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FHWA-NHI  
10-034  
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# 8.3-A4-3

## SOIL INTERACTION ANALYSIS FOR CULVERT STRUCTURES PRECAST SPLIT BOX BURIED 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,  $\nu_m =$  0.5

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

Unit Weight  $\gamma_m =$  130 pcf

#### Seismicity

$F_{pga}$  PGA = 0.42

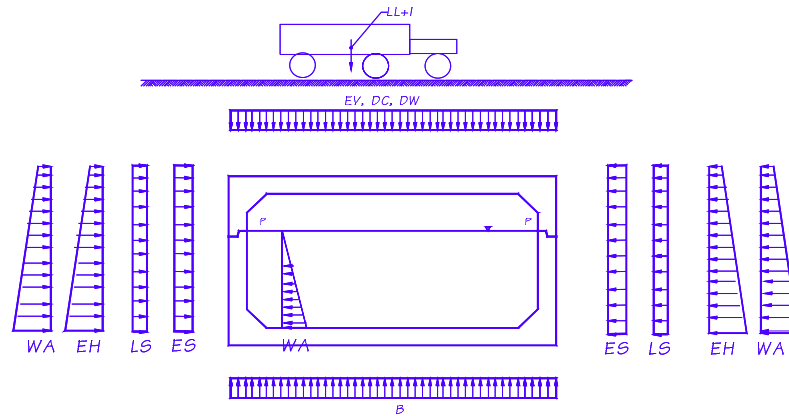
### II. GEOMETRY

The preliminary sizing of structure



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

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



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:

$$\begin{aligned} \text{Area} &= 1 * 1.17 = && 1.17 \text{ ft}^2 \\ I &= 1 * 1.17^3 / 12 = && 0.13 \text{ ft}^3 \end{aligned}$$

**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  $\gamma_{max}$  can be estimated by using:

$$\gamma_{max} = V_s / C_{se} \tag{13-3}$$

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

$$\gamma_{max} = \tau_{max} / G_m \tag{13-5}$$

$$\gamma_{max} = 1524 / 1460000 = \boxed{0.00104} \tag{13-6}$$

$$\begin{aligned} \tau_{max} &= \text{maximum earthquake induced shear stress} = (F_{PGA} PGA) \sigma_V R_d \tag{13-7} \\ &= 0.42 * 3900 * 0.9301 = && 1524 \text{ psf} \end{aligned}$$

Per WSDOT BDM Section 8.3.4 B, the ground acceleration can be reduced 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.

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

$$\begin{aligned} R_d &= \text{Stress reduction factor} \\ &= 1 - 0.00233 z \quad \text{for } z < 30 \text{ ft.} \quad \leftarrow \text{control} \\ R_d &= 1.00 - 0.00233*30 = 0.9301 \end{aligned}$$

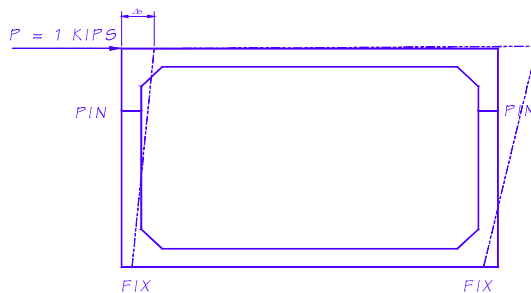
B. Free-field relative displacement  $\Delta$  free-field is calculated:

$$\begin{aligned} \Delta_{\text{free-field}} &= h * \gamma_{\text{max}} \\ \Delta_{\text{free-field}} &= 14' * 0.00104 = \boxed{0.18} \text{ in.} \end{aligned} \quad (13-20)$$

#### V. DETERMINING THE RACKING COEFFICIENT $K_s$

(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  $\Delta_s = 0.0202$  in.

$$K_s \text{ is calculated} = 1 \text{ kips} / 0.0202'' = \begin{matrix} \boxed{50} \text{ k/in} \\ \boxed{594} \text{ k/ft} \end{matrix}$$

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

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

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

$$F_r = (1460/594)*(20/14) = \boxed{3.51}$$

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### VII. DERIVING THE RACKING RATIO ( $R_{rec}$ )

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

For non-slip interface:

$$R_r = \frac{4(1 - \nu_m)F_r}{3 - 4\nu_m + F_r}$$

(13-23)

$$R_{rec} = (4*(1-0.5)*3.51)/(3-4*0.5+3.51) = 1.5566$$

For full-slip interface:

$$R_r = \frac{4(1 - \nu_m)F_r}{2.5 - 3\nu_m + F_r}$$

(13-24)

$$R_r = (4*(1-0.5)*3.51)/(2.5-3*0.5+3.51) = 1.5566 \leftarrow \text{Used}$$

### VIII. DETERMINING THE RACKING DEFORMATION TO THE STRUCTURE

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

$$\Delta_s = R_{rec} * \Delta_{free-field}$$

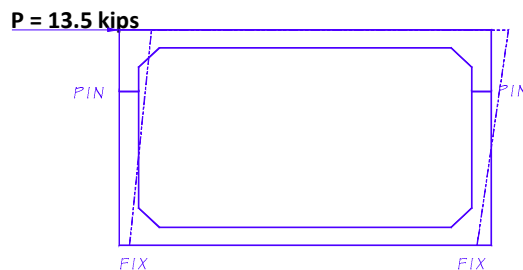
(13-25)

$$\Delta_s = 1.5566 * (0.18) = 0.273 \text{ in.}$$

### IX. CALCULATING RACKING-INDUCED INTERNAL FORCES

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

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



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

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### X. VERTICAL FORCE DUES TO VERTICAL ACCELERATION

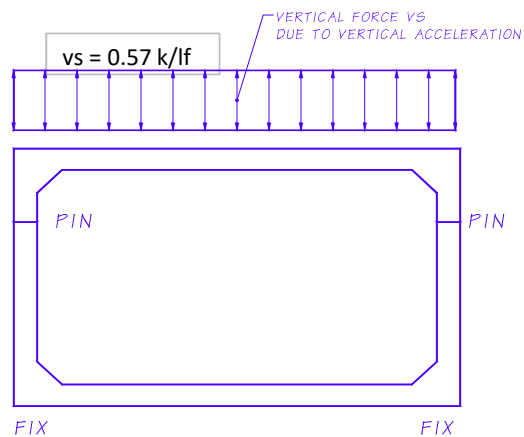
#### (Step 7 of FHWA-NHI-10-034, chapter 13.5.1)

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 = $(16' H * 0.130 \text{ k/cf}) =$	2.08 k/lf width and length
Dead load of top slab = $(1.17' \text{ thick} * 0.16) =$	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 attenuation 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 = $VS = 2/3 \text{ PGA} * 0.9 * 2.27$	0.57 k/lf width and length
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### 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:

Extreme I = 1.0 DC + 1.0 EH + 1.0 EV + 1.0 ES + 0.5 LL + 1.0 WA + 1.0 EQ
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EQ = lateral racking + vertical acceleration