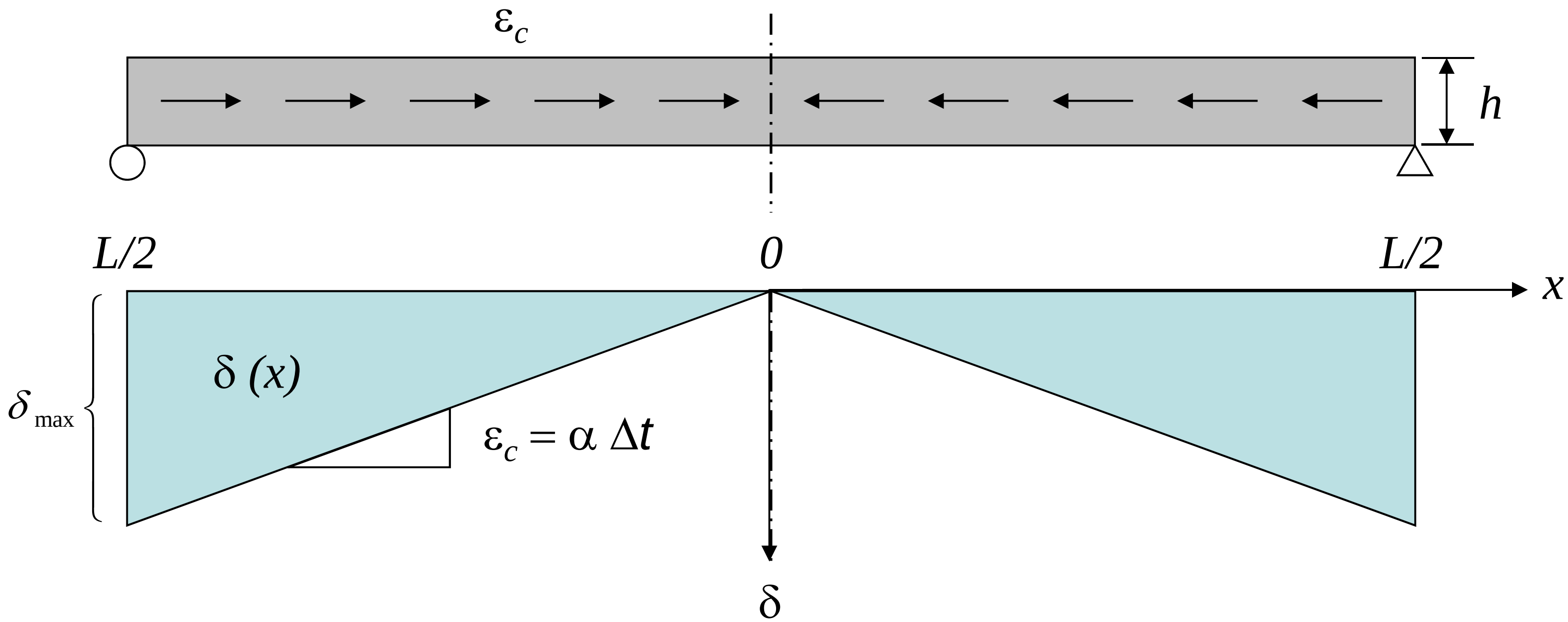
Rigid Pavement Mechanics

Friction Stresses

Unrestrained Slab



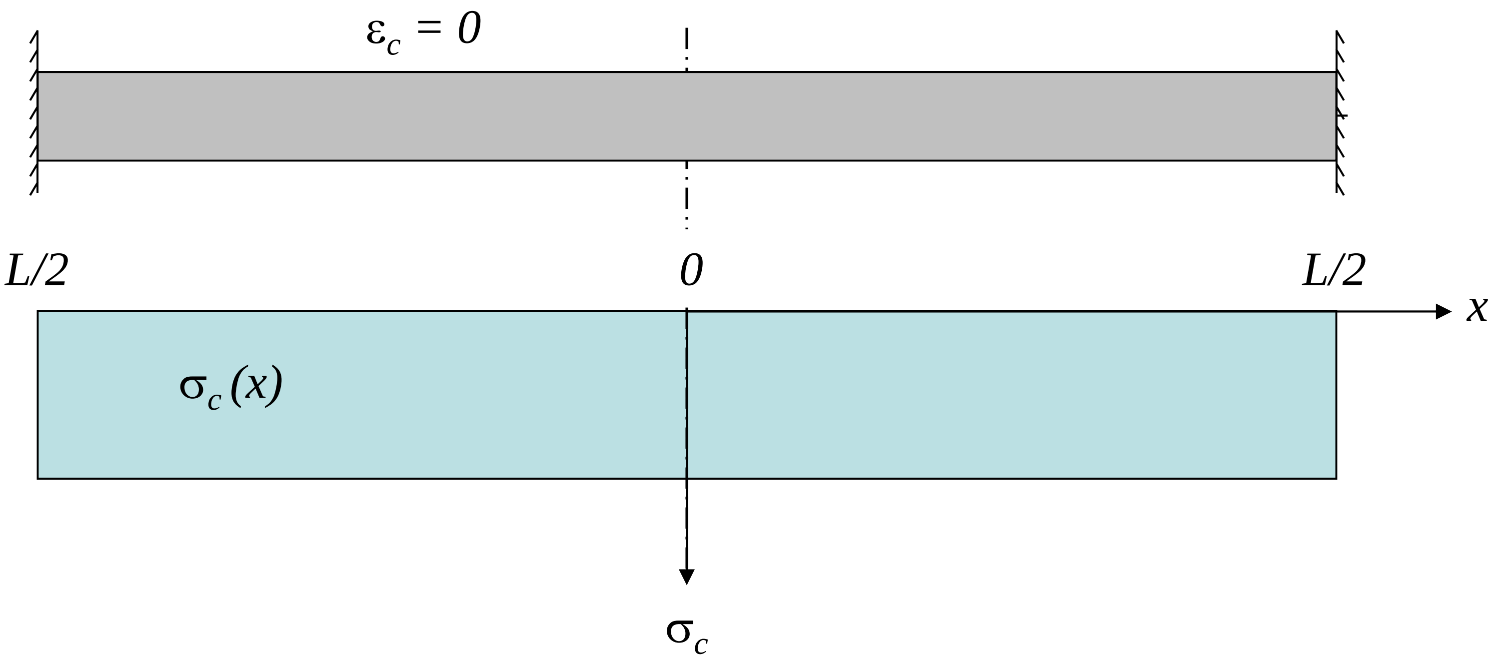
$$\delta_{\max} = \alpha \frac{L}{2} \Delta t$$

Coefficient of Thermal Expansion

Aggregate Type	Coefficient (10^{-6} in/in/^{o}F)
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

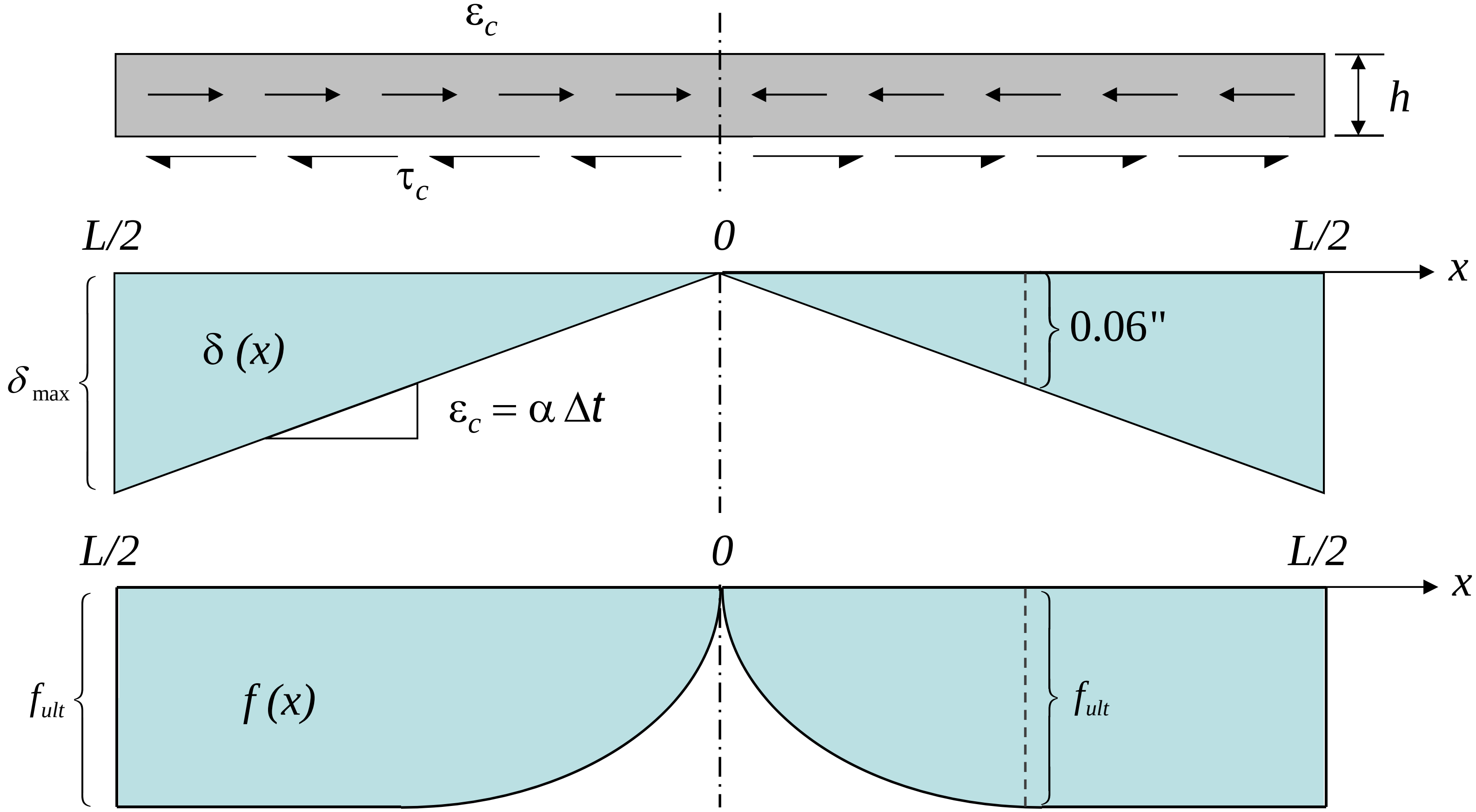
Average 5.5

Fully Restrained Slab



$$\sigma_c = E_c \varepsilon_c = E_c \alpha \Delta t$$

Partially Restrained Slab

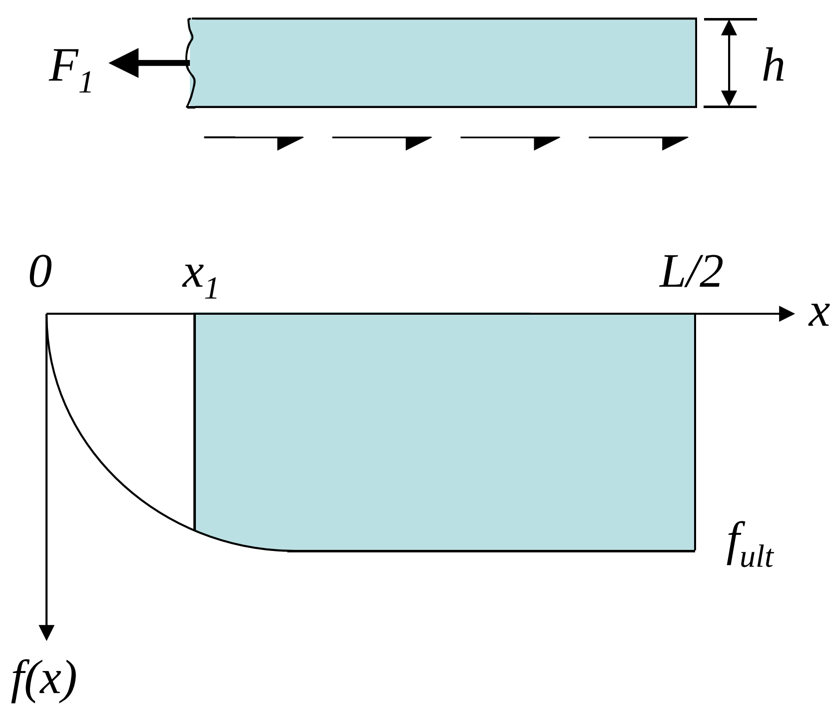


Friction Stresses

$$\left.\begin{aligned} \tau(x) &= \sigma(x)\, f(x) \\ \\ \sigma(x) &= \gamma_c h = \text{const} \end{aligned}\right\} \tau(x) = \gamma_c h\, f(x)$$

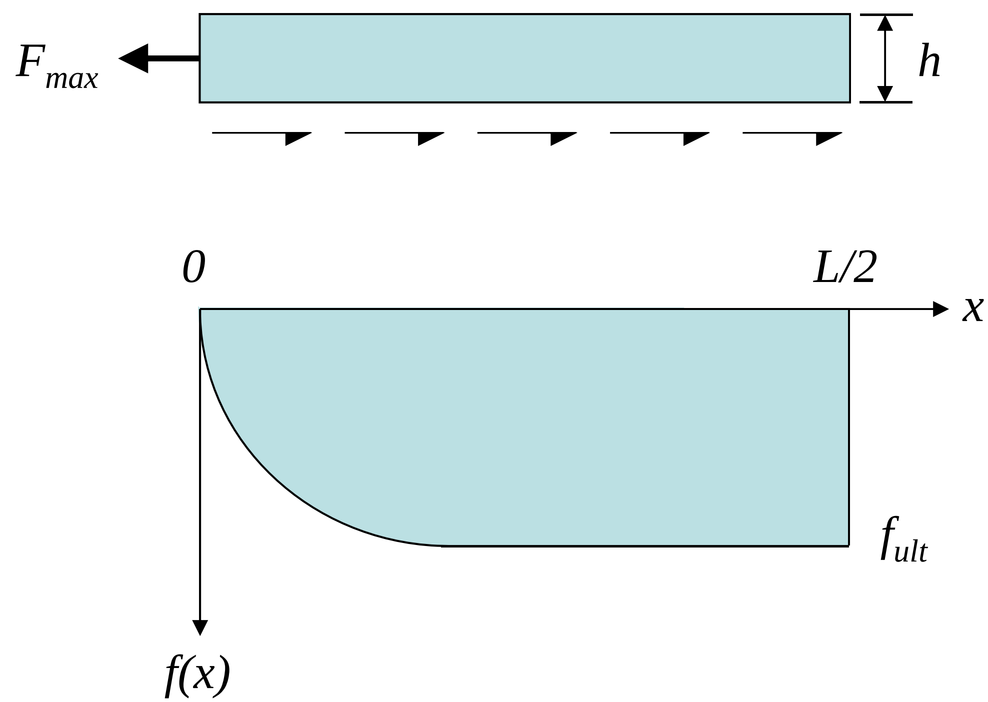
Friction Stresses

$$F_1 = \gamma_c h \int_{x_1}^{L/2} f(x)\,dx$$



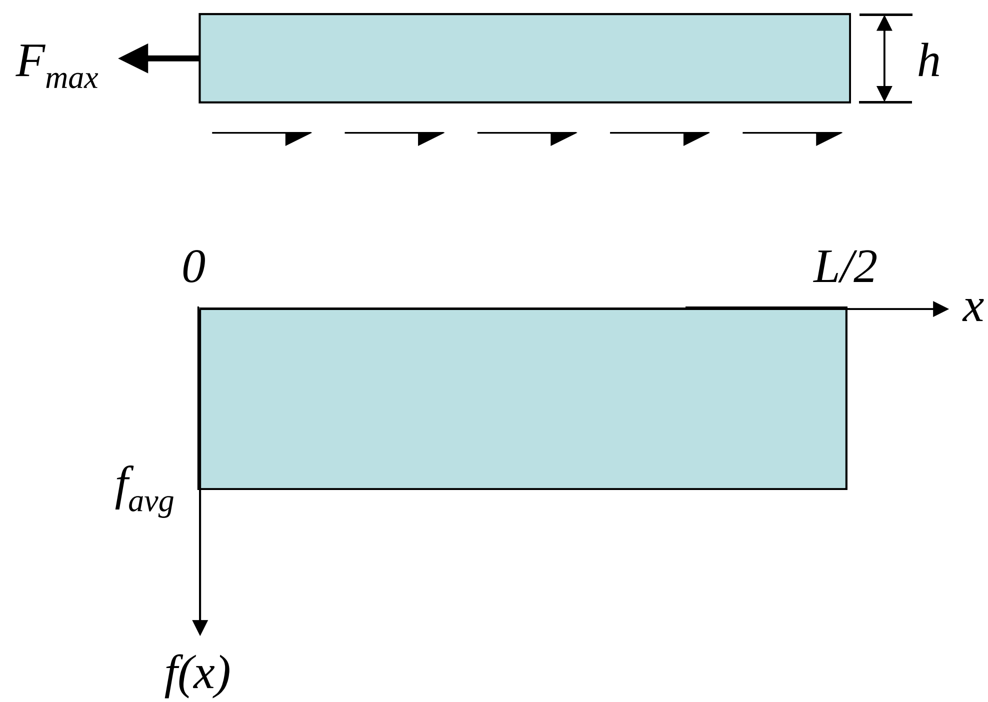
Friction Stresses

$$F_{\max} = \gamma_c h \int_0^{L/2} f(x)\,dx$$



Friction Stresses

$$F_{\max} = \gamma_c h \frac{L}{2} f_{avg}$$

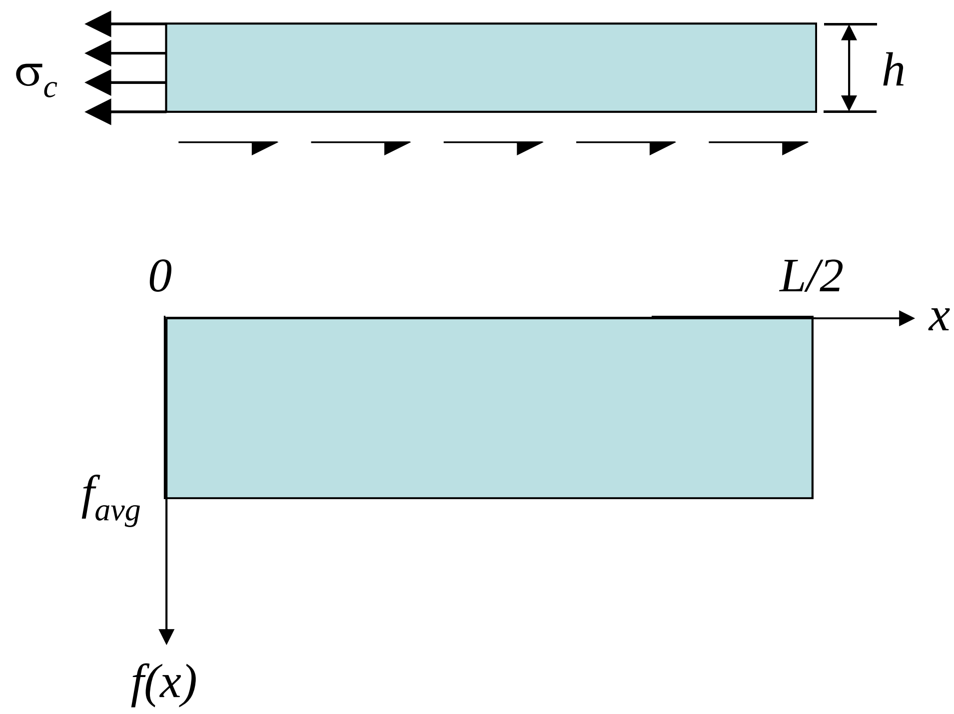


Friction Coefficient

Type of Material Beneath Slab	f_{avg}
Lime stabilized soil	1.8
Asphalt stabilized soil	1.8
Cement stabilized soil	1.8
River gravel	1.5 (standard)
Crushed stone	1.5 (standard)
Sandstone	1.2
Natural subgrade	0.9

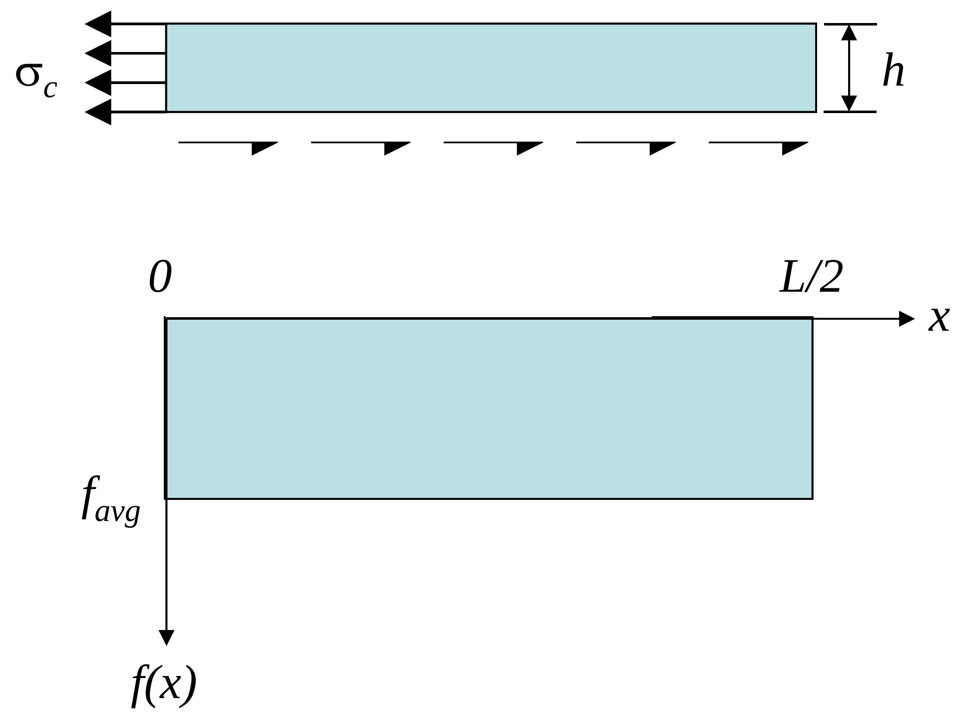
Friction Stresses

$$\sigma_c h = \gamma_c h \frac{L}{2} f_{avg}$$



Friction Stresses

$$\sigma_c = \gamma_c \frac{L}{2} f_{avg}$$



Example

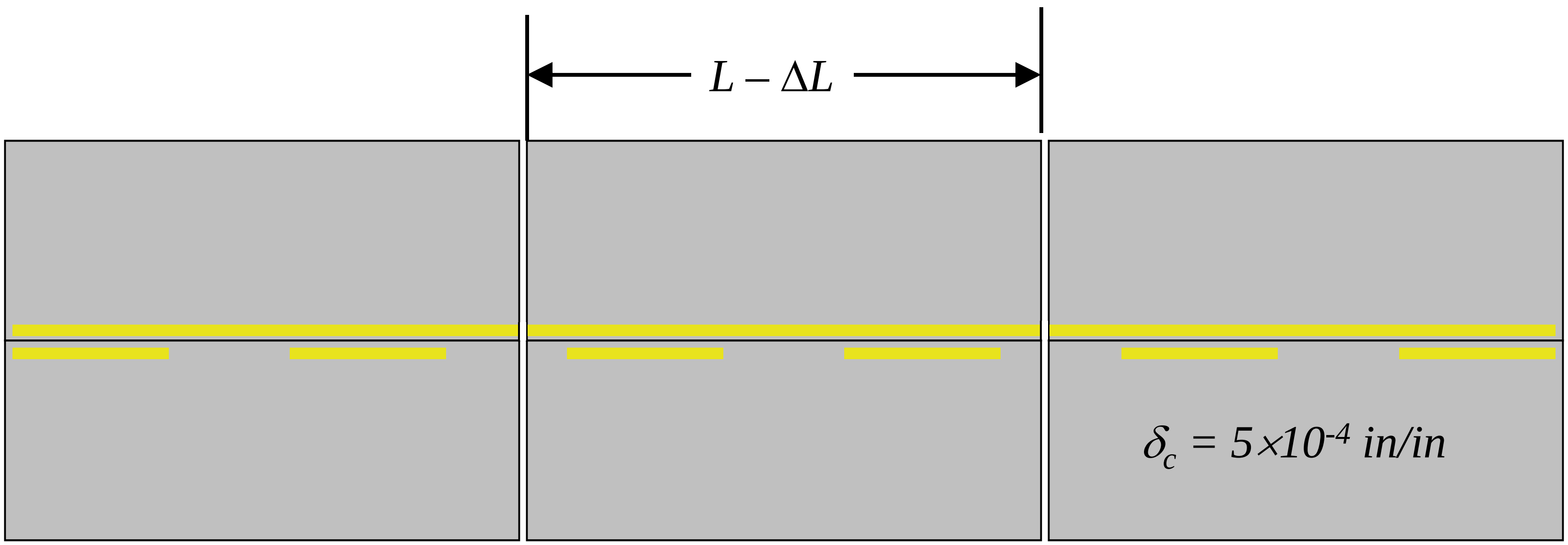
Calculate the longitudinal tensile stress that will develop in a concrete slab 50′ long due to a drop in temperature.

Slab Length & Joint Opening

Aggregate Interlock

Source: WSDOT Pavement Guide Interactive CD-ROM

Joint Opening



$$\Delta L = L\left(\alpha_c \Delta t + \delta_c\right)$$

Unrestrained Slab

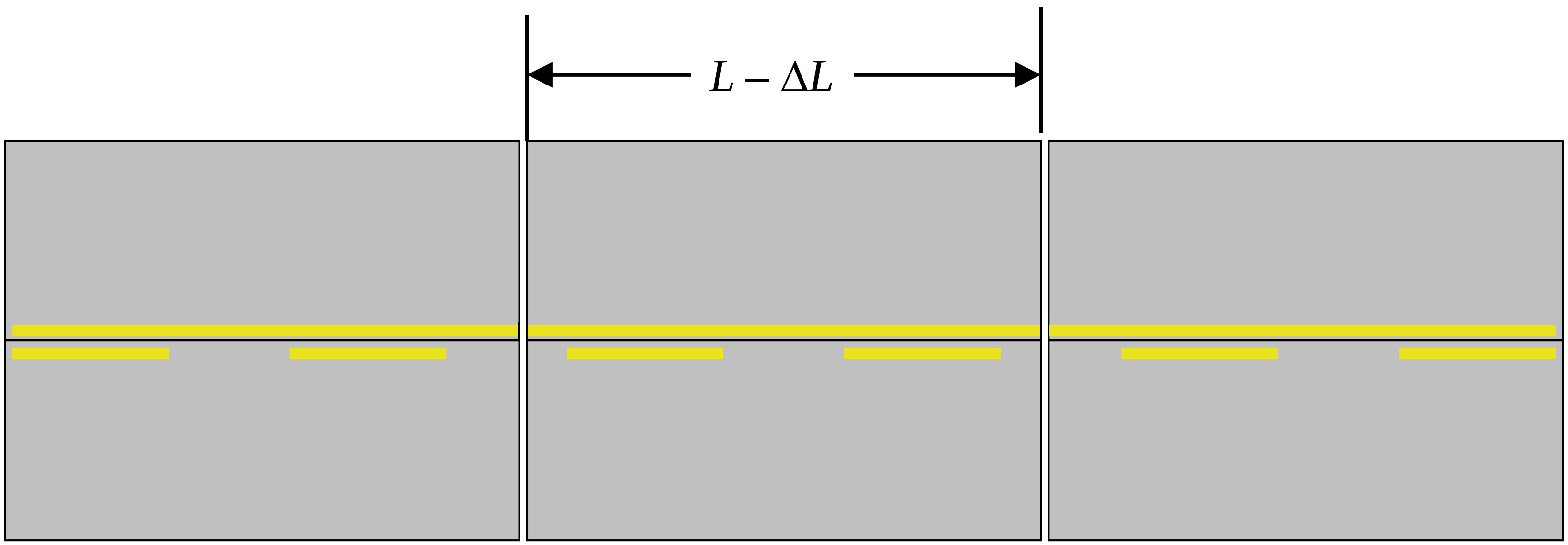
Shrinkage Strain

AASHTO Pavement Design Guide

Tensile Strength (psi)	Shrinkage Strain (in/in)
300 or less	0.0008
400	0.0006
500	0.00045
600	0.0003
700 or more	0.0002

Average 0.0005

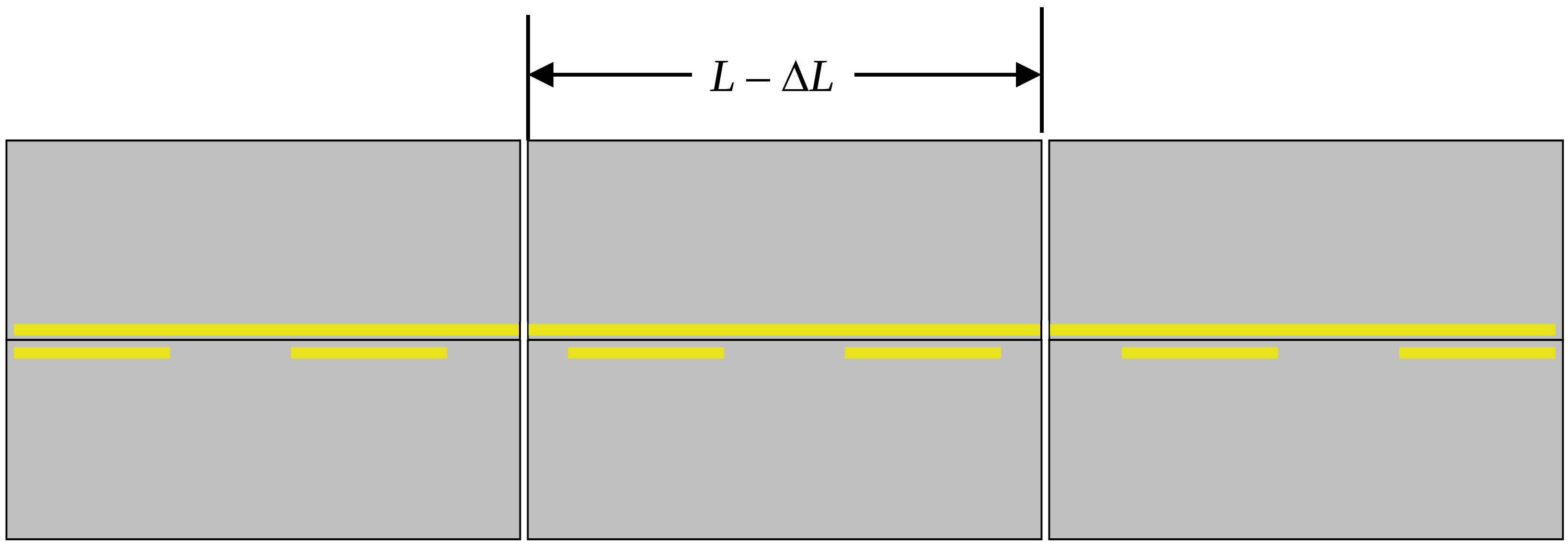
Joint Opening



$$\Delta L = CL\left(\alpha_c \Delta t + \delta_c\right)$$

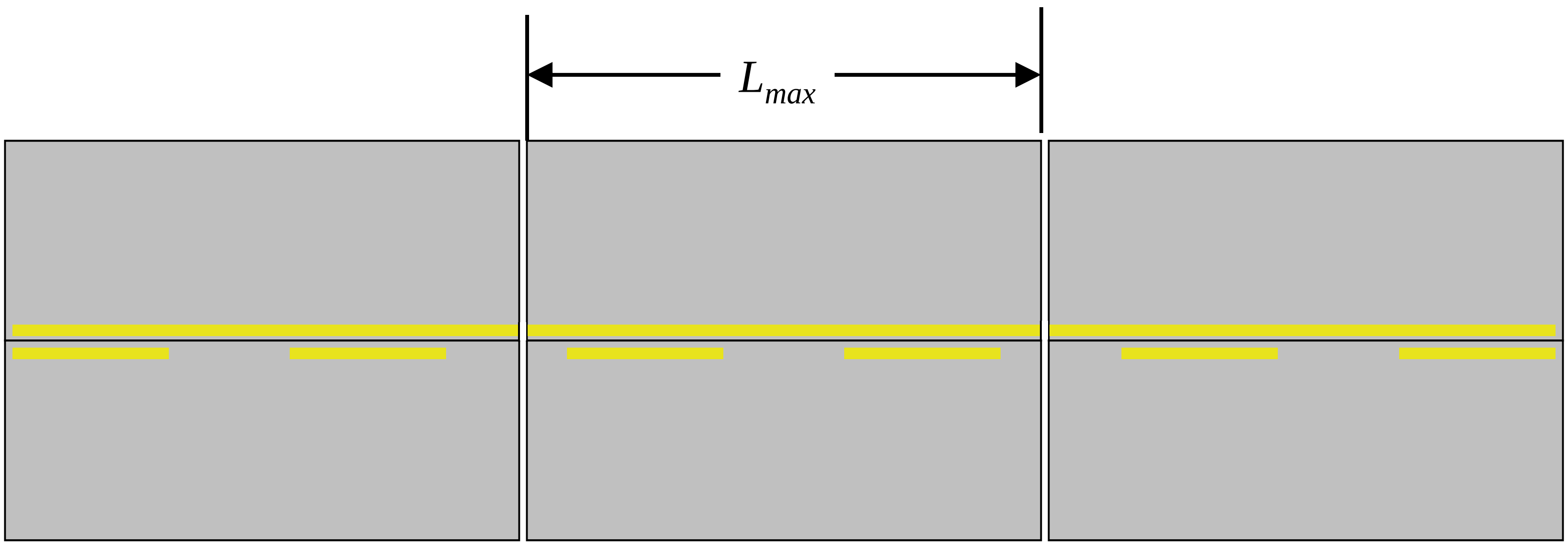
Partially Restrained Slab

Joint Opening



$$\Delta L = CL\left(\alpha_c \Delta t + \delta_c\right) \quad \begin{cases} C = 0.65 \;\; for\ stabilized\ base \\ C = 0.8 \;\; for\ unstabilized\ base \end{cases}$$

Maximum Slab Length



$$CL_{\max}\left(\alpha_c \Delta t + \delta_c\right) \le 0.04''$$

Aggregate Interlock

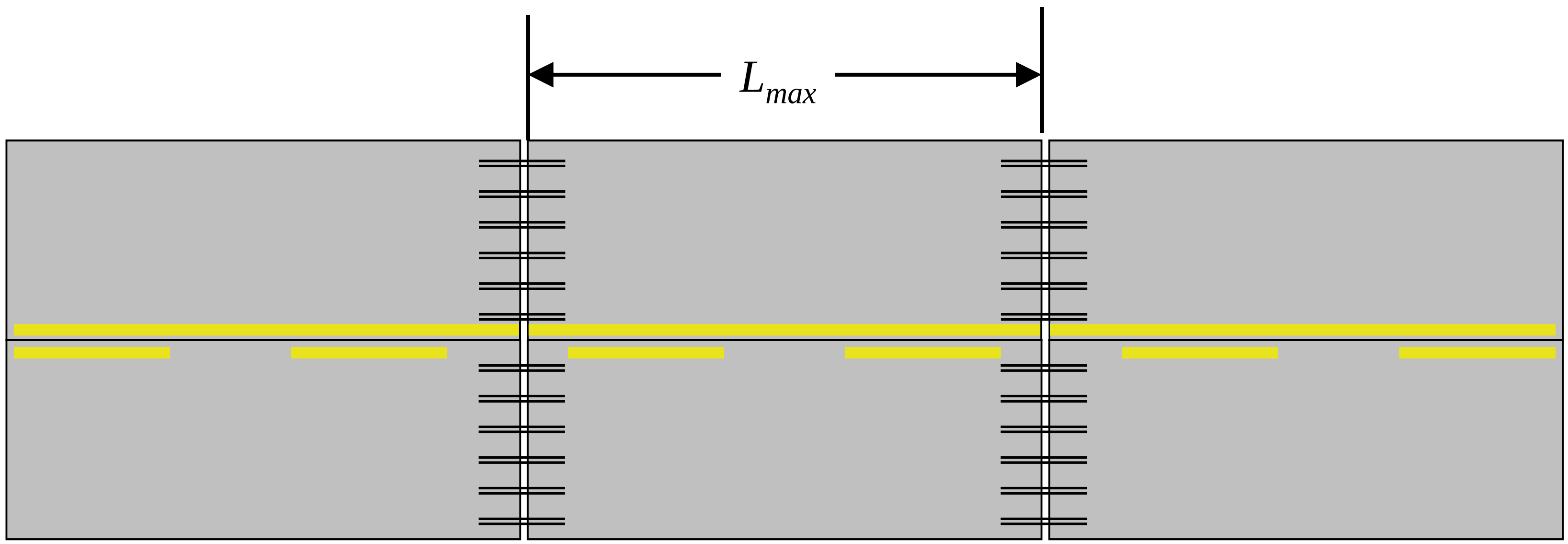
Example

Find the maximum allowable slab length for a design temperature drop of 60°F for a slab on a stabilized base.

Dowel Bars

Source: WSDOT Pavement Guide Interactive CD-ROM

Maximum Slab Length



$$CL_{\max}\left(\alpha_c \Delta t + \delta_c\right) \leq 0.25''$$

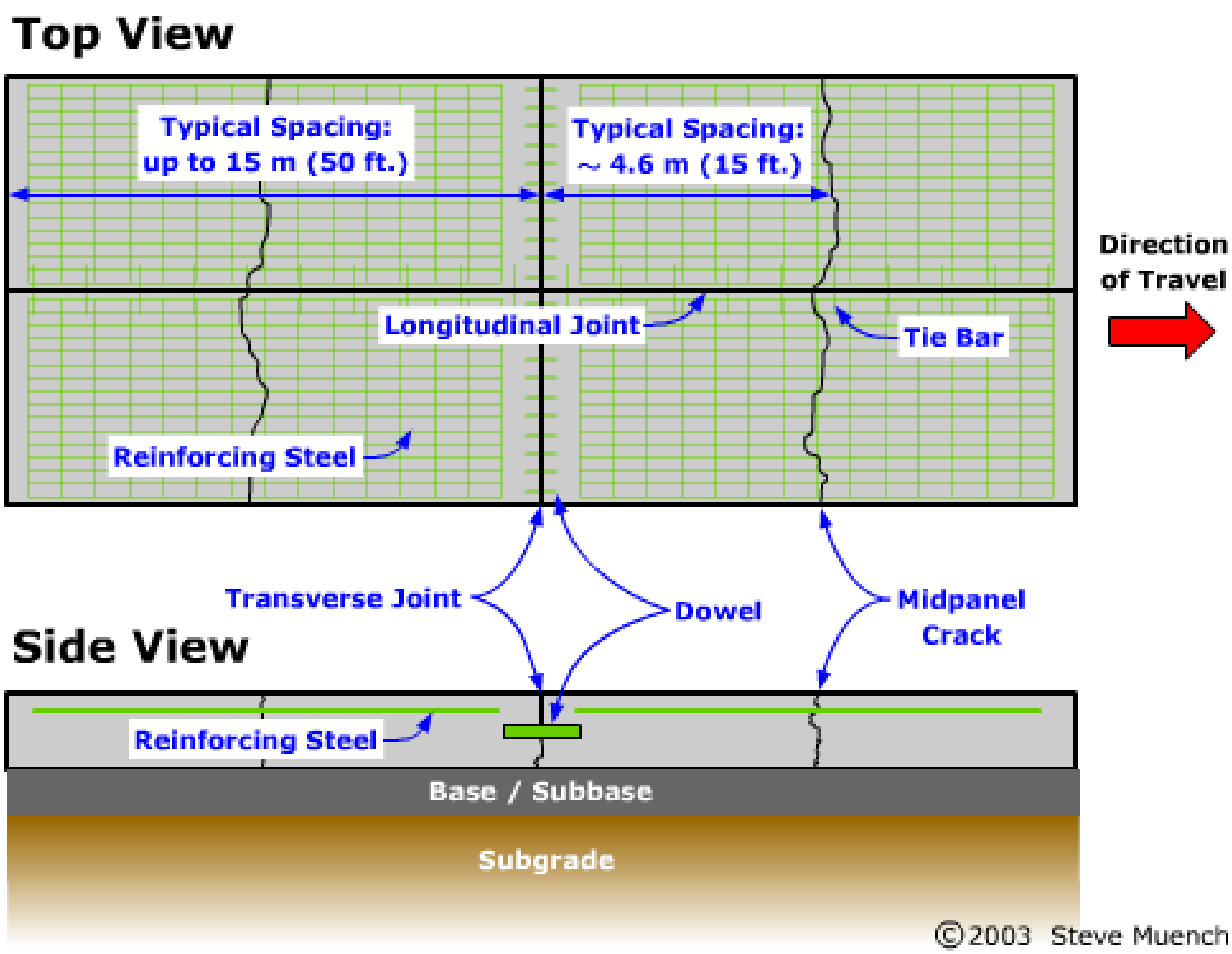
Doweled Joints

Temperature Steel

Wire Reinforcement

Source: http://rebar.ecn.purdue.edu/wwr/

JRCP



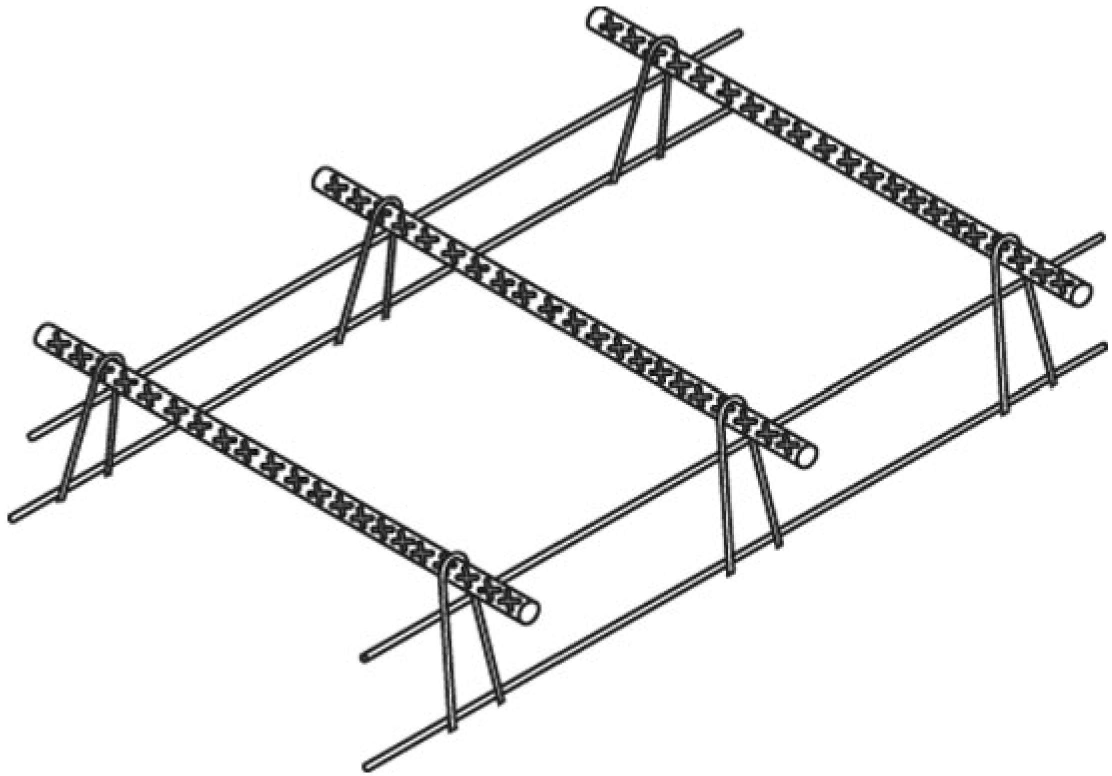
Source: WSDOT Pavement Guide Interactive CD-ROM

Tie Bars

Tie Bars

Source: WSDOT Pavement Guide Interactive CD-ROM

Tie Bar Baskets



Source: http://www.daytonsuperior.com/

Tie Bars

Source: http://www.dot.state.oh.us/

Tie Bar Steel Area

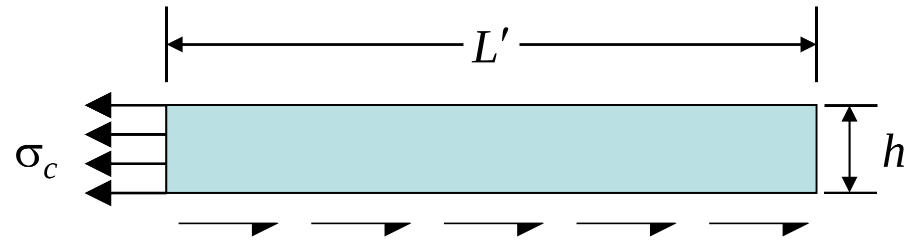
$$A_s f_s = \sigma_c h$$

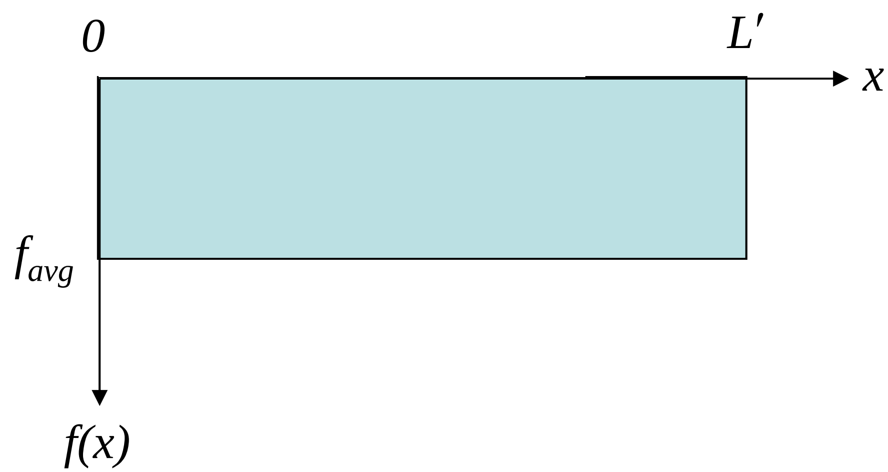
$$\Downarrow$$

$$A_s = \frac{\sigma_c h}{f_s}$$

Friction Stresses

$$\sigma_c h = \gamma_c h L' f_{avg}$$





Tie Bar Spacing

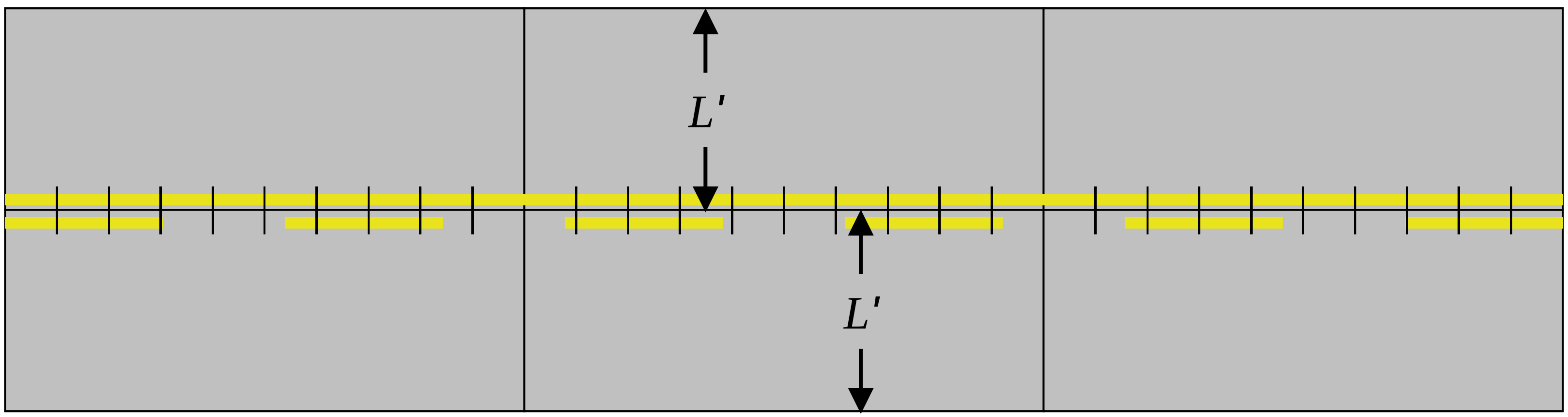
$$A_s = \frac{A_{bar}}{s_{bar}} = \frac{\gamma_c L' f_{avg} h}{f_s}$$

$f_s = \frac{2}{3} f_y$

Steel Reinforcing Bar

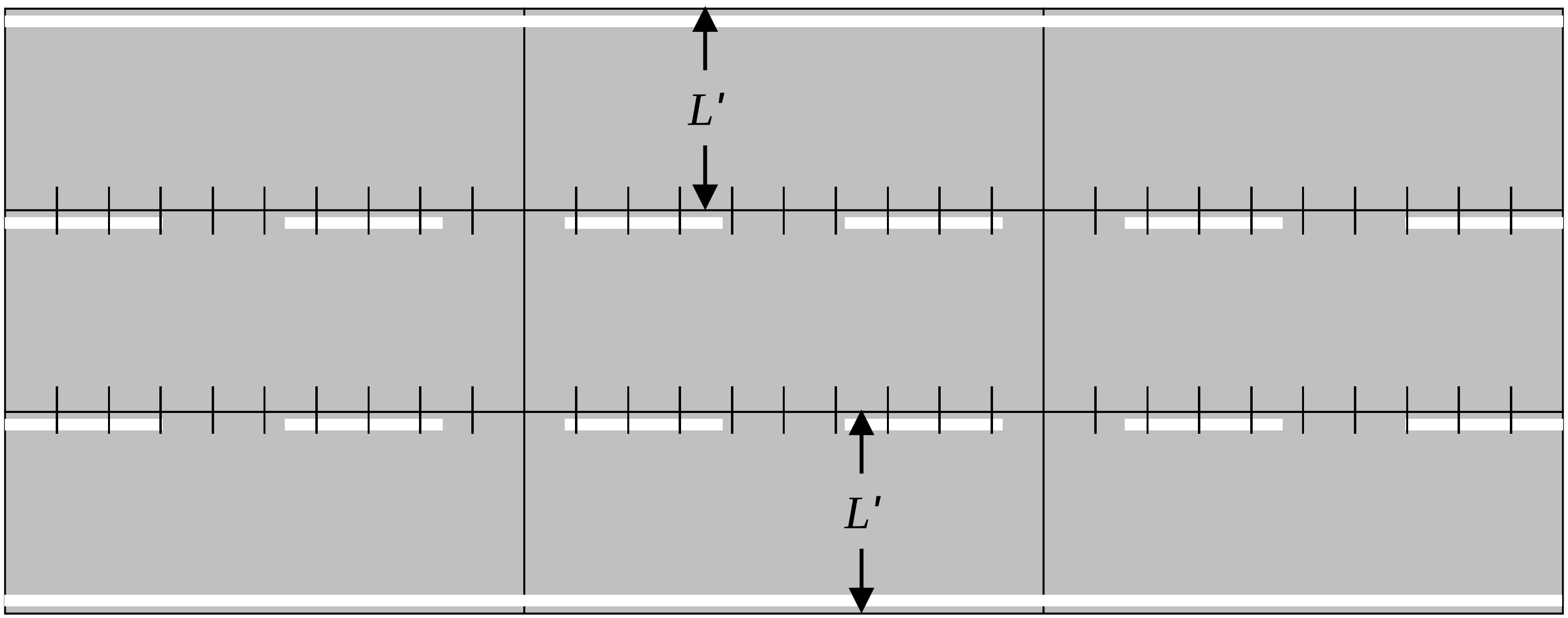
f_y = 40,000 or 60,000 psi

Tie Bar Spacing



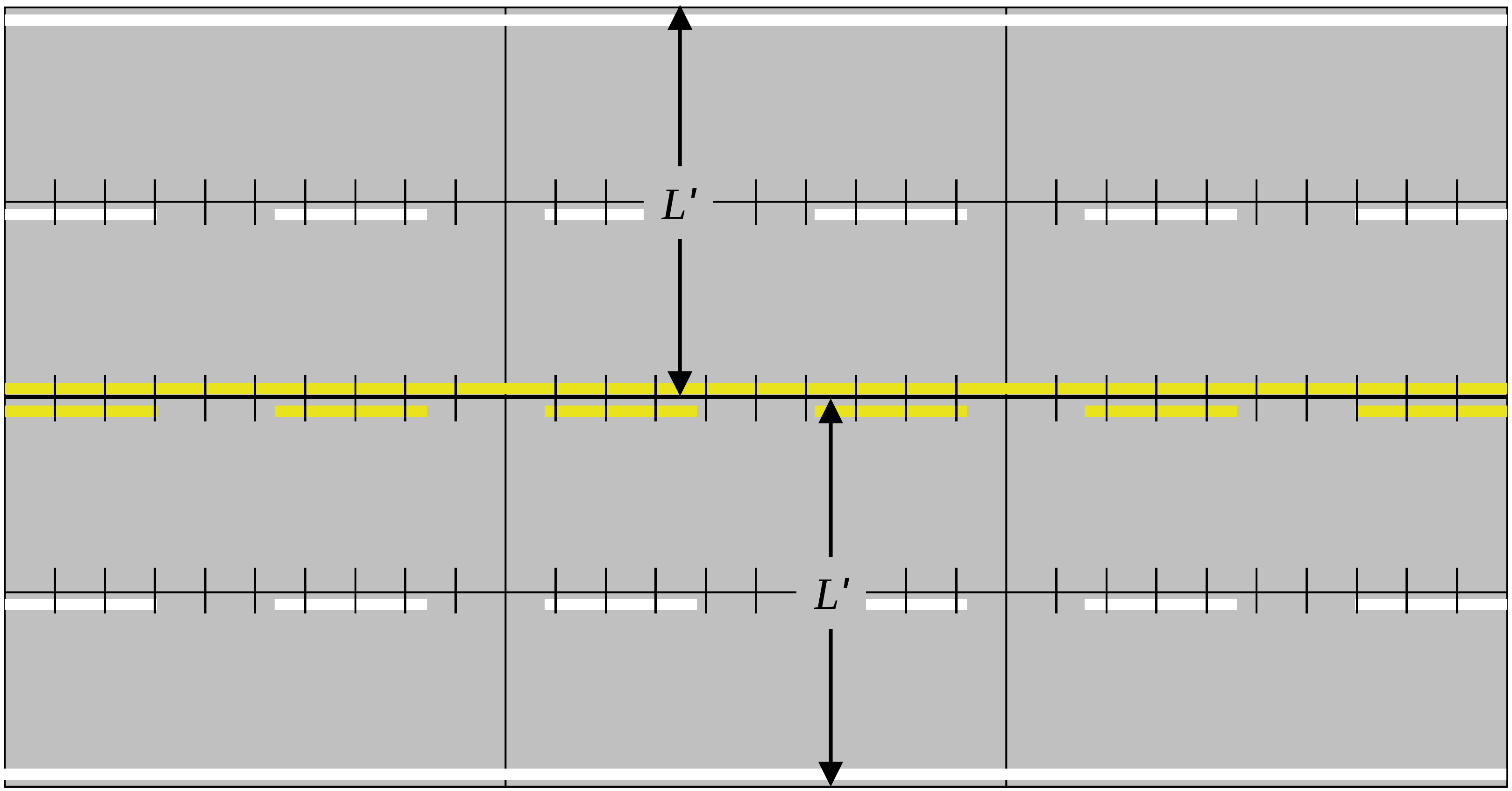
$L' = distance\ to\ nearest\ free\ edge$

Tie Bar Spacing



$L' =$ *distance to nearest free edge*

Tie Bar Spacing



$L' =$ *distance to nearest free edge*

Example

Determine the amount of steel required for a highway consisting of two 12' driving lanes with 10' shoulders on each side. Assume a 10" concrete slab resting on a gravel base and a 60-ksi yield stress for the rebar.

Tie Bar Spacing

$$A_s = \frac{A_{bar}}{s_{bar}} = \frac{\gamma_c L' f_{avg} h}{f_s}$$

$$\Downarrow$$

$$s_{bar} = \frac{A_{bar}}{A_s} = \frac{A_{bar} f_s}{\gamma_c L' f_{avg} h}$$

Standard Rebar Sizes

Bar Size	Weight (lb/ft)	Nominal Diameter (in)	Nominal Area (in^2)
#3	0.376	3/8	0.11
#4	0.668	1/2	0.20
#5	1.043	5/8	0.31
#6	1.502	3/4	0.44
#7	2.044	7/8	0.60
#8	2.670	1.000	0.79
#9	3.400	1.128	1.00
#10	4.303	1.270	1.27
#11	5.313	1.410	1.56
#14	7.650	1.693	2.25
#18	13.60	2.257	4.00

Tie Bar Spacing

Note : 48" maximum spacing recommended.

BAR SIZE		# 4 BAR										# 5 BAR									
GRADE STEEL		GRADE 40					GRADE 60					GRADE 40					GRADE 60				
DIST TO FREE EDGE (ft.)		10	12	16	22	24	10	12	16	22	24	10	12	16	22	24	10	12	16	22	24
PVMT THICKNESS	TYPE OF JOINT																				
9"	Warp	37	31	23	17	16	48	47	35	25	23	48	48	36	26	24	48	48	48	40	36
	Butt	26	22	16	12	11	40	34	25	18	16	42	35	26	19	17	48	48	39	29	26
10"	Warp	34	28	22	16	14	48	42	32	23	20	48	44	33	24	22	48	48	48	36	32
	Butt	24	20	16	11	10	36	30	23	16	14	38	31	24	17	16	48	47	35	26	23
11"	Warp	31	25	20	15	13	47	38	29	21	19	48	40	30	22	20	48	48	44	32	30
	Butt	22	18	14	11	9	34	27	21	15	14	34	29	21	16	14	48	43	31	23	21
12"	Warp	28	23	18	13	12	42	35	27	19	18	44	36	28	20	18	48	48	41	30	28
	Butt	20	16	13	9	9	30	25	19	14	13	31	26	20	14	13	47	39	29	21	20

Warp joint: a sawed or construction joint with a keyway

Butt joint: a construction joint with no keyway

Source: FHWA Technical Advisory T 5040.30

Tie Bar Length

$$\underbrace{\mu\left(2\pi r\ell\right)}_{\textit{bond strength}} = \underbrace{f_s\left(\pi r^2\right)}_{\textit{steel strength}}$$

$\mu =$ allowable bond stress (assume 350 psi)

$\ell =$ embedment length (half the bar length)

$f_s =$ allowable bar stress

$r =$ bar radius (half the bar diameter)

Tie Bar Length

$$t = 2\ell = \frac{1}{2}\left(\frac{f_s d}{\mu}\right)$$

$\mu =$ allowable bond stress (assume 350 psi)

$\ell =$ embedment length (half the bar length)

$f_s =$ allowable bar stress

$r =$ bar radius (half the bar diameter)