Reference
FHWA-NHI 10-034 Otherwise noted

APPENDIX 8.3-B3

SOIL INTERACTION ANALYSIS FOR CULVERT STRUCTURES
PRECAST SPLIT BOX BURRIED STRUCTURE
per

"Technical Manual for Design and Construction of Road Tunnels – Civil Elements". FHWA-NHI-10-034.

I. GEOTECH INFORMATION

Soil Material

Effective Young Modulus, E_m =

Poisson's, v_m = 0.5

Effective Shear Modulus G_m = 1E+06 psf **1460** ksf

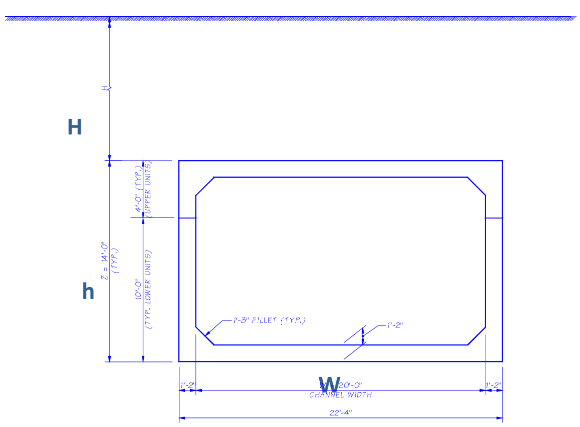
Unit Weight γ_m = 130 pcf

Seismicity

F_{pga} PGA = 0.42

II. GEOMETRY

The preliminary sizing of structure

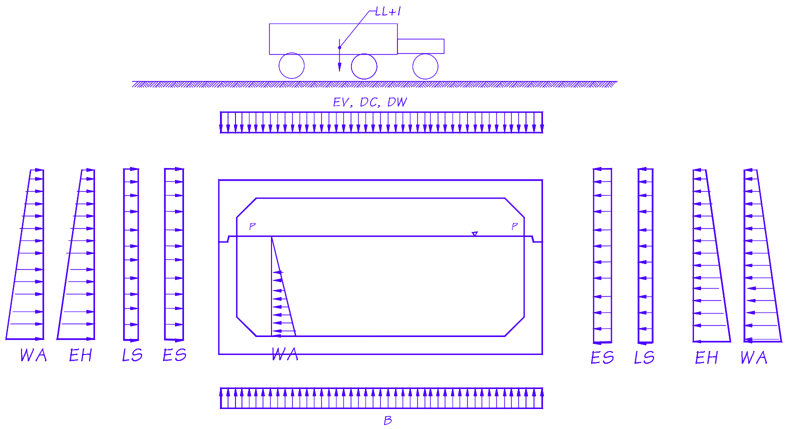


H = 16 ft
h = 14 ft
w = 20 ft
z =H+d 30 ft

t wall = 1.17 ft
t roof = 1.17 ft

III. DESIGNING THE STRUCTURE PER STATIC CONDITIONS - STRENGTH AND SERVICE

The structure first is designed for Strength and Service per loading below:



LOADING DIAGRAMS

Preliminary design for this structure requires the wall and roof thickness of 1'-2", the input for the displacement analysis below is based on 1' length structure:

Area = 1 * 1.17 = 1.17 ft2

$I = 1 * 1.17^3 / 12 =$ 0.13 ft3

IV. ESTIMATING FREE-FIELD GROUND STRAIN AND FREE FIELD RELATIVE DISPLACEMENT

(Step 1 of FHWA-NHI-10-034, chapter 13.5.1)

A. The maximum free-field ground shear strain γ_{max} can be estimated by using:

$$\gamma_{max} = V_s / C_{se} \qquad (13\text{-}3)$$

For culvert with buried depth less than 50', the maximum free-field ground shear strain can be estimated by the equation below:

$$\gamma_{max} = \tau_{max} / G_m \qquad (13\text{-}5)$$

γ_{max} = 1524/1460000 = 0.00104 (13-6)

τ_{max} = maximum earthquake induced shear stress = $(F_{PGA}\, PGA)\sigma_V\, R_d$ (13-7)

= 0.42*3900*0.9301 = 1524 psf

Per WSDOT BDM Section 8.3.4 B, the ground acceleration can be reduded according to the depth of soil cover above, the Ground Motion Attenuation is shown on Table 1. For depth = 16' the ratio of ground motion to motion at buried structure = 1.0.

$\sigma_v = \gamma_m(H + d)$ = 130*(16+14') = 3900 psf

Rd = Stress reduction factor
= 1 - 0.00233 z for z < 30 ft. ← control
Rd = 1.00-0.00233*30 = 0.9301

B. Free-field relative displacement Δ free-field is calculated:

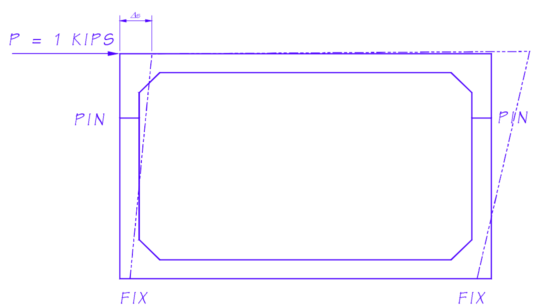
$\Delta_{free-field} = h * \gamma_{max}$ (13-20)

$\Delta_{free-field} =$ 14' * 0.00104= 0.18 in.

V. DETERMING THE RACKING COEFFICIENT Ks

(Step 2 of FHWA-NHI-10-034, chapter 13.5.1)

Use simple frame analysis either GTStrudl, or CSI Bridge to determine the racking stiffness by apply lateral unit force at roof level. The structural racking stiffness is defined ratio of force over displacement.



From GTStrudl model with 1 kips at top of wall as shown, the deflection in determining for
Δs = 0.0202 in.

Ks is calculated = 1 kips /0.0202" = 50 k/in
594 k/ft

VI. DERIVING THE FLEXIBILITY RATIO (Frec) - SOIL STRUCTURE INTERACTION

(Step 3 of FHWA-NHI-10-034, chapter 13.5.1)

$F_r = \left(\frac{G_m}{K_s}\right) * \left(\frac{w}{h}\right)$ (13-21)

Fr= (1460/594)*(20/14) = 3.51

VII. DERIVING THE RACKING RATIO (Rrec)

(Step 4 of FHWA-NHI-10-034, chapter 13.5.1)

For non-slip interface:

$$\boldsymbol{R_r} = \frac{\boldsymbol{4(1-v_m)F_r}}{\boldsymbol{3-4v_m+F_r}}$$ (13-23)

R rec = (4*(1-0.5)*3.51)/(3-4*0.5+3.51)) = 1.5566

For full-slip interface:

$$\boldsymbol{R_r} = \frac{\boldsymbol{4(1-v_m)F_r}}{\boldsymbol{2.5-3v_m+F_r}}$$ (13-24)

Rr = (4*(1-0.5)*3.51)/(2.5-3*0.5+3.51)) = 1.5566 Used

VIII. DETERMINING THE RACKING DEFORMATON TO THE STRUCTURE

(Step 5 of FHWA-NHI-10-034, chapter 13.5.1)

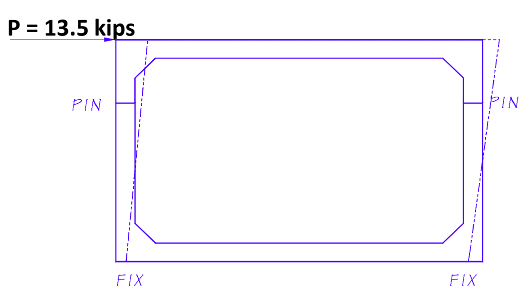
$$\Delta_S = \boldsymbol{R_{rec}} * \Delta_{free-field}$$ (13-25)

Δs = 1.5566 *(0.18) = 0.273 in.

IX. CALCULATING RACKING-INDUCED INTERNAL FORCES

(Step 6 of FHWA-NHI-10-034, chapter 13.5.1)

From GTStrudl, find the internal for of the structure with displacement of 0.273 in or equipvalent to 13.5 kips.



The induced shear and moment of lateral racking force are combined with vertical load for Extreme case below.

X. VERTICAL FORCE DUES TO VERTICAL ACCELERATION

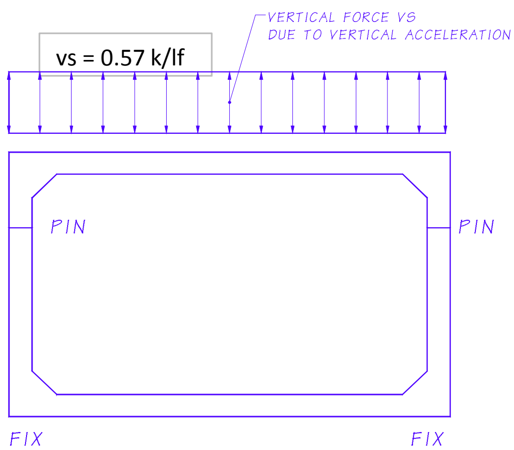
(Step 7 of FHWA-NHI-10-034, chapter 13.5.1)

The vertical seismic force can be determined by pseudo static loading per section 13.5.1.3.

The vertical seismic coefficient can be used as 2/3 of PGA =	0.28	
Dead of 30' overburden = (16' H * 0.130 k/cf) =	2.08	k/lf width and length
Dead load of top slab = (1.17' thick * 0.16) =	0.1888	k/lf width and length
Total DL =	2.27	k/lf width and length

From BDM Section 8.3.4 B, the ground motion attentuation ratio of 0.9 is applied since the depth of to top of buried structure is within the range of 20' to 50'.

Vertical Seismic force = VS = 2/3 PGA * 0.9 * 2.27	0.57	k/lf width and length



XI. COMBINING THE FORCES FROM THE RACKING AND VERTICAL ABOVE INTO THE EXTREME I LOADING

(Step 8 of FHWA-NHI-10-034, chapter 13.5.1)

The structure is designed for Extreme Loading per loading below:

$\boxed{\text{Extreme I} = 1.0\ DC + 1.0\ EH + 1.0\ EV + 1.0\ ES + 0.5\ LL + 1.0\ WA + 1.0\ EQ}$

EQ = lateral racking + vertical acceleration