WESTERN BRIDGE ENGINEERS' SEMINAR
MASH IMPLEMENTATION FOR CALIFORNIA BRIDGE RAILINGS

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Division of Engineering Services

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Calfornia Bridge Railings

1. Bridge Railings are an important highway safety system:
    a. retain and redirect vehicles
    b. retain non-motorized travelers, such as bicyclists and pedestrians
2. Most bridge railing systems in California Standard Plans are approved under the *NCHRP 350* guidelines for crash testing, which are sunsetting.
3. New bridge railing systems are under development to comply with *Manual for Assessing Safety Hardware (MASH) 2016.*

Crash Test Requirements for Roadside Safety Hardware

Crash testing is the most common method of evaluating performance.

1. Early procedures included:
   a) Highway Research Circular 482 (1962)
   b) NCHRP Report 115, 118,153 (1971, 1972, 1974)
   c) Transportation Research Circular 191 (1978)
   d) NCHRP Report 230 (1980)
2. National Cooperative Highway Research Program (NCHRP) Report 350 , 1993. *sunsetting*
3. Manual for Assessing Safety Hardware (MASH), 1st Edition 2009, 2nd Edition 2016.

Implementation of Crash Test Requirements for Bridge Railings

Publication	Year	Implementation for New Construction and Full Replacements (note 1)
NCHRP 350 (note 2)	1993	Implementation by late 1990's
MASH, 1st Edition	2009	New bridge railing standards must comply with MASH; standards approved under NCHRP 350 can still be used
MASH, 2nd Edition	2016	Will no longer allow use of NCHRP 350 approved railings by MASH implementation dates

1. As-built bridge railings can remain in place, in accordance with owner-operator policies and guidelines.

2. Most bridge railings in the California Standard Plans are approved under NCHRP 350.

California MASH Implementation

Caltrans Memorandum (December 2016):

" For contracts on the California State Highway System with an advertising date after the dates shown, only safety hardware evaluated using MASH 2016 will be allowed for new permanent installations and full replacements:"

Safety Hardware Device	Advertising Date
Bridge rails, transitions, and all other longitudinal barriers	October 31, 2019

In California, based on the 2015 National Bridge Inventory:

- There are 25,318 bridges in CA (state and local)
- Since 2004, 1036 new bridges have been built, 521 bridges have undergone major reconstruction
- There is work proposed on 4296 bridges

Manual for Assessing Safety Hardware (MASH) – why?

1. Overall goals:
   a) Improved performance of roadside safety hardware
   b) Enhanced safety for motorists
2. Next step in evolution of roadside safety testing and evaluation.
3. Reflects updated test vehicles and impact scenarios.
4. Performance criteria includes:
   a) Structural adequacy
   b) Occupant risk
   c) Post-impact response

Key Differences
NCHRP 350 vs MASH

Test Vehicles:

	NCHRP 350	MASH
Small car	1,800 lb	2,420 lb
Pickup truck	4,400 lb	5,000 lb
Single unit truck (SUT)	17,600 lb	22,000 lb

Key Differences NCHRP 350 vs. MASH

Test Matrices:

	NCHRP 350	MASH
Small car impact angle	20 degrees	25 degrees
Single unit truck (SUT) impact speed	50 mph	56 mph

Impact Severity:

Test	NCHRP 350	MASH
3-10 Small car		+206%
3-11 Pickup truck		+13%
4-12 Single unit truck (SUT)		+56% (note 1)

1. Sheikh and Bligh (2011), "*Determination of Minimum Height and Lateral Design Load for MASH Test Level 4 Bridge Rail*".

Overview of Bridge Railing Systems

Caltrans initiated five research projects to meet MASH criteria:

Bridge Railing	Test Leve l	Description	Status
1. Concrete Barrier Type 732SW	TL-2	Concrete parapet with 6' minimum sidewalk, H= 32" above sidewalk plus handrail or chain link railing	Complete. See Caltrans Standard Plans.
2. Concrete Barrier Type 836/842	TL-4	Solid concrete, H=36" to 42"	Analysis/design complete, approval pending
3. California ST-75	TL-4	Steel post-and-beam, H=36" or 42"	Analysis/design complete, crash test pending.
4. Concrete Barrier Type 85	TL-4	Concrete post-and-beam, H=36" or 42"	Analysis/design complete, crash test pending.
5. California ST-70SM	TL-4	Steel post-and beam, sidemount, H=42"	Approval pending.

General Design Considerations

1. Effective bridge railings must comply with structural design specifications as well as crash test performance.
2. The bridge railings shall be designed and crash tested for the combination condition (vehicle plus bike/ped).
3. Test Level 4 loads shall be used for the structural design for all Standard Plan bridge railing systems. Increased impact severity shall be considered for Test 4-12.

Test Levels for California Bridge Railings

The following test levels are used for longitudinal barriers on the California State Highway System:

Test Level	Test Vehicle	Application
TL-2	Small Car	Bridge railings with sidewalks, low-speed locations only
TL-3	Small Car, Pickup Truck	Roadway, roadside, median barrier on the bridge
TL-4	TL-3 plus Single Unit Truck	Bridge railings (adjacent to vehicular traffic), protection of bridge elements
TL-5	TL-3 plus Van-Type Tractor Trailer	Bridge railings, high truck AADT

Minimum Bridge Railing Heights

The following minimum heights shall be used for MASH bridge railing systems in California:

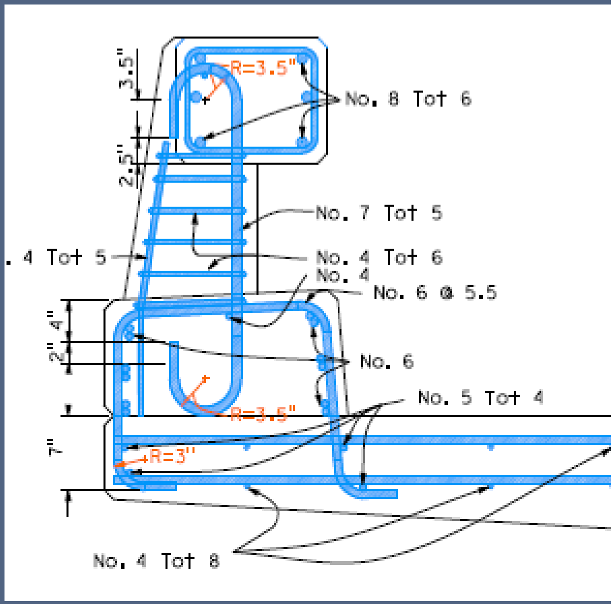
Project Location	Railing Type			
	Vehicular		Combination (vehicular w/ bike or peds)	
	350	MASH	350	MASH
Low Speed (TL-2, 45 mph or less)	27"	32"	42"	42"
High Speed (TL-4, greater than 45 mph) *Pedestrians must be separated from traffic by a vehicular railing	32"	36" (note 1)	42"	42"

1. Sheikh and Bligh (2011), "*Determination of Minimum Height and Lateral Design Load for MASH Test Level 4 Bridge Rail*".

Structural Design – Bridge Railing Systems

1. AASHTO LRFD Bridge Design Specifications, Sixth Edition with California Amendments
   a) Applicable: new bridges and bridge railing replacements, traffic railings on rigid systems

2. Design components (Limit States):
   a) Bridge Railing (Strength and Extreme)
   b) Connection to the Deck (Extreme Event)
   c) Deck and Overhang (Strength and Extreme Event)



3. Construction specifications:
   a) Structural concrete, f'c=3600 psi, A706 Grade 60 rebar
   b) Structural steel ASTM A709, Grade 50, ASTM A500, Grade B

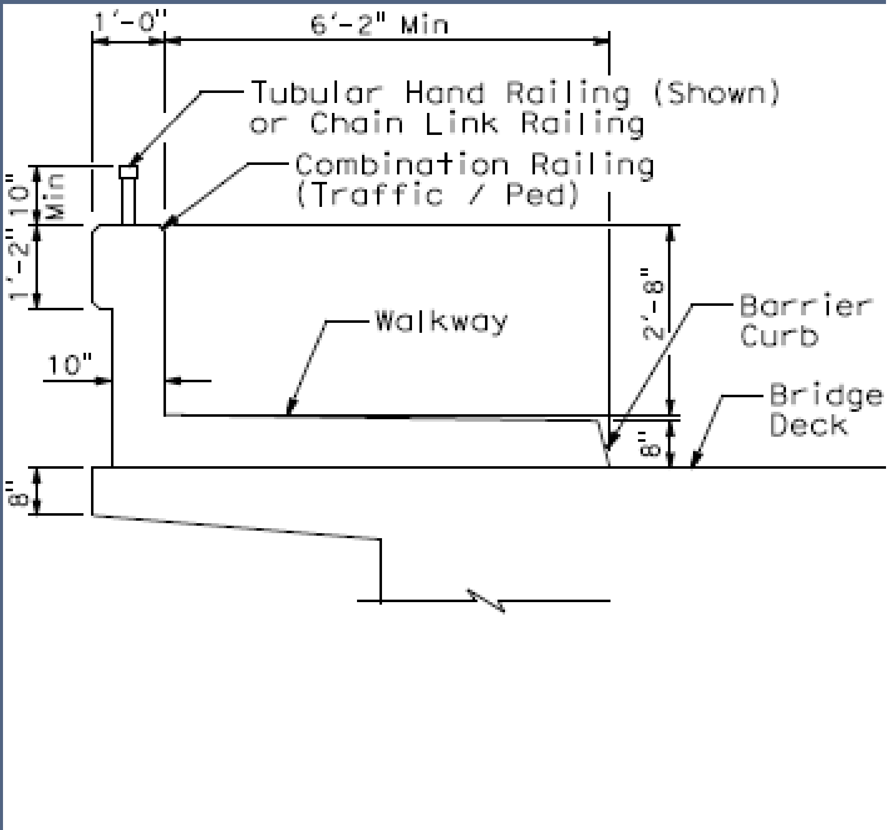
Concrete Barrier Type 732SW

Bridge Railing	Test Level	Description	Status
1. Concrete Barrier Type 732SW	TL-2	Concrete parapet with 6' minimum sidewalk, H= 32'' above sidewalk	Complete. See Caltrans Standard Plans.

Concrete Barrier Type 732SW

Description:

1. Replaces Concrete Barrier Type 26
2. Low speed locations only
3. First MASH bridge railing in CA
4. Sidewalk width can vary from 6' to 10' in support of "Complete Streets".
5. Must include tubular hand railing or chain link railing
6. ADA compliant
7. Suitable for stage construction

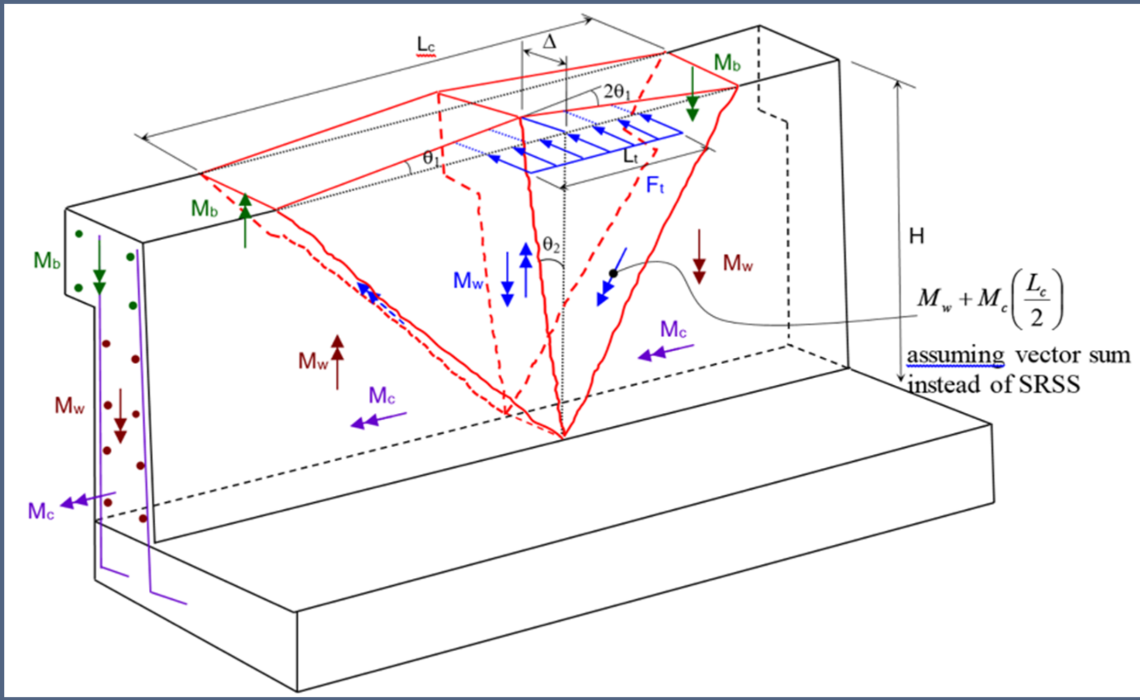


CONCRETE BARRIER TYPE 732SW

Type 732SW Analysis and Design

Modified yield line analysis per LRFD, Section 13, Appendix A

Additional reinforcement provided at deck joints and end block.



Type 732SW Crash Testing

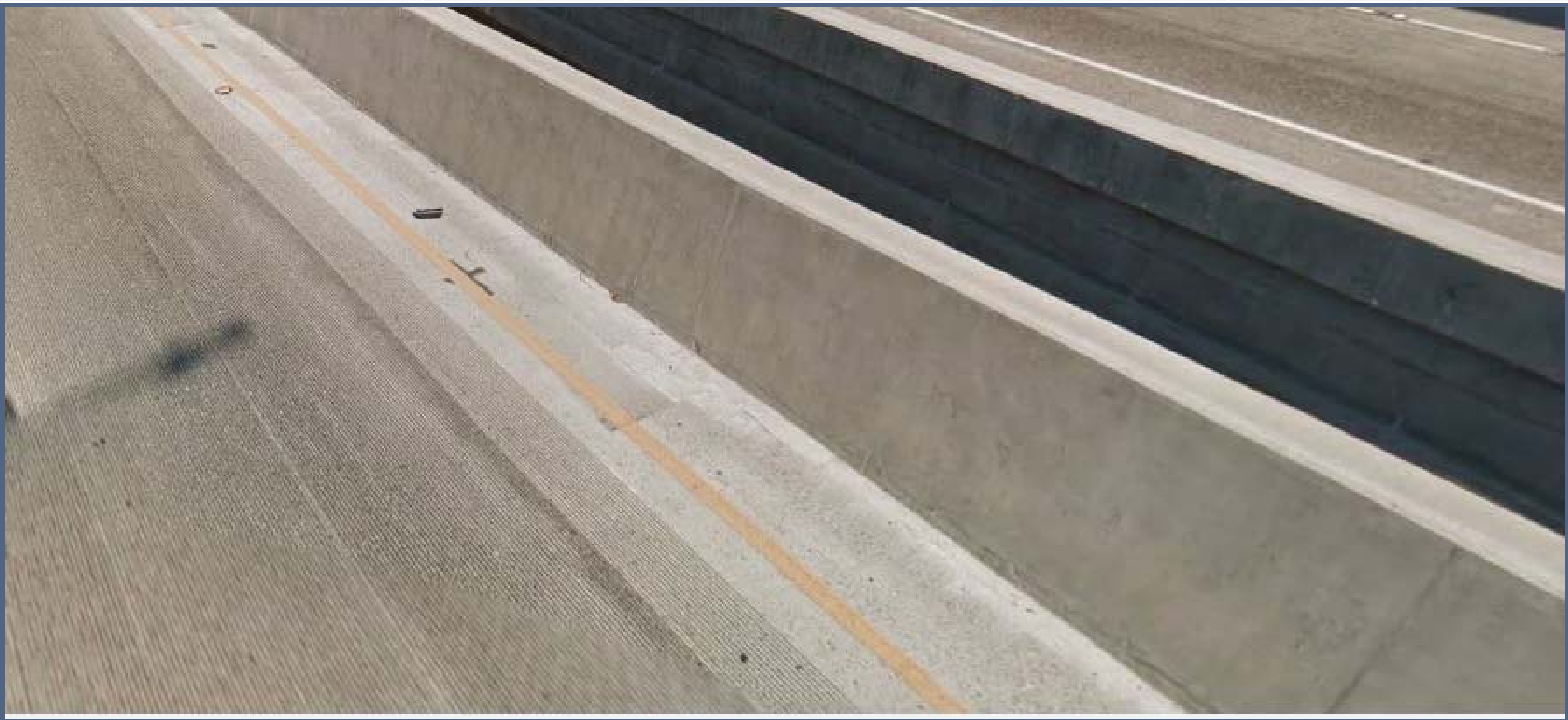
1. Three crash tests were conducted under MASH:
   a) Test 3-11, pickup at TL-3
   b) Test 3-10, small car at TL-3. The ridedown acceleration was outside MASH limits
   c) Test 2-10, small car at TL-2

2. The Type 732SW bridge rail is recommended for approval on California highways requiring TL-2 bridge rails with pedestrian traffic.

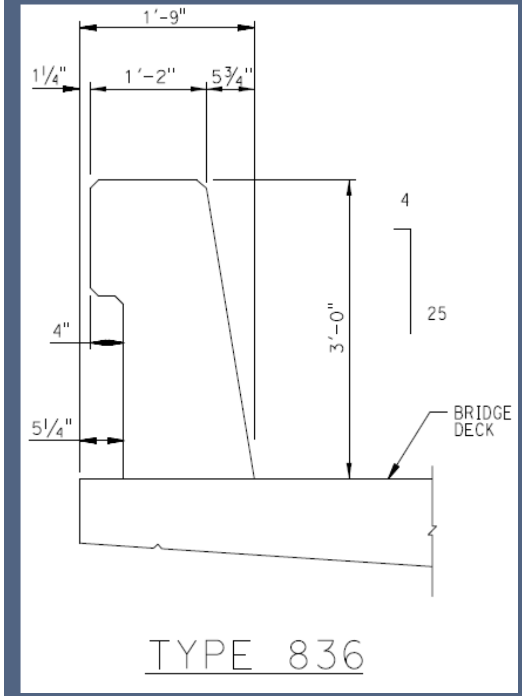
3. Since it is symmetric, the Type 732SW is also recommended in locations where a reverse hit is possible.

Concrete Barrier Type 836/842

Bridge Railing	Test Level	Description	Status
2. Concrete Barrier Type 836/842	TL-4	Solid concrete, H=36" to 42"	Analysis/design complete, approval pending

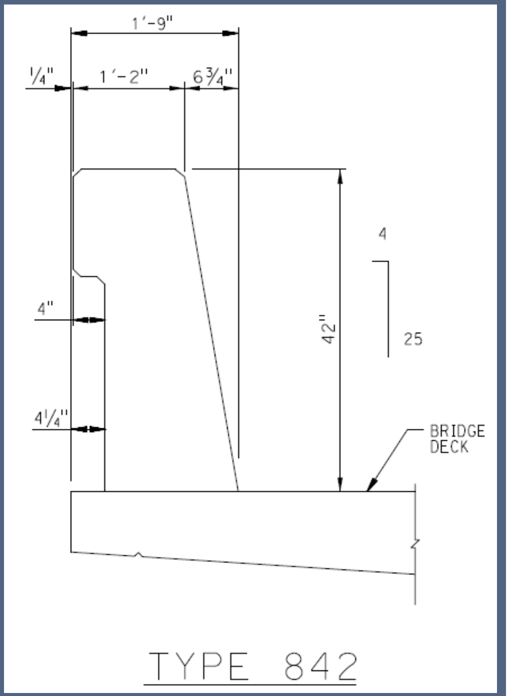


Concrete Barrier Type 836/842



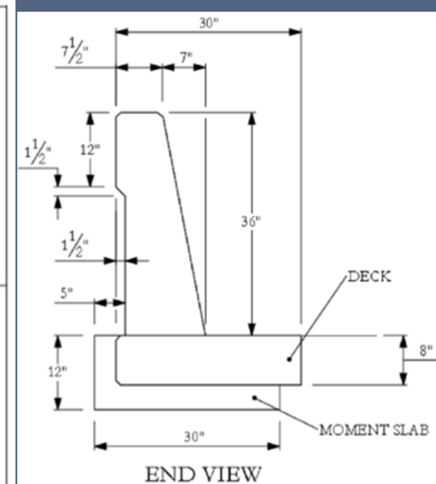
Description:

1. Replaces Concrete Barrier Type 732/736/742 (NCHRP 350 TL-4)
2. Single slope barrier at 9.1 degrees
3. High or low speed locations
4. Height can vary from 36" to 42" for vehicular or combination applications
5. Occupies 1'-9" of deck width.



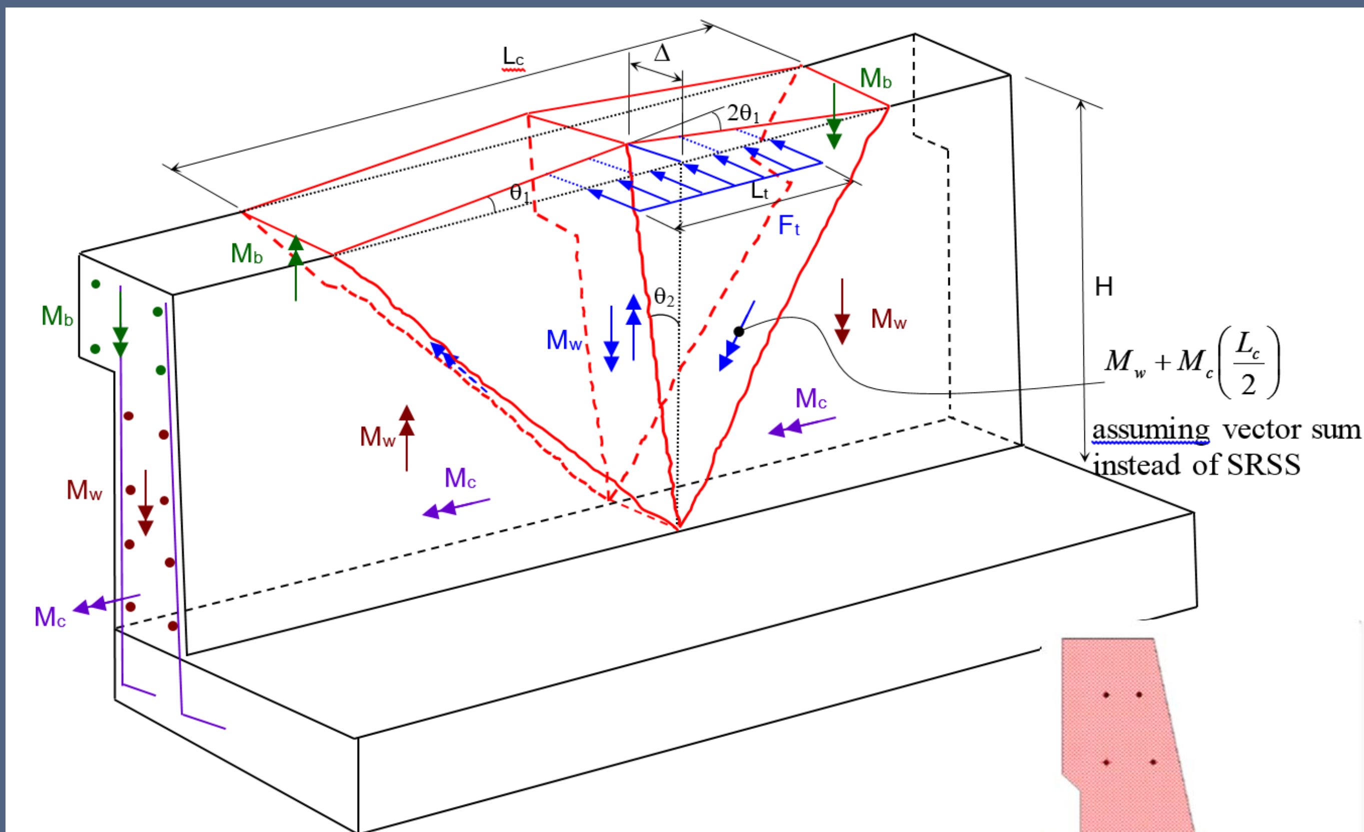
Type 836/842 Analysis and Design

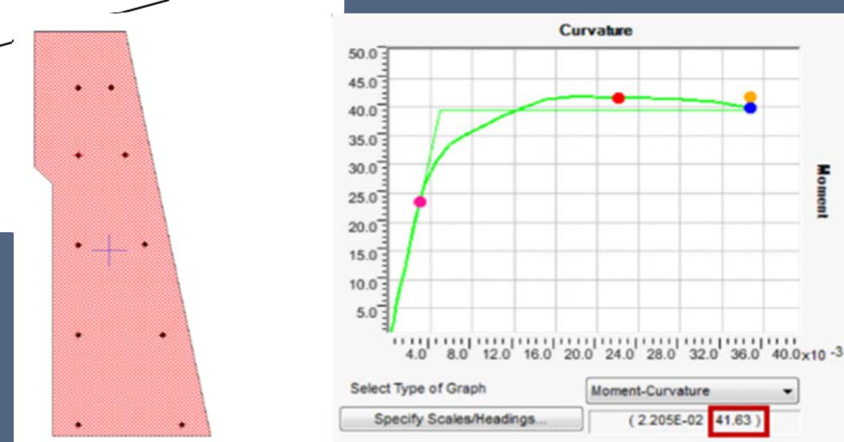
1. Texas Transportation Institute (TTI) conducted MASH TL-4 crash testing on a 36” tall reinforced concrete Single Slope Traffic Rail (SSTR). The SSTR was used as a basis of 836/842 design.
2. No additional crash tests are planned. See AASHTO Article 13.7.3.1.1 and Commentary C13.7.3.1.1



Type 836/842 Analysis and Design

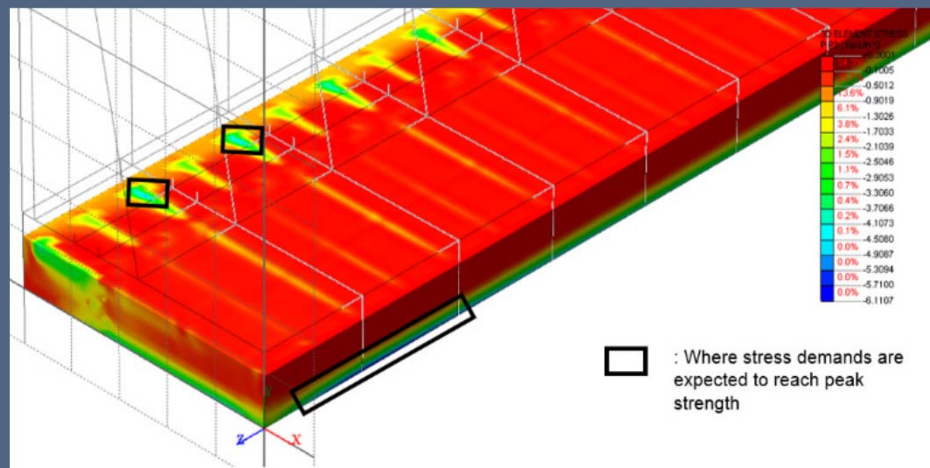
Step 1: Determine Ultimate Resistance of the SSTR



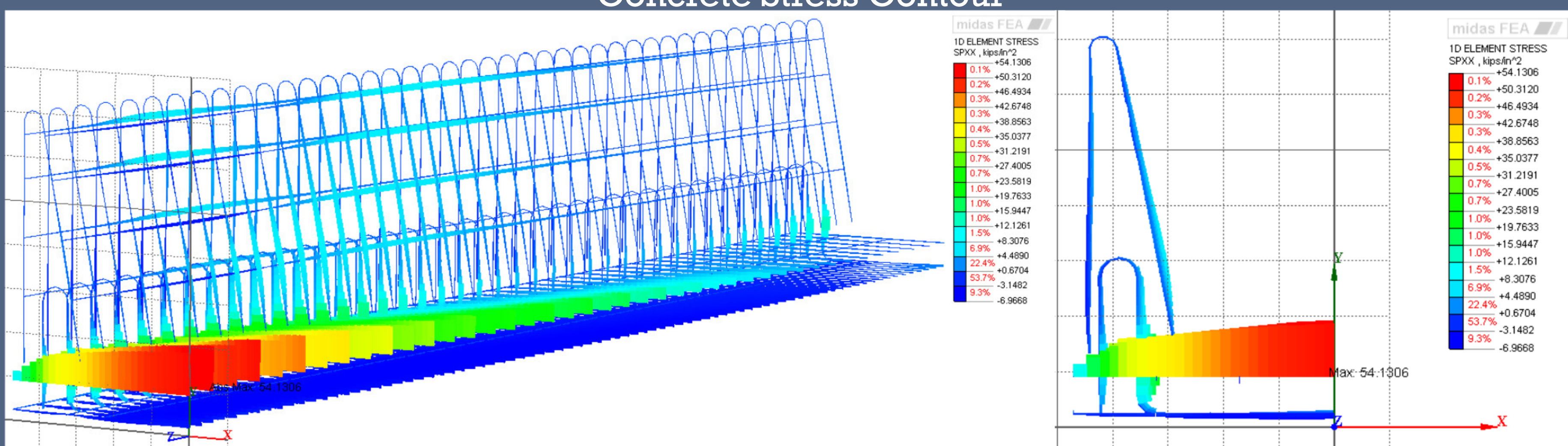


Type 836/842 Analysis and Design

Step 2: Conduct FEA for stress/strain level of the SSTR under TL4 loading



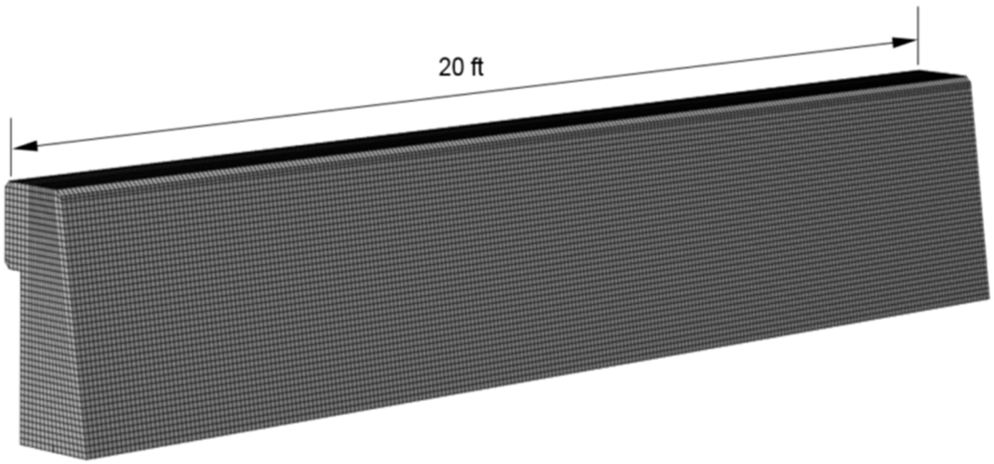
Concrete Stress Contour

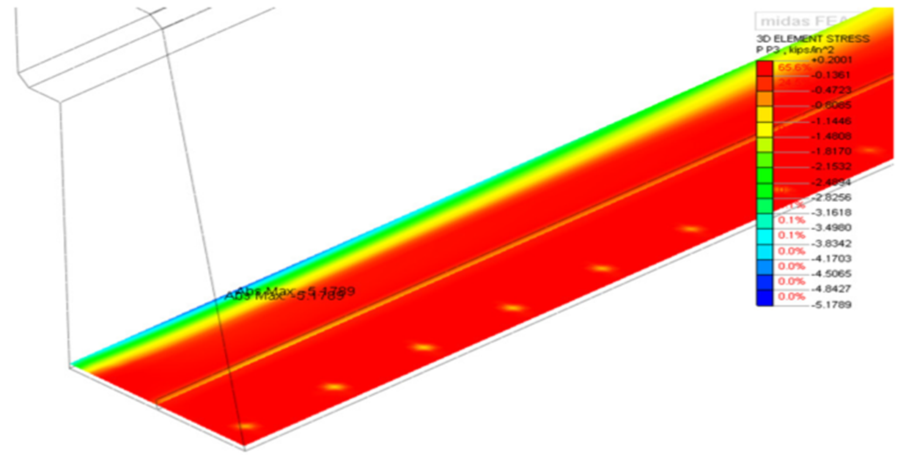


Reinforcing Steel Stress

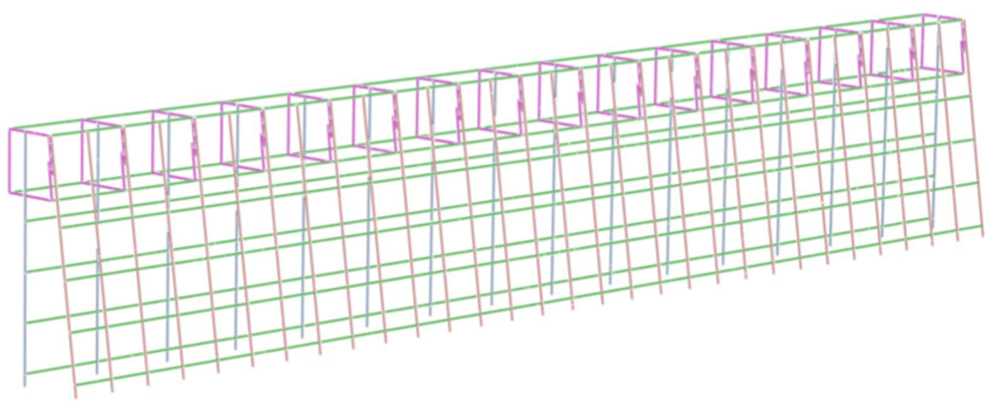
Type 836/842 Analysis and Design

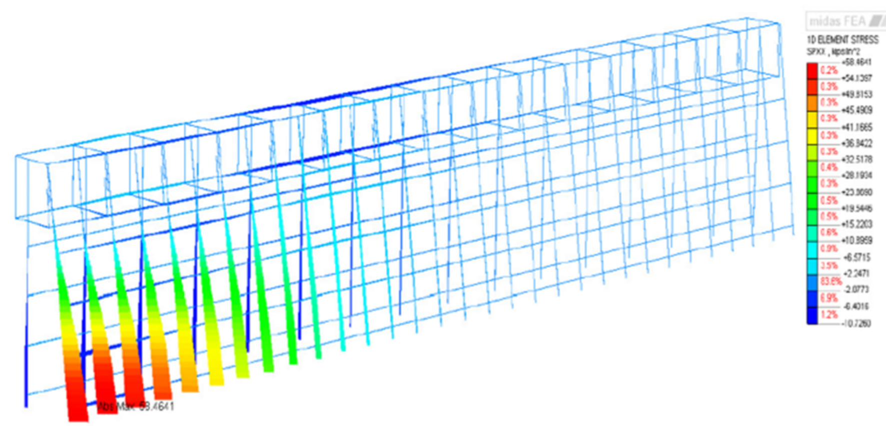
Step 3: Improve the SSTR for 836/842 and conduct FEA on 842





Concrete

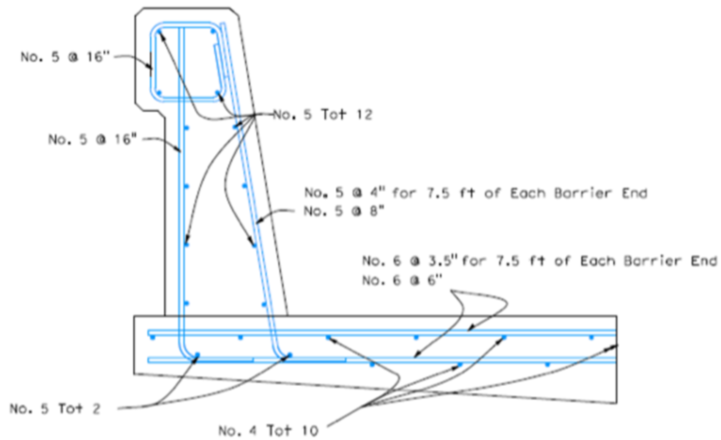




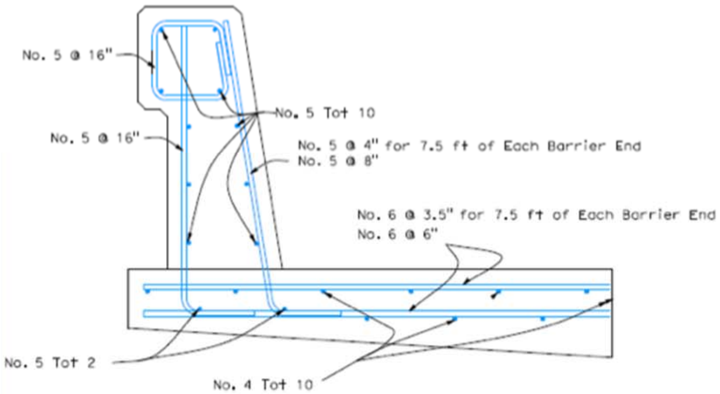
Reinforcing Steel

Type 836/842 Analysis and Design

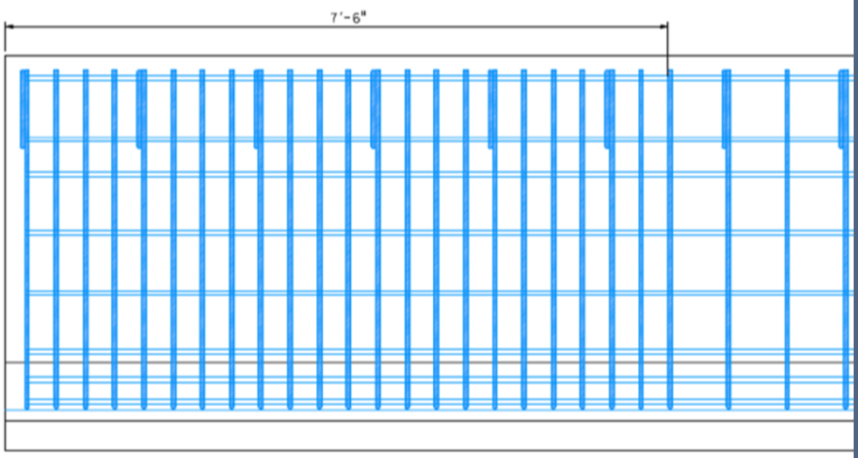
Step 4: Design 836/842 including overhang and detailing



Section - Type 842



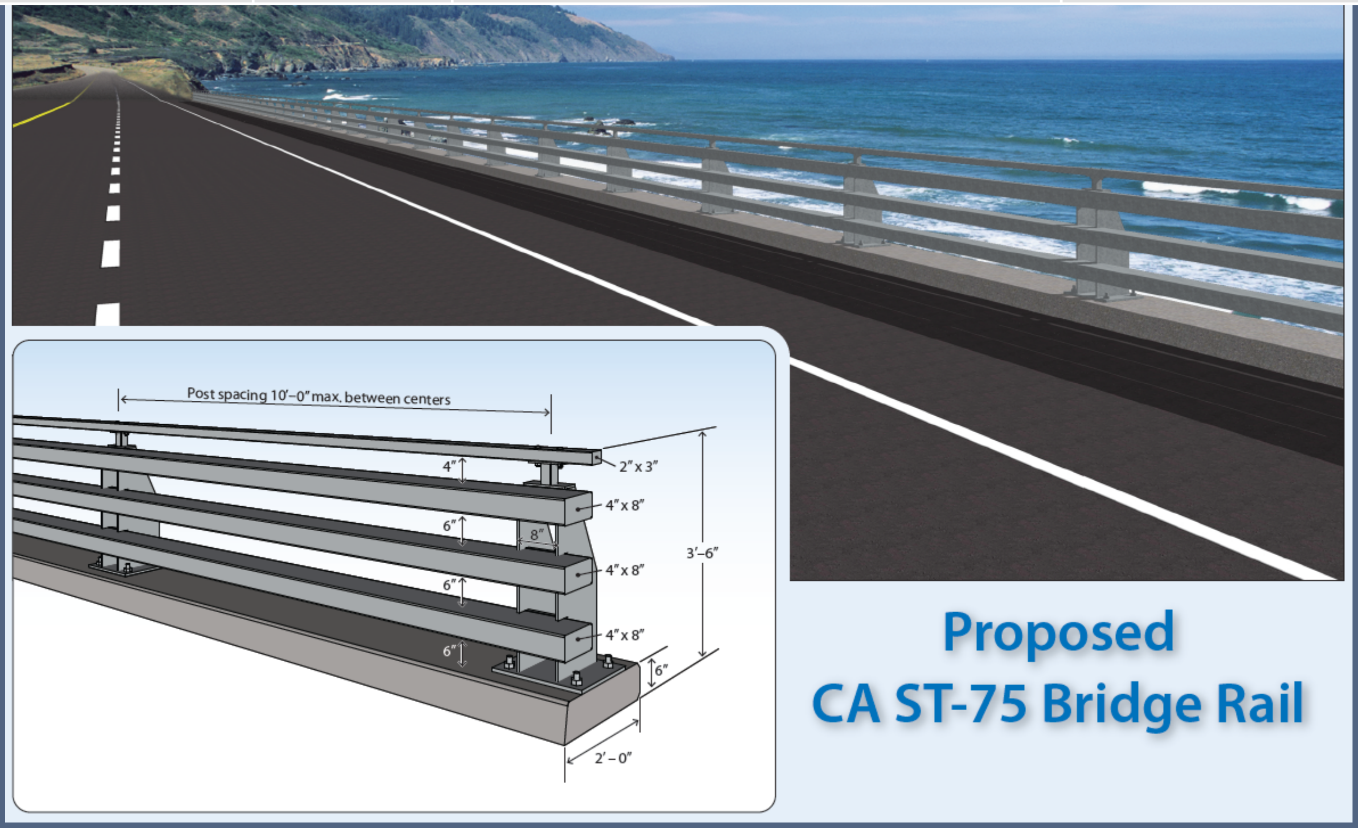
Section - Type 836



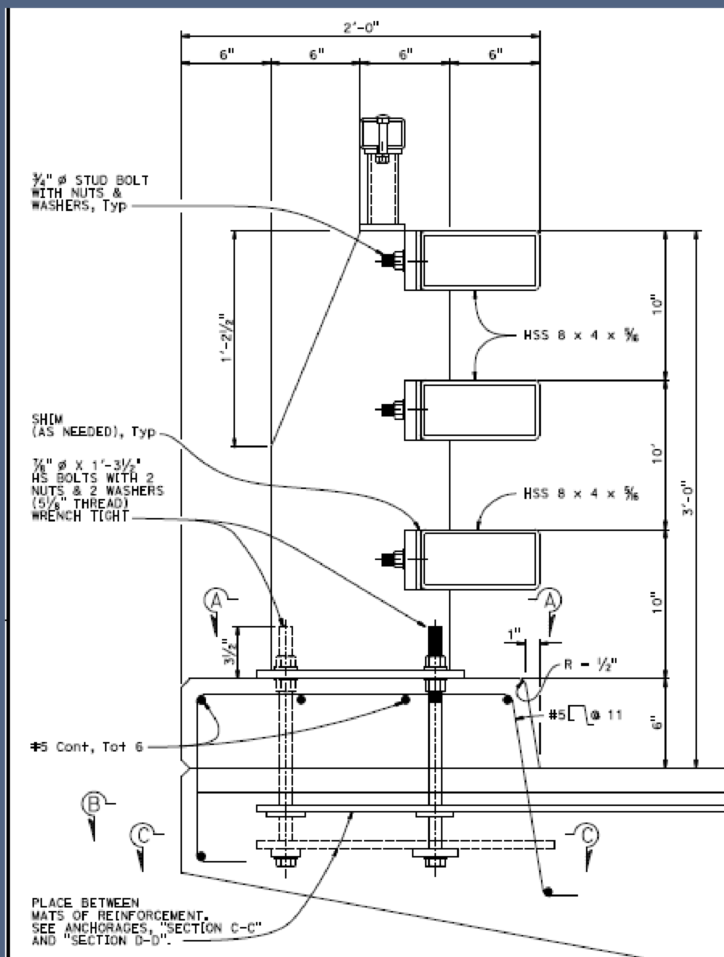
Elevation

California ST-75 Bridge Railing

Bridge Railing	Test Level	Description	Status
3. California ST-75	TL-4	Steel post-and-beam, H=36" or 42"	Analysis/design complete, crash test pending.



California ST-75 Bridge Railing

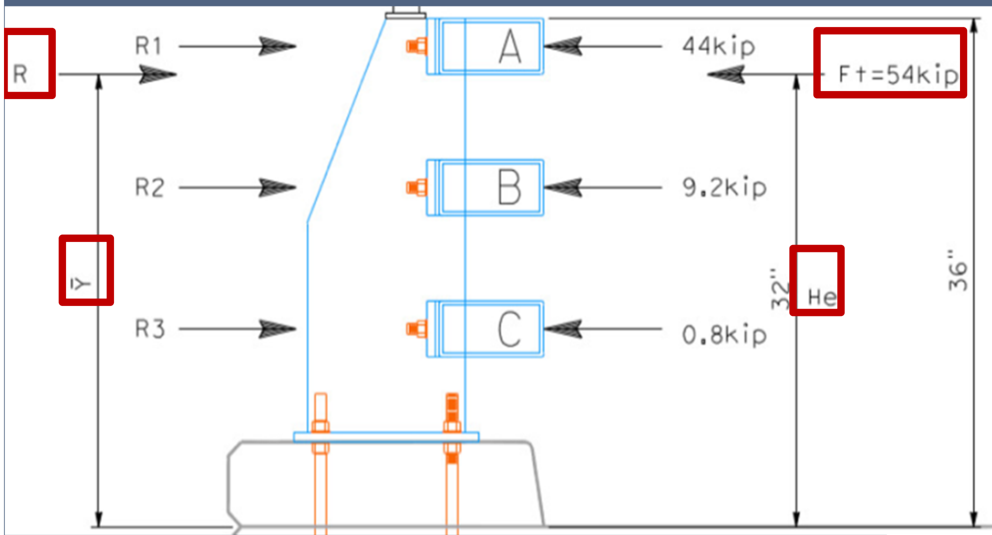


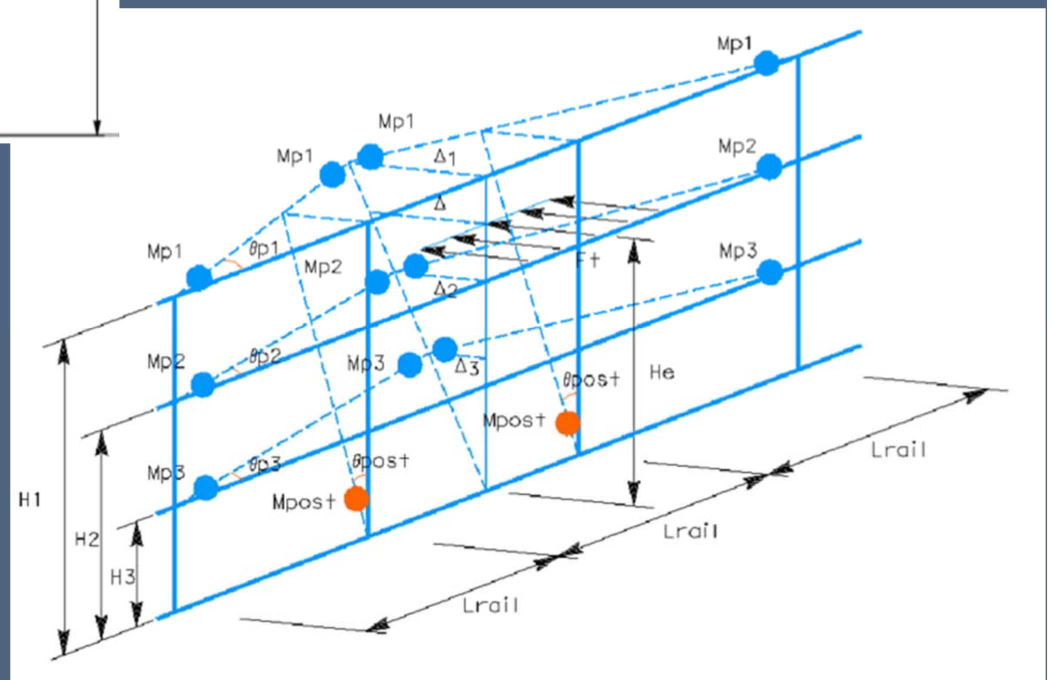
Description:

1. Vehicular rail with bicycle railing on top.
2. Aesthetic see-through bridge rail.
3. Replaces all current steel post-and beam bridge rails.
4. Design and crash tested as one unit.
5. Posts are spaced at 10' on center.
6. High or low speed locations
7. Occupies 2'-0"of deck width.

ST-75 Analysis and Design

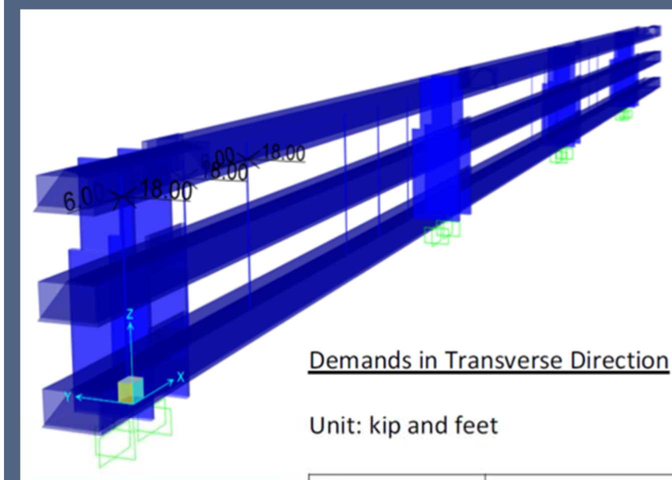
- Step 1: Check the ultimate resistance, R (using virtual work method) and its resultant location against the TL 4 impact load, Ft

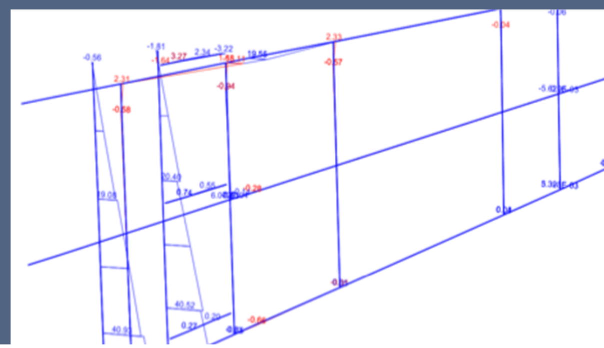


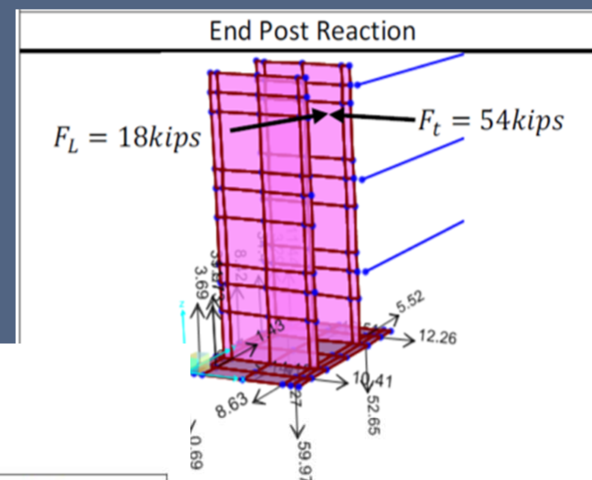


ST-75 Analysis and Design

- Step 2: Perform FEA study for demands on the barrier components (Rail, Post, Base Plate, & Curb) under four different loading cases (LCs)
  - LC 1: Ft is applied at midpoint of exterior span (between endpost and interior post)
  - LC 2: Ft is applied at end post
  - LC 3: Ft is applied at midpoint of interior span
  - LC 4: Ft is applied at interior post







Demands in Transverse Direction

Unit: kip and feet

Loading Condition	LC1			LC2			LC3			LC4		
	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}
Post Lt Plate	20.5	47.6	0.5	**24.4**	**59.7**	**0.9**	24.1	44.5	0.6	21.5	52.7	0.9
Post Rt Plate	24.6	42.8	0.6	**29.4**	57.6	**0.6**	15.9	39.6	0.5	29.3	**57.8**	0.5
Top Rail	**28.1**	**76.5**	**4.0**	17.4	19.5	2.1	22.4	62.3	2.4	16.3	9.1	1.7
Mid Rail	2.1	8.2	0.8	1.0	1.0	0.3	**4.0**	**11.4**	**1.7**	2.0	1.3	0.5
Bot Rail	**1.0**	**2.9**	**0.6**	1.0	1.0	0.5	0.5	1.5	0.3	0.6	0.4	0.4
Rolled Bar	24.6	2.9	0.7	26.7	**3.3**	**1.8**	21.3	2.5	0.8	**27.3**	3.1	1.4

V_{CT}: Max shear demand M_{CT}: Max flexural demand T_{CT}: Max torsional demand

ST-75 Analysis and Design

- Step 3: Check strength of each barrier component against the demands in Step 2 and Conduct detailing

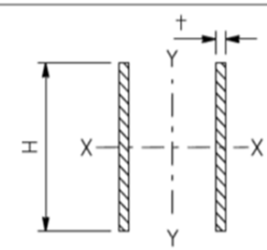
TUBE: HSS 8x4x5/16 - ASTM A500 Gr. B
Plastic Modulus: $Z = 16.1\ in^3$

SLEEVE: HSS 7x3x5/16 – ASTM A500 Gr. B
Plastic Modulus: $Z = 11.1\ in^3$

Yield Strength = $f_y = 46\ ksi$
Tensile Strength = $f_u = 58\ ksi$

See AISC page 5-10 and ASTM A500 Grade B for material property.

Rail



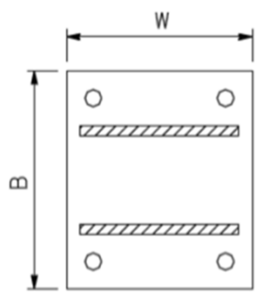
* Section at rail is used to determine plastic modulus.

Size: PL 12 x ¾ - ASTM A36
*H = 9 inch for plastic modulus
t = 0.75 inch
Yield Strength = $f_y = 36\ ksi$
Min. Tensile Strength = $f_u = 58\ ksi$
Plastic Modulus*:

$$Z_{post\_X} = 2 \times \frac{t \times H^2}{4} = 30.4\ in^3$$

Post spacing = 10 feet

Post



Size: ASTM A 36
W = 14”
B = 16”
t = 0.75 inch

Yield Strength = $f_y = 36\ ksi$
Min. Tensile Strength = $f_u = 58\ ksi$

Base Plate

Size: 1"Ø - ASTM F1554 Grade 105

No.: Total 4 EA per post

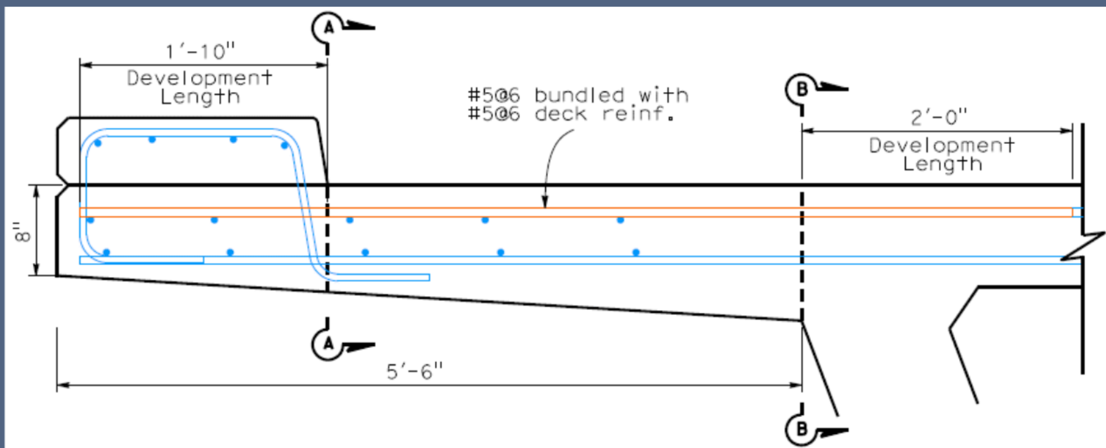
Min. Tensile Strength = $f_u = 125\ ksi$

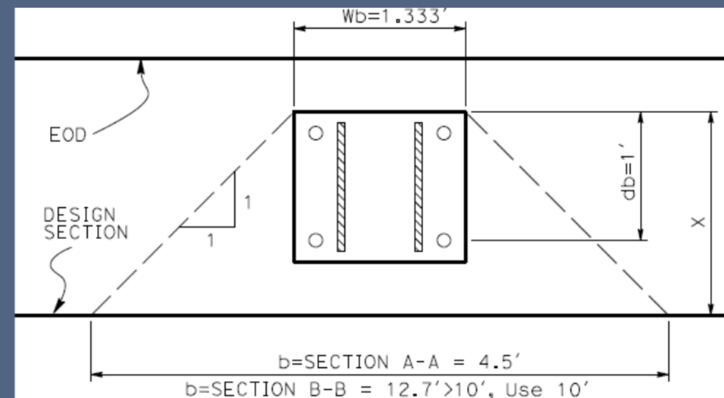
Yield Strength = $f_y = 105\ ksi$

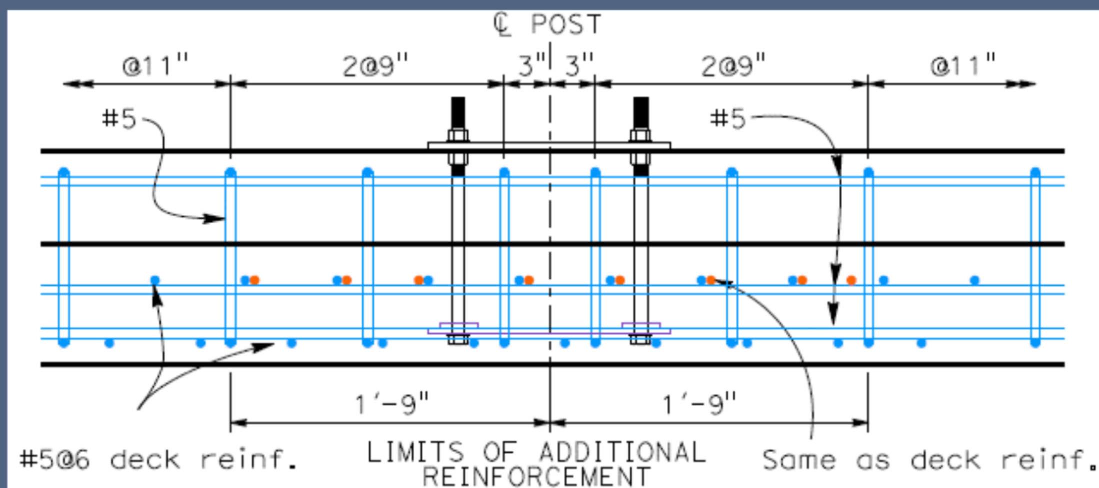
Anchor Bolt

ST-75 Analysis and Design

- Step 4: Design Overhang and Conduct detailing

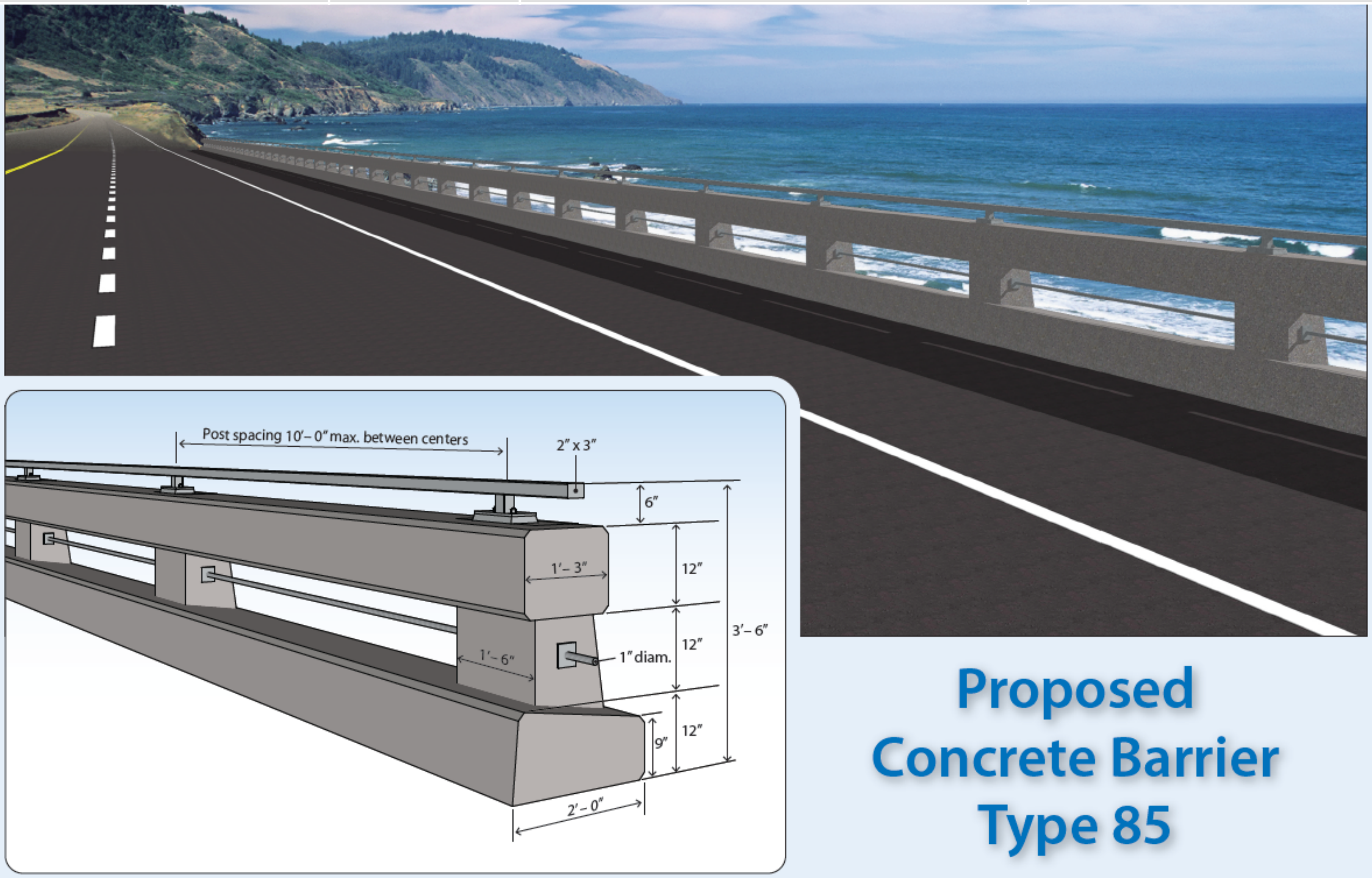




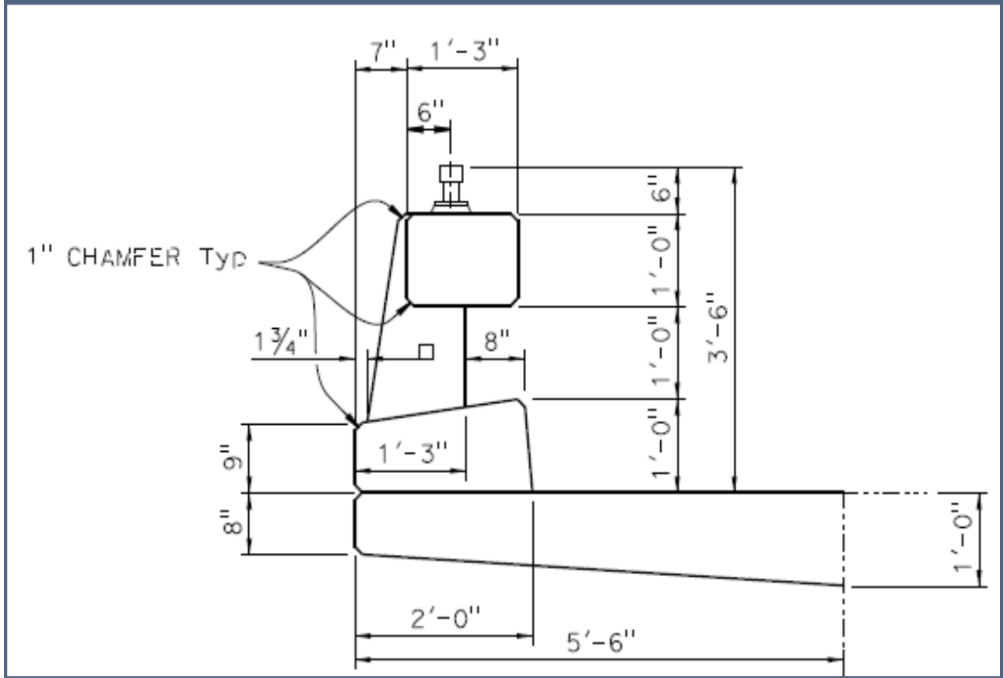


Concrete Barrier Type 85

Bridge Railing	Test Level	Description	Status
4. Concrete Barrier Type 85	TL-4	Concrete post-and-beam, H=36" or 42"	Analysis/design complete, crash test pending.



Concrete Barrier Type 85



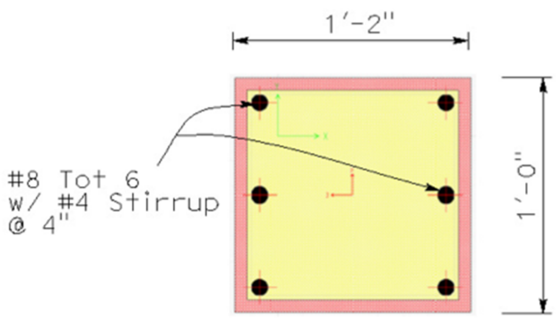
Description:

1. Vehicular rail with bicycle railing on top.
2. Aesthetic see-through bridge rail.
3. Replaces all current concrete post-and beam bridge rails.
4. Posts are spaced at 10' on center.
5. High or low speed locations
6. Occupies 2'-0"of deck width.

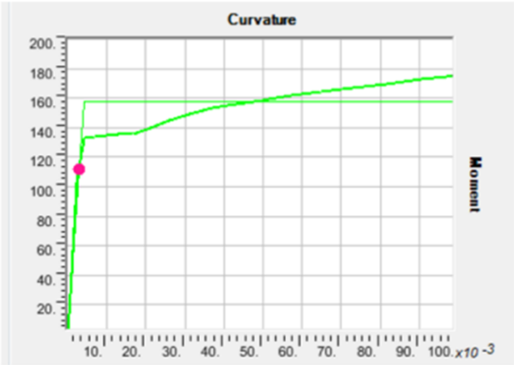
Type 85 Analysis and Design

- Step 1: Conduct Section Analysis on Post and Rail for Plastic Moment, Mp

Rail:

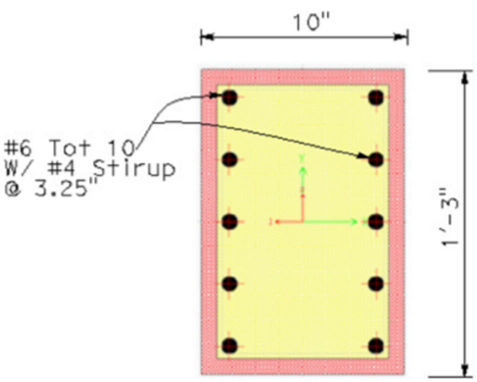


Cross section of rail defined in CSiBridge

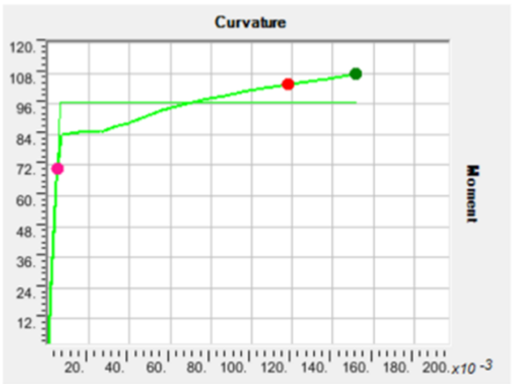


Moment (kip-ft)-Curvature (rad/ft)

Post:



Cross section of rail defined in CSiBridge

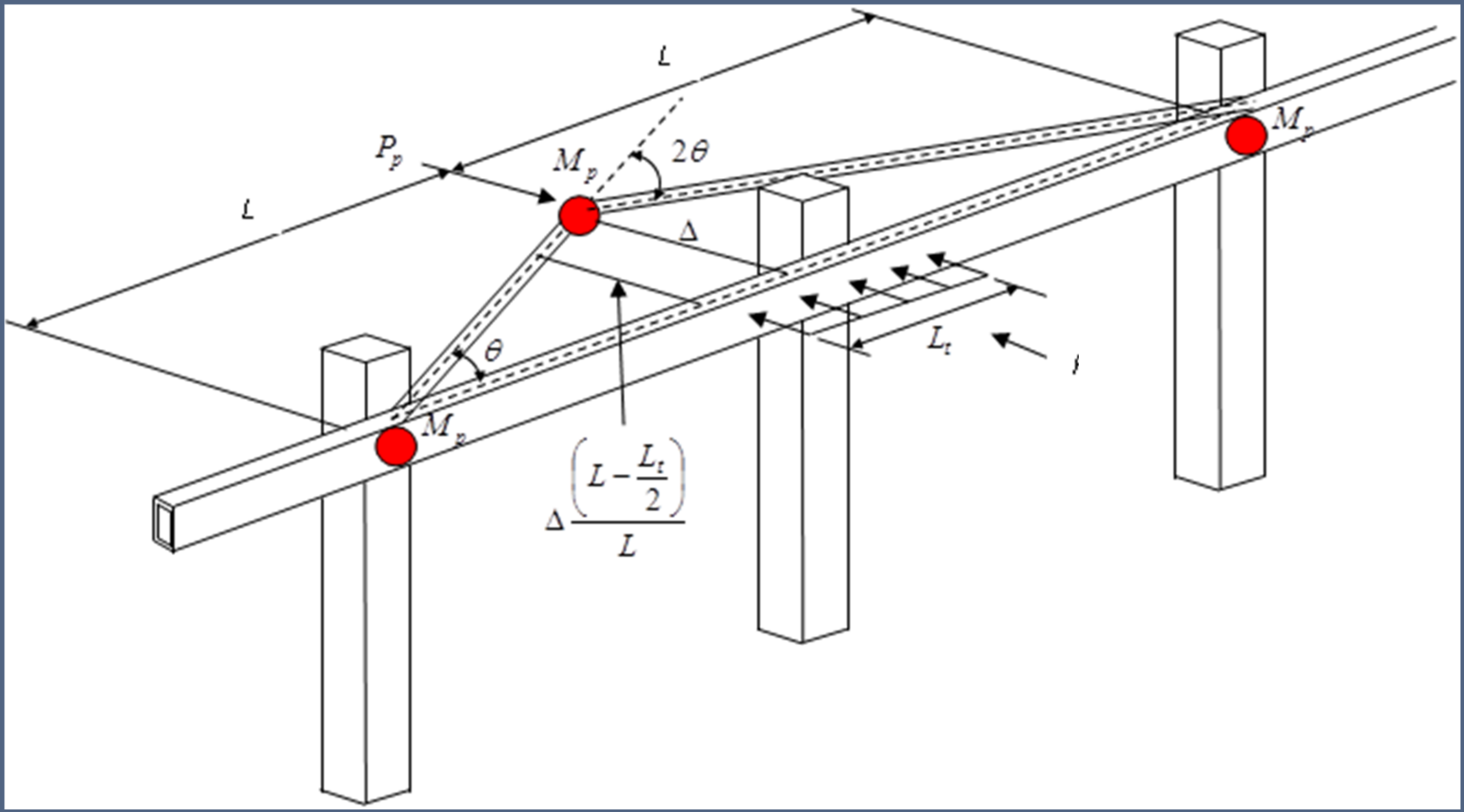


Moment (kip-ft)-Curvature (rad/ft)

Idealized plastic moment, $M_p = 96.5\ kip - ft$

Type 85 Analysis and Design

- Step 2: Check the ultimate resistance, R (using virtual work method) against the TL 4 impact load, Ft



Type 85 Analysis and Design

- Step 3: Perform FEA study for demands on the barrier components (Rail, Post,& Curb) under four different loading cases (LCs)
  - LC 1: Ft is applied at midpoint of exterior span (between endpost and interior post)
  - LC 2: Ft is applied at end post
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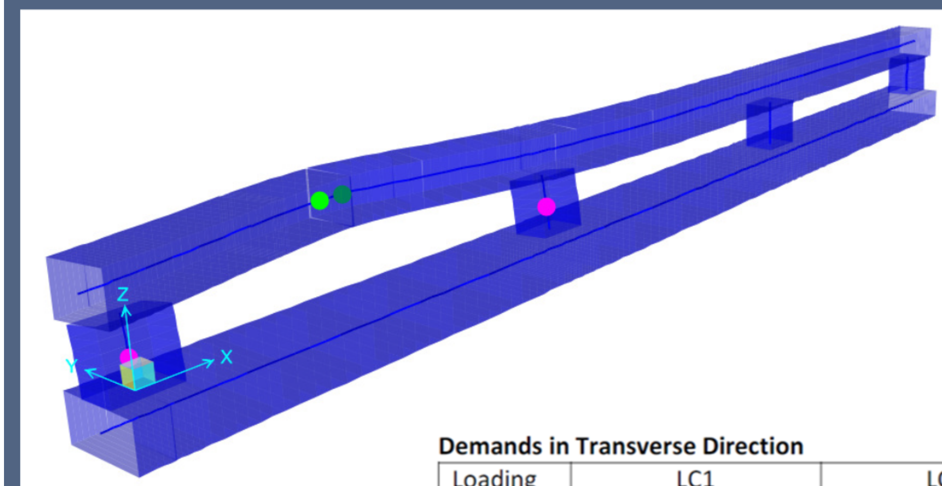
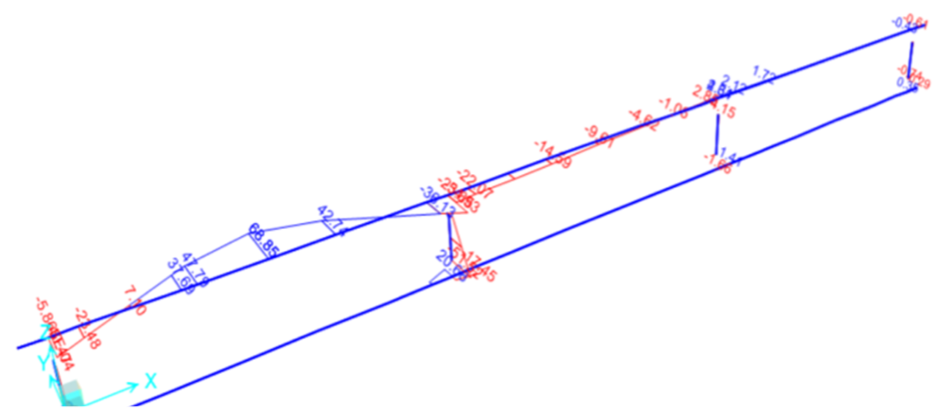
  - LC 4: Ft is applied at interior post





Demands in Transverse Direction

Loading Condition	LC1			LC2			LC3			LC4		
	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}	V_{CT}	M_{CT}	T_{CT}
Rail	30.1 [1)]	**69** [2)]	6	**39.5** [1)]	29.8 [4)]	7	28.8 [1)]	65.4 [2)]	5.6	11 [1)]	10.2	**7.2**
Post	32.9	51.5 [3)]	**40.5**	49	**78.9** [3)]	17	31.4	49 [3)]	29.4	**51.5**	75.6 [3)]	5.3
Curb	21.7	**21.5**	33 [5)]	**27.4**	14.4	**50.7** [5)]	20.6	19.6	31.8 [5)]	25.8	8.2	49.6 [5)]

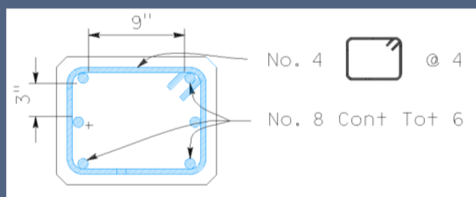
V_{CT}: Maximum shear demand (kips)

M_{CT}: Maximum flexural demand (kips)

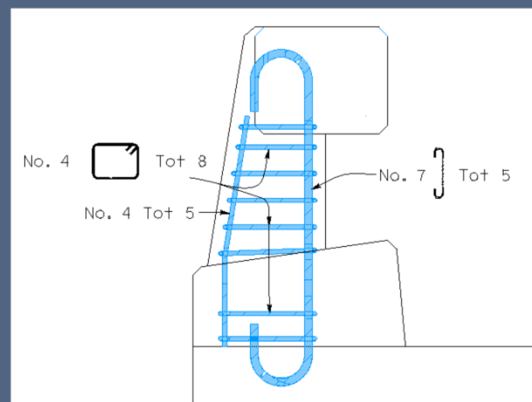
T_{CT}: Maximum torsional demand (kips)

Type 85 Analysis and Design

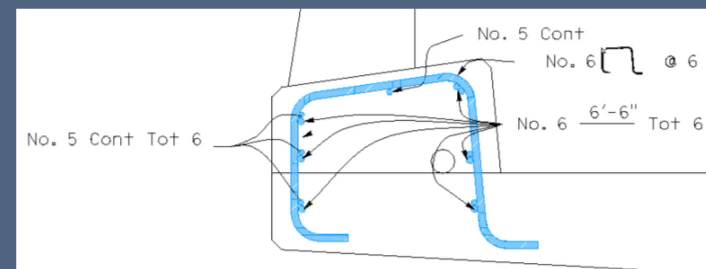
- Step 4: Check strength of each barrier component (including overhang) against the demands in Step 3 and conduct detailing



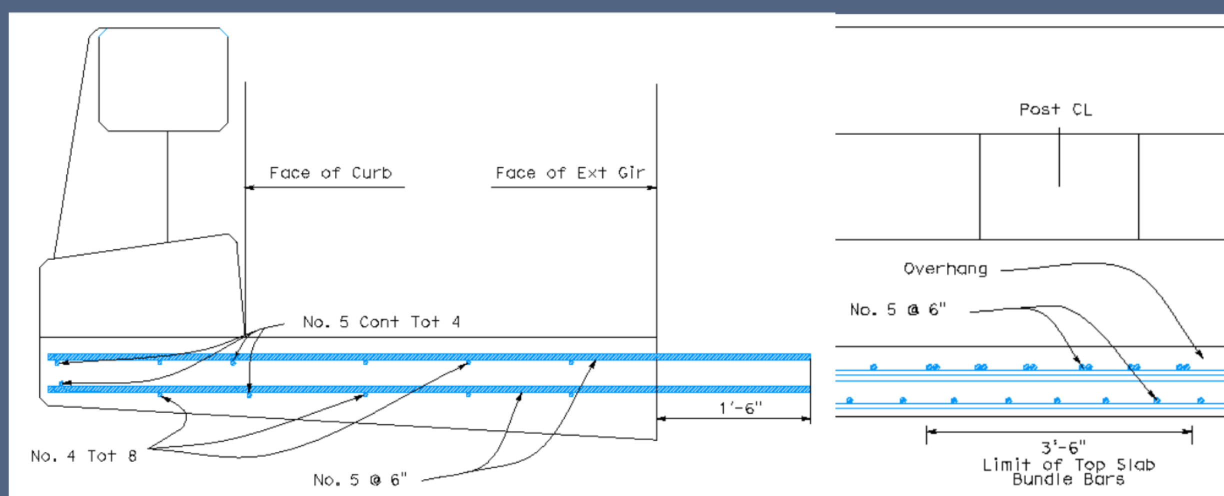
Rail



Post



Curb

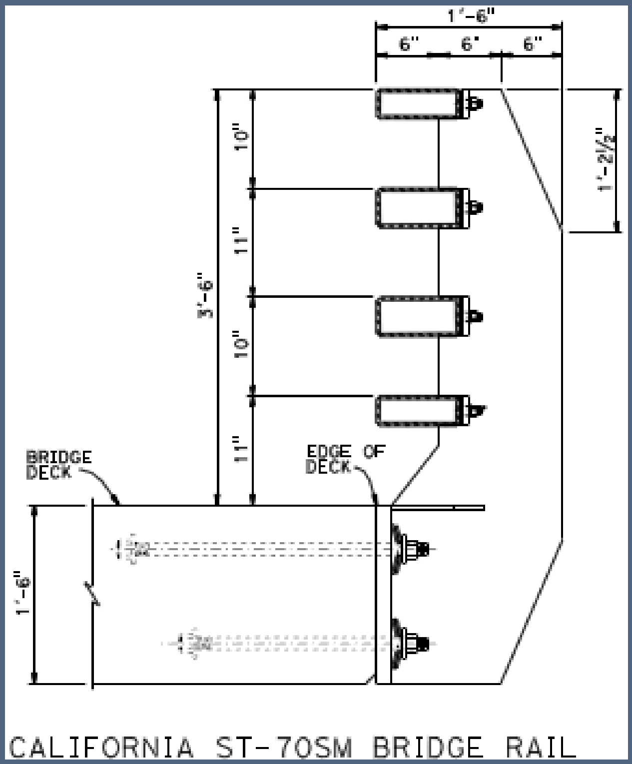


Overhang

California ST-70SM

Bridge Railing	Test Level	Description	Status
5. California ST-70 SM	TL-4	Steel post-and beam, sidemount, H=42''	Approval pending.

California ST-70SM



Description:

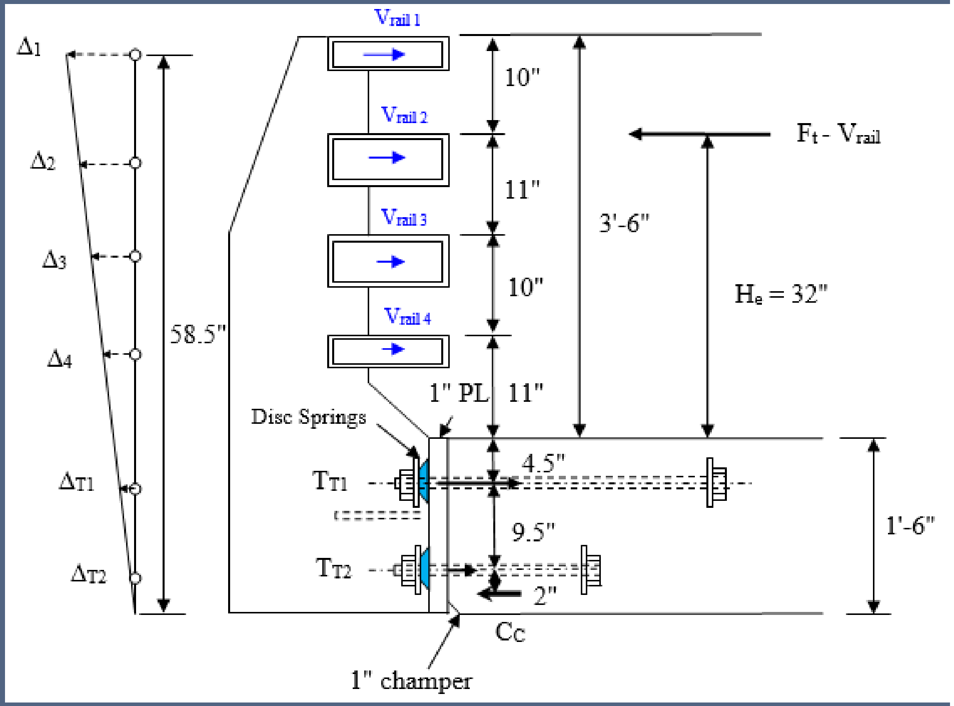
1. Vehicular rail, side mounted
2. Intended for locations with limited right of way, good for snow country,
3. Posts are spaced at 10' on center.
4. Five pairs of disk springs per interior post to diffuse energy and distribute load to adjacent posts
5. High or low speed locations
6. Width is 1'-6" beyond edge of deck

ST-70SM Analysis and Design

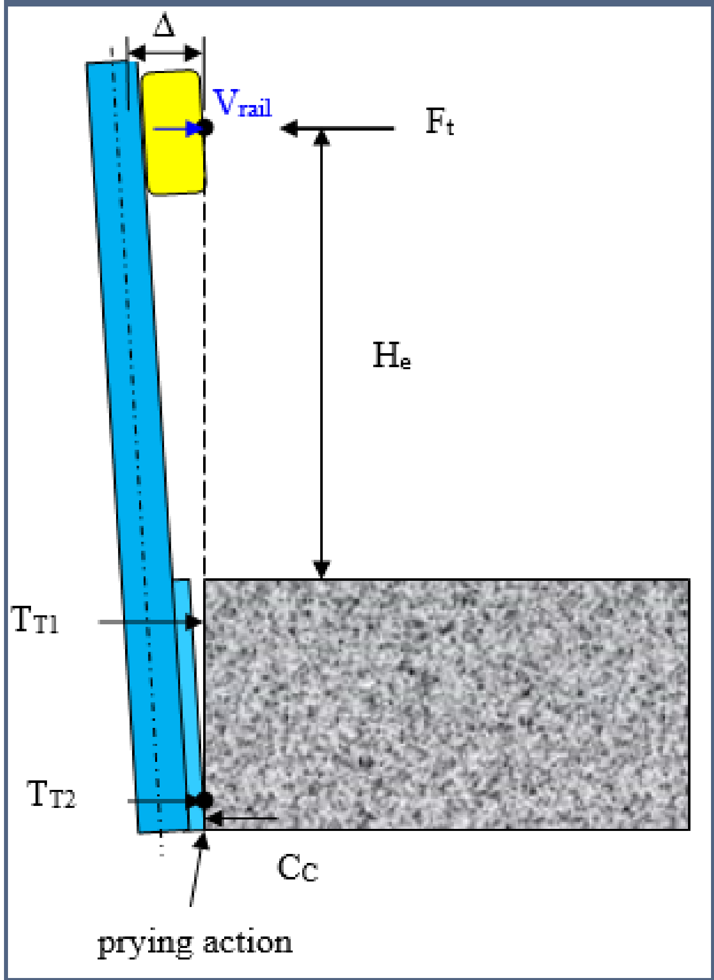
1. The objective of this research project was to design a side mounted bridge rail:
   a) that will minimize vehicle impact damage to bridge decks
   b) satisfy MASH 2009 Test Level 4 for longitudinal barriers.

2. The design strategy allows a small deflection at interior rail posts using springs.

3. This allows a part of the collision force to transfer through the shear force in rails to the adjacent posts.



ST-70SM Analysis and Design



1. In order to distribute the collision force, the post needs to deform backwards to allow the formation of plastic hinges.

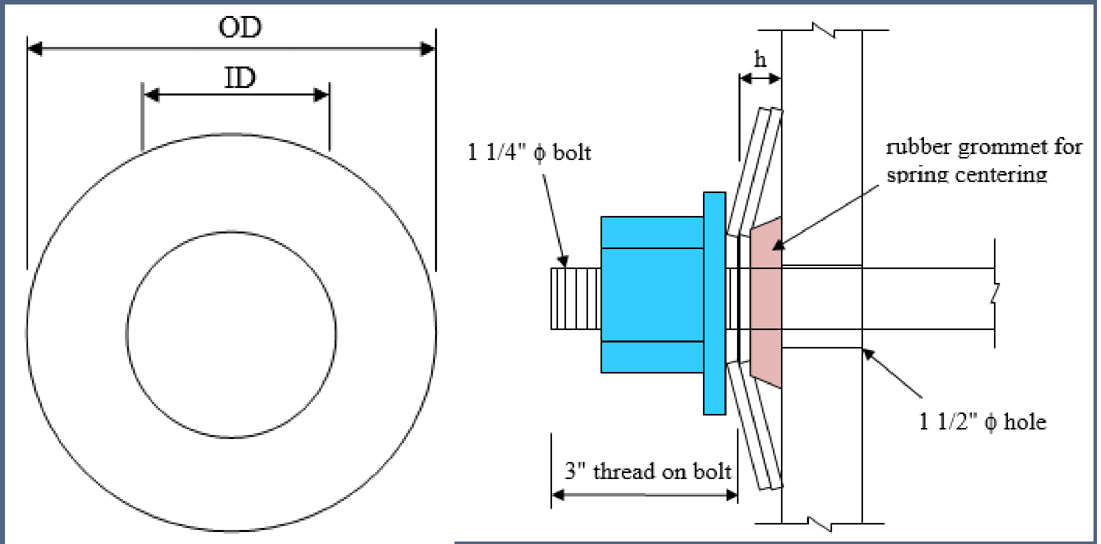
2. Springs were incorporated into the design to allow small movement.

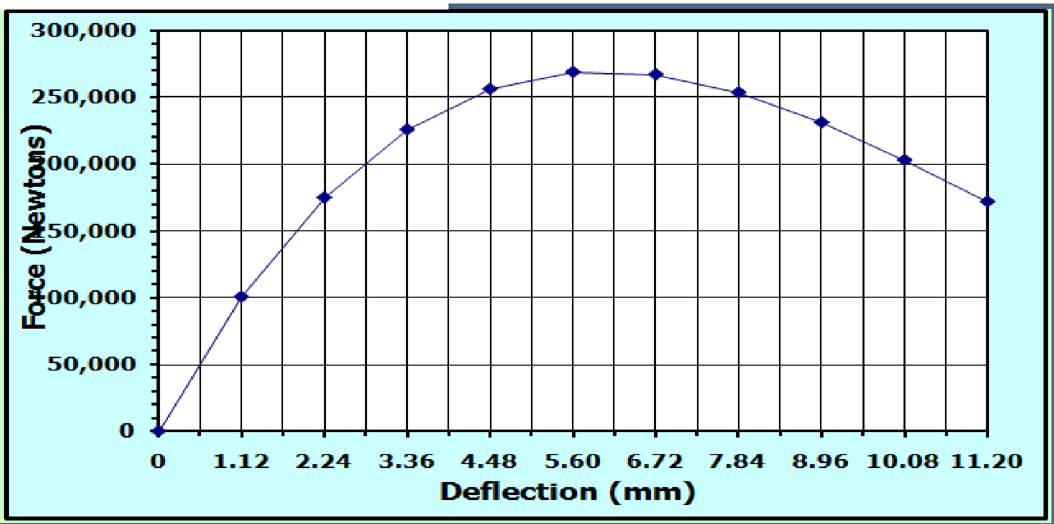
3. This approach will limit the damage to the springs instead of the bridge deck, reducing the design force for the bridge overhang.

ST-70SM Analysis and Design

Disc Springs:

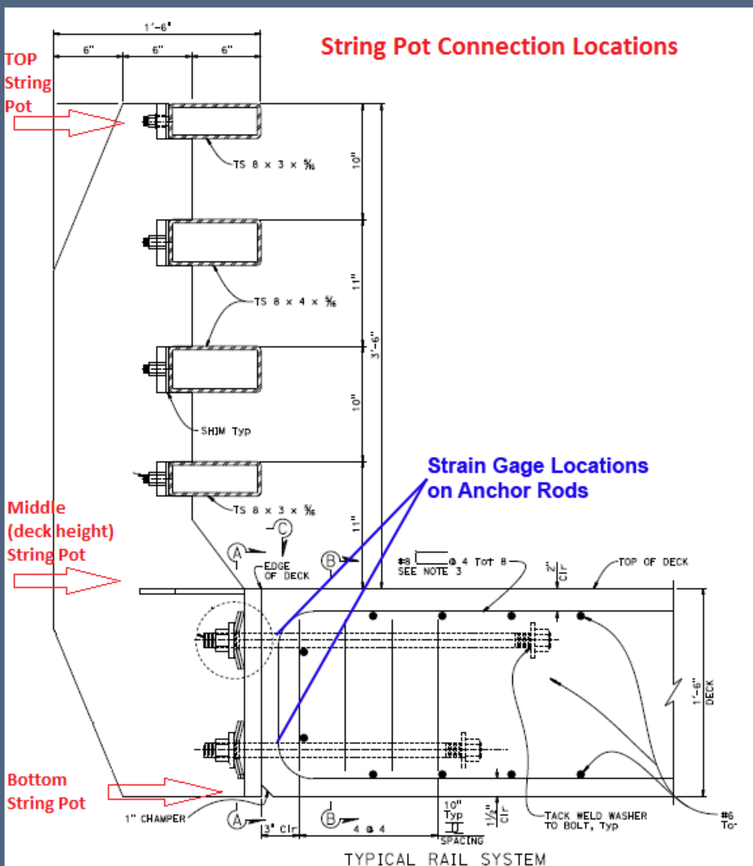
1. Theoretical maximum load rated at ~45k lbs
2. Two springs were stacked in series
   a) OD = 5 inches
   b) ID = 1.5 inches
   c) Height = 0.625 inches
      Thickness = 0.25
3. When fully compressed, allow 3/8" of movement

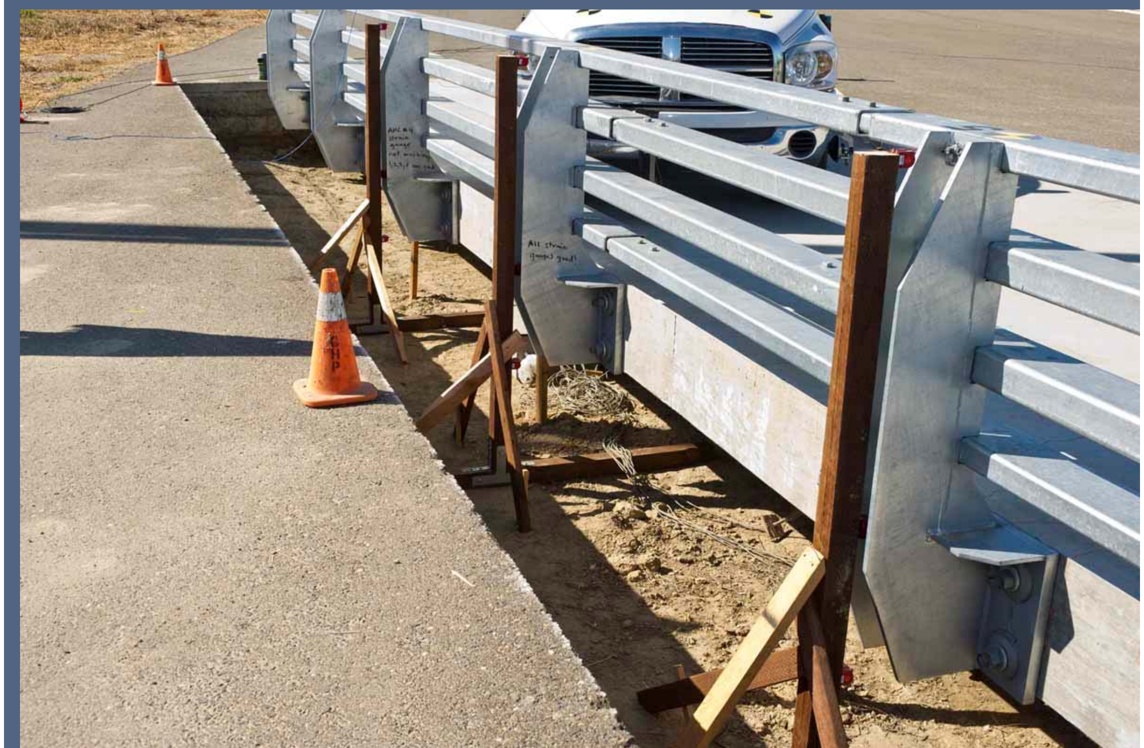




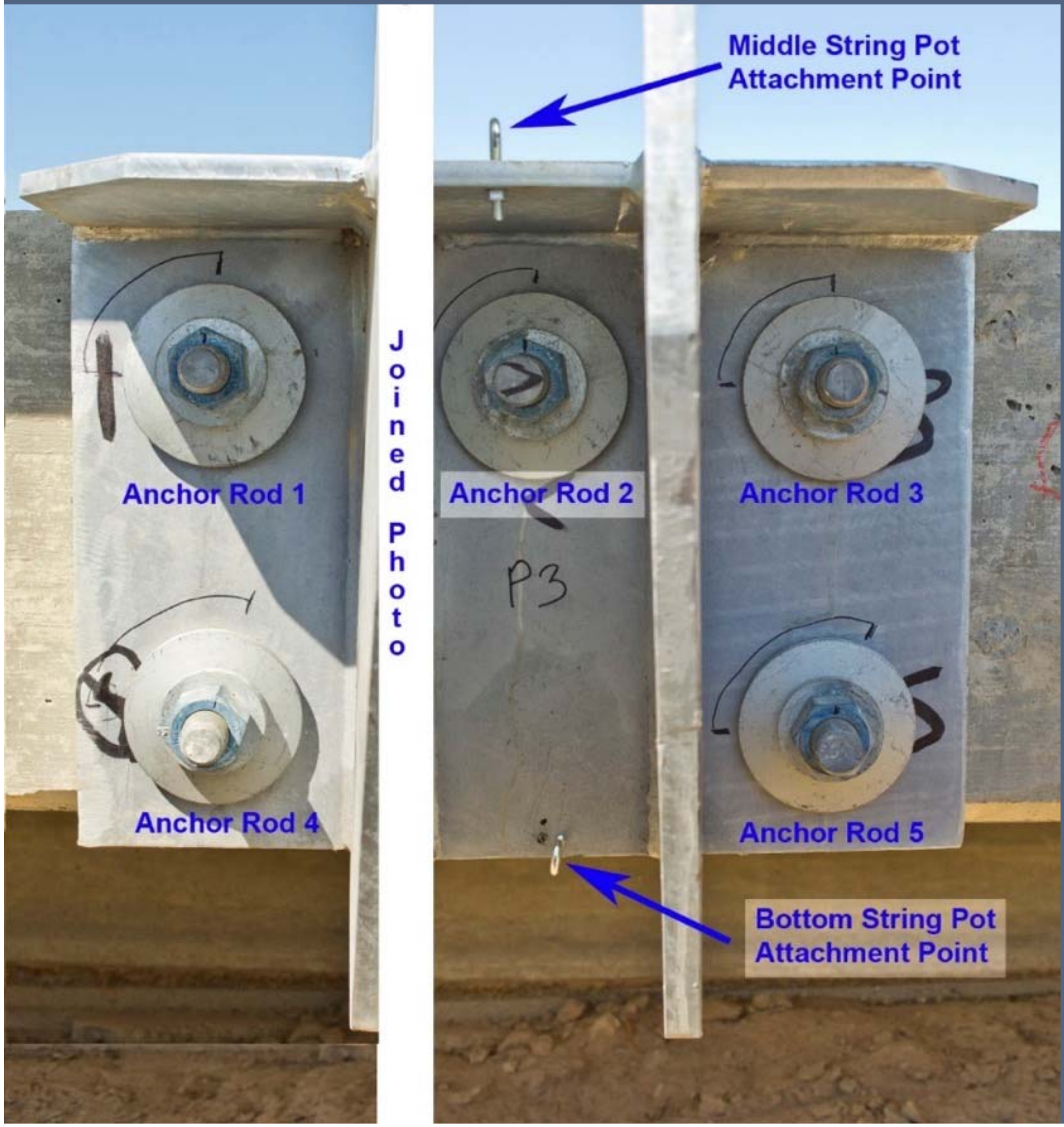
ST-70SM Field Performance

Bridge Rail Instrumentation





ST-70SM Field Performance



Disc Spring Preload

1. A 10-kip preload was applied on each anchor rod
2. A verified torque wrench was used to develop the 10-kip load (corresponding to 158 ft-lbs)

ST-70SM Field Performance

TL-4 Crash tests:

Vehicle	Test	Disc Spring Damage
Pickup Truck	4-11	Plastic deformation for upper sets at Post 4
Small Car	4-10	No damage
Single unit truck (SUT)	4-12	Plastic deformation for upper sets at Posts 2 and 3. Minor concrete spalling at Post 3.

California ST-70SM

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Test Performance Conclusions:

1. The California ST-70SM Side Mounted Bridge Rail meets the criteria set in the American Association of State Highway and Transportation Officials' Manual for Assessing Safety Hardware 2009 as a Test Level 4 longitudinal barrier.
    a) The side mounted bridge rail can successfully redirect a pickup at 62 mph (100 km/h) and 25°.
    b) The side mounted bridge rail can successfully redirect a 1100C small car at 62 mph (100 km/h) and 25°.
    c) The side mounted bridge rail can successfully redirect a 10000S single-unit van body at 56 mph (90 km/h) and 15°

2. Impacts similar to pickup truck and single unit truck tests would require inspection of the disc springs and disc replacement if necessary.

Next Steps for California

1. Adopt MASH compliant railing systems by others.
2. Continue to participate in the Midwest/TTI pooled fund studies and other national research
3. Submit research proposals for future systems by Caltrans:
    a) SHPO compliant aesthetic bridge railings
    b) ABC friendly MASH compliant barrier
    c) Combination traffic railings (vehicular plus bike/ped)

Thank you

For more information, please visit us at
http://www.dot.ca.gov/research/operations/roadsidesafety/index.htm