Design of Highway Bridges

Transportation System:

Big part is Transportation network

① repair or Build Bridges are too expensive

{ Turkeys → Arch stone Bridge
{ oldest steel bridge → 1760's SW london

USA ⇒ ≈1850's philadelphia

homework due date next wednesday:
- ½ page → The Real cause of I-35W
- : Bridge colaps
- give me some Bullet points
- : what was wrong / : ways to prevent it

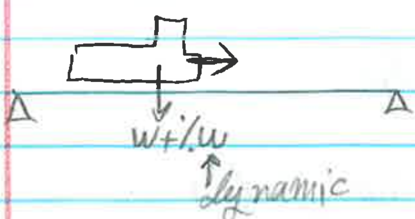
Redundensy: putting more reactions than you need

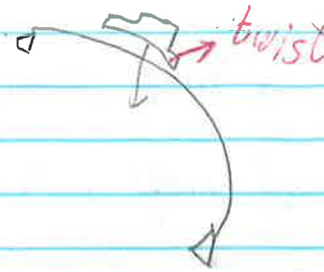
Golden Rule: $\frac{x-1}{1} = \frac{1}{x} \Rightarrow x = 1.618$

$\Rightarrow \frac{L}{W} = 1.618$

Look at 2 formula on page 41 top of the page

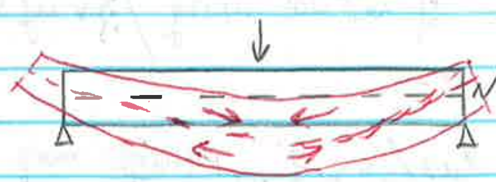
{ super structure → up of beams
{ sub structure → Blow girder





Bridge Companants:

1. Approach slap
2. Seat
3. hammer head/Bent → sitting on more than 1 column
   ↳ sitting on one colume
4. Slap/Reprap
   ↳ use if it is Not under water
   ↳ use if it is under water
5. Girder (principle Element)
6. Diaphram
7. Pedestal



8. Deck (then place an extra layer on Deck to protect the deck)

home work: due date is NEXT MONDAY

- Page 73 → Answer q # 4.15
- u have to read chapter 4 to answer
  - suspention
  - Arch bridge

$\phi P_n > \gamma P_u$

- ϕ → <1
- γ → >1
- adding these two means LRFD
- P_u → Actual load
- P_n → load capacity

LRFD
↳ load → Factor
→ Resistant → Design

samples

⇒

n	$f'_c = x_i$
1	3.10
2	3.3
3	3.05
⋮	⋮
N → 176	$\Sigma x_i = ?$

mean: $\bar{x} = \frac{\Sigma x_i}{N} = 3.94$ Ksi

standard deviation: $\sigma = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{N-1}} = \sqrt{\frac{(3.1-3.94)^2 + (3.3-3.94)^2 + \dots}{176-1}} = .615$ Ksi

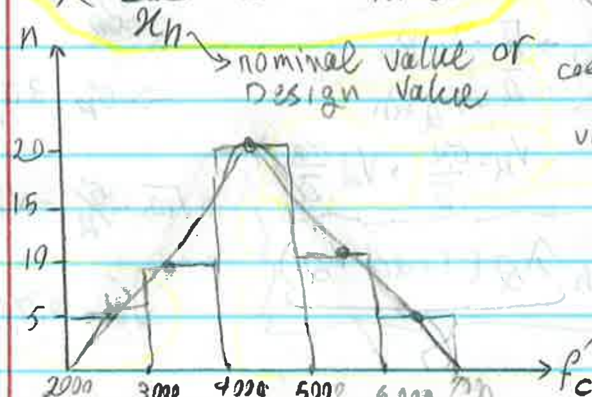
(→ Variance: $\frac{\Sigma(x_i - \bar{x})^2}{N-1}$)

$\lambda = \frac{\bar{x}}{x_n}$ ⇒ bias factor

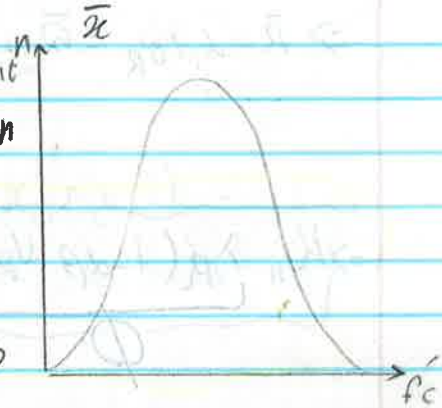
x_n → nominal value or Design value

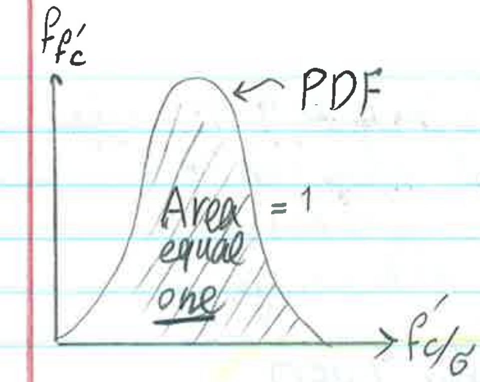
$CoV = V = \frac{\sigma}{\bar{x}}$

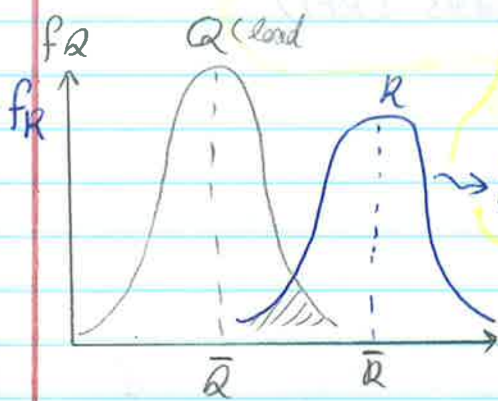
CoV ↓ coefficient of variation



⇒







Probability Density Functions:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right]$$

$$-\infty < x < +\infty$$

$$P_f = \frac{1}{1} - F_u\left(\frac{\bar{R}-\bar{Q}}{\sqrt{\sigma_R^2+\sigma_Q^2}}\right)$$

↳ β = Safety index

β		chance of failure
2.5	→	1 in 100
3	→	1 in 1000
3.5	→	1 in 10,000

$\Rightarrow \bar{R} - \bar{Q} = \beta\sqrt{\sigma_R^2+\sigma_Q^2}$ And

Math $\Rightarrow \sqrt{\sigma_R^2+\sigma_Q^2} \simeq \alpha(\sigma_R+\sigma_Q)$

$\sigma_R/\sigma_Q = \frac{1}{3}$ to 3

$\rightarrow \sigma_R/\sigma_Q = 3$

$\rightarrow \sigma_R = 3\sigma_Q$

$\rightarrow \sqrt{10}\ \sigma_R = \alpha/4\ \sigma_R$

$\rightarrow \alpha = 0.75$

$\Rightarrow \bar{R} - \bar{Q} = \beta\alpha(\sigma_R+\sigma_Q)$

$\Rightarrow \bar{R} - \alpha\beta\sigma_R = \bar{Q} + \alpha\beta\sigma_Q \rightarrow \bar{R} = \lambda_R R_n$

$\bar{Q} = \lambda_Q Q_n$

$V_R = \frac{\sigma_R}{\bar{R}},\ V_Q = \frac{\sigma_Q}{\bar{Q}}$

$$\Rightarrow R_n \underbrace{\lambda_R(1-\alpha\beta V_R)}_{\phi} = Q_n \underbrace{\lambda_Q(1+\alpha\beta V_Q)}_{\gamma}$$

Controling crack length deflection ...

Service I : normal operation wind speed 55 mph
→ crack control
→ calculate comprsive stress

service II : steel structure
→ yelding
→ slip critical connection

service III : concerete
→ tension in Prestressed

service IV : concrete
→ tention in prestressed column to control crack

capacity

strengh I : Normal Bridge condition

strengh II : owner specified vehicle

strengh III : wind > 55 mph

strengh IV : D/L extream'ly very load
→ sharp span

strengh V : strengh III condition (High wind) + live load

Check => Example 6.2 (p 88) $\beta = \frac{\bar{R} - \bar{Q}}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$

6.3 (90)

=> Accurate $\beta = \frac{R_n \lambda_R (1 - K V_R)[1 - \ln(1 - K V_R)] - \bar{Q}}{\sqrt{[R_n V_R \lambda_R (1 - K V_R)]^2 + \sigma_Q^2}}$

next wednesday — homework: 6.2/6.3/6.5/6.7/6.8
page 94

Chapter 5: $\eta_i \gamma_i Q_i \leq \phi R_n$ (Read by your self)

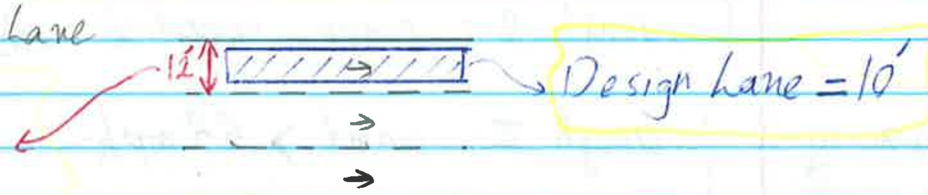
→ $\eta_D \times \eta_R \times \eta_I$

ductility, Redundancy, importance

for max value of γ_i: $\eta_i = \eta_D \times \eta_R \times \eta_I \geq 0.95$

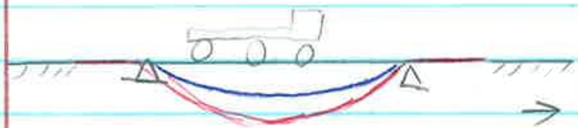
for min value of γ_i: $\eta_i = 1/\eta_D \times \eta_R \times \eta_I \leq 1.0$

Chapter 7: Lane



Chapter 8: (include ch. 2 and 3 spec) Read by your self

Truck loads → legal load
→ over load → Permit
→ Rating



→ Strength: Fracture

$M_Q > M_R$

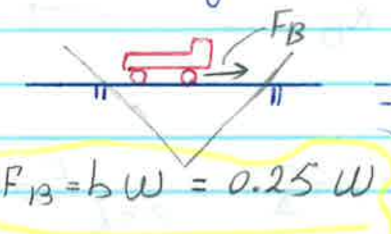
Bridge:

1. Trucks, Lane Load, Impact factor, fatigue issue

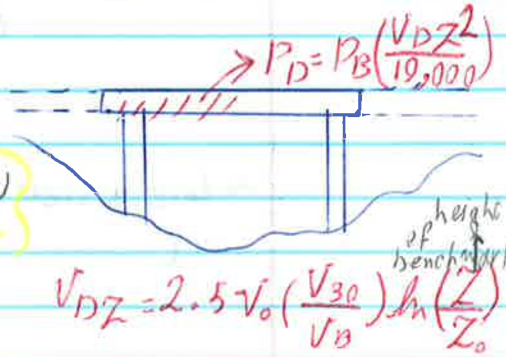
Extra Issues:

ⓐ

ⓑ Braking Force

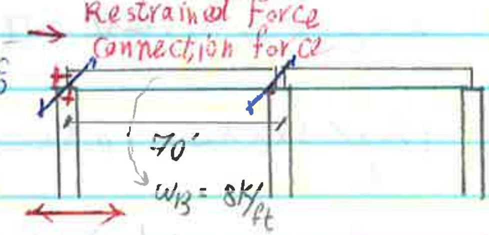


ⓒ Wind Force



Look at Exp 8.1 in book

Seismic loads:



Exp 8.2:

$A_S = 0.083$ $\quad F_{EQ} = A_S W_D = 0.083 \times 560 = 46^K$

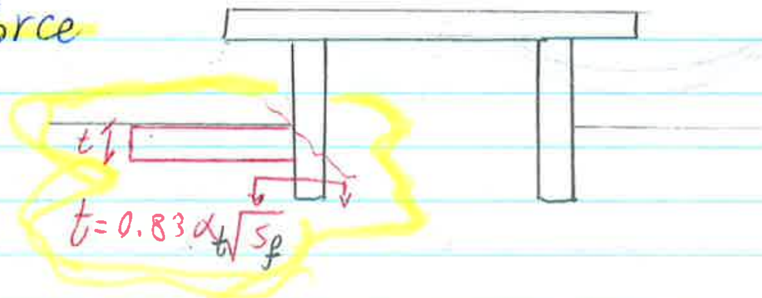
Earthquake

Bridge is in table 8-13

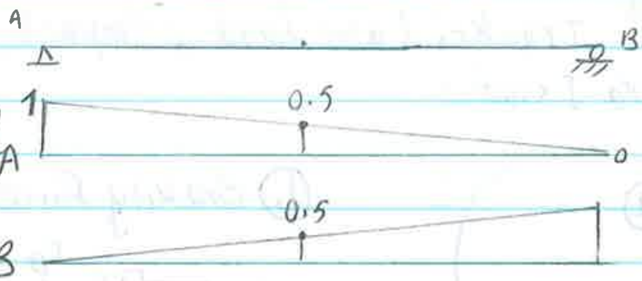
Zone 1 } ⟸ $A_S = 0.083$ → $A_S > 0.05$ $\underset{\text{table 8-16}}{\Longrightarrow}$ $F_{EQ} = 0.25 \times 560 = 140^K$

$\begin{cases} F_{CL} = 140^K \\ F_{CT} = 70^K \end{cases}$

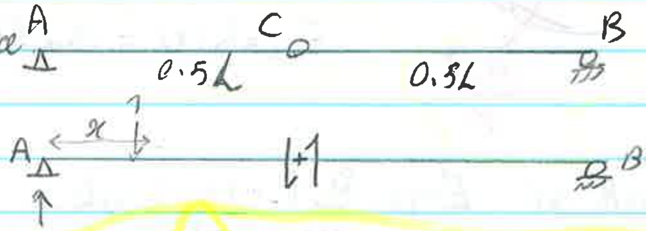
Ice Force



Chapter 2:



we have a shear force on C



$0 < x < 0.5L$

$$\Sigma M_C = 0 \Rightarrow R_A \times 0.5L - 1(0.5L - x) - M_C = 0$$

$$\left(\frac{L - x}{L}\right) \times 0.5L - (0.5L - x) - M_C = 0 \Rightarrow M_C = x/2$$

$$\Sigma V = 0 \Rightarrow R_A - 1 - V_C = 0 \Rightarrow \frac{L - x}{L} - 1 - V_C = 0 \Rightarrow V_C = -x/L$$

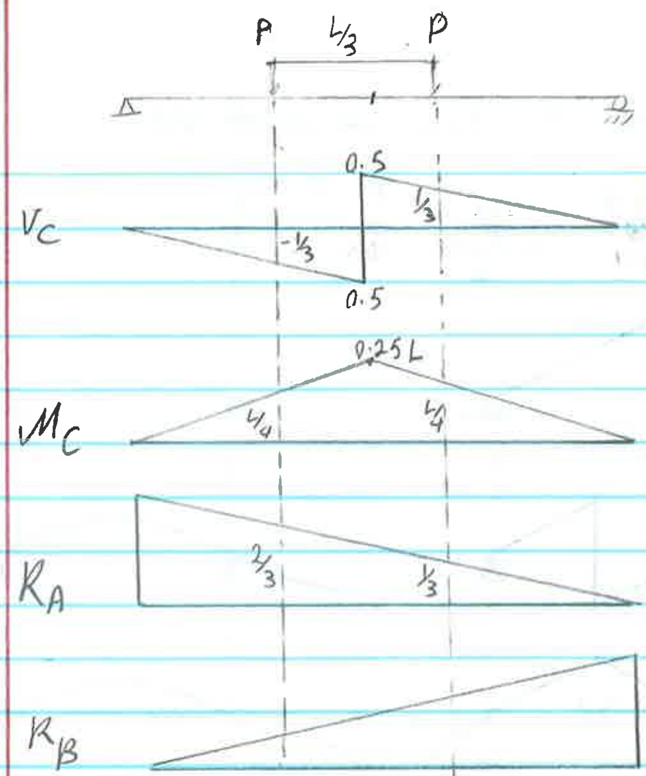
$$\Sigma M_A = 0 \Rightarrow 1(x) - R_B(L) = 0 \Rightarrow R_B = x/L$$

$\frac{L}{2} < x < L$

$$R_B = x/L \; ; \; R_A + R_B - 1 = 0 \; ; \; R_A = 1 - R_B = \frac{L - x}{L}$$

$$M_B = R_B \times 0.5L \quad R_A - V_C = 0 \; ; \; V_C = R_A = \frac{L - x}{L}$$

$$M_C = R_A + 0.5L = \frac{L - x}{L} \times 0.5L = 0.5(L - x$$



$V_C = P(-\frac{1}{3}) + P(\frac{1}{3})$

$M_C = P(\frac{L}{6}) + P(\frac{L}{6})$

$R_A = P(\frac{2}{3}) + P(\frac{1}{3})$

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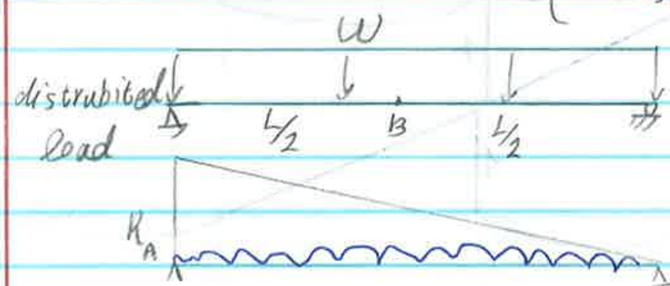
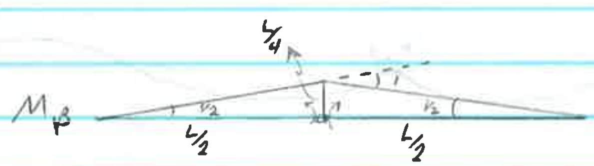
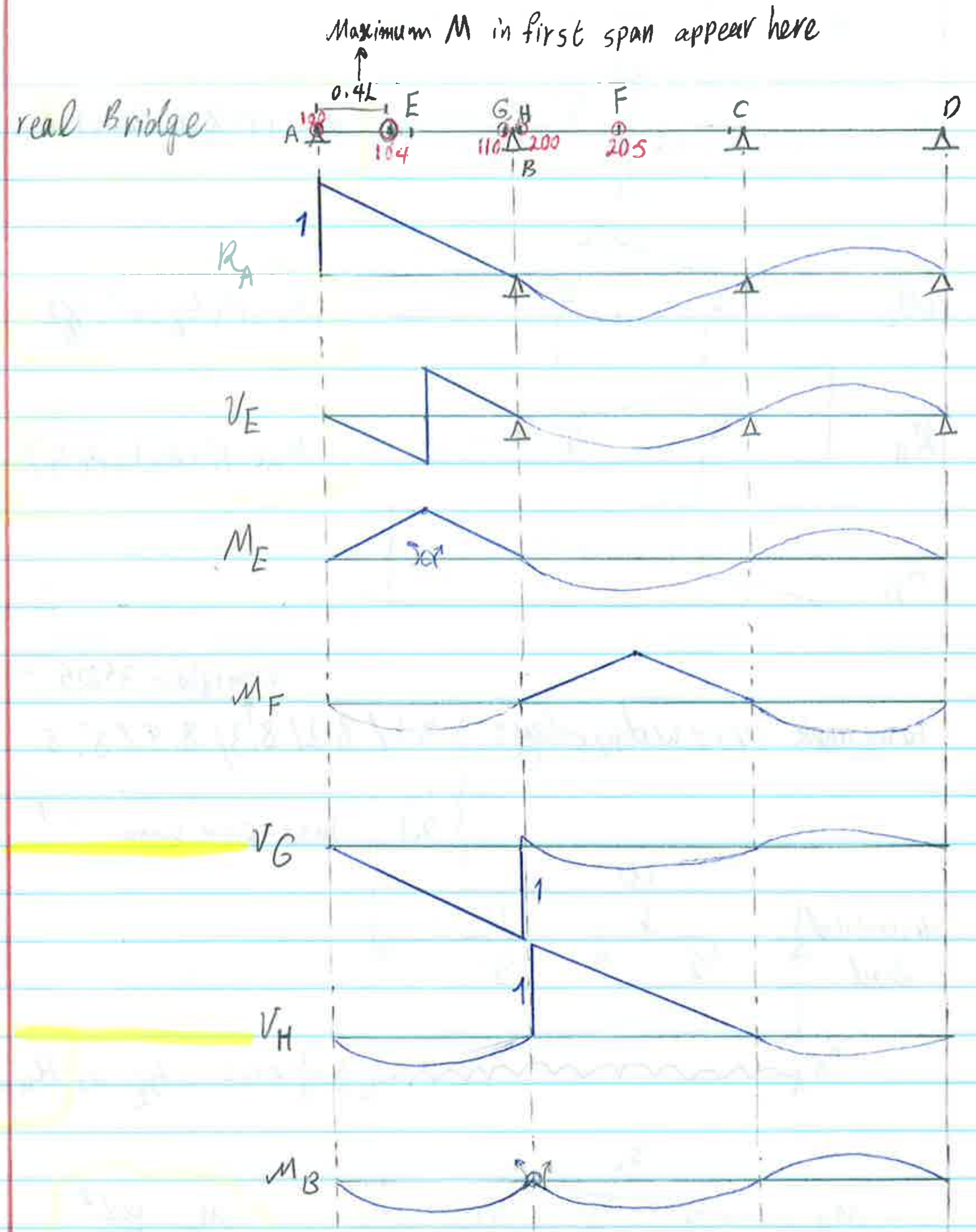
homework next wednesday: { 8.1 / 8.2 / 8.3 / 8.4 / 8.5
9.1 → Just First beam



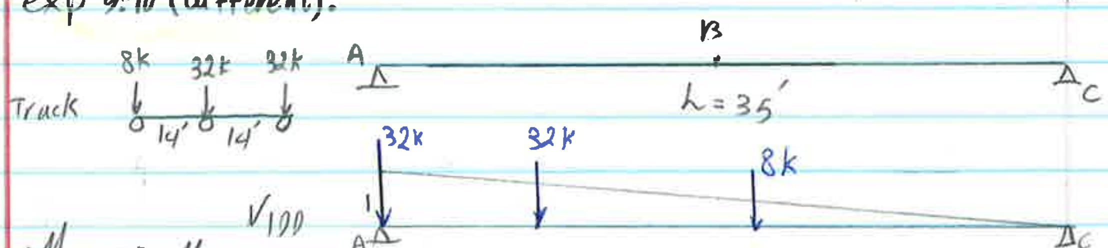
$A = \frac{1}{2} \times 1 \times L = \frac{L}{2} \Rightarrow R_A = W \times A = \frac{WL}{2}$



$M_B = \frac{WL^2}{8}$



exp 9.10 (different):



$M_{max} = M_{105}$

$V_{max} = V_{100}$

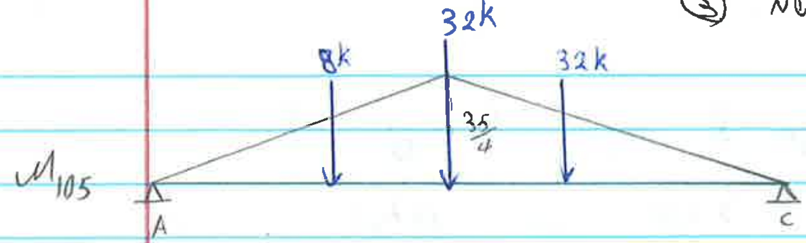
$$V_{100} = 32(1) + 32\left(\frac{1}{35}(35-14)\right) + 8\left(\frac{1}{35}(35-2\times14)\right) = 52.8^K$$

use exp 9.10

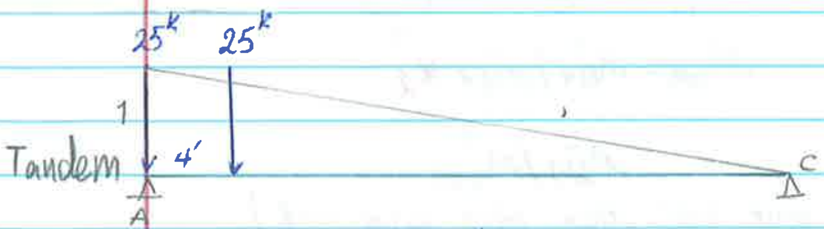
① repeat exp 9.10 for span 70 (9.1)

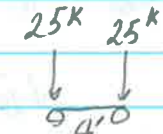
② Δ L Δ L Δ (9.3) Draw

③ Next page $V_{100}^{-/+} / M_{104}^{-/+} / M_{200}^{-/+} / V_{200}^{-/+}$

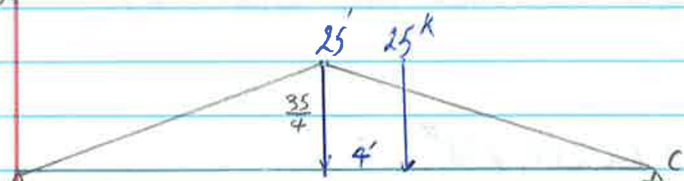


$$M_{105} = 32\left(\frac{35}{4}\right) + 32\left(\frac{35/4}{17.5}(17.5-14)\right) + 8\left(\frac{35/4}{17.5}(17.5-14)\right) = 350\ k'$$





$$\Rightarrow V_{100} = 25(1) + 25\left(\frac{1}{35}\times 31\right) = 47.1^k$$



$$\Rightarrow M_{105} = 25\left(\frac{35}{4}\right) + 25\left(\frac{35/4}{17.5}\times(17.5-4)\right) = 387.5^k$$

Lane Load: $V_{100} = \frac{1}{2}(1\times 35)\times 0.64 = 11.2^k \quad \left\{= \frac{wL}{2}\right.$

$M_{105} = \frac{1}{2}\left(\frac{35}{4}\times 35\right)\times 0.64 = 98k' \quad \left\{= \frac{wL^2}{8}\right.$

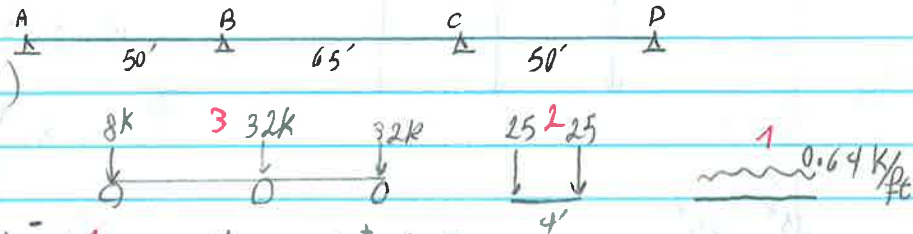
Design Chart

	V_{100}	M_{105}
Truck	52.8^k	$358^{k'}$
Tandem	47.1^k	387.5^k
Lane	11.2^k	$98k'$
(1.33 Truck + Lane)	max $1.33\times 52.8 + 11.2 = 81.9$	$1.33\times 350 + 98 = 563.5$
(1.33 Tandem + Lane)	$1.33\times 47.1 + 11.2 = 73.8$	$1.33\times 387.5 + 98 = 613.4$ max

homework: { 9.3 (2^{nd})
9.4 (use 9.1 same 70')

Repeat Chart for page 148 with software

home work:
(Next wednesday)



$V_{max} = V^{+}_{100} / V^{-}_{100}$ *1 $\quad M_{max} = M^{+}_{104} / M^{-}_{104}$ *2

$V^{-}_{200} / V^{+}_{200} \quad M^{-}_{204} / M^{+}_{204}$

(first solve 9.12 by your self then solve homework)

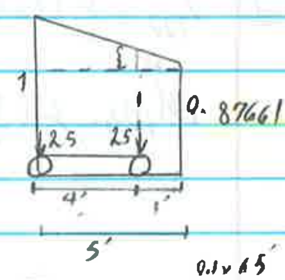
lane load

$V^{+}_{100} = 0.458 \times (L=50) \times 0.64 = 14.656^{k}$

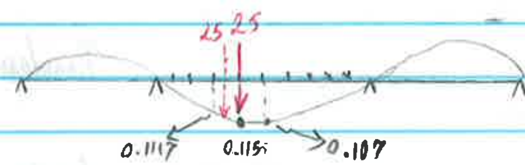
$V^{-}_{100} = (-0.0922) \times (L=50) \times 0.64 = -2.95^{k}$

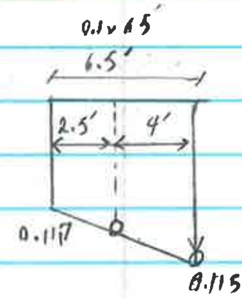
tandem

$V^{+}_{100} = 25 + 25 \left[0.87661 + \frac{1-0.87661}{5} \times 1\right] = 47.5^{k}$



$V^{-}_{100} =$





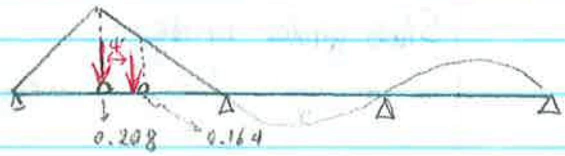
Desig lane load

$M^{+}_{104} = 0.64 \times 0.1032\, L^{2} \rightarrow (50^{2})$
$= 165.12'k$

$M^{-}_{104} = 0.64 \times (-0.0369) \times 50^{2}$
$= -59.04'k$

Tandem

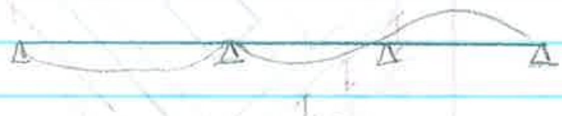
$V^-_{100} =$



design Lane Load

Max Negative M will happen on 200 or 300

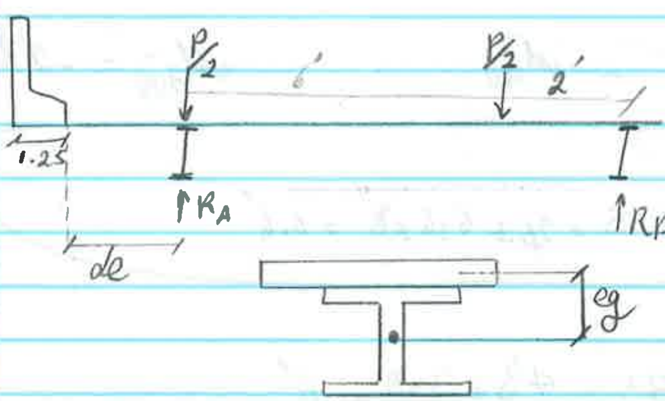
$M^-_{200} = (0.64) \times (-0.1506) \times 50^2$



$M^+_{200} = (0.64)(0.0165) \times 50^2$

Distribution Factor: Convert truck on a single beam ↓ M/V on single girder of multiple truck

*Calculations should not only cover single lane load but also multiple lane load.



$\Sigma M_B = 0 \Rightarrow \frac{P}{2} \times 2 + \frac{P}{2} \times 8 - R_A \times 8 = 0$

1 lane Truck ↖

$\Rightarrow R_A = 0.625P$

$\Rightarrow mR_A = 0.625P \times 1.2$
$= 0.75P$

Girder spacing

homework : * Exp 11.2 (Page.179) [S = 10' / length of span L = 70']
Next wednesday Give me answer w/ table 6.6 in Lecture

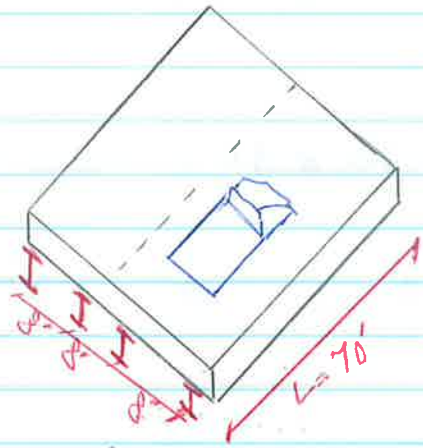
* Exp 11.8 (L = Span length = 70' / Deck thickness = 25")
[page (194)]

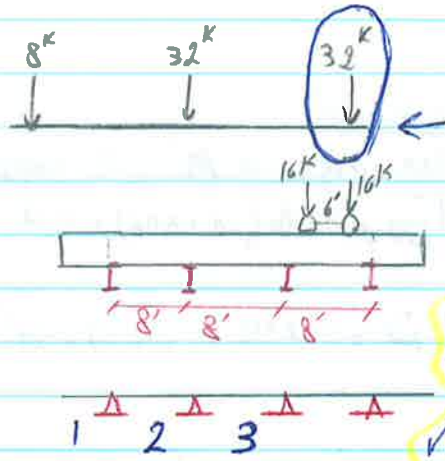
* Prop 11.11 (S = 10') (pag 199)

* Exp 11.15 (L = 150) Box span = 15' (p 211)

Slab girder bridge:

we learn how to design girders but How to design deck =?

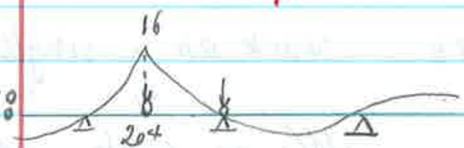




$M^+_{max} = M^+_{204}$ or M^+_{205}

$M^-_{max} = M^-_{300}$

Prob 11.11: (P199) homework

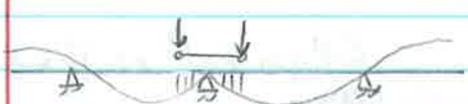


M^+_{204}

M^+_{205}

$M^+_{204} = 23.5\ K'$

$M^+_{205} = 21.1\ K'$ } $23.5\ K'$



M^-_{300}

$M^-_{300} = -23.09\ K'$

$S_W^+ = 26 + 6.6\ S = 26 + 6.6 \times 8'' = 6.6'$

$S_W^- = 48 + 3S = 48 + 3 \times 8'' = 6'$

$M_d^+ = 23.5/6.6 = 3.56\ K'/ft$

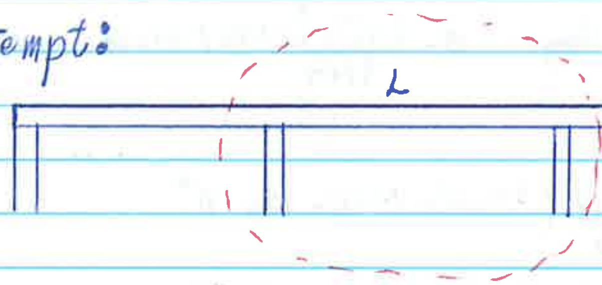
$M_d^- = -23.09/6 = -3.85\ K'/ft$

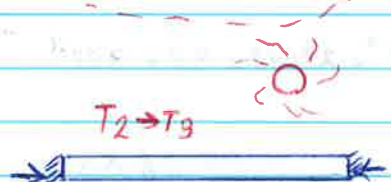
chapter 12:
Temperature, Shrinkge, Creep

shrinkge: Deformation due to lost moisture

Creep: Deformation due to Sustained load

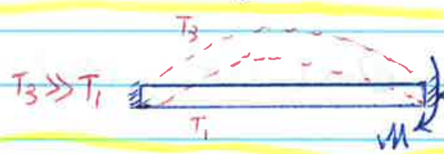
* Tempt:





1. Uniform Tempt. Change
2. Gradiant Tempt. Change

1. uniform tempt. change $\sigma = \alpha(\Delta T)E$ (compression) (−)



$N = EA\epsilon = EA\frac{\alpha}{A}\Sigma T_{ai}A_i$

$\Rightarrow \sigma = E\frac{\alpha}{A}\Sigma T_{ai}A_i$

2. Gradiant Tempt. change

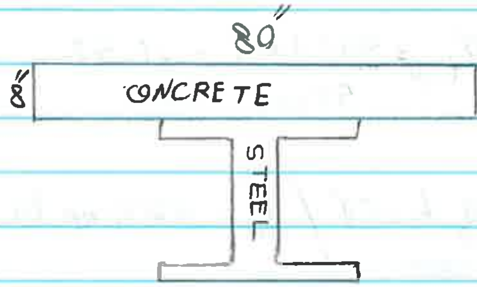
$\sigma = \frac{\alpha}{A}E\Sigma T_{ai}A_i$ (−)

$M = EI\Psi = EI\frac{\alpha}{I}\Sigma T_{ai}\bar{y}_iA_i + \frac{\Delta T_i}{d_i}I_i$

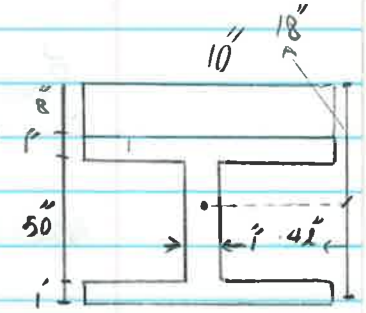
$\sigma_{bending} = \frac{C}{I} \times EI\frac{\alpha}{I}\Sigma T_{ai}\bar{y}_iA_i + \frac{\Delta T_i}{d_i}I_i$ (+ top, − bott)

$\Rightarrow \sigma = \frac{M}{I}$

Exp 12.1

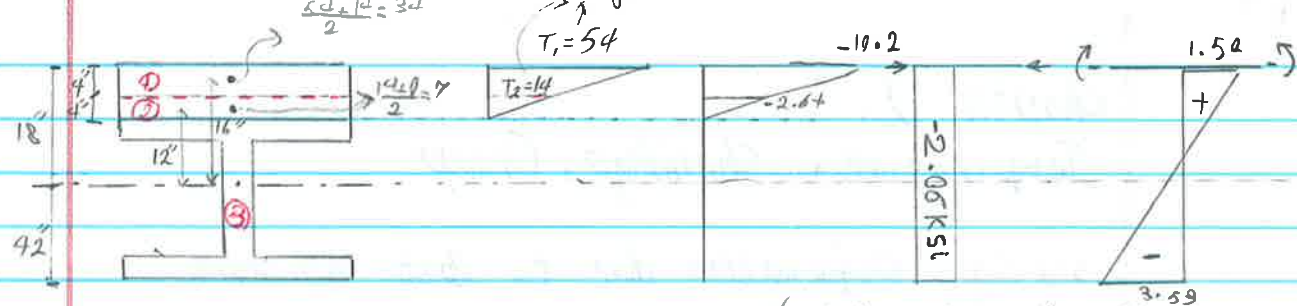


$\Rightarrow$ convert to steel $\Rightarrow \frac{80}{n} = 10" \Rightarrow$



homework ; { repeat this problem
repeat Exp 13.4 (with Deck=10" and f'_c= 5 ksi and H=75) (draw graph)
repeat Exp 13.5 (with Deck=10" and f'_c= 5 ksi and H=75) (draw —) }

→ page 128



⇒ Uniform temp. change : $\left[\begin{array}{l}\sigma = 6.5\times10^{-6}(14)\times29000 = 2.64\ ksi\ (-) \\ \sigma = 6.5\times10^{-6}(54)\times29000 = 10.2\ ksi\ (-)\end{array}\right.$

Gradient temp. change: $\sigma = \frac{6.5\times10^{-6}\times29000}{80+70}[34\times40+7\times40] = 2.06\ ksi\ (-)$

whole Area

$\epsilon = \frac{\alpha}{A}\sum T_i \times A_i = \frac{6.5\times10^{-6}}{8\times10}(34\times40+7\times40) = 133\times10^{-6}$

$N = \epsilon\times E\times A = 133\times10^{-6}\times29000\times80 = 309^{k}$

$\sigma = \frac{N}{A} = \epsilon\times E = \frac{309}{80+[(10\times2)+(50\times1)]} = 2.06\ ksi\ (-)$

① ⇒ $I = \frac{10\times4^3}{12} = 53.3$ ② ⇒ $I = 53.3$ ③ ⇒ $I = \dots$

$I_{total} = 53.3 + (4\times10)\times(\quad)^2 + \dots + \dots = 57450$

$\psi = \frac{\alpha}{I}\left(T_{avg}\,\bar{y}_i A_i + \frac{\Delta T_i}{d_i} I_i\right)$

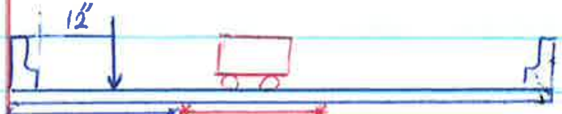
$\Rightarrow \psi = \frac{6.5\times10^{-6}}{57450}\left(34\times16\times40 + \frac{40}{4}\times53.3 + 7\times12\times40 + \frac{14}{4}\times53.3\right) = 2.9\times10^{-6}$

$M = EI\psi = 29000\times57450\times2.9\times10^{-6} = 404.4\ k'$

$\sigma_{bottom} = \frac{404.4\times42}{57455} = -3.53$ $\sigma_{top} = \frac{404.4\times18}{57450} = +1.52$

homework { do slab bridge by L=50' / f'_c = 3 ksi up to sec I
others are the same }

Sec G. Calculate live-load force effects.



Edge Strip = Calculate = 62.5" = 11.83'

	V	M
Track	52.8 k	350 k'
V_{LL+IM}	81.4	613.4 k'

$E = 142'' = 11.83'$

we use ② (edge strip)

Sec I:

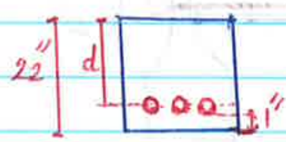
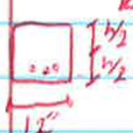


Table C.4 : p 506

if tension stress $< 0.8 f_r$ ⇒ concrete will not crack.

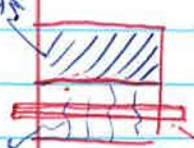
$f_r = 0.24\sqrt{f'_c}$

$0.8 \times 0.24 \times \sqrt{4.5} = 0.41$ ksi



$\Rightarrow f_c = \frac{Mc}{I} = \frac{M \times h/2}{\frac{bh^3}{12}}$

$f_c = \frac{M}{bh^2/6} = \frac{93.36 \times 12}{12 \times \frac{22}{6}} = 1.25$



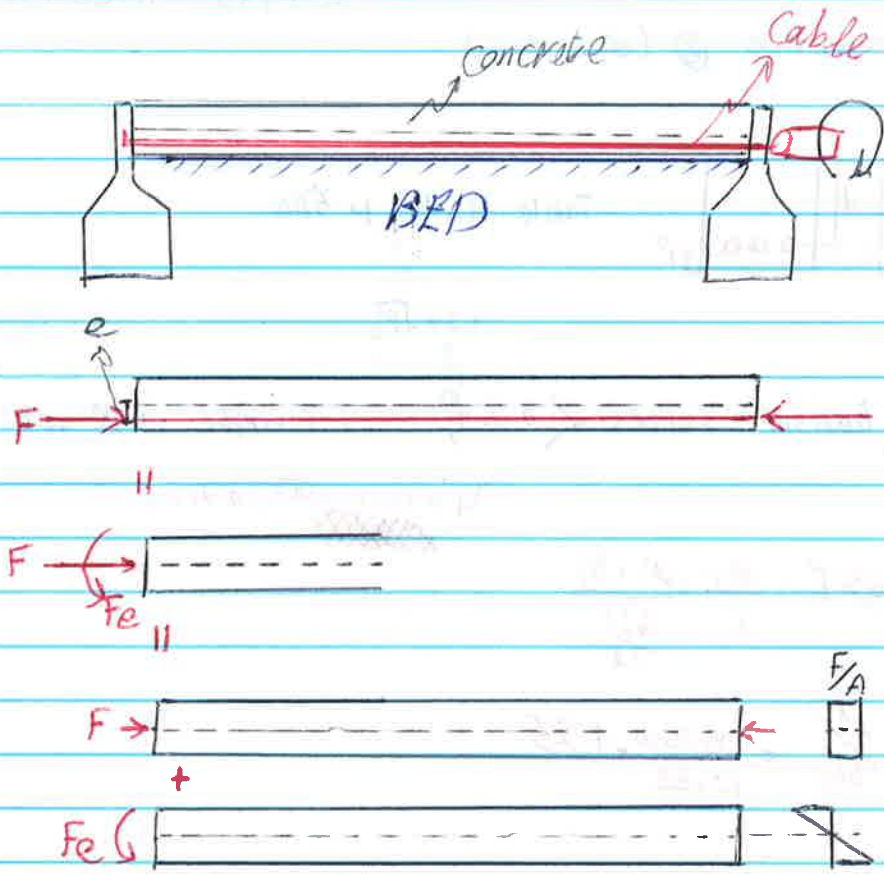
$n = \frac{E_s}{E_c} = \frac{29000}{1820\sqrt{f'_c}} \simeq 7$

$\rightarrow n A_s = 14$

homework: solve step by step 15.1 with span 5 @ 9ft = 45ft for part I of prestressed bridg chapter16:

we use table p.251 and 252 and Appendix p.505

Prestressed bridg:



[redacted]

Bridge Management

Bridge design/consulting → New design

→ Bridge management

↑

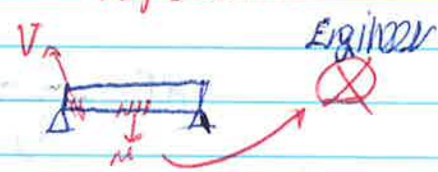
AL DOT

maintenance ↓ inspectors

Permitting

BMS = Bridge Management System

SHM = Structural Health Monitoring



permitting (Rating) → Rutine/Regular circumstances

$$M_u = 1.25\,DL + 1.75(LL + IM)$$

Strength I → $M_u < \phi M_n$ capacity ✓

Service I → compression stress ✓

Service III → tension stress ✓

Fatigue → ... ✓

@ 30 years later ⇒ the bridge is safe or not

o Rating

- inventory (Regular traffic) ① HL-93
- permitting F16 / Tanks ②

(or)

ΦV_n / ΦM_n ← C

① LFD formula: $RF = \frac{C - A_1 D}{A_2 L (I+1)}$ ≥ 1.2

- A_1 → Load factor for dead Load (1.3)
- D → dead load (weight)
- I → Impact factor
- L → Live load (Truck)
- A_2 → Load factor for live load (2.16)

$RF = \frac{\text{Truck Load Capacity}}{\text{Actual Truck}} \geq 1.2$

RF ≥ 1.2 ok ✓

② $RF = \frac{C - A_1 D}{A_2 L (I+1)}$

A_2 → will be less; I → 0.1

because It happens once in 1000 year

for FRP Design we use ACI 440

Steel Bridge