From design to practice

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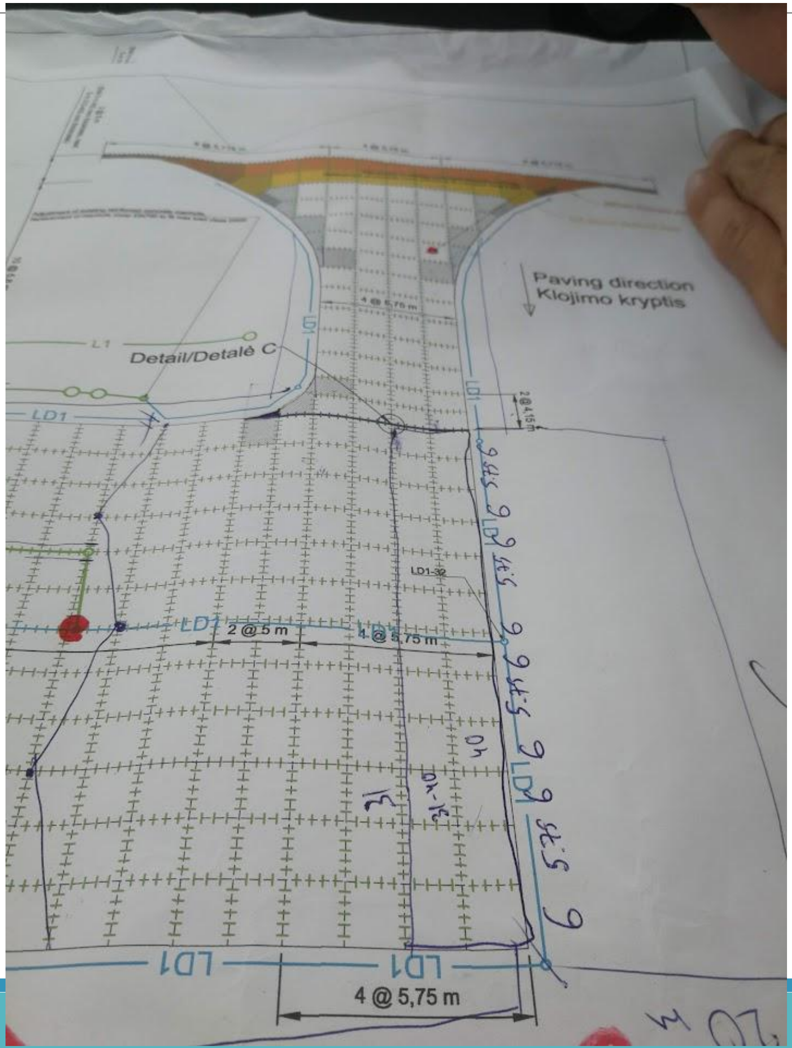
Dowels for a good load transfer but are they working as we think?



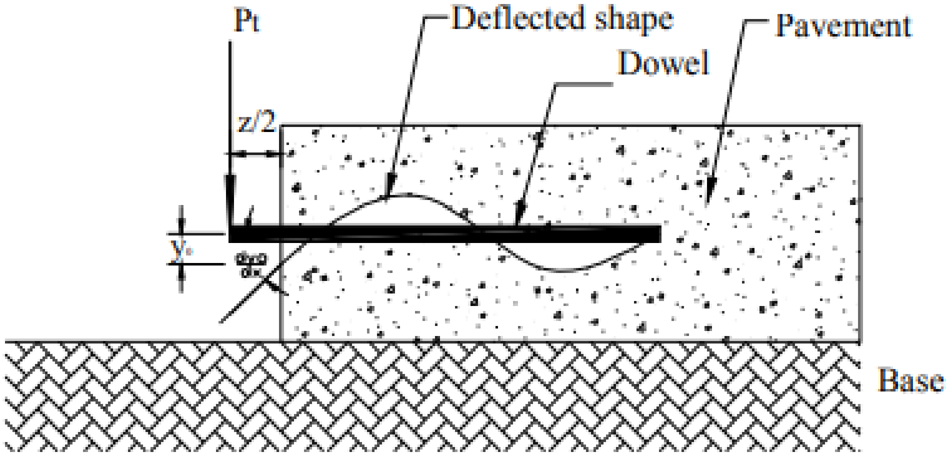


Figure 96. Diagram. Slope and deflection of dowel at joint face.

$$M_0 = \frac{-P_t z}{2} \quad (10)$$

$$\frac{dy_0}{dx} = \frac{-P_t}{2\beta^2 E_d I_d}(1 + \beta z) \quad (11)$$

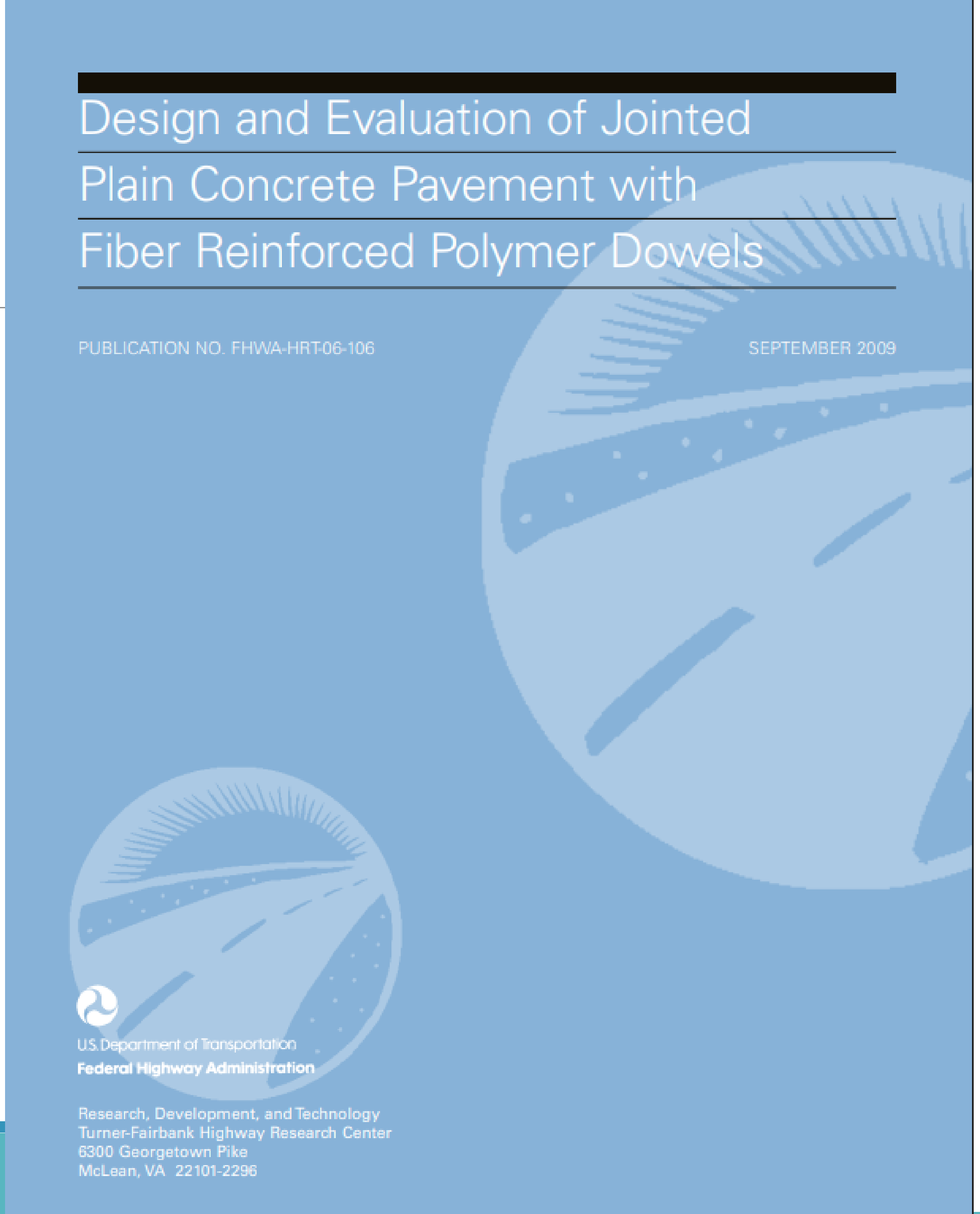
$$y_0 = \frac{P_t(2 + \beta z)}{4\beta^3 E_d I_d} \quad (12)$$

Where:

β = Relative stiffness of the dowel bar encased in concrete (cm^{-1} (inch^{-1})).
K_0 = Modulus of dowel support (kg/cm^3 (pci)).
E_d = Modulus of elasticity of the dowel bar (MPa (psi)).
I_d = Moment of inertia of the dowel bar (cm^4 (inch^4)).
P_t = Load transferred through the dowel (metric ton (lb)).
d = Diameter of dowel bar (cm (inch)).
z = Joint width (cm (inch)).

$$\beta = \sqrt[4]{\frac{k}{4EI}}$$

$$\beta = \sqrt[4]{\frac{K_0 d}{4E_d I_d}}$$


Design and Evaluation of Jointed Plain Concrete Pavement with Fiber Reinforced Polymer Dowels

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Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Active dowels – radius of relative stiffness

$$l_r = \sqrt[4]{\frac{E_c h^3}{12(1-\nu^2)k}}$$

Where:

E_c = Modulus of elasticity of the pavement concrete (MPa (psi)).

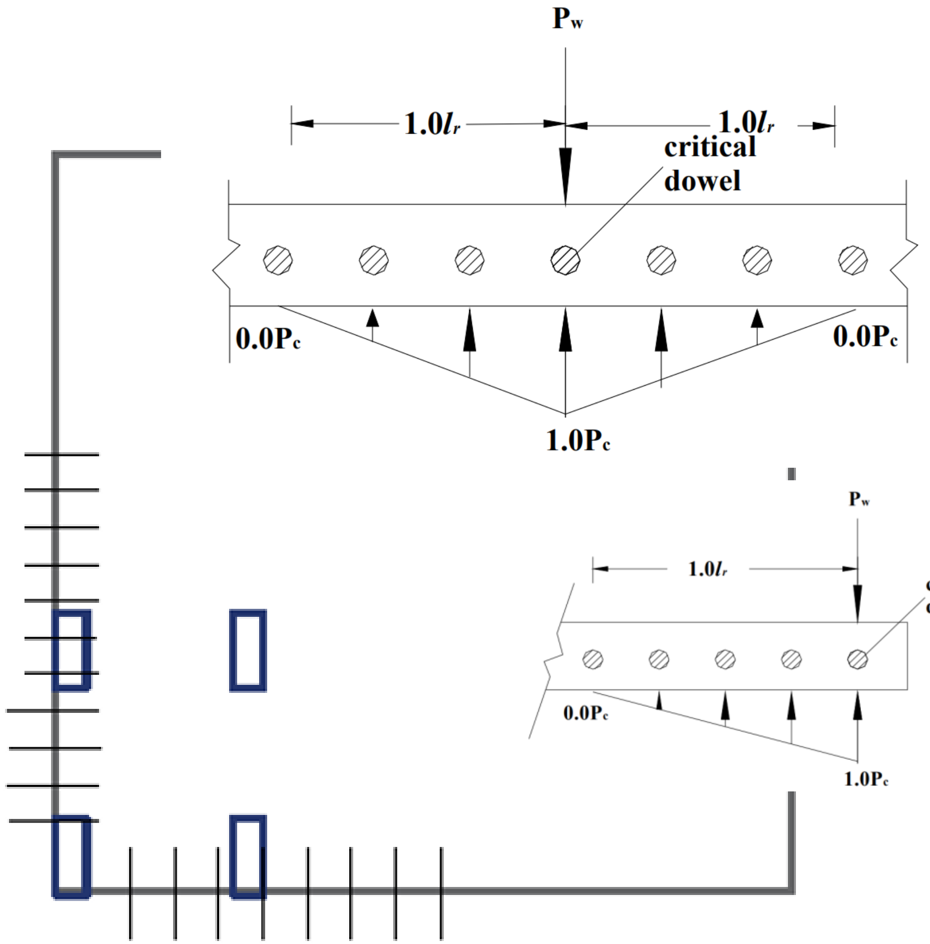
E_c = $57{,}000(f_c')^{0.5}$.

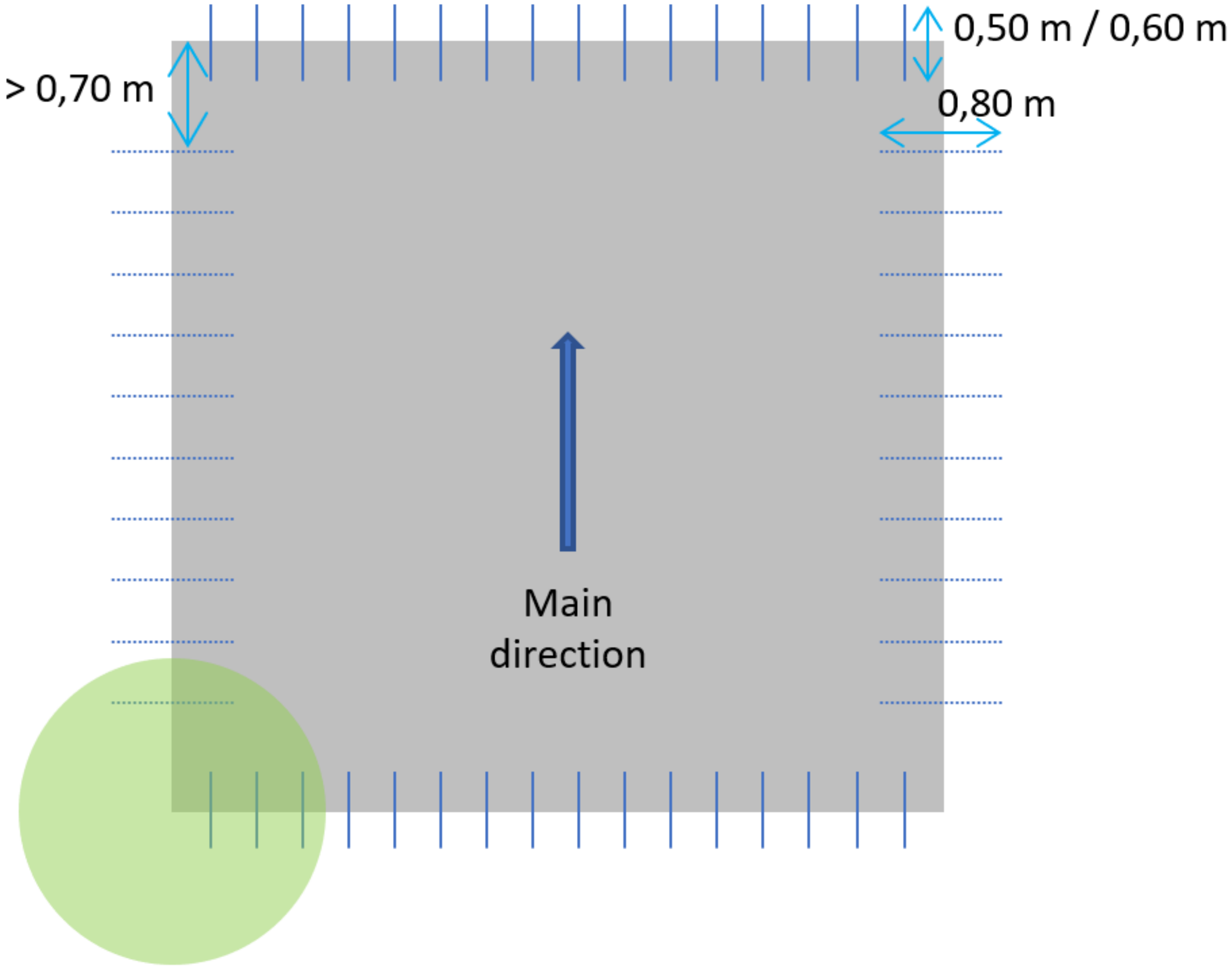
h = Pavement thickness (cm (inch)).

ν = Poisson's ratio for the pavement concrete.

k = Modulus of subgrade reaction (g/cm^3 (pci)).

$$P_c = \frac{P_t}{\text{number of effective dowels}}$$





Dowels work together

Dowel Bar Deflection

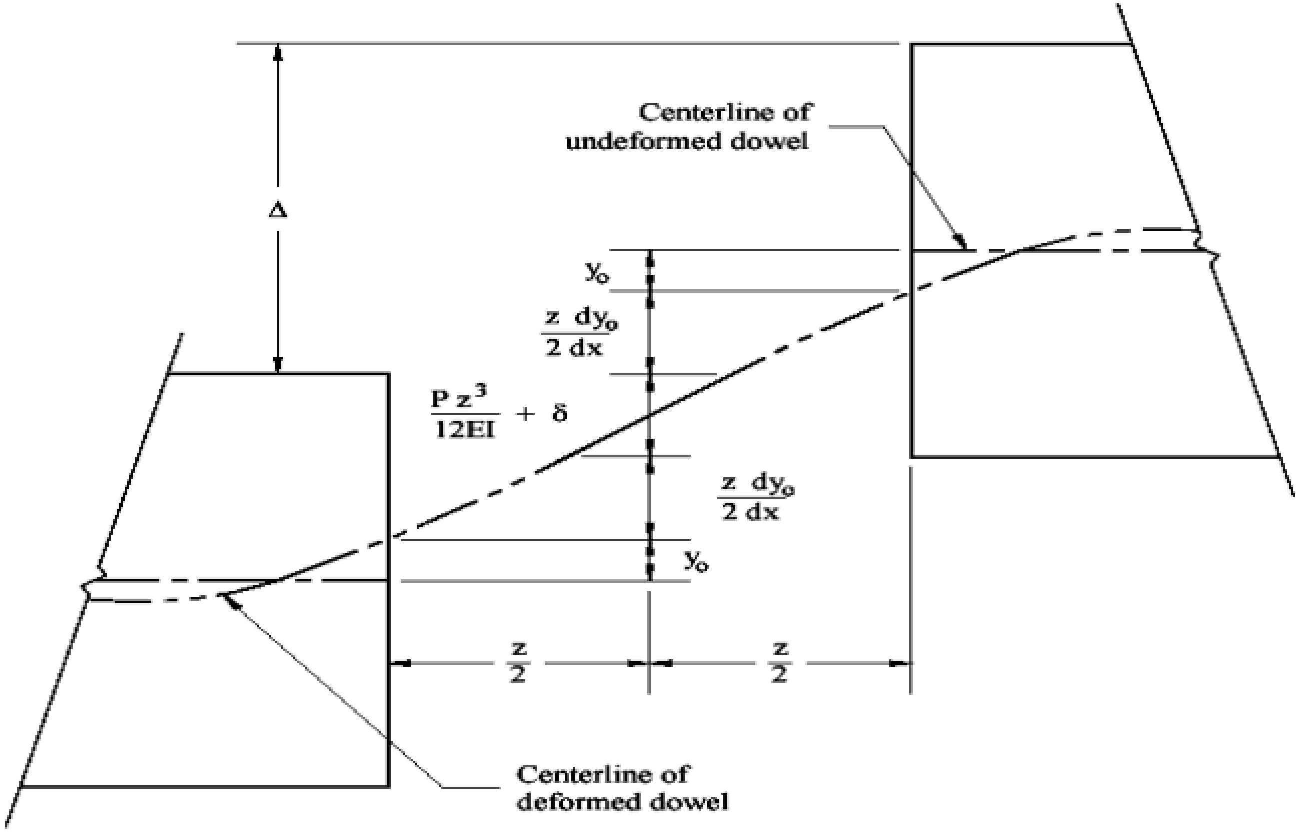


Figure 100. Diagram. RD between concrete slabs (Porter and Guinn).[19]

$$\Delta = 2y_0 + z\left(\frac{dy_0}{dx}\right) + \delta + \frac{Pz^3}{12EI}$$

Where:

y_0 = Dowel deflection (from equation 12).

$z\left(\frac{dy_0}{dx}\right)$ = Deflection due to the slope of dowel

$$\delta = \frac{\lambda P_t z}{AG}$$

Where:

λ = Form factor, equal to 10/9 for solid circular section.

A = Cross-sectional area of the dowel bar.

G = Shear modulus.

P_t = Load transferred by critical dowel.

z = Joint width.

$\frac{Pz^3}{12\,EI}$ = Flexural deflection.

Bearing stress between dowel/concrete interfaces

$$\sigma_b = K y_0 = K P_c \frac{2+\beta z}{4\beta^3 E_d I_d}$$

$$f_b = \frac{(4-d) f_c'}{3}$$

Where:
f_b = Allowable bearing stress (MPa (psi)).
d = Dowel diameter (cm (inch)).
f_c' = Ultimate compressive strength of concrete slab (MPa (psi)).

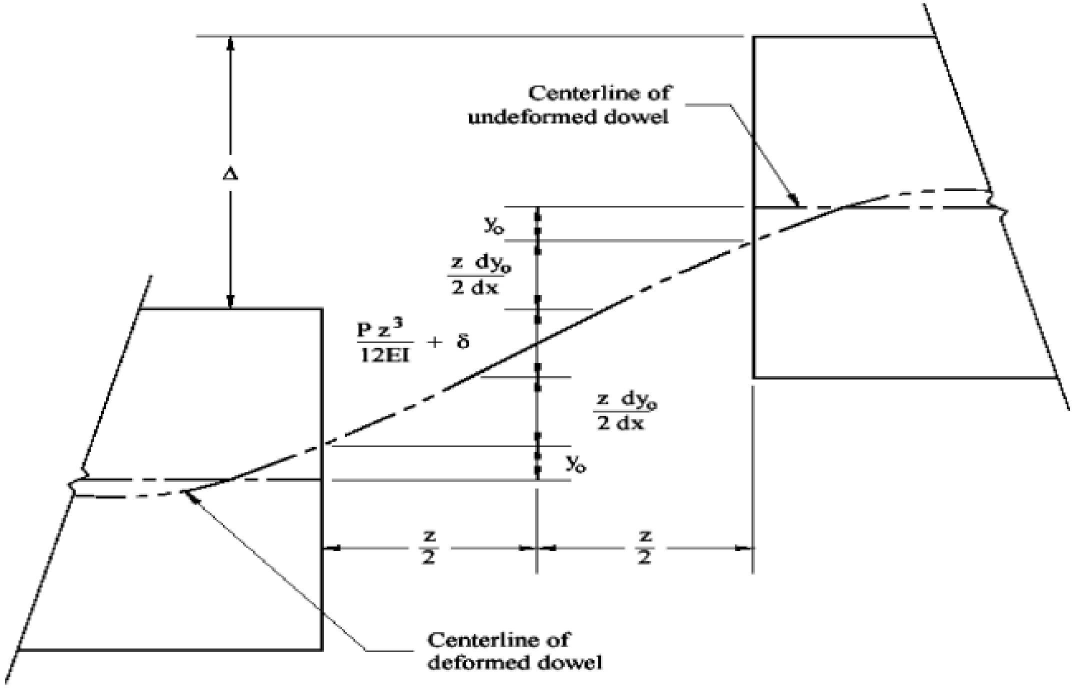


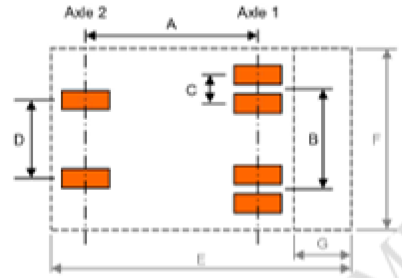
Figure 100. Diagram. RD between concrete slabs (Porter and Guinn).[19]

Industrial pavement with reach stackers

Case		1	2	3	4	5
Material		Steel	Steel	GFR	GFR	GFR
Diameter	mm	35	35	35	35	40
Distance, h.o.h	mm	300	250	250	200	250
E-mod	GPa	210	210	50	50	50
G-mod	GPa	80	80	33,8	33,8	33,8
Load transfer		45%				
Thickness concrete pavement	mm	325				
Max. force	kN	262				
Max. shear stress	MPa	41.0	33.6	33.6	41.0	25.7
% of admitted shear stress	%	22%	18%	17%	21%	13%
Max. vertical movement	mm	0.252	0.206	0.303	0.166	0.238
Max. concrete stress	MPa	51,8	42,5	61.9	34,2	48,7
% of max. concrete strength	%	99%	81%	118%	65%	100%

	Parameter	Units	Value
General Info	Safe Working Load	t	46
	Machine Self Weight	t	85
Geometry	A – Wheelbase	m	7.5
	B – Spacing of Front Wheels c/c	m	3.7
	C – Width between Wheels c/c (Front)	m	0.6
	D – Spacing of Rear Wheels c/c	m	3.1
	E – Overall Length	m	10.1
	F – Overall Width	m	6.1
	G – Spreader Width	m	2.5
	No. of Axles	-	2
	Wheels Per Axle 1 (Front)	-	4
	Wheels Per Axle 2 (Rear)	-	2
Wheel Loads and Information	Unladen Load Per Axle 1 (Front)	kN	420
	Unladen Load Per Axle 2 (Rear)	kN	450
	Maximum Operational Laden Load Per Axle 1 (Front)	kN	1050
	Maximum Operational Laden Load Per Axle 2 (Rear)	kN	280
	Tyre Pressure	kPa	1,100

Geometry



Dowels in the Flemisch standard specifications (SB 250)

13.11 Glasvezelversterkte kunststofproducten voor voegen in cementbetonverhardingen

13.11.1 Deuvels

Glasvezelversterkte kunststofdeuvels zorgen voor de lastoverdracht ter plaatse van dwarsvoegen.

Het zijn rechte gladde staven, vrij van bramen en andere oneffenheden. Ter hoogte van de eindvlakken zijn er geen uitsteeksels buiten de nominale diameter van de staaf. Ze dienen bestand te zijn tegen corrosie en tegen een sterk alkalische omgeving.

De nominale diameter is 25 mm of 30 mm en de nominale lengte is 500 mm of 600 mm.

De glasvezelversterkte kunststofdeuvels voldoen aan volgende eisen:

- E-modulus ≥ 45 GPa;
- afschuifsterkte volgens ASTM D7617/D7617M-11 ≥ 150 MPa.

13.11.2 Ankerstaven

Glasvezelversterkte kunststofankerstaven zijn geribde staven die zorgen voor de verbinding ter plaatse van langsvoegen. Ze dienen bestand te zijn tegen corrosie en tegen een sterk alkalische omgeving.

De nominale diameter is 16 mm en de nominale lengte is 600 mm, 800 mm of 1000 mm.

De glasvezelversterkte kunststofankerstaven voldoen aan volgende eisen:

- E-modulus ≥ 45 GPa;
- afschuifsterkte volgens ASTM D7617/D7617M-11 ≥ 150 MPa.

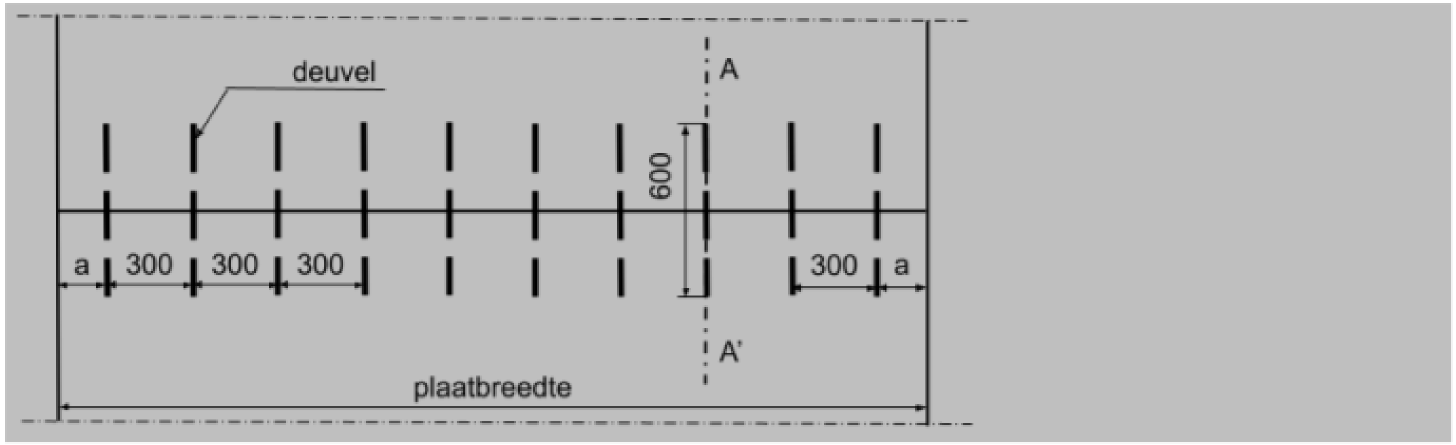
13.11.3 Steunen

Glasvezelversterkte kunststofsteunen zijn vervaardigd uit gladde glasvezelversterkte kunststofwapening. Ze dienen bestand te zijn tegen corrosie en tegen een sterk alkalische omgeving. Iedere steun moet zonder zichtbare vervorming weerstaan aan een puntbelasting van 250 kg.

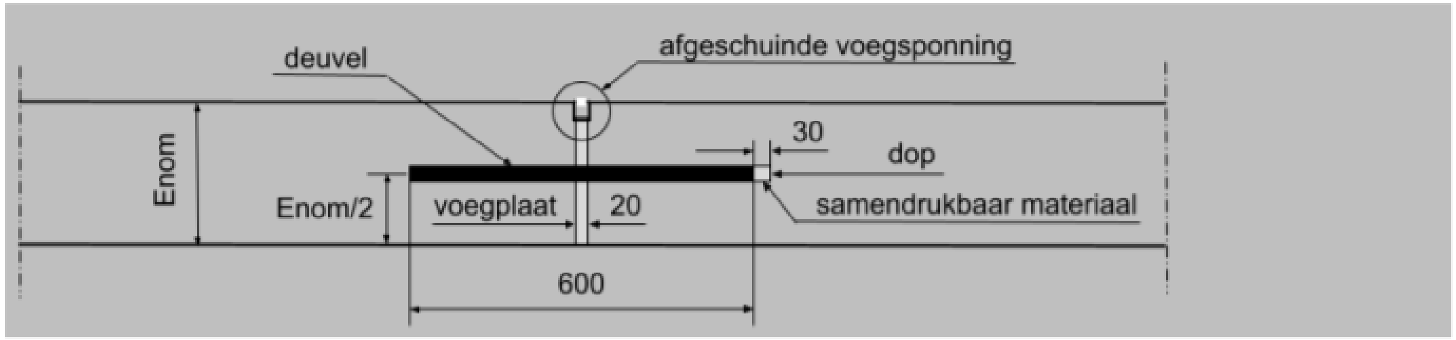
De glasvezelversterkte kunststofsteunen voldoen aan volgende eisen:

- E-modulus ≥ 45 GPa;
- afschuifsterkte volgens ASTM D7617/D7617M-11 ≥ 150 MPa.

Diameter dowels in relation to the type of material



Figuur 6-1.3-2: bovenaanzicht dwarse uitzettingsvoeg (alle maten in mm), 150 ≤ a < 300



Figuur 6-1.3-3: dwarse uitzettingsvoeg, doorsnede A – A' (alle maten in mm)

Diameter 25 mm for steel dowels

Diameter 30 mm for GFR for heavy loaded pavements (B1 to B5)

Diameter 25 mm for GFR for other type of roads

Case 1: positioning of the dowels

20 cm doweled JPCP

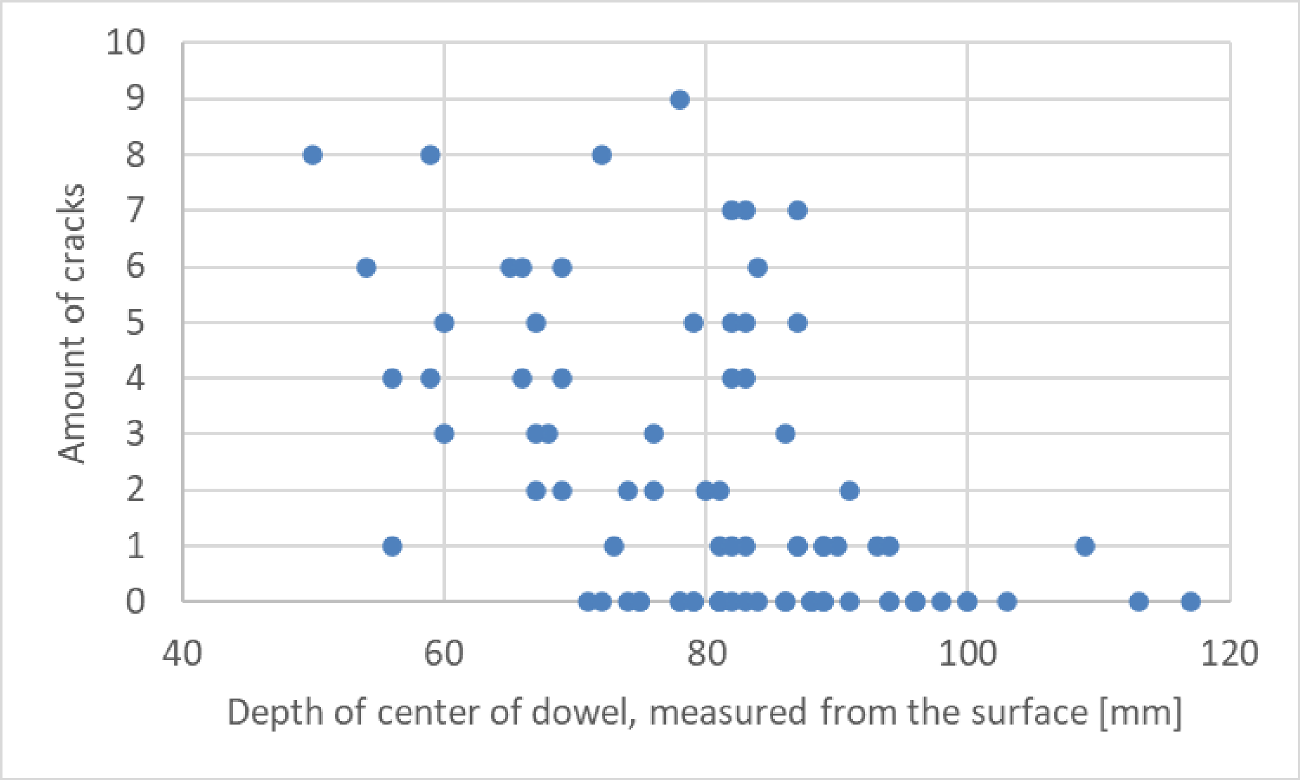
5 cm asphalt interlayer

20 cm lean concrete

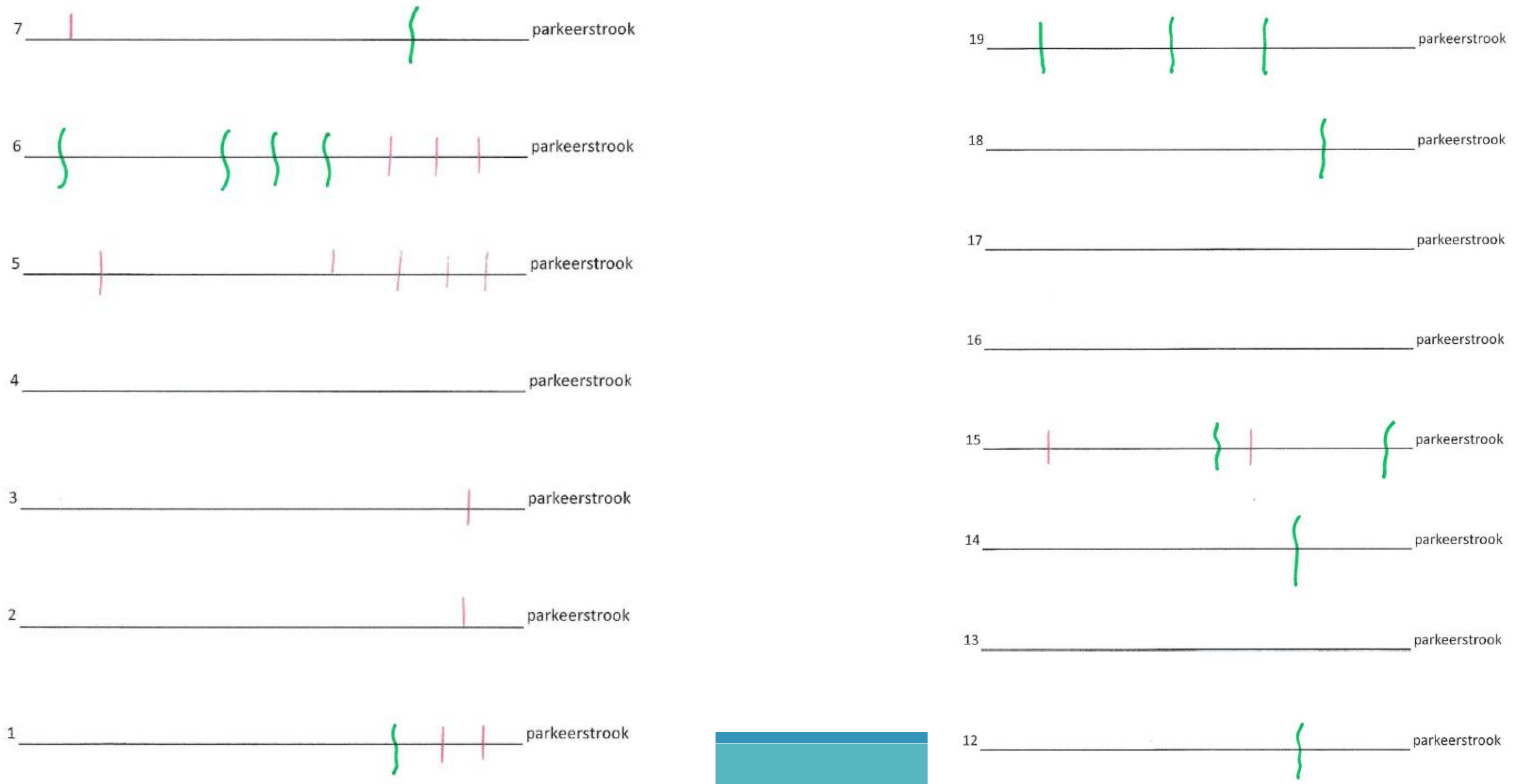
Placement of the concrete:

13-14 March 2017

Relation between cracks and coverage

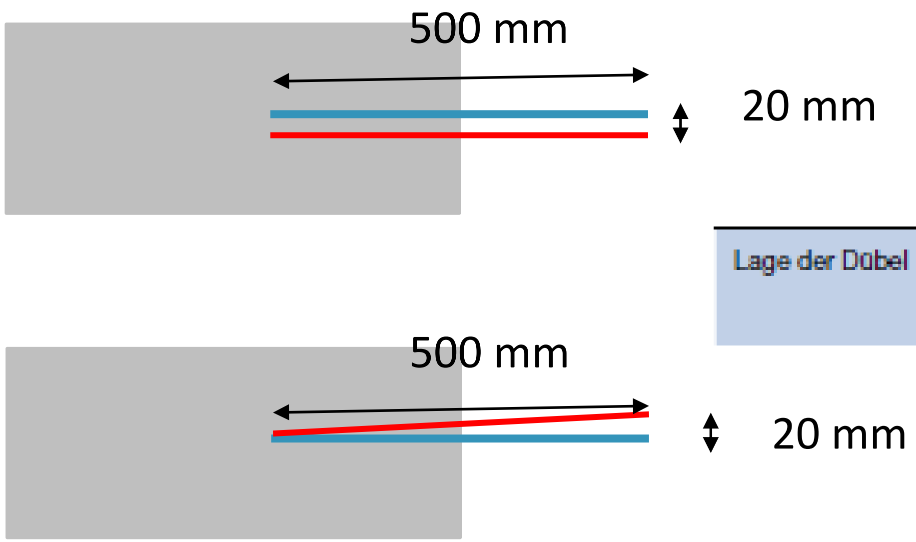


Cracks after 7 (red) and 14 (green) months

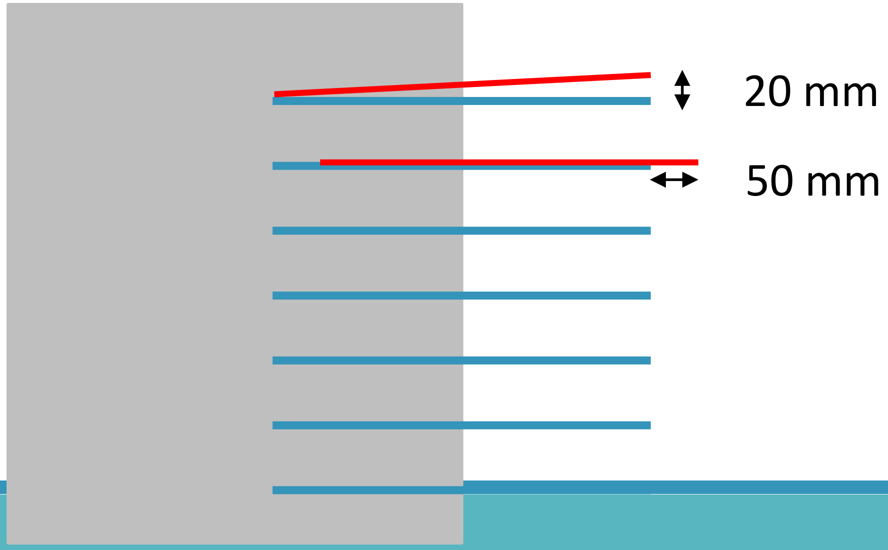


Positioning of dowels!

Section view



Plan view



ZTV Beton - StB

Lage der Dübel	SV, I – III	Schräglage ≤ 20 mm bezogen auf Dübellänge von 500 mm Abweichung von der Höhenlage in Dübelmitte ≤ 20 mm Verschiebung senkrecht zur Fuge ≤ 50 mm

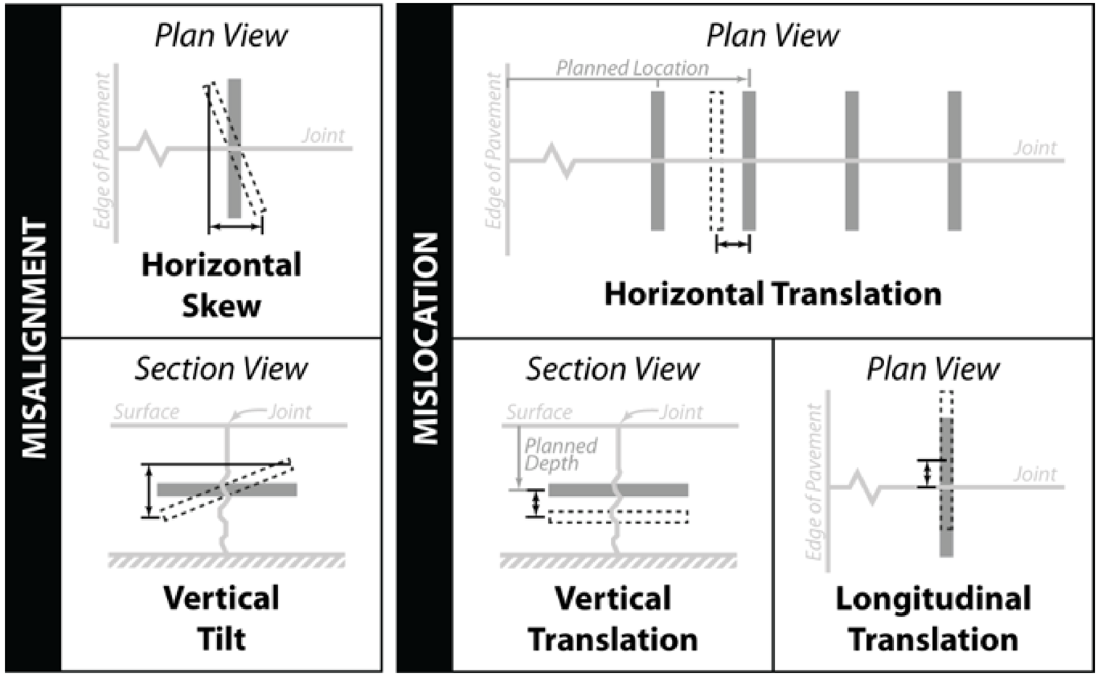
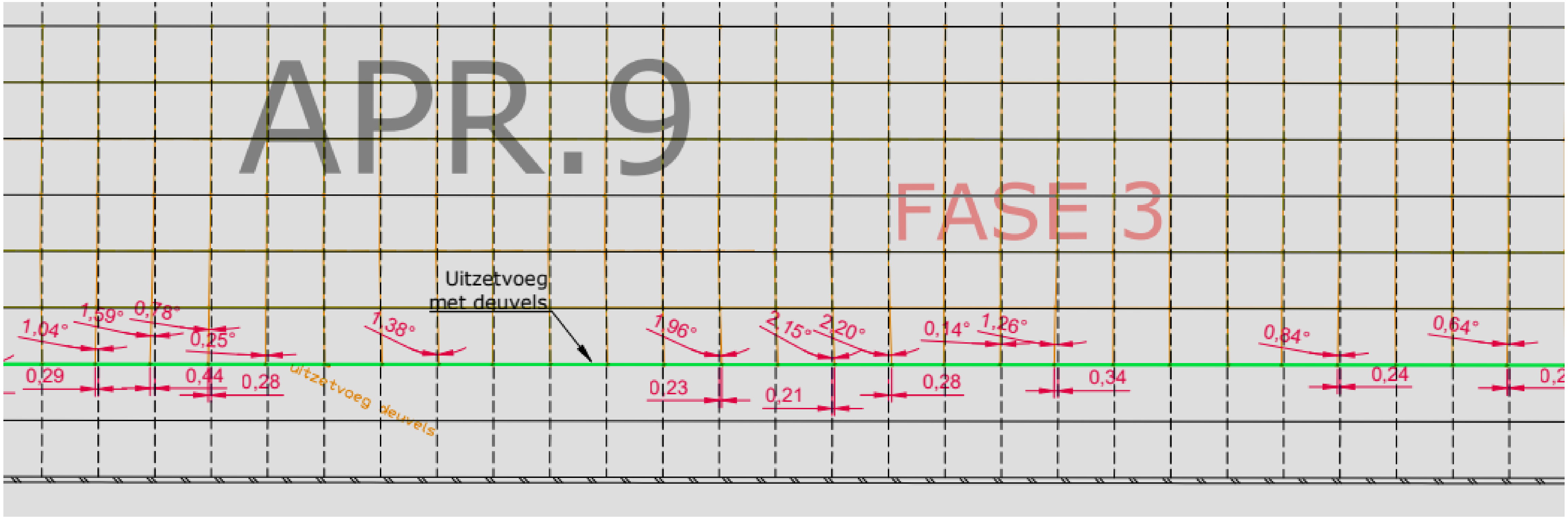


Figure 1 - The five types of dowel bar misalignment and mislocation (after FHWA 2007)



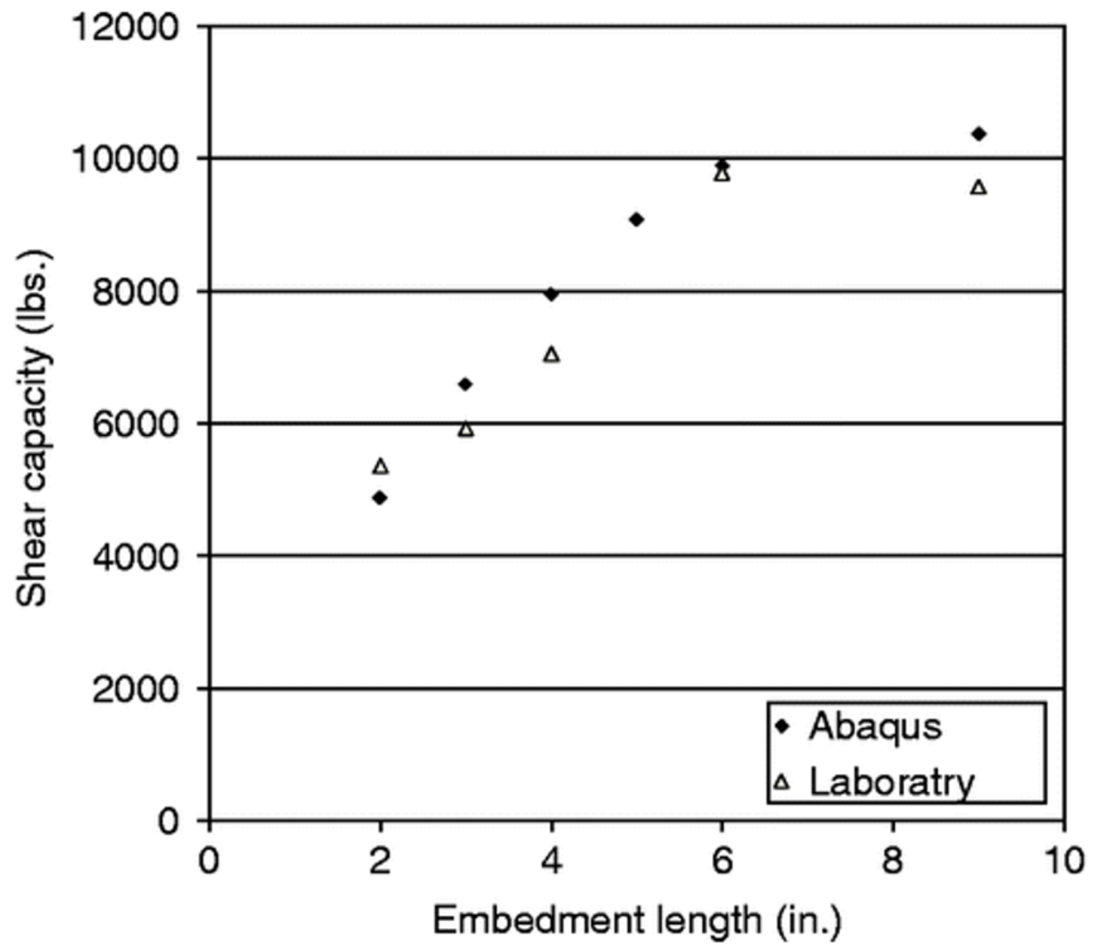
Case 2: misalignement of the joint

Diameter dowels 30 mm – length 600 mm – interdistance 300 mm
Concrete thickness 400 mm

Joint	Misalignement [mm]	Min. length dowel over joint (first dowel at 150 mm from edge, then 300 mm) [mm]							Amount of active dowels
		1	2	3	4	5	6	7	
1	0,09	213	218	224	229	234	240	245	7
3	0,29	19	36	54	71	88	106	123	2
4	0,44	0	0	0	0	0	5	32	0
5	0,28	28	45	62	79	96	112	129	2
6	0,25	58	73	88	103	118	133	148	4
14	0,23	77	91	105	118	132	146	160	5
16	0,21	96	109	122	134	147	159	172	6
17	0,28	28	45	62	79	96	112	129	2
20	0,34	0	0	11	31	52	72	93	0
25	0,24	67	82	96	110	125	139	154	4
28	0,22	87	100	113	126	139	153	166	6

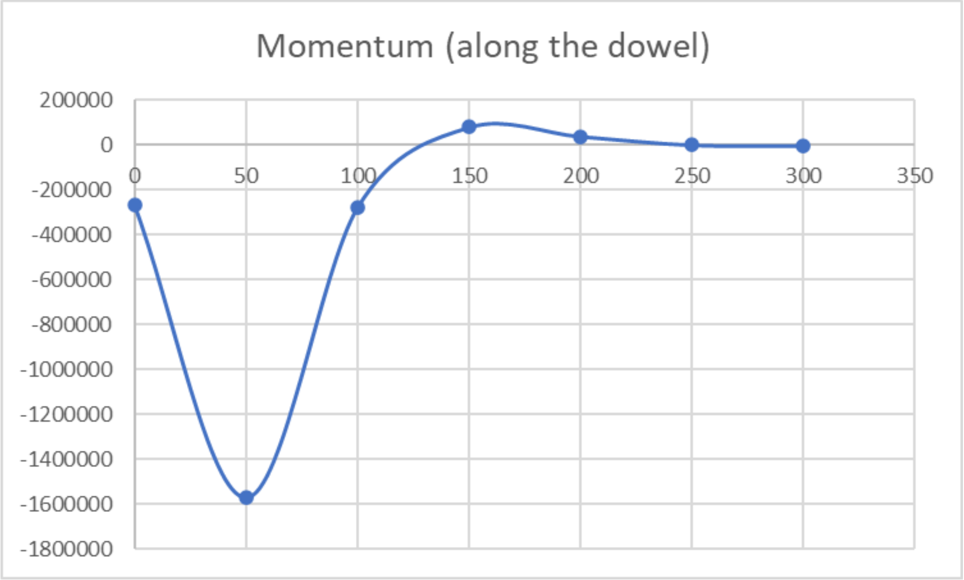
Max. hor. displacement: 200 mm

Influence of length on load transfer



2 dowels were sufficient for the load transfer

But concrete bearing stress will increase significantly



10 inch = 25,4 cm

Conclusions

Dowels work together!

Steel dowels are the reference, but do we really need that high load transfer? Corrosion is main factor of misfunctioning of dowels

Alignment is crucial

Diameter and interdistance become important for heavy duty pavements