16.8 ANALYSIS OF DECK OVERHANGS ON EXISTING BRIDGES FOR VEHICULAR COLLISION FORCES ON RAILS

16.8.1 GENERAL

This BDM provides guidance for the analysis of deck overhangs on existing bridges for rail collision forces in accordance with the *AASHTO-CA BDS-8*.

16.8.2 DESIGN CASES

Article A13.4.1 in AASHTO-BDS[1] requires a bridge overhang to satisfy three design cases:

Design Case 1: The transverse force (F_t) and longitudinal force (F_L) specified in Article A13.2 – Extreme Event II limit state load combination.

Design Case 2: The vertical force (F_V) specified in Article A13.2 – Extreme Event II limit state load combination.

Design Case 3: The loads as specified in Article 3.6.1 that occupy the overhang – Strength I limit state load combination.

Design Case 1 represents the limit state during a vehicular collision with the rail. Design Case 2 represents the limit state after a collision in which it is assumed that a collided truck is resting on top of the barrier. Design Case 3 is for Strength I Limit State under gravity live loads and is covered in Bridge Design Memo (BDM) 9.4 *Typical Deck, Typical Overhang, and Soffit Design*.

16.8.3 DESIGN ASSUMPTIONS

A vehicular collision force on a structure is applied for a small fraction of a second. Therefore, the analysis of a structure under the collision force should theoretically include the effects of strain rate. To simplify the analysis for Design Case 1, a conventional static force approach is required in accordance with CA Amendment A13.4.2. The following design assumptions based on the requirements of CA Amendment A13.4.2 are used in this example.

1. Expected material properties from BDM 16.4 *Material Properties for Existing Structures* for existing bridges are used for the overhang capacity under Design Case 1 and Design Case 2. Expected material properties are used to provide a more realistic estimate of design strength under extreme event limit states. In addition, studies show that material strengths under fast strain-rate loads are larger than the nominal strengths under static loads for both concrete and bar reinforcement, and the required development lengths of bar reinforcement under

fast strain-rate loads are smaller than those required under static loading conditions.

2. The height of the barrier, H_r, is used as the moment arm at both overhang critical sections to determine M_{ct}. The moment arm is theoretically dependent on the thickness of the overhang at the section being analyzed.

3. The top transverse reinforcement in the overhang resists the transverse moment due to collision, M_{ct}, and the bottom transverse reinforcement resists the transverse tensile force due to collision, T. When axial force and bending moment are applied to an element simultaneously, that element should theoretically be considered as a beam-column and analyzed accordingly. However, analysis shows that accounting for the two force effects independently in the manner described is acceptable.

4. The effect of the longitudinal collision force (F_L) is negligible.

16.8.4 EVALUATION OF EXISTING DECK OVERHANG

Figure 16.8.4-1 shows an example of an existing deck overhang with a Concrete Barrier Type 836 rail replacement. The bridge overhang needs to be evaluated at the toe of the barrier rail (Section A) and at the end of the deck overhang and exterior girder juncture (Section B). Figure 16.8.4-2 shows a cross-section of the existing overhang.

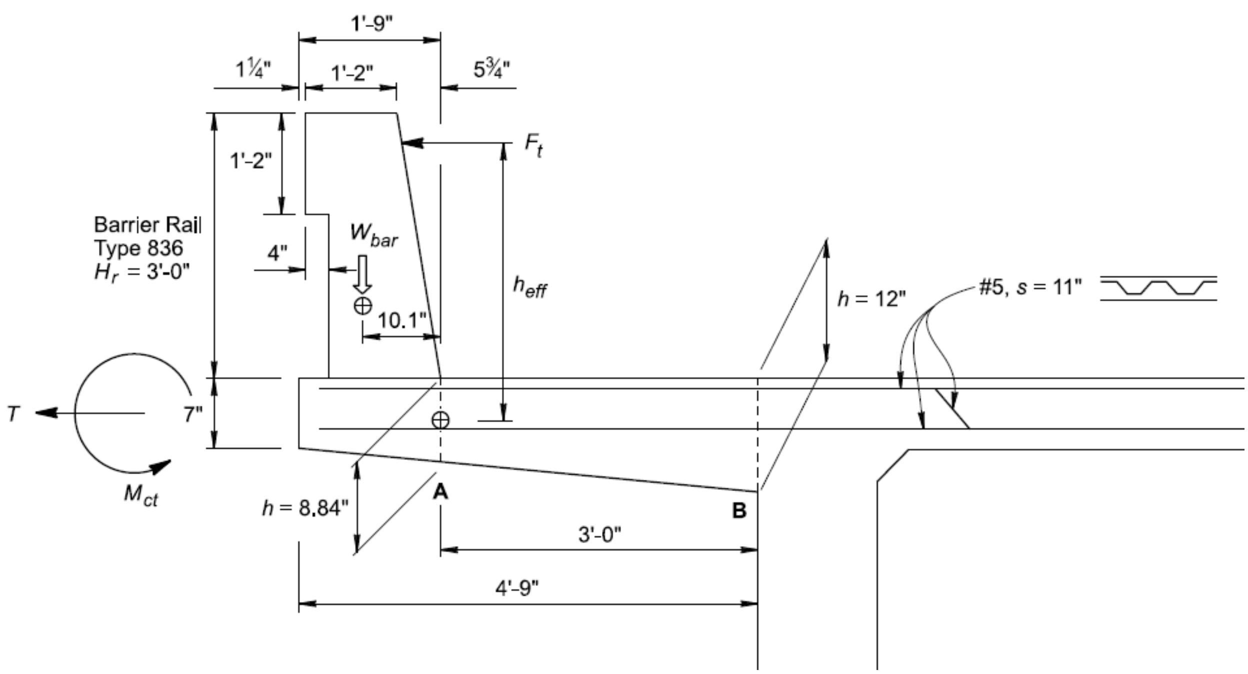

Figure 16.8.4-1 Example of Existing Deck Overhang

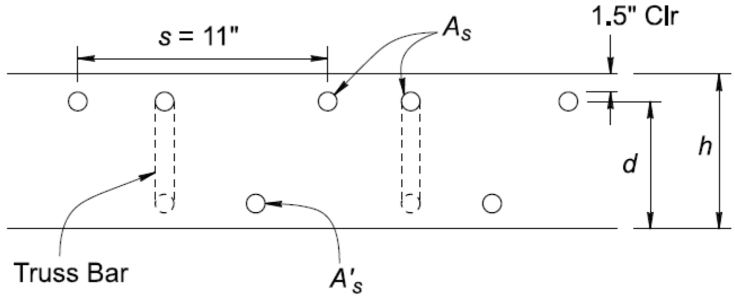

Figure 16.8.4-2 Deck Overhang Cross-Section

Design parameters:

Weight of Concrete Barrier Type 836, W_{bar} = 0.541 kip/ft

Height of Concrete Barrier Type 836, H_r = 3.0 ft

Effective Moment Arm from F_t to Centroid of the Overhang Cross-Section, h_{eff} ≈ 3.0 ft

Horizontal distance from toe of barrier to center of mass of Concrete Barrier Type 836 = 10.1 in.

Deck overhang transverse reinforcement: #5, s = 11”, A_s = 0.676 in^2/ft, A'_s = 0.338 in^2/ft

Gross diameter of transverse reinforcement (#5): d_b = 0.69 in.

Transverse traffic railing design force = collision force: F_t = 54 kip for Test Level 4

Clear concrete cover of top reinforcement: Clr = 1.5 in.

Thickness of deck overhang: h = varies

Specified minimum yield strength of reinforcement: f_y = 60 ksi

Design compressive strength of concrete: f'_c = 3.25 ksi

16.8.4.1 Design Case 1

Figure 16.8.4.1-1 shows the effective distribution lengths of the deck overhang for rail collision forces, as shown in CA Amendment Article CA13.4.2. The collision force is distributed over 10 ft at the top of the rail for portions further than 5 ft from a deck joint and over 5 ft for portions within 5 ft of a deck joint. The distribution length increases at a 45-degree spread down the barrier and into the deck. Results from finite element analyses have verified that the effective distribution lengths shown in Figure 16.8.4.1-1 are conservatively acceptable.

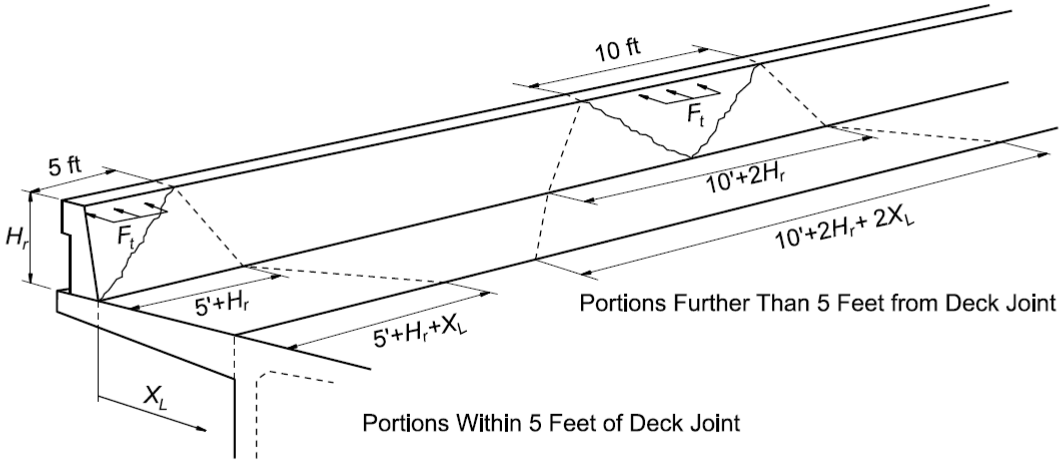

Figure 16.8.4.1-1 Effective Length of Deck Overhang Resisting Rail Collision Force

a) At Portions Further Than 5 ft from Deck Joint

The effective length that resists the transverse collision force, F_t, in the deck overhang is 10 ft at the top of the barrier rail plus two times the height of the barrier rail, as shown in Figure 16.8.4.1-1. Thus, the transverse demands per unit distance in the deck overhang can be calculated as follows:

$$T = \frac{F_t}{10 + 2H_r + 2X_L} \quad \text{(CA A13.4.2-1)}$$

$$M_{ct} = \frac{F_t H_r}{10 + 2H_r + 2X_L} \quad \text{(CA A13.4.2-2)}$$

Where,

F_t	=	transverse traffic railing design force (from AASHTO-BDS Table A13.2-1) (kip)
H_r	=	height of railing (ft)
M_{ct}	=	deck overhang transverse moment per unit length due to F_t (kip-ft/ft)
T	=	deck overhang transverse tensile force per unit length due to F_t (kip/ft)
X_L	=	transverse distance from the toe of railing to the deck overhang section being considered (ft)

The flexural capacity per foot of the overhang can be calculated using conventional reinforced concrete analysis. The tensile capacity of the deck overhang is assumed as the tensile capacity of the bottom reinforcing steel within the effective distribution length.

$$c = \frac{A_s f_{ye}}{0.85 f'_{ce} \beta_1 b} \quad \text{16.8.4.1-1}$$

$$a = \beta_1 c \quad \text{16.8.4.1-2}$$

$$M_{ne} = A_s f_{ye}\left(d - \frac{a}{2}\right) \quad \text{16.8.4.1-3}$$

$$T_{ne} = A'_s f_{ye} \quad \text{16.8.4.1-4}$$

Where,

A_s	=	area of top transverse reinforcement in deck overhang (in.^{2}/ft)
A'_s	=	area of bottom transverse reinforcement in deck overhang (in.^{2}/ft)
a	=	depth of equivalent rectangular compression stress block (in.)
b	=	unit length of deck overhang = 12 in.
c	=	distance from the extreme compressive fiber to the neutral axis (in.)
d	=	distance from extreme compressive fiber to the centroid of tensile reinforcement (in.)
f'_{ce}	=	expected compressive strength of concrete = 5 ksi
f_{ye}	=	expected yield strength of reinforcement = 68 ksi
M_{ne}	=	expected flexural resistance per unit length of deck overhang (kip-ft/ft)
T_{ne}	=	expected tensile resistance per unit length of deck overhang (kip/ft)
β_1	=	concrete stress block factor as specified in Article 5.6.2.2 = 0.80

Table 16.8.4.1-1 summarizes the demands at Section A and Section B in the deck overhang for the effect of gravity loads, live loads, and the transverse collision force. Note that a uniformly distributed live load in the vertical direction is 1.0 kip/ft and located at 1.0 ft away from the curb or face of the barrier rail as specified in Article 3.6.1.3.4 of AASHTO-BDS.

Table 16.8.4.1-1 Transverse Demand in Deck Overhang for Portions Further Than 5 ft from Deck Joint

Section	Moment Due to Barrier Rail Weight, M_{DRail} (kip-ft/ft)	Moment *Due to Overhang Weight,* M_{DOH} (kip-ft/ft)	Moment *Due to Live Load,* M_{LL} (kip-ft/ft)	Moment Due to Collision Force, M_{ct} (kip-ft/ft)	Tension Force due to Collision Force, T (kip/ft)
A	0.455	0.146	0	10.125	3.375
B	2.078	1.222	2.0	7.364	2.455

Table 16.8.4.1-2 summarizes the corresponding capacity per foot at Section A and Section B of the deck overhang.

Table 16.8.4.1-2 Transverse Capacity of Deck Overhang for Portions Further Than 5 ft from Deck Joint

Section	h (in.)	A_s (in.^{2}/ft)	A'_s (in.^{2}/ft)	c (in.)	a (in.)	d (in.)	M_{ne} (kip-ft/ft)	T_{ne} (kip/ft)
A	8.84	0.676	0.338	1.13	0.901	7.00	25.09	22.98
B	12	0.676	0.338	1.13	0.901	10.15	37.16	22.98

Extreme Event II Load combinations are evaluated using Equation 1.3.2.1-1 in AASHTO-BDS with load factor γ_i = 1.0 (or 0.5 for live load), resistance factor ϕ = 1.0, and load modifier η_i = 1.0.

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \qquad \text{(AASHTO 1.3.2.1-1)}$$

Where:

Q_i = force effect

R_n = nominal resistance

R_r = factored resistance: ϕR_n

γ_i = load factor: a statistically based multiplier applied to force effects

ϕ = resistance factor: a statistically based multiplier applied to nominal resistance

η_i = load modifier: a factor relating to ductility, redundancy, and operational classification

1. At Section A

$M_u = 1.0M_{DC} + 0.5M_{LL+IM} + 1.0M_{ct}$

$= 1.0(0.455 + 0.146) + 0.5(0) + 1.0(10.125)$

$= 10.726$ (kip-ft/ft) $< \phi M_{ne} = 25.09$ (kip-ft/ft)

$T_u = 1.0T = 3.375$ (kip/ft) $< \phi T_{ne} = 22.98$ (kip/ft)

2. At Section B

$M_u = 1.0M_{DC} + 0.5M_{LL+IM} + 1.0M_{ct}$

$= 1.0(2.078 + 1.222) + 0.5(1.33 \text{ x } 2.0) + 1.0(7.364)$

$= 12.0$ (kip-ft/ft) $< \phi M_{ne} = 37.16$ (kip-ft/ft)

$T_u = 1.0T = 2.455$ (kip/ft) $< \phi T_{ne} = 22.98$ (kip/ft)

b) At Portions Within 5 ft of Deck Joint

The effective length that resists the transverse collision force, F_t, in the deck overhang is 5 ft at the top of the barrier rail plus the height of the barrier rail, as shown in Figure 16.8.4.1-1 Thus, the transverse demands per unit distance in the deck overhang can be calculated as follows:

$$T = \frac{F_t}{5 + H_r + X_L} \quad \text{(CA A13.4.2-3)}$$

$$M_{ct} = \frac{F_t H_r}{5 + H_r + X_L} \quad \text{(CA A13.4.2-4)}$$

Table 16.8.4.1-3 Transverse Demand in Deck Overhang for Portions Within 5 ft of Deck Joint

Section	Moment Due to Barrier Rail Weight, M_{DRail} (kip-ft/ft)	Moment *Due to Overhang Weight,* M_{DOH} (kip-ft/ft)	Moment *Due to Live Load,* M_{LL} (kip-ft/ft)	Moment Due to Collision Force, M_{ct} (kip-ft/ft)	Tension Force due to Collision Force, T (kip/ft)
A	0.455	0.146	0	20.250	6.750
B	2.078	1.222	2.0	14.727	4.909

The flexural capacities per unit length of the overhang shown in Table 16.8.4.1-4 are the same as those of (a), given the same typical section reinforcement. However, if there is additional reinforcing steel at the deck joints, this should be included in the capacity calculations.

Table 16.8.4.1-4 Transverse Capacity of Deck Overhang for Portions Within 5 ft of Deck Joint

Section	h (in.)	A_s (in.^{2}/ft)	A'_s (in.^{2}/ft)	c (in.)	a (in.)	d (in.)	M_{ne} (kip-ft/ft)	T_{ne} (kip/ft)
A	8.84	0.676	0.338	1.13	0.901	7.00	25.09	22.98
B	12	0.676	0.338	1.13	0.901	10.15	37.16	22.98

1. At Section A

$$M_u = 1.0M_{DC} + 0.5M_{LL+IM} + 1.0M_{ct}$$
$$= 1.0(0.455 + 0.146) + 0.5(0) + 1.0(20.25)$$
$$= 20.85 \text{ (kip-ft/ft)} < \phi M_{ne} = 25.09 \text{ (kip-ft/ft)}$$

$$T_u = 1.0T = 6.75 \text{ (kip/ft)} < \phi T_{ne} = 22.98 \text{ (kip/ft)}$$

2. At Section B

$$M_u = 1.0M_{DC} + 0.5M_{LL+IM} + 1.0M_{ct}$$
$$= 1.0(2.078 + 1.222) + 0.5(1.33 \times 2.0) + 1.0(14.73)$$
$$= 19.36 \text{ (kip-ft/ft)} < \phi M_{ne} = 37.16 \text{ (kip-ft/ft)}$$

$$T_u = 1.0T = 4.909 \text{ (kip/ft)} < \phi T_{ne} = 22.98 \text{ (kip/ft)}$$

16.8.4.2 Design Case 2

Design Case 2 represents a collided truck resting on top of the barrier rail after a collision. A similar approach to Design Case 1 can be used by replacing the transverse collision force, F_t, with the vertical force, F_v, applied on top of the barrier rail. The effective distribution lengths of the deck overhang shown in Figure 16.8.4.2-1 can be used for Design Case 2. The 0.5*(*LL*+*IM*) term in Table 3.4.1-1 in AASHTO-BDS can be excluded for Design Case 2 because the chance of other vehicles occupying the overhang region within the effective distribution length is remote.

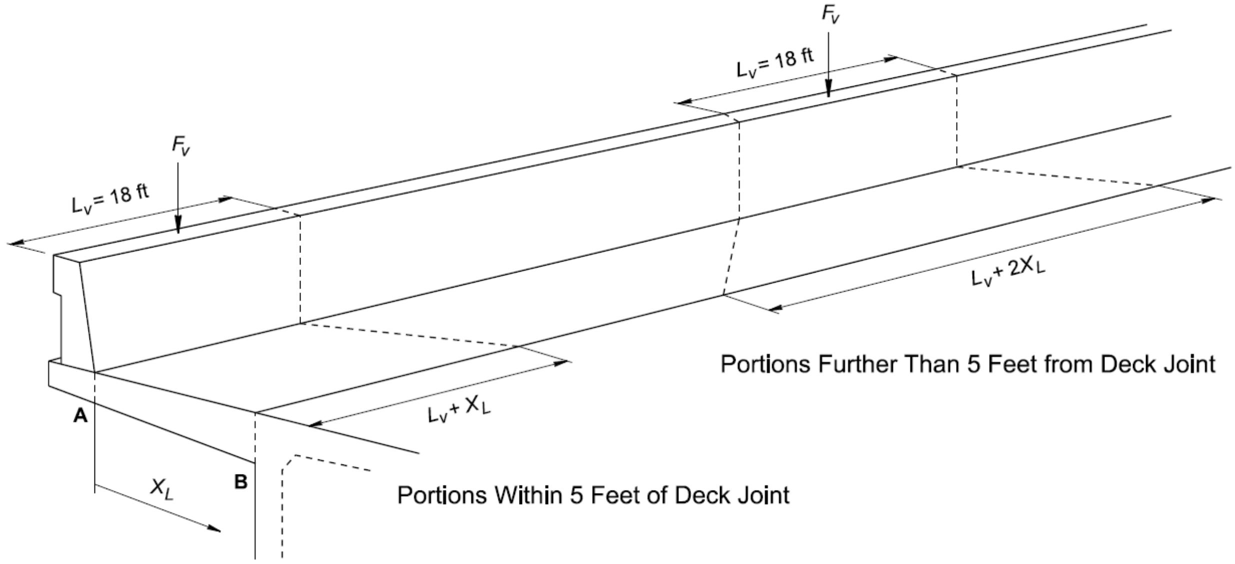

Figure 16.8.4.2-1 Effective Length of Deck Overhang Resisting F_v

a) **At Portions Further than 5 ft from Deck Joint**

$$M_{cv} = \frac{F_v X_L}{L_v + 2X_L} \tag{16.8.4.2-1}$$

b) **At Portions Within 5 ft of Deck Joint**

$$M_{cv} = \frac{F_v X_L}{L_v + X_L} \tag{16.8.4.2-2}$$

Where:

F_v = vertical force of vehicle laying on top of railing (from AASHTO Table A13.2-1) (kip)

L_v = longitudinal distribution length of vertical force, F_v, on top of railing (from AASHTO Table A13.2-1) (ft)

M_{cv} = deck overhang transverse moment per unit length due to F_v (kip-ft/ft)

X_L = transverse distance from toe of railing to the deck overhang section being considered (ft)

16.8.5 REFERENCES

1. AASHTO (2017), *AASHTO LRFD Bridge Design Specifications*, 8th Edition, American Association of State Highway and Transportation Officials, Washington DC.
2. Caltrans (2024), Bridge Design Memo 9.4 *Typical Deck, Typical Overhang, and Soffit Design*, California Department of Transportation, Sacramento, CA
3. Caltrans (2022), Bridge Design Memo 16.4 *Material Properties for Existing Structures,* California Department of Transportation, Sacramento, CA
4. Caltrans. (2019). *California Amendments to AASHTO LRFD Bridge Design Specifications – 8th Edition*, California Department of Transportation, Sacramento, CA.
5. Gutierrez, Jim (2019a), Caltrans internal study - *Nonlinear Finite Element Analysis of an Existing Bridge with a Type 842 Barrier Rail Upgrade*, California Department of Transportation, Sacramento, CA.
6. Gutierrez, Jim (2019b), Caltrans internal study - *Nonlinear Finite Element Analysis of an Existing Bridge with a Type 85 Barrier Rail Upgrade*, California Department of Transportation, Sacramento, CA.