How Low Can You Go: Various Materials Used by MDOT to Reduce Lateral Earth Loading Pressures

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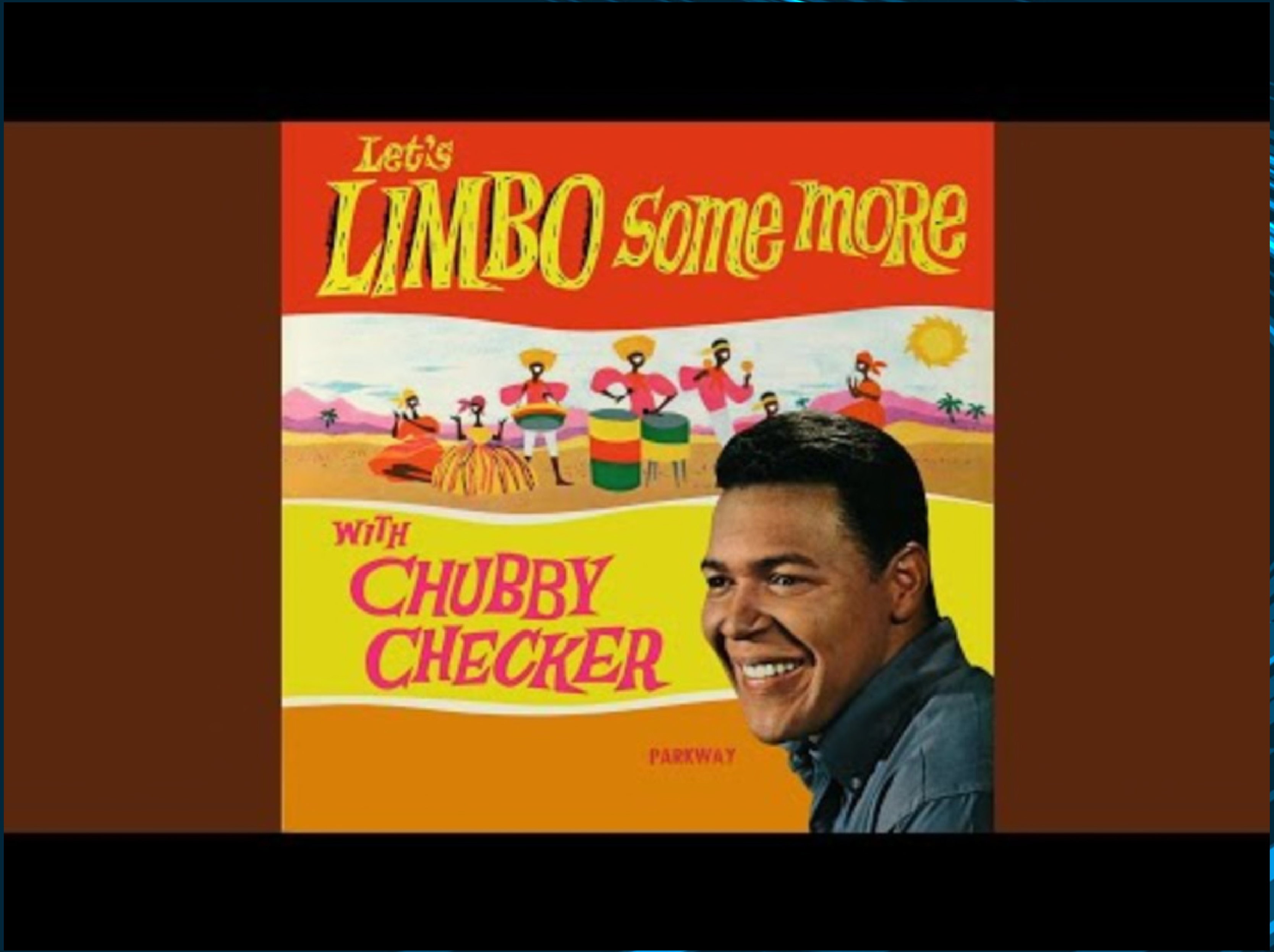
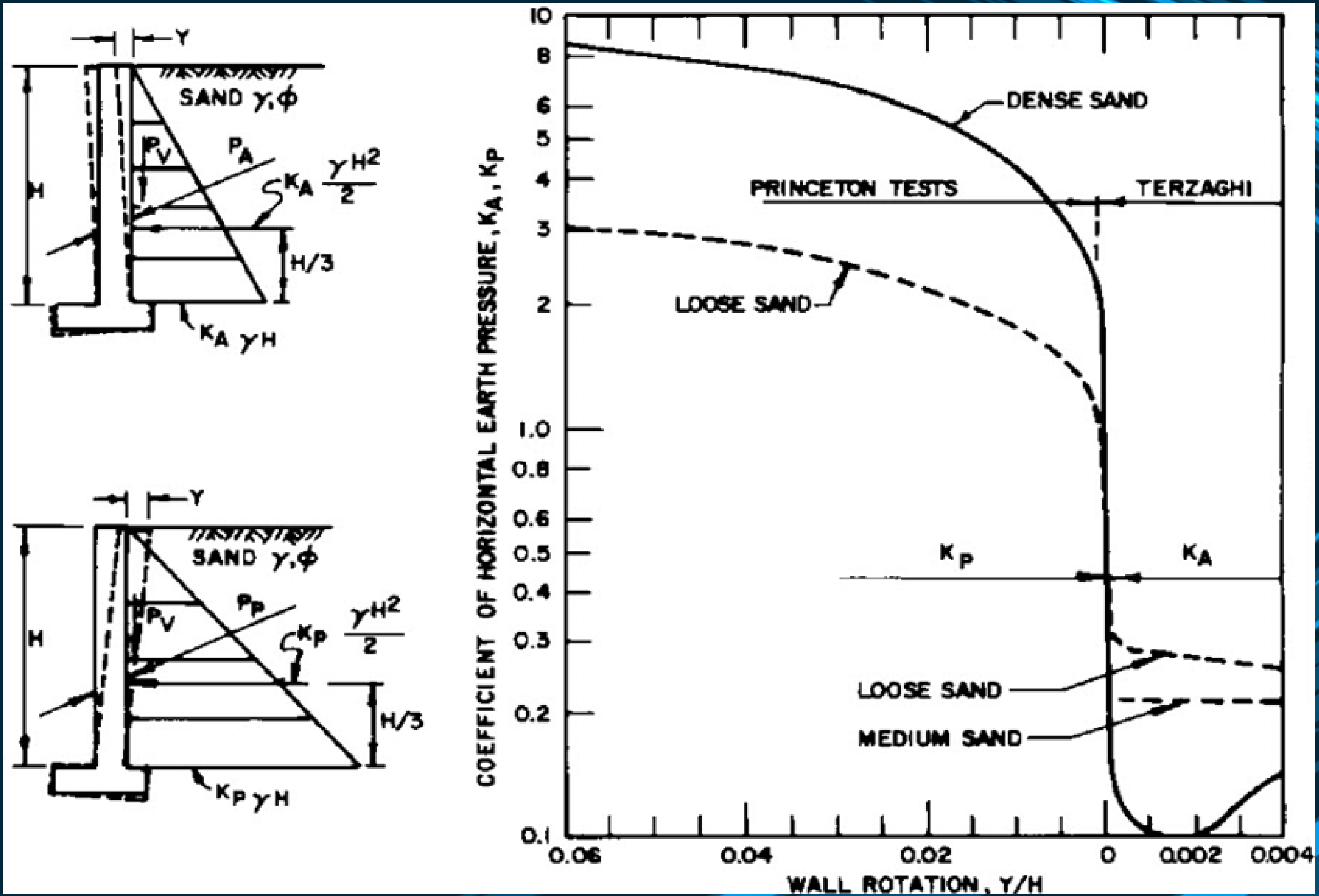
Michigan Department of Transportation

Not what I'm talking about



What is Lateral Earth Pressure



NAVFAC
DM7.02, Figure 1

Lateral Wall Rotations for Earth Pressures

Table C3.11.1-1—Approximate Values of Relative Movements Required to Reach Active or Passive Earth Pressure Conditions (Clough and Duncan, 1991)

Type of Backfill	Values of Δ/H	
	Active	Passive
Dense sand	0.001	0.01
Medium dense sand	0.002	0.02
Loose sand	0.004	0.04
Compacted silt	0.002	0.02
Compacted lean clay	0.010	0.05
Compacted fat clay	0.010	0.05

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Coulomb Lateral Earth Pressure

3.11.5.3—Active Lateral Earth Pressure Coefficient, k_a

Values for the coefficient of active lateral earth pressure may be taken as:

$$k_a = \frac{\sin^2(\theta + \phi'_f)}{\Gamma\,[\sin^2\theta \sin(\theta - \delta)]} \qquad (3.11.5.3\text{-}1)$$

in which:

$$\Gamma = \left[1 + \sqrt{\frac{\sin(\phi'_f + \delta)\sin(\phi'_f - \beta)}{\sin(\theta - \delta)\sin(\theta + \beta)}}\right]^2 \qquad (3.11.5.3\text{-}2)$$

where:

δ = friction angle between fill and wall (degrees)
β = angle of fill to the horizontal, as shown in Figure 3.11.5.3-1 (degrees)
θ = angle of back face of wall to the horizontal, as shown in Figure 3.11.5.3-1 (degrees)
ϕ'_f = effective angle of internal friction (degrees)

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Rankine Earth Pressure

$$K_a = \frac{1 - \sin \phi}{1 + \sin \phi} = \tan^2(45^\circ - \phi/2)$$

For level back slopes, 0 wall friction angle and long cantilever abutment heels.

AASHTO Abutment Design

- Where the wall is supported by a soil foundation:

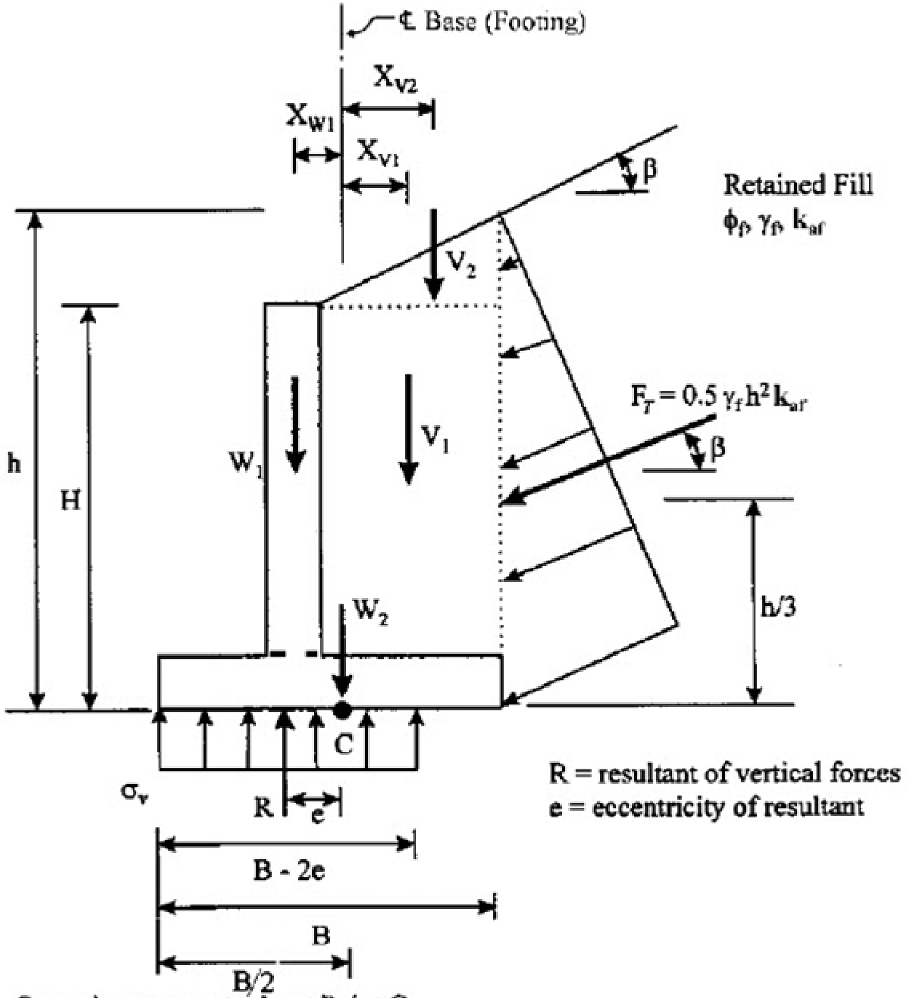
the vertical stress shall be calculated assuming a uniformly distributed pressure over an effective base area as shown in Figure 11.6.3.2-1.

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\Sigma V}{B - 2e} \qquad (11.6.3.2\text{-}1)$$

where:

ΣV = the summation of vertical forces, and the other variables are as defined in Figure 11.6.3.2-1



Summing moments about Point C:

$$e = \frac{(F_T Cos\beta)h/3 - (F_T \sin\beta)B/2 - V_1X_{V1} - V_2X_{V2} + W_1X_{W1}}{V_1 + V_2 + W_1 + W_2 + F_T \sin\beta}$$

Figure 11.6.3.2-1—Bearing Stress Criteria for Conventional Wall Foundations on Soil

AASHTO 3.11.5 - Earth Pressure: EH

Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	*DC* *DW* *EH* *EV* *ES* *EL* *PS* *CR* *SH*	*LL* *IM* *CE* *BR* *PL* *LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	*DR*	Use One of These at a Time *EQ*	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	γ_{TU}	γ_{TG}	γ_{SE}	γ_{DR}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	γ_{TU}	γ_{TG}	γ_{SE}	γ_{DR}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.00	—	1.00	γ_{TU}	γ_{TG}	γ_{SE}	γ_{DR}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	γ_{TU}	—	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	1.00	1.00	1.00	γ_{TU}	γ_{TG}	γ_{SE}	γ_{DR}	—	—	—	—	—
Extreme Event I	1.00	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00	1.00	—	—	—	—
Extreme Event II	1.00	0.5/ 1.00	1.00	—	—	1.00	—	—	—	1.00	—	1.00	1.00	1.00/	1.00
Service I	1.00	1.00	1.00	1.00	1.00	1.00	γ_{TU}	γ_{TG}	γ_{SE}	1.00	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	γ_{TU}	—	—	—	—	—	—	—	—
Service III	1.00	γ_{LL}	1.00	—	—	1.00	γ_{TU}	γ_{TG}	γ_{SE}	1.00	—	—	—	—	—
Service IV	1.00	—	1.00	1.00	—	1.00	γ_{TU}	—	1.00	1.00	—	—	—	—	—
Fatigue I—*LL*, *IM* & *CE* only	—	1.75	—	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—*LL*, *IM* & *CE* only	—	0.80	—	—	—	—	—	—	—	—	—	—	—	—	—

Notes: For Service I, the load factor for *EV* equals 1.2 for Stiffness Method Soil Failure as shown in Table 3.4.1-2.
The value of γ_P shall be taken from Tables 3.4.1-2 and 3.4.1-3.
The value of γ_{LL} shall be taken from Table 3.4.1-4.
The value of γ_{SE} shall be taken from Table 3.4.1-5.
The value of γ_{TU} shall be taken from Table 3.4.1-6.
For Structural Strength, the load factor for *DR*, γ_{DR}, equals 1.10 and for Geotechnical Strength, γ_{DR} equals 0.00.

AASHTO 3.11.5 - Earth Pressure: EH

Table 3.4.1-2—Load Factors for Permanent Loads, γ_p

Type of Load, Foundation Type	Load Factor	
	Maximum	Minimum
DC: Component and Attachments	1.25	0.90
DC: Strength IV only	1.50	0.90
DW: Wearing Surfaces and Utilities	1.50	0.65
EH: Horizontal Earth Pressure		
• Active	1.50	0.90
• At-Rest	1.35	0.90
• Apparent earth pressure (*AEP*) for anchored walls	1.35	N/A
EL: Locked-in Construction Stresses	1.00	1.00
EV: Vertical Earth Pressure		
• Overall and Compound Stability	1.00	N/A
• Retaining Walls and Abutments	1.35	1.00
• MSE wall internal stability soil reinforcement loads		
o Stiffness Method		
▪ Reinforcement and connection rupture	1.35	N/A
▪ Soil failure – geosynthetics (Service I)	1.20	N/A
o Coherent Gravity Method	1.35	N/A
• Rigid Buried Structure	1.30	0.90
• Rigid Frames	1.35	0.90
• Flexible Buried Structures		
o Metal Box Culverts, Structural Plate Culverts with Deep Corrugations, and Fiberglass Culverts	1.50	0.90
o Thermoplastic Culverts	1.30	0.90
o All others	1.95	0.90
• Internal and Compound Stability for Soil Failure in Soil Nail Walls	1.00	N/A
ES: Earth Surcharge	1.50	0.75

AASHTO 3.11.5.1 - Earth Pressure: EH

Lateral Earth Pressure

$p = k\gamma_s z$ (AASHTO Equation 3.11.5.1-1)

Where:

p = lateral earth Pressure (ksf)

k = coefficient of lateral earth pressure

γ_s = unit weight of soil (kcf)

z = depth below the surface of earth (ft)

How low can you go?

Sand Backfill

MDOT Class II Sand Backfill (Backfill, Structure, CIP) is the preferred backfill for abutments.

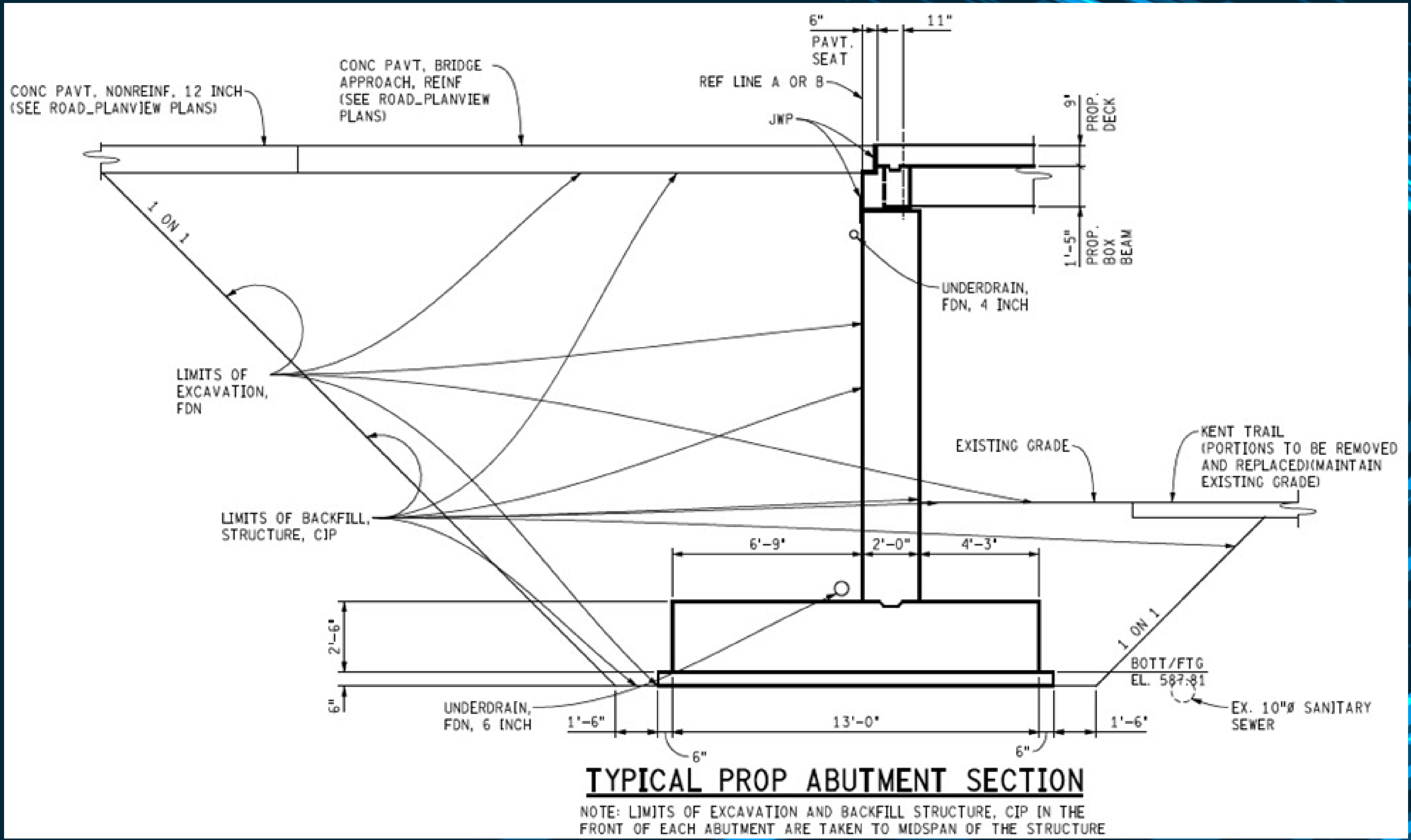
γ_s = unit weight of soil (kcf)

0.120 kcf

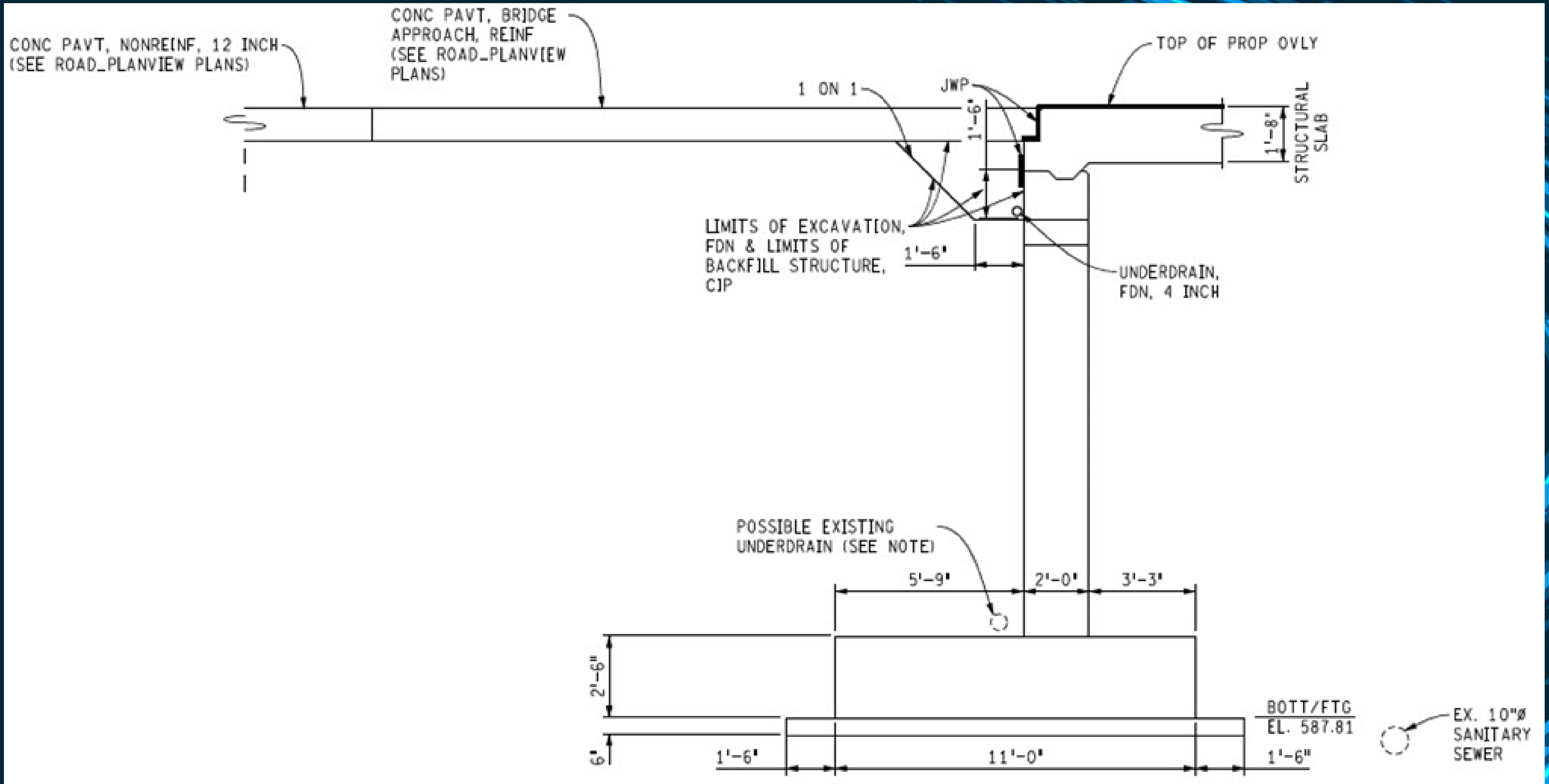
k = coefficient of lateral earth pressure

0.30

Sand Backfill Details (LRFD)



Sand Backfill Details (LFD, HS20)



TYPICAL EXISTING ABUTMENT SECTION

NOTE: EXISTING PLANS DO NOT CLEARLY SHOW ANY UNDERDRAINS BEHIND THE EXISTING ABUTMENT. IF EXISTING UNDERDRAIN IS ENCOUNTERED AT THIS LOCATION, SPLICE EXISTING UNDERDRAIN TO PROPOSED UNDERDRAIN FDN, 6 INCH, BEHIND PROPOSED PORTIONS OF ABUTMENT, INCLUDED FOR PAYMENT IN THE BID ITEM "UNDERDRAIN, FDN, 6 INCH".

Sand Backfill Benefits

- Backfill is readily available
- Simple construction that contractors are familiar with
- Easy to work with in the future (widenings or part-width reconstruction)

Sand Backfill Drawbacks

- Requires good compaction
- Need to make sure it is free draining (can’t have too many fines)
- Need to make sure that good drainage is provided
- Need to make sure that underdrain outlets are installed correctly

Sand Backfill

How low can you go?

Open-Graded Crushed Gravel Backfill

MDOT 46G Backfill (Aggregate, Special) (similar to a AASHTO #57) has been used as backfill behind abutments when a slightly lighter weight but highly frictional material is needed.

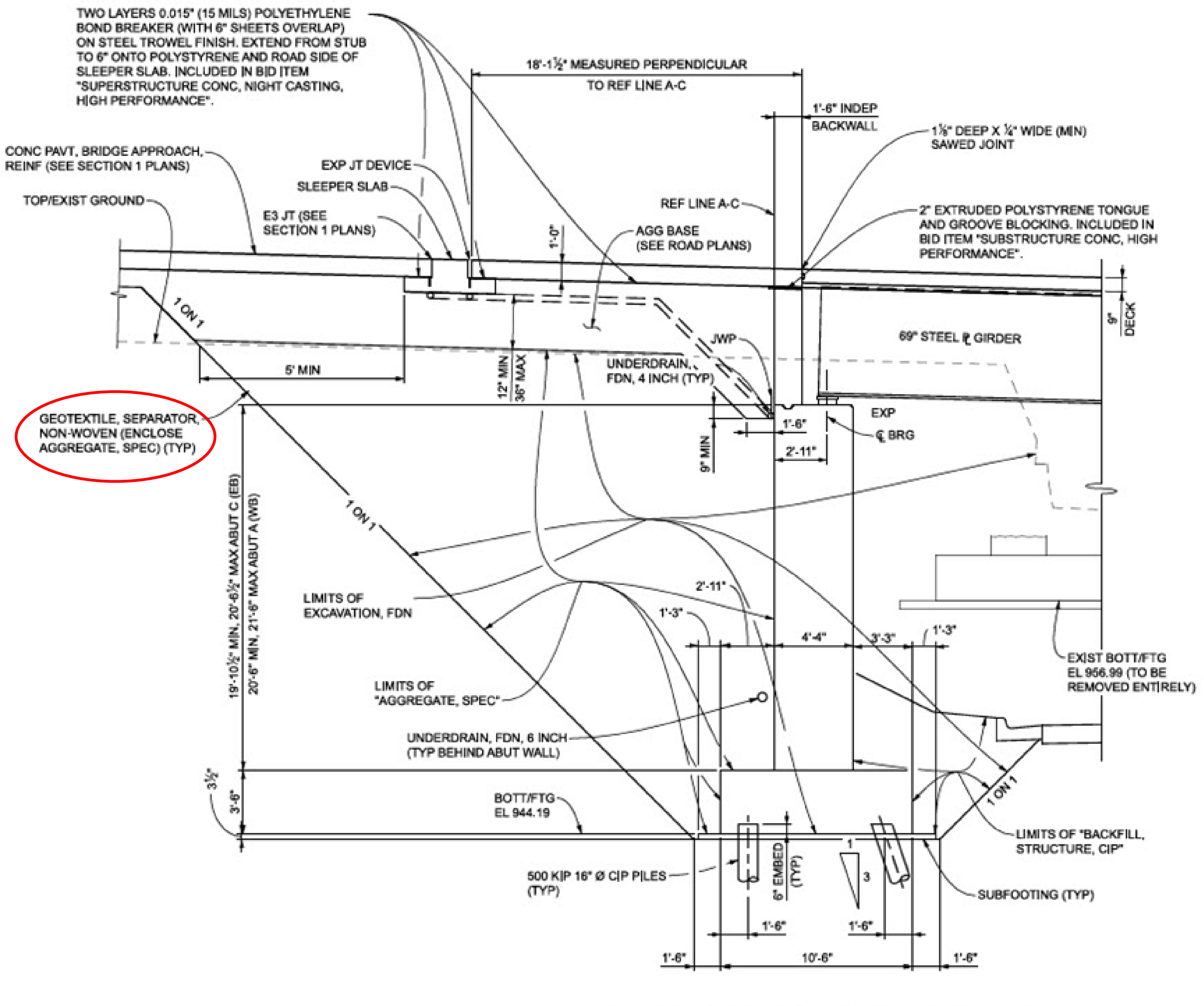
γ_s = unit weight of soil (kcf)

0.100 kcf

k = coefficient of lateral earth pressure

0.24

Open-Graded Crushed Gravel Backfill Details



TYPICAL ABUTMENT A OR C SECTION

Open-Graded Crushed Gravel Backfill Benefits

- Backfill is readily available
- Simple construction
- No density (method placement)
- Easier to work with in the future (widenings or part-width reconstruction)

Open-Graded Crushed Gravel Backfill Drawbacks

- Requires method placement compaction (not typical)
- Need to encapsulate it in a non-woven geotextile separator to prevent fines from infiltrating into it
- Need to make sure that underdrain outlets are installed correctly

Open-Graded Crushed Gravel Backfill

How low can you go?

Low Density Cellular Concrete Backfill

MDOT typically uses Class II. The wet unit weight is 30 pcf and 28-day compressive strength is 40 psi.

Table 1: LDCCF Minimum Physical Properties

	Class II	Class III	Class IV
Maximum cast wet density	30 pcf(a)	36 pcf(a)	42 pcf(a)
72-hour Compressive Strength(c)	10 psi(b)	10 psi(b)	10 psi(b)
28-day Compressive Strength(c)	40 psi(b)	80 psi(b)	120 psi(b)

a. pounds per cubic foot
b. pounds per square inch
c. Tested per *ASTM C495/C495M*, except specimens are not to be oven-dried.

γ_s = unit weight of soil (kcf)

0.030 kcf

k = coefficient of lateral earth pressure

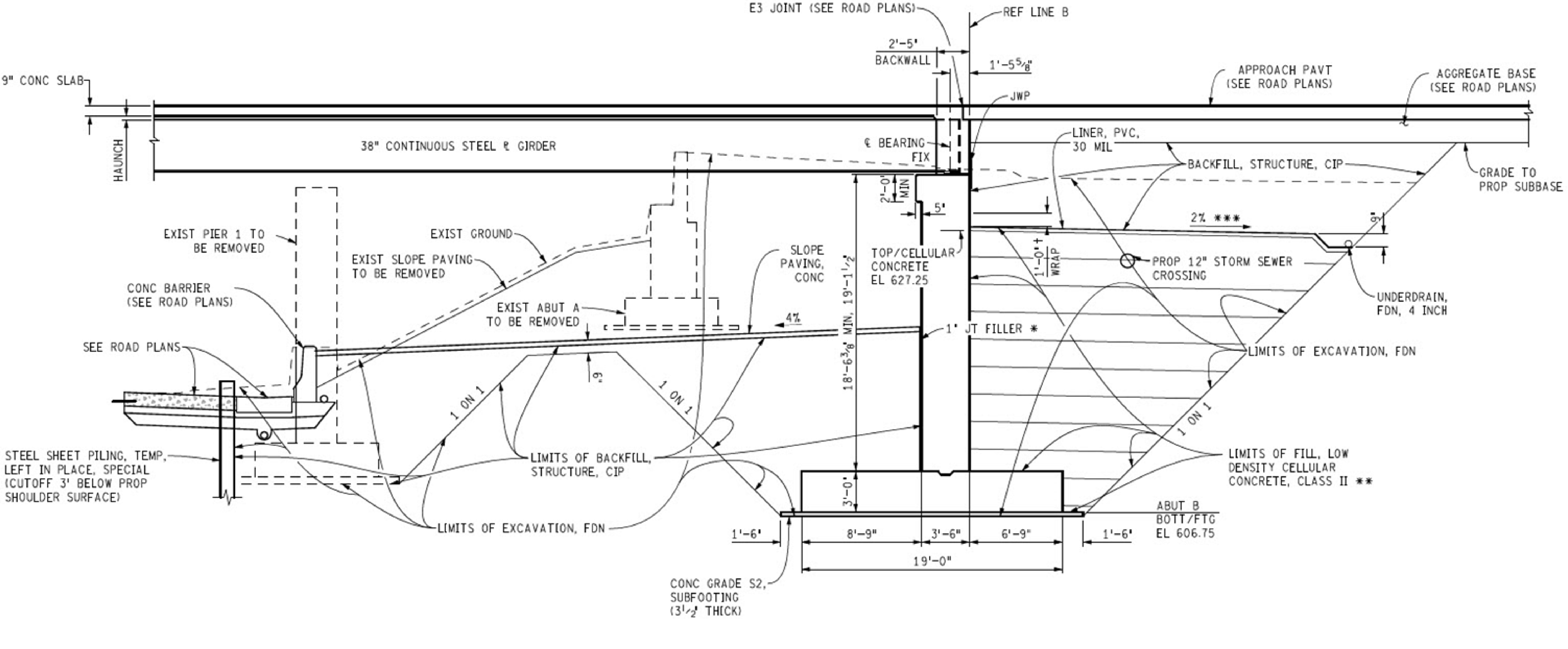
IT DEPENDS

MDOT places in 2 ft lifts (max) due to heat of hydration concerns

Each lift has 0-60 psf lateral pressure initially

Final condition has 30 psf uniform lateral pressure

Low Density Cellular Concrete Backfill



SECTION THRU ABUTMENT B

Low Density Cellular Concrete Benefits

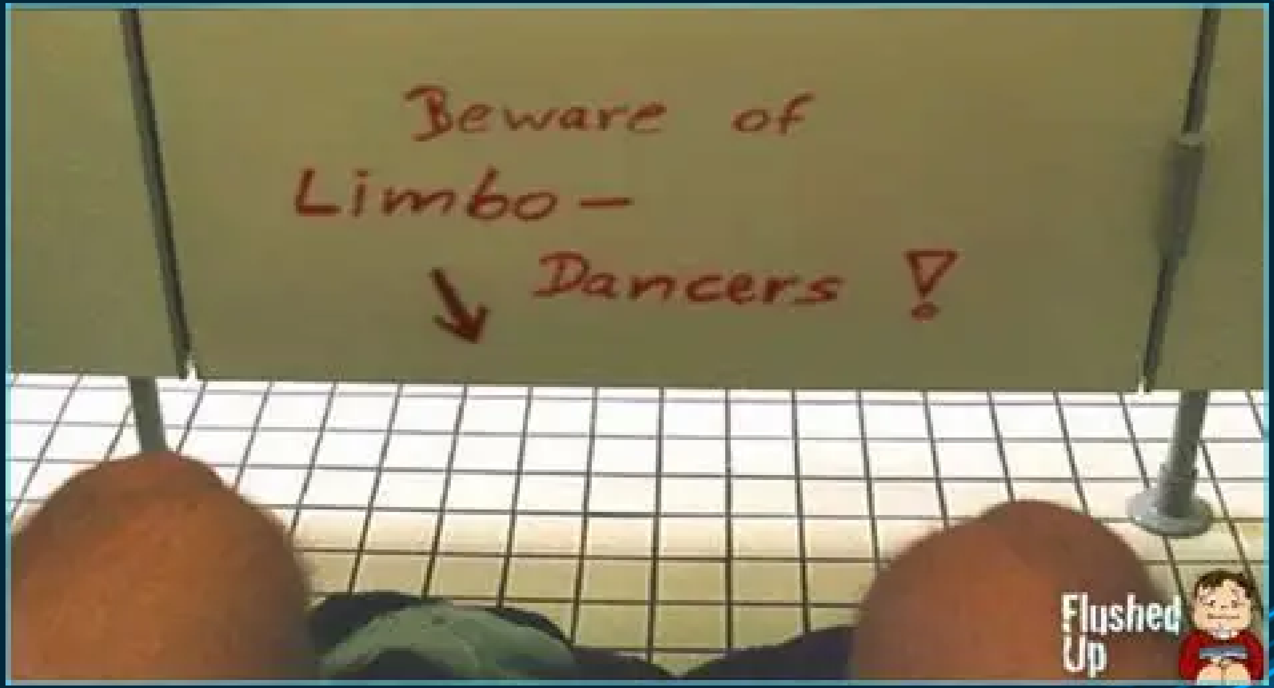
- Low density
- Easily placed (think milkshake)
- Can be placed around utilities
- Can be excavated out later, if needed (not desirable though)

Low Density Cellular Concrete Drawbacks

- Need to place in 2 ft lifts in order to limit excessive heat due to heat of hydration. This limits production rates.
- It flows extremely well, so location of underdrains need to be located outside of the low density cellular concrete to keep it from plugging the underdrain.
- Shouldn't be placed below the groundwater table if it can be avoided (it can become buoyant).
- It needs a specialty contractor to mix and place the material.
- Need to account for drainage structures and ancillary structure foundations.

Low Density Cellular Concrete

How low can you go?



Flowable Fill Backfill

MDOT has two different types of flowable fill. One is non-structural and the other is structural. When use as backfill for abutment Structural Flowable Fill should be used. This has a 28 day strength between 75 and 150 psi.

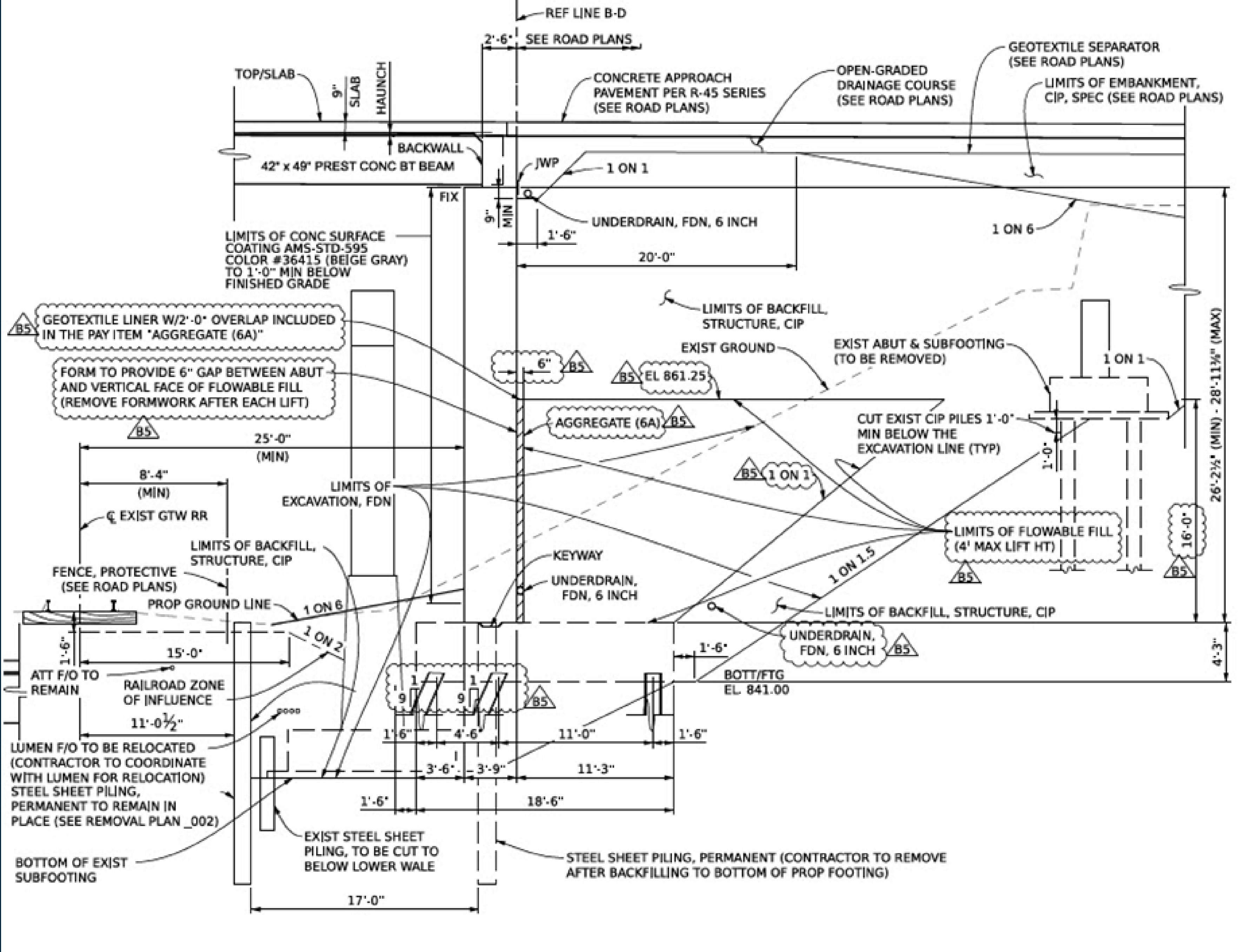
γ_s = unit weight of soil (kcf)

0.130 kcf

k = coefficient of lateral earth pressure

IT DEPENDS on the details on construction sequence

Flowable Fill Backfill Details



ABUTMENT D SECTION

STEEL SHEETING WALERS AND STRUTS ARE NOT SHOWN FOR CLARITY

Flowable Fill Benefits

- Commonly available material
- Easily placed
- Utilities can be placed within it
- Can be excavated out later, if needed.

Flowable Fill Drawbacks

- Difficult to pump due to the high sand content
- Need to form one side against an abutment and then remove it.
- Need to account for drainage structures and ancillary structure foundations.

How low can you go?

Expanded Polystyrene (Geofoam) Blocks

MDOT typically uses EPS29. It has a unit weight of 1.8 pcf and an unconfined compressive strength of at least 10.9 psi.

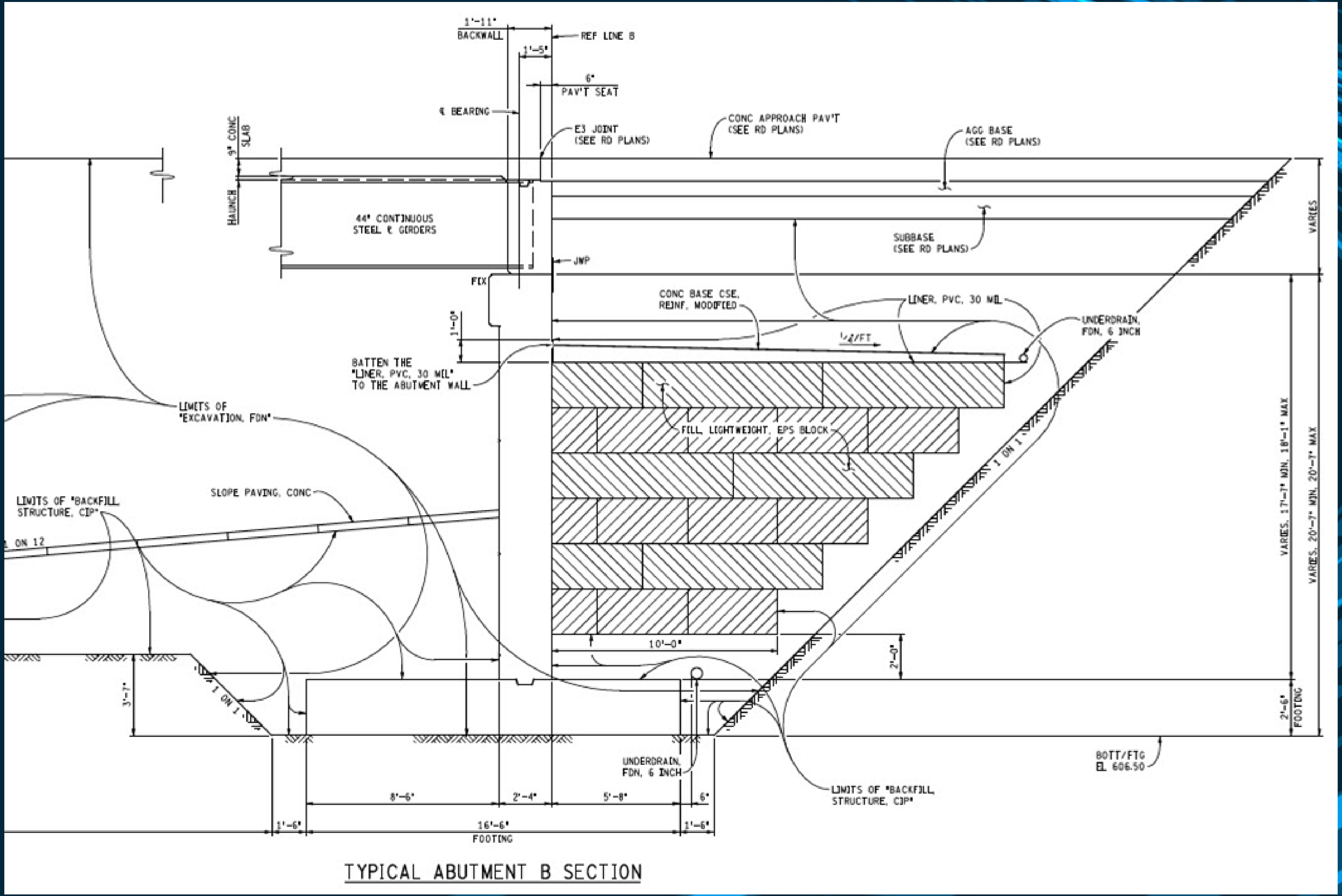
γ_s = unit weight of soil (kcf)

0.018 kcf

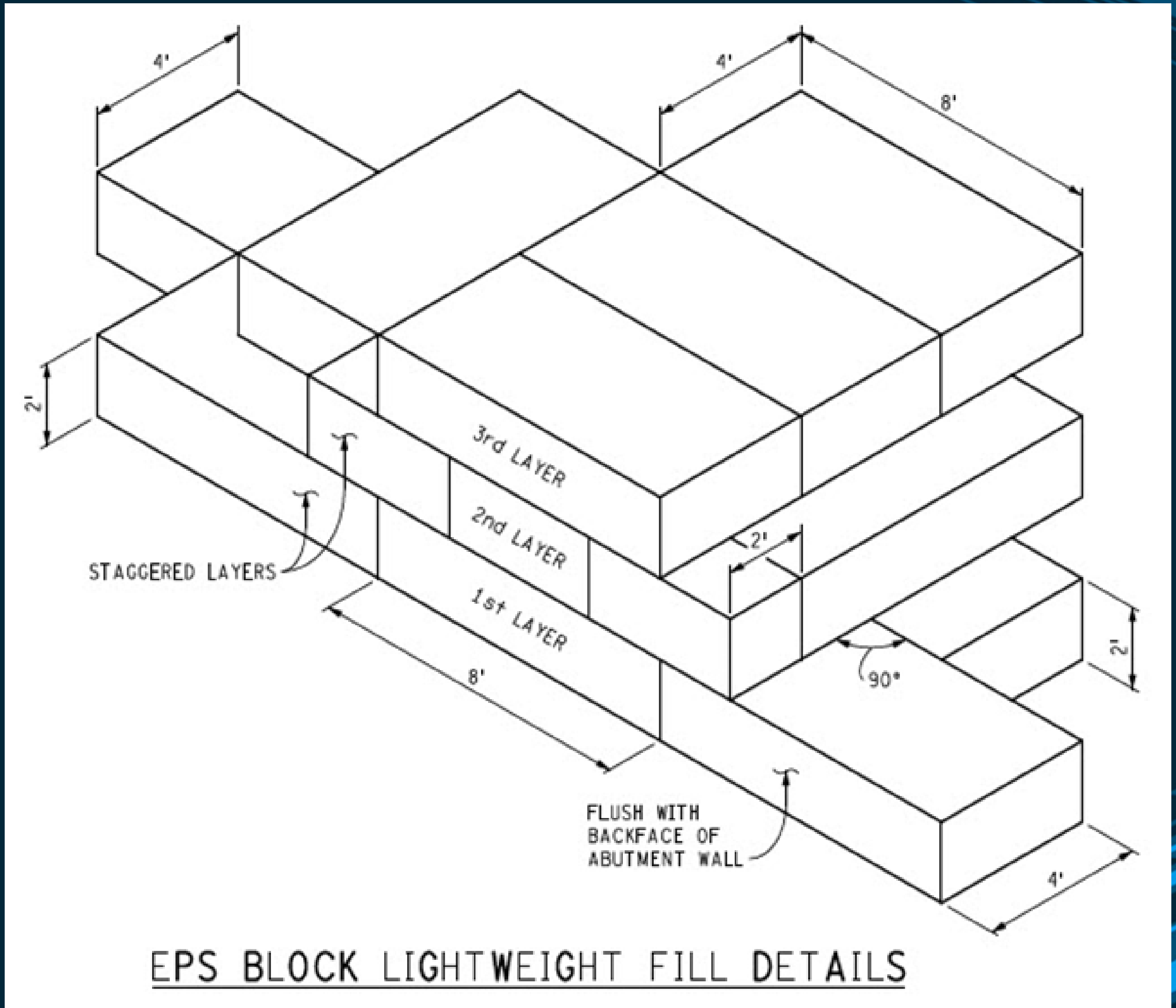
k = coefficient of lateral earth pressure

IT DEPENDS on the details and construction sequence

Expanded Polystyrene (Geofoam) Blocks



Expanded Polystyrene (Geofoam) Blocks



Expanded Polystyrene (Geofoam) Blocks Benefits

- Lightest weight material
- Very low to virtually no lateral earth pressure when placed far enough behind the abutment
- Can place it quickly if there aren't any layout issues

Expanded Polystyrene (Geofoam) Blocks Drawbacks

- Not many suppliers
- The cost is tied to the price of oil
- Typically price quotes are only firm for 6 months, which is the shelf life of the resin
- Dissolves in gas/diesel spills
- Need to protect it from spills with a geomembrane
- Typically need a concrete cap to reduce construction loads and to help protect it from spills
- Need to slope the concrete cap away from the abutment
- Can float (especially during construction)
- Need to account for drainage structures and ancillary structure foundations.

Expanded Polystyrene (Geofoam) Blocks

How low can you go?

Geosynthetic Reinforced Soil (GRS)

MDOT typically uses 3/8 inch minus crushed stone. A high strength woven geotextile with a strength of 4,800 #/ft in both directions is used for reinforcement.

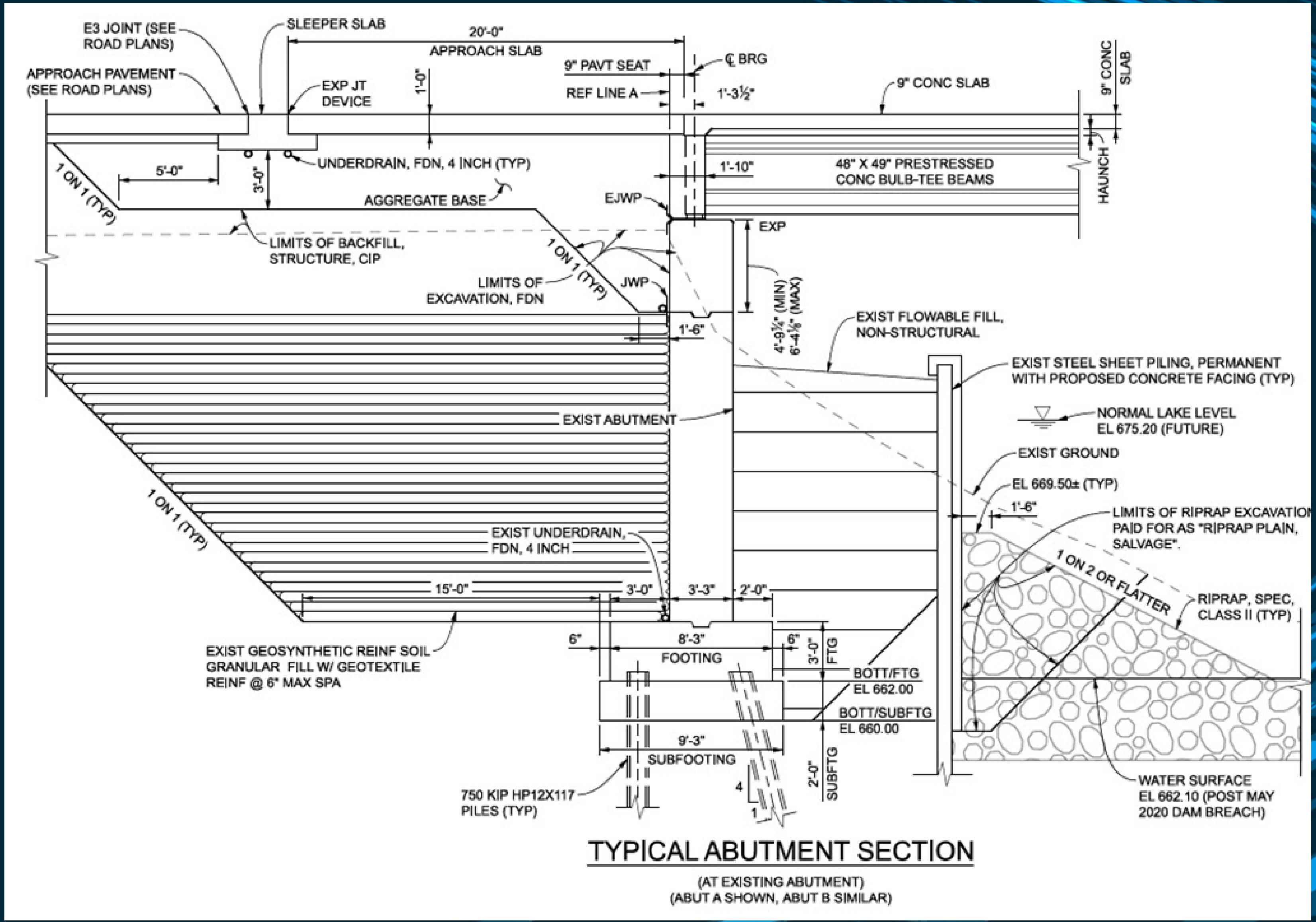
γ_s = unit weight of soil (kcf)

0.100 kcf

k = coefficient of lateral earth pressure

0

Geosynthetic Reinforced Soil (GRS) Typical



Geosynthetic Reinforced Soil (GRS) Benefits

- Zero lateral earth pressure
- Not buoyant
- No special materials
- No specialty contractors
- No density testing required (method placement)

Geosynthetic Reinforced Soil (GRS) Drawbacks

- Twice as many lifts to construct (every 6 inches)
- Need to test the material to confirm the friction angle of 38 degrees
- No density testing required (method placement, not typically done)

Geosynthetic Reinforced Soil (GRS)

Michigan Department of Transportation

Other Types of Lightweight Fills

- Ultra lightweight foamed glass aggregate
  - Very lightweight, highly frictional material
  - Inert
  - Limited supplies
  - Used by MDOT on a trial basis
- Expanded Shale Aggregate
  - Lighter weight, highly friction material
  - Inert
  - No MDOT experience, but open to it.
- Slag Aggregate
  - Lighter weight material (85-90 pcf), highly frictional
  - Difficult to obtain due to changes in steel production

Lightweight Fill Unit Prices

Sand Backfill (Backfill, Structure, CIP) – 2024: $36.75 CYD

- 2025 (through 7/14/25) : $42.33 CYD

Aggregate, Special - $100.90 CYD

Low Density Cellular Concrete - $130 to $211 CYD

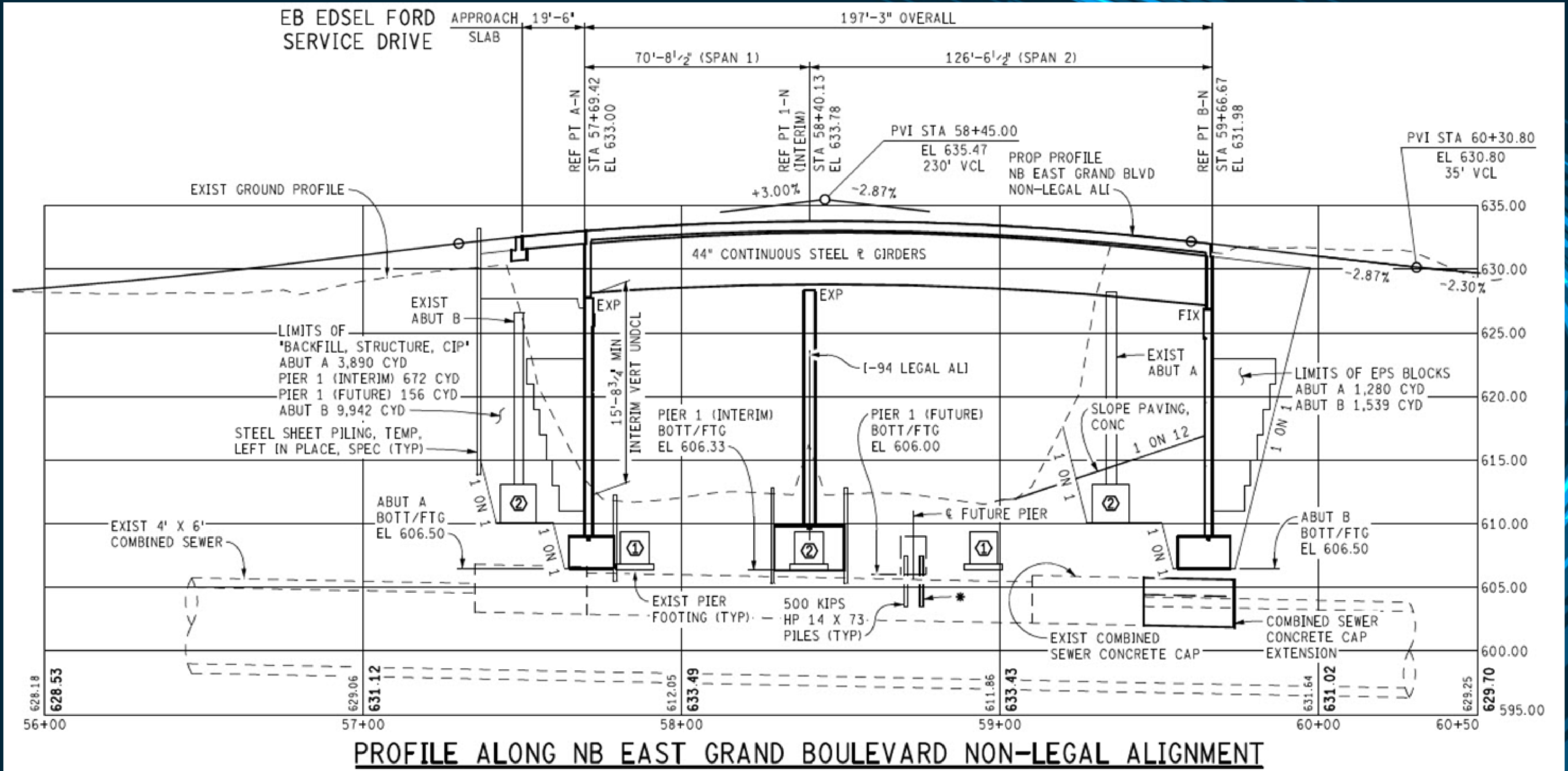
Expanded Polystyrene Block

- Expanded Polystyrene Block - $225 CYD
- PVC Liner - $20.07 SYD
- Concrete Base Course - $225 CYD

Geosynthetic Reinforced Fill

- Geosynthetic Reinforce Fill - $117.14 CYD
- Geotextile Reinforcement - $5.71 SYD

Example Project



Abutment Costs

EPS Blocks – 2,819 cyd @ $155.07 = $437,142.33

PVC Liner – 1,145 syd @ $13.14 = $15,045.30

Concrete Base Course – 221 cyd @ $350.00 = $77,350

Total = $529,537.63 for the lightweight fill system

Without lightweight fill

Each pile is 136 ft long

Additional 122 piles would be needed between both abutments

Price for HP14x73 is $90/ft

Total piling cost would be 122 * 136 ft * $90/ft = $1,493,280

Additional Backfill, Structure, CIP: $41.32 * 3040 cyd = $125,612.80

Total: $1,618,892.80

Savings: $1,618,892.80 - $529,537.63 = $1,089,355.17

Questions?

Thank you!