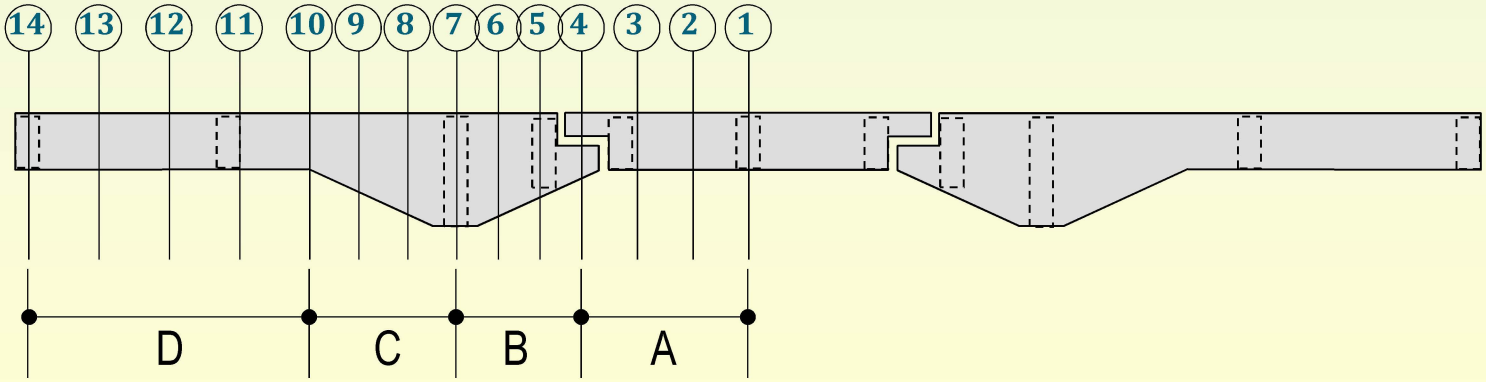
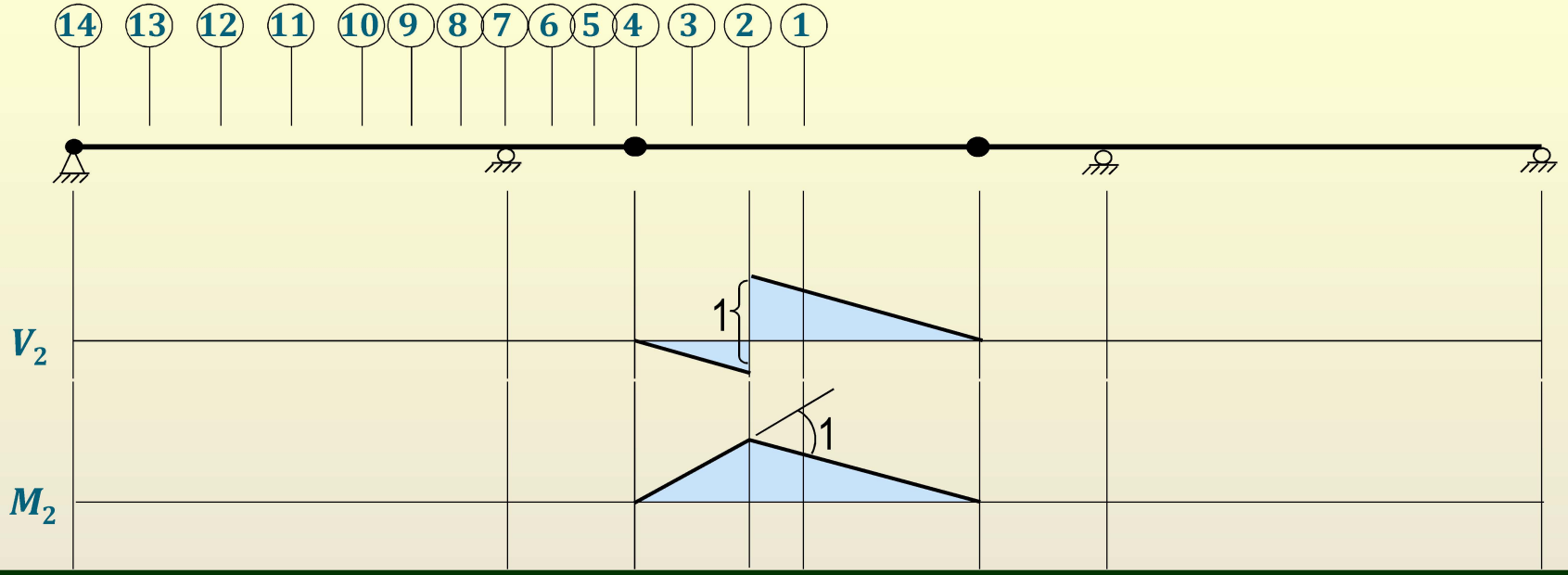
INTERIOR GIRDER : LIVE LOAD ANALYSIS



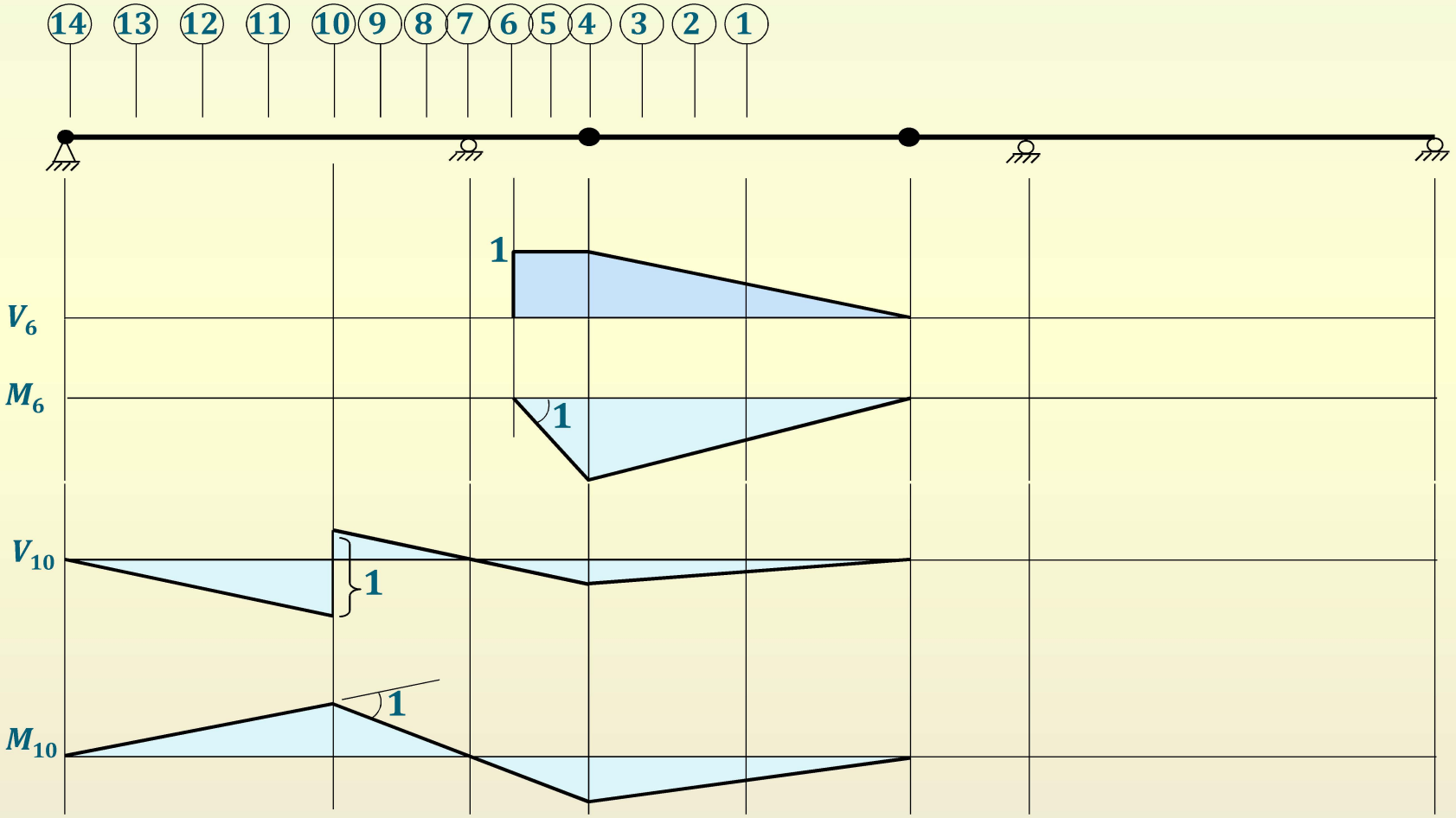
I.L. FOR SHEAR AND MOMENT AT ALL 14 DESIGN SECTIONS NEED TO BE DRAWN

A FEW ARE SHOWN BELOW.....



INTERIOR GIRDER : LIVE LOAD ANALYSIS

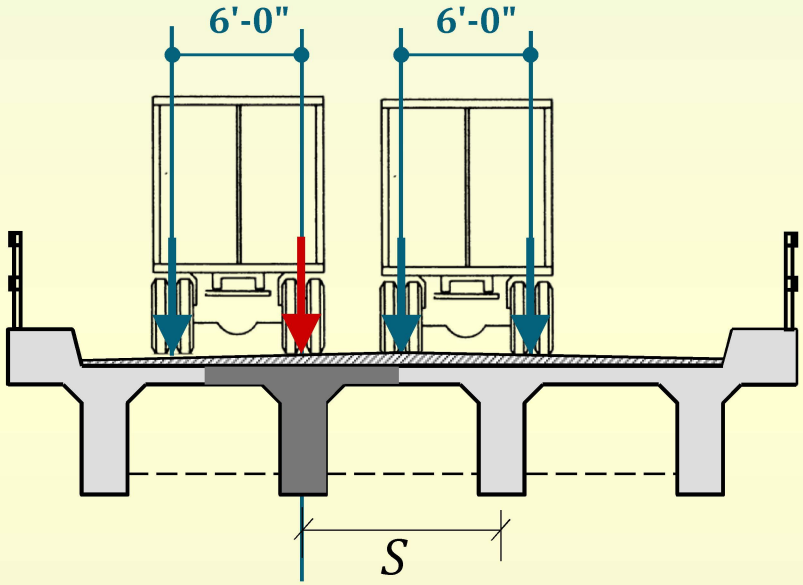
INFLUENCE LINES CONTD……



IL of M = 12 diagrams [M = 0 at 4 and 14], IL of V=15 diagrams [two at 7]

INTERIOR GIRDER : LIVE LOAD ANALYSIS

LIVE LOAD MULTIPLIER



Truck wheel on one side may act directly on an interior girder. The other wheel shall be a distance apart from the girder. Thus full vehicle axle load may not act on one girder. This is considered using a distribution factor. (AASHTO Table 4.6.2.2.2b-1 and 4.6.2.2.3a-1)

INTERIOR GIRDER: Two or more lanes are loaded

Distribution factor for moment, $\alpha_{i,m} = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12.0\,Lt_s^3}\right)^{0.1}$

Distribution factor for shear, $\alpha_{i,v} = 0.2 + \frac{S}{12} - \left(\frac{S}{35}\right)^{2.0}$

L for Use in Live Load Distribution Factor Equations

Force Effect	*L* (ft)
Positive Moment	The length of the span for which moment is being calculated
Negative Moment—Near interior supports of continuous spans from point of contraflexure to point of contraflexure under a uniform load on all spans	The average length of the two adjacent spans
Negative Moment—Other than near interior supports of continuous spans	The length of the span for which moment is being calculated
Shear	The length of the span for which shear is being calculated
Exterior Reaction	The length of the exterior span
Interior Reaction of Continuous Span	The average length of the two adjacent spans

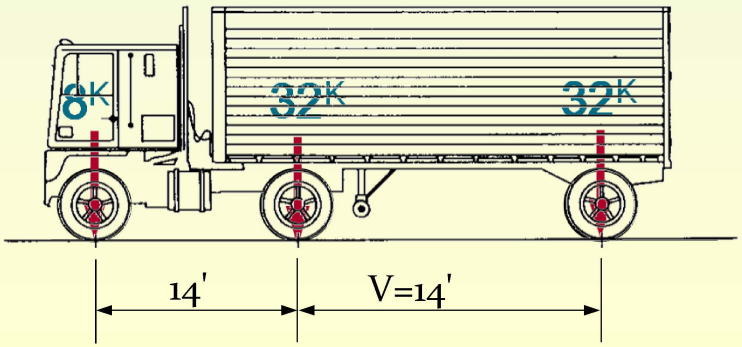
Range of Applicability

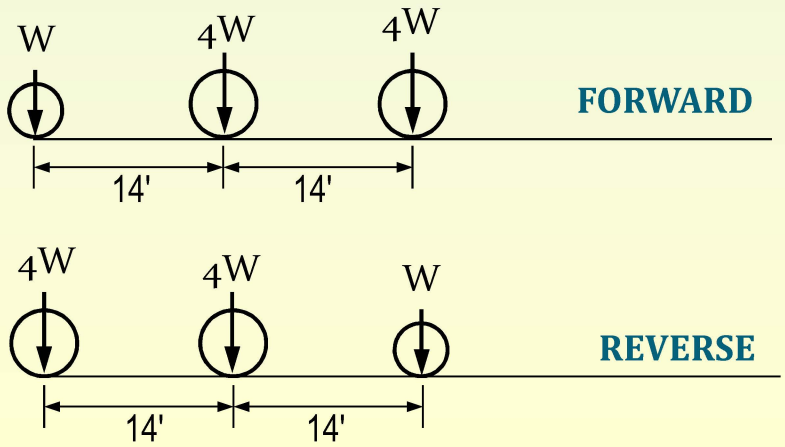
$$3.5 \le S \le 16.0$$
$$4.5 \le t_s \le 12.0$$
$$20 \le L \le 240$$
$$N_b \ge 4$$
$$10{,}000 \le K_g \le 7{,}000{,}000$$

$$\left(\frac{K_g}{12.0\,Lt_s^3}\right)^{0.1} = \mathbf{1.05}$$

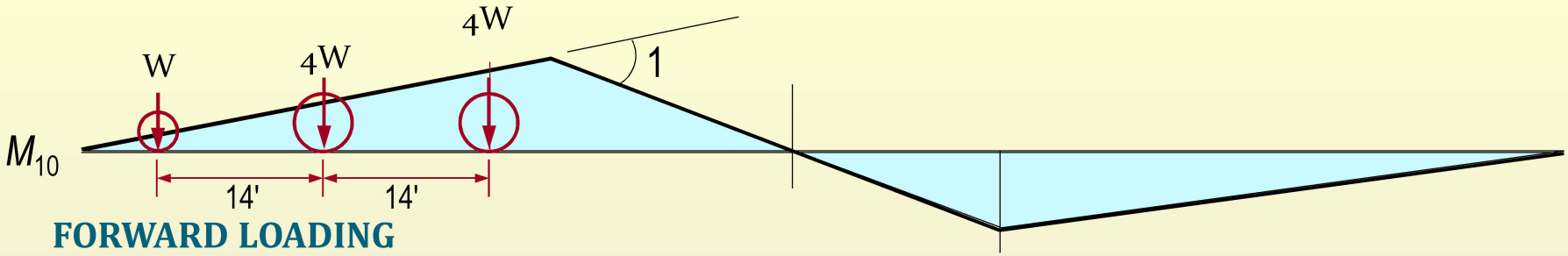
INTERIOR GIRDER : LIVE LOAD ANALYSIS

DESIGN HS20-44 TRUCK LOAD

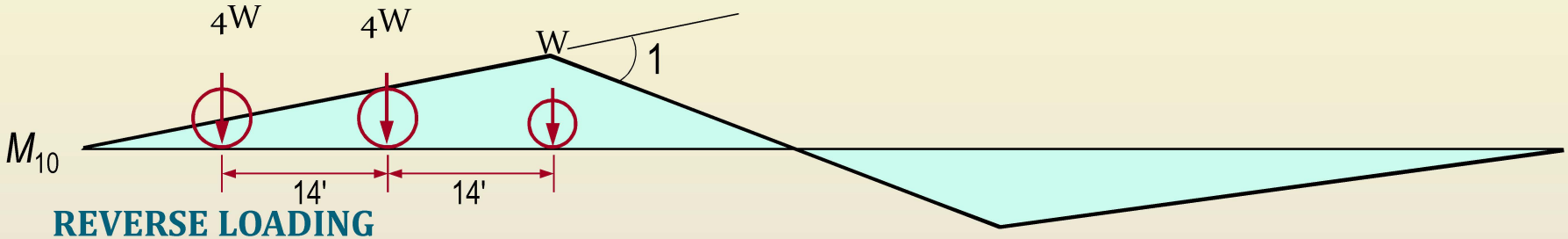




APPLICATION OF DESIGN WHEEL LOAD: MAX. POSITIVE MOMENT AT SECTION 10



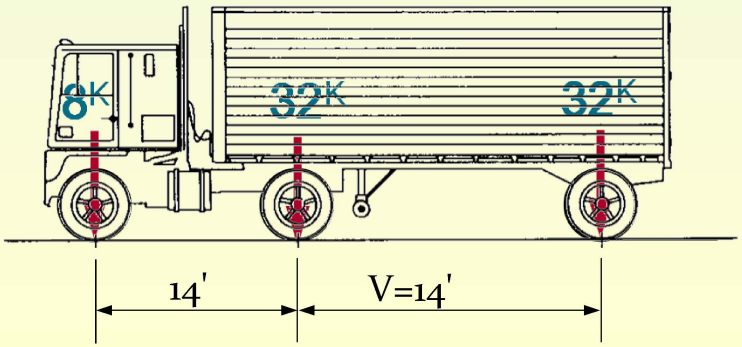
FORWARD LOADING

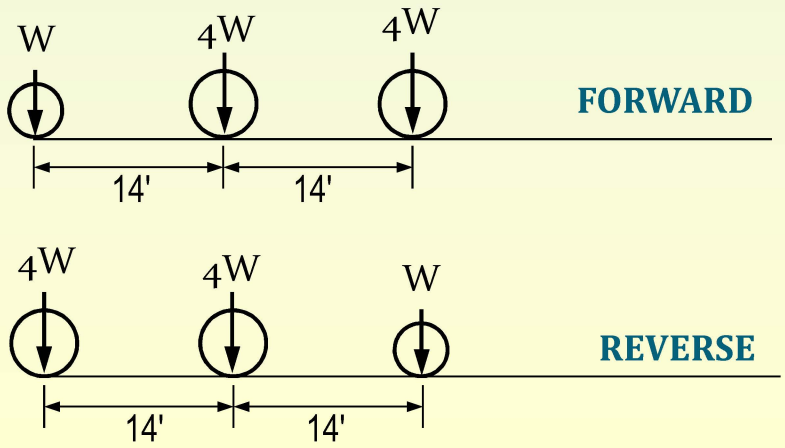


REVERSE LOADING

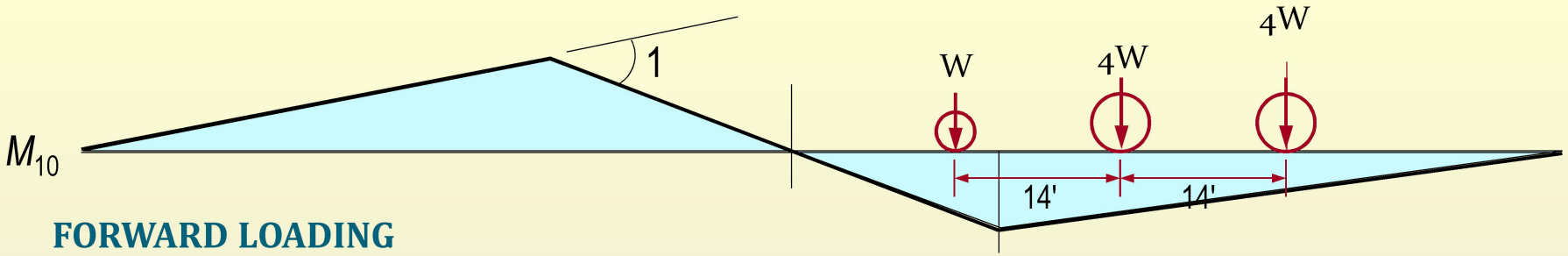
INTERIOR GIRDER : LIVE LOAD ANALYSIS

DESIGN HS20-44 TRUCK LOAD

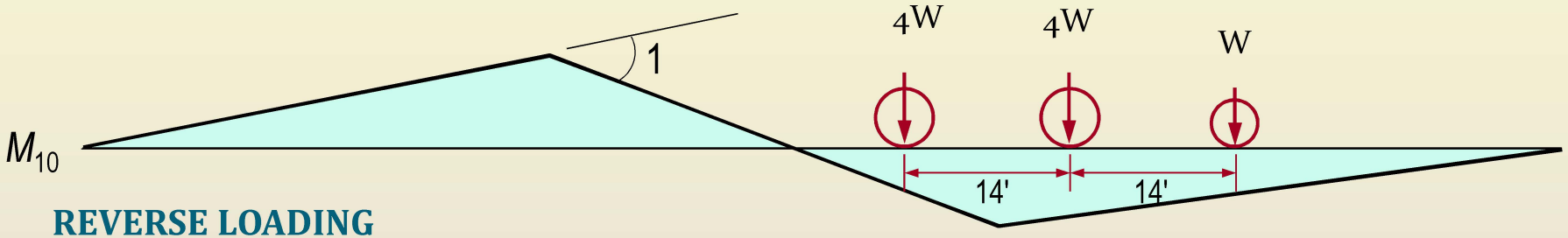




APPLICATION OF DESIGN WHEEL LOAD: MAX. NEGATIVE MOMENT AT SECTION 10



FORWARD LOADING



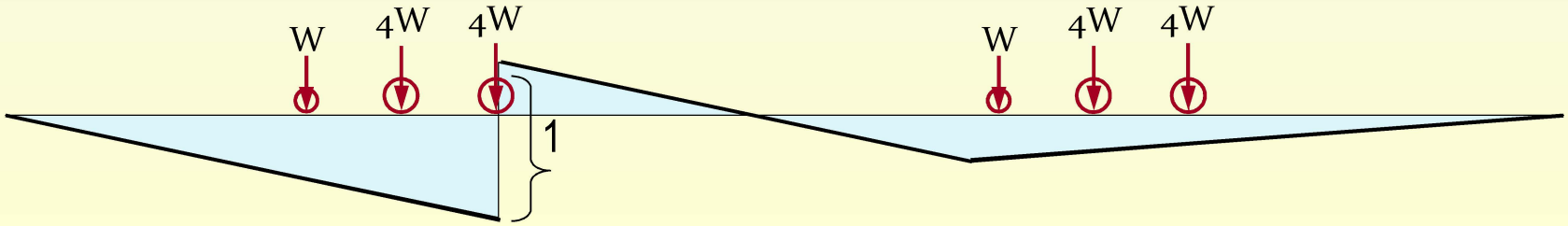
REVERSE LOADING

INTERIOR GIRDER : LIVE LOAD ANALYSIS

DESIGN SHEAR AT SECTION 10

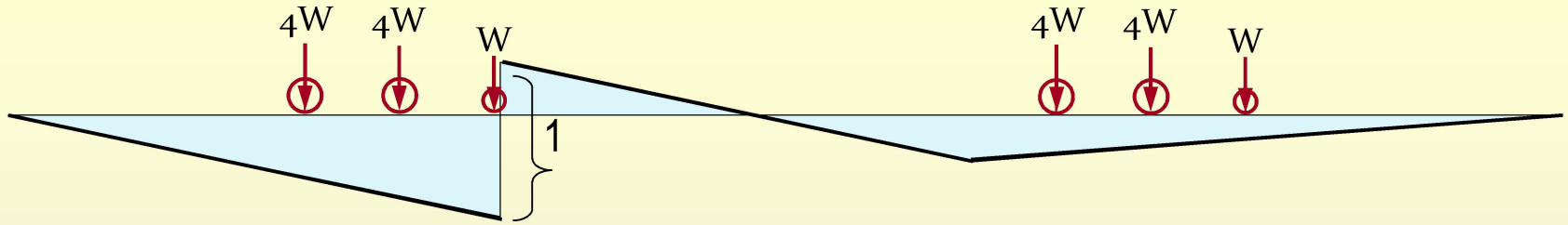
FOR MAXIMUM NEGATIVE: FORWARD LOADING

Possible Alternate Position

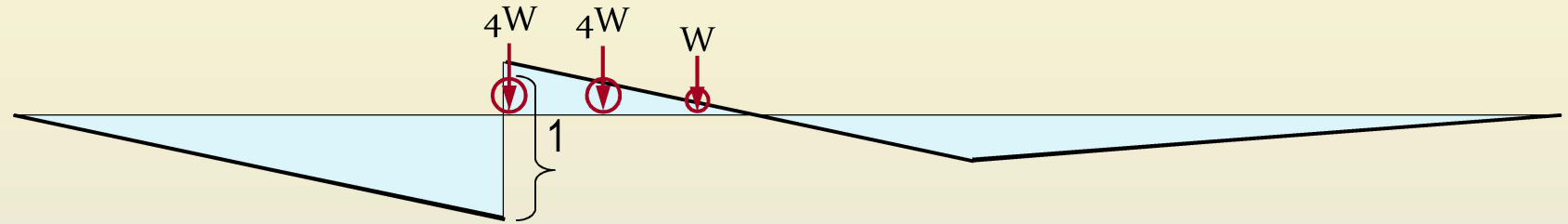


FOR MAXIMUM NEGATIVE: REVERSE LOADING

Possible Alternate Position

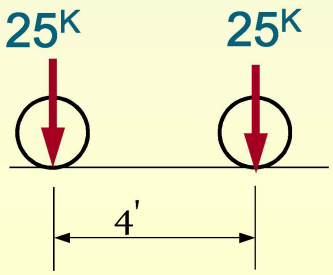


FOR MAXIMUM POSITIVE: REVERSE LOADING

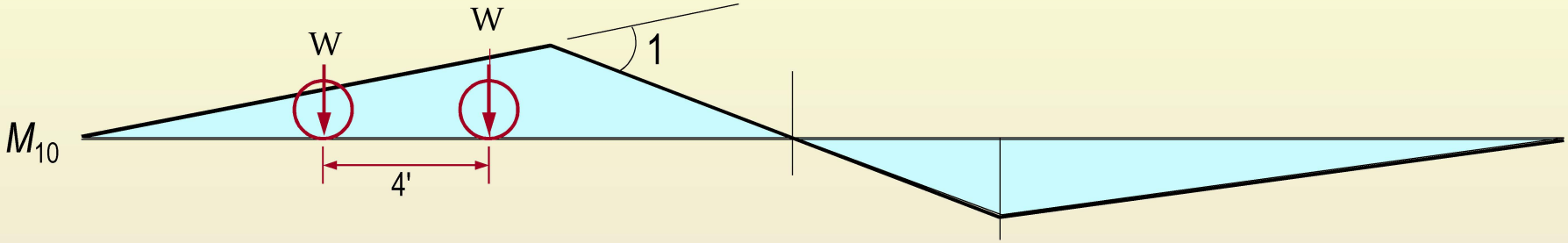


INTERIOR GIRDER : LIVE LOAD ANALYSIS

DESIGN TANDEM LOAD



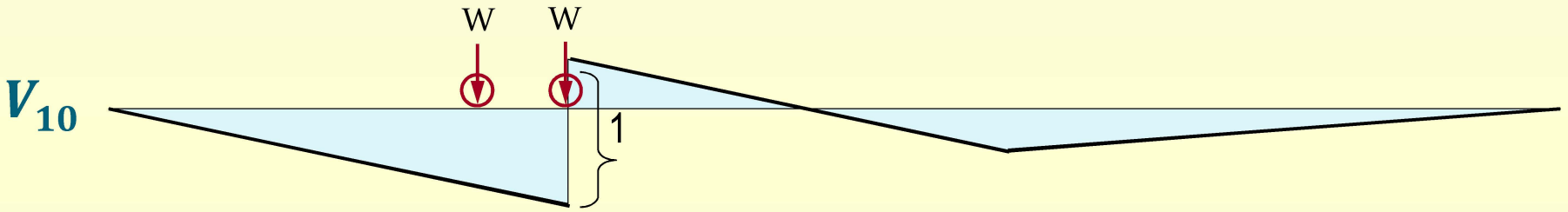
APPLICATION OF DESIGN TANDEM LOAD



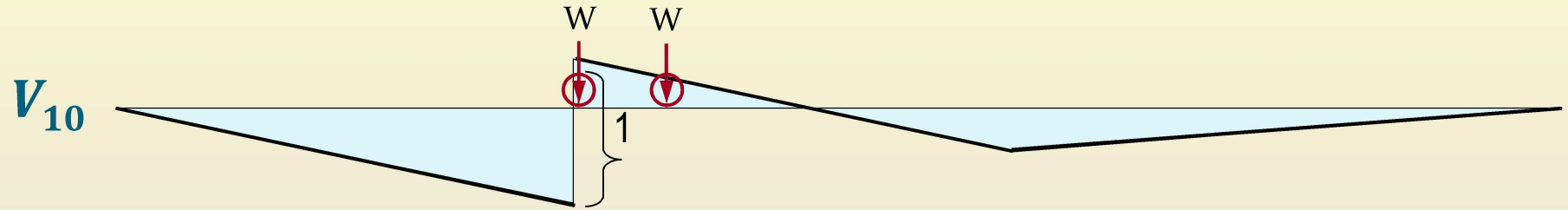
INTERIOR GIRDER : LIVE LOAD ANALYSIS

DESIGN TANDEM LOAD

FOR MAXIMUM NEGATIVE



FOR MAXIMUM POSITIVE

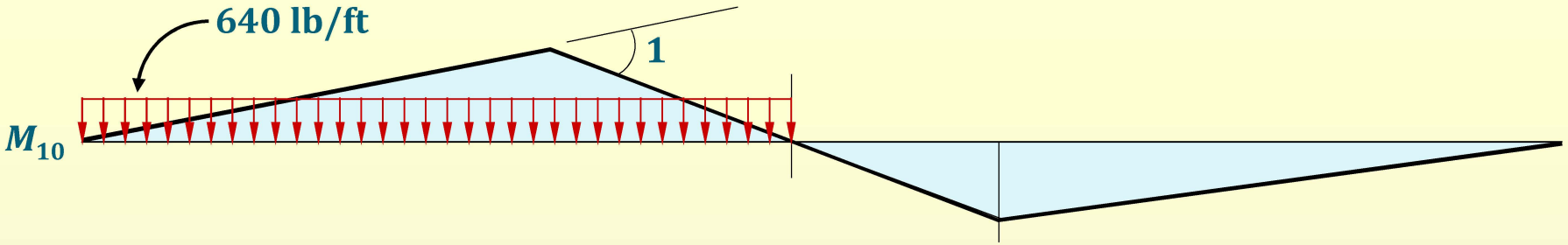


INTERIOR GIRDER : LIVE LOAD ANALYSIS

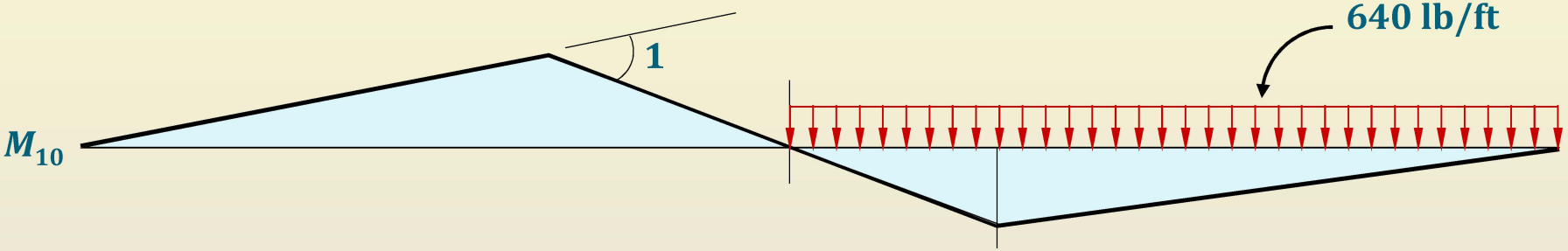
EQUIVALENT LANE LOAD

Equivalent lane load must be used in addition to design wheel load to represent truck train.

FOR POSITIVE MAXIMUM



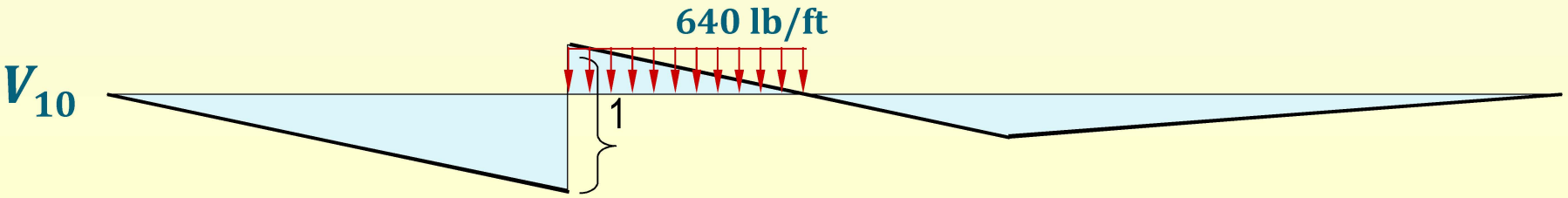
FOR NEGATIVE MAXIMUM



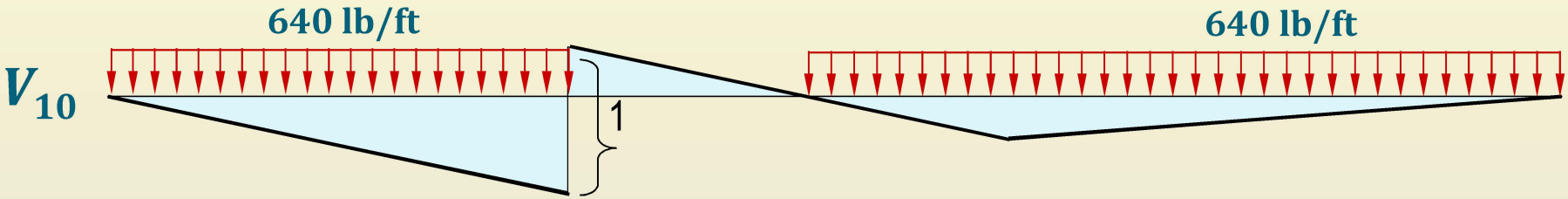
INTERIOR GIRDER : LIVE LOAD ANALYSIS

EQUIVALENT LANE LOAD

FOR MAXIMUM POSITIVE



FOR MAXIMUM NEGATIVE



INTERIOR GIRDER : LOAD COMBINATION

COMBINATION OF SHEAR: INTERIOR GIRDER

	Self weight Shear (DC)	Wearing Course Shear (DW)	$\alpha_{i,v}$	Truck Load Shear (Positive)	Tandem Load Shear (Positive)	Lane Load Shear (Positive)	(1 + IM/100)	Combined Positive Shear (Truck), 1.25a+1.5b+1.75cgd+1.75f	Combined Positive Shear (Tandem), 1.25a+1.5b+1.75cge+1.75f	Truck Load Shear (Negative)	Tandem Load Shear (Negative)	Lane Load Shear (negative)	Combined Negative Shear (Truck), 1.25a+1.5b+1.75cg j + 1.75l	Combined Negative Shear (Tandem), 1.25a+1.5b+1.75cgk + 1.75l	Design Shear (Abs max of h, I, m, n)
Factor	1.25	1.5		1.75	1.75	1.75									
Loc	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1															
2															
3															
4															
5															
6															
7L															
7R															
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10															
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12															
13															
14															

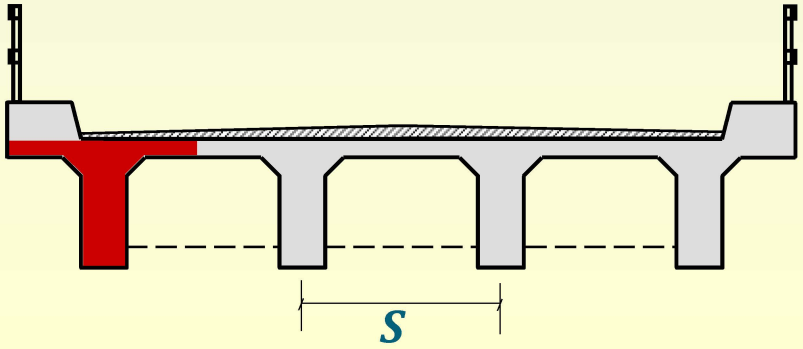
INTERIOR GIRDER : LOAD COMBINATION

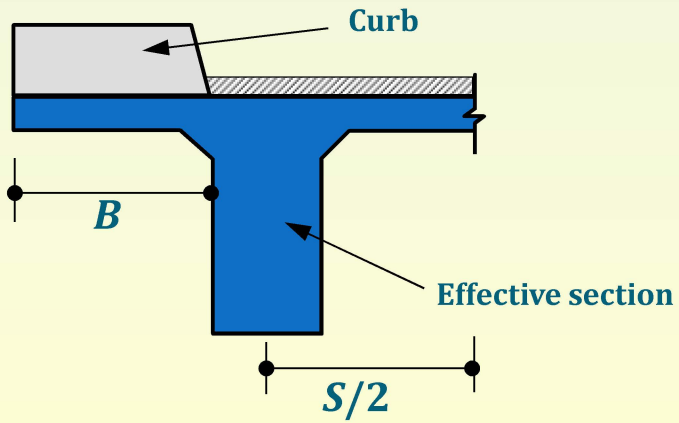
COMBINATION OF MOMENT: INTERIOR GIRDER

	Self weight Moment (DC)	Wearing Course Moment (DW)	$\alpha_{i,m}$	Truck Load Moment (Positive)	Tandem Load Moment (Positive)	Lane Load Moment (Positive)	(1 + IM/100)	Combined Positive Moment (Truck), 1.25a+1.5b+1.75cgd+1.75f	Combined Positive Moment (Tandem), 1.25a+1.5b+1.75cge+1.75f	Truck Load Moment (Negative)	Tandem Load Moment (Negative)	Lane Load Moment (negative)	Combined Negative Moment (Truck), 1.25a+1.5b+1.75cg j + 1.75l	Combined Negative Moment (Tandem), 1.25a+1.5b+1.75cgk + 1.75l	Design Positive Moment (Max of h, i)	Design Negative Moment (Max of m, n)
Factor	1.25	1.5		1.75	1.75	1.75										
Loc	a	b	c	d	e	f	g	h	i	j	k	l	m	n		
1																
2																
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DESIGN OF EXTERIOR GIRDER

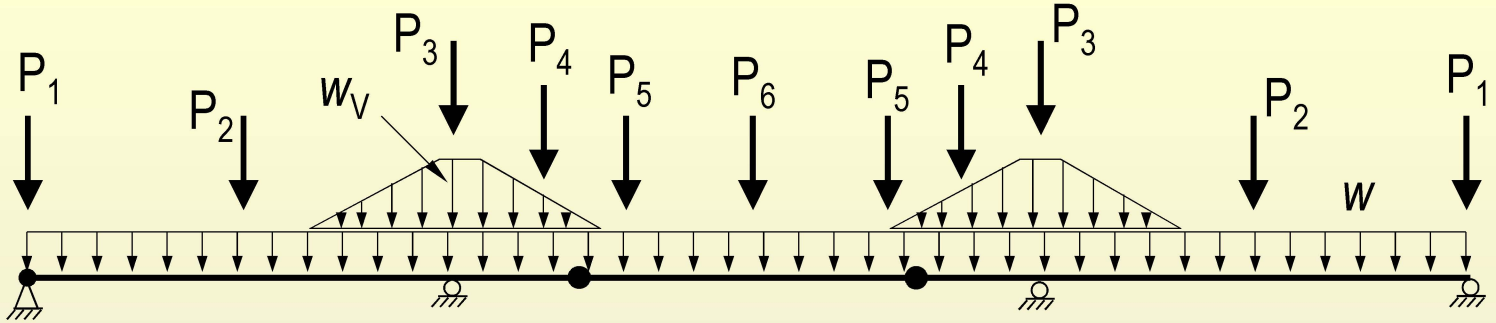
DEAD LOAD ANALYSIS





w shall be contributed by

1. Exterior girder section, curb, railing and (DC)
2. wearing surface (DW)



Loads from diaphragm P_1, P_2 etc. shall be halved.

Trapezoidal load w_V shall remain unchanged.

Constant udl *w* shall be recalculated.

Based on above loading, draw the SFD and BMD and determine values at 14 locations as before.

DESIGN OF EXTERIOR GIRDER

LIVE LOAD ANALYSIS

Distribution factor for moment

$$\alpha_{e,m} = e\alpha_{i,m}$$

$$e = 0.77 + \frac{d_e}{9.1}$$

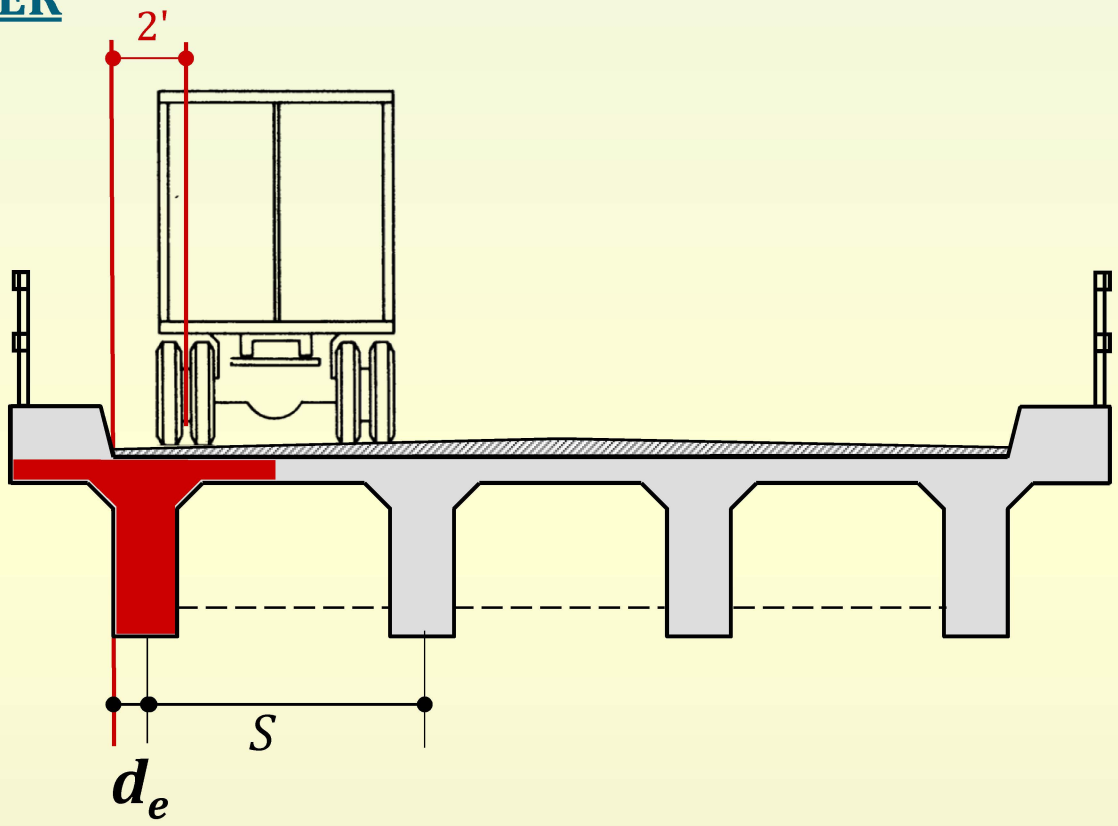
$$-1.0 \le d_e \le 5.5$$

Distribution factor for shear

$$\alpha_{e,v} = e\alpha_{i,v}$$

$$e = 0.6 + \frac{d_e}{10}$$

Here d_e is in feet.



Now prepare the load combination tables for shear and moment. Dead load values shall be recalculated based on revised loading (DC and DW). Live load values may be directly copied from previous load combination tables and combinations may be performed with α values for exterior girder.

INTERIOR GIRDER : LOAD COMBINATION

COMBINATION OF SHEAR: INTERIOR GIRDER

	Self weight Shear (DC)	Wearing Course Shear (DW)	$\alpha_{e,v}$	Truck Load Shear (Positive)	Tandem Load Shear (Positive)	Lane Load Shear (Positive)	(1 + IM/100)	Combined Positive Shear (Truck), 1.25a+1.5b+1.75cgd+1.75f	Combined Positive Shear (Tandem), 1.25a+1.5b+1.75cge+1.75f	Truck Load Shear (Negative)	Tandem Load Shear (Negative)	Lane Load Shear (negative)	Combined Negative Shear (Truck), 1.25a+1.5b+1.75cg j + 1.75l	Combined Negative Shear (Tandem), 1.25a+1.5b+1.75cgk + 1.75l	Design Shear (Abs max of h, I, m, n)
Factor	1.25	1.5		1.75	1.75	1.75									
Loc	a	b	c	d	e	f	g	h	i	j	k	l	m	n	
1															
2															
3															
4															
5															
6															
7L															
7R															
8															
9															
10															
11															
12															
13															
14															

INTERIOR GIRDER : LOAD COMBINATION

COMBINATION OF MOMENT: INTERIOR GIRDER

	Self weight Moment (DC)	Wearing Course Moment (DW)	$\alpha_{e,m}$	Truck Load Moment (Positive)	Tandem Load Moment (Positive)	Lane Load Moment (Positive)	(1 + IM/100)	Combined Positive Moment (Truck), 1.25a+1.5b+1.75cgd+1.75f	Combined Positive Moment (Tandem), 1.25a+1.5b+1.75cge+1.75f	Truck Load Moment (Negative)	Tandem Load Moment (Negative)	Lane Load Moment (negative)	Combined Negative Moment (Truck), 1.25a+1.5b+1.75cg j + 1.75l	Combined Negative Moment (Tandem), 1.25a+1.5b+1.75cgk + 1.75l	Design Positive Moment (Max of h, i)	Design Negative Moment (Max of m, n)
Factor	1.25	1.5		1.75	1.75	1.75										
Loc	a	b	c	d	e	f	g	h	i	j	k	l	m	n		
1																
2																
3																
5																
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8																
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10																
11																
12																
13																

REINFORCEMENT DESIGN OF T-GIRDERS (AASHTO 2012 Section 5)

Resistance factor φ

Moment	0.90
Shear	0.90

Positive Steel (T-section, bottom steel)

$$A_s \geq \frac{M_u}{\phi f_y\left(d-\frac{a}{2}\right)} \approx \frac{M_u}{\phi f_y(jd)}$$

Assume $jd \approx 0.95d$

Check $A_s \geq A_{s,\min} = \frac{200}{f_y} b_w d$

where, f_y is in psi

Effective flange width, b_e of T-Girder

b_e = Spacing of girders = S

Check, $a = \frac{A_s f_y}{0.85 f_c' b_e}$

Revise, $A_s = \frac{M_u}{\phi f_y\left(d-\frac{a}{2}\right)}$

Revise, $a = \frac{A_s f_y}{0.85 f_c' b_e}$

Determine, β_1

Depth of neutral axis, $c = a/\beta_1$

Check $c < {}^3/_8\, d$ (tension controlled)

Finally, $\phi M_n = \phi A_s f_y\left(d-\frac{a}{2}\right) \geq M_u$

Negative Steel (Rectangular Section, top steel)

Design procedure same as before except that use beam web width b_w instead of b_e.

REINFORCEMENT DESIGN OF T-GIRDERS (AASHTO 2012 Section 5)

Design for Shear

Shear reinforcement required when $V_u > 0.5\phi V_c$ (V_u and V_c are in kip)

If $V_u > 0.25\phi f_c' b_w d$ then section has to be revised. (f_c' in ksi, b_w and d are in inch)

Nominal shear resistance, $V_n = V_c + V_s$
where $V_c = 0.0316\beta(\sqrt{f_c'})b_w d$, where $\beta = 2.0$

Stirrup spacing, $s = \dfrac{\phi A_v f_y d}{V_u - \phi V_c}$

Minimum transverse reinforcement, $A_v \geq 0.0316\sqrt{f_c'}\dfrac{b_w s}{f_y}$

where, A_v in in^2, f_c' in ksi, b_w is beam web width in inch, s is stirrup spacing in inch, f_y in ksi.

Shear stress in concrete $v_u = V_u/(\phi b_w d)$

Maximum stirrup spacing:

$s_{max} = 0.8d \leq 24$" when $v_u < 0.125 f_c'$

$s_{max} = 0.4d \leq 12$" when $v_u \geq 0.125 f_c'$

SKIN REINFORCEMENT

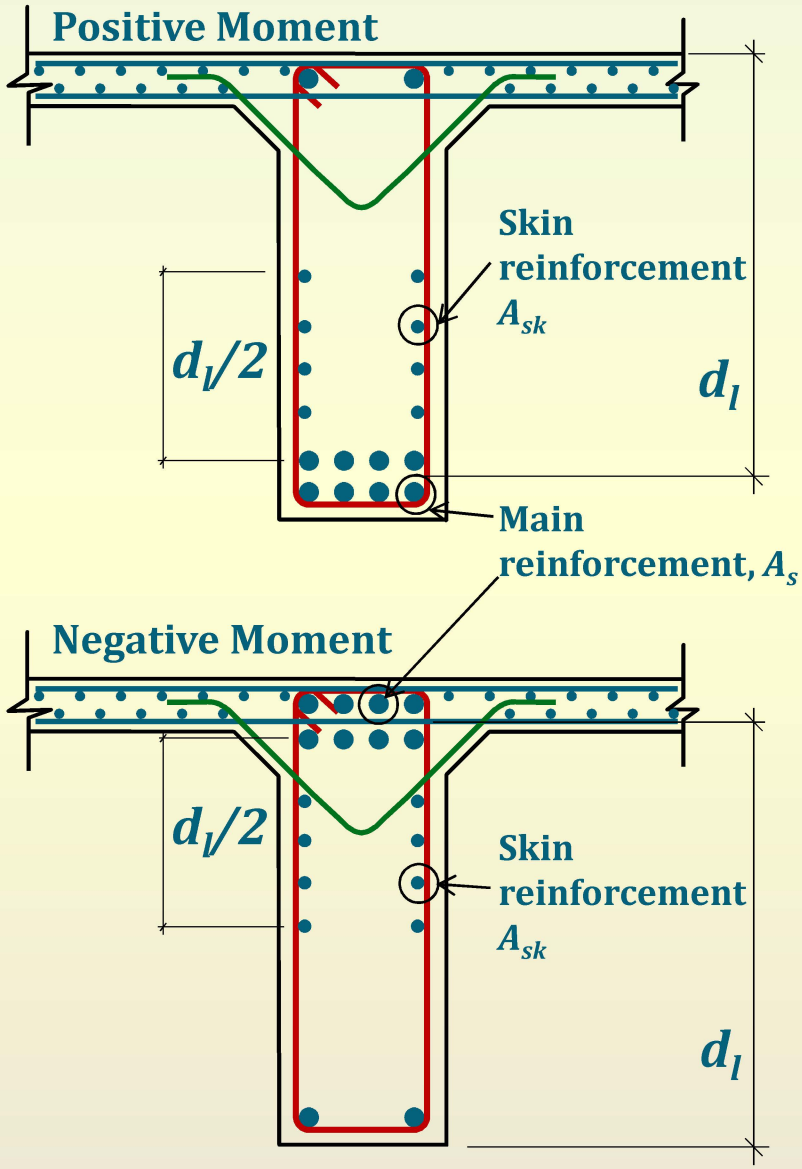
If d_ℓ of non-prestressed or partially prestressed concrete members exceeds 3.0 ft, longitudinal skin reinforcement shall be uniformly distributed along both side faces of the component for a distance d_ℓ /2 (inch) nearest the flexural tension reinforcement.

The area of skin reinforcement A_{sk} in in^2/ft of height on each side face shall satisfy:

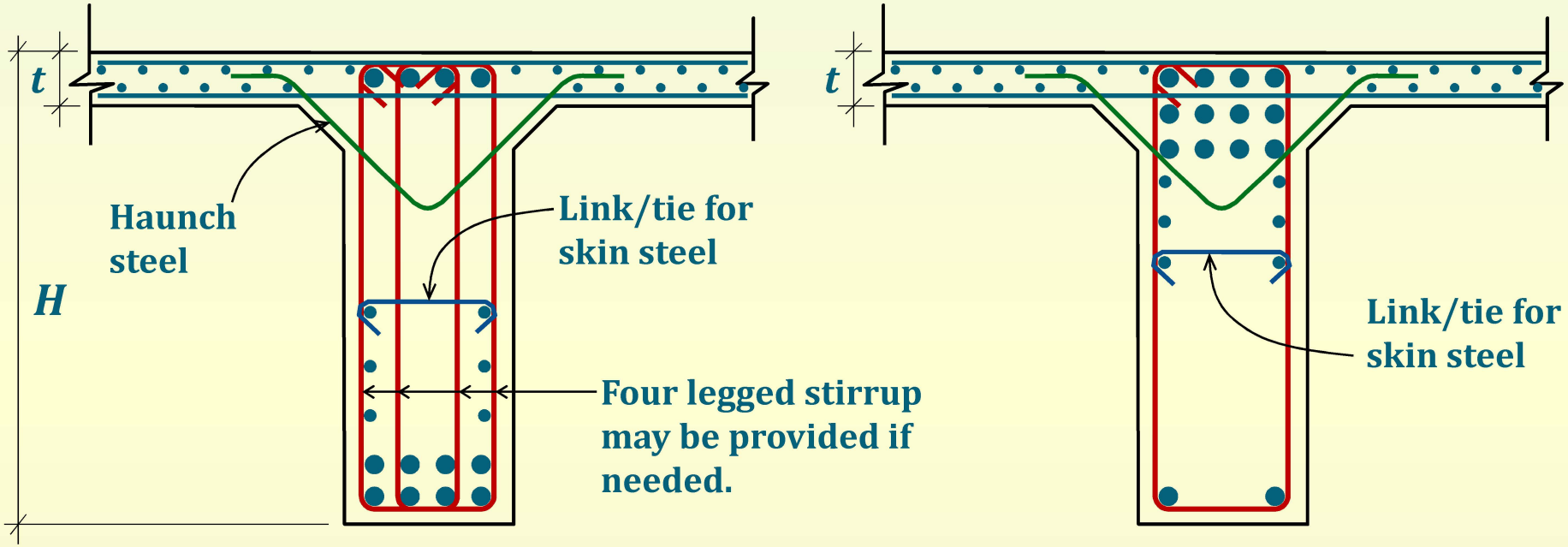
$$A_{sk} \geq 0.012(d_l - 30) \leq \frac{A_s}{4}$$

However, the total area of longitudinal skin reinforcement (per face) need not exceed one-fourth of the required flexural tensile reinforcement A_s.

The maximum spacing of the skin reinforcement shall not exceed either $d_\ell/6$ or 12.0 in.



REINFORCEMENT DETAILING OF T-GIRDERS



Haunch Steel

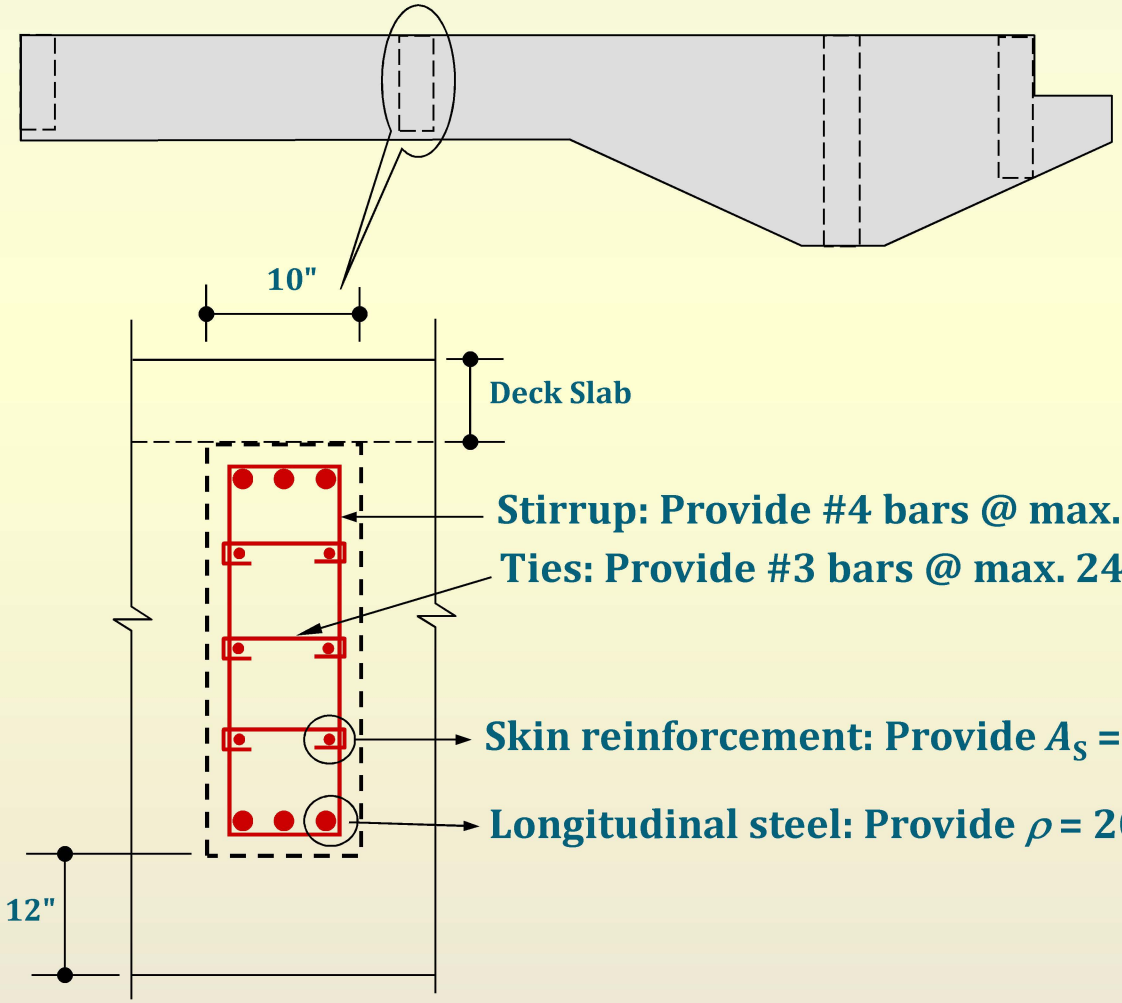
Provide #3 or #4 bar @ 6” ~ 9” c/c along the length of the girder

Link/Tie for skin reinforcement

Provide #3 or #4 bars. Vertical and longitudinal spacing may not exceed 24”.

DESIGN OF DIAPHRAGMS

NON LOAD BEARING.
FOR STABILITY OF MAIN GIRDERS.



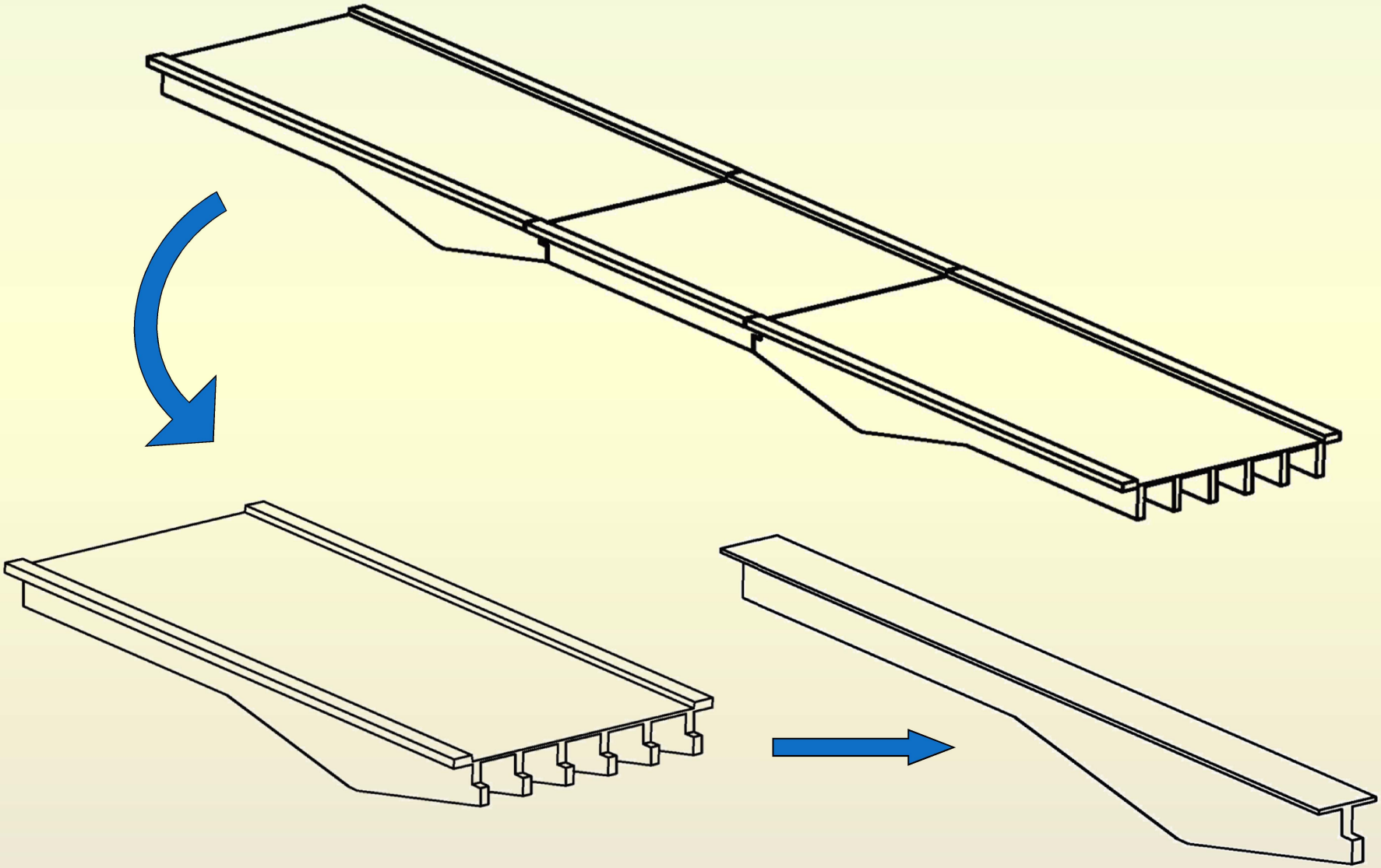
Stirrup: Provide #4 bars @ max. 18" on centers.

Ties: Provide #3 bars @ max. 24" on centre.

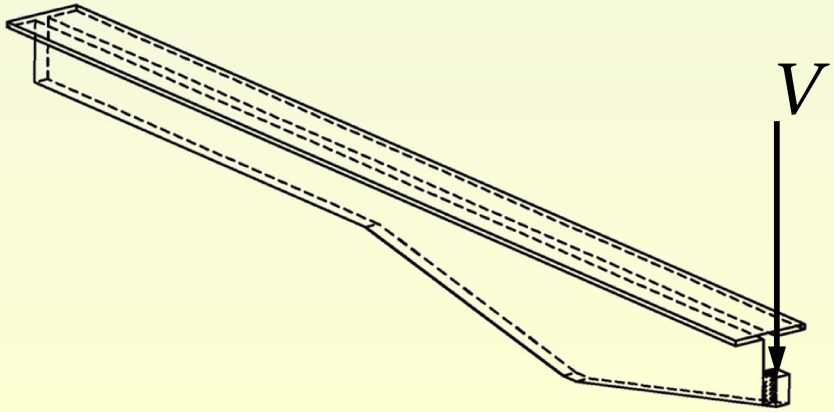
Skin reinforcement: Provide $A_S = 0.002bt$

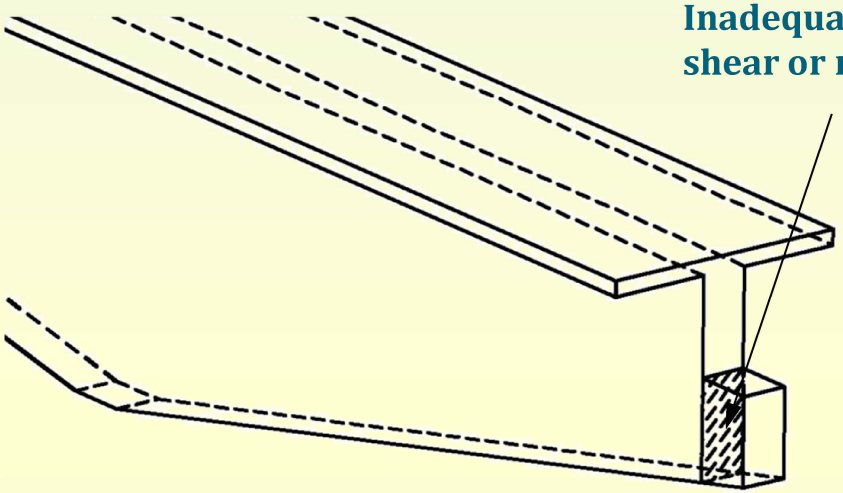
Longitudinal steel: Provide $\rho = 200/f_y$ at top and bottom.

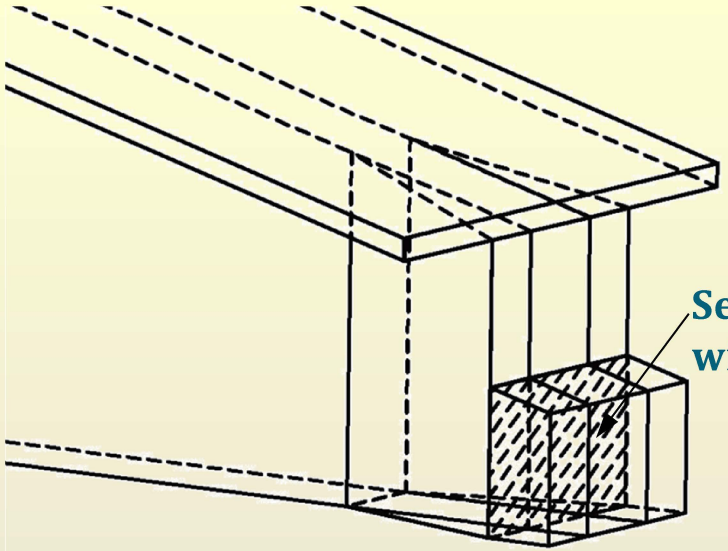
DESIGN OF ARTICULATION

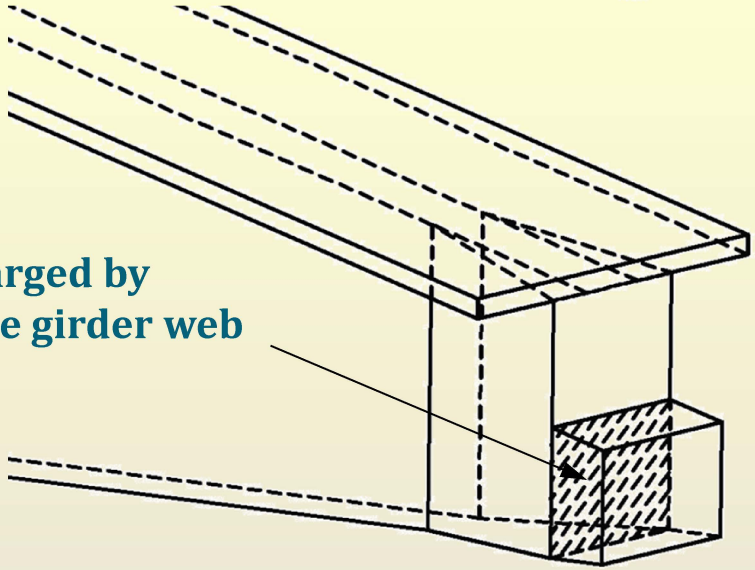


DESIGN OF ARTICULATION

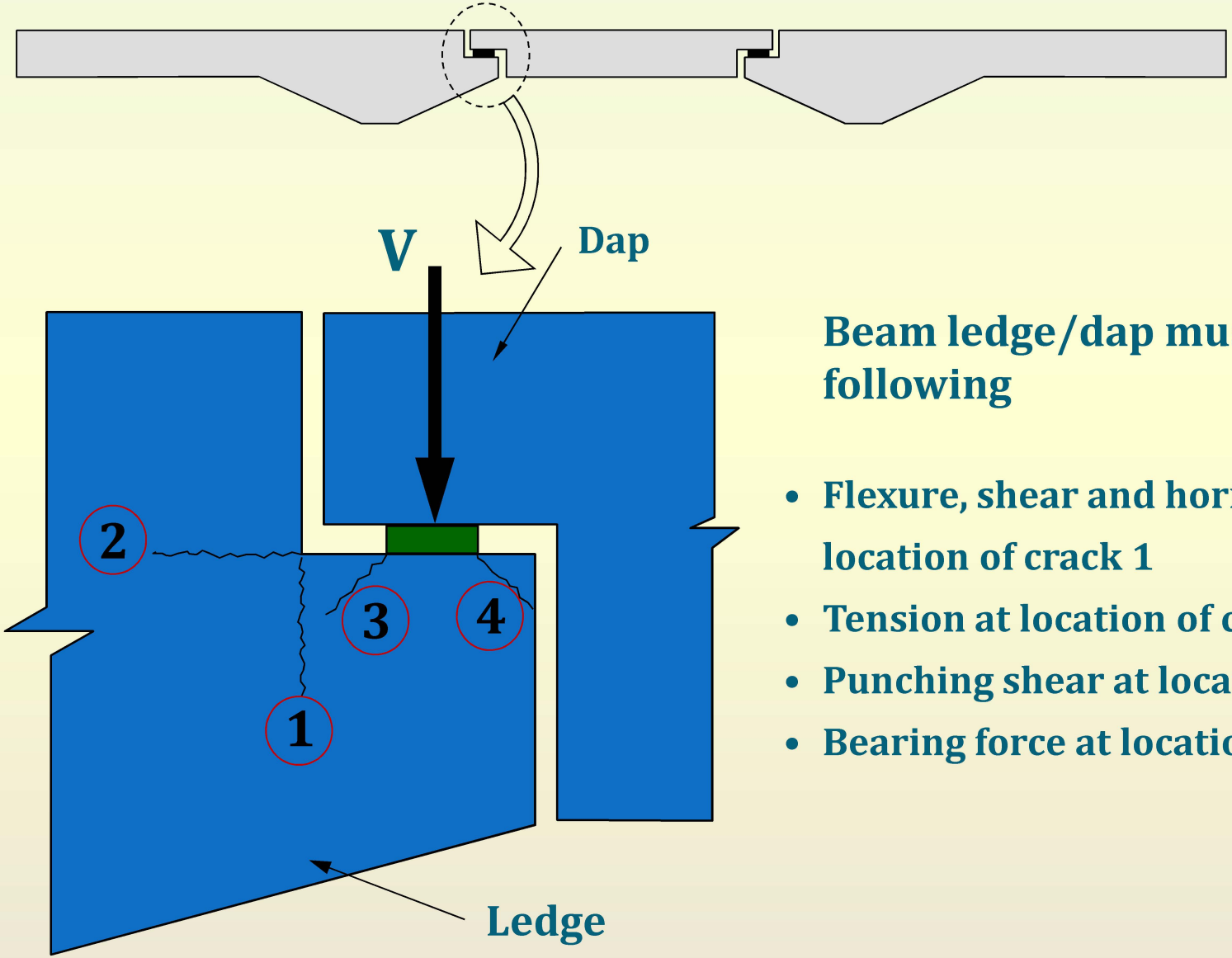








DESIGN OF ARTICULATION

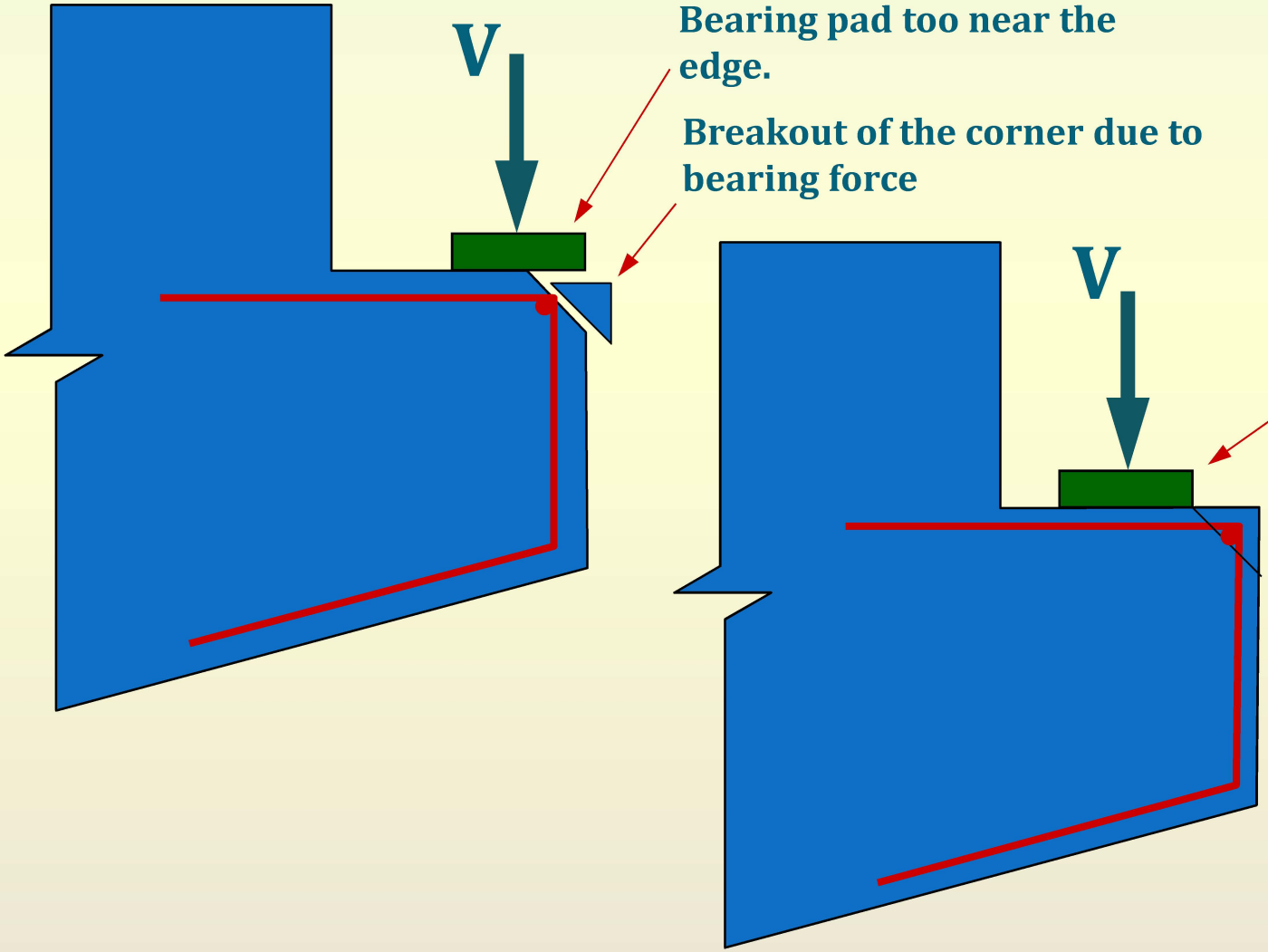


Beam ledge/dap must resist the following

- Flexure, shear and horizontal forces at location of crack 1
- Tension at location of crack 2
- Punching shear at location of crack 3
- Bearing force at location of crack 4

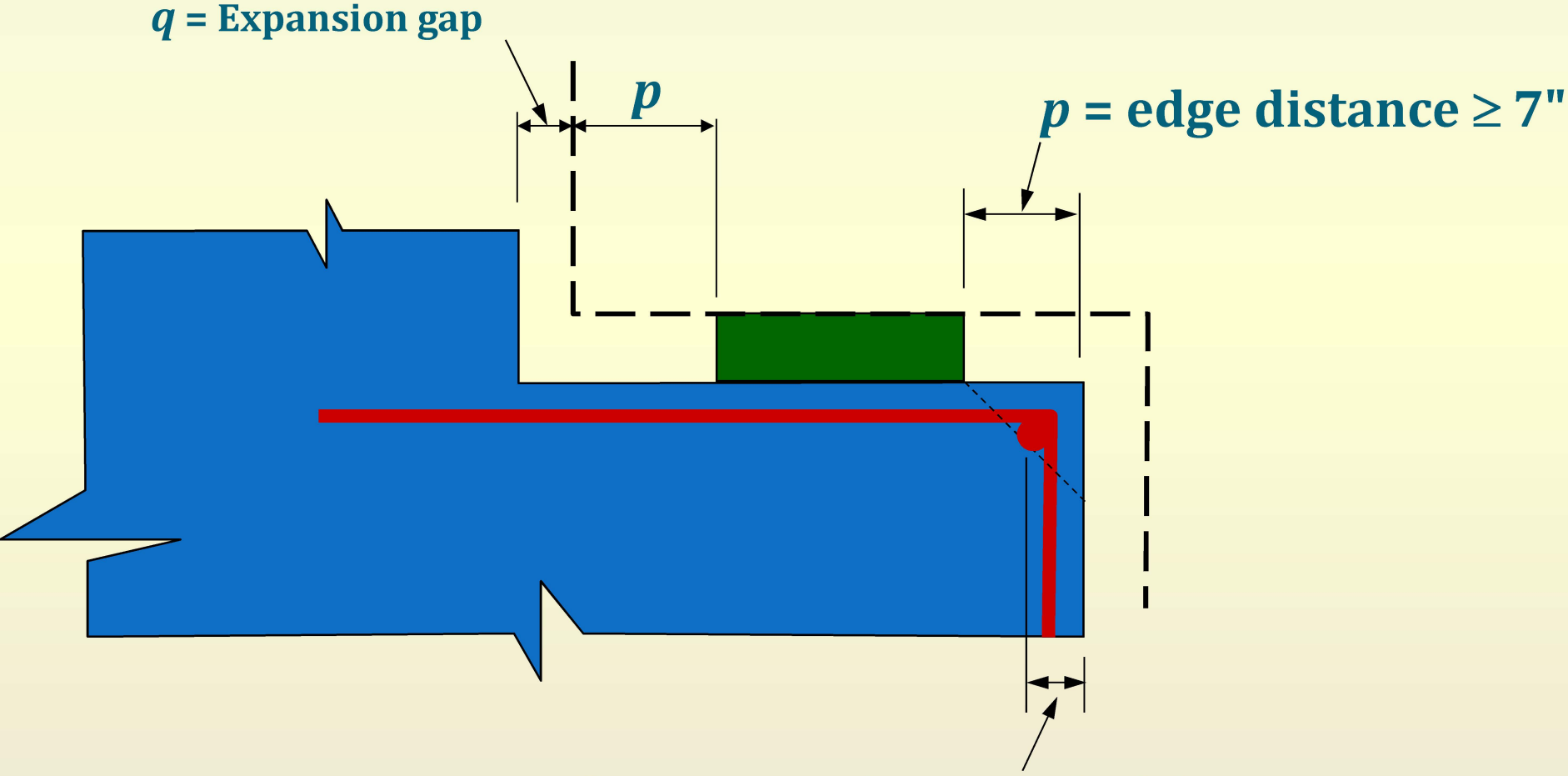
DESIGN OF ARTICULATION

Clearance Requirement around bearing pad.



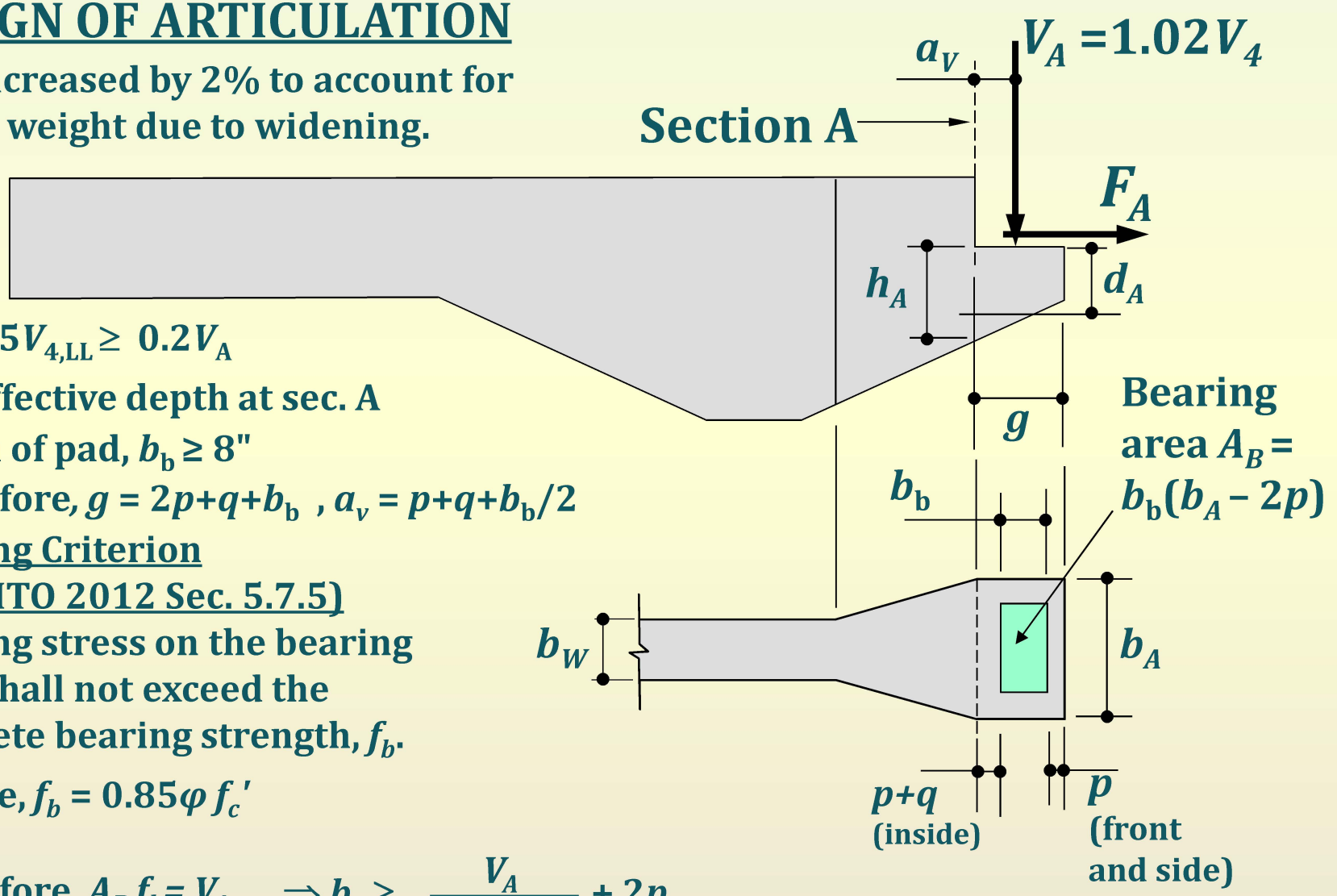
DESIGN OF ARTICULATION

Clearance Requirement around bearing pad.



DESIGN OF ARTICULATION

V_4 is increased by 2% to account for excess weight due to widening.



$F_A = 0.5V_{4,LL} \geq 0.2V_A$

d_A = effective depth at sec. A

Width of pad, $b_b \geq 8"$

Therefore, $g = 2p+q+b_b$, $a_v = p+q+b_b/2$

Bearing area $A_B = b_b(b_A - 2p)$

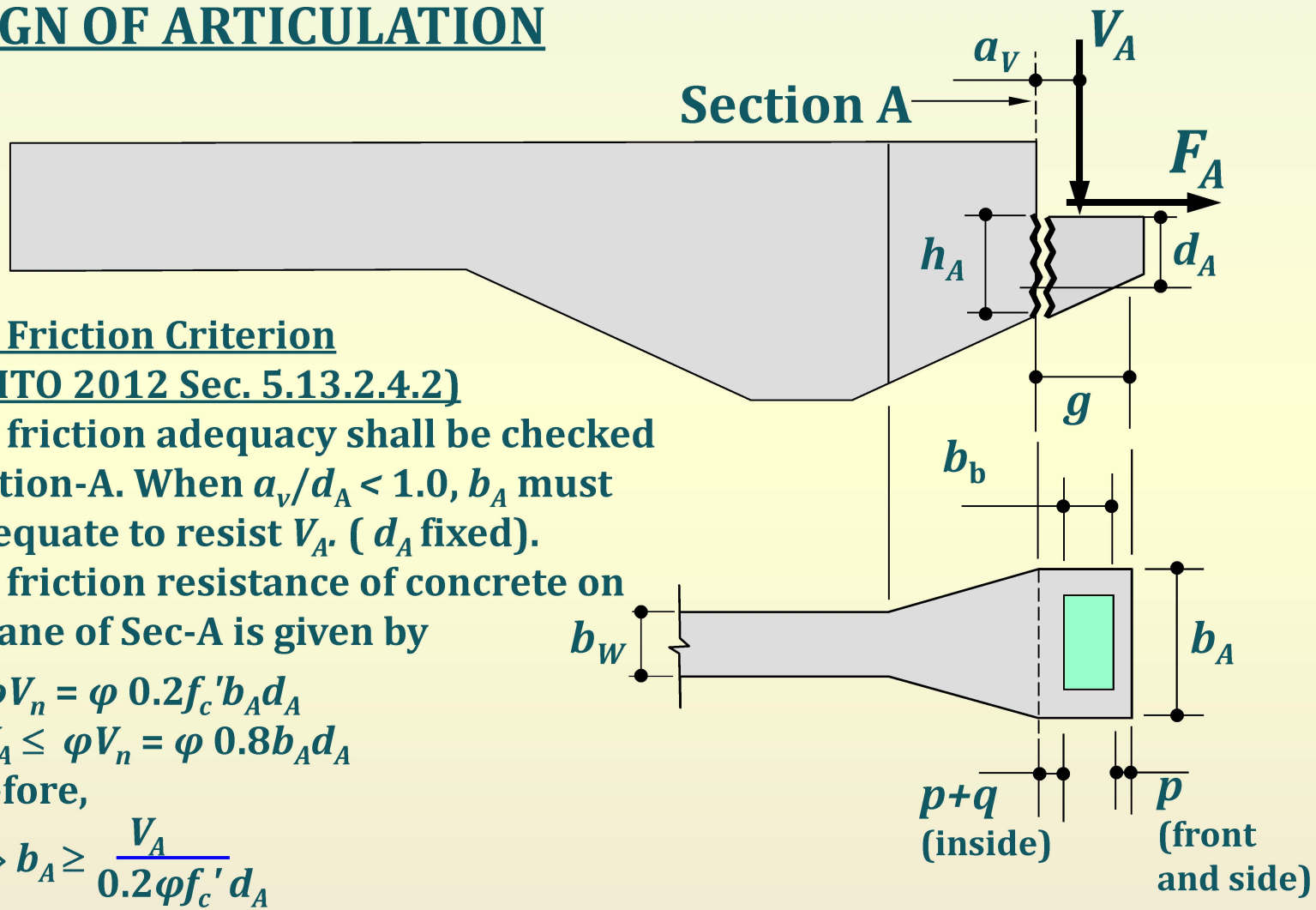
Bearing Criterion (AASHTO 2012 Sec. 5.7.5)

Bearing stress on the bearing area shall not exceed the concrete bearing strength, f_b.

Where, $f_b = 0.85\varphi f_c'$

Therefore, $A_B f_b = V_A \quad \Rightarrow b_A \geq \dfrac{V_A}{b_b f_b} + 2p$

DESIGN OF ARTICULATION



Shear Friction Criterion (AASHTO 2012 Sec. 5.13.2.4.2)

Shear friction adequacy shall be checked at Section-A. When $a_v/d_A < 1.0$, b_A must be adequate to resist V_A. (d_A fixed).

Shear friction resistance of concrete on the plane of Sec-A is given by

$V_A \le \varphi V_n = \varphi\ 0.2 f_c' b_A d_A$

And $V_A \le \varphi V_n = \varphi\ 0.8 b_A d_A$

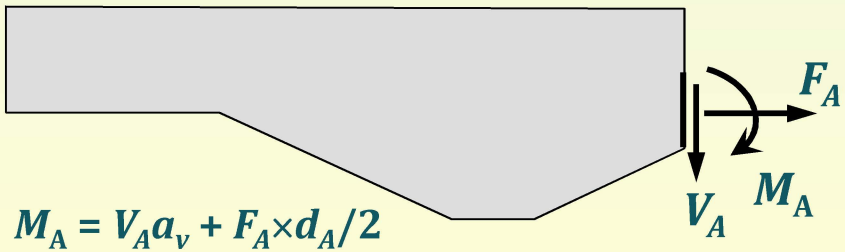
Therefore,

$$\Rightarrow b_A \ge \frac{V_A}{0.2\varphi f_c' d_A}$$

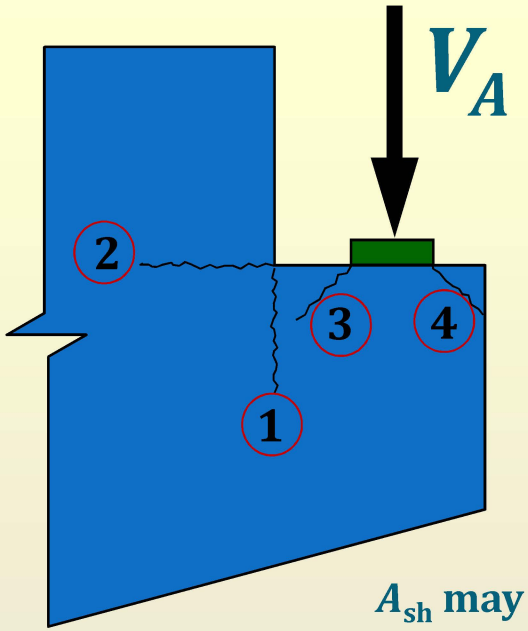
$$\text{or, } \Rightarrow b_A \ge \frac{V_A}{\varphi\ 0.8 d_A}$$

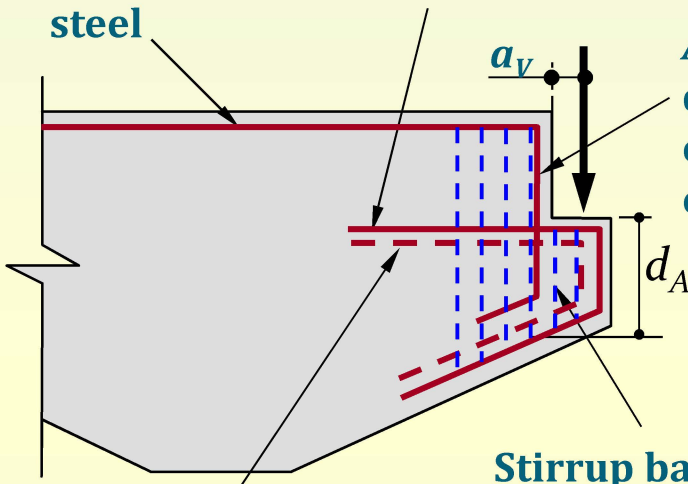
Final value of b_A shall be the larger of the value obtained from bearing and shear friction criteria.

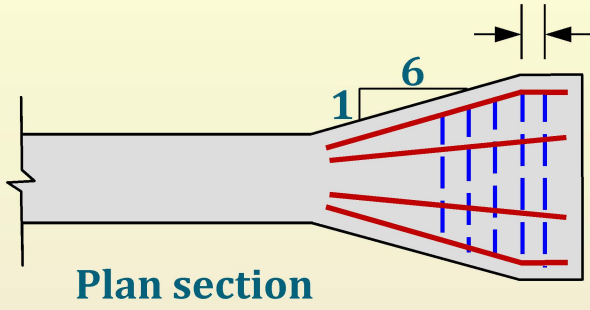
DESIGN OF ARTICULATION



$M_A = V_A a_v + F_A \times d_A/2$

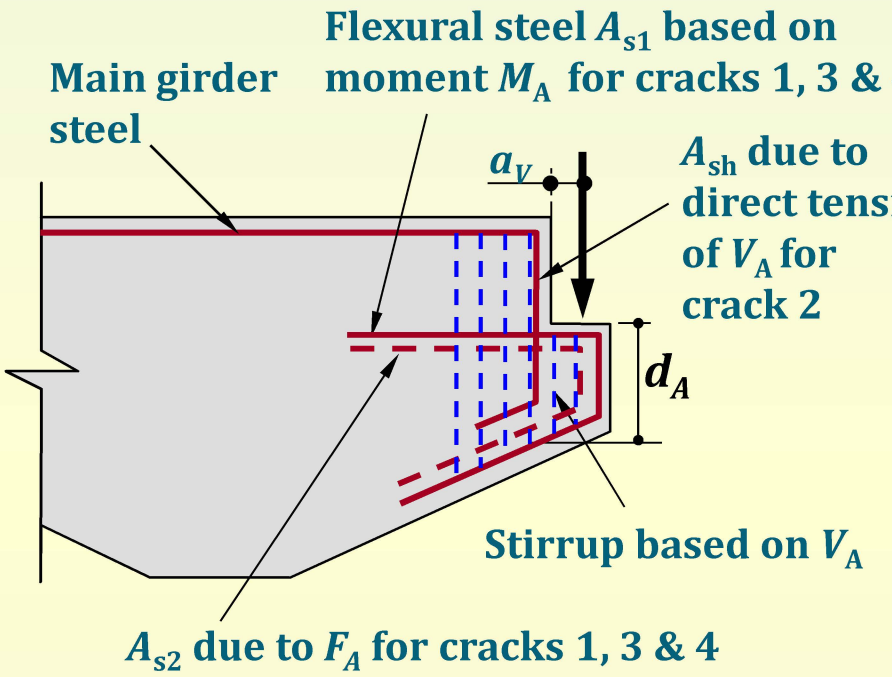






A_{sh} may be provided by extending and bending the main top bar as required. Similarly, A_{s1} and A_{s2} may be provided by extending and bending the girder bottom steel.

DESIGN OF ARTICULATION



$$A_{s1} = \frac{M_A}{\varphi f_y (d_A - a/2)}, \quad a = \frac{A_{s1} f_y}{0.85 f'_c b_A}, \quad \varphi = 0.9$$

$$A_{sh} = \frac{V_A}{\varphi f_y}, \quad A_{s2} = \frac{F_A}{\varphi f_y}, \quad \varphi = 0.85$$

SHEAR FRICTION REINFORCEMENT

Shear friction criterion: $a_v/d_A < 1.0$

$V_A = \varphi \{ c A_{cv} + \mu A_{vf} f_y \}$, V_A in lb

$\varphi = 0.9$ for shear, $c = 145$ psi

$A_{cv} = b_A \times d_A$ = shear area (in^2)

$\mu = 1.4$ = friction factor, f_y in psi

A_{vf} = shear steel crossing the shear plane, in^2, may be merged with A_{s2} and A_{s1}.

Conventional flexural shear criterion: $a_v/d_A > 1.0$

$$s = \frac{\varphi A_v f_v d_A}{V_A - \varphi V_c}, \quad V_c = 0.0316 \beta (\sqrt{f_c'}) b_A d_A$$

Check $s_{max} < 12"$ or $d_A/2$

Though conventional flexural shear steel is required only when $a_V/d_A > 1$, we shall, nevertheless, provide such steel even when $a_V/d_A < 1$.

DESIGN OF ARTICULATION

DETAILING OF ARTICULATION

