RAILROAD BRIDGE APPROACH EMBANKMENT SETTLEMENT MITIGATION

Presented by

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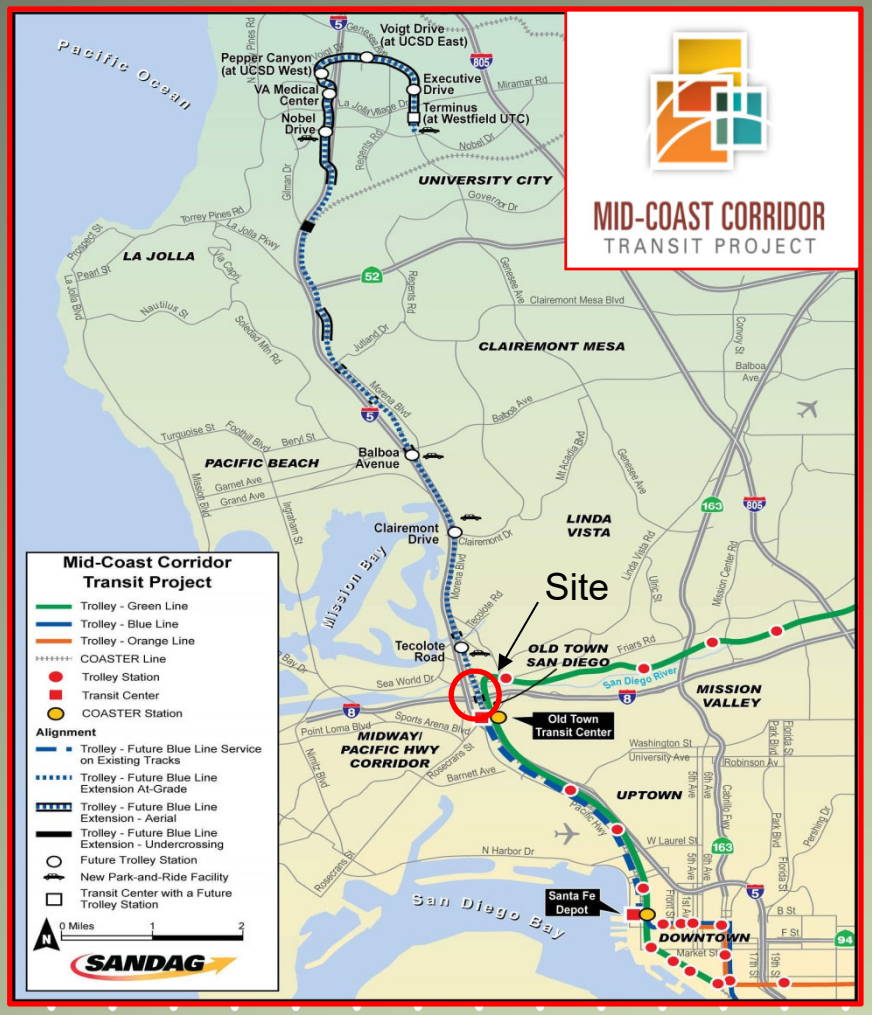


NORTH COUNTY TRANSIT DISTRICT

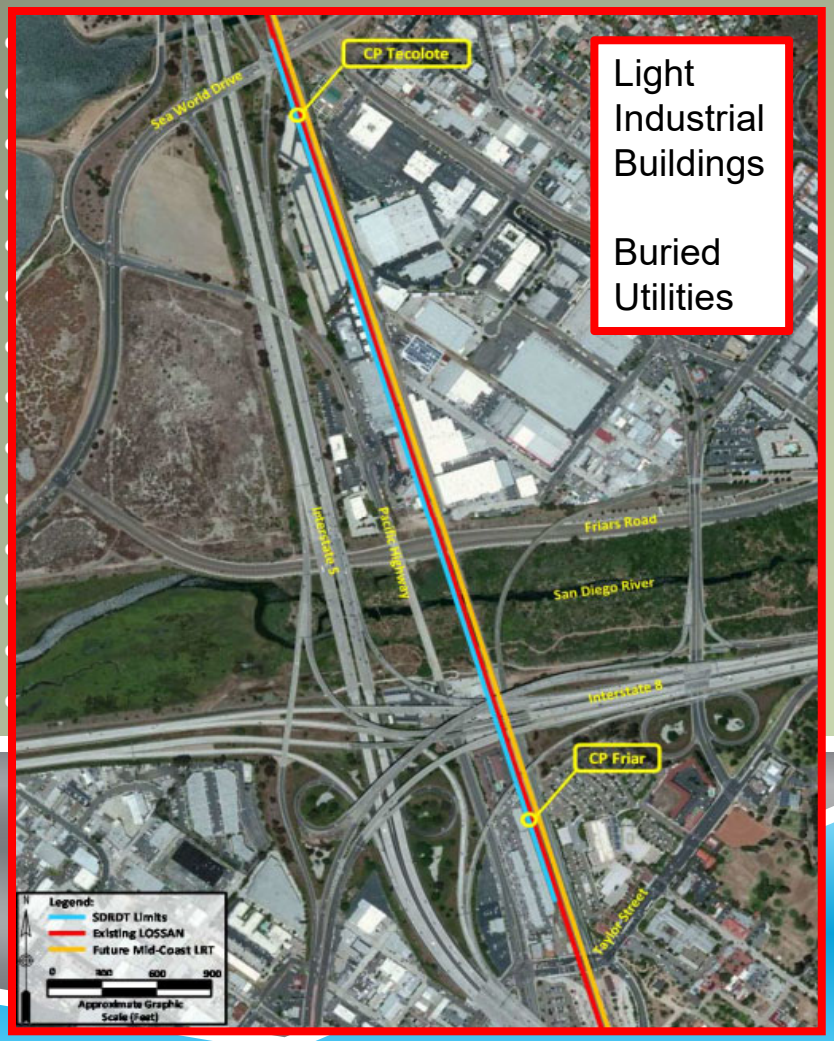
SANDAG

900’ River Crossing

- LOSSAN Double Track Bridge
- MTS LRT Double Track Bridge

Approach Embankment

1,520’ long and up to 15’ High

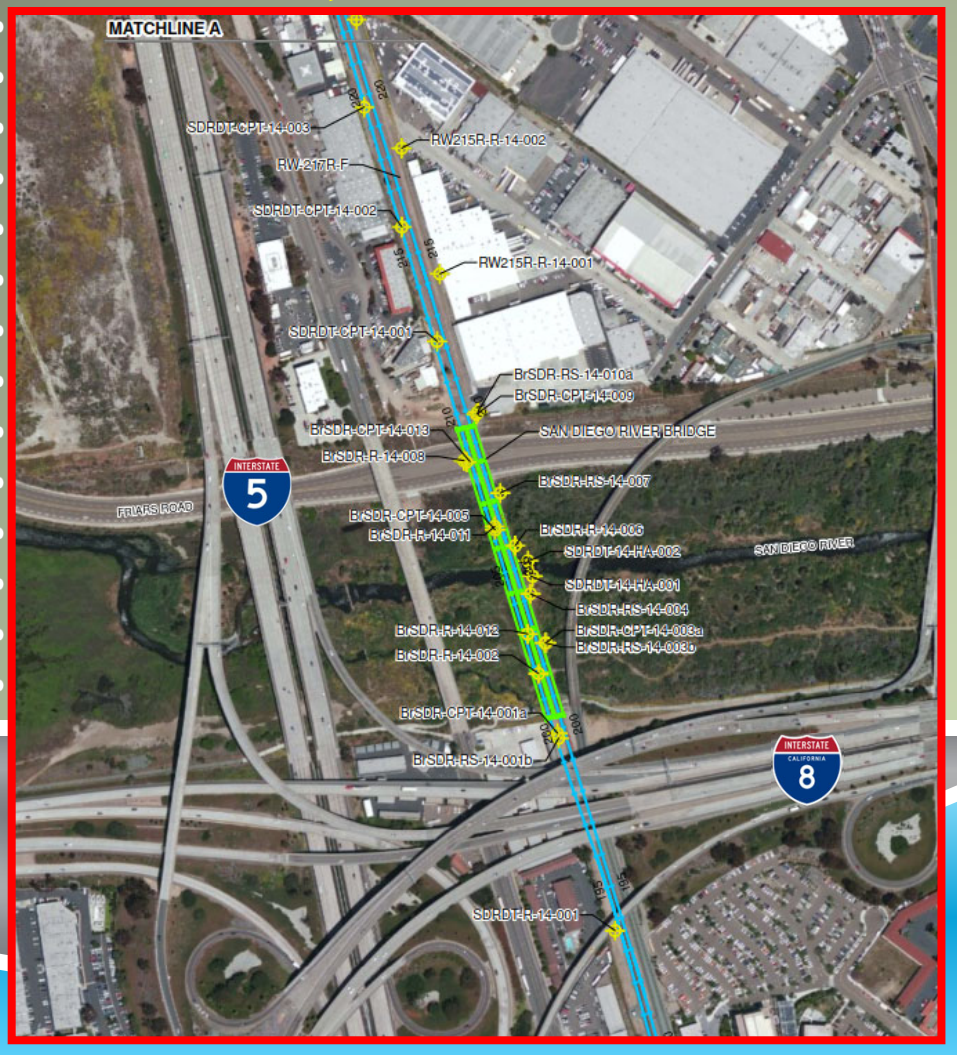


Light Industrial Buildings

Buried Utilities

Field Explorations

- Boreholes (HSA, Rotary Wash, Sonic)
- CPTs w/ Shear Wave Velocity
- Geophysical Survey (ReMi and MASW)



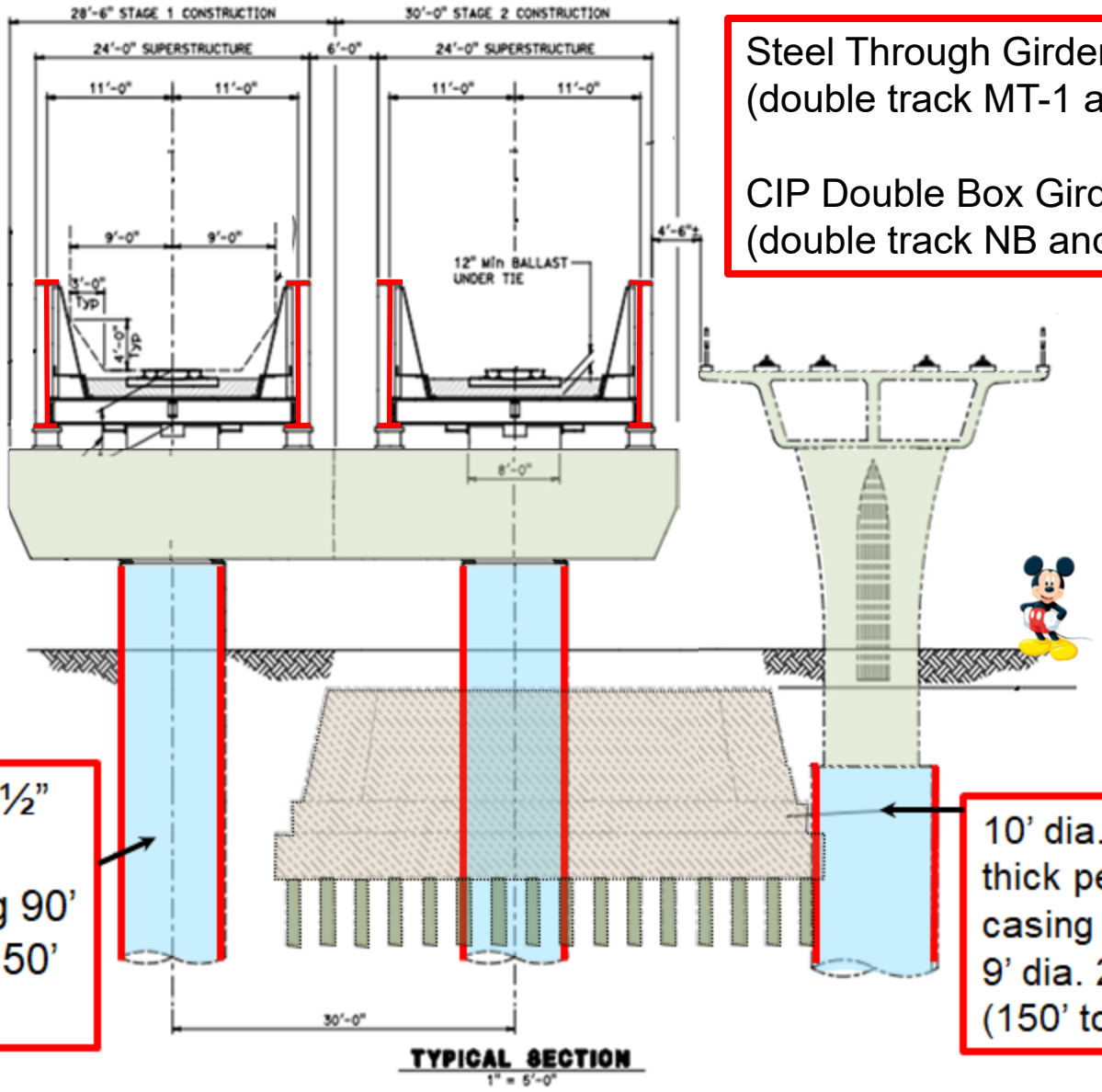
Preconstruction Site Conditions along Friars Road and Tack Alignment

Existing 900’ MT-1 Bridge to be Demolished

Views to South and North

Steel Through Girder Bride
(double track MT-1 and MT-2)

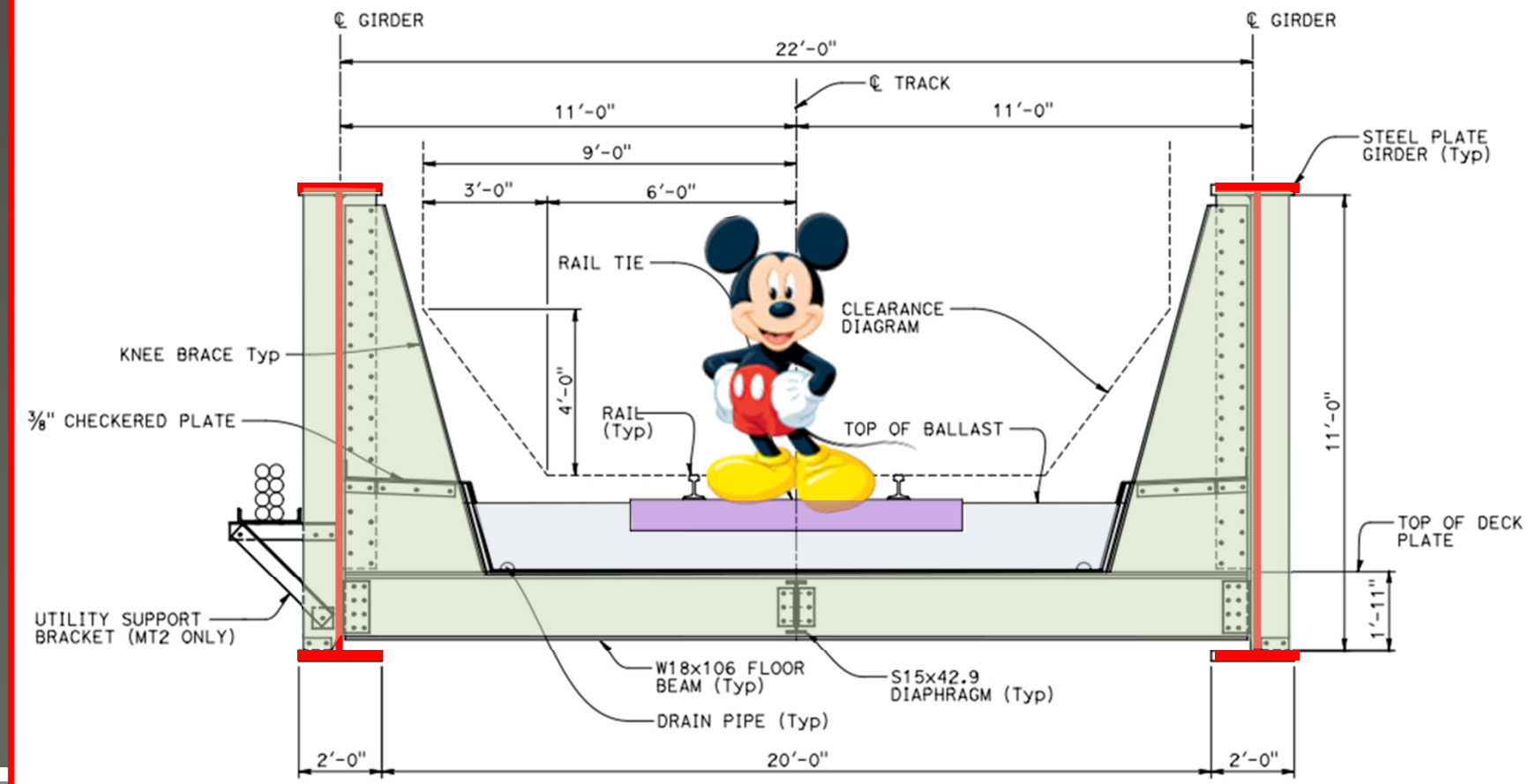
CIP Double Box Girder Bridge
(double track NB and SB)



TYPICAL SECTION
1" = 5'-0"

9' dia. w/ 1-½" thick perm. steel casing 90' then 8' dia. 50' (140' total)

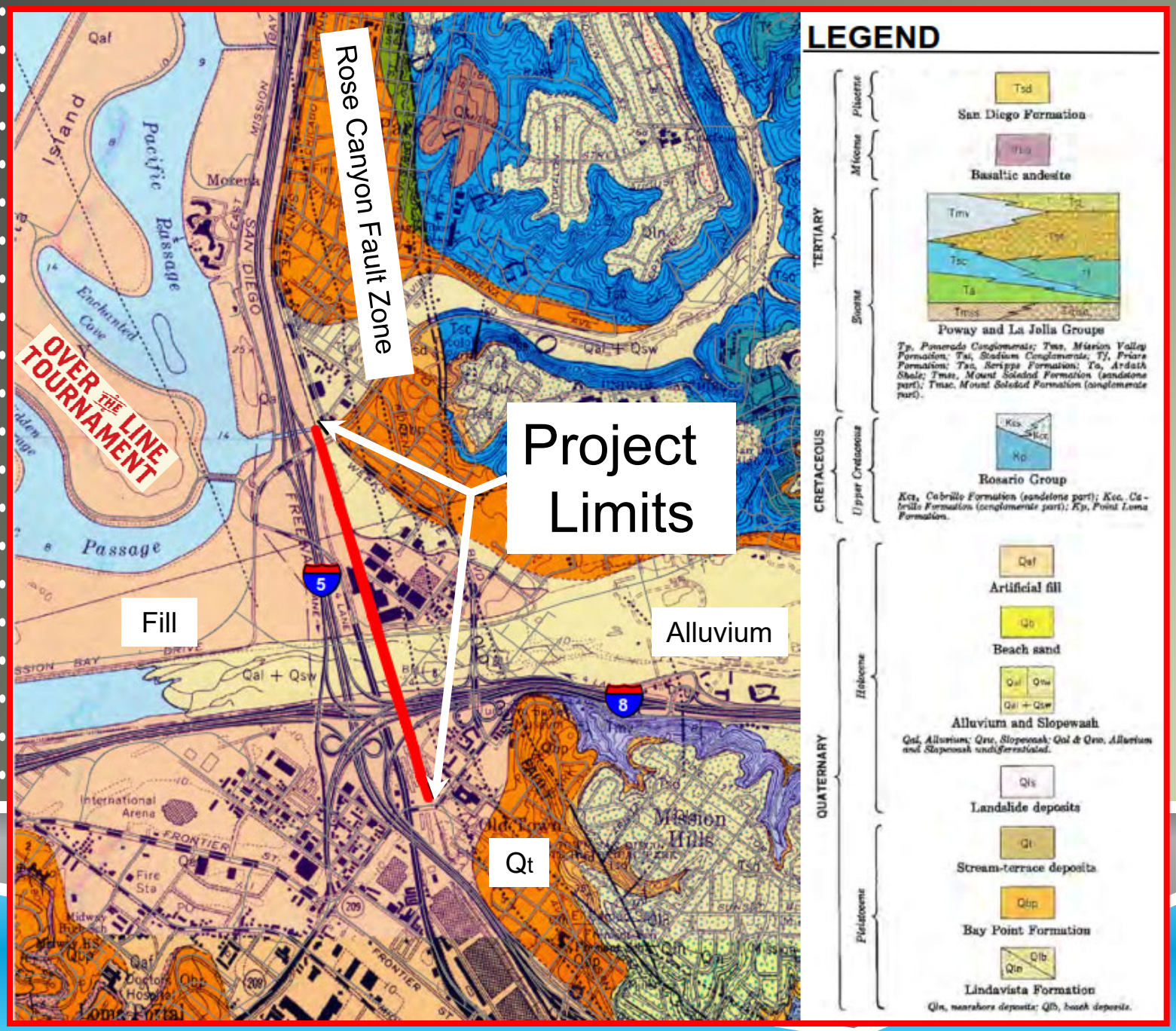
10' dia. w/ 1-½" thick perm. steel casing 130' then 9' dia. 20' (150' total)

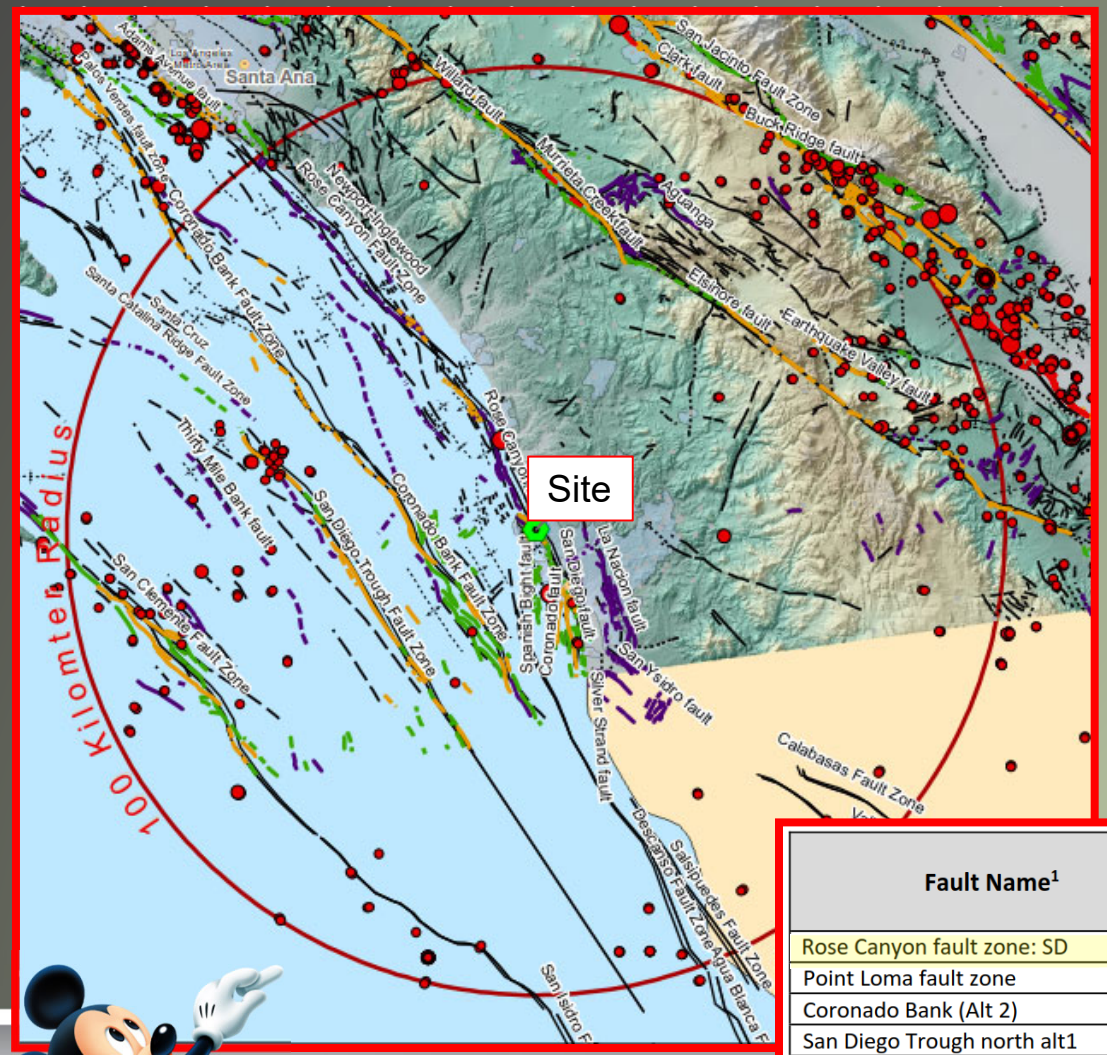


TYPICAL SECTION

½" = 1′-0"


LATE NIGHT WITH SETH MEYERS
A CLOSER LOOK


Rose Canyon Fault Zone
Project Limits
Fill
Alluvium
Qt
OVER THE LINE TOURNAMENT
Qaf
Qal + Qsw
LEGEND
TERTIARY
Pliocene
Miocene
Eocene
Tsd
San Diego Formation
Basaltic andesite
Poway and La Jolla Groups
CRETACEOUS
Upper Cretaceous
Rosario Group
QUATERNARY
Holocene
Artificial fill
Beach sand
Alluvium and Slopewash
Landslide deposits
Pleistocene
Stream-terrace deposits
Bay Point Formation
Lindavista Formation



Regional Faults and Historic Earthquake Epicenters (100 km radius)

Fault Rupture Data

Fault Name[1]	R_{RUP} (miles)[2]	Fault Type [3]	Maximum Moment Magnitude[4]	Slip Rate (inches/year)[5]
Rose Canyon fault zone: SD	0.1	SS	6.8	0.08
Point Loma fault zone	2.0	N	6.3	n/a
Coronado Bank (Alt 2)	12.9	SS	7.4	0.12
San Diego Trough north alt1	24.0	SS	7.3	0.08
Newport Inglewood: Offshore	30.2	SS	7.2	0.04
Elsinore: Julian	40.8	SS	7.7	0.12
San Clemente	47.2	SS	7.5	0.10
San Felipe fault	48.8	SS	6.3	n/a
San Joaquin Hills	60.1	R	7.0	0.02
San Jacinto: Coyote Creek	61.6	SS	7.3	0.20
San Jacinto: Anza	64.5	SS	7.7	0.74

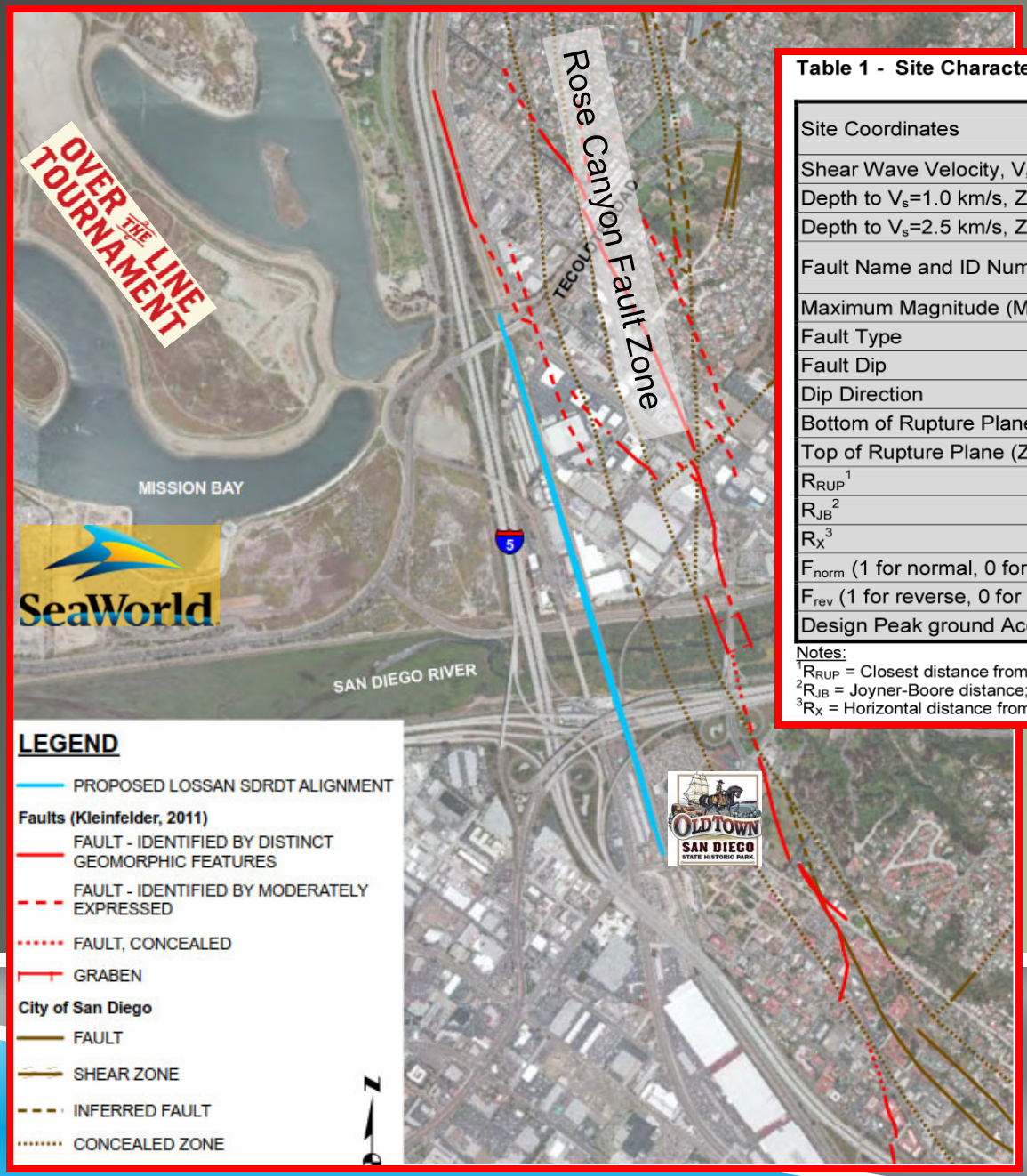


Table 1 - Site Characteristics and Governing Fault Parameters

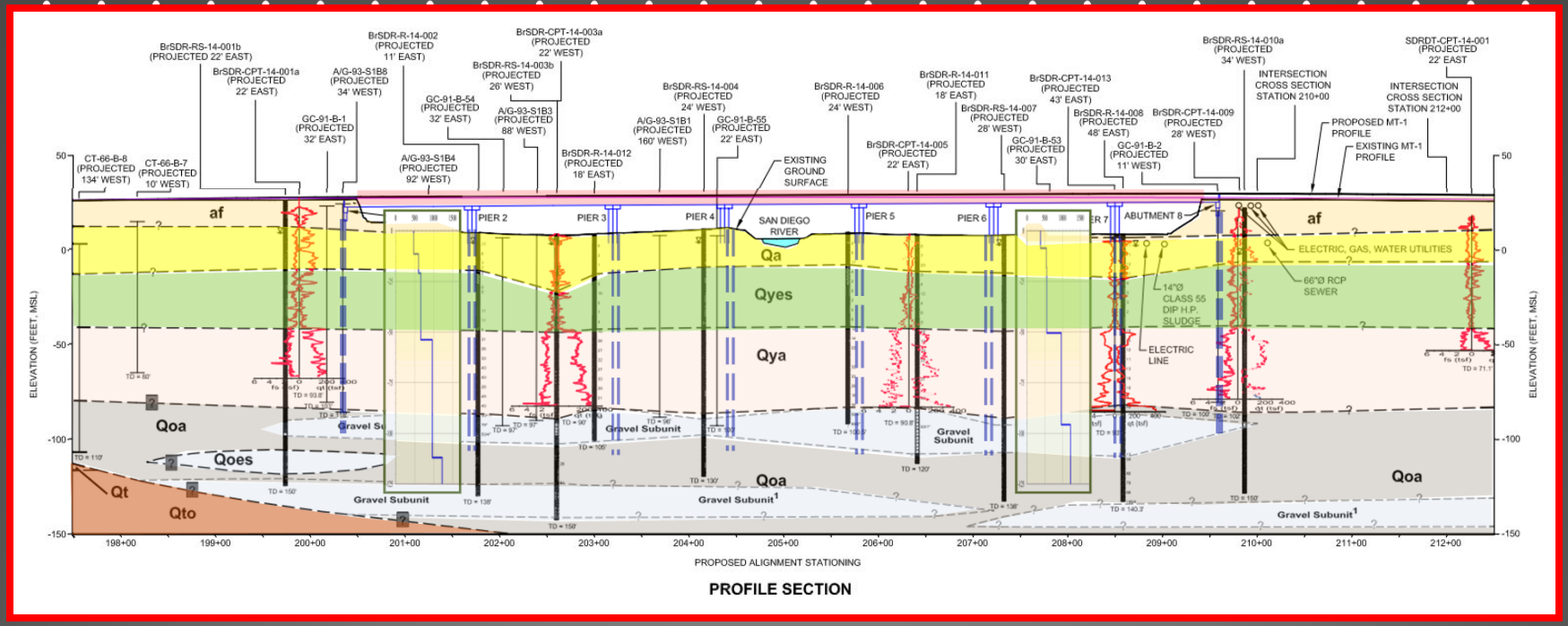
Site Coordinates	Latitude = 32.761855 degrees, Longitude = -117.202319 degrees
Shear Wave Velocity, V_{s30}	2,200 ft/s (671 m/s)
Depth to V_s=1.0 km/s, $Z_{1.0}$	NA (Not located in a basin)
Depth to V_s=2.5 km/s, $Z_{2.5}$	NA (Not located in a basin)
Fault Name and ID Number	Rose Canyon fault zone (San Diego section), ID No. 405
Maximum Magnitude (M_{Max})	6.8
Fault Type	Strike Slip
Fault Dip	90 degrees
Dip Direction	Vertical
Bottom of Rupture Plane	8.0 miles (13 km)
Top of Rupture Plane (Z_{tor})	0 mile (0 km)
R_{RUP}[1]	0.17 miles (0.27 km)
R_{JB}[2]	0.17 miles (0.27 km)
R_X[3]	0.17 miles (0.27 km)
F_{norm} (1 for normal, 0 for others)	0
F_{rev} (1 for reverse, 0 for others)	0
Design Peak ground Acceleration (PGA)	0.542

Notes:
[1] R_{RUP} = Closest distance from the site to the fault rupture plane.
[2] R_{JB} = Joyner-Boore distance; the shortest horizontal distance to the surface projection of the rupture area.
[3] R_X = Horizontal distance from the site to the fault trace or surface projection of the top of the rupture plane.

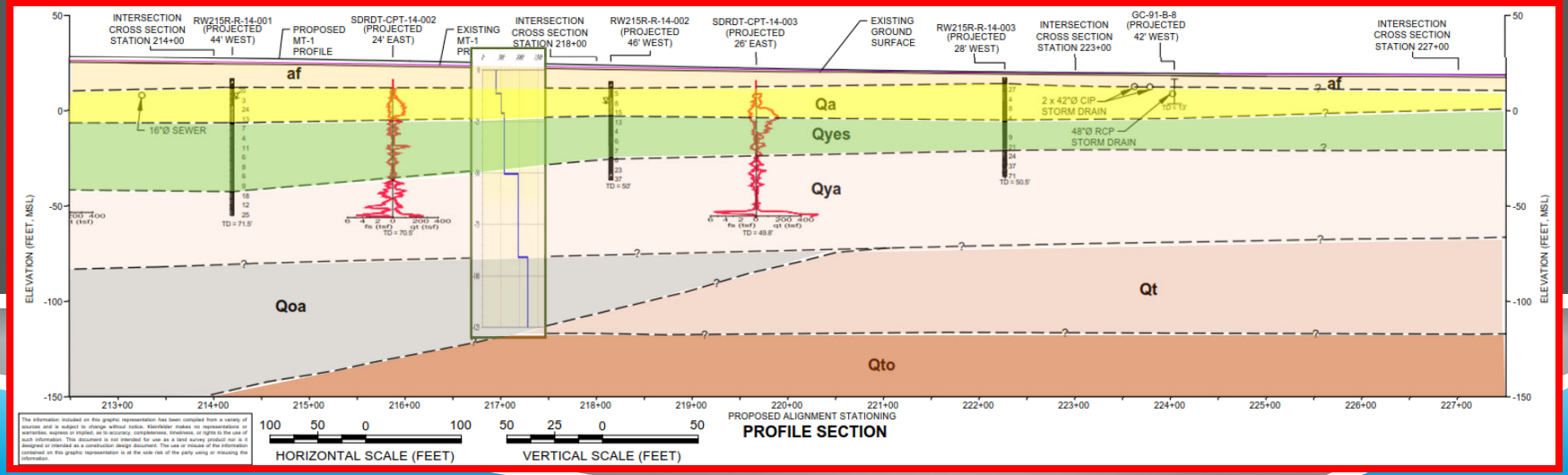
M_{max} = 6.8

R_{RUP} = 1,000’

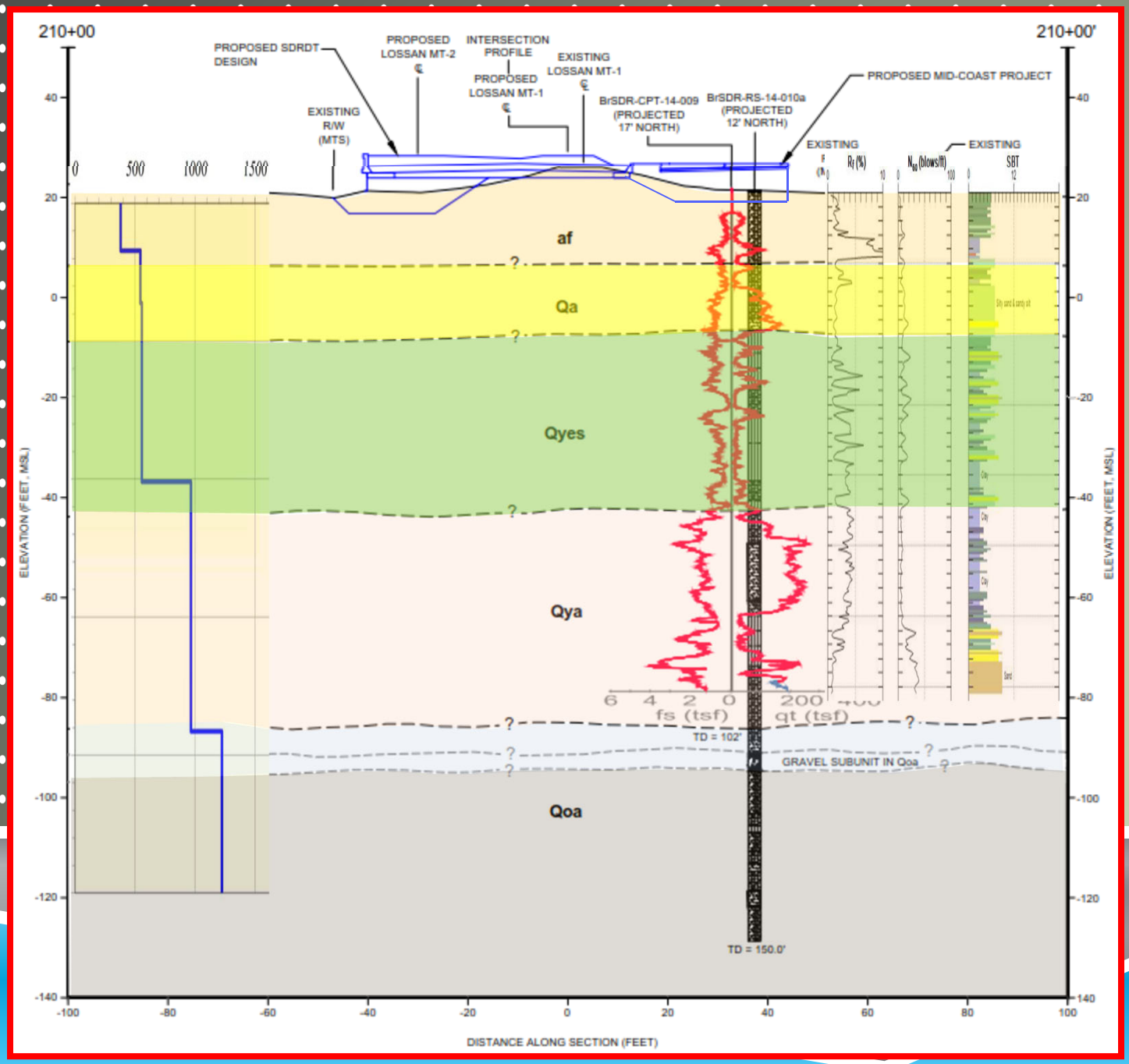
PGA = 0.542 g

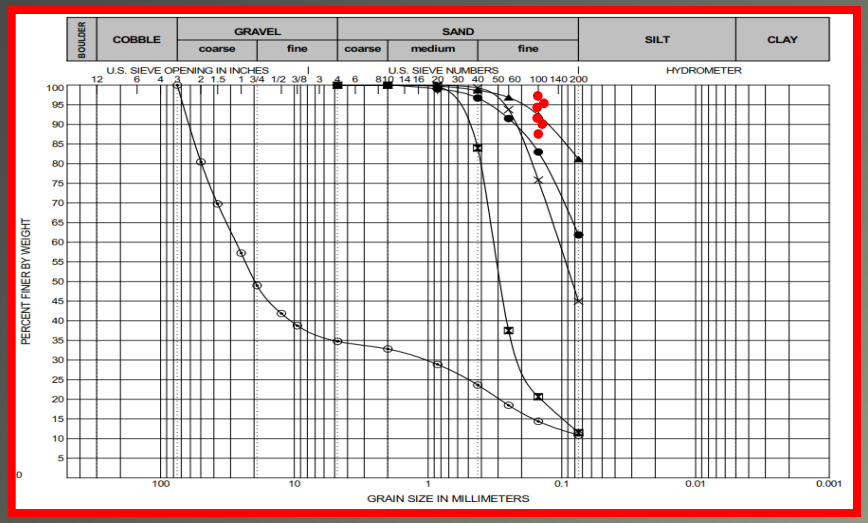


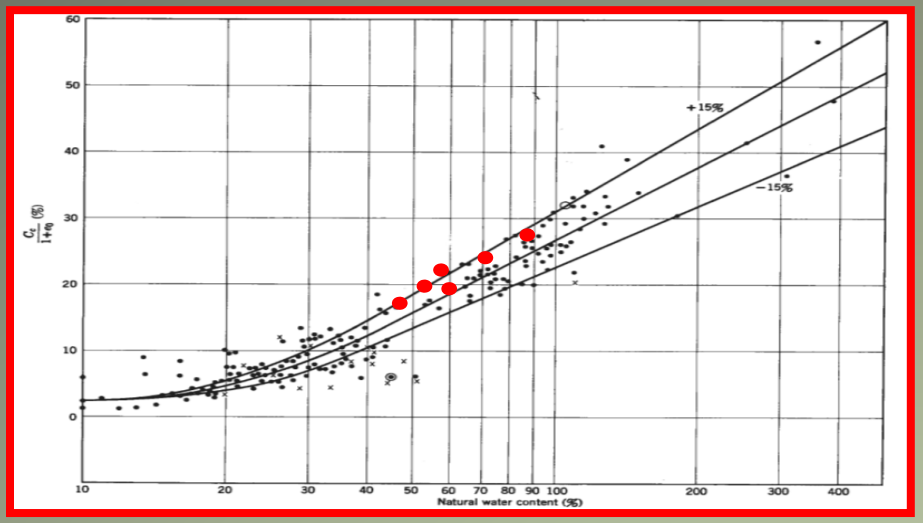
PROFILE SECTION

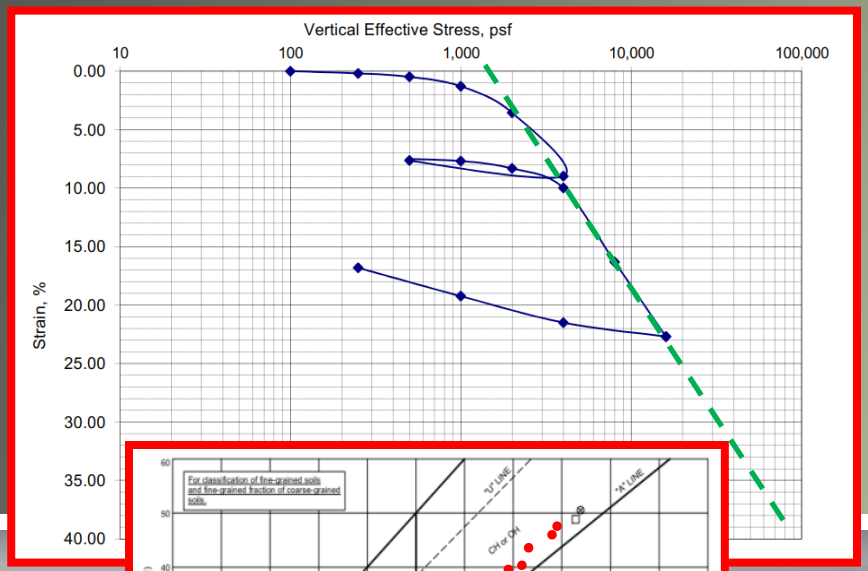


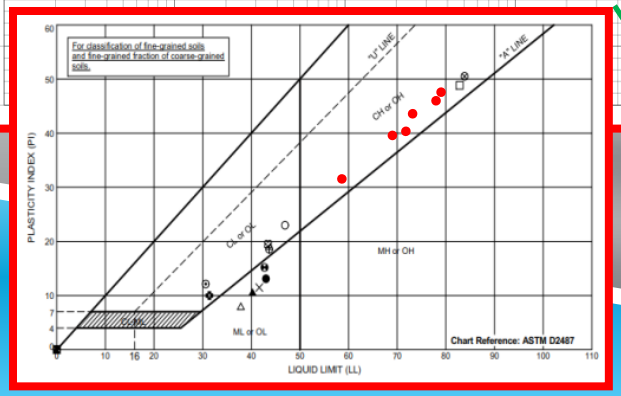
PROFILE SECTION


210+00
210+00'
PROPOSED SDRDT DESIGN
PROPOSED LOSSAN MT-2 ℄
INTERSECTION PROFILE
PROPOSED LOSSAN MT-1 ℄
EXISTING LOSSAN MT-1 ℄
EXISTING R/W (MTS)
BrSDR-CPT-14-009 (PROJECTED 17' NORTH)
BrSDR-RS-14-010a (PROJECTED 12' NORTH)
PROPOSED MID-COAST PROJECT
EXISTING
EXISTING
0
500
1000
1500
af
Qa
Qyes
Qya
Qoa
TD = 102'
TD = 150.0'
GRAVEL SUBUNIT IN Qoa
fs (tsf)
qt (tsf)
ELEVATION (FEET, MSL)
DISTANCE ALONG SECTION (FEET)









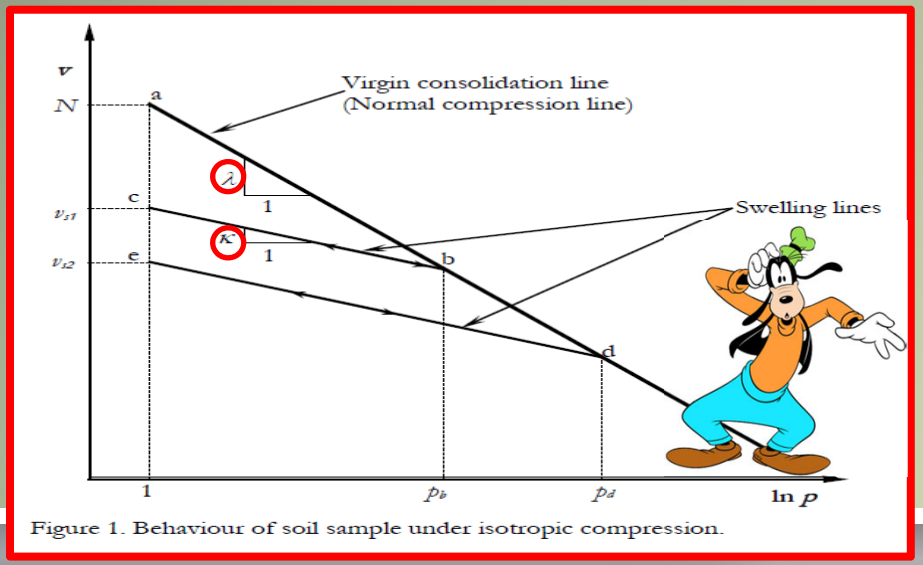
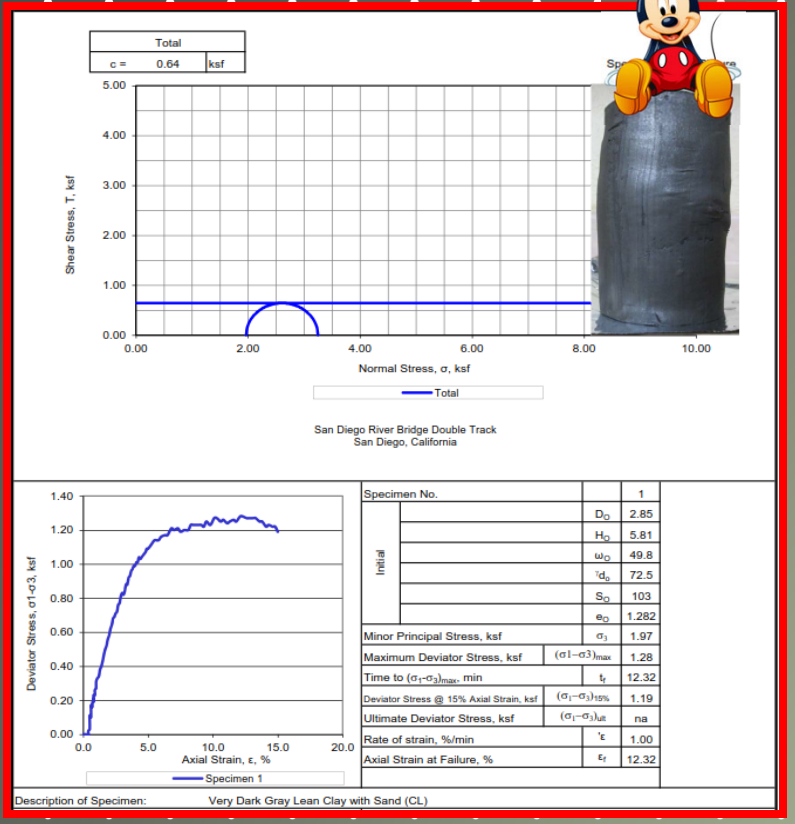
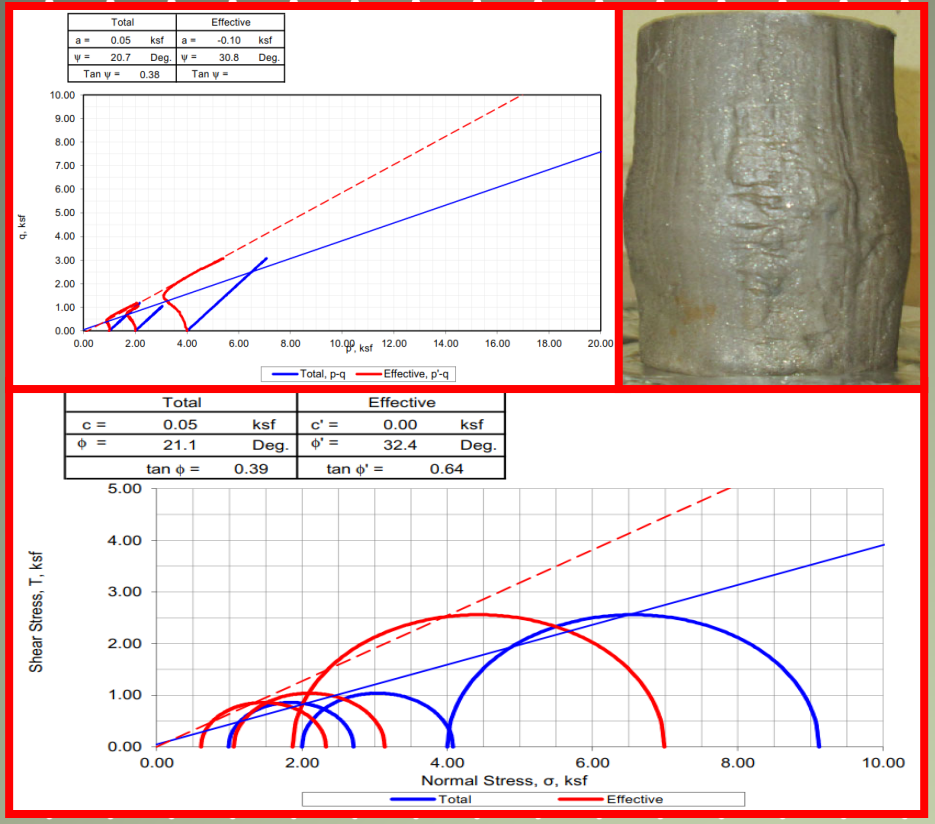


Figure 1. Behaviour of soil sample under isotropic compression.

Modified Cam-Clay Consolidation Parameters

λ = virgin CSL and κ = unload/reload (compression)





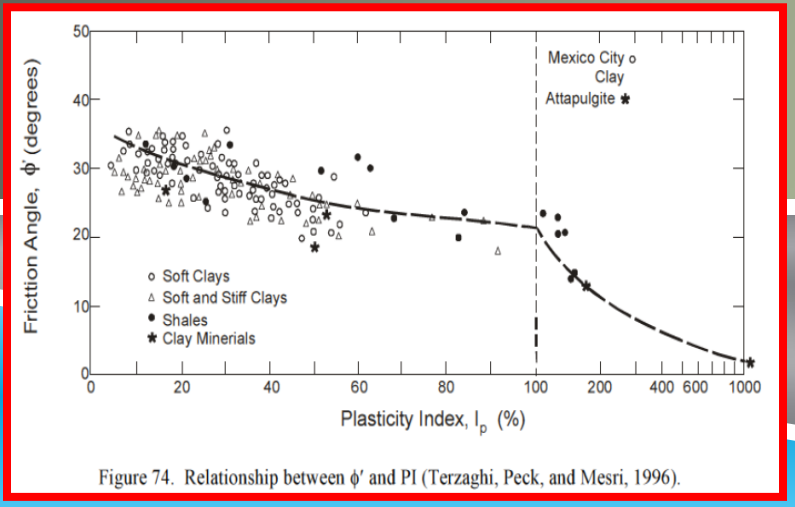
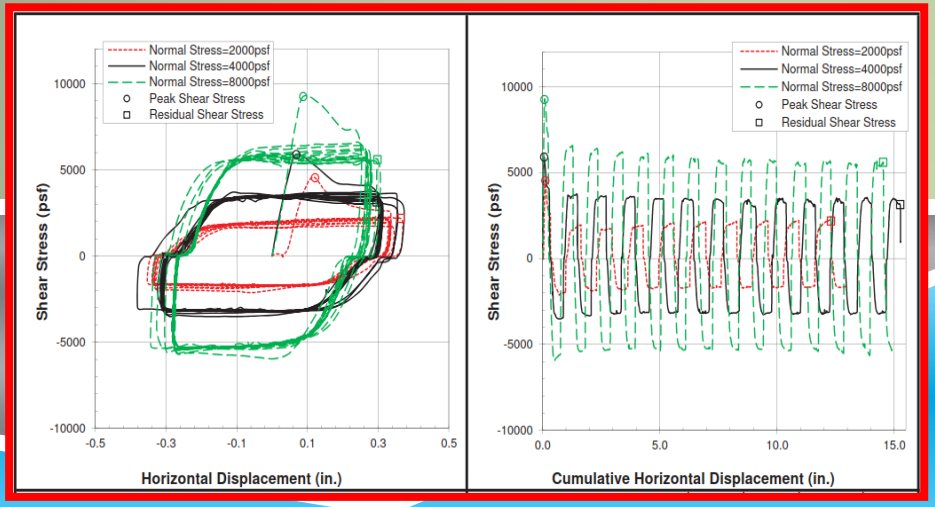
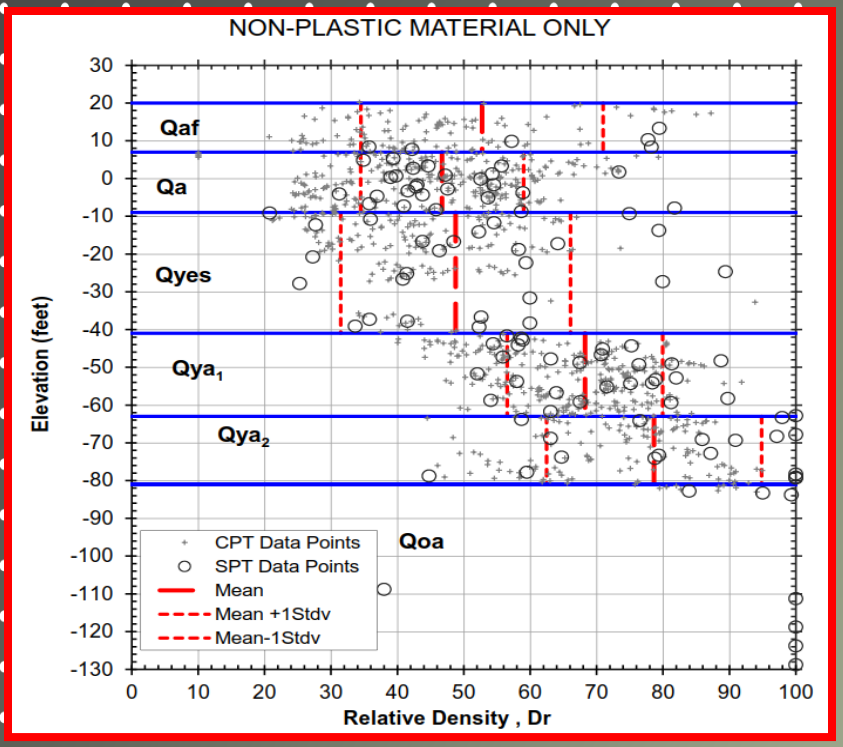
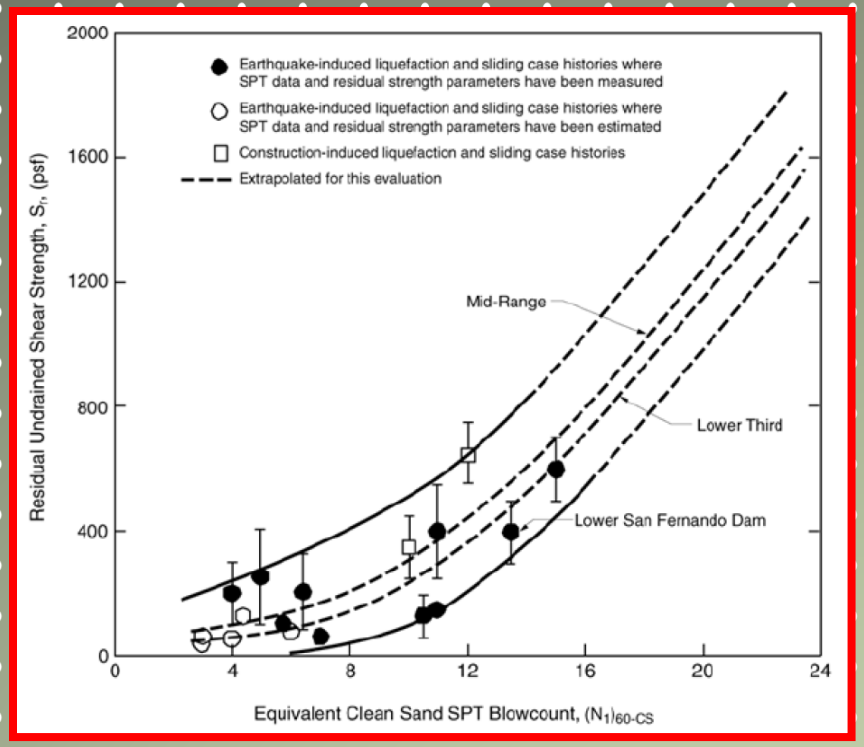


Figure 74. Relationship between ϕ′ and PI (Terzaghi, Peck, and Mesri, 1996).







Development of Residual Undrained Shear Strength for Liquefied Soil Materials

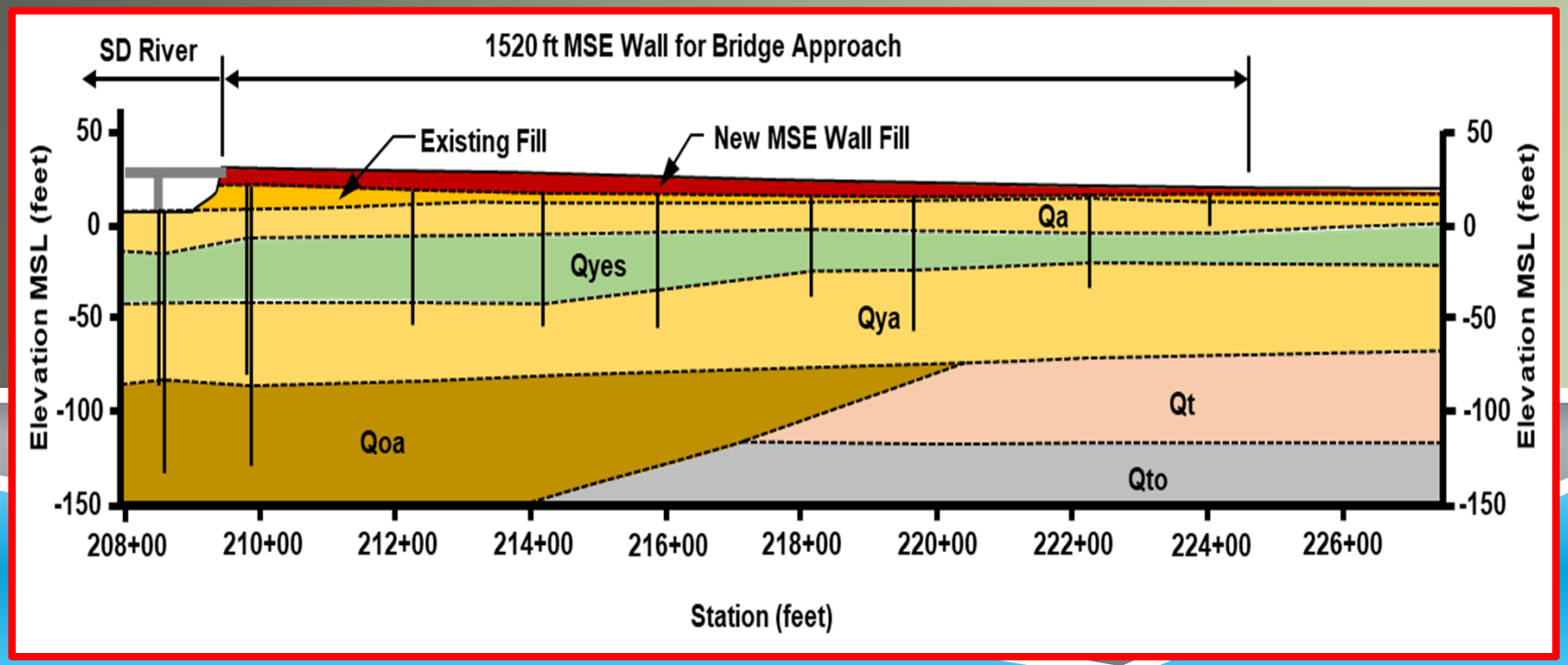
Results of liquefaction triggering analysis are presented in the Calculation Package – Liquefaction Triggering Analysis for San Diego River Bridge. Residual undrained shear strength parameters are needed for liquefiable soil to analyze post-liquefaction conditions. Ledezma and Bray's (2010) relationship was used to estimate the residual strength ratio per the following equation:

$$\frac{S_{u,res}}{\sigma'_{v0}} = \exp\left(\frac{N_{1,60-CS-Sr}}{8.9} - 3.5\right); 0 \le N_{1,60-CS} \le 20$$

$$\mu_{\frac{S_{ur}}{\sigma'_{vc}}} \approx \exp\left(\frac{\mu_{N_{1,60-CS}}}{8} - 3.5\right) \times \left[1 + \frac{\left(0.3\mu_{N_{1,60-CS}}\right)^2}{158}\right]$$

$$\sigma_{\frac{S_{ur}}{\sigma'_{vc}}} \approx 0.4\mu_{\frac{S_{ur}}{\sigma'_{vc}}}$$

Geologic Unit	Liquefaction/Compressibility Potential
Artificial Fill (af)	Not liquefiable above the groundwater table. Compressible undocumented fills throughout alignment..
Recent Alluvial Deposits (Qa)	Generally liquefiable when below groundwater. Low to moderately compressible.
Young Estuarine Deposits (Qyes)	Non- to Low-plasticity zones are marginally liquefiable. Moderate to highly compressible plastic zones.
Young Alluvial Deposits (Qya) Old Alluvium Deposits (Qoa) Old Estuarine Deposits (Qoes)	Too dense to liquefy. Low to very low compressibility.



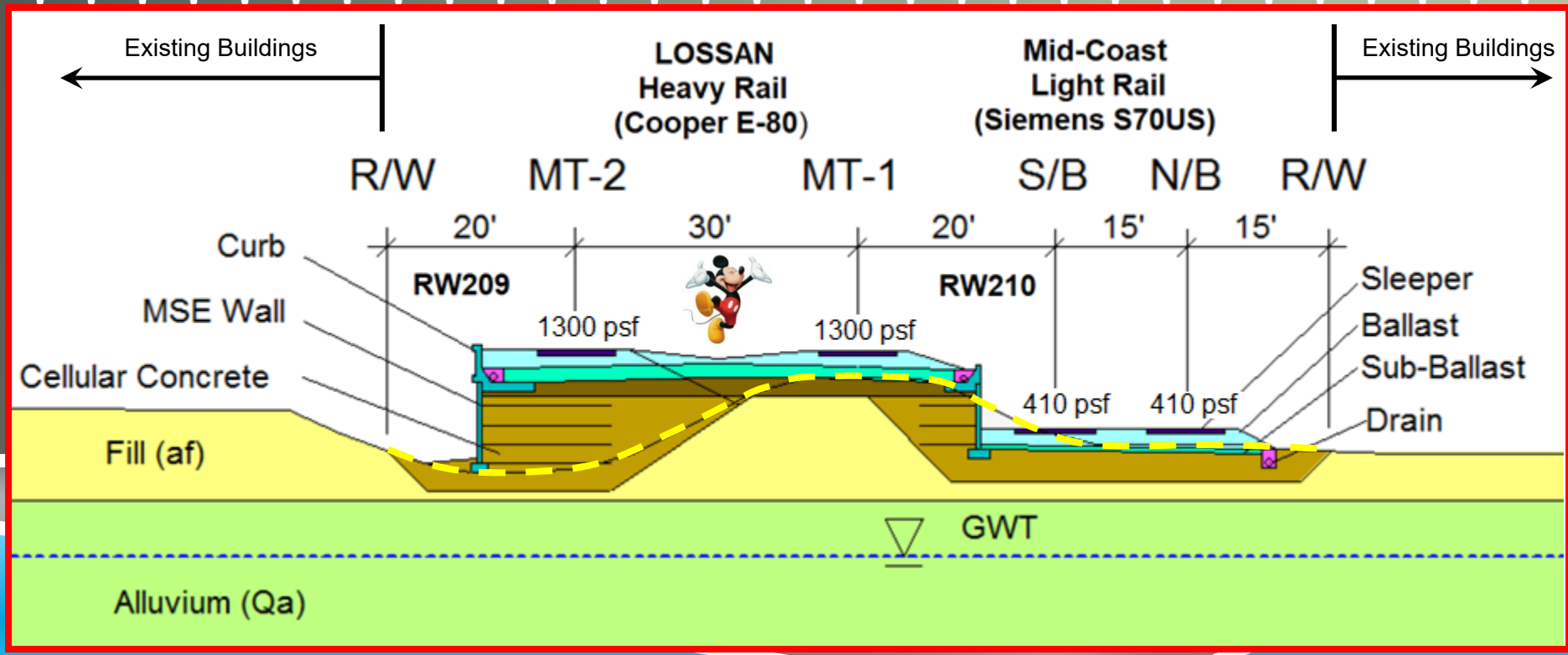
SUMMARY OF GEOTECHNICAL PARAMETERS

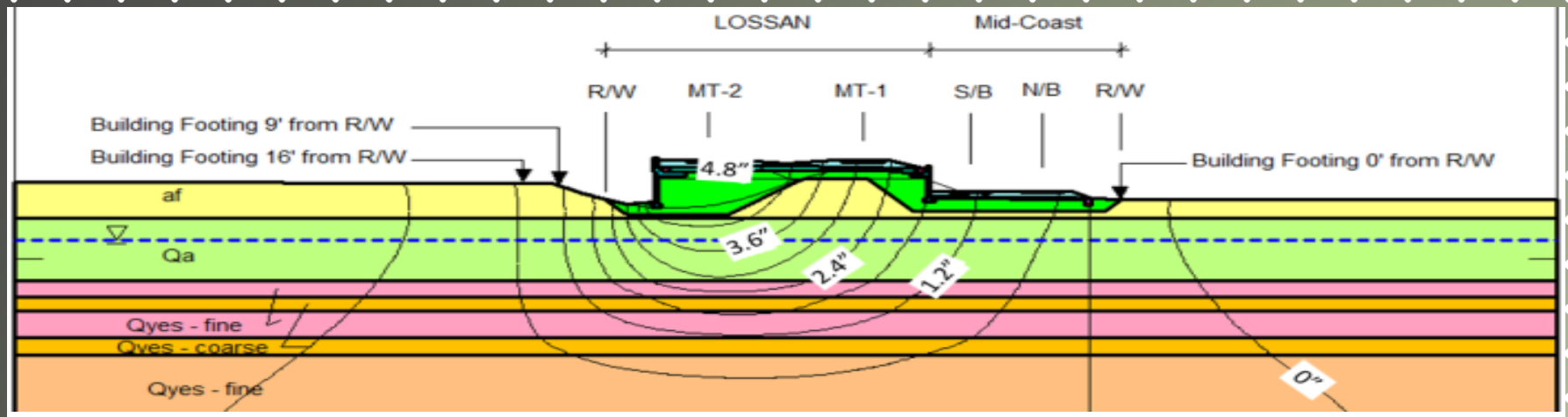
Material	Approx. Elev. (ft)	γ_t (pcf)	φ' (deg)	Su or c' (psf)	$S_{u,r}$ (psf)	OCR / Void Ratio	Drained Poisson Ratio (ν)	Elastic Modulus (ksf)
Qaf	15 to 7	120	33°	c' = 100	-	-	0.33	200
Qa	7 to -9	119	32°	c' = 0	440	-	0.33	100
Qyes (sandy)	-9 to -41	118	32°	c' = 50	170	-	0.33	100
Qyes (silt/clay)	-9 to -20 -20 to -30 -30 to -41	114 115 116	-	Su = 800 Su = 1,000 Su = 1,200	-	1.2 / 1.1 1.3 / 1.0 1.4 / 0.9	-	Note (1)
Qya_1 (upper)	-41 to -63	129	35°	0	1,040	-	0.33	400
Qya_2 (lower)	-63 to -81	132	37°	0	1,040	-	0.33	800
Qoa (gravelly)	<-81	141	42°	0	-	-	0.33	3,000
Qoa (sandy)	<-81	135	38°	0	-	-	0.33	2,000
Qoes	<-81	141	42°	0	-	-	0.33	3,000
Ballast	Embank.	120	40°	0	-	-	0.33	1,000
Sub-Ballast	Embank.	120	40°	0	-	-	0.33	1,000
Class II LCCF	Embank.	30	38°	0	-	-	0.22	68,000
Class IV LCCF	Embank.	42	38°	0	-	-	0.22	120,000
Stone Column	Grd. Imp.	110	40°	0	-	-	0.33	1,300
Compac. Grout	Grd. Imp.	120	-	36,000	-	-	0.25	180,000
Rigid Inclusion	Grd. Imp.	130	-	100,000	-	-	0.20	300,000
Concrete	Grd. Imp.	150	-	300,000	-	-	0.15	500,000

Note (1): Modified Cam-Clay Consolidation Parameters

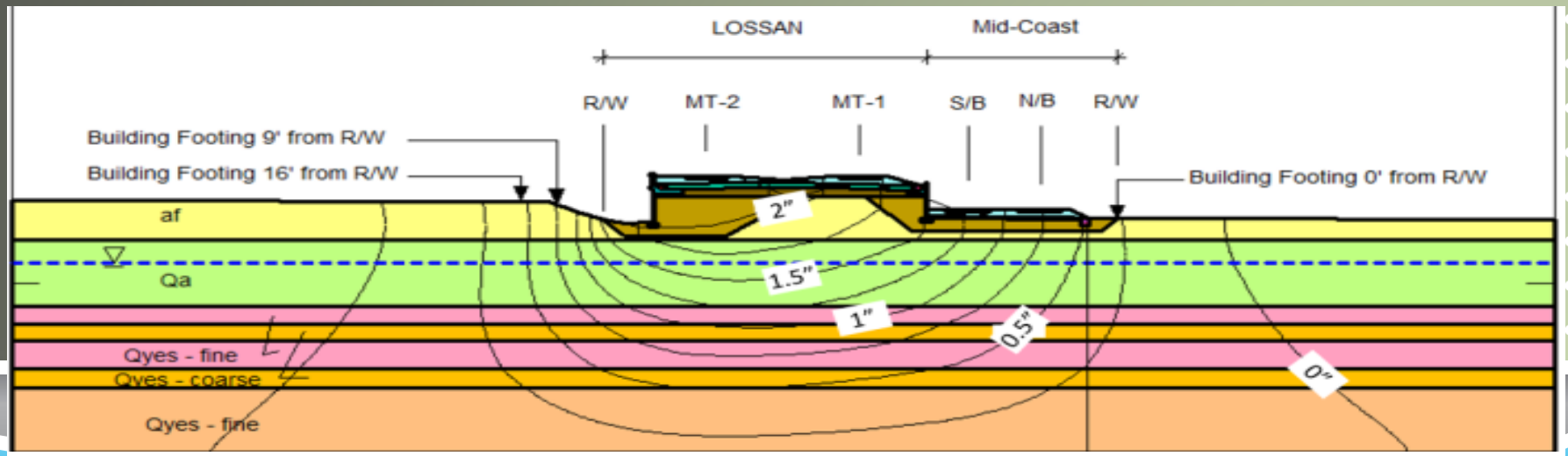
λ = 0.13 (virgin) and κ = 0.033 (unload/reload)


7767
BNSF

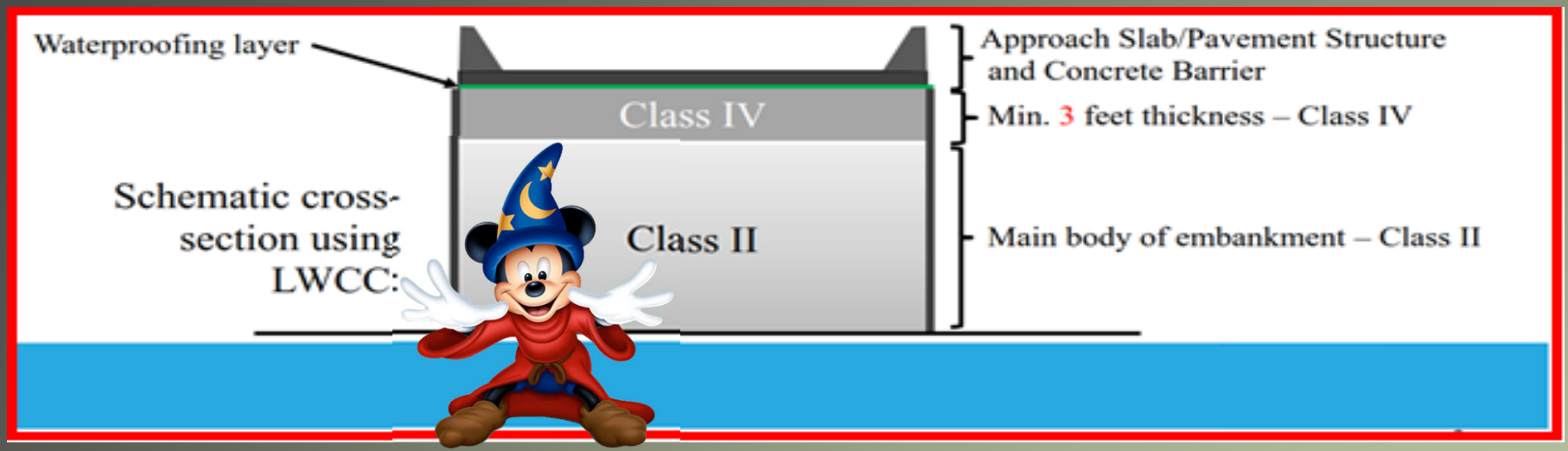

Existing Buildings
LOSSAN
Heavy Rail
(Cooper E-80)
Mid-Coast
Light Rail
(Siemens S70US)
Existing Buildings
R/W
MT-2
MT-1
S/B
N/B
R/W
20'
30'
20'
15'
15'
Curb
MSE Wall
Cellular Concrete
Fill (af)
RW209
RW210
1300 psf
1300 psf
410 psf
410 psf
Sleeper
Ballast
Sub-Ballast
Drain
GWT
Alluvium (Qa)

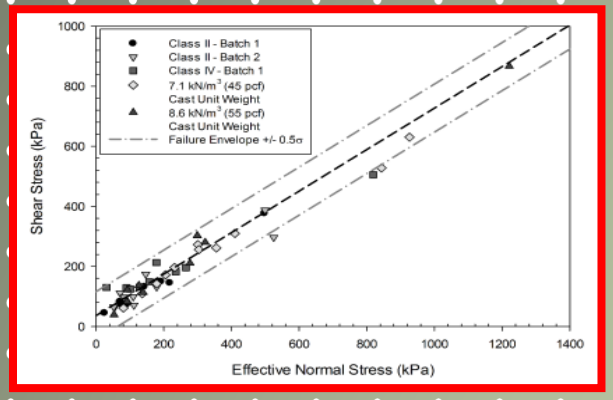


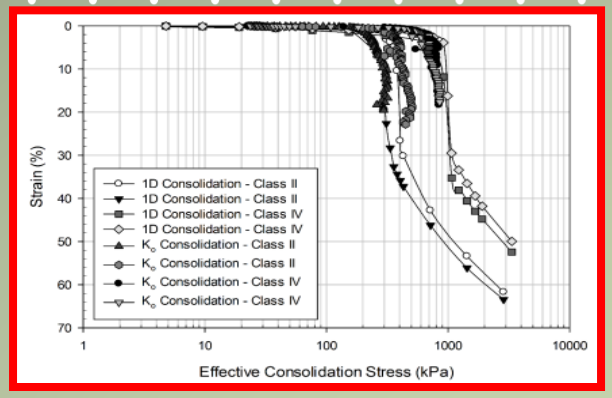
Vertical Settlement with Normal Weight Soil Backfill and No Ground Improvement. Maximum Settlement 4.8" @ MT-2

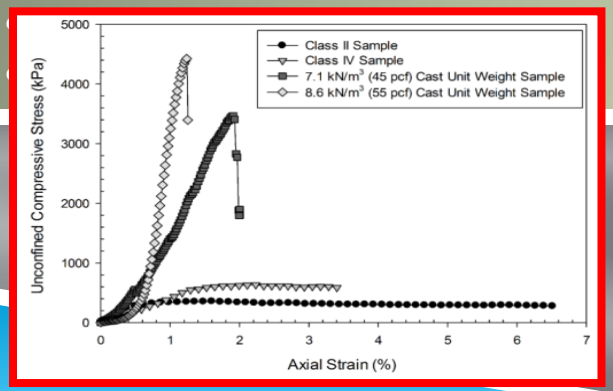


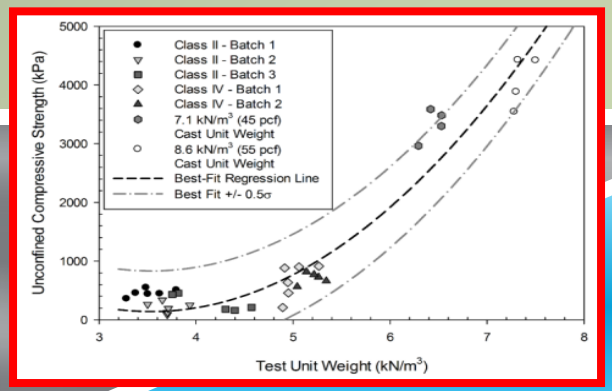
Vertical Settlement with LCCF Backfill and No Ground Improvement. Maximum Settlement 2" @ MT-2


Waterproofing layer
Class IV
Class II
Schematic cross-section using LWCC:
Approach Slab/Pavement Structure and Concrete Barrier
Min. 3 feet thickness – Class IV
Main body of embankment – Class II


Class II - Batch 1
Class II - Batch 2
Class IV - Batch 1
7.1 kN/m³ (45 pcf) Cast Unit Weight
8.6 kN/m³ (55 pcf) Cast Unit Weight
Failure Envelope +/- 0.5σ
Shear Stress (kPa)
Effective Normal Stress (kPa)


1D Consolidation - Class II
1D Consolidation - Class II
1D Consolidation - Class IV
1D Consolidation - Class IV
K₀ Consolidation - Class II
K₀ Consolidation - Class II
K₀ Consolidation - Class IV
K₀ Consolidation - Class IV
Strain (%)
Effective Consolidation Stress (kPa)


Class II Sample
Class IV Sample
7.1 kN/m³ (45 pcf) Cast Unit Weight Sample
8.6 kN/m³ (55 pcf) Cast Unit Weight Sample
Unconfined Compressive Stress (kPa)
Axial Strain (%)


Class II - Batch 1
Class II - Batch 2
Class II - Batch 3
Class IV - Batch 1
Class IV - Batch 2
7.1 kN/m³ (45 pcf) Cast Unit Weight
8.6 kN/m³ (55 pcf) Cast Unit Weight
Best-Fit Regression Line
Best Fit +/- 0.5σ
Unconfined Compressive Strength (kPa)
Test Unit Weight (kN/m³)

Stone column 2.1 (calculations according to Priebe)

Grid & Foundation properties

Foundation pressure	50.00 kPa	Grid type :	Rectangular
Foundation type	Rectangular	X column distance :	1.50 m
Foundation length (L) :	500.00 m	Y column distance :	1.50 m
Foundation width (B) :	8.00 m	Automatic calc. No of colums	
Calculate as infinite		No of columns :	1665
Settlements calculation according to	Theory of elasticity		
Effective overburden pressure q :	0.00 kPa		

Column material

Unit weight :	19.00	kN/m^3
G.W.T.	4.30	m
Unit weight :	10.00	kN/m^3
Constrained modulus :	100.00	MPa
Friction angle :	40.00	Degrees

Project title

LOSSAN - Sta. 212+00 (D=0.6, S=1.5)

Soil data input

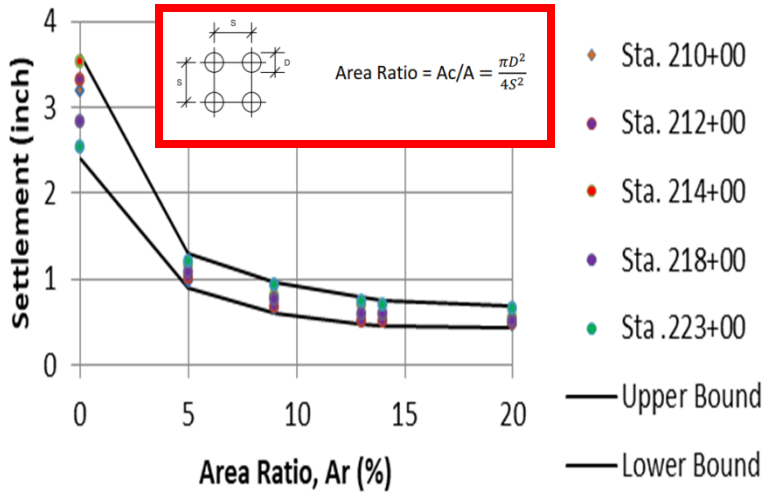
No	Bottom Level (m)	Diameter (m)	A/Ac	Ds (Mpa)	Dc/Ds	Gamma (kPa)	Poisson ratio	Phi (degrees)	Coh. (kPa)
1	2.4	.6	8.50	11.25	8.89	18.9	.33	33	0
2	7.5	.6	8.50	7.5	13.33	18.7	.33	32	0
3	8.1	.6	8.50	2	50.00	17.9	.33	25	0
4	8.4	.6	8.50	7.5	13.33	18.6	.33	32	0
5	8.8	.6	8.50	2	50.00	17.9	.33	25	0
6	9.9	.6	8.50	7.5	13.33	18.6	.33	32	0
7	10.5	.6	8.50	2	50.00	17.9	.33	25	0
8	10.8	.6	8.50	7.5	13.33	18.6	.33	32	0
9	11	.6	8.50	2	50.00	17.9	.33	25	0

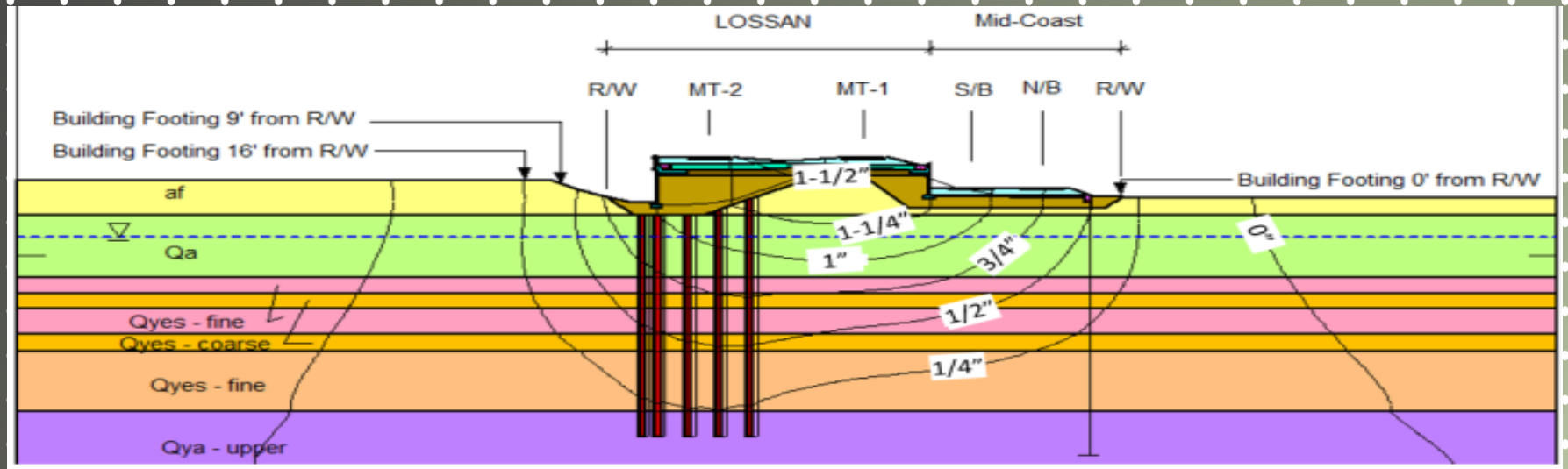
Add row | Delete row | Clear all

Load data | Save data | View results

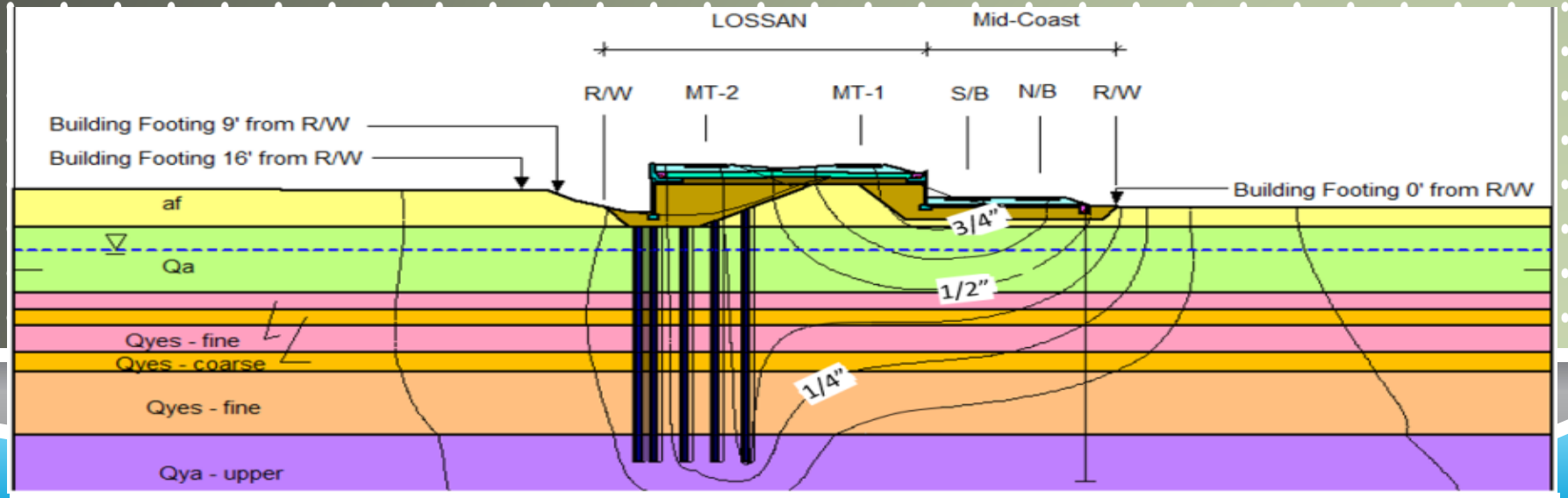
Ground Improvement using Stone Columns with Square Spacing
Length = 1500 feet, Width = 24 feet, Loading = 1000 psf
Estimated Settlement (inches)

	Spacing	8'	6'		5'	
	Diameter	24"	24"	30"	24"	30"
Area Ratio	0%	5%	9%	14%	13%	20%
Sta. 210+00	3.19"	0.96"	0.65"	0.54"	0.59"	0.47"
Sta. 212+00	3.31"	1.01"	0.68"	0.56"	0.61"	0.49"
Sta. 214+00	3.52"	1.16"	0.81"	0.65"	0.72"	0.56"
Sta. 218+00	2.84"	1.07"	0.76"	0.59"	0.68"	0.51"
Sta. 223+00	2.53"	1.20"	0.93"	0.76"	0.85"	0.66"





Vertical Settlement with LCCF and Stone Columns. Maximum Settlement 1.2" @ MT-2 and 1.5" @ MT-1



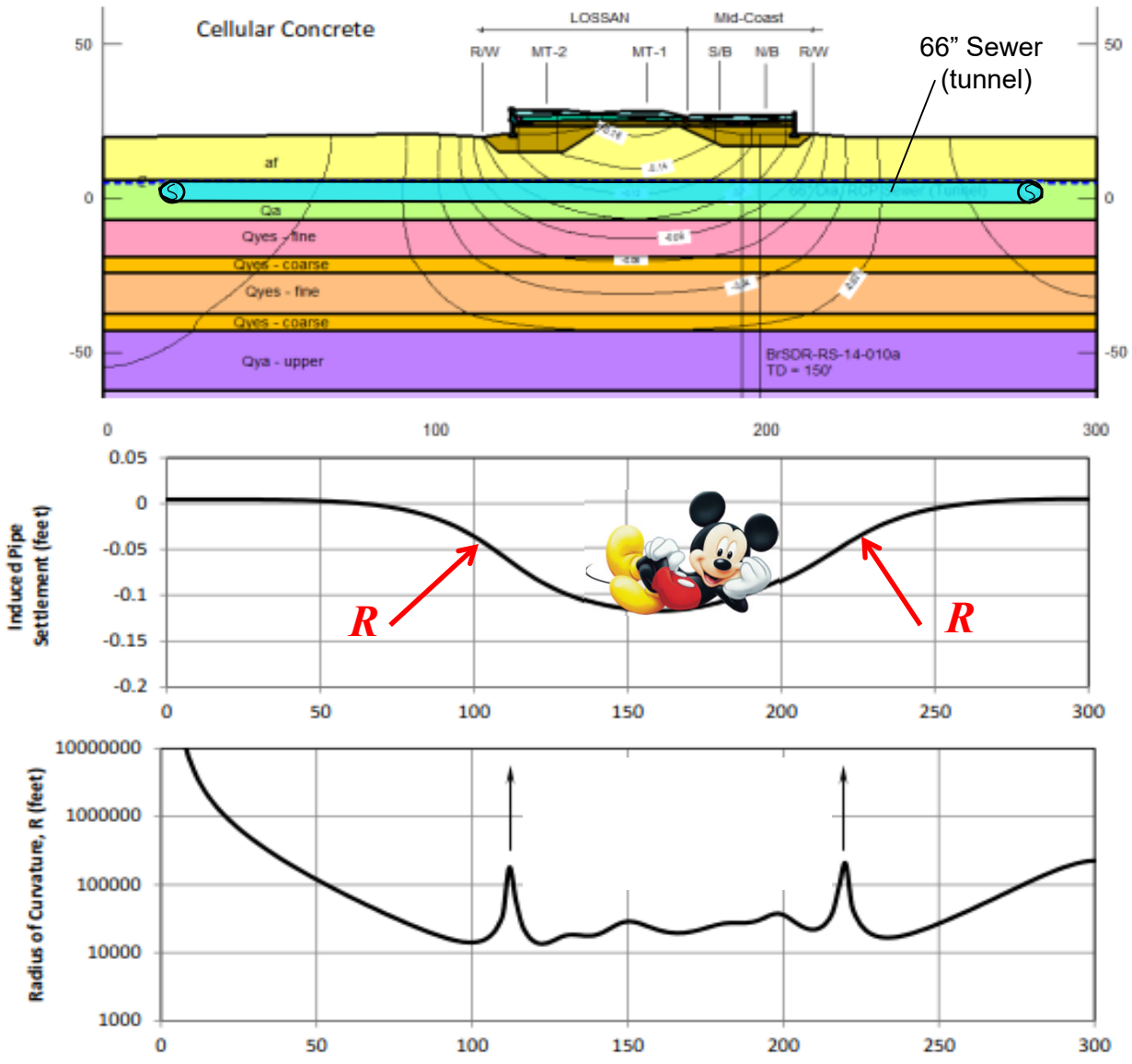
Vertical Settlement with LCCF and Rigid Inclusions. Maximum Settlement ½" @ MT-2 and ¾" @ MT-1

Settlement Analyses Results for Station 214+00

MSE Wall Backfill	Ground Improvement	Maximum Settlement (inch)	Settlement along West R.O.W. (inch)	Differential Settlement between MT-1 Rails (inch)	Settlement by parked Locomotive (inch)	Yield Acceleration (g)
Structure Backfill	None	4.8	1.3	0.5	1.6	0.40
LCCF	None	2.0	0.7	0.2	1.2	0.45
LCCF	Stone Columns	1.2	0.5	0.1	0.2	0.47
LCCF	Rigid Inclusions	0.5	0.2	< 0.1	0.1	0.87

Rigid Inclusion Geometry and Properties

18” diameter
f'_c = 2500 psi
E = 2.8×10^6 psi
Area Ratio = 4.2%
7’ equilateral triangular pattern



1. Over-excavation to +15' MSL below MT-2 and +17' MSL below Mid-Coast track alignments.
2. Embankment mainly consists of cellular concrete, sub-ballast and ballast.
3. Maximum induced settlement along pipe invert at elevation +0' MSL = 0.12' (1.4")
4. Minimum radius of curvature along pipe invert at elevation +0' MSL = 13,600'

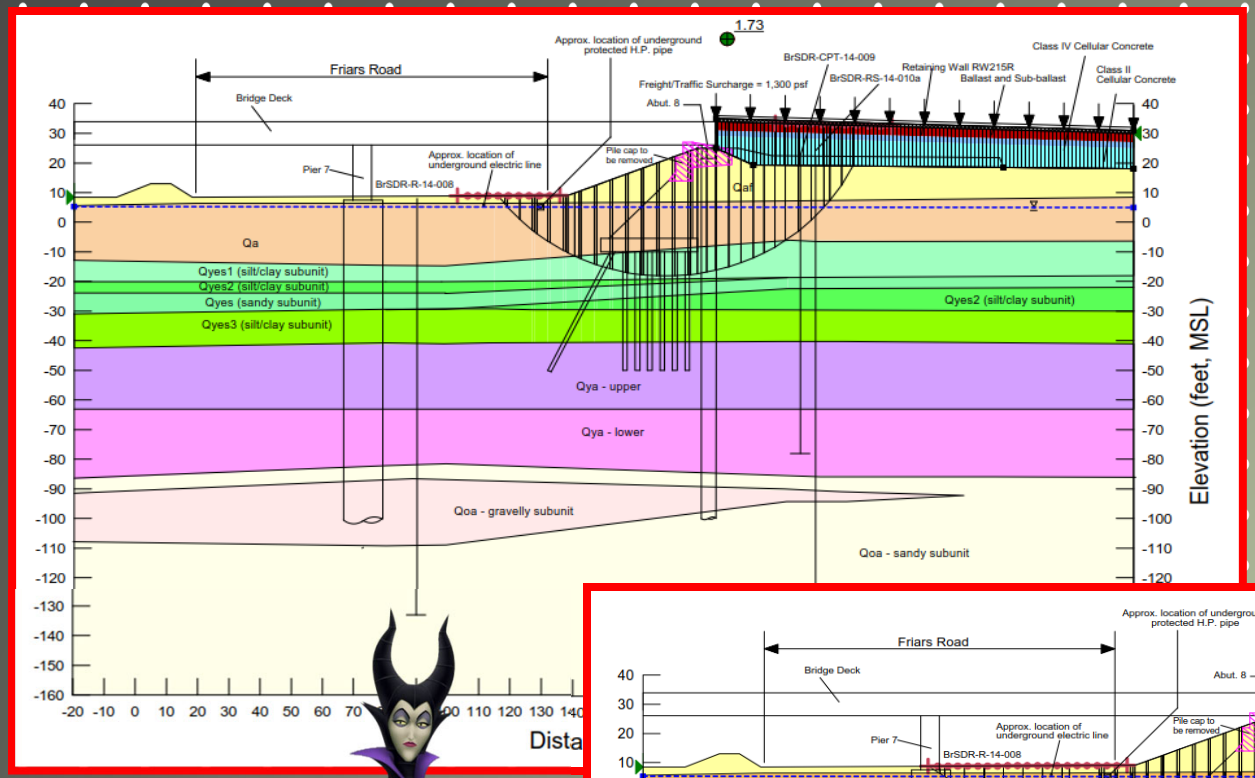
Potential Settlement of Existing 66" Diameter Sewer (Tunnel) with Invert @ +0' msl

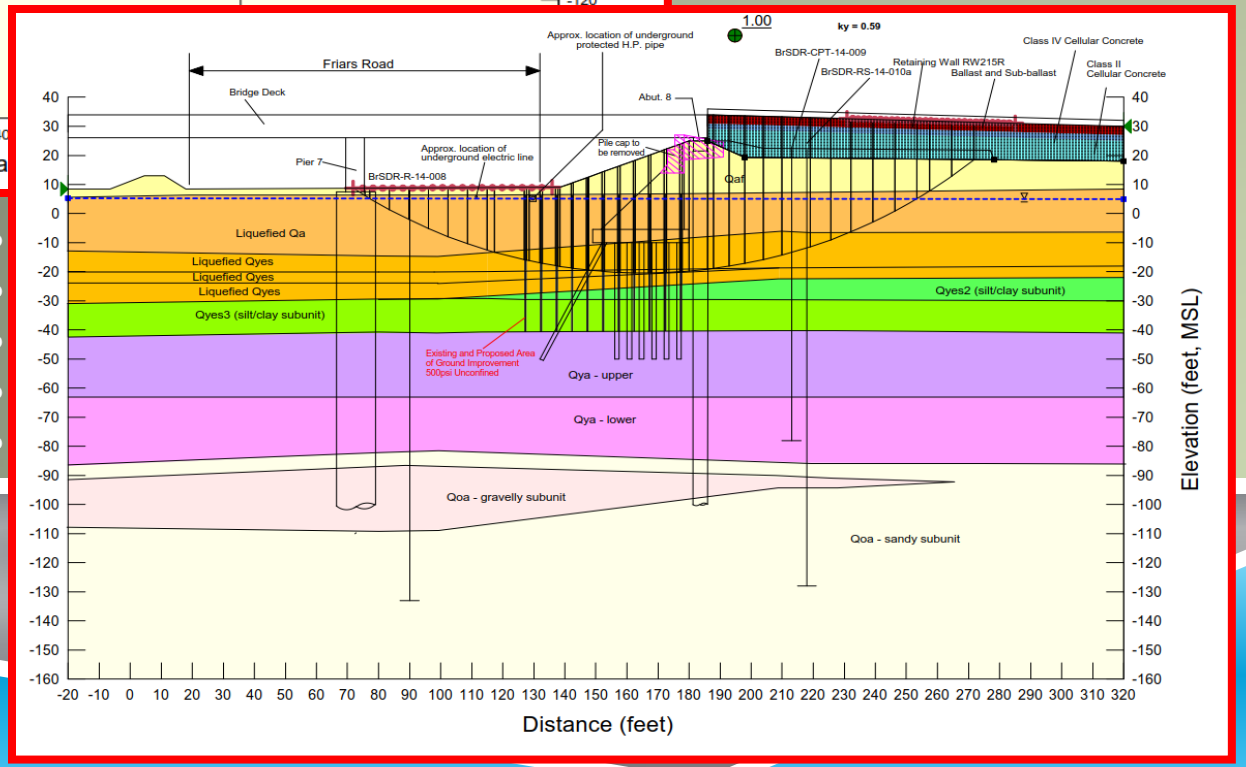
Radius of Curvature from Induced Settlement >13,600'

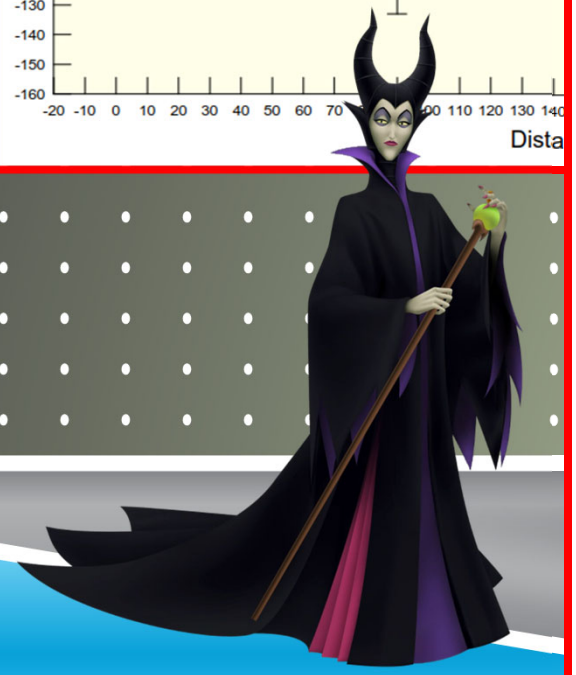
$$R = \left| \frac{\left(1 + \left(\frac{dy}{dx}\right)^2\right)^{3/2}}{\frac{d^2y}{dx^2}} \right|$$

Abutment 8
Stability Analyses

- Static Stability
- Seismic Stability
- Seismic Settlement
- Post-Liq. Settlement
- Yield Acceleration
- Lateral Spreading

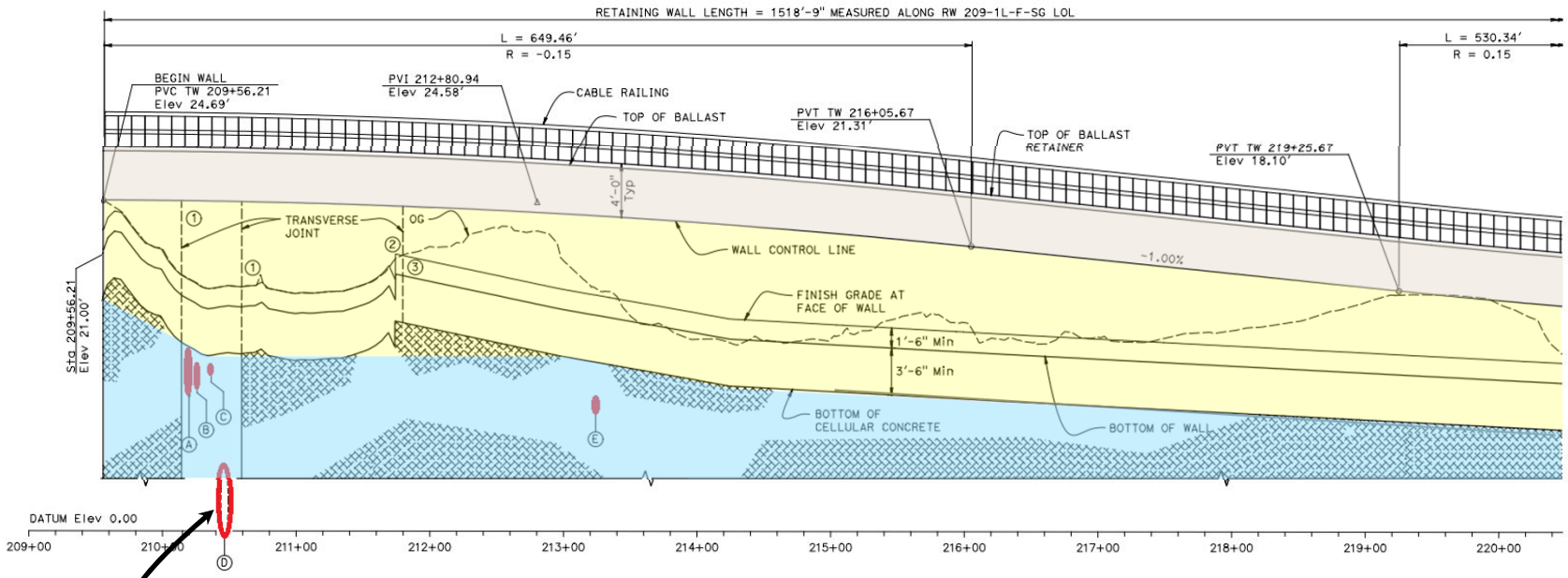






Abutment 8
Compaction Grouting

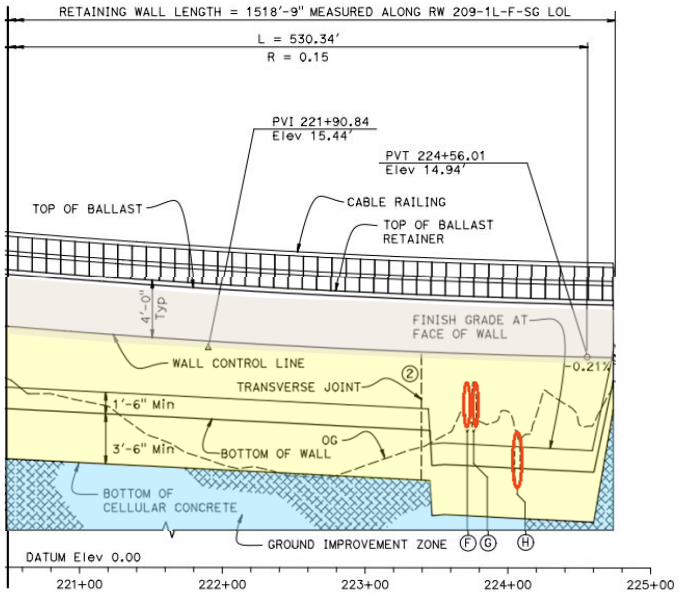
Final Conditions
along Friars Road



Existing Buried Utilities

- (A) 230 kV ELECTRIC LINE - TP Elev 13.00'±
- (B) 20" GAS LINE WITH 30" CASING - TP Elev 12.50'±
- (C) 8" CIP WATER LINE - TP Elev 12.50'±
- (D) 66" RCP SEWER LINE - TP Elev 5.00'±
- (E) 16" CIP SEWER LINE - TP Elev 10.00'±
- (F) 42" CMP STORM DRAIN - TP Elev 13.00'±
- (G) 42" CMP STORM DRAIN - TP Elev 13.00'±
- (H) 42" RCP STORM DRAIN - TP Elev 9.50'±

MIRRORED ELEVATION



Load Resistance Factor Design (LRFD) per AASHTO LRFD Bridge Design Specifications (4th Edition) as modified by the CALTRANS California Amendments

Load and Resistance Factors

BEARING PRESSURE &REINFORCEMENT TENSION & PULL-OUT	Strength I(Static)	Extreme Event I (Seismic)
Vertical Dead Load (MSE Backfil-) -Tension & Pull-Out force in Internal Stability	1.35	1.00
Vertical Dead Load, Pull-Out Resisting force.	1.00	1.00
Horizontal Earthpressure due to Random Backfill	1.75	1.00
Horizontal Earthpressure due to Live Load surcharge	1.75	0.50
Live Load Weight	1.75	0.50
Dynamic Earthpressure and RE mass Dynamic Inertia Force (Extreme Event I)	-----	1.00
Tensile Resistance of soil reinforcements	0.75	1.00
Resistance Factor for Pull Out of Strips (Internal Stability).	0.77	1.20
SLIDING & OVERTURNING		
Vertical Dead Load	1.00	1.00
Horizontal Earthpressure due to Random Backfill	1.75	1.00
Horizontal Earthpressure due to Live Load surcharge	1.75	0.50
Dynamic Earthpressure and RE mass Dynamic Inertia Force (Extreme Event I)	-----	1.00
Resistance Factor for Base Sliding (Mass Stability)	1.00	1.00

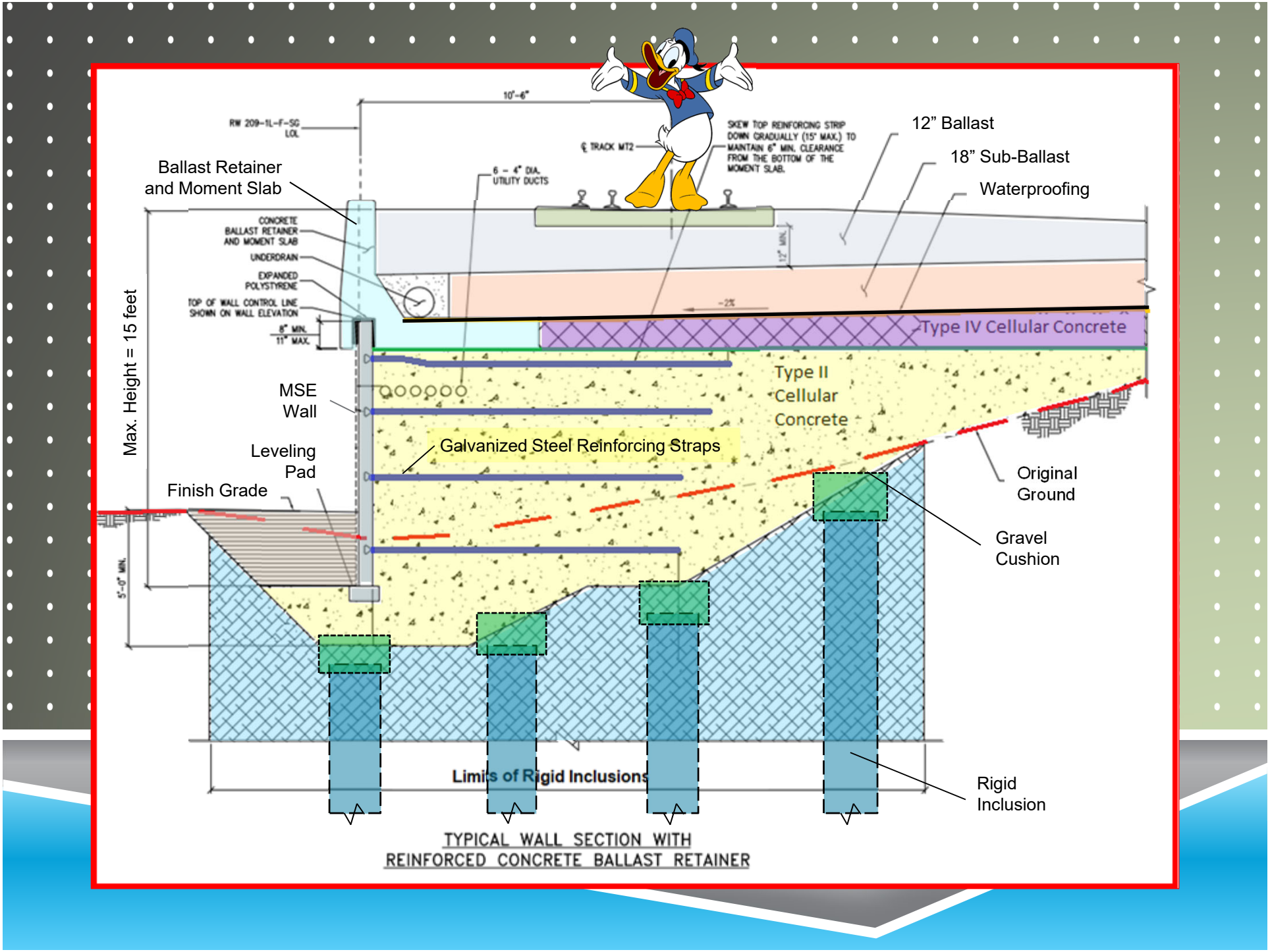
AASHTO
THE VOICE OF TRANSPORTATION

Design Earthquake

As = PGA x Site Coefficient = 0.54 x 1.0

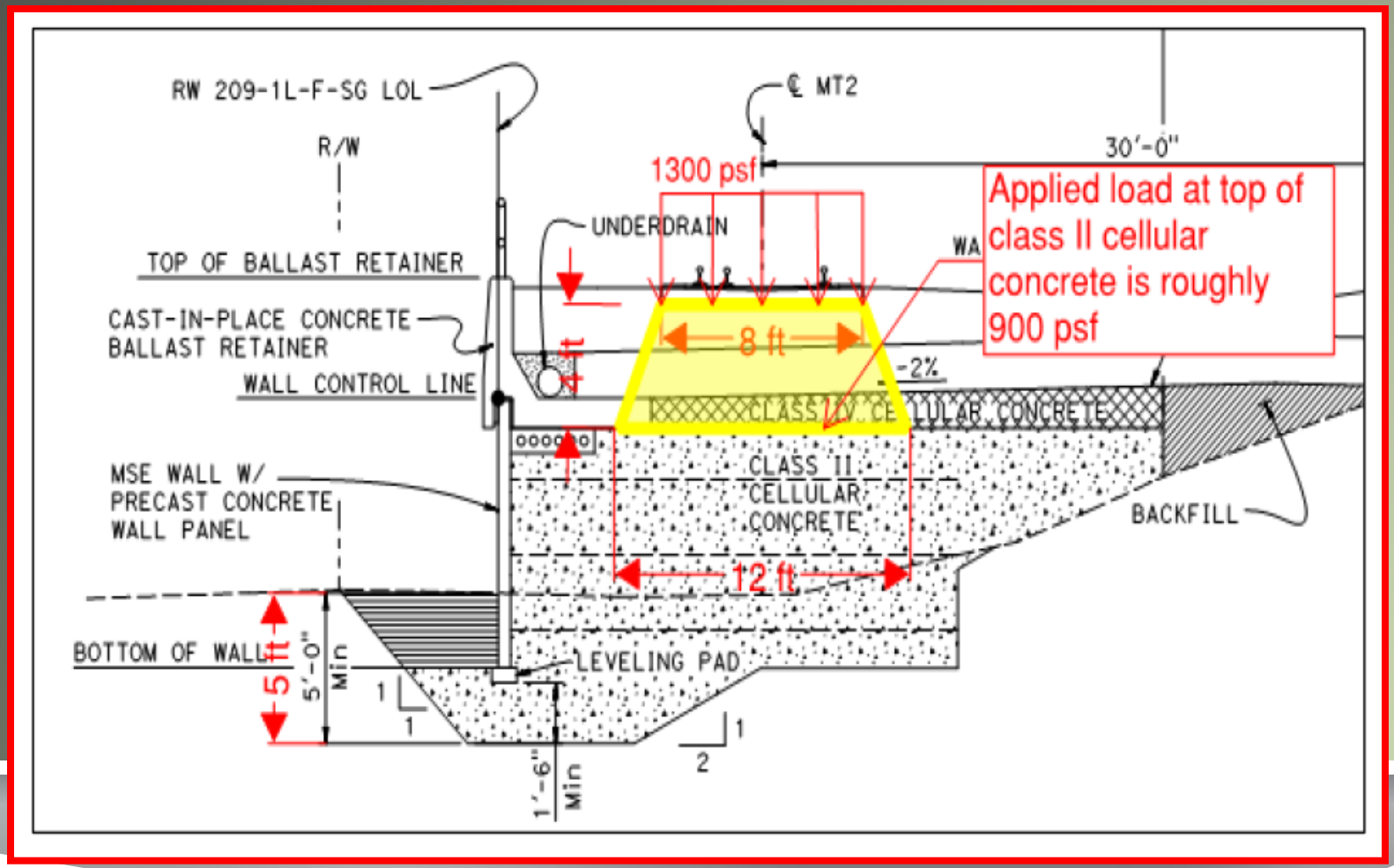
As = k_h for non-yielding walls

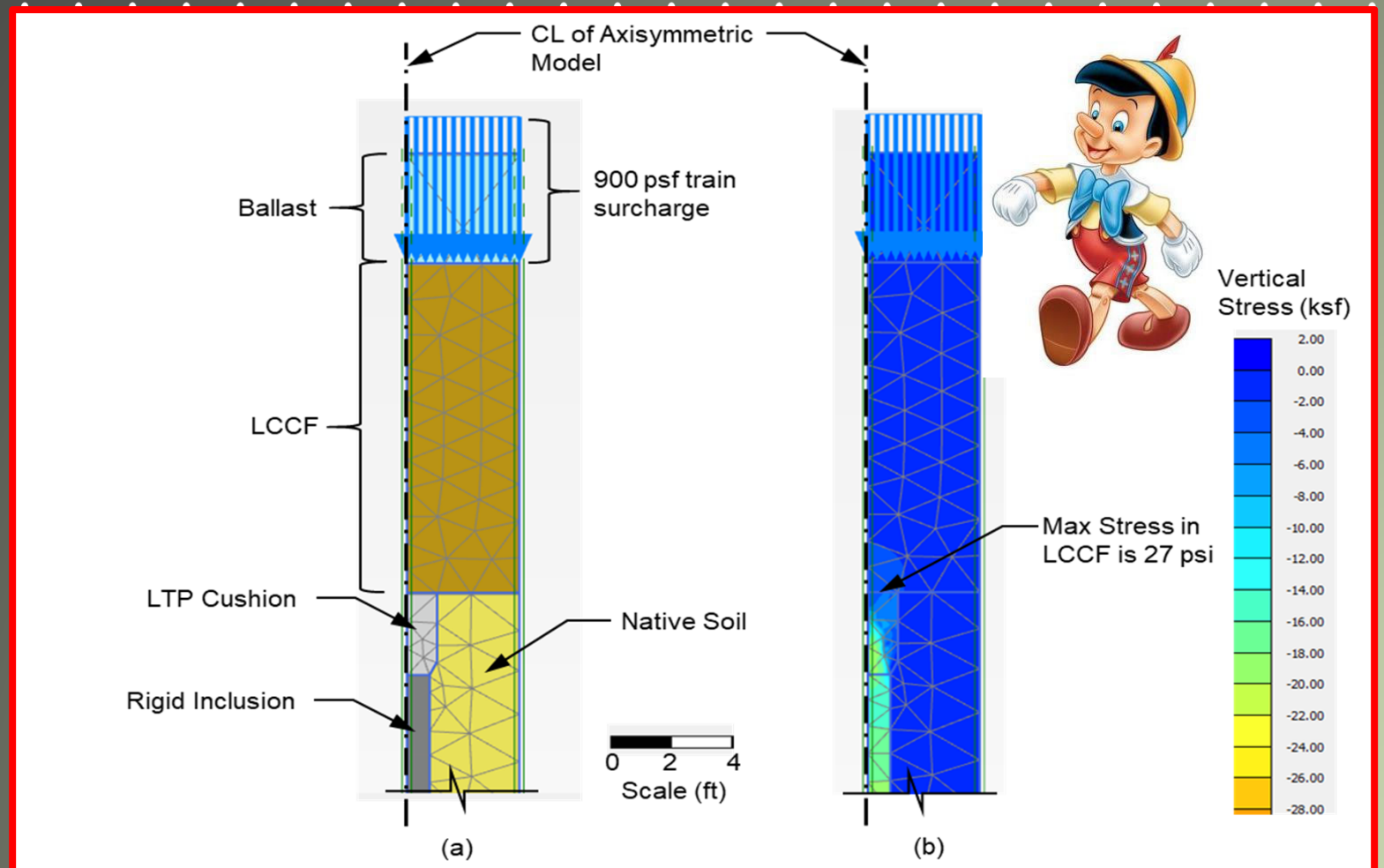
Caltrans



TYPICAL WALL SECTION WITH REINFORCED CONCRETE BALLAST RETAINER

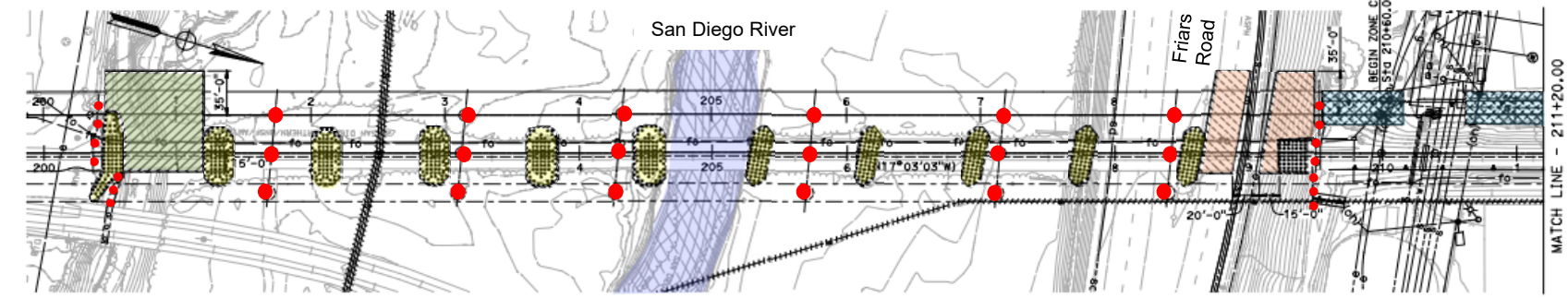
Cooper E-80 Loading Transmitted through LCCF and down to Rigid Inclusions





(a) Axisymmetric Finite Element Model of Ground with Rigid Inclusion

(b) Vertical Stress Distribution near Gravel Cushion



LEGEND

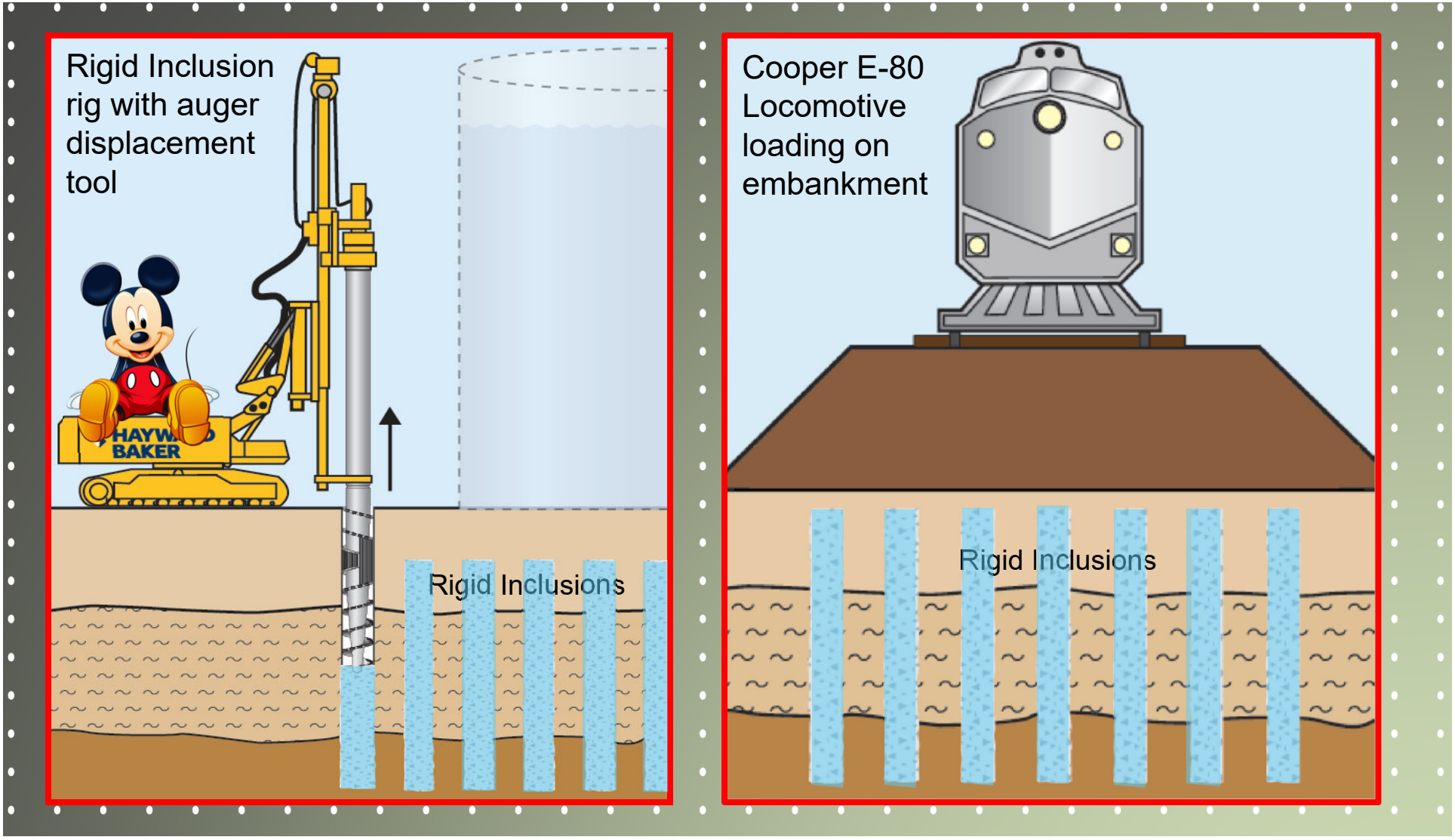
- Compaction Grouting (1)
- Compaction Grouting (2)
- Rigid Inclusions

ZONE	APPROXIMATE AREA (ft^2)	ELEVATION AT TOP OF TREATMENT ZONE (ft)	ELEVATION AT BOTTOM OF TREATMENT ZONE (ft)		NOTES
A	5,000	+5	-45		1
B	5,000	+5	-45		1, 2
C	37,000	VARIES	Sta RANGE	Elev	2, 3
			209+56 to 215+00	-50	
			215+00 to 216+00	-45	
			216+00 to 217+00	-40	
			217+00 to 218+00	-35	
			218+00 to 224+73	-30	

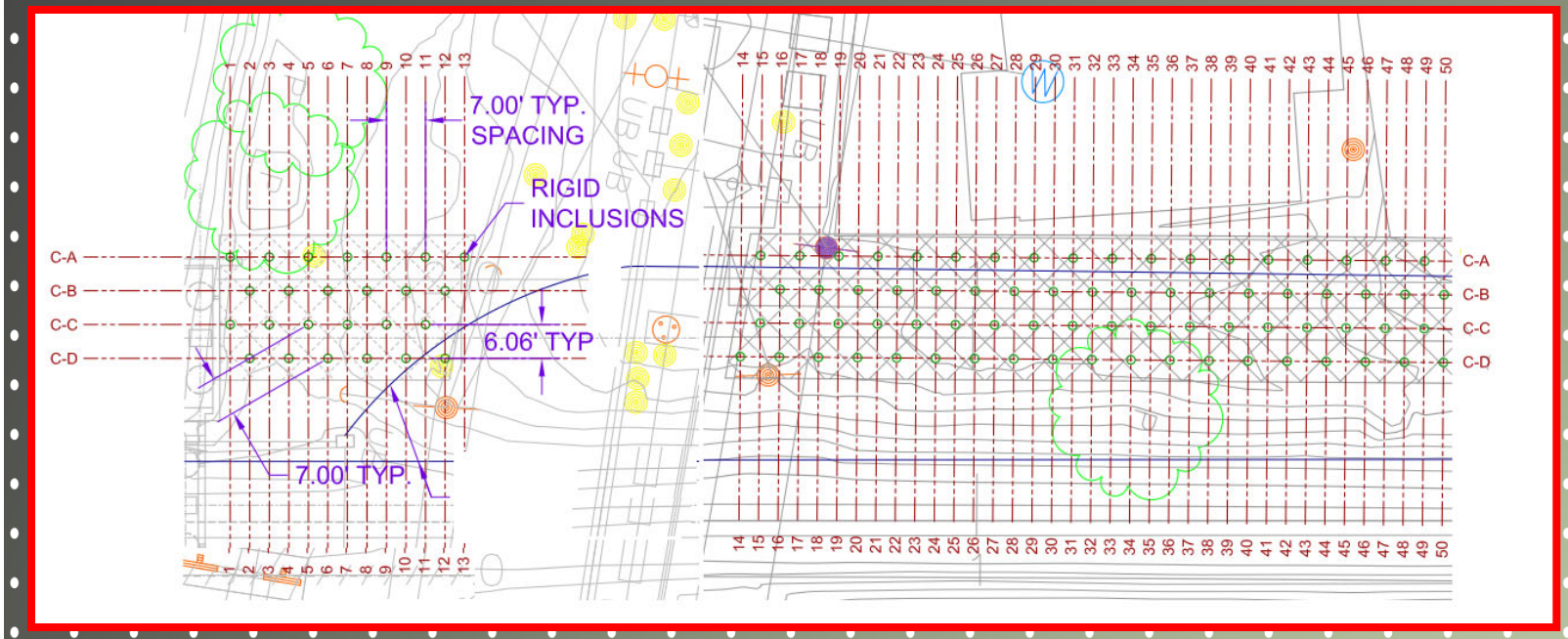
NOTES:

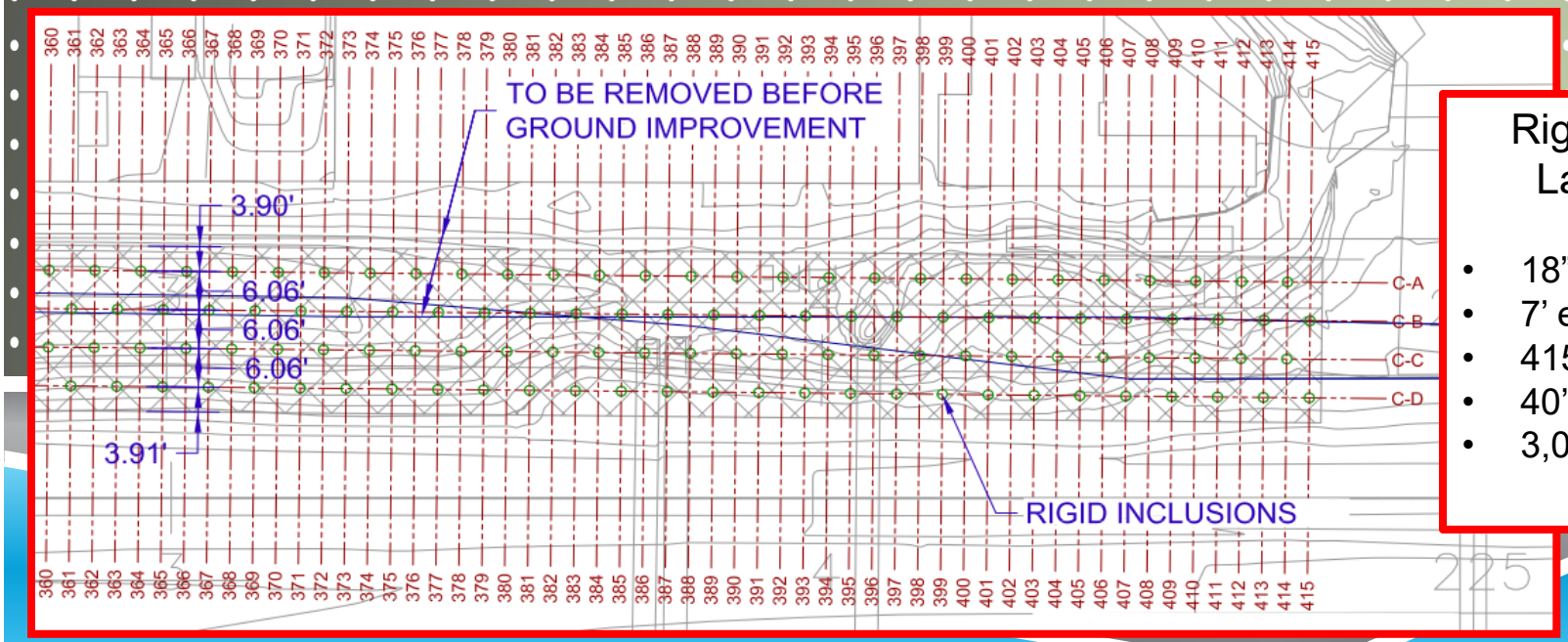
1. Ground Improvement zone to extend between existing footings
2. Ground Improvement zone to avoid conflict with existing underground utilities
3. See Retaining Wall Section for top elevation treatment zone

Ground Improvement Layout for Entire Project (Compaction Grouting and Rigid Inclusions)



Schematics of Rigid Inclusion Installation and Ultimate Embankment Loading





Rigid Inclusion Layout Plan

- 18” diameter
- 7’ equi. triangle
- 415 rows
- 40’ to 60’ deep
- 3,000 cy concrete

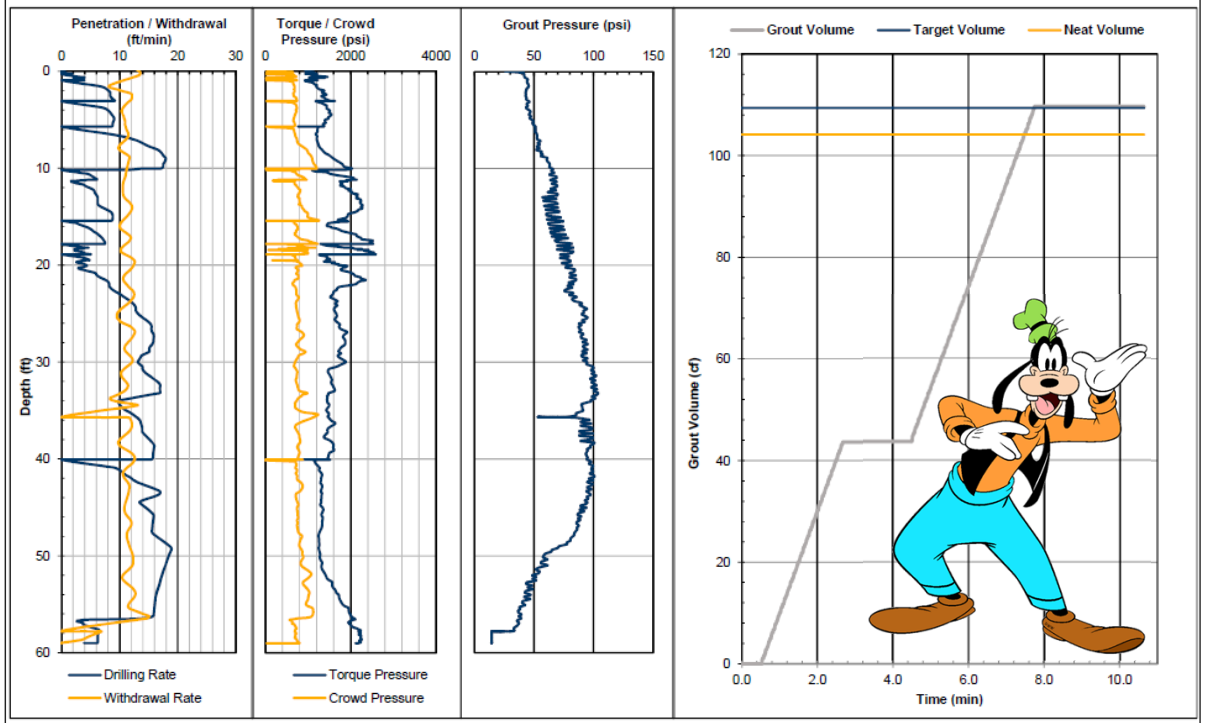
Rigid Inclusion Installation Data Acquisition Graphics

HAYWARD BAKER
A KELLER COMPANY

Rigid Inclusion Installation Report

Double Track

RI Name:	cc 120	**Installation Date:**	5/10/2017	**Neat Volume:**	104.18 cf	**Stroke Count:**	196
Job No.:	820136	**Diameter:**	18.00 in	**Actual Volume:**	109.69 cf	**Stroke Factor:**	0.56 cf
Location:	San Diego, CA	**Installed Length:**	58.99 ft	**Grout Factor:**	1.053	**Target Grout Factor:**	1.05



THINK SAFE

Frequent live rail activity with Bombardier certified watchman always present

Working platform only a couple of feet above GWT

Ground Clearing and Grubbing

Rigid Inclusion Location Markers

Rigid Inclusion Installation Drilling and Grout Injection

Giant steps are what you take walking on the moon…

Safety First !

16” Gas Pipeline Relocated

Timber Piles Cutoff at Ground Level

Rigid Inclusions Installed between Piles

Rigid Inclusions
marching onward
one after another…
after another…
after another…

Special ground prep
in very soft ground
areas after RI
installation

Geotextile
installation
team at work...

…after another…
after another…
after another…

Placement 2’ dia. x 3’ deep compacted plug of ¾” gravel cushion between RI and LCCF

Settlement monitoring of existing buildings, adjacent MT-1 rails and other surface features

Total Station survey of positioned mirrors, reflectors and placards during and after construction

Delivery of the miracle elixir… lightweight cellular concrete (LCCF)

Begin placement of LCCF foundations level adjacent to gas pipeline

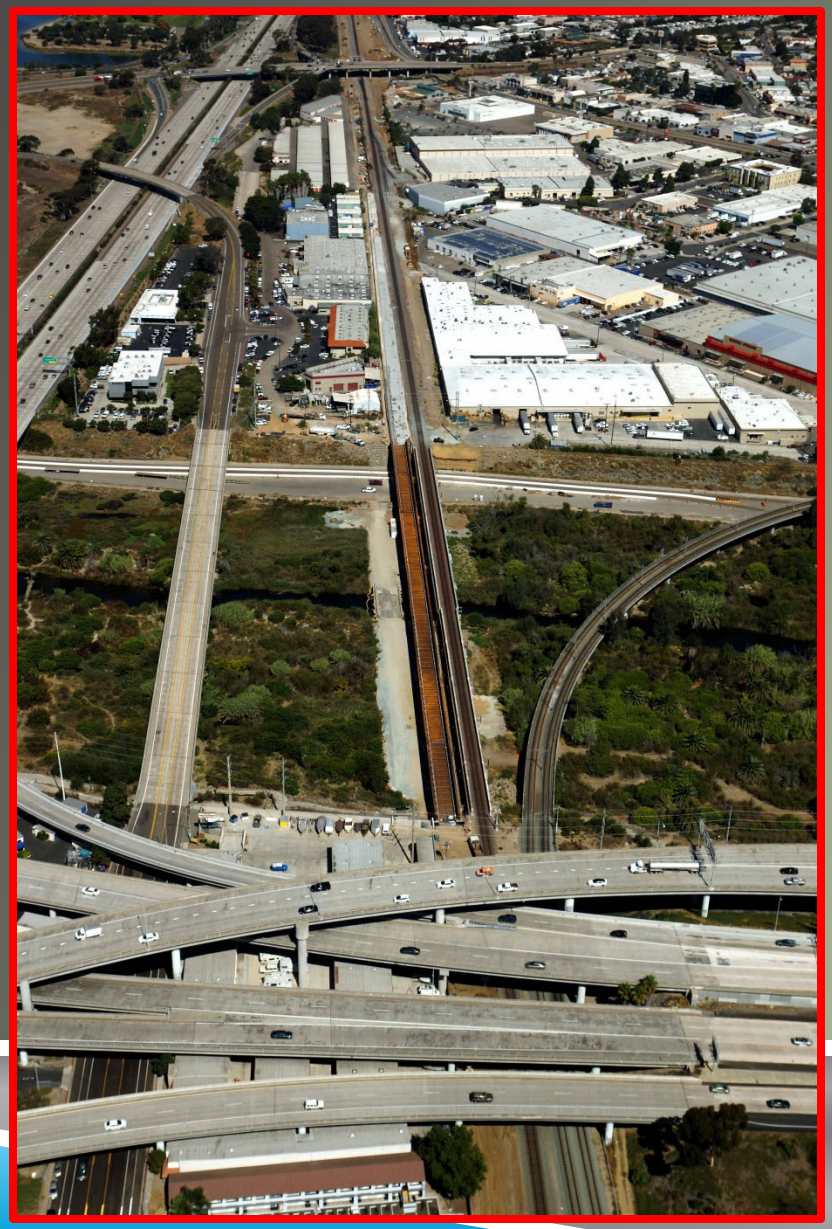
Simple 2’ lift formwork panels every 200’

Placement of leveling pad and MSE wall precast panels

Placement of galvanized steel reinforcement straps…and more LCCF pumping

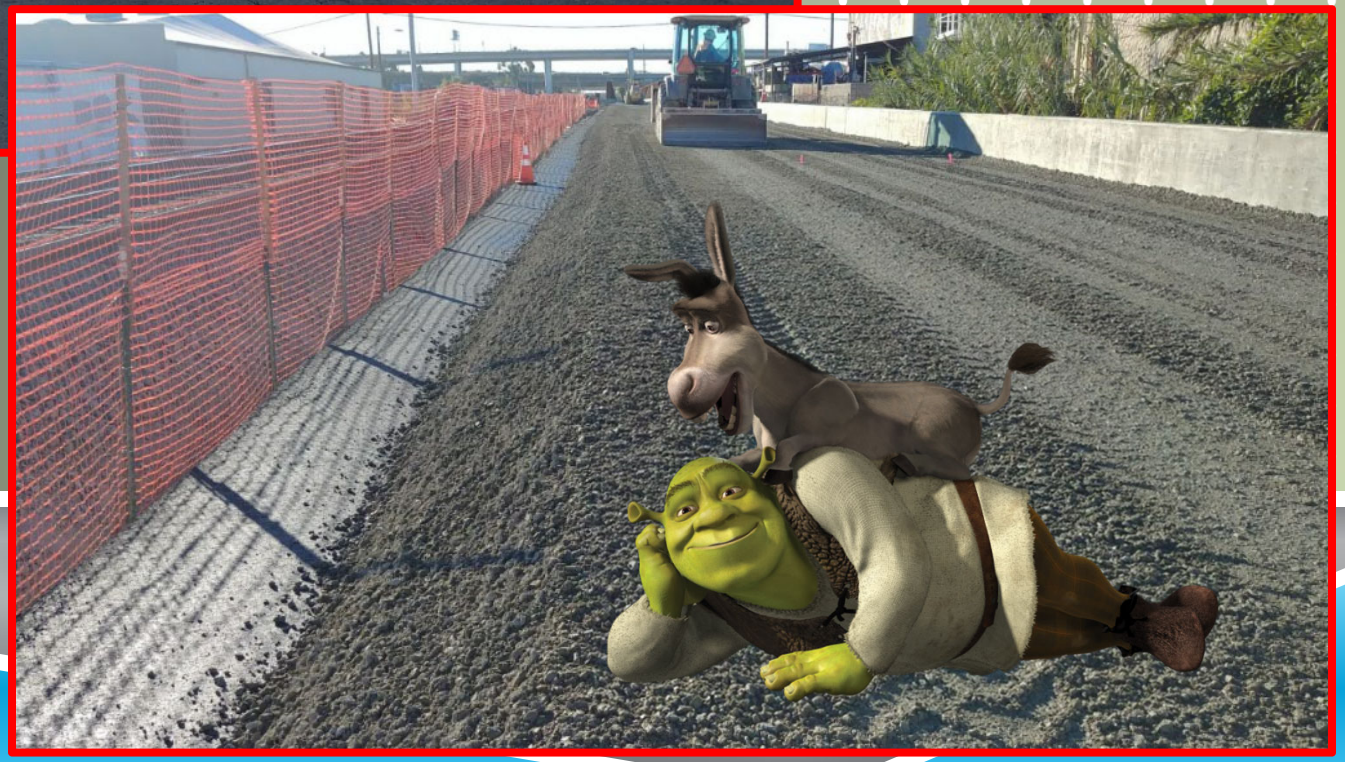
Reinforcement straps supported on highchair stirrups which are enveloped by the low density fluid LCCF


Plenty of work left to do…



Install waterproofing, ballast retainer and moment slab

Place asphalt sealing layer and subballast (Class 2 AB)



Finishing touches and post-construction settlement monitoring

SETTLEMENT MONITORING

(buried pipes and conduits not instrumented)

New MT-2 < ½”

Existing MT-1 < ¼”

Existing MT-1 Cross Tilt < 0.5°

Adjacent Buildings < ¼”


2103
2103
COASTER

LOSSAN

SANDAG

NORTH COUNTY TRANSIT DISTRICT

MID-COAST CORRIDOR TRANSIT PROJECT

WSP

KLEINFELDER
Bright People. Right Solutions.

HAYWARD BAKER

MCTC
Mid-Coast Transit Constructors
Stacy and Witbeck . Herzog . Skanska

JACOBS

Thanks to ALL !

SPECIALTY CONCRETE CONTRACTORS
CELL-CRETE CORPORATION

RMA Companies

REINFORCED EARTH

MORGNER

Pacific Drilling Co.

CASCADE

GREGG

SOUTHWEST GEOPHYSICS, INC.