Scour Calculations Review Illustrated

By Raymond Morgan, PE

ADEQ
Arizona Department of Environmental Quality

Summary of Presentation Topics

1. Arizona Administrative Code guidelines on the design of sewer lines across floodways.
2. Definition of a floodway
3. Review of pressure sewer design crossing a floodway
4. Review of vertical scour calculations of washes that the pressure sewer crosses.
5. Review of horizontal bank erosion potential calculations of washes that the pressure sewer crosses.
6. Review of the design report statements
7. Review of the soils report that the design report uses to justify the tractive force calculations for potential bank erosion
8. Review of ADWR Watercourse System for Sediment Balance

Rule Review

R18-9-E301.B Performance. An applicant shall design, construct, and operate a sewage collection system so that the sewage collection system:

1. Provides adequate wastewater flow capacity for the planned service area;
2. Minimizes sedimentation, blockage, and erosion through maintenance of proper flow velocities throughout the system;
3. Prevents releases of sewage to the land surface through appropriate sizing, capacities, and inflow and infiltration prevention measures throughout the system;
4. Protects water quality through minimization of exfiltration losses from the system;
5. Provides for adequate inspection, maintenance, testing, visibility, and accessibility;
6. Maintains system structural integrity; and
7. Minimizes septic conditions in the sewage collection system.

Rule Review

R18-9-E301.D.2.c If sewer lines cross or are constructed in floodways;

i. Place the lines at least 2 feet below the level of the 100-year storm scour depth and calculated 100-year bed degradation and construct the lines using ductile iron pipe or pipe with equivalent tensile strength, compressive strength, shear resistance, and scour protection.

ii. If it is not possible to maintain the 2 feet of clearance specified in subsection (D)(2)(c)(i), using the process described in R18-9-A312(G), provide a design that ensures that the sewer line will withstand any lateral and vertical load for the scour and bed degradation conditions specified in subsection (D)(2)(c)(i);

iii. Ensure that sewer lines constructed in a floodway extend at least 10 feet beyond the boundary of the 100-year storm scouring;

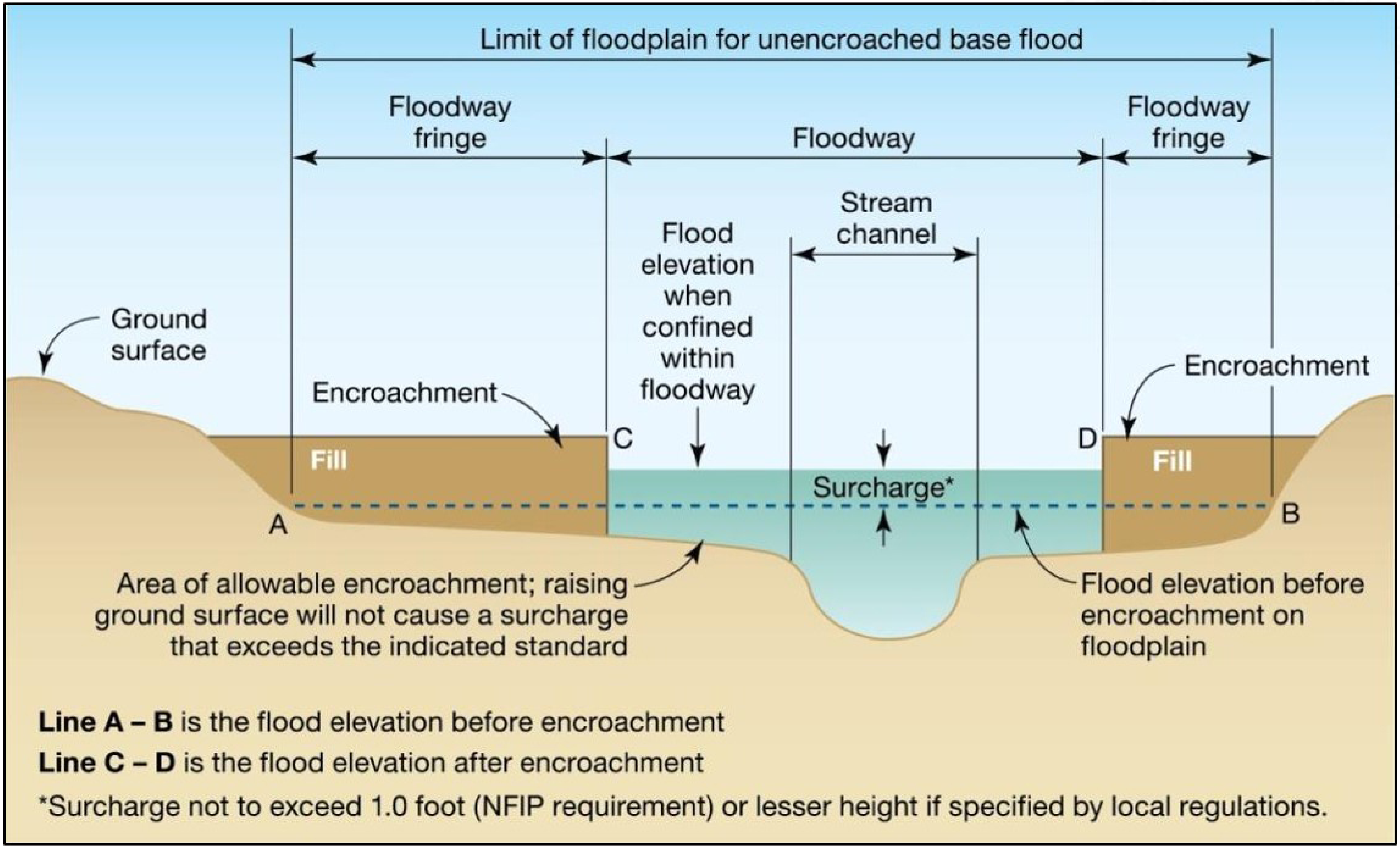
iv. If a sewer line is constructed in a floodway and is longer than the applicable maximum manhole spacing distance in subsection (D)(3)(a), using the process described in R18-9-A312(G), provide a design that ensures the performance standards in subsection (B) are met; and

Definitions

What is a floodway?

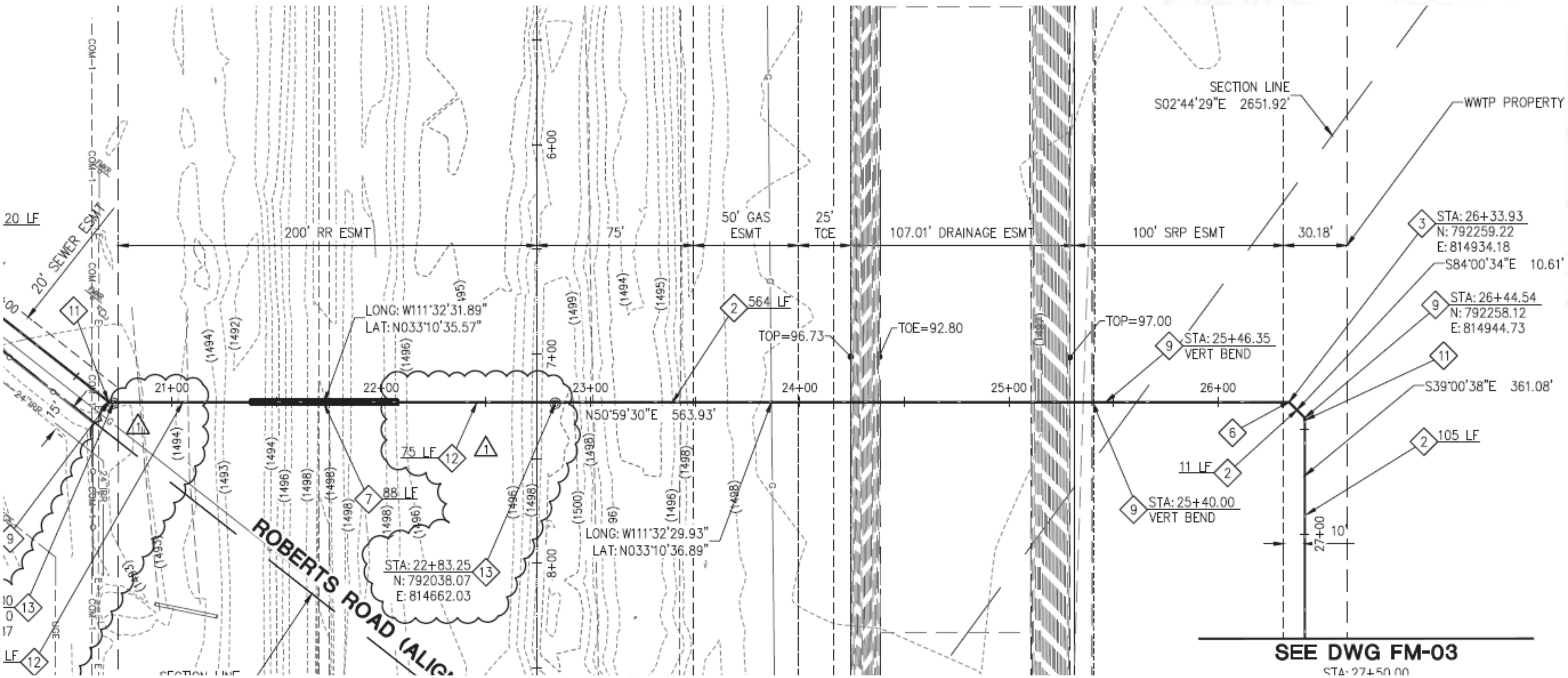
FEMA Definition - A "Regulatory Floodway" means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. FEMA Glossary, July 8, 2020, https://www.fema.gov/glossary/floodway.

Definitions Illustrated

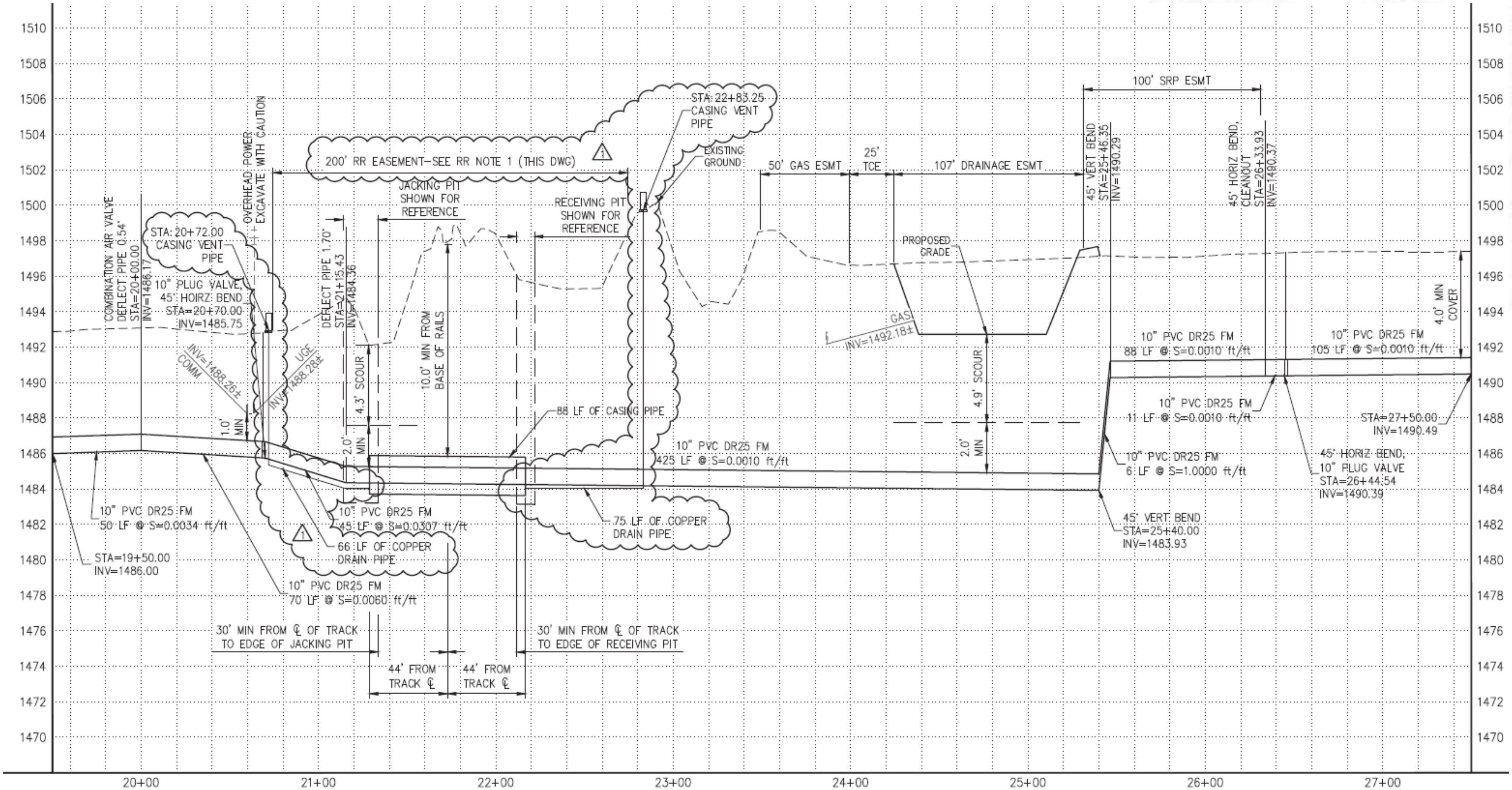


Flood Insurance Studies (2 of 3), https://emilms.fema.gov/is_0280/groups/37.html

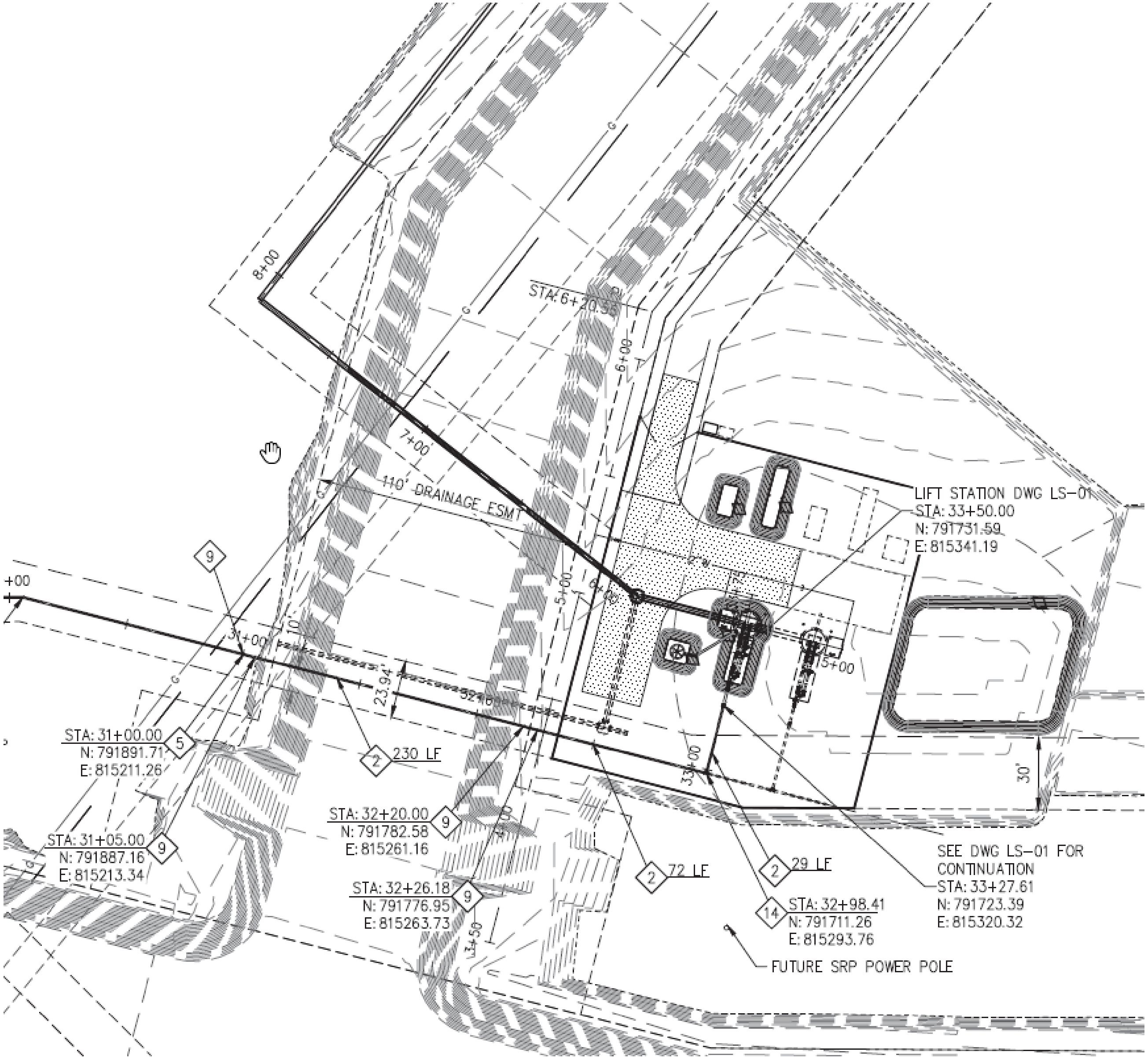
Initial Design



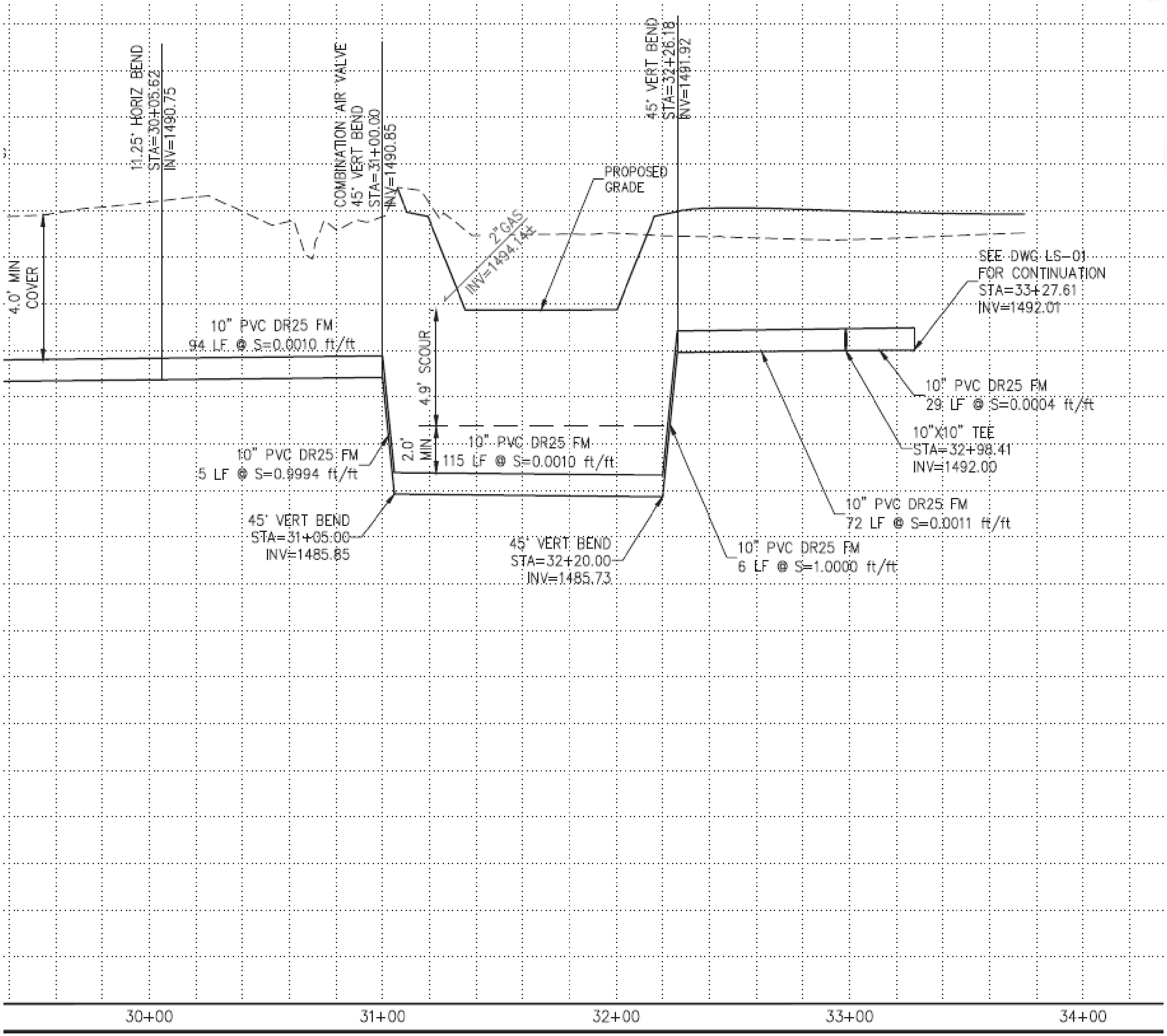
Initial Design



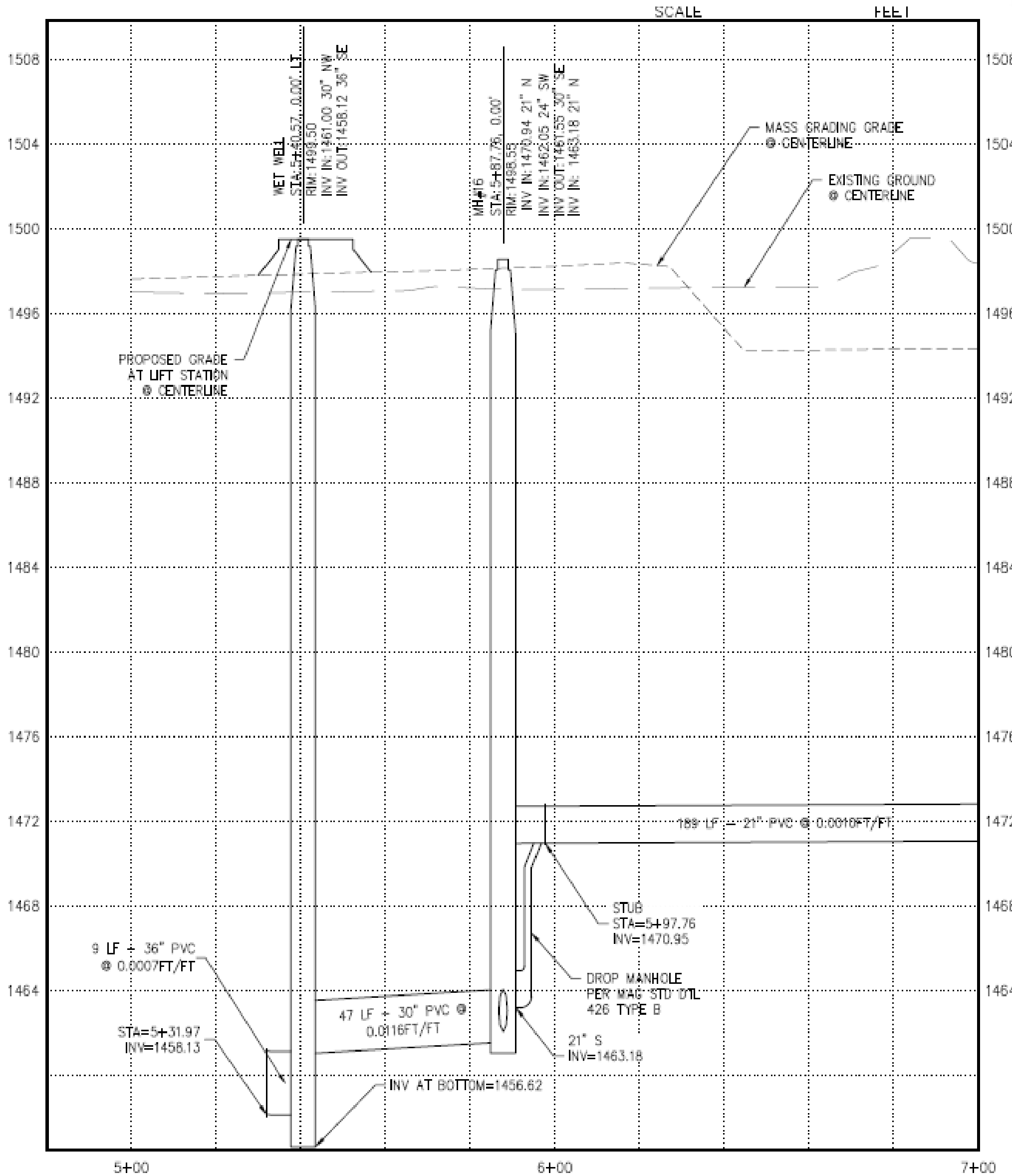
Initial Design



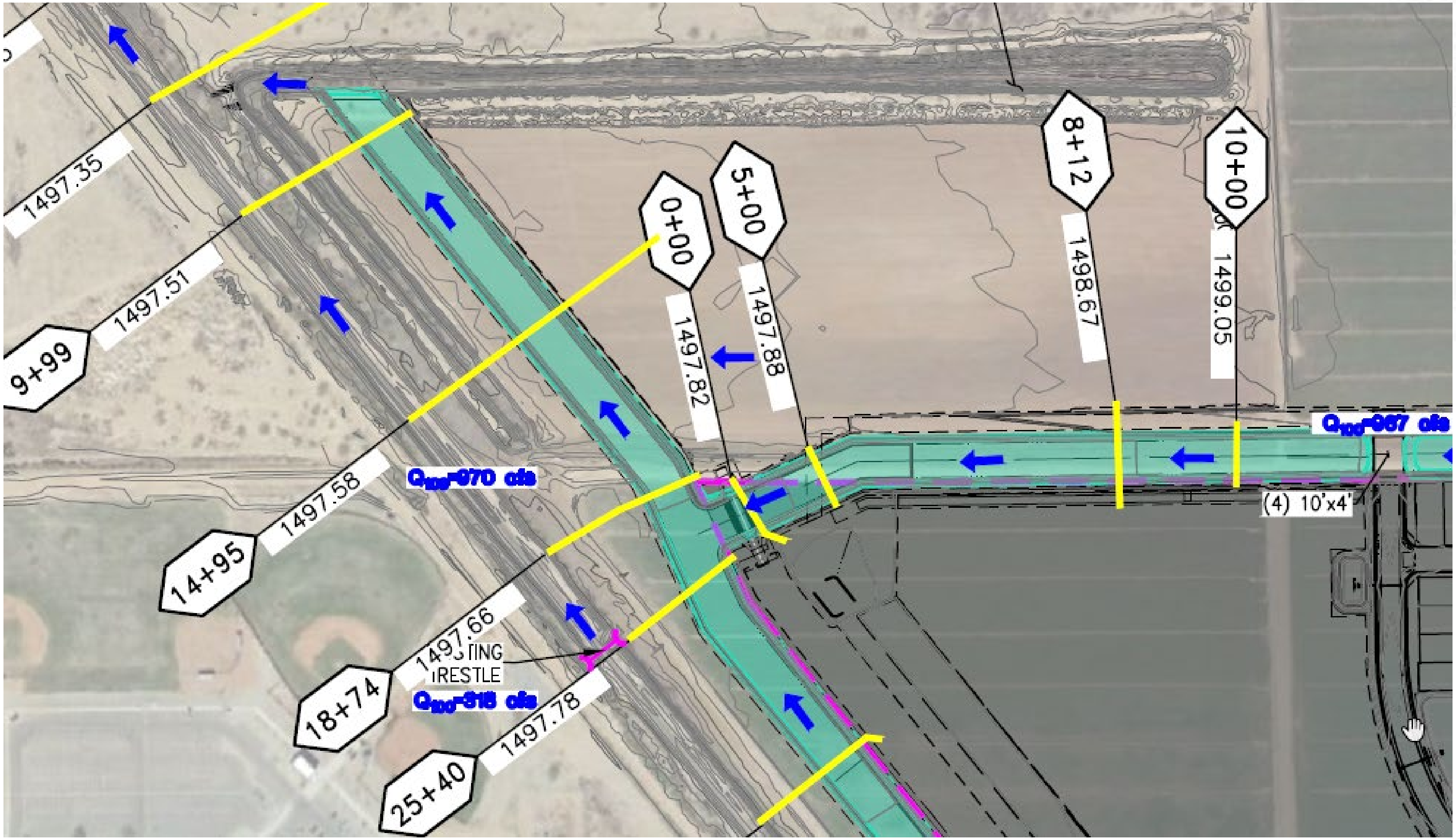
Initial Design



Initial Design



Initial Design – Stormwater Flows



Initial Design – Scour Summary Table

FINAL SCOUR CALCULATION SUMMARY TABLE

Project:

Prepared by:

Date:

Location	Station	Flow Rate[1] (cfs)	General Scour [1] (ft)	Long Term Degradation [2] (ft)	Bedform Scour [3] (ft)	Low Flow Scour [4] (ft)	Factor of Safety [5] (ft)	Design Scour Depth[2] = ([1]+[2]+[3]+[4])*[5] (ft)
Western Channel	9+98 - 18+73	970	0.9	1.2	0.2	1.5	1.3	**4.9**
West of Railroad	9+98 - 18+73	318	0.7	0.6	0.5	1.5	1.3	**4.3**

Notes:

(1)- Peak flowrate values were taken from the XXXXXXX Drainage Report.

(2)- Per Arizona State Standard SSA 5-96 Level I (1996) the minimum long term and general scour depth shall be 3 feet.

Initial Design – Total Scour Components

CHANNEL SCOUR CALCULATION

Project:
Prepared by:
Date:

Flowrate: Peak flowrate values were taken from Wood/Patel Master Drainage Report

Design Storm 100-Year
Model Name: Temporary Channels Output

Drainage Corridor / Section ...stern Channel Station: 9+98 - 18+73
Flowrate 970 cfs

General Scour- Regime Equations

1. Lacey's Equation

$$y_{gs} = k_l * 0.47 (Q / f)^{1/3}$$

where:
y_{gs} = general scour depth (ft)
k_l = adjustment coefficient for Lacey's Equation (0.25 for straight reaches)
Q = design discharge, (ft^3/s)
f = Lacey's silt factor = $1.76(D_m)^{1/2}$
D_m = mean grain size of bed material, (mm)

D_m	f	Q	k_l	y_{gs}
1.20	1.9280	970	0.25	0.9

2. Blench Equation

$$y_{gs} = k_b * [q_f^{2/3} / F_{bo}^{1/3}]$$

where:
y_{gs} = general scour depth (ft)
k_b = adjustment coefficient for Blench's Equation (0.6)
q_f = design discharge per unit width ($ft^3/s/ft$)
F_{bo} = Blench's "zero bed factor" in ft/s^2 from *Chart for Estimating F_{bo}* (Pemberton and Lara, 1984)

k_b	q_f	F_{bo}	y_{gs}
0.6	2.04	1.8	0.8

Initial Design – Total Scour Components

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Long Term Degradation

Arizona State Standard SSA 5-96 Level I (1996)

$$d_{lts} = 0.02\,(Q_{100})^{0.6}$$

where:
d_{lts} = long term scour depth, (ft)
Q_{100} = 100-year peak flowrate, (ft^3/s)

Q_{100}	d_{lts}
967	1.2

Bedform Scour

Simons and Senturn (1992)

$$y_{bfs} = 0.5\,d_h$$

where:
y_{bfs} = bedform scour depth, (ft)
d_h = dune height for subcritical flow with $F_r < 0.7$, (ft)
$d_h = 0.066 * Y_h^{1.21}$
d_h = dune height for supercritical flow with $F_r > 0.7$, (ft)
$d_h = 0.28 * \pi * Y_h * F_r^2$
Y_h = hydraulic Depth of Flow (ft)
F_r = Froude number

Y_h	F_r	d_h	y_{bfs}
0.57	0.90	0.41	0.2

Average General Scour Depth =	0.9	ft
Long Term Degradation Depth =	1.2	ft
Bedform Scour Depth =	0.2	ft
Low Flow Scour =	1.5	
Factor of Safety =	1.3	
Design Scour Depth =	4.9	ft

Initial Design – Lateral Erosion Calculations

TRACTIVE FORCE ANALYSIS

Project:

Prepared by:

Date:

Trapezoidal

Q =	967	cfs
S =	0.0009	ft/ft
D50 =	0.042	ft
m (left) =	4.0	H:1V
m (right) =	4.0	H:1V
w=	65.0	ft
d1 =	3.0	ft
n=	0.030	

n = 0.030

% error = 0.00 %

OK

SF = 1.10

td = 0.234 psf

	it1	it2	it3	it4	it5	it6	it7	it8	it9	it10	
d =	3.0	3.5	3.7	3.8	3.8	3.8	3.8	3.8	3.8	3.8	ft
A =	231.0	279.1	295.6	300.7	302.2	302.7	302.8	302.9	302.9	302.9	sf
Pw =	89.7	94.1	95.5	96.0	96.1	96.2	96.2	96.2	96.2	96.2	ft
Rh =	2.6	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	ft
T =	89.0	93.2	94.6	95.1	95.2	95.2	95.2	95.2	95.2	95.2	ft
da =	2.6	3.0	3.1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	ft
b =	1.0	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	
Fr =	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
f(Fr) =	1.3	1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.7	
f(REG) =	609.5	794.7	859.9	880.1	886.2	887.9	888.5	888.6	888.7	888.7	
f(CG) =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
n =	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	
Q =	645	856	933	957	964	966	967	967	967	967	cfs
diff =	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

Q: volumetric flowrate of channel

S: channel bed slope

Initial Design – Lateral Erosion Soils Table

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PERMISSIBLE SHEAR STRESS SUMMARY TABLE

Project:
Prepared
Date:

Typical Permissible Shear Stresses for Bare Soil and Stone Linings		
Lining Category	Lining Type	Permissible Shear Stress (psf)
Bare Soil Cohesive (PI = 10)	Clayey sands	0.037 - 0.095
	Inorganic silts	0.027 - 0.11
	Silty sands	0.024 - 0.072
Bare Soil Cohesive (PI ≥ 20)	Clayey sands	0.094
	Inorganic silts	0.083
	Silty sands	0.072
	Inorganic clays	0.14
Bare Soil Non-cohesive (PI < 10)	Finer than coarse sand D_{75} < 0.05 in.	0.02
	Fine gravel D_{75} = 0.3 in.	0.12
	Gravel D_{75} = 0.6 in.	0.24
Gravel Mulch/Riprap	Coarse gravel D_{50} = 1 in.	0.4
	Very coarse gravel D_{50} = 2 in.	0.8
Rock Riprap	D_{50} = 0.5 ft.	2.4
	D_{50} = 1.0 ft.	4.8

NOTES:

1) Table 2.3, Design of Roadside Channels with Flexible Linings, Publication No. FHWA-NHI-05-114, September 2005

Initial Design Report

Per the Arizona State Standard for Watercourse System Sediment Balance (SSA 5-96), lateral migration guidelines are provided for riverine floodplains, alluvial channels, and sand and gravel mining operations. The Roberts Road and Western Channels are engineered channels and therefore do not qualify under any of the above categories defined within SSA 5-96. The channels are not expected to be erosive and do not meet the generally accepted definition of a regional watercourses (drainage areas greater than 30 square miles), per SSA 5-96. Therefore, the generally accepted minimum lateral erosion of 10 feet was used for the Roberts Road Channel and Western Channel. Additionally, please note that all drainage elements within the Phantom Project, including the Roberts Road and Western Channels are the responsibility of the HOA, and are required to be maintained so as to preserve the original channel cross section. This includes both the repair of eroded areas and the removal of any sediment build-up.

Initial Design Report – AZ State Standard for Erosion

*For the purpose of application of these guidelines, erosion hazard area and watercourse system sediment balance standards will apply to all watercourses identified by the Federal Emergency Management Agency as part of the National Flood Insurance Program, all watercourses which have been identified by the local floodplain administrator as having significant potential flood hazards and all watercourses with drainage areas more than 1/4 square mile or a 100-year discharge estimate of more than 500 cubic feet per second. Application of these guidelines will not be necessary if the local community or county has in effect a drainage, grading or stormwater ordinance which, in the opinion of the Department, results in the same or greater level of flood protection as application of these guidelines would ensure.

*From Arizona State Standard for Watercourse System for Sediment Balance (SSA 5-96)

Initial Design Report – AZ State Standard for Erosion

For watercourses which have drainage areas of less than 30 square miles, the recommended setback allowances are as follows:

for straight channel reaches or reaches with minor curvature: $\text{setback} = 1.0(Q_{100})^{0.5}$

for channels with obvious curvature or channel bend: $\text{setback} = 2.5(Q_{100})^{0.5}$

where setback is in feet and Q_{100} is in cubic feet per second.

Initial Design Report

Per the Hydraulic Engineering Circular No. 15, Third Edition: Design of Roadside Channels with Flexible Linings (Federal Highway Administration, September 2005), the allowable tractive force approach has been utilized to demonstrate that the channel banks for the Roberts Road and Western Channels (identified in Section 5.2) are not erosive for the flow conditions associated with the 100-year storm event. Parameters used to perform these calculations have been referenced from the hydraulic model completed as part of the Phantom Parcels C, D, E, & F Final Drainage Reports. Per the Geotechnical Subsurface Exploration for Phantom Phase 1, completed by Phantom Geotechnical & Materials, Inc. in 2017 the site soils consist of coarse grained site surface and subsurface soils with medium plasticity clayey sand, varying amounts of gravel, and medium plasticity clayey sandy gravel. As the channels will be earthen lined, for the purposes of this analysis the channels have been assumed as bare non-cohesive soil (gravel) with a maximum allowable shear stress of 0.24 psf, per Table 2.3 of the Design of Roadside Channels with Flexible Linings as gravel is the dominant soil type per the results of the geotechnical site investigation. The results of the hydraulic modeling and allowable tractive force approach calculations indicate that the maximum calculated shear stress does not exceed the allowable value for any of the channel reaches in the vicinity of the pipeline crossings.

Initial Design – Lateral Erosion Soils Table

PERMISSIBLE SHEAR STRESS SUMMARY TABLE

Project:

Prepared

Date:

Typical Permissible Shear Stresses for Bare Soil and Stone Linings		
Lining Category	Lining Type	Permissible Shear Stress (psf)
Bare Soil Cohesive (PI = 10)	Clayey sands	0.037 - 0.095
	Inorganic silts	0.027 - 0.11
	Silty sands	0.024 - 0.072
Bare Soil Cohesive (PI ≥ 20)	Clayey sands	0.094
	Inorganic silts	0.083
	Silty sands	0.072
	Inorganic clays	0.14
Bare Soil Non-cohesive (PI < 10)	Finer than coarse sand $D_{75} < 0.05$ in.	0.02
	Fine gravel $D_{75} = 0.3$ in.	0.12
	Gravel $D_{75} = 0.6$ in.	0.24
Gravel Mulch/Riprap	Coarse gravel $D_{50} = 1$ in.	0.4
	Very coarse gravel $D_{50} = 2$ in.	0.8
Rock Riprap	$D_{50} = 0.5$ ft.	2.4
	$D_{50} = 1.0$ ft.	4.8

NOTES:

1) Table 2.3, Design of Roadside Channels with Flexible Linings, Publication No. FHWA-NHI-05-114, September 2005

Soils Report – Boring Locations

Soils Report – B-79 Boring Log

Alpha Project Number:		Log of Boring No.	B-79
Project Name:		Client:	
Project Location:	West of Schnepf Road and North of Bella Vista Road	Boring Location:	See site plan

Remarks: Flood irrigated cropland with dirt access roads.

Sample Type	Blows Per 6"	Dry Density (PCF)	Moisture (%)	Depth (Feet)	Relative Density (Coarse Grained/ Fine Grained)	USCS Code	Description of Subsurface Conditions
						CL	**GRAVELLY SANDY CLAY** Medium brown, medium particle size, subangular particles, slightly damp, medium plasticity, weakly cemented.
				1			
			10.0	2			
R	27 30	85.4	13.7	3	Very Dense/ Hard		
				4			
				5			
S	11 11 14			6	Medium Dense/ Very Stiff		

Soils Report – General Boring Log Information

Sieve Screens Not Included In Test

Percent Passing By Weight

					Silt or Clay	Sand								Gravel									Moisture
						Fine			Medium			Coarse		Fine				Coarse					
Sample Number	Location & Depth	USCS	LL	PI	#200	#100	#50	#40	#30	#16	#10	#8	#4	1/4"	3/8"	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	3"	%
33272	B1 @ 0 - 5'	SC	34	15	24								70										9.2
33275	B10 @ 0 - 5'	SC	33	19	27								65										4.8
33276	B14 @ 0 - 5'	SC	34	11	38								80										8.4
33277	B16 @ 0 - 5'	SC	41	25	32								70										9.0
33278	B21 @ 0 - 5'	GC	54	35	23								53										6.5
33279	B23 @ 0 - 5'	SC	39	22	19								72										7.4
33280	B26 @ 0 - 5'	SC	39	26	32								72										2.7
33281	B27 @ 0 - 5'	GC	40	21	20								53										7.2
33282	B29 @ 0 - 5'	GC	29	14	24								59										7.9
33283	B31 @ 0 - 5'	GC	43	27	29								58										7.8
33284	B34 @ 0 - 5'	SC	39	23	31								70										5.2
33293	B35 @ 0 - 5'	SC	33	17	22	29	39	44	48	56	69	75	91	87	91	88	94	97	100	100	100	100	6.7
33286	B38 @ 0 - 5'	SC	48	31	40								84										6.2
33273	B4 @ 0 - 5'	SC	33	16	27								77										5.4
33294	B44 @ 0 - 5'	CL	39	19	56	67	77	81	83	91	91	93	94	97	100	100	100	100	100	100	100	100	15
33292	B5 @ 0 - 5'	SC	38	20	41	52	65	71	77	85	89	90	95	95	97	99	100	100	100	100	100	100	4.8
33287	B51 @ 0 - 5'	GP-GC	32	16	11								36										5.1
33288	B55 @ 0 - 5'	GC	36	21	15								51										5.1
33289	B58 @ 0 - 5'	SC	32	15	34								89										12
33295	B61 @ 0 - 5'	SC	41	22	47	64	81	88	90	96	96	97	97	99	100	100	100	100	100	100	100	100	14
33290	B68 @ 0 - 5'	CL	39	21	57	67	76	80	81	85	85	85	85	100	100	100	100	100	100	100	100	100	11
33274	B7 @ 0 - 5'	SC	37	20	22								63										8.9
33291	B79 @ 0 - 5'	CL	39	20	54								85										10
33296	B84 @ 0 - 5'	SC	23	11	33	48	68	77	84	92	95	96	99	97	98	100	99	100	100	100	100	100	8.5

Revised Design Report

Per the Hydraulic Engineering Circular No. 15, Third Edition: Design of Roadside Channels with Flexible Linings (Federal Highway Administration, September 2005), the allowable tractive force approach has been utilized to determine the erosive potential of the Roberts Road and Western Channels (identified in Section 5.2) for the flow conditions associated with the 100-year storm event. Parameters used to perform these calculations have been referenced from the hydraulic model completed as part of the Phantom Parcels C, D, E, & F Final Drainage Reports. Per the Geotechnical Subsurface Exploration for Phantom Project Phase 1, completed by Phantom Geotechnical & Materials, Inc. in 2017 the site soils adjacent to the site consist of Gravelly sandy clay, classified as CL (B-79 and B-80). As the channels have been lined with native soil, for the purposes of the tractive force method calculations the channels have been assumed as "clayey sands" with a maximum allowable shear stress of 0.094 psf, per Table 2.3 of the Design of Roadside Channels with Flexible Linings. The results of the hydraulic modeling and allowable tractive force approach calculations indicate that the maximum calculated shear stress exceeds the allowable value for only the Roberts Road Channel. Therefore, lateral erosion calculations have been prepared only for the Roberts Road Channel. The Western Channel sections have utilized the generally accepted minimum lateral erosion value of 10 feet. The lateral erosion calculations utilized have been referenced from the Flood Control District of Maricopa County Drainage Design Manual Vol II – Hydraulics, Section 11.9.2

Revised Design at Station 32+00

HORIZONTAL SCOUR CALCULATION SUMMARY TABLE

Project:
Prepared by:
Date:

Location	Station	Flow Rate[1] (cfs)	Design Vertical Scour Depth Zt (ft)	Channel Depth[2] D (ft)	Lateral Erosion Distance[3] L=6(D+Zt) (ft)
Roberts Road Channel	10+00 - 0+00	967	4.9	4.0	53.7

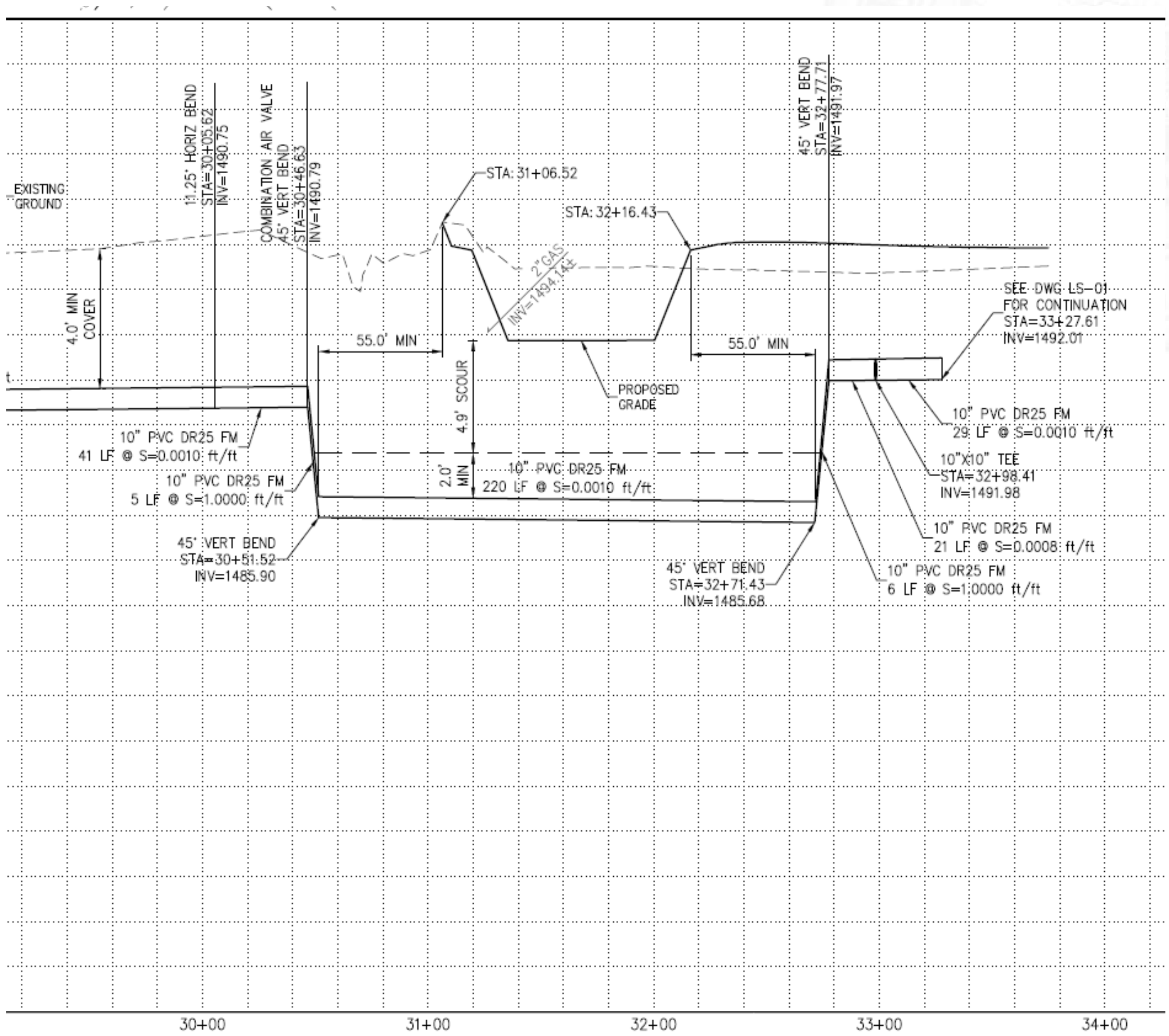
Notes:

(1)- Peak flowrate values obtained from the Master Drainage Report for Phantom Project.

(2)- Channel depth has been referenced from the hydraulic models prepared for Phantom Parcels C, D, E, & F

(3)- Lateral Erosion Distance calculations have been referenced from Flood Control District of Maricopa County Drainage Design Manual Vol II - Hydraulics, Section 11.9.2

Revised Design at Station 32+00



Things to Consider During the Design Review

1. The Arizona Administrative Code (AAC) requires the following issues to be addressed:
   a. 100-year scour depth
   b. 100-year bed degradation
   c. 100-year lateral migration (aka scour) of the drainageway banks
2. The AAC does not specify the specific method to do these calculations.
3. Therefore, the designer can choose the calculation method but they must follow that method fully and consistently.
4. The designer should show the calculation formulas, provide the reference to the calculation procedure and provide the results of the calculations. If the calculation procedure is not readily available on the internet, they should provide a copy of that procedure to the agency reviewer.

Things to Consider During the Design Review

5. The statements in the design report cannot be relied upon at face value. They need to be confirmed in the calculations and associated reference documents.
6. Is the design consistent with the calculations and associated reference documents?
7. Does the design work to protect the infrastructure from 100-year storm events?
8. Is the design governed by facts or assumptions? A design based upon assumptions is directly related to those assumptions. If the assumption is flawed, then the design will be flawed. To put this thought another way – a conclusion is no better than the assumptions it is founded upon.

Any Questions?

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