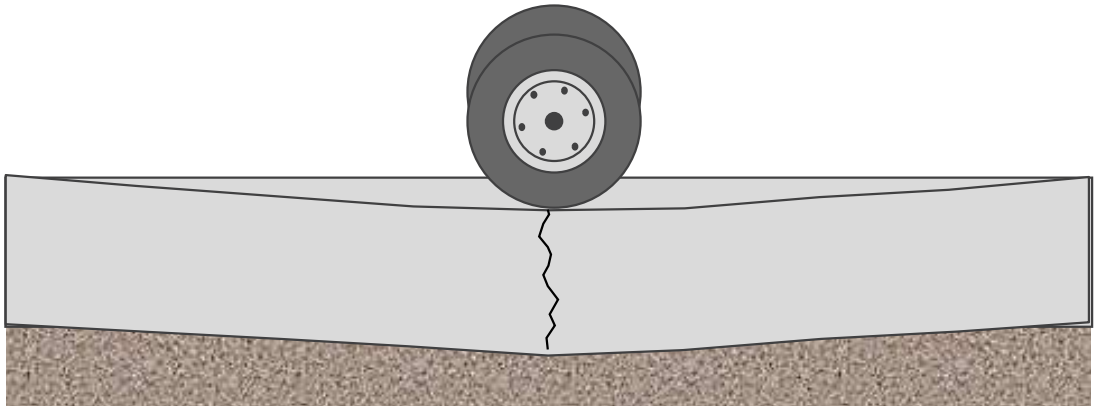




- Compressive strength: ~4000 psi
- Flexural strength: ~600 psi

Pavement Design Principle #1:

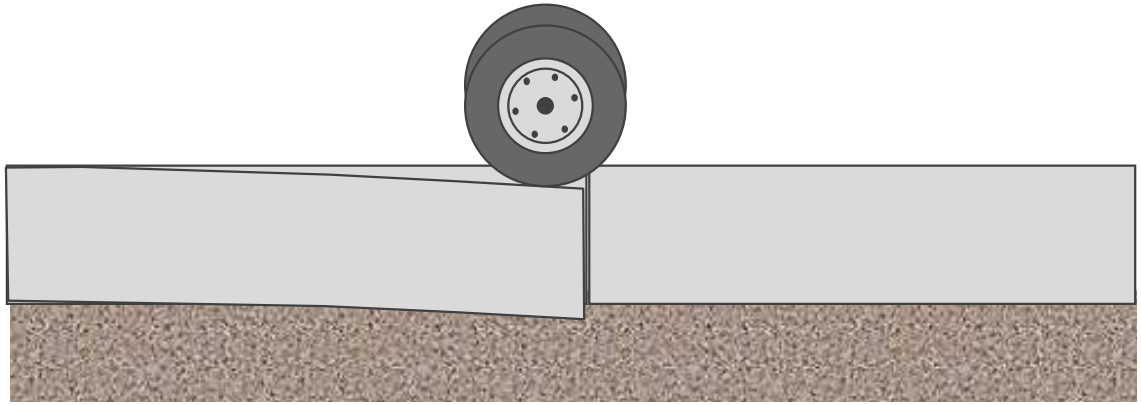
Stress / Fatigue



- Limit stresses to reduce fatigue due to repeated loadings
- Design slab to account for certain amount of fatigue at design life

Pavement Design Principle #2:

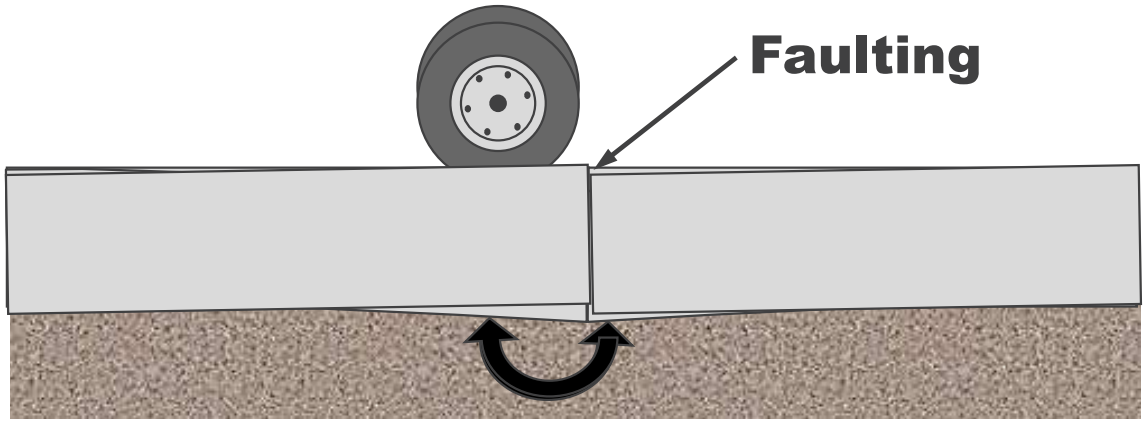
Deflection / Erosion / Pumping



- Better support (higher k-value) will lower deflections
- Load transfer will lower deflections

Pavement Design Principle #2:

Deflection / Erosion / Pumping



- Non-erodible base (agg. instead of soil) will help limit erosion/pumping/faulting
- Load transfer will help too

Concrete Pavement Thickness Design

- Directly related to the amount of truck traffic
- Also:
  - Subgrade (soil) and base layers
  - Concrete strength
  - Load transfer between slabs

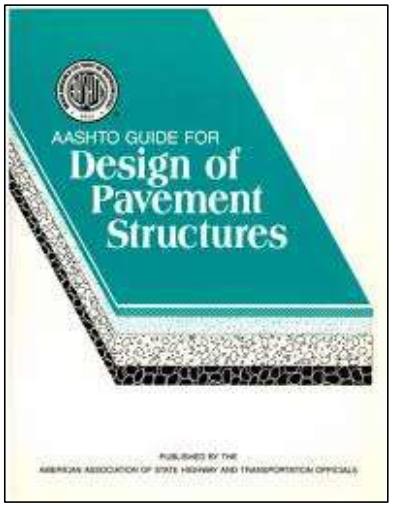
Concrete Pavement Thickness Design

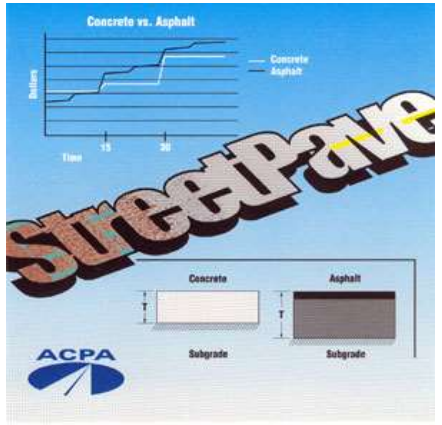
- Basic inputs you need:
  - Design life (typ. 20+ yrs)
  - Traffic (ADT, % trucks)
  - Subgrade / base (soil type, agg. thickness)
  - Concrete strength (flexural)
  - Reliability (typ. 80% to 95%)

Design Methodologies, Publications, Guides, Software, Programs, etc.

Concrete Pavement Design Methodologies

- AASHTO 1993 Pavement Design Procedure
- 1984 PCA / ACPA StreetPave
- Pavement ME
- Westergaard analysis





$$\sigma_c = \frac{3P}{h^2}\left[1 - \left(\frac{a_1}{l}\right)^{0.6}\right]$$

$$\sigma_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 0.359\right]$$

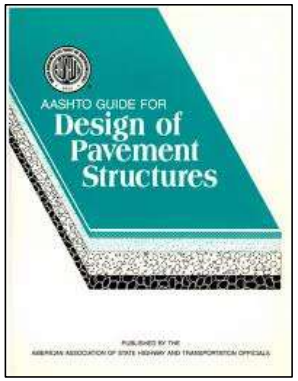
$$\sigma_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 1.069\right]$$

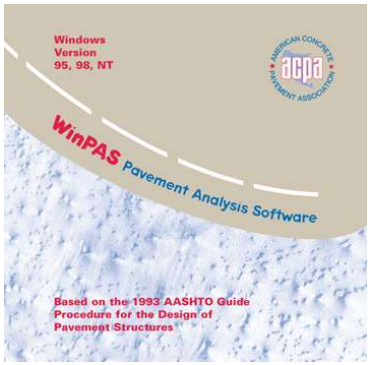
$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

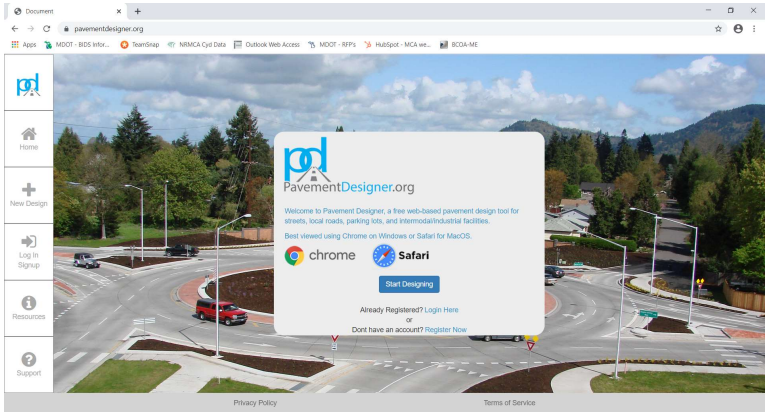
Guides / Software to Use by Pavement Type

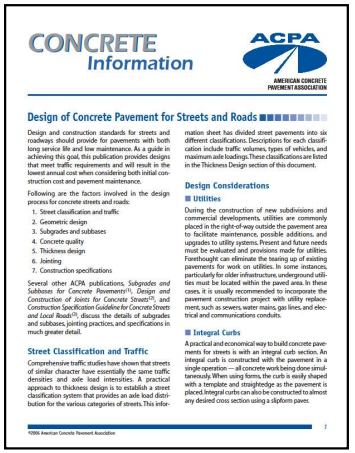
Highways

- AASHTO 93
  - WinPAS
- Pavement ME
  - $$,$$$
- StreetPave
  - www.pavementdesigner.org





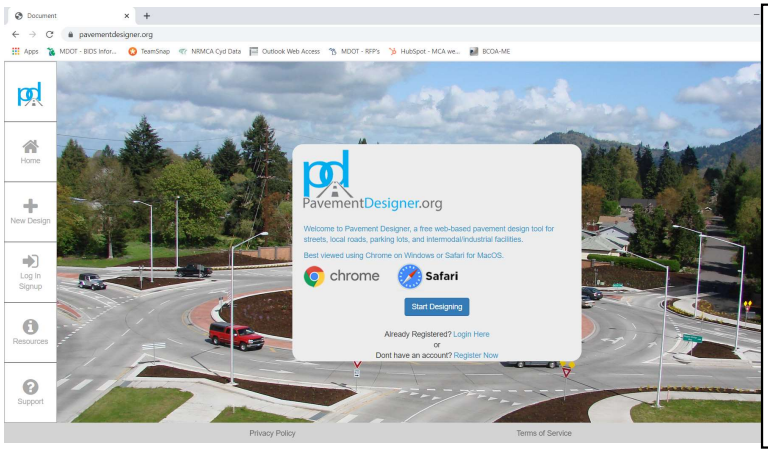


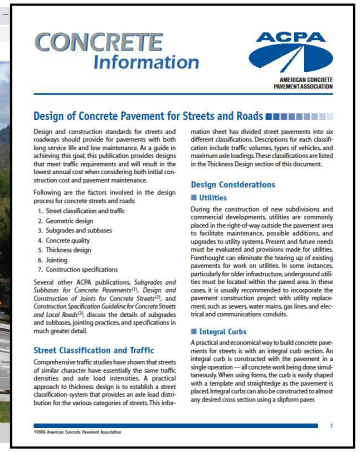


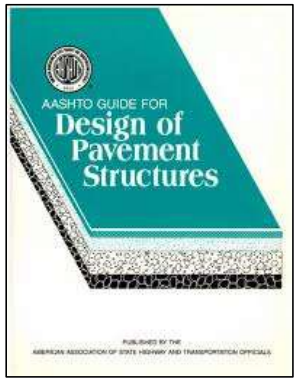
Guides / Software to Use by Pavement Type

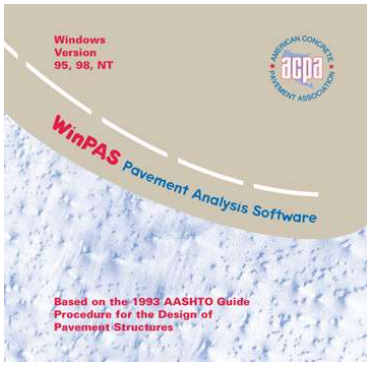
Roads / Streets

- StreetPave
  - www.pavementdesigner.org
- AASHTO 93
  - WinPAS
- Pavement ME
  - $$,$$$





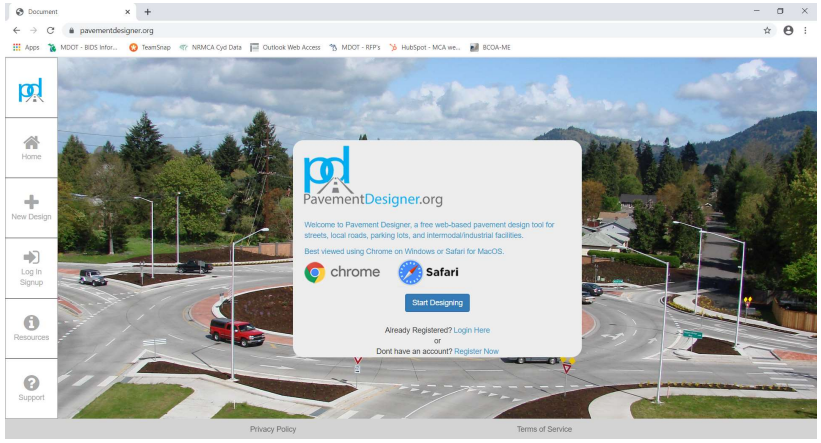


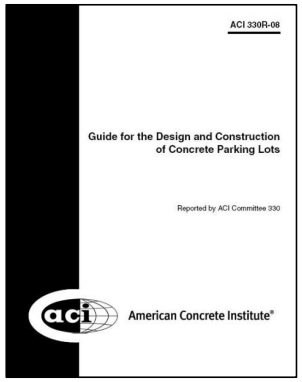


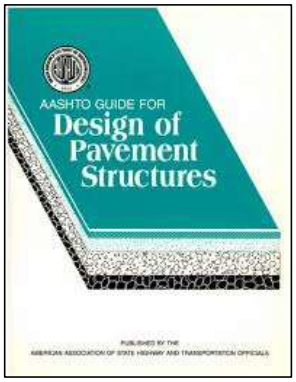
Guides / Software to Use by Pavement Type

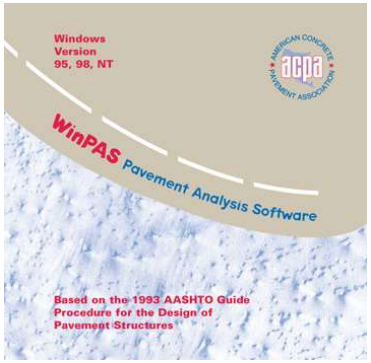
Parking Lots

- StreetPave
  - www.pavementdesigner.org
- ACI 330R-08
  - guide
- AASHTO 93
  - WinPAS





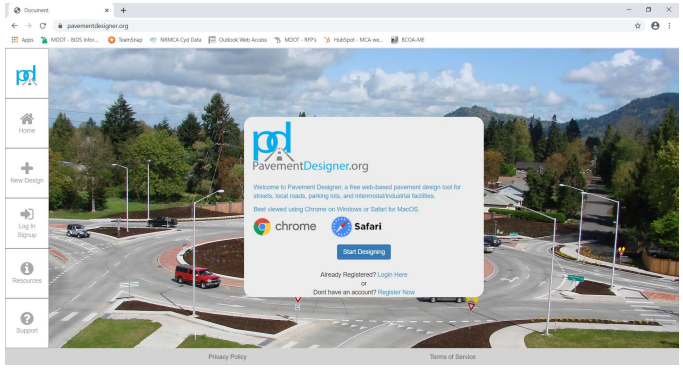


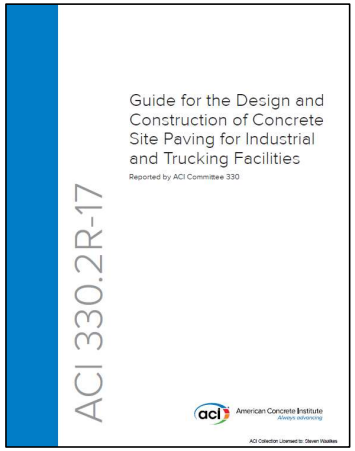


Guides / Software to Use by Pavement Type

Industrial / Trucking

- StreetPave
  - www.pavementdesigner.org
- ACI 330.2R-17
  - guide
- Westergaard analysis
  - spreadsheet





$$\sigma_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 1.069\right]$$

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

Design Examples

Highway – using AASHTO 93 / WinPAS

Highway Example

20,000 ADT; 7% trucks

Concrete

Agg. base

Subgrade modulus = 3500 psi

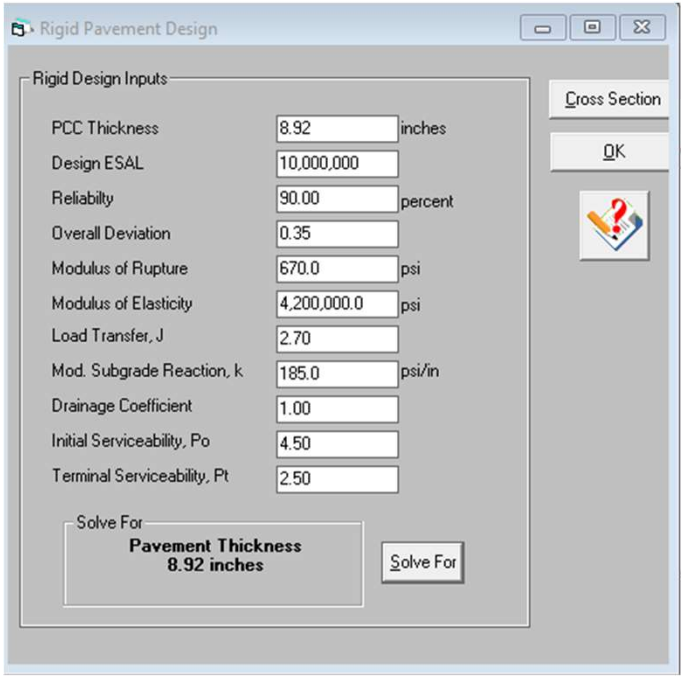
Other design inputs & decisions: Design Life; Reliability/Deviation; Concrete Strength & Elasticity; Dowels/Edge Support; Agg. Base Thickness; Serviceability

Highway Example – Design Inputs

- 10,000,000 ESALs (18-kip equivalent single axle loads)
  - Roughly equal to 20,000 ADT; 7% trucks; 20-year design
- 90% reliability; 0.35 overall deviation
- 670 psi flexural strength; 4,200,000 psi elastic modulus
- Doweled joints (J = 2.7)
- k-value = 185 psi/in; (3500 psi subgrade modulus w/ 6" agg. base)
- C_d = 1.0; Initial Serviceability = 4.5; Terminal Serv. = 2.5

Highway Example – AASHTO 93 Thickness Design

WinPAS software:



Recommended Design:

- 9" P1M concrete (3500HP)
- 6" agg. base (21AA crushed conc.)
- Dowels
- Tied concrete shoulders

MDOT designs typ. range from 9" to 13"

Design Examples

Street/Local Road – using pavementdesigner.org

Street / Road Example

Minor Arterial: 10,000 ADT; 5% trucks

Concrete

Agg. base

Subgrade modulus = 3500 psi

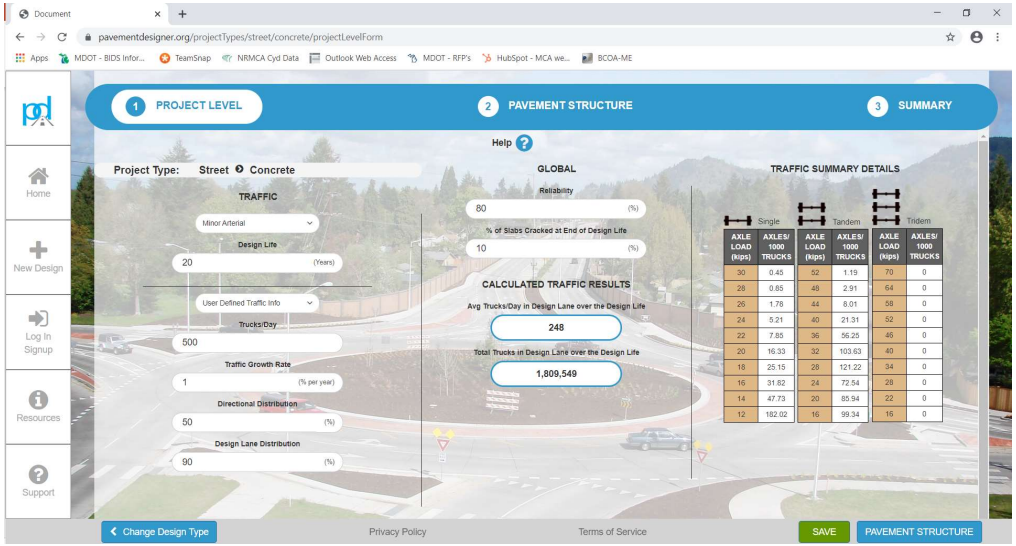
Other design inputs & decisions: Design Life; Reliability/% Slabs Cracked; Concrete Strength & Elasticity; Fibers/Edge Support; Agg. Base Thickness

Street / Road Example – Design Inputs

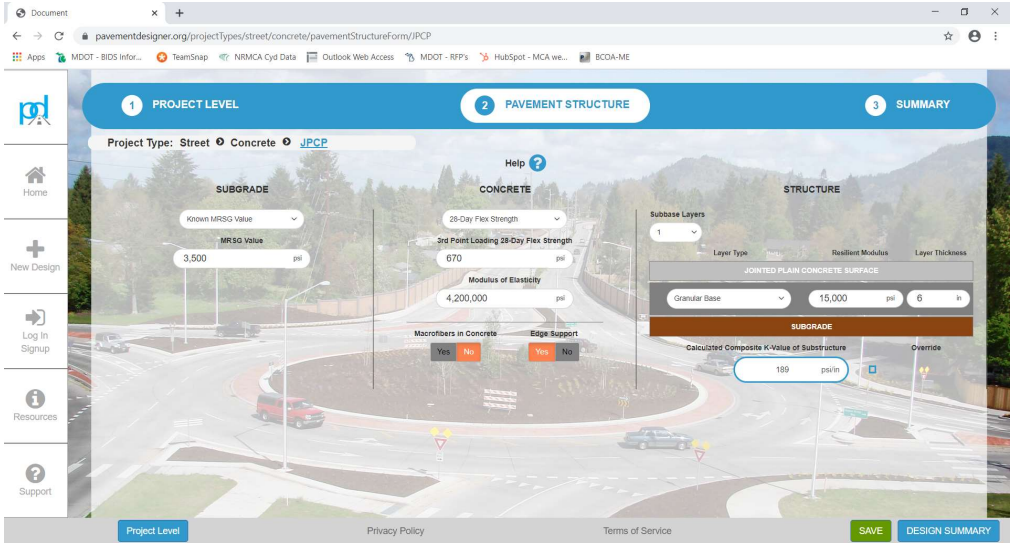
- 4-Lane Minor Arterial; 10,000 ADT; 5% trucks; 20-year design
  - 50% directional split; 90% in design lane (right lane)
- 80% Reliability; 10% Slabs Cracked
- 670 psi flexural strength; 4,200,000 psi elastic modulus
- No macrofibers in mix; Tied curb & gutter
- k-value = 189 psi/in; (3500 psi subgrade modulus w/ 6" agg. base)

Street / Road Example – pavementdesigner.org

Project-Level Inputs:

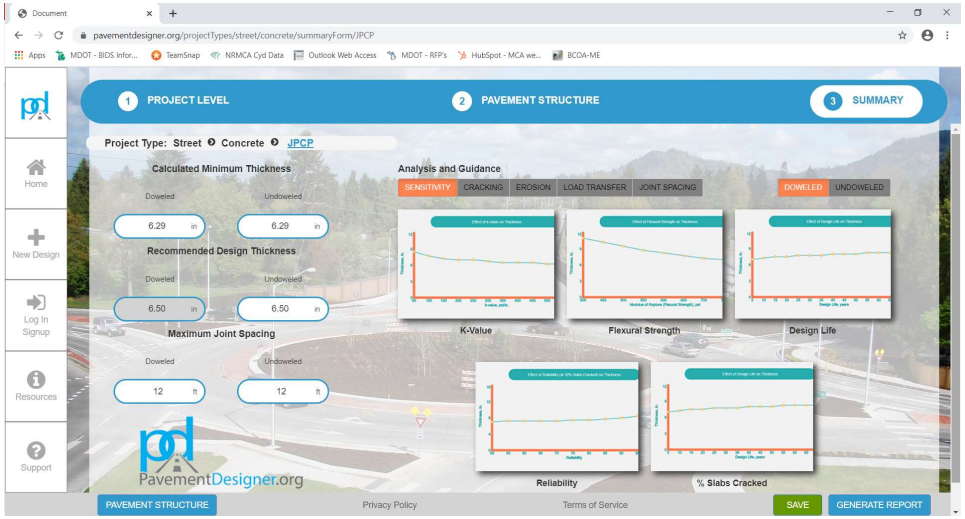


Pavement Structure:



Street / Road Example – pavementdesigner.org

Summary:



Recommended Design:

- 6.5 inches of concrete
- 6" agg. base (21AA crushed conc.)
- Tied curb & gutter
- 12 foot joint spacing

Typ. Michigan Concrete Road/Street Designs

- Residential ⇨ 3 to 50 trucks/day
  - 4"-6" concrete, 3500 psi min. → M_R = 650 psi
  - 4" to 6" agg. base → k = 125 psi/in
- Collector, Business ⇨ 50 to 700 trucks/day
  - 5"-7" concrete, 3500 psi min. → MR = 650 psi
  - 4" to 6" agg. base → k = 125 psi/in
- Arterial, Industrial ⇨ 300 to 1500 trucks/day
  - 6-9" concrete, 4000 psi min. → MR = 650 psi
  - 4" to 8" agg. base → k = 150 psi/in

* NOTE: "Truck" = any heavy vehicle, i.e. delivery trucks, buses, etc.

Design Examples

Parking Lot– using ACI 330R-08

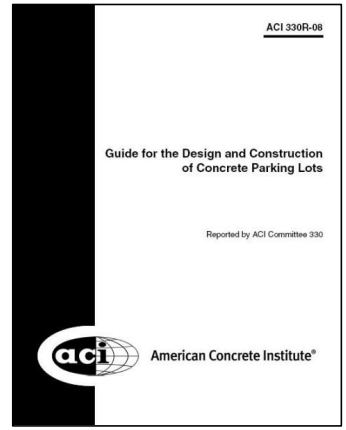
Parking Lot Example

Car parking: ~1 truck/day

Concrete

Agg. base

Subgrade modulus = 3500 psi



Other design inputs & decisions: Agg. Base Thickness; Concrete Strength

Parking Lot Example – ACI 330R-08

Traffic:

Table 3.3—Traffic categories*

1. Car parking areas and access lanes—Category A		
2. Shopping center entrance and service lanes—Category B		
3. Bus parking areas, city and school buses Parking area and interior lanes—Category B Entrance and exterior lanes—Category C		
4. Truck parking areas—Category B, C, or D		
Truck type	Parking areas and interior lanes	Entrance and exterior lanes
Single units (bobtailed trucks)	Category B	Category C
Multiple units (tractor trailer units with one or more trailers)	Category C	Category D

*Select A, B, C, or D for use with Table 3.4.

Subgrade / Base:

Table 3.1—Subgrade soil types and approximate support values (Portland Cement Association 1984a,b; American Concrete Pavement Association 1998)

Type of soil	Support	*k*, psi/in.	CBR	*R*	SSV
Fine-grained soils in which silt and clay-size particles predominate	Low	75 to 120	2.5 to 3.5	10 to 22	2.3 to 3.1
Sands and sand-gravel mixtures with moderate amounts of silt and clay	Medium	130 to 170	4.5 to 7.5	29 to 41	3.5 to 4.9
Sand and sand-gravel mixtures relatively free of plastic fines	High	180 to 220	8.5 to 12	45 to 52	5.3 to 6.1

Notes: CBR = California bearing ratio; *R* = resistance value; and SSV = soil support value. 1 psi = 0.0069 MPa, and 1 psi/in. = 0.27 MPa/m.

Table 3.2—Modulus of subgrade reaction *k**

Subgrade *k* value, psi/in.	Sub-base thickness			
	4 in.	6 in.	9 in.	12 in.
	Granular aggregate subbase			
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

Parking Lot Example – ACI 330R-08

Table 3.4—Twenty-year design thickness recommendations, in. (no dowels)

		k = 500 psi/in. (CBR = 50; R = 86)				k = 400 psi/in. (CBR = 38; R = 80)				k = 300 psi/in. (CBR =26; R = 67)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.5
	A (ADTT = 10)	4.0	4.0	4.0	4.5	4.0	4.0	4.5	4.5	4.0	4.5	4.5	4.5
	B (ADTT = 25)	4.0	4.5	4.5	5.0	4.5	4.5	5.0	5.5	4.5	4.5	5.0	5.5
	B (ADTT = 300)	5.0	5.0	5.5	5.5	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0
	C (ADTT = 100)	5.0	5.0	5.5	5.5	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0
	C (ADTT = 300)	5.0	5.5	5.5	6.0	5.5	5.5	6.0	6.0	5.5	6.0	6.0	6.5
	C (ADTT = 700)	5.5	5.5	6.0	6.0	5.5	5.5	6.0	6.5	5.5	6.0	6.5	6.5
	D (ADTT = 700)†	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
		k = 200 psi/in. (CBR = 10; R = 48)				k = 100 psi/in. (CBR = 3; R = 18)				k = 50 psi/in. (CBR = 2; R = 5)			
	MOR, psi:	650	600	550	500	650	600	550	500	650	600	550	500
Traffic category*	A (ADTT =1)	4.0	4.0	4.0	4.5	4.0	4.5	4.5	5.0	4.5	5.0	5.0	5.5
	A (ADTT = 10)	4.5	4.5	5.0	5.0	4.5	5.0	5.0	5.5	5.0	5.5	5.5	6.0
	B (ADTT = 25)	5.0	5.0	5.5	6.0	5.5	5.5	6.0	6.0	6.0	6.0	6.5	7.0
	B (ADTT = 300)	5.5	5.5	6.0	6.5	6.0	6.0	6.5	7.0	6.5	7.0	7.0	7.5
	C (ADTT = 100)	5.5	6.0	6.0	6.5	6.0	6.5	6.5	7.0	6.5	7.0	7.5	7.5
	C (ADTT = 300)	6.0	6.0	6.5	6.5	6.5	6.5	7.0	7.5	7.0	7.5	7.5	8.0
	C (ADTT = 700)	6.0	6.5	6.5	7.0	6.5	7.0	7.0	7.5	7.0	7.5	8.0	8.5
	D (ADTT = 700)†	7.0	7.0	7.0	7.0	8.0	8.0	8.0	8.0	9.0	9.0	9.0	9.0

*ADTT = average daily truck traffic. Trucks are defined as vehicles with at least six wheels; excludes panel trucks, pickup trucks, and other four-wheel vehicles. Refer to Appendix A. k = modulus of subgrade reaction; CBR = California bearing ratio; R = resistance value; and MOR = modulus of rupture.

†Thickness of Category D (only) can be reduced by 1.0 in. (25 mm) if dowels are used at all transverse joints (that is, joints located perpendicular to direction of traffic).
Note: 1 in. = 25.4 mm; 1 psi = 0.0069 MPa; and 1 psi/in. = 0.27 MPa/m.

Recommended Design:

- 4.0 inches of concrete
- 4" agg. base (21AA crushed conc.)

Typ. Michigan Concrete Parking Lot Designs

- Car parking
  - 4"-5" concrete, 3500 psi min.
  - 4" to 6" agg. base

⇨ 1 to 2 trucks/day
→ M_R = 650 psi
→ k = 125 psi/in

- Drive, Perimeter Lanes
  - 5" concrete, 3500 psi min.
  - 4" to 6" agg. base

⇨ Up to 20 trucks/day
→ MR = 650 psi
→ k = 125 psi/in

- Truck Areas
  - 6-7" concrete, 3500 psi min.
  - 4" to 8" agg. base

⇨ 100 to 700 trucks/day
→ MR = 650 psi
→ k = 125 psi/in

* NOTE: "Truck" = any heavy vehicle, i.e. delivery trucks, buses, etc.

Design Examples

Industrial Facility– using pavementdesigner.org

Industrial Example

Log Storage / Sorting Yard: Front Loader (CAT 986H)

Concrete

Agg. base

Subgrade modulus = 3500 psi

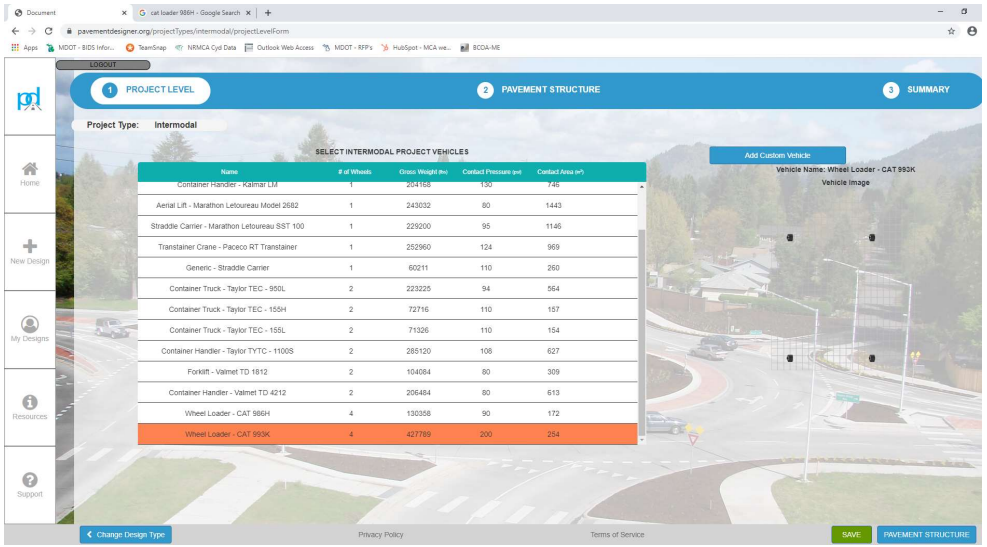
Other design inputs & decisions: Agg. Base Thickness; Concrete Strength & Elasticity

Industrial Example – Design Inputs

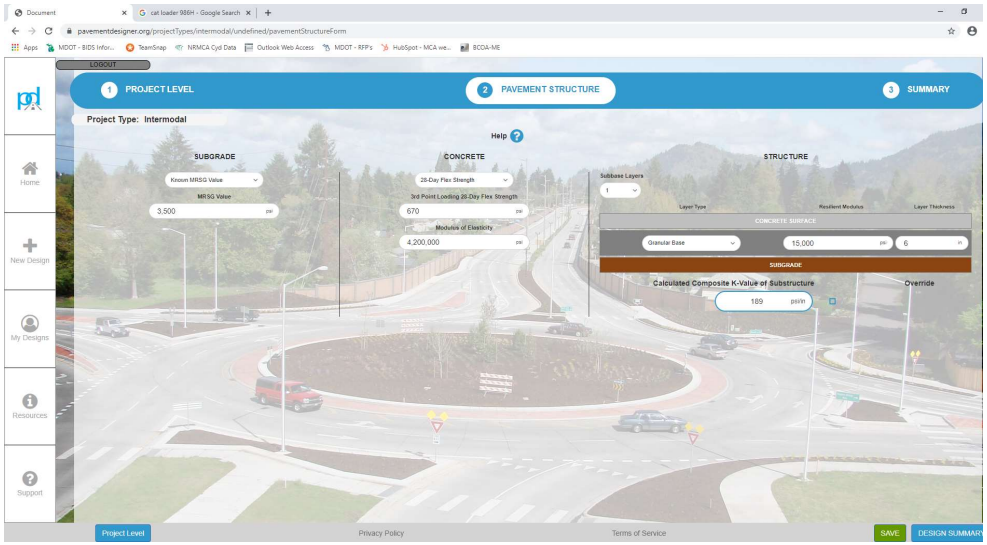
- 4 wheels; 130,000 lbs GVW; 90 psi tire pressure
- 670 psi flexural strength; 4,200,000 psi elastic modulus
- k-value = 189 psi/in; (3500 psi subgrade modulus w/ 6" agg. base)

Industrial Example – pavementdesigner.org

Project-Level Inputs:

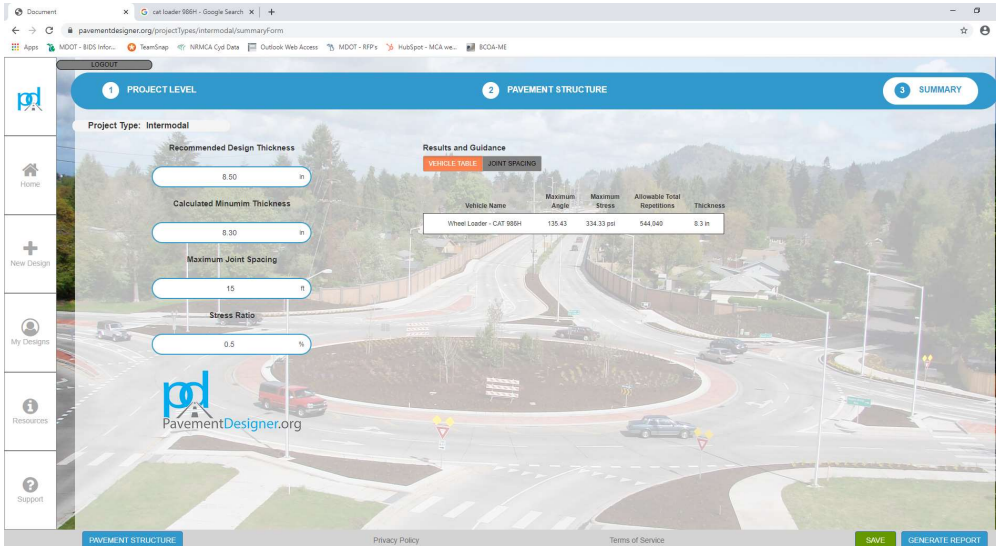


Pavement Structure:



Industrial Example – pavementdesigner.org

Summary:



Recommended Design:

- 8.5 inches of concrete
- 6" agg. base (21AA crushed conc.)
- 15 foot joint spacing

Design Examples

Truck Loading/Parking Area– using ACI 330.2R-17

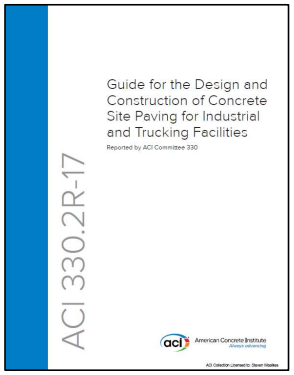
Truck Loading / Parking Area Example

Distribution Center; 250 trucks/day

Concrete

Agg. base

Subgrade modulus = 3500 psi



Other design inputs & decisions: Agg. Base Thickness; Concrete Strength

Thickness tables in ACI330.2R-17 based on 30-year design, 85% reliability, 15% slabs cracked

Truck Area Example – ACI 330.2R-17

Subgrade:

Table 3.3—Modulus of subgrade reaction, *k*, for typical subgrade soils (ACPA 2006)

Soil type	Support	Typical *k*-values, pci (MN/m³)
A. Fine grained with high amounts of silt/clay	Low	75 to 120 (20 to 34)
B. Sand and sand-gravel with moderate silt/clay	Medium	130 to 170 (35 to 49)
C. Sand and sand-gravel with little or no silt/clay	High	180 to 220 (50 to 60)

Base:

Table 3.4.3.1b—Composite *k*-values for unbound granular subbase on unstabilized subgrade (ACPA 2006)

Soil type*	Soil layer *k*-value, pci (MN/m³)	Thickness of unbound granular subbase			
		4 in. (100 mm)	6 in. (150 mm)	9 in. (225 mm)	12 in. (300 mm)
A	100 (27)	130 (35)	140 (38)	160 (43)	190 (52)
B	150 (41)	170 (48)	185 (50)	215 (58)	255 (69)
C	200 (54)	220 (60)	230 (62)	270 (73)	320 (87)

*Refer to Table 3.3.

Truck Area Example – ACI 330.2R-17

Table 4.7.3k—Thickness (*d*) and joint spacing (JS) for over-the-road truck category major arterial: with dowels in contraction joints; *k* = 150 pci (41 MN/m³)

No. of trucks per day design lane	Modulus of rupture, psi (MPa)					
	550 (3.8)		650 (4.5)		750 (5.2)	
	d, in. (mm)	Max. JS, ft (m)	*d*, in. (mm)	Max. JS, ft (m)	*d*, in. (mm)	Max. JS, ft (m)
100	8.0 (200)	15 (4.6)	7.0 (180)	14 (4.3)	6.5 (165)	13 (4.0)
200	8.0 (200)	15 (4.6)	7.5 (190)	15 (4.6)	7.0 (180)	14 (4.3)
500	8.5 (215)	15 (4.6)	7.5 (190)	15 (4.6)	7.0 (180)	14 (4.3)
1000	8.5 (215)	15 (4.6)	8.0 (200)	15 (4.6)	7.0 (180)	14 (4.3)

Recommended Design:

- 7.5 inches of concrete
- 6" agg. base (21AA crushed conc.)
- 15 foot joint spacing
- Doweled joints

Concrete Thickness Design Summary

- Highways: AASHTO 93 (WinPAS: www.acpa.org)
- Streets/Roads: www.pavementdesigner.org
- Parking Lots: ACI 330R (www.concrete.org)
- Industrial: www.pavementdesigner.org
- Trucking: ACI 330.2R (www.concrete.org)

or just contact Steve Waalkes swaalkes@miconcrete.net 616-633-9629

Questions?

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616-633-9629

ALSO, PLEASE SEND SUGGESTIONS
FOR ADDITIONAL CONCRETE WEBINAR TOPICS!

For the current webinar schedule:
https://info.miconcrete.org/lunch-and-learn