Permanent Vertical Loads

Dead Load – DC

For the purpose of calculating the self-weight of reinforced concrete, assume γ_{conc}= 150 lb/ft.^{3} Note this is different than the assumed unit weight of concrete used to determine material properties such as modulus of elasticity or the modulus of rupture. The load w_{DC} is applied uniformly across the top slab.

$$w_{DC} = \gamma_{conc}\left(\frac{t}{12}\right)$$

Where:

t	=	top slab thickness (in.)
γ_{conc}	=	unit weight of concrete, assumed to be 0.150 k/ft.^{3}

Vertical Earth Pressure – EV

The vertical pressure due to granular or cohesive backfill is based on an assumed unit weight of soil equal to 120 lb./ft.^{3}. Note that the load due to pavement is not included in this calculation. For the purpose of this calculation, the pavement should be assumed to be 12 in. thick unless known to be different.

Per Article 12.11.2.2.1, the vertical earth pressure is modified by a factor that takes into account the installation method. Due to the stringent requirements for a trench installation and the general incompatibility with normal construction methods, the assumed installation methods for box culverts shall be the embankment method. This requires the calculated earth pressure to be increased by the embankment factor, F_e, which is a function of the box width and the height of the soil above the top of the top slab. The thickness of the pavement should be subtracted from the fill height to determine the height of the soil column on the box. The load due to vertical earth pressure is applied uniformly across the top slab.

$$F_e = 1+0.20\frac{H}{B_c}$$

$$F_e = 1 + 0.2H / B_c \qquad \text{Eq. 12.11.2.2.1-2}$$

$$F_e <= 1.15$$

$$w_{EV(M)} = w_{EV}F_e$$

where:

- H = height of soil column on top of the box (ft.)
- w_{EV} = normal uniform vertical earth pressure on top of the top slab due to the soil column (kip/ft.^{2})
- F_e = embankment factor calculated according to Equation 12.11.2.2.1-2
- B_c = total width across the top of the culvert (ft.)
- $w_{EV(M)}$ = modified uniform vertical earth pressure on top of the top slab due to the soil column that has been modified for the installation method (kip/ft.^{2})

Future Wearing Surface – DW

Unless otherwise specified, the pavement should be assumed to be 12 in. thick. For the purpose of calculating the weight of pavement, assume γ_{pavt} = 150 pcf. The future wearing surface should be provided as indicated on the approved TSL. If no TSL is required, the FWS should be assumed to be equal to 50 lb/ft.^{2}. The load w_{DW} is applied uniformly across the top slab.

$$w_{DW} = \gamma_{pavt}\left(\frac{t_{pavt}}{12}\right) + FWS$$

where:

- t_{pavt} = thickness of the pavement (in.)
- γ_{pavt} = unit weight of the pavement; assumed to be 0.150 kip/ft.^{3}

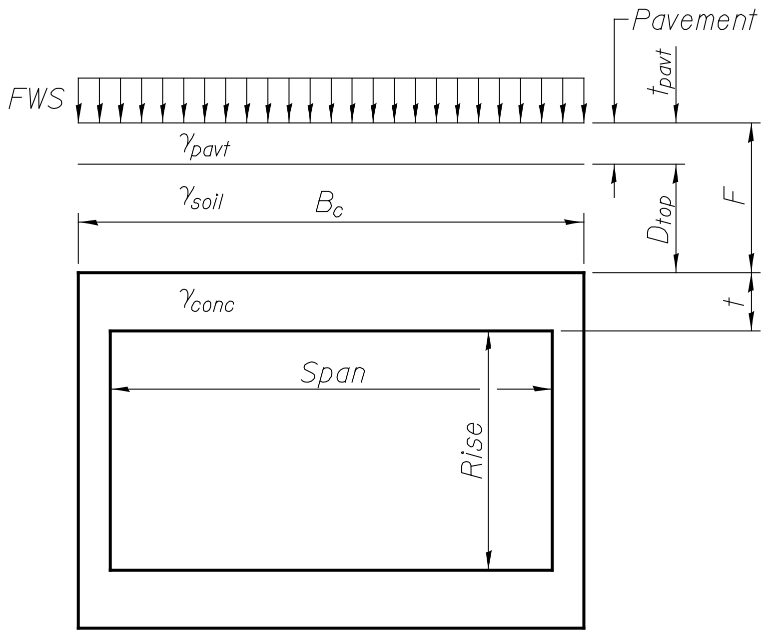

Figure 1 – Permanent Vertical Loads

Live Loads

Application

Per Articles 12.11.2.1, 3.6.1.3 and 3.6.1.2.6, the application of live load is different for single box culverts and for multiple box culverts. Designers should apply live load to all box culverts except when:

- For single box culverts, the fill height is greater than 8 feet and greater than the span of the box. For the purpose of this provision, "span" may be considered to be the clear span of the box culvert, which is the distance between the inside faces of the sidewalls.
- For multiple box culverts, the fill height is greater than the distance between the inside faces of the exterior walls. The application of live load will be required for almost all multiple box culverts with typical highway cross-sections.

Impact

Per Article 12.11.2.1, calculate the dynamic load allowance (impact) according to Article 3.6.2.2.

$$IM = 33(1 - 0.125D_E) \geq 0\% \qquad \text{Eq. 3.6.2.2-1}$$

Where:

D_E = fill height, F (ft.)

Multiple Presence

The multiple presence factor is found in Table 3.6.1.1.2-1. The adjustment to the factor noted at the end of Article C3.6.1.1.2 is not used. Per Article 12.11.2.1, box culverts shall be designed for a single lane of traffic with the application of the multiple presence factor for one loaded lane. This is applicable where traffic is moving parallel to the span. For box culverts with skews greater than 30^0, the culvert shall also be checked for one or more lanes of traffic moving perpendicular to the span (parallel to the sidewalls) with the application of the appropriate multiple presence factor for the number of loaded lanes. In this case, the largest force effects from either direction of vehicle movement should be used for design.

AASHTO Table 3.6.1.1.2-1	
Number of Loaded Lanes	Multiple Presence Factor, m
1	1.20
2	1.00
3	0.85
>3	0.65

Live Load Vehicles and Load Distribution

Per Article 12.11.2.1, the provisions of Article 3.6.1.3 shall be used. Specifically for culvert top slabs, Article 3.6.1.3.3 is used. It states that culvert top slabs shall be designed for the effects of the axles of the design vehicles from Articles 3.6.1.2.2 and 3.6.1.2.3. In other words, the lane load is neglected for all culvert top slabs. Note the 15 foot limitation applies to only slab bridges. The design truck of Article 3.6.1.2.2 and the design tandem of Article 3.6.1.2.3 shall be used.

According to Article 12.11.2.1 live load distribution is dependent on fill height. The distribution of live loads for fills < 2 feet shall be according to Article 4.6.2.10 and for fills ≥ 2 feet shall be according to Article 3.6.1.2.6. Notice that both Articles 12.11.2.1 and 3.6.1.2.6 use the term "wheel load" instead of axle load. This is modified by Article C3.6.1.3.3 for top slabs of box culverts which states "The design load is always an axle load; single wheel loads are not considered."

Live Load Distribution For Fills < 2 Feet

For fills < 2 feet, the live load distribution shall be according to Article 4.6.2.10.

For the typical application where the traffic is moving parallel to the span, the dimensions of the patch load shall be calculated according to Article 4.6.2.10.2.

The equation for the patch dimension transverse to the direction of vehicle movement for both the design truck and tandem regardless of fill depth is:

$$E = 96 + 1.44S \qquad \text{Eq. 4.6.2.10.2-1}$$

where:

E	=	equivalent distribution dimension perpendicular to the span (inch)
S	=	clear span (feet)

The equation for the patch dimension parallel to the direction of vehicle moments is:

$$E_{span} = L_T + LLDF(H) \qquad \text{Eq. 4.6.2.10.2-2}$$

where:

E_{span}	=	equivalent distribution dimension parallel to the span (inch)
L_T	=	length of tire contact area parallel to span, 10 inches per Article 3.6.1.2.5
$LLDF$	=	live load distribution factor, 1.15 per Article 3.6.1.2.6
H	=	fill height, F (in.)

Note that the use of the variables E, E_{span}, and L_T are inconsistent with the nomenclature used in this design guide. To remain consistent with the definition of patch dimensions used in this design guide as transverse and parallel to the direction of vehicle movement the variables used to define the tire patch dimensions are w_t and w_p, respectively and the variables used to define the total patch dimensions are l_t and l_p, respectively.

Therefore:

$$E = l_t$$

$$E_{span} = l_p$$

$$L_T = w_p$$

Equation 4.6.2.10.2-2 is consistent with the requirements for distribution of live load through fills ≥ 2 feet found in Article 3.6.1.2.6. Therefore Equation 4.6.2.10.2-2 is applicable to determine the patch dimension parallel to the direction of vehicle movement for the design truck or tandem regardless of fill height when the vehicle movement is parallel to the span. To simplify calculations according to Culvert Manual section 3.4.6, the live load patch for the design truck or tandem may be taken as the combination of both wheels for trucks or all four wheels for tandems for all fill heights. This is discussed in further detail in the section for distribution for fills ≥ 2 feet for the design tandem.

With units in terms of feet and with variables consistent with this design guide, the equations for the patch dimensions for an individual axle of the design truck are:

$$l_t = 8 + 0.12S$$

$$l_p = \frac{w_p}{12} + 1.15F = 0.83 + 1.15F$$

For the design tandem, the axle spacing is added. Therefore the equations for the patch dimensions for the two axles of the design tandem are:

$$l_t = 8 + 0.12S$$

$$l_p = s_a + \frac{w_p}{12} + 1.15F = 4.83 + 1.15F$$

where:

l_t = patch dimension transverse to the direction of movement (ft.)

l_p = patch dimension parallel to the direction of movement (ft.)

w_p = tire patch dimension parallel to the direction of movement, 10 inches per Article 3.6.1.2.5

s_a = axle spacing, 4 feet for design tandem per Article 3.6.1.2.3

S = clear span (feet)

F = fill height, the distance from the top of the roadway surface to the top of the box (ft.)

For the special case where the top slab of the culvert is the driving surface (i.e. zero fill), the equations for the distribution dimension parallel to the direction of vehicle movement are used with F = 0. Therefore the equations become:

l_p = 0.83 ft. Design Truck

l_p = 4.83 ft. Design Tandem

Designers are cautioned to not use point loads for analysis. Calculate l_p based on the tire patch and distribution of the load through fill (i.e. Equation 4.6.2.10.2-2) as discussed above. The difference in the results of the analysis is typically small for moments but can be very significant for shears which may result in thicker than required slabs if point loads are used.

For single box culverts with typical span lengths, one design truck rear axle patch will likely produce maximum forces. For multiple box culverts, more than one axle patch with the axle spacing range of 14 to 30 feet per Article 3.6.1.2.2 will need to be investigated to produce maximum forces. Note that the axle spacing is the distance between axles not the axle patches.

Therefore the distance between the axle patches of the design truck is:

$$g_a = s_a - l_p$$

where:

g_a = distance between the rectangular areas of the individual axle patches (feet)

s_a = axle spacing, rear axle varies from 14 to 30 feet and front axle is 14 feet for design truck per Article 3.6.1.2.2

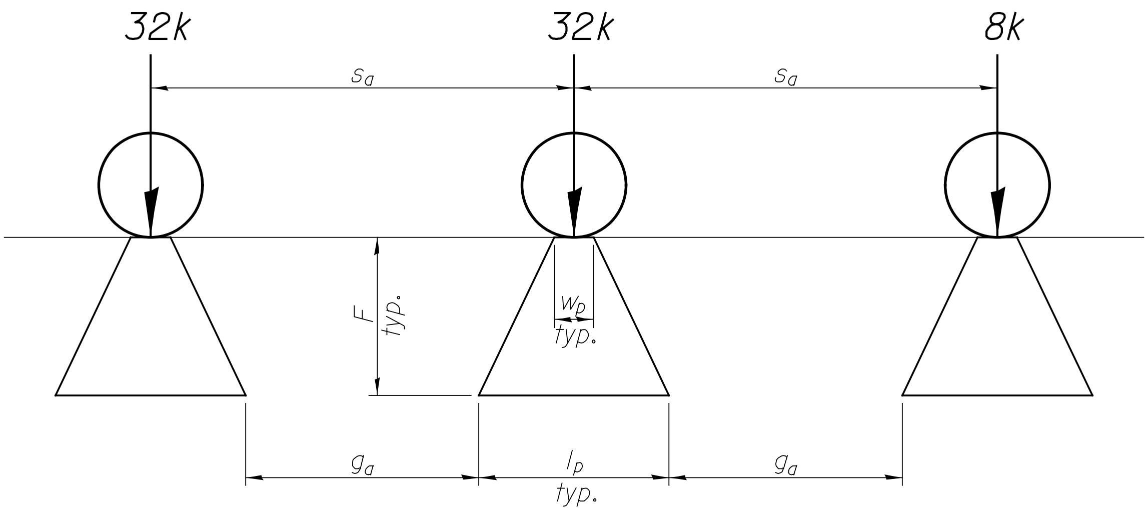

Figure 2 – Truck Load Distribution Through Fill Parallel to Movement

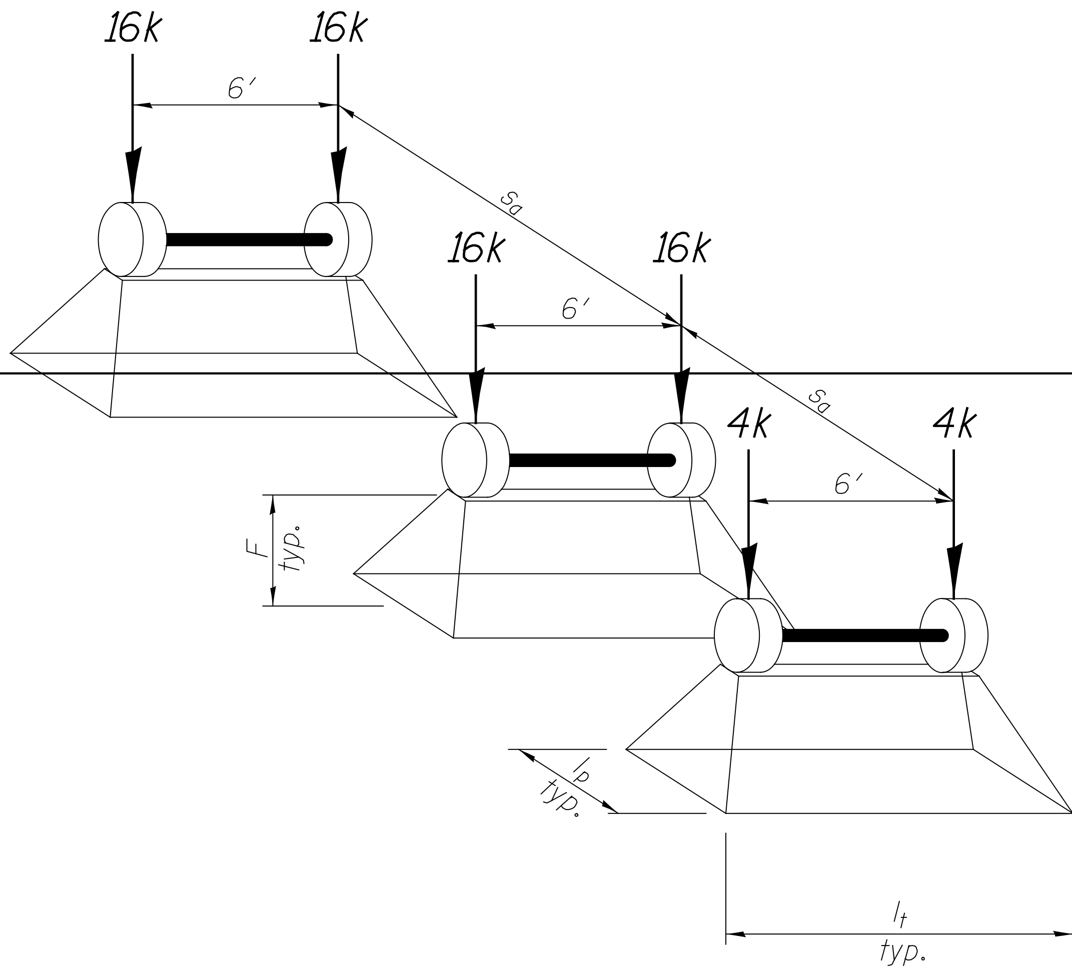

Figure 3 – Isometric of Truck Load Distribution

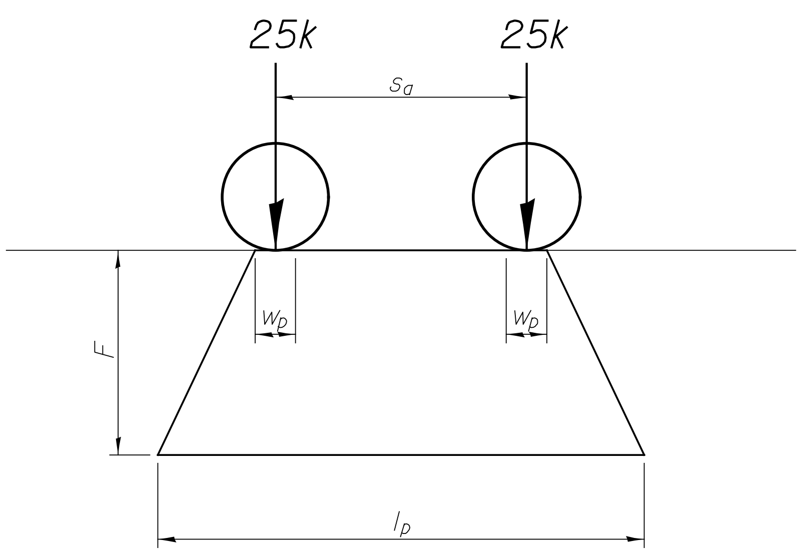

Figure 4 – Tandem Load Distribution Through Fill Parallel to Movement

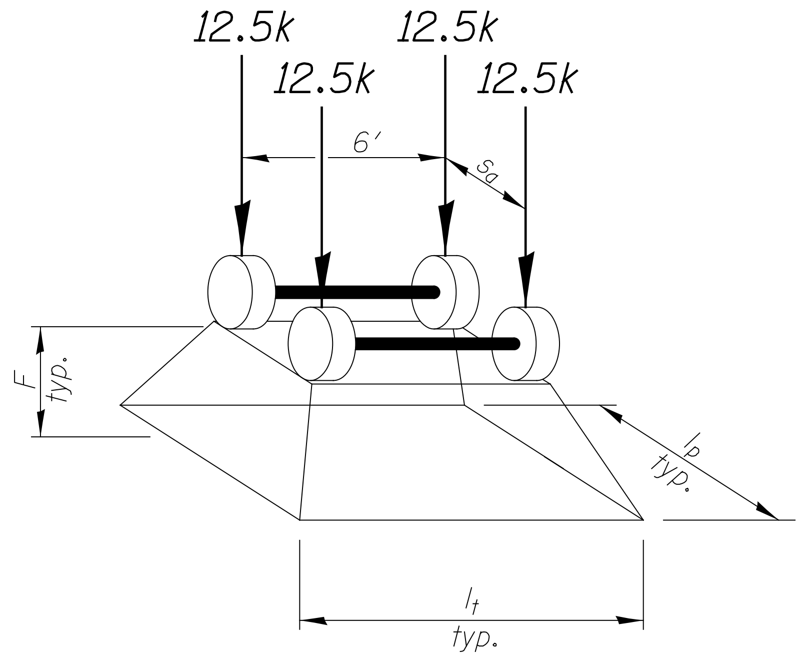

Figure 5 – Isometric of Tandem Load Distribution

Live Load Distribution For Fills < 2 Feet - Vehicles Moving Parallel to Sidewalls

Per Article 4.6.2.10.3, when traffic travels perpendicular to the span (parallel to the sidewalls) the patch dimension parallel to the direction of vehicle movement shall be calculated using the equations in Article 4.6.2.1 for both the design truck and tandem. These equations are for the distribution of one axle. Since the two axles of the design tandem are always assumed to overlap, the 4 feet axle spacing should be added. The equations in Table 4.6.2.1.3-1 for the patch dimension parallel to the direction of vehicle movement for one axle in units of inches are:

$E = 26.0 + 6.6S$ For +Moments

$E = 48.0 + 3.0S$ For –Moments

With units in terms of feet, variables consistent with this design guide and the design tandem axle spacing included, the equations for the patch dimension parallel to the direction of vehicle movement are:

	+Moment	–Moment
Design Truck	$l_p = 2.17 + 0.55S$	$l_p = 4.00 + 0.25S$
Design Tandem	$l_p = 6.17 + 0.55S$	$l_p = 8.00 + 0.25S$

where:

S = clear span (ft.)

l_p = patch dimension parallel to the direction of movement (ft.)

The patch dimension transverse to the direction of vehicle movement shall be calculated using the procedure for distribution of live load through fill according to Article 3.6.1.2.6.

$$l_t = s_w + \frac{w_t}{12} + LLDF(F)$$

where:

l_t = patch dimension transverse to the direction of movement (ft.)

s_w = wheel spacing, 6 feet for design truck and tandem per Figure 3.6.1.2.2-1 and Article 3.6.1.2.3

w_t = tire patch dimension transverse to the direction of movement, 20 inches per Article 3.6.1.2.5

LLDF = live load distribution factor, 1.15 per Article 3.6.1.2.6

F = fill height, the distance from the top of the roadway surface to the top of the box (ft.)

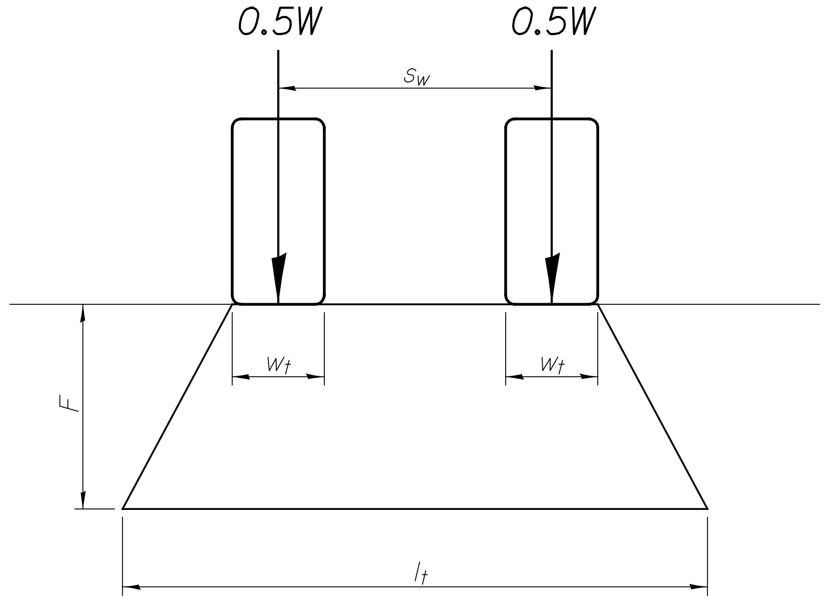

Figure 6 – Live Load Distribution Through Fill Transverse to Movement

For both the design truck and tandem the equation becomes:

$$l_t = 6\text{ ft.} + \frac{20\text{ in.}}{12} + 1.15(F) = 7.67\text{ ft.} + 1.15F$$

For the special case where the top slab of the culvert is the driving surface (i.e. zero fill), the equation for the patch dimension transverse to the direction of vehicle movement is used with F = 0. Therefore the equation for both the design truck and tandem becomes:

$$l_t = 7.67\text{ ft.}$$

For culverts with skews greater than 30º, where traffic is traveling primarily perpendicular to the span (parallel to the sidewalls), live loads traveling parallel to the span should also be checked and the largest force effects from either direction of travel should always be used for design.

Live Load Distribution For Fills ≥ 2 Feet - Design Truck

Per Article 3.6.1.2.6, for fills ≥ 2 feet, the patch dimensions of an individual axle of the design truck shall be calculated using the following equations:

$$l_t = s_w + \frac{w_t}{12} + LLDF(F)$$

$$l_p = \frac{w_p}{12} + LLDF(F)$$

where:

l_t	=	patch dimension transverse to the direction of movement (ft.)
l_p	=	patch dimension parallel to the direction of movement (ft.)
w_t	=	tire patch dimension transverse to the direction of movement, 20 inches per Article 3.6.1.2.5
w_p	=	tire patch dimension parallel to the direction of movement, 10 inches per Article 3.6.1.2.5
s_w	=	wheel spacing, 6 feet for design truck per Figure 3.6.1.2.2-1
LLDF	=	live load distribution factor, 1.15 per Article 3.6.1.2.6
F	=	fill height, the distance from the top of the roadway surface to the top of the box (ft.)

For the design truck, the equations become:

$$l_t = 7.67 + 1.15F$$

$$l_p = 0.83 + 1.15F$$

When areas from individual axles overlap, the total load shall be uniformly distributed over the total overlapping area. Depending on the fill height, the clear span and the number of box culvert cells, multiple scenarios may need to be investigated to determine the maximum design forces because of the variable rear axle spacing of the design truck.

The clear distance between the distributed areas of the axles may be calculated using the following equation.

$$g_a = s_a - l_p$$

where:

g_a	=	distance between the rectangular areas of the individual axle patches

(feet)

s_a = axle spacing, rear axle varies from 14 to 30 feet and front axle is 14 feet for design truck per Article 3.6.1.2.2

To illustrate, for F = 15 feet:

$$l_t = 7.67 \text{ ft.} + 1.15(15 \text{ ft.}) = 24.92 \text{ ft.}$$

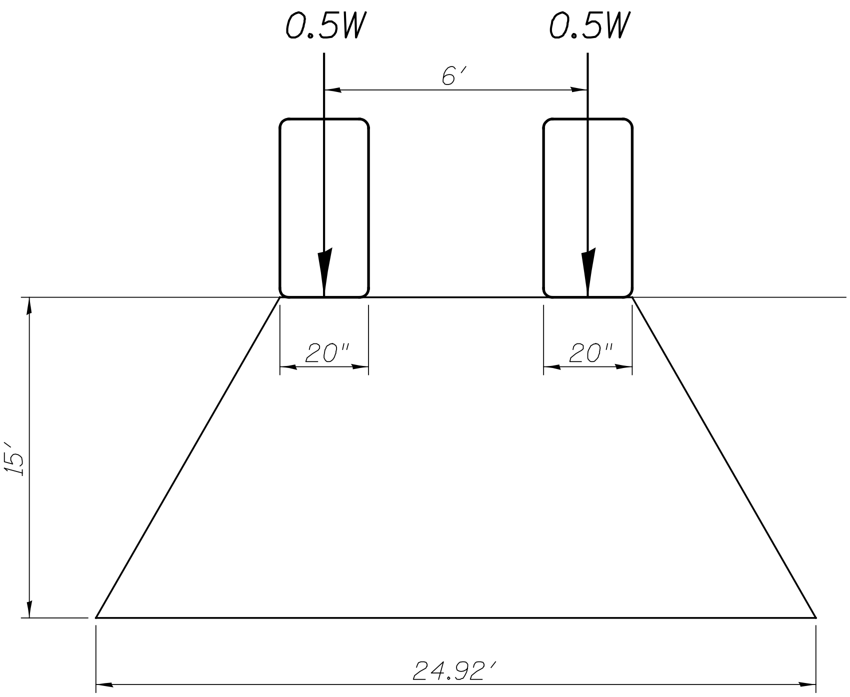

Figure 7 – Truck Load Distribution Transverse to Movement with 15 Feet of Fill

One axle:

$$W_{1\ axle} = 32 \text{ kip}$$

$$l_{p\ 1\ axle} = 0.83 \text{ ft.} + 1.15(15 \text{ ft.}) = 18.08 \text{ ft.}$$

$$A_{1\ axle} = l_t\left(l_{p\ 1\ axle}\right) = 24.92 \text{ ft.}(18.08 \text{ ft.}) = 450.6 \text{ ft.}^2$$

$$w_{1\ axle} = \frac{W_{1\ axle}}{A_{1\ axle}} = \frac{32 \text{ k}}{450.6 \text{ ft.}^2} = 0.071 \text{ kip/ft.}^2$$

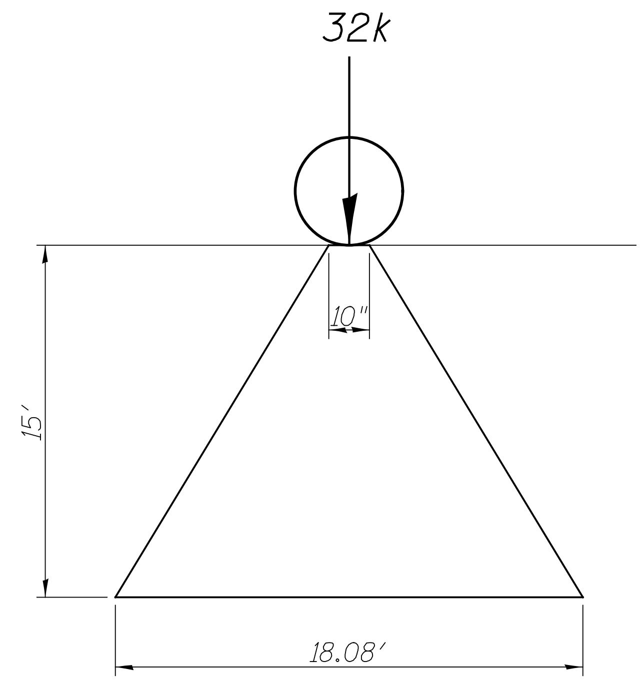

Figure 8 – Truck Load Distribution Parallel to Movement for 1 Rear Axle with 15 Feet of Fill

Two axles:

$$W_{2\ axle} = 64\ kip$$

$$l_{p\ 2\ axle} = 14\ ft. + 0.83\ ft. + 1.15(15\ ft.) = 32.08\ ft.$$

$$A_{2\ axle} = l_t\left(l_{p\ 2\ axle}\right) = (24.92\ ft.)(32.08\ ft.) = 799.4\ ft.^2$$

$$w_{2\ axle} = \frac{W_{2\ axle}}{A_{2\ axle}} = \frac{64\ k}{799.4\ ft.^2} = 0.080\ kip/ft.^2$$

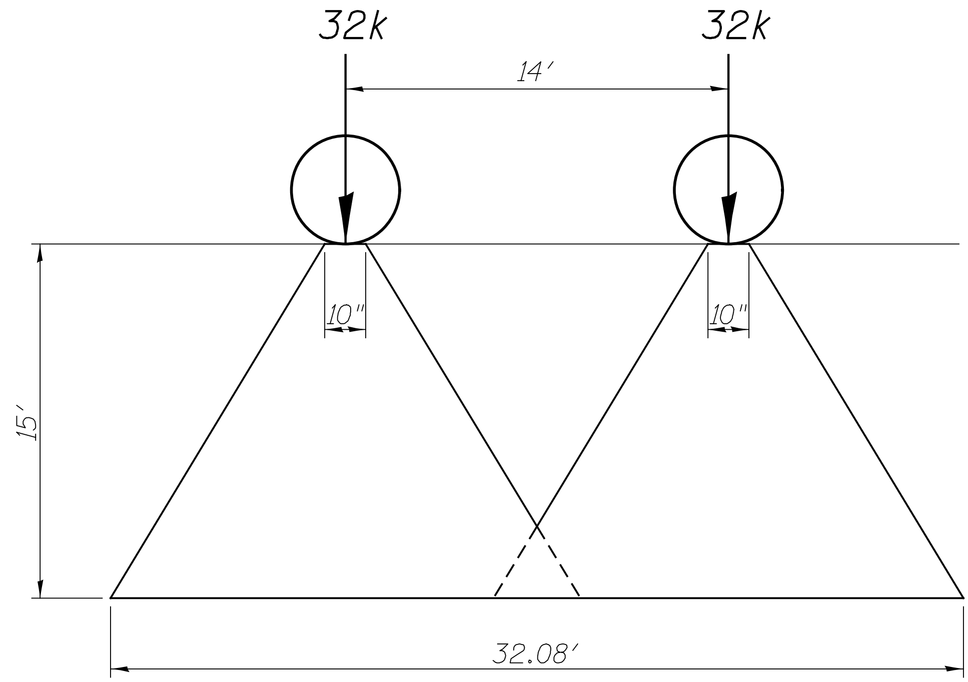

Figure 9 – Truck Load Distribution Parallel to Movement for 2 Rear Axles with 15 Feet of Fill

Three axles:

$$W_{3\ axle} = 72\ kip$$

$$l_{p\ 3\ axle} = 14\ ft. + 14\ ft. + 0.83\ ft. + 1.15(15\ ft.) = 46.08\ ft.$$

$$A_{3\ axle} = l_t\left(l_{p\ 3\ axle}\right) = (24.92\ ft.)(46.08\ ft.) = 1148\ ft.^2$$

$$w_{3\ axle} = \frac{W_{3\ axle}}{A_{3\ axle}} = \frac{72\ k}{1148\ ft.^2} = 0.063\ kip/ft.^2$$

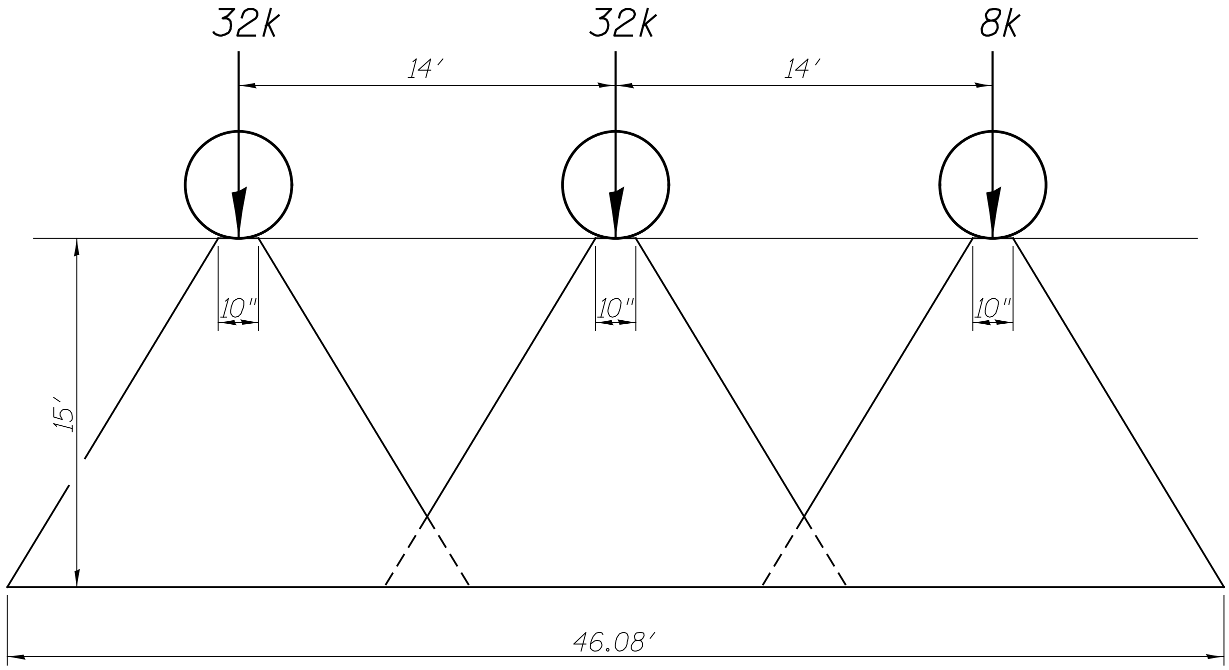

Figure 10 – Truck Load Distribution Parallel to Movement for All 3 Axles with 15 Feet of Fill

where:

l_{p1axle} = patch dimension parallel to the direction of movement for one rear axle

l_{p2axle} = patch dimension parallel to the direction of movement for two rear axles with a rear axle spacing of 14 feet

l_{p3axle} = patch dimension parallel to the direction of movement for all three axles with a rear axle spacing of 14 feet

A_{1axle} = area of the rectangular patch load created by the distribution of one rear axle through fill

A_{2axle} = area of the rectangular patch load created by the distribution of two rear axles through fill

A_{3axle} = area of the rectangular patch load created by the distribution of all three axles through fill

W_{1axle} = load from one rear axle

W_{2axle} = load from two rear axles

W_{3axle} = load from all three axles

w_{1axle} = pressure due to one rear axle

w_{2axle} = pressure due to two rear axles

w_{3axle} = pressure due to all three axles

Live Load Distribution For Fills ≥ 2 Feet - Design Tandem

The distribution dimension parallel to the direction of vehicle movement shall be the total width of the two axle patches taking into account the axle spacing. This will provide for easier calculation of a single patch load compared to that required for two narrowly spaced patch loads and will produce higher live load shears and moments in the top slab.

Per Article 3.6.1.2.6, for fills ≥ 2 feet, the patch dimensions of the two axles of the design tandem shall be calculated using the following equations:

$$l_t = s_w + \frac{w_t}{12} + LLDF(F)$$

$$l_p = s_a + \frac{w_p}{12} + LLDF(F)$$

where:

l_t = patch dimension transverse to the direction of movement (feet)

l_p = patch dimension parallel to the direction of movement (feet)

w_t = tire patch dimension transverse to the direction of movement, 20 inches per Article 3.6.1.2.5

w_p = tire patch dimension parallel to the direction of movement, 10 inches per Article 3.6.1.2.5

s_a = axle spacing, 4 feet for design tandem per Article 3.6.1.2.3

s_w = wheel spacing, 6 feet for design tandem per Article 3.6.1.2.3

LLDF = live load distribution factor, 1.15 per Article 3.6.1.2.6

F = fill height, the distance from the top of the roadway surface to the top of the box (ft.)

For the design tandem, these equations become:

$$l_t = 7.67 + 1.15F$$

$$l_p = 4.83 + 1.15F$$

Note that the equation for l_t is the same for both the design truck and tandem.

The area of the patch for the design tandem is:

$$A_{tandem} = l_t(l_p) = 37.1 + 14.4F + 1.32F^2$$

The pressure due to the design tandem (without impact or multiple presence facto) is:

$$W_{tandem} = 50 \text{ k}$$

$$w_{tandem} = \frac{W_{tandem}}{A_{tandem}} = \frac{50}{37.1 + 14.4F + 1.32F^2} \text{ kip/ft.}^2$$

Application of the Provisions of Article 4.6.2.10 Applied to Article 3.6.1.2.6

The last paragraph of Article 3.6.1.2.6 states that the live load effects distributed through fill need not be greater than that calculated using Article 4.6.2.10. The paragraph uses the term “moments”. The concept of this provision is that culverts with fills ≥ 2 feet do not need to be designed for higher live load forces than a culvert with < 2 feet of fill. Therefore this provision should be used for both shears and moments in the top slab.

For fills ≥ 2 feet, this effectively places a lower limit on l_t or l_p, depending on the direction of travel. This has no influence on the design of culvert top slabs where the traffic is moving parallel to the span, which is illustrated below. However, it may lower the design forces when the vehicle moves perpendicular to the span (parallel to the sidewalls).

To illustrate for the condition of traffic moving parallel to the span, Equation 4.6.2.10.2-1 and the provisions of Article 3.6.1.2.6 can be compared, and the span length where the provision may have an effect can be calculated. At a fill of 2 feet, the previously derived equation for distribution transverse to the direction of vehicle movement (parallel to the sidewalls) becomes:

l_t=7.67 ft. + 1.15F = 7.67 ft. + 1.15(2 ft.) = 9.97 ft.

Set Equation 4.6.2.10.2-1 equal to 9.97 feet and solve for S.

$$E = 8 + 0.12S = 9.97 \text{ ft.}$$
$$S = 16.4 \text{ ft.}$$

This shows that the span must be greater than 16.4 feet before the use of this provision is advantageous. The span length will increase as the fill height increases. Since most culvert clear spans are typically less than 14 feet, the lower limit allowed by this provision has no effect for the typical culvert with traffic moving parallel to the span.

This provision does apply when the vehicle is moving perpendicular to the span (parallel to the sidewalls). For this case, the provisions of Article 4.6.2.10.3 may be used to calculate l_p. The larger value of l_p calculated according to Articles 3.6.1.2.6 and 4.6.2.10.3 should be used for design. This will reduce the calculated pressure and the force effects on the top slab.

The following equations are from Table 4.6.2.1.3-1 written in units of feet rather than in inches.

	+Moment	–Moment
Design Truck	l_p = 2.17 ft. + 0.55S	l_p = 4.0 ft.+0.25S
Design Tandem	l_p = 6.17 ft. + 0.55S	l_p = 8.0 ft. +0.25S

The table shows that this provision will only be applicable for fills between 2 and 7 feet. According to Article C3.6.1.2.6, this provision is only applicable to the top slab of culverts. The factored axial load in the sidewall at these fill depths will not significantly impact the sidewall design, therefore small differences in the applied live load will not either. If the load from Article 4.6.2.10.3 is used to design the top slab it may also be used to determine the forces in the sidewall to simplify calculations.

For culverts with skews greater than 30º, where traffic is traveling primarily perpendicular to the span (parallel to the sidewalls), live loads traveling parallel to the span should also be checked and the largest force effects from either direction of travel should always be used for design.

Horizontal Loads

Horizontal Earth Pressure – EH

The horizontal earth pressure is used to calculate the shear and moment in the sidewall and the axial force in the top and bottom slabs.

Per Article 3.11.5.1, use the following equation to determine the horizontal soil pressure at any point below the fill surface.

$$p = k\gamma_s z \qquad \text{Eq. 3.11.5.1-1}$$

where:

p	=	horizontal earth pressure due to the backfill (kip/ft.^{2})
k	=	coefficient of horizontal earth pressure, assumed to be 0.5 for at-rest pressure
γ_s	=	unit weight of the backfill, γ_{soil}, assumed to be 0.120 kip/ft.^{3}
z	=	distance below the bottom of the pavement (feet)

The value of $k = 0.5$ was selected to be consistent with the practice of other state DOT's and with the ASTM C1577 specifications. Since $k = 0.5$ and $\gamma_{soil} = 0.120$ kcf, the equivalent fluid pressure used for design can be assumed to be equal to 60 lb/ft.^{2}.

The provisions of Article 3.11.7, which specifies a 50 percent reduction in the horizontal earth pressure, where such pressure may reduce forces from other loads, shall be used when minimum earth pressure produces a greater design requirement than the maximum earth pressure. Since the corners of culverts are assumed to be pinned, this will only be required for the design of the top and bottom slabs for the condition of maximum moment and minimum axial force. In this case, the minimum equivalent fluid pressure is 30 lb/ft.^{2}. This reduction shall be combined with the minimum load factor of 0.9 from Table 3.4.1-2, even though it is not required according to the AASHTO LRFD specifications.

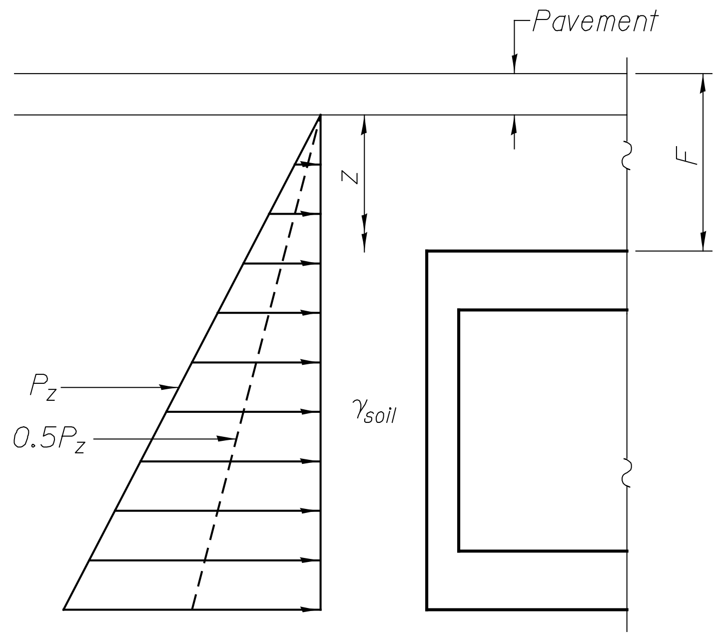

Figure 11 – Horizontal Earth Pressure EH

Uniform Surcharge Load – ES

Pavement and FWS are both treated as a surcharge load. Per Article 3.11.6.1, use the following equation to determine the uniform horizontal pressure.

$$\Delta_p = k_s q_s \qquad \text{Eq. 3.11.6.1-1}$$

where:

Δ_p = uniform horizontal earth pressure due to the surcharge (kip/ft.^{2})

k_s = coefficient of horizontal earth pressure, assumed to be 0.5 for at-rest pressure

q_s = uniform vertical surcharge applied to the top of the backfill (kip/ft.^{2})

For a typical 12 in. thick pavement and 50 lb/ft.^{2} future wearing surface, the vertical pressure, w_{DW}, is equal to 0.200 kip/ft.^{2}. Therefore, for typical culver designs Δ_p is:

$$q_s = w_{DW} = 0.200 \text{ kip/ft.}^2$$

$$\Delta_p = 0.5\left(0.200 \text{ kip/ft}^2\right) = 0.100 \text{ kip/ft.}^2$$

This value may used for routine culvert designs.

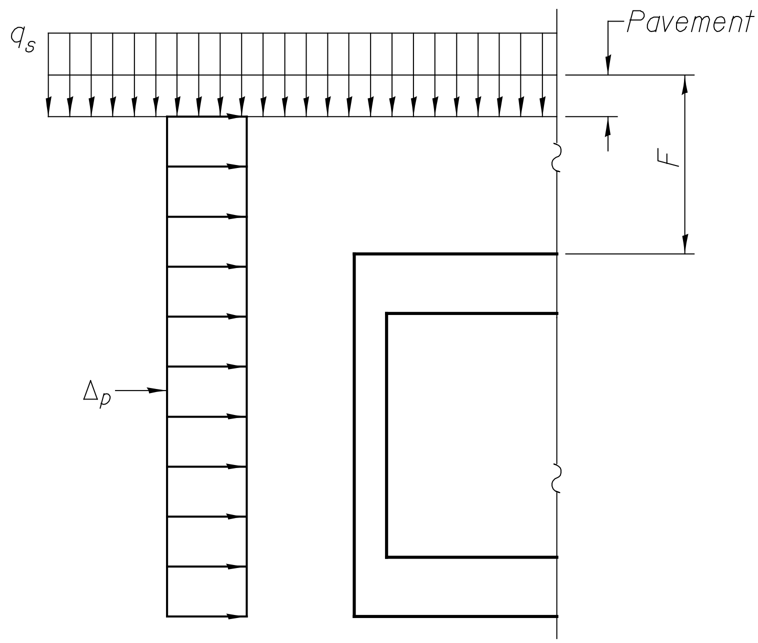

Figure 12 – Uniform Surcharge Load ES

Live Load Surcharge – LS

Use the provisions of Article 3.11.6.4. Applicability of live load surcharge shall be according to Article 3.6.1.2.6. The "equivalent height" referred to in the AASHTO LRFD specifications shall be determined by calculating the distance from the top of the pavement surface to the bottom of the bottom slab.

For culverts with skew ≤ 30 degrees, Table 3.11.6.4-1 *Equivalent Height of Soil for Vehicular Loading on Abutments Perpendicular to Traffic* shall be used. For culverts with skew > 30 degrees, Table 3.11.6.4-2 *Equivalent Height of Soil for Vehicular Loading on Retaining Walls Parallel to Traffic* shall be used with the distance from the back face of the wall to the edge of traffic equal to 0.0 feet. Use the following equation to determine the uniform horizontal pressure.

$$\Delta_p = k\gamma_s h_{eq} \qquad \text{Eq. 3.11.6.1-1}$$

where:

Δ_p = uniform horizontal earth pressure due to the live load surcharge (kip/ft.^{2})

k	=	coefficient of horizontal earth pressure, assumed to be 0.5 for at-rest pressure
γ_s	=	unit weight of the backfill, γ_{soil}, assumed to be 0.120 kip/ft.^{3}
h_{eq}	=	equivalent height of soil for vehicular loading from Table 3.11.6.4-1 or Table 3.11.6.4-2 (feet)

The following table is a combination of Tables 3.11.6.4-1 and 3.11.6.4-2 presented in a modified format for ease of use.

Distance from Top of Pavement to Bottom of Bottom Slab (feet)	h_{eq} (ft.) Skew	
	≤ 30	> 30
5.0	4.0	5.0
10.0	3.0	3.5
≥ 20.0	2.0	2.0

For practical design purposes, the designer may opt to forgo the interpolation and use the larger value. The design of culvert sidewalls is not sensitive to small changes in LS. Also, for culverts with skews greater than 30º, where both directions of vehicle traffic are being investigated, the larger value of LS may be used in combination with the loading from both directions of vehicle movement to simplify calculations.

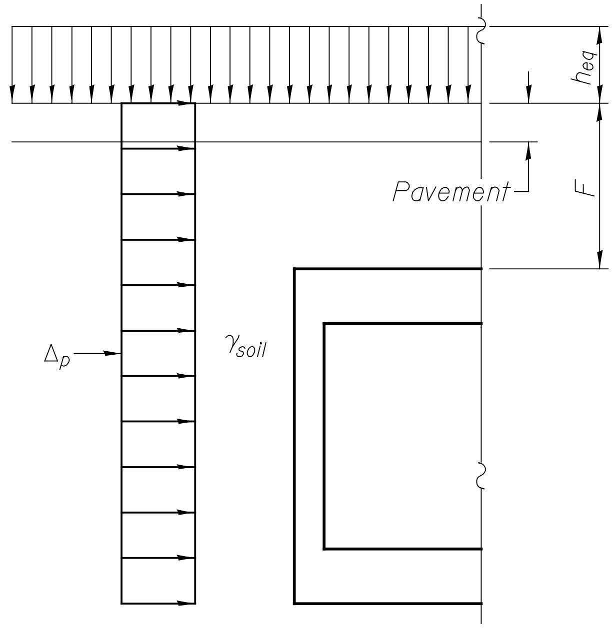

Figure 13 – Live Load Surcharge LS

Worked Example 1: Permanent Vertical Loads

Determine the uniform permanent vertical loads applied to the top of the top slab of a cast in place single 12 x 12 box culvert with 6 feet of fill. The top slab is 12½ in. thick, the bottom slab is 13½ in. thick and the sidewalls are 12 in. thick. The pavement thickness is 12 in. and the future wearing surface is 50 lb/ft.^{2}.

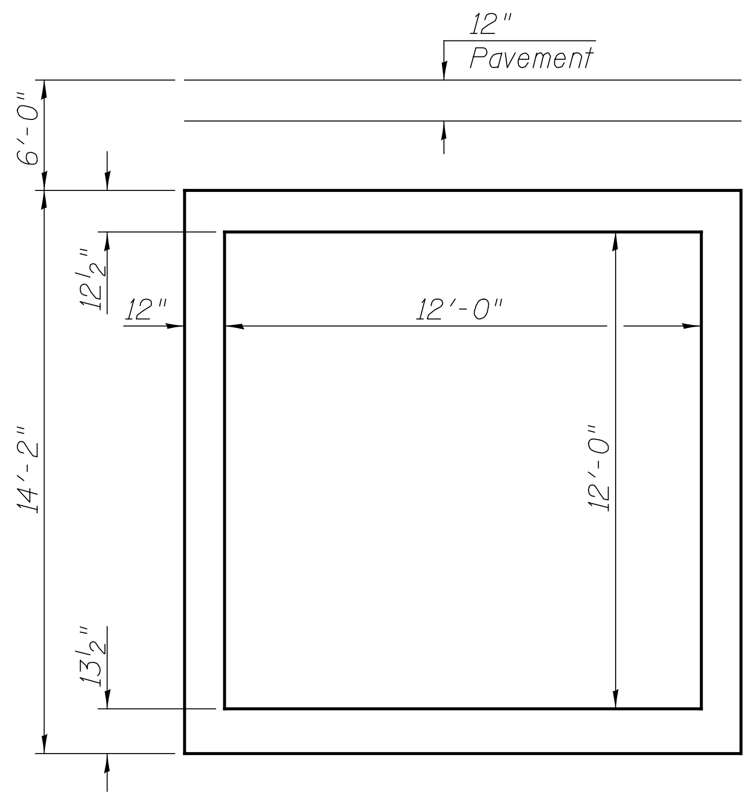

Figure 14 – Worked Example 1 – Culvert Cross Section

Dead Load – DC

The dead load of the top slab is:

$$w_{DC} = \gamma_{conc}\left(\frac{t_{topslab}}{12}\right) = (0.150 \text{ kip/ft.}^3)\left(\frac{12.5 \text{ in.}}{12}\right) = 0.156 \text{ kip/ft.}^2$$

Vertical Earth Pressure – EV

$$H = F - t_{pavt} = 6.0\text{ ft. } -1.0\text{ ft.}=5.0\text{ ft.}$$

$$w_{EV}=\gamma_{soil}H=(0.120\text{ kip/ft.}^3)(5.0')=0.600\text{ kip/ft.}^2$$

Modify soil pressure for embankment conditions per Article 12.11.2.2.1.

$$F_e = 1 + \frac{0.2(H)}{B_c} \leq 1.15$$

$$B_c = S + 2\left(\frac{t_{sidewall}}{12}\right) = 12.0\text{ ft.} + 2\left(\frac{12\text{ in.}}{12}\right) = 14.00\text{ ft.}$$

$$F_e = 1 + \frac{0.2(5.0\text{ ft.})}{14.00\text{ ft.}} = 1.07 < 1.15$$

$$w_{EV(M)} = w_{EV}\ F_e = (0.600\text{ kip/ft.}^2)(1.07) = 0.642\text{ kip/ft.}^2$$

Pavement and FWS - DW

Given 12” thick pavement and 50 lb/ft.^{2} of future wearing surface:

$$w_{DW} = \gamma_{pavt}\left(\frac{t_{pavt}}{12}\right) + FWS = \left(0.150\text{ kip/ft.}^3\right)\left(\frac{12\text{ in.}}{12}\right) + 0.050\text{ kip/ft.}^2 = 0.200\text{ kip/ft.}^2$$

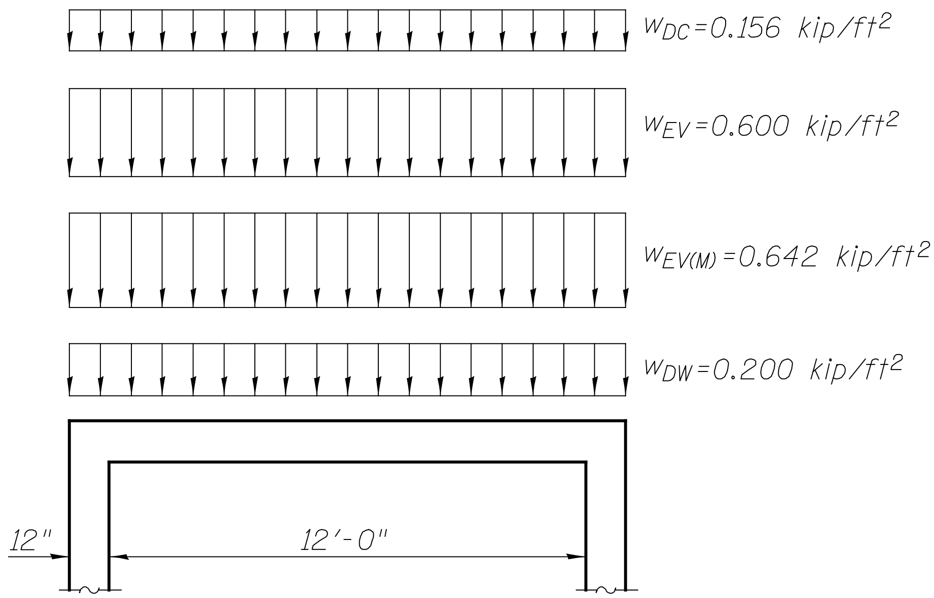

Figure 15 – Worked Example 1 – Permanent Vertical Load Summary

Worked Example 2: Live Load Distribution with Fill $\leq$ 2 Feet

Determine the uniform live loads applied to the top of the top slab of a cast in place single 10 x 7 box culvert with 1.5 feet of fill. The top slab is 11½" thick, the bottom slab is 12½" thick and the sidewalls are 7" thick. The culvert is not skewed, therefore live loads traveling parallel to the span will be calculated.

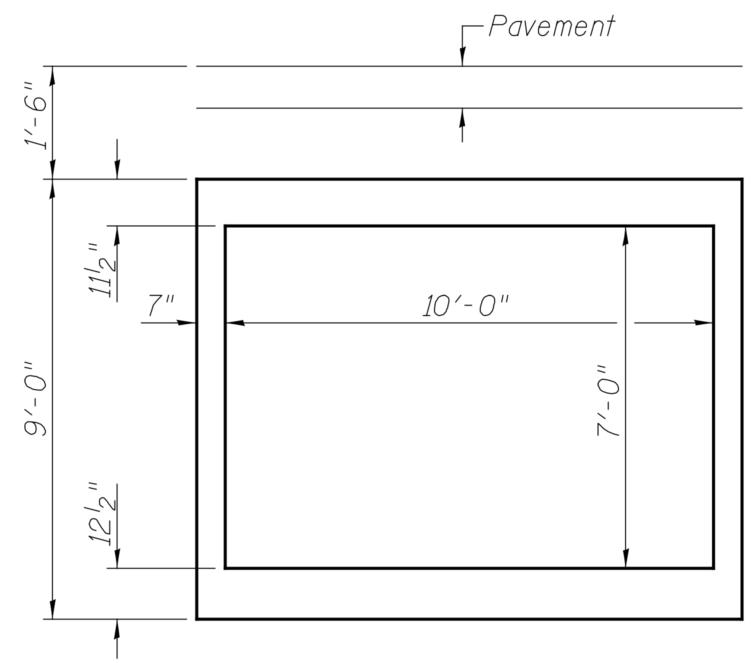

Figure 16 – Worked Example 2 & 3 – Culvert Cross Section

Impact

Calculate impact according to Article 3.6.2.2.

$$IM = 0.33(1-0.125D_E) \geq 0$$

$$D_E = F = 1.5 \text{ ft.}$$

$$IM = 0.33(1-0.125(1.5 \text{ ft.})) = 0.268$$

Multiple Presence

The multiple presence factor for culvert design is determined assuming one lane of traffic for traffic traveling parallel to the span per Article 12.11.2.1. Per Article 3.6.1.1.2:

$$MP = 1.2$$

Truck

For this example, the rear two axles with the minimum 14' spacing will be the controlling configuration when investigating the truck loading. The traffic travels primarily parallel to the span and the fill height is less than 2 feet, therefore use Article 4.6.2.10.2 to determine distribution dimensions.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 0.83 \text{ ft.} + 1.15F = 0.83' + 1.15(1.5 \text{ ft.}) = 2.56 \text{ ft.}$$

Determine if the patch areas of the two rear axles overlap. The clear distance between the patch loads from the two rear axles is:

$$g_a = s_a - l_p = 14 \text{ ft.} - 2.56 \text{ ft.} = 11.44 \text{ ft.}$$

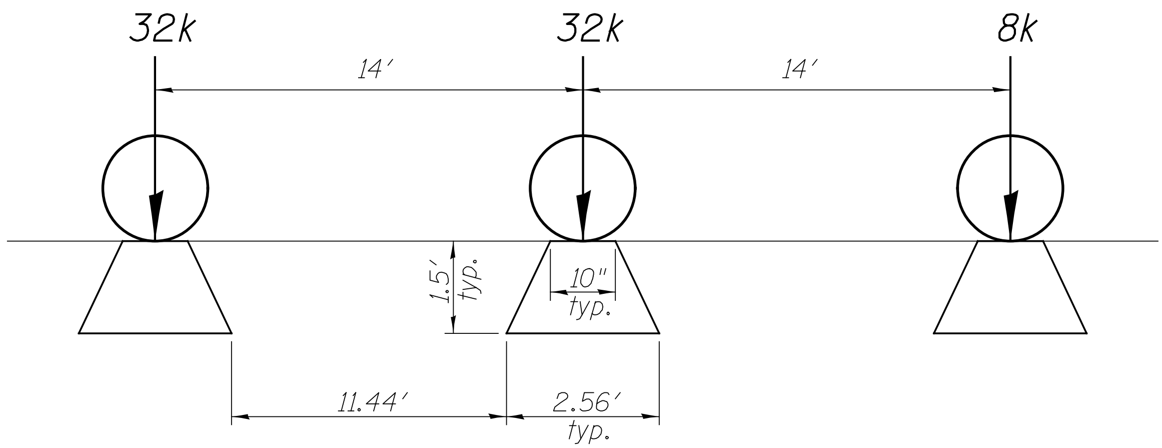

Figure 17 – Worked Example 2 – Truck Load Distribution Parallel to Movement

The patch loads from the two individual axles do not overlap. For this example, the two rear axle patch loads cannot be on the culvert at the same time. Therefore, the loading from the truck will be from only one axle.

Patch dimension transverse to the direction of vehicle movement:

$$l_t = 8 \text{ ft.} + 0.12S$$

$$S = 10 \text{ ft.}$$

$$l_t = 8 + 0.12(10 \text{ ft.}) = 9.20 \text{ ft.}$$

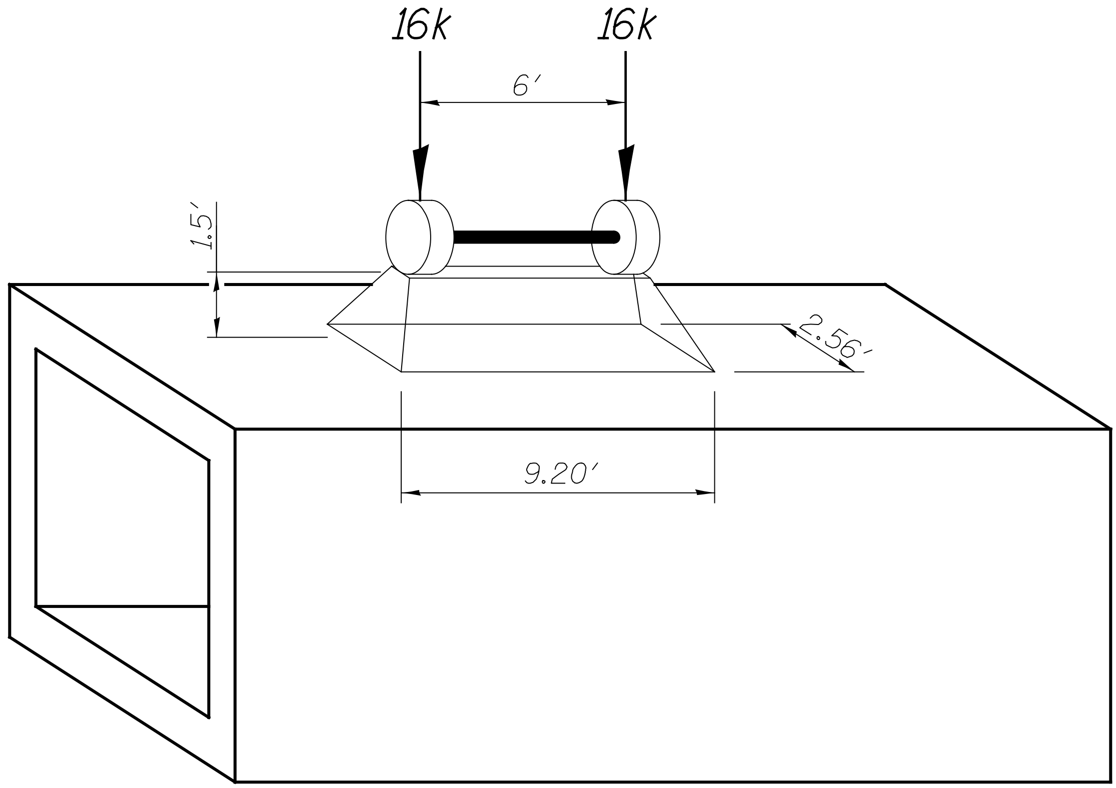

Figure 18 – Worked Example 2 – Isometric of Truck Load Distribution

Live load pressure due to the Truck:

$$w_{LL_{truck}} = \frac{32 \text{ k}}{l_p l_t} = \frac{32 \text{ k}}{(2.56 \text{ ft.})(9.20 \text{ ft.})} = 1.36 \text{ kip/ft.}^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1+IM)MP = (1.36\ kip/ft.^2)(1 + 0.268)(1.2) = 2.07\ kip/ft.^2$$

The Truck load consists of a 2.07 kip/ft.^{2} pressure with a length of 2.56 ft.

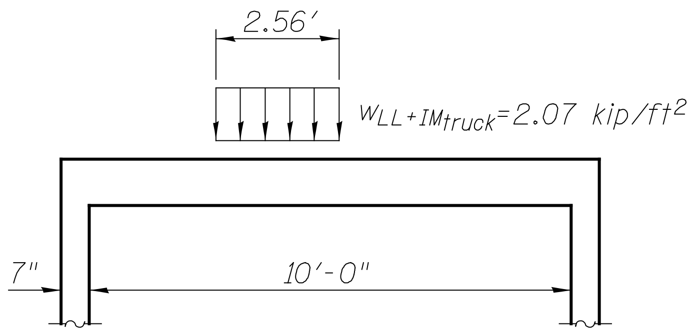

Figure 19 – Worked Example 2 – Truck Load

Tandem

The two axles of the tandem are applied to the structure. The four individual wheels of the tandem are assumed to act together, therefore the pressures from the wheels are assumed to overlap whether or not they actually do. The traffic travels primarily parallel to the span and the fill height is less than 2 feet, therefore use Article 4.6.2.10.2 to determine distribution dimensions.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 4.83' + 1.15F = 4.83' + 1.15(1.5') = 6.56'$$

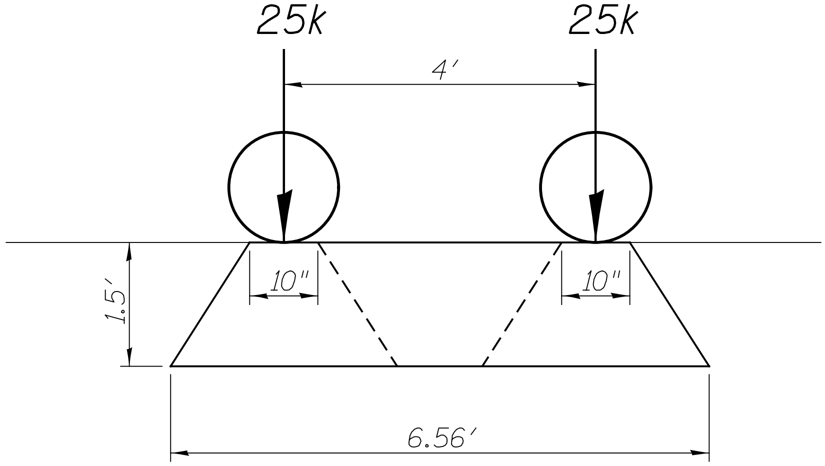

Figure 20 – Worked Example 2 – Tandem Load Distribution Parallel to Movement

Patch dimension transverse to the direction of vehicle movement (Same as for the Truck):

$$L_t = 9.20 \text{ ft.}$$

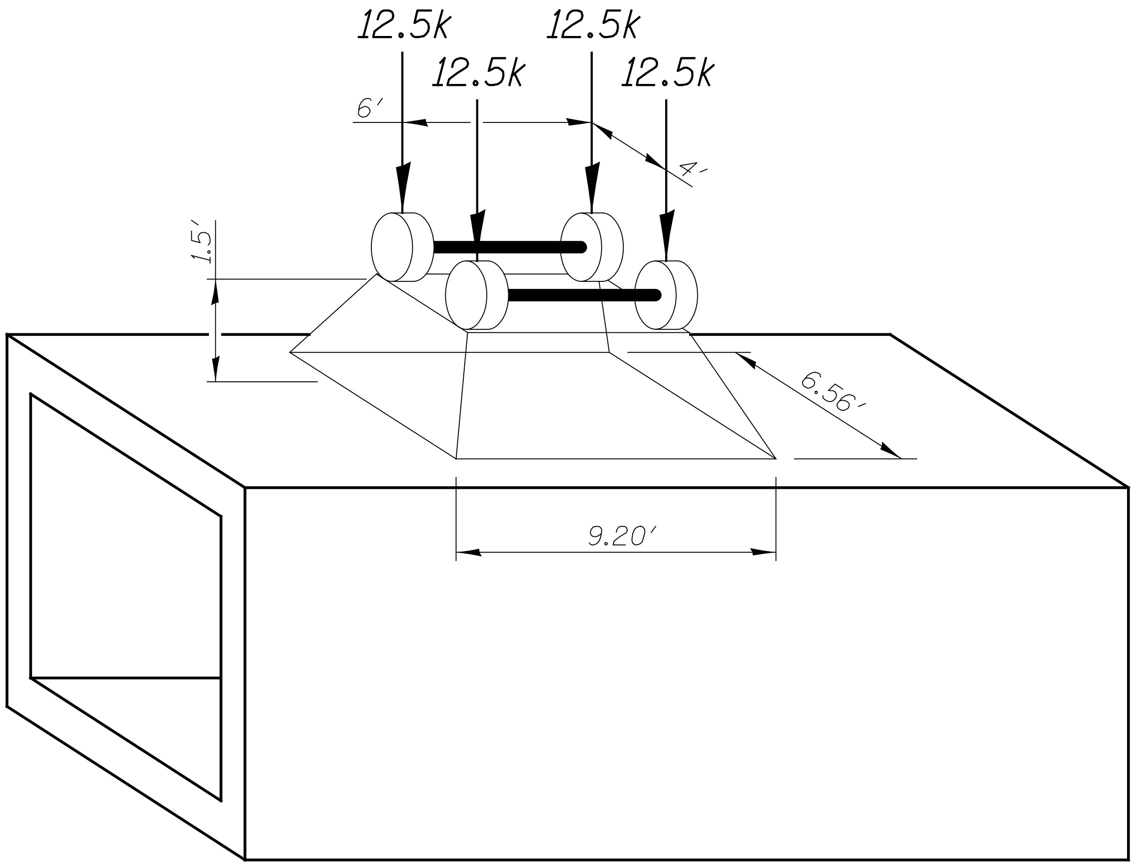

Figure 21 – Worked Example 2 – Isometric of Tandem Load Distribution

Live load pressure due to the Tandem:

$$w_{LL_{tandem}} = \frac{2(25\text{ k})}{l_p l_t} = \frac{2(25\text{ k})}{(6.56\text{ ft.})(9.20\text{ ft.})} = 0.828\text{ kip/ft.}^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.828\text{ kip/ft.}^2)(1+0.268)(1.2) = 1.26\text{ kip/ft.}^2$$

The Tandem load consists of a 1.26 kip/ft.^{2} pressure with a length of 6.56 ft.

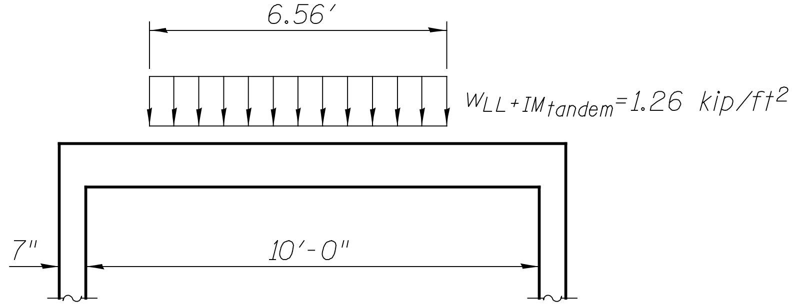

Figure 22 – Worked Example 2 – Tandem Load

Worked Example 3: Live Load Distribution with Fill < 2 Feet and Parallel Traffic

Determine the uniform live loads applied to the top of the top slab of a cast in place single 10 x 7 box culvert with 1.5 feet of fill. The top slab is 11½ in. thick, the bottom slab is 12½ in. thick and the sidewalls are 7 in. thick. The culvert is skewed 90º, therefore live loads traveling perpendicular to the span (parallel to the sidewalls) will be calculated. For cross section of example culvert see Worked Example 2.

Impact

Impact was calculated in Worked Example 2:

$$IM = 0.268$$

Multiple Presence

The multiple presence factor for culvert design is determined assuming one lane of traffic for traffic traveling parallel to the span per Article 12.11.2.1. For traffic traveling perpendicular to the span, the loads should be calculated for multiple lanes of traffic as applicable. For the culvert and fill height in this example, no more than two lanes will be applicable. Per Article 3.6.1.1.2:

$$MP = 1.2 \text{ for one lane}$$

$$MP = 1.0 \text{ for two lanes}$$

Truck (One Lane)

For this example, the rear two axles with the minimum 14' spacing will be the controlling configuration when investigating the truck loading. The traffic travels primarily perpendicular to the span and the fill height is less than 2 feet, therefore use Article 4.6.2.10.3 to determine distribution dimensions. Since this is a single box the +M distribution equation is used.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 2.17 \text{ ft.} + 0.55S$$

$$S = 10 \text{ ft.}$$

$$l_p = 2.17 \text{ ft.} + 0.55(10 \text{ ft.}) = 7.67 \text{ ft.}$$

Since this dimension is less than the minimum 14' axle spacing, the axle patches from the rear axles do not overlap. Therefore, the loading from the truck will be from only one axle.

Patch dimension transverse to the direction of vehicle movement for one lane:

$$l_{t1} = 7.67 \text{ ft.} + 1.15F$$

$$F = 1.5 \text{ ft.}$$

$$l_{t1} = 7.67 \text{ ft.} + 1.15(1.5 \text{ ft.}) = 9.39 \text{ ft.}$$

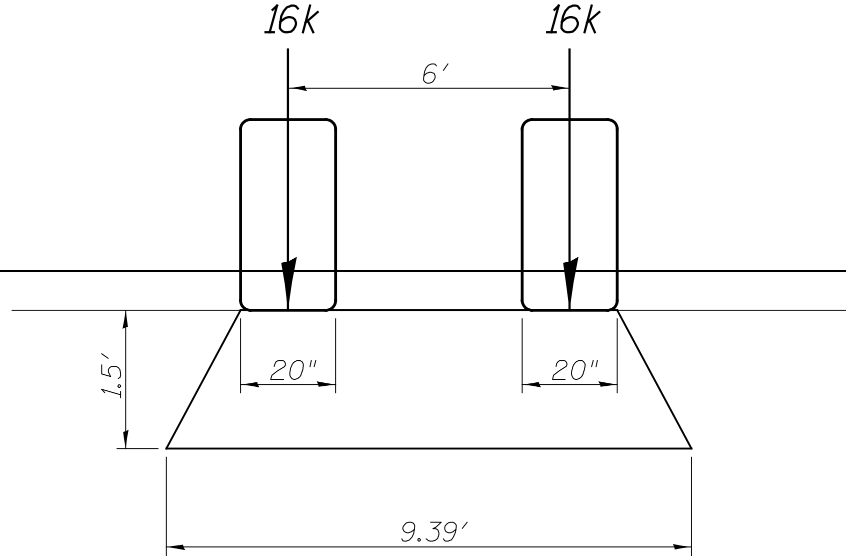

Figure 23 – Worked Example 3 – Truck Load Distribution Transverse to Movement (1 Lane)

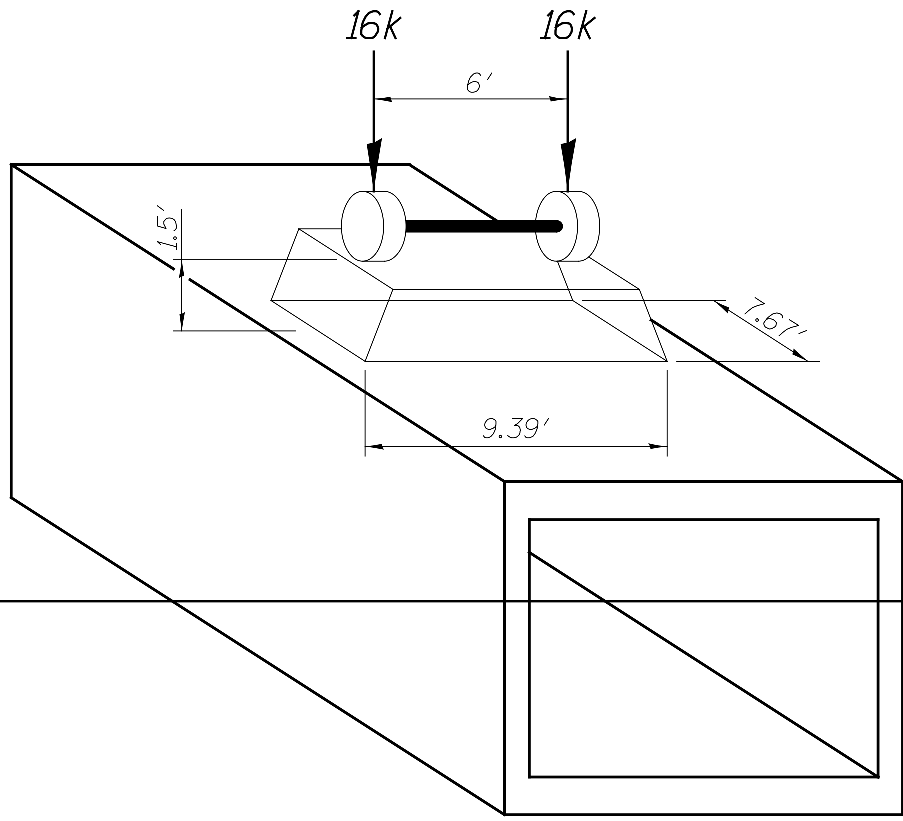

Figure 24 – Worked Example 3 – Isometric of Truck Load Distribution (1 Lane)

Live load pressure due to the Truck:

$$w_{LL_{truck}} = \frac{32\ k}{l_p l_{t1}} = \frac{32\ k}{(7.67\ ft.)(9.39\ ft.)} = 0.444\ kip/ft.^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1+IM)MP = (0.444\ kip/ft.^2)(1 + 0.268)(1.2) = 0.676\ kip/ft.^2$$

The one lane Truck load consists of a 0.676 kip/ft.^{2} pressure with a length of 9.39 ft.

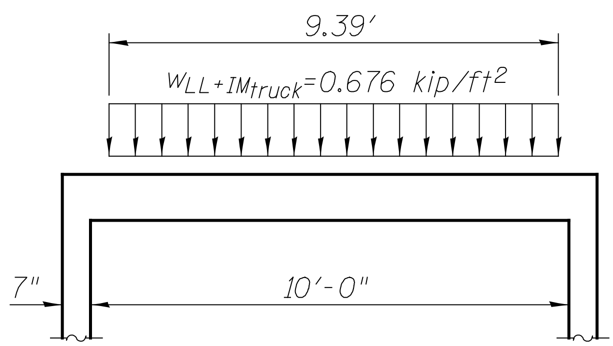

Figure 25 – Worked Example 3 – Truck Load (1 Lane)

Truck (Two Lane)

The patch dimension parallel to the direction of vehicle movement is the same as for the one lane case which was previously calculated and is equal to 7.67 ft.

The patch dimension transverse to the direction of vehicle movement for one axle was previously calculated and is equal to 9.39 ft. The spacing between the adjacent axles is according to Article 3.6.1.3.1 which states that the center of any wheel load may not be closer than 2 ft. from the edge of the design lane. Therefore the minimum spacing between adjacent wheels of two axles in adjacent lanes is 4 ft.

Determine if the patch areas of two axles in adjacent lanes overlap. The clear distance between patch loadings from two axles in adjacent lanes is:

g_a = 4 ft. - (l_{t1}- 6 ft.) = 4 ft. - (9.39 ft. - 6 ft.) = 0.61 ft.

The patch loads from two axles in adjacent lanes do not overlap.

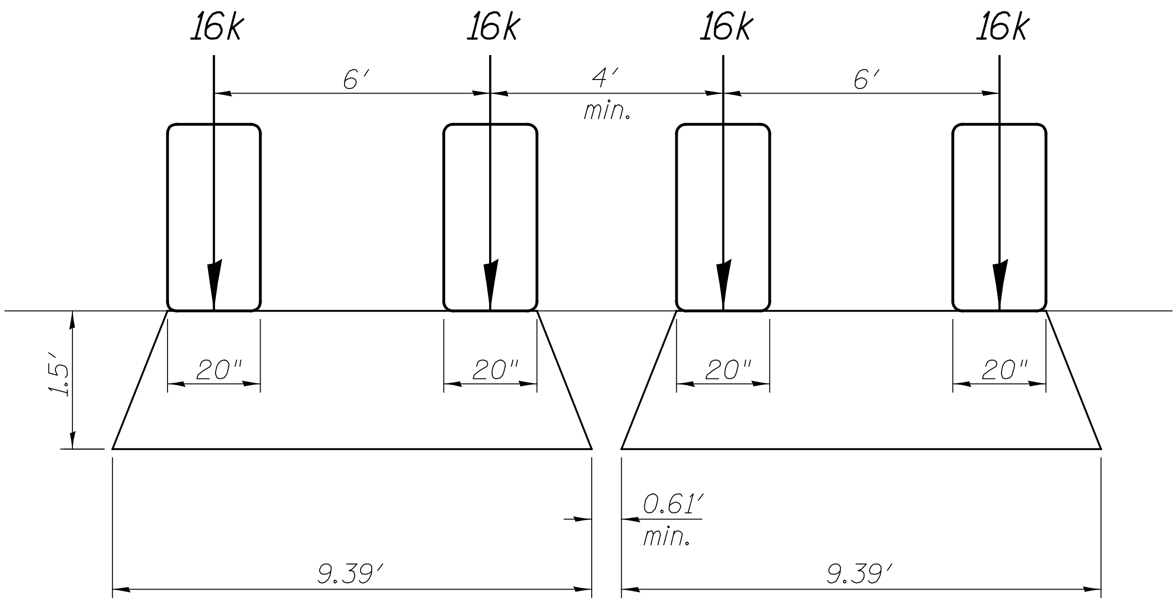

Figure 26 – Worked Example 3 – Truck Load Distribution Transverse to Movement (2 Lane)

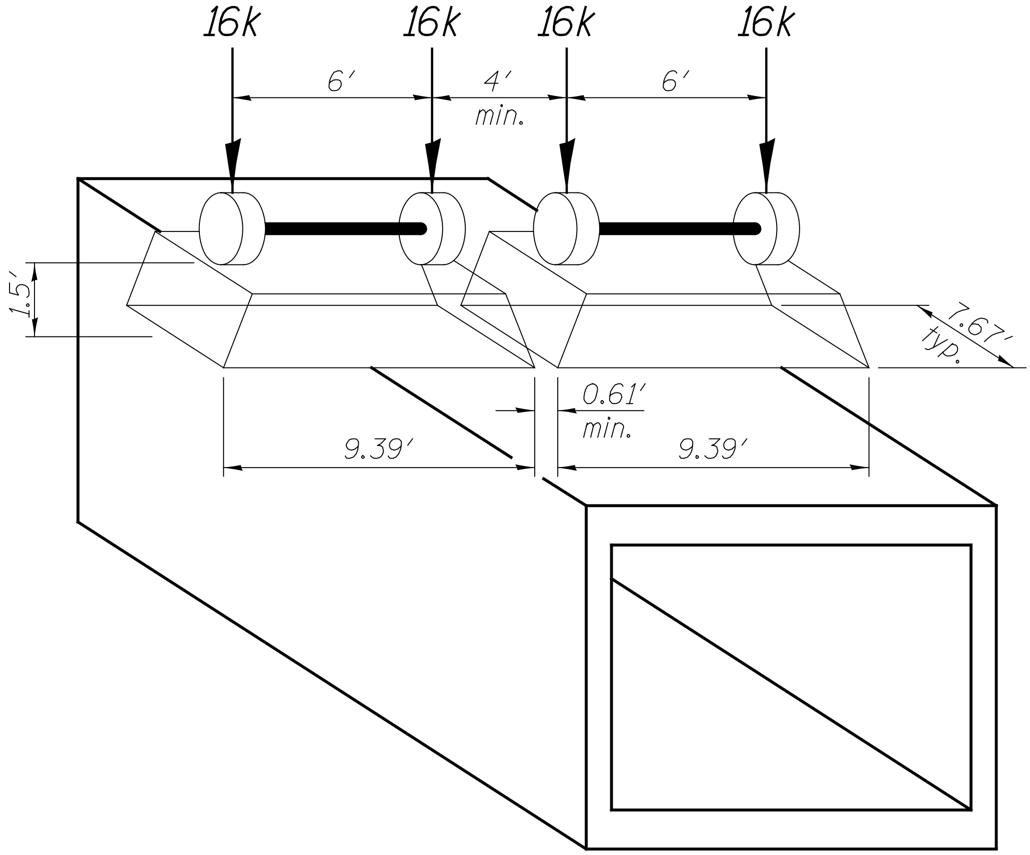

Figure 27 – Worked Example 3 – Isometric of Truck Load Distribution (2 Lane)

Live load pressure due to the two lane Truck load is the same as for the one lane case:

$$w_{LL_{truck}} = 0.444 \text{ kip/ft.}^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1+IM)MP = (0.444 \text{ kip/ft.}^2)(1 + 0.268)(1.0) = 0.563 \text{ kip/ft.}^2$$

The two lane Truck load consists of two 0.563 kip/ft^2 pressures with a length of 9.39' and spaced at a minimum of 0.61'.

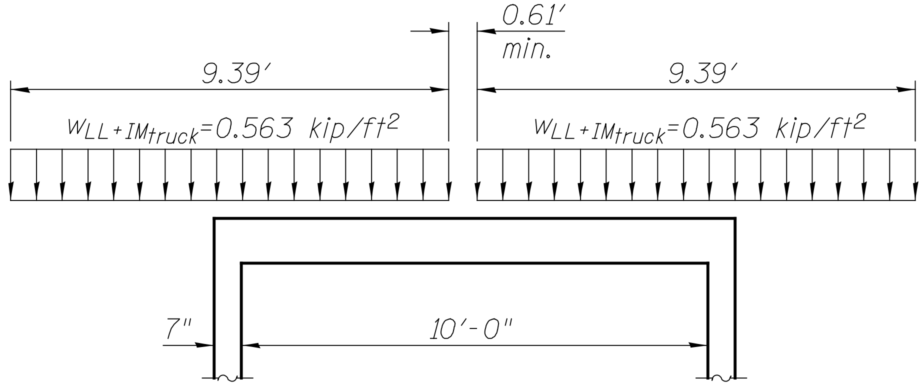

Figure 28 – Worked Example 3 – Truck Load (2 Lane)

Tandem (One Lane)

The two axles of the tandem are applied to the structure. The four individual wheels of the tandem are assumed to act together, therefore the pressures from the wheels are assumed to overlap whether or not they actually do. The traffic travels primarily perpendicular to the span and the fill height is less than 2 feet, therefore use Article 4.6.2.10.3 to determine distribution dimensions. Since this is a single box the +M distribution equation is used.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 6.17 \text{ ft.} + 0.55S = 6.17 \text{ ft.} + 0.55(10 \text{ ft.}) = 11.67 \text{ ft.}$$

Patch dimension transverse to the direction of vehicle movement for one lane (Same as for the Truck):

l_{t1} = 9.39 ft.

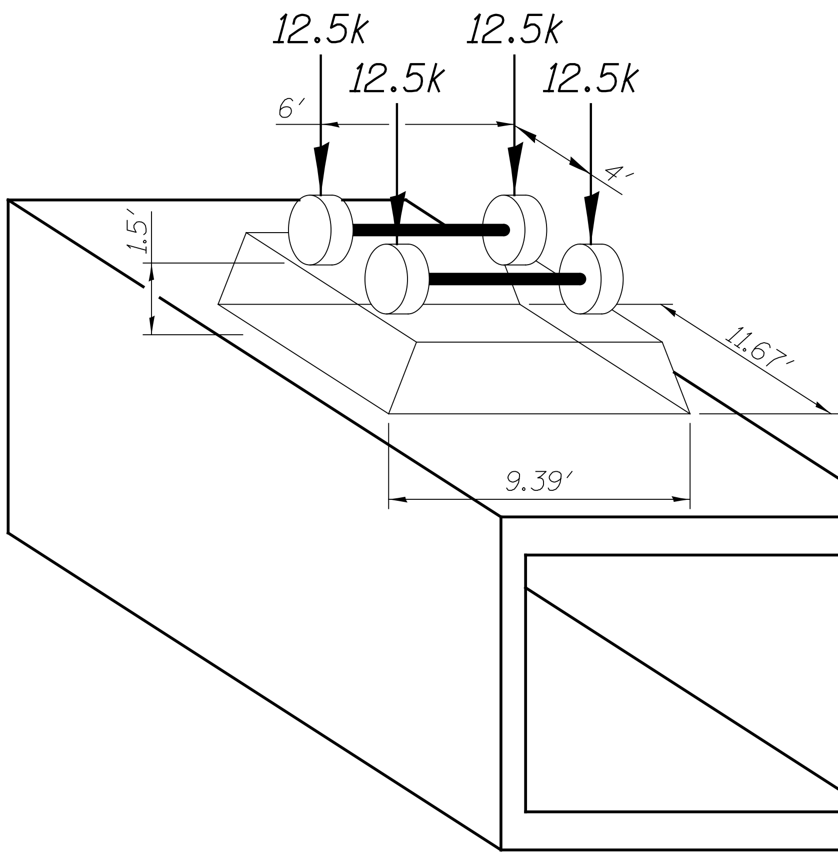

Figure 29 – Worked Example 3 – Isometric of Tandem Load Distribution (1 Lane)

Live load pressure due to the Tandem:

$$w_{LL_{tandem}} = \frac{2(25\ \text{k})}{l_p l_{t1}} = \frac{2(25\ \text{k})}{(11.67\ \text{ft.})(9.39\ \text{ft.})} = 0.456\ \text{kip/ft.}^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.456\ \text{kip/ft}^2)(1+0.268)(1.2) = 0.694\ \text{kip/ft.}^2$$

The one lane Tandem load consists of a 0.694 kip/ft.^{2} pressure with a length of 9.39 ft.

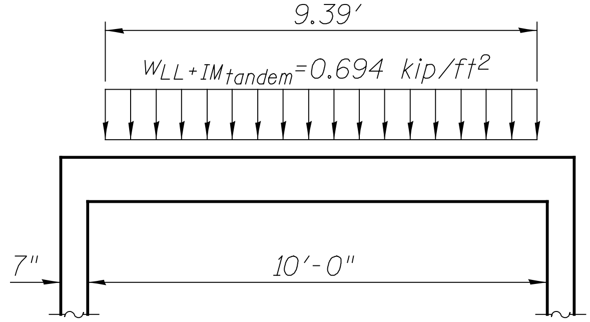

Figure 30 – Worked Example 3 – Tandem Load (1 Lane)

Tandem (Two Lane)

The patch dimension parallel to the direction of vehicle movement is the same as for the one lane case which was previously calculated and is equal to 11.67 ft.

The patch dimension transverse to the direction of vehicle movement for one axle and the distance between the patch areas for two axles in adjacent lanes is the same as for the truck which were previously calculated and are equal to 9.39 ft. and 0.61 ft., respectively.

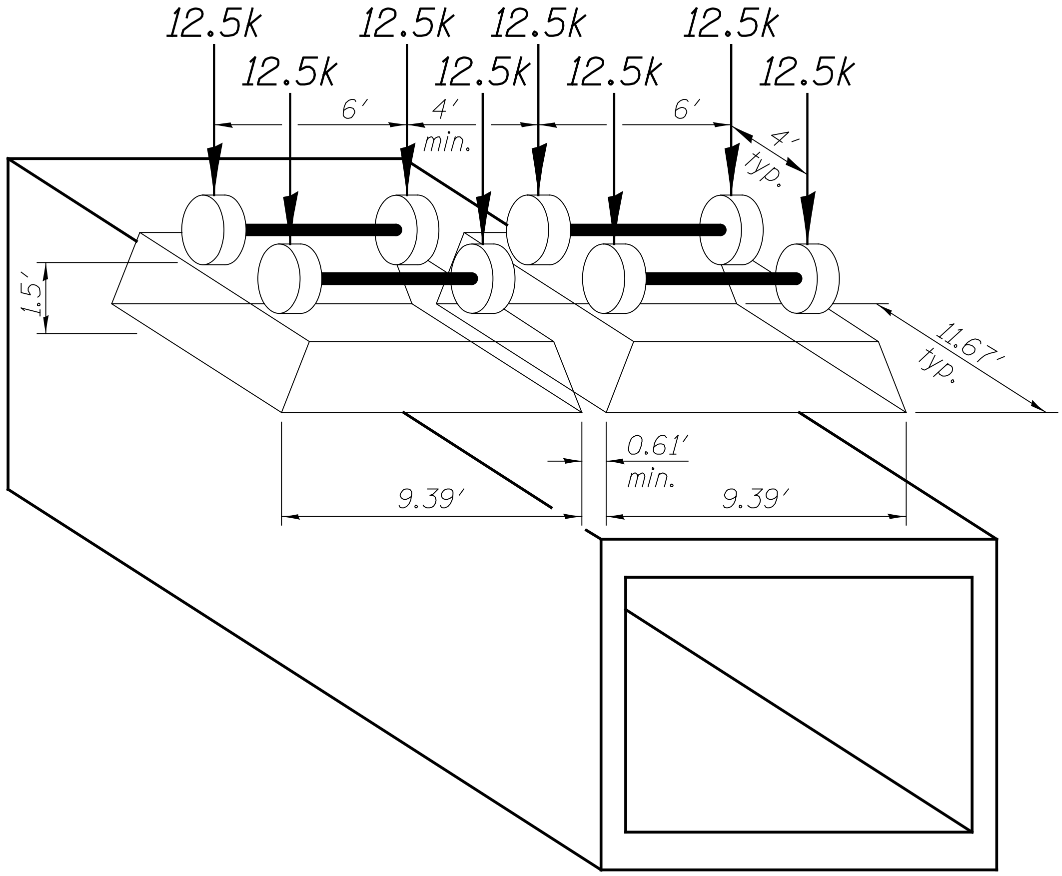

Figure 31 – Worked Example 3 – Isometric of Tandem Load Distribution (2 Lane)

Live load pressure due to the two lane Tandem load is the same as for the one lane case:

$$w_{LL_{tandem}} = 0.456 \text{ kip/ft.}^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.456 \text{ kip/ft.}^2)(1+0.268)(1.0) = 0.578 \text{ kip/ft.}^2$$

The two lane Tandem load consists of two 0.578 kip/ft.^{2} pressures with a length of 9.39 ft. and spaced at a minimum of 0.61 ft.

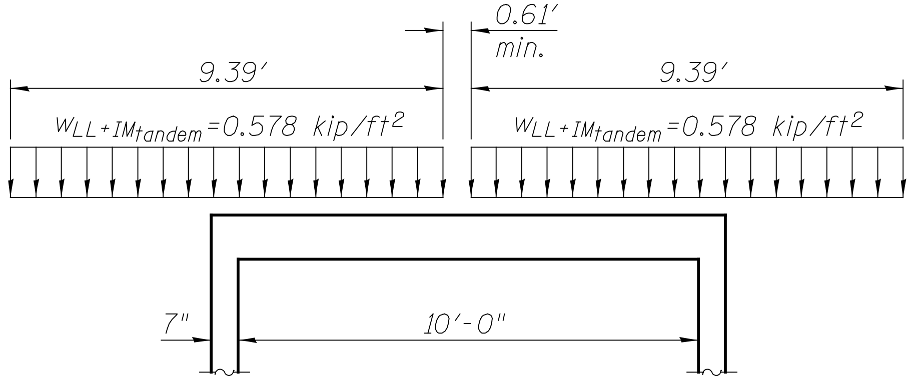

Figure 32 – Worked Example 3 – Tandem Load (2 Lane)

For single box culverts with skews of 90º or multiple box culverts with skews greater than 30º, live loads traveling parallel to the span should also be checked and the largest force effects from either direction of travel should always be used for design. Therefore, the force effects would be calculated for the loads in this Worked Example and compared to those calculated using the loads from Worked Example 2 and the larger values would be used to design the culvert.

Worked Example 4: Live Load Distribution with Fill ≥ 2 Feet

Determine the uniform live loads applied to the top of the top slab of a cast in place single 11 x 7 box culvert with 6 feet of fill. The top slab is 12 in. thick, the bottom slab is 13 in. thick and the sidewalls are 7½ in. thick. The culvert is not skewed, therefore live loads traveling parallel to the span will be calculated.

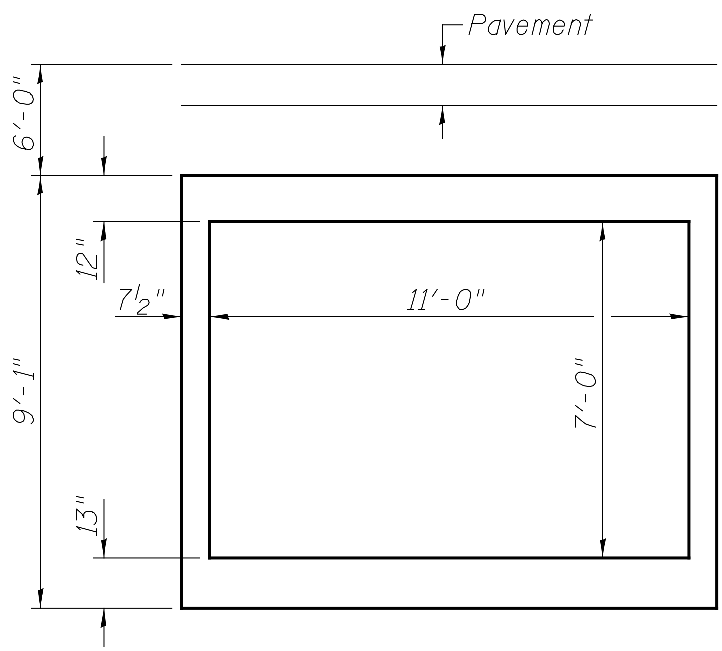

Figure 33 – Worked Example 4 & 5 – Culvert Cross Section

Impact

Calculate impact according to Article 3.6.2.2.

$$IM=0.33(1-0.125D_E)\geq 0$$

$$D_E = F = 6.0 \text{ ft.}$$

$$IM = 0.33(1-0.125(6.0 \text{ ft.})) = 0.083$$

Multiple Presence

The multiple presence factor for culvert design is determined assuming one lane of traffic for traffic traveling parallel to the span per Article 12.11.2.1. Per Article 3.6.1.1.2:

$$MP = 1.2$$

Truck

For this example, the rear two axles with the minimum 14 ft. spacing will be the controlling configuration when investigating the truck loading. The fill height is greater than 2 feet, therefore use Article 3.6.1.2.6 to determine distribution dimensions.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 0.83 \text{ ft.} + 1.15F = 0.83 \text{ ft.} + 1.15(6.0 \text{ ft.}) = 7.73 \text{ ft.}$$

Determine if the patch areas of the two rear axles overlap. The clear distance between the patch loads from the two rear axles is:

$$g_a = s_a - l_p = 14 \text{ ft.} - 7.73 \text{ ft.} = 6.27 \text{ ft.}$$

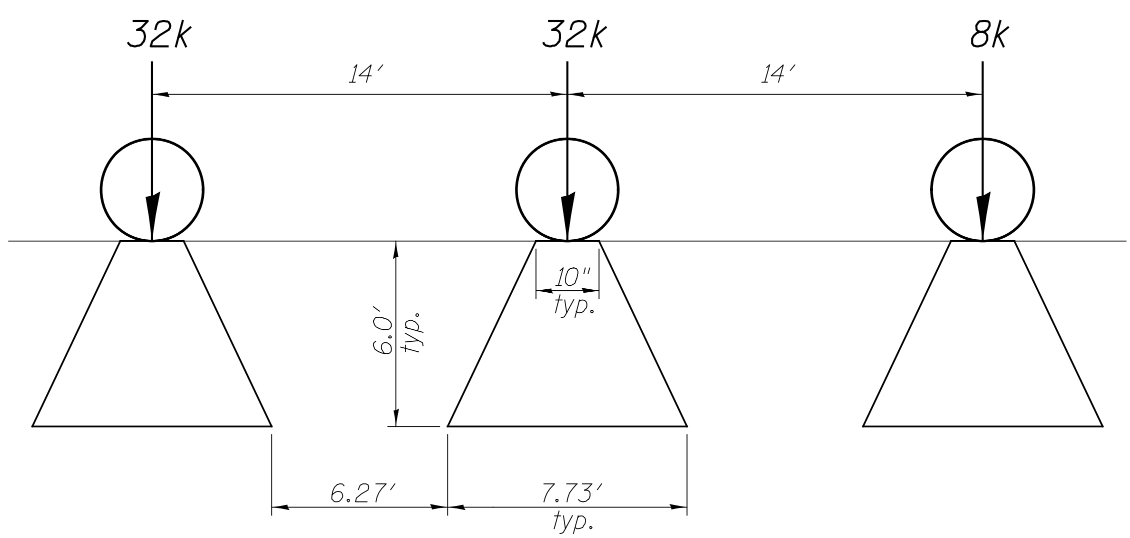

Figure 34 – Worked Example 4 – Truck Load Distribution Parallel to Movement

The patch loads from the two individual axles do not overlap. For this example, the two rear axle patch loads cannot be on the culvert at the same time. Therefore, the loading from the truck will be from only one axle.

Patch dimension transverse to the direction of vehicle movement:

$$l_t = 7.67 \text{ ft.} + 1.15F = 7.67 \text{ ft.} + 1.15(6.0 \text{ ft.}) = 14.57 \text{ ft.}$$

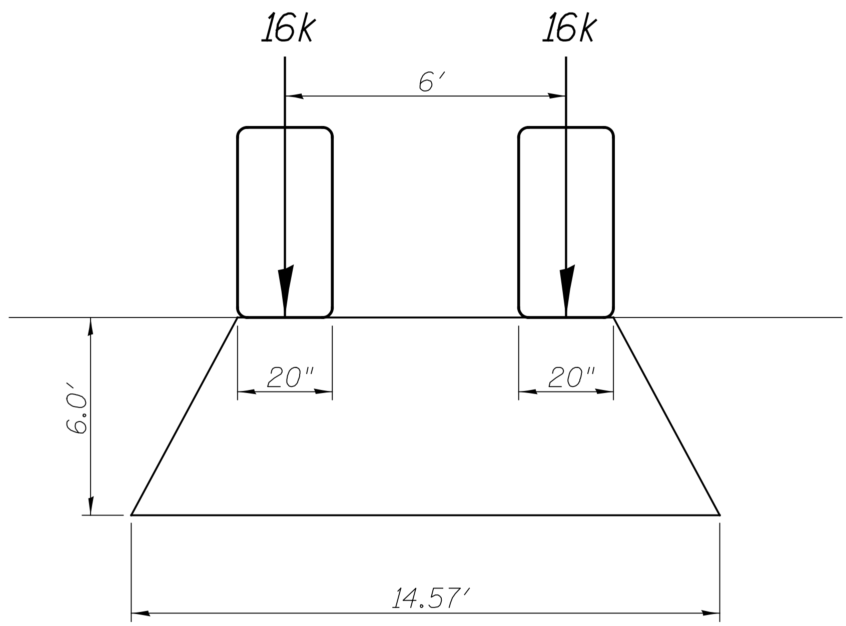

Figure 35 – Worked Example 4 – Truck Load Distribution Transverse to Movement

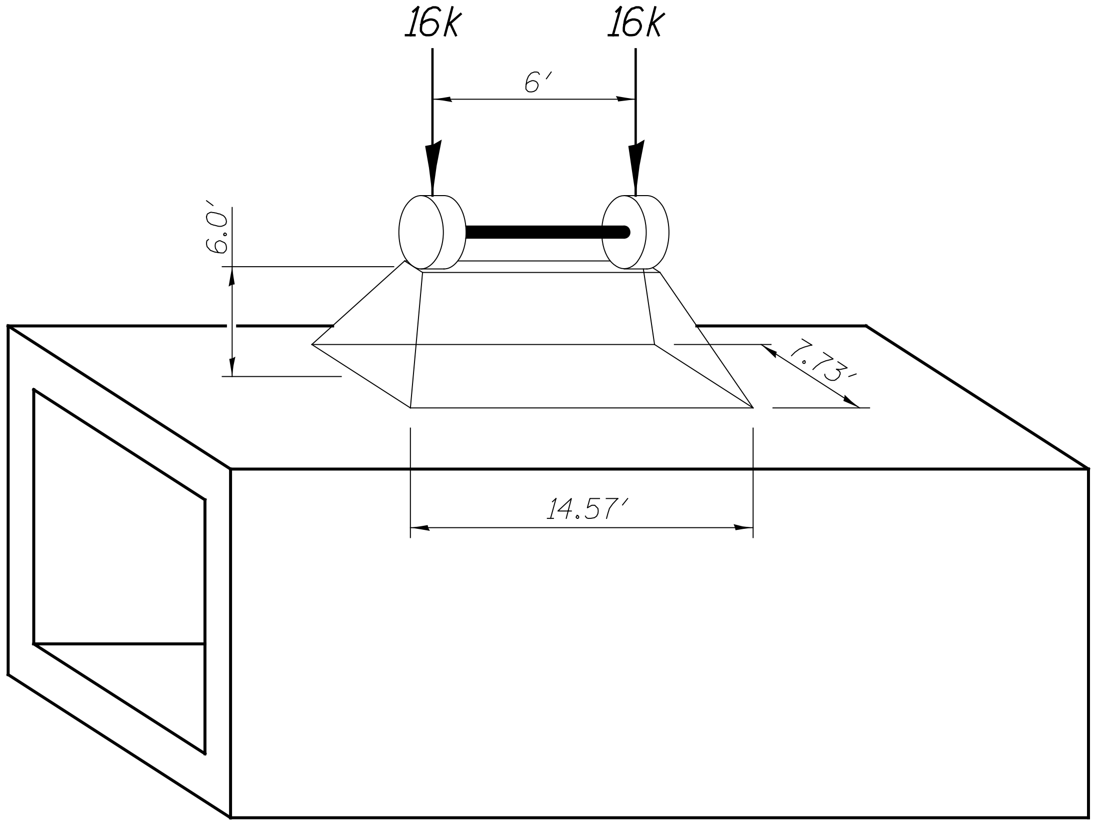

Figure 36 – Worked Example 4 – Isometric of Truck Load Distribution

Live load pressure due to the Truck:

$$w_{LL_{truck}} = \frac{32\ k}{l_p l_t} = \frac{32\ k}{(7.73\ ft.)(14.57\ ft.)} = 0.284\ kip/ft.^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1 + IM)MP = (0.284\ kip/ft.^2)(1 + 0.083)(1.2) = 0.369\ kip/ft.^2$$

The Truck load consists of a 0.369 kip/ft.^{2} pressure with a length of 7.73 ft.

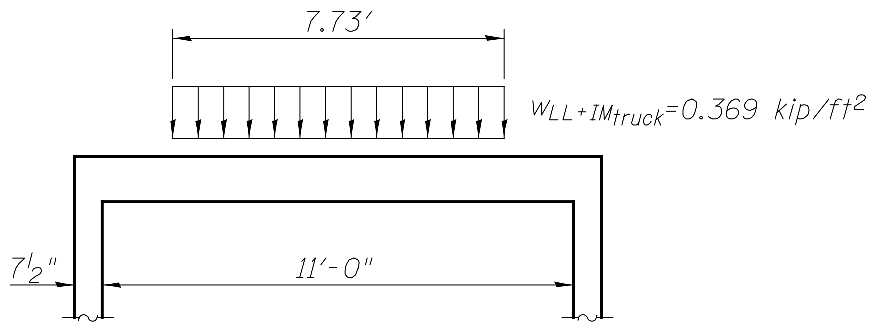

Figure 37 – Worked Example 4 – Truck Load

Tandem

The two axles of the tandem are applied to the structure. The four individual wheels of the tandem are assumed to act together, therefore the pressures from the wheels are assumed to overlap whether or not they actually do. The fill height is greater than 2 feet, therefore use Article 3.6.1.2.6 to determine distribution dimensions.

Patch dimension parallel to the direction of vehicle movement:

$$l_p = 4.83\ ft. + 1.15F = 4.83\ ft. + 1.15(6.0\ ft.) = 11.73\ ft.$$

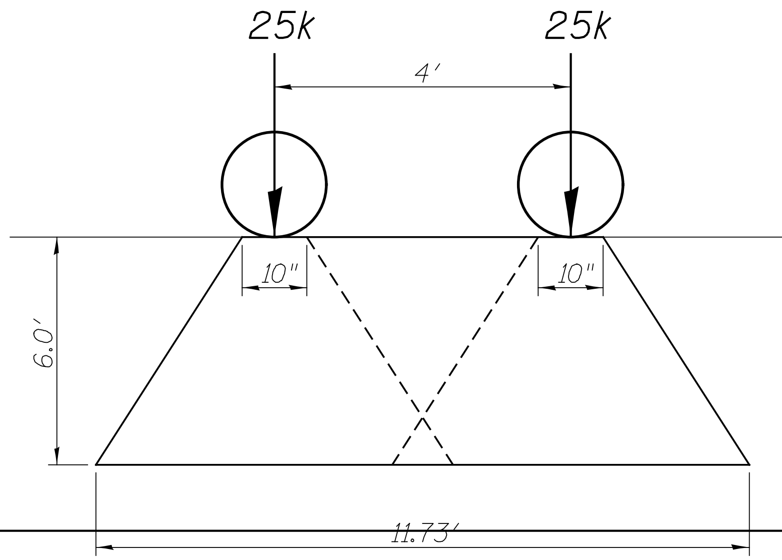

Figure 38 – Worked Example 4 – Tandem Load Distribution Parallel to Movement

Patch dimension transverse to the direction of vehicle movement (Same as for the Truck):

$$l_t = 14.57 \text{ ft.}$$

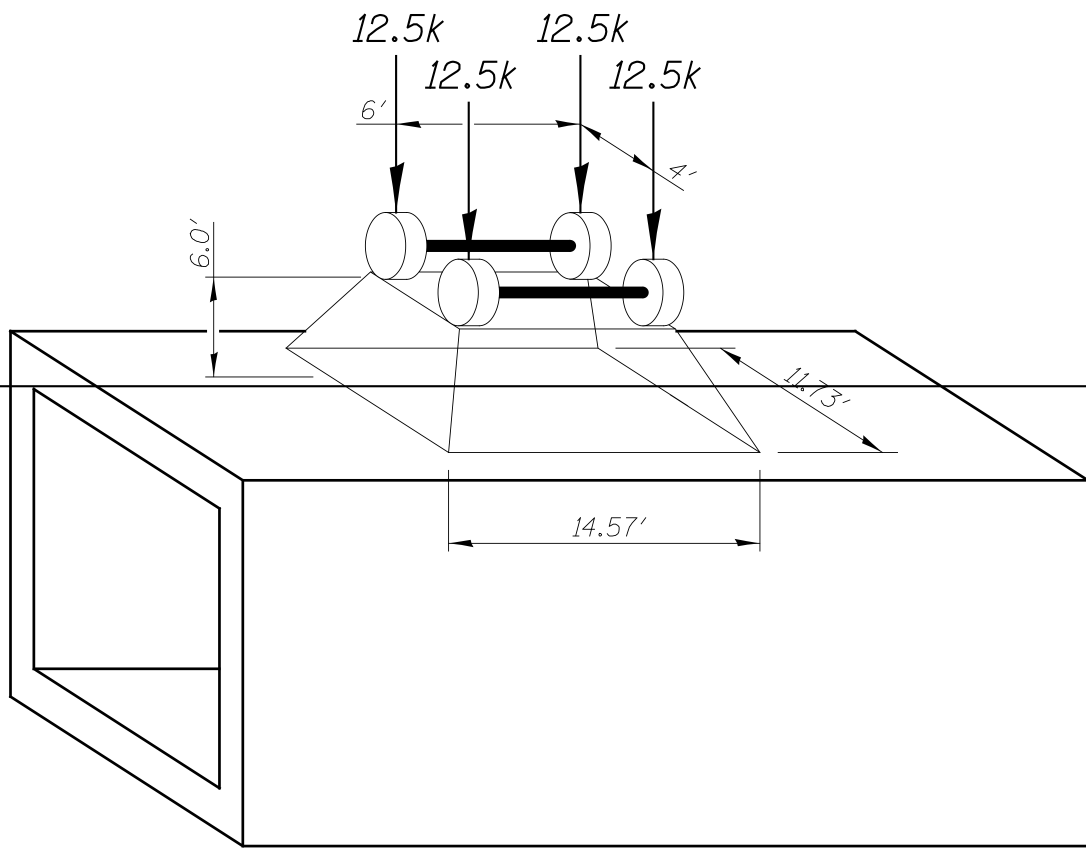

Figure 39 – Worked Example 4 – Isometric of Tandem Load Distribution

Live load pressure due to the Tandem:

$$w_{LL_{tandem}} = \frac{2(25\text{ k})}{l_p l_t} = \frac{2(25\text{ k})}{(11.73\text{ ft.})(14.57\text{ ft.})} = 0.293\text{ kip/ft.}^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.293\text{ kip/ft}^2)(1+0.083)(1.2) = 0.381\text{ kip/ft}^2$$

The Tandem load consists of a 0.381 kip/ft^2 pressure with a length of 11.73'.

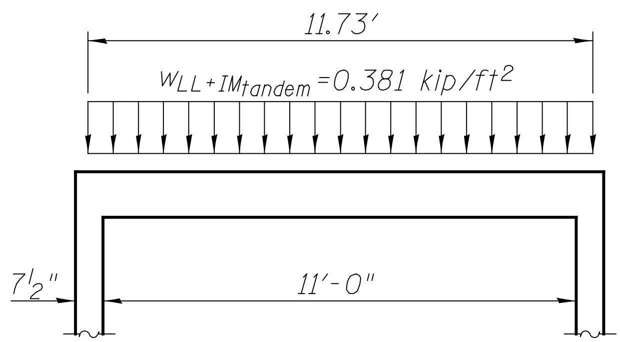

Figure 40 – Worked Example 4 – Tandem Load

Worked Example 5: Live Load Distribution with Fill ≥ 2 Feet and Parallel Traffic

Determine the uniform live loads applied to the top of the top slab of a cast in place single 11 x 7 box culvert with 6 feet of fill. The top slab is 12 in. thick, the bottom slab is 13 in. thick and the sidewalls are 7½ in. thick. The culvert is skewed 90º, therefore live loads traveling perpendicular to the span (parallel to the sidewalls) will be calculated. For cross section of example culvert see Worked Example 4.

Impact

Impact was calculated in Worked Example 4:

$$IM = 0.083$$

Multiple Presence

The multiple presence factor for culvert design is determined assuming one lane of traffic for traffic traveling parallel to the span per Article 12.11.2.1. For traffic traveling perpendicular to the span, the loads should be calculated for multiple lanes of traffic as applicable. For the culvert and fill height in this example, no more than two lanes will be applicable. Per Article 3.6.1.1.2:

$$MP = 1.2 \text{ for one lane}$$

$$MP = 1.0 \text{ for two lanes}$$

Truck (One Lane)

For this example, the rear two axles with the minimum 14 ft. spacing will be the controlling configuration when investigating the truck loading. The fill height is greater than 2 feet, therefore use Article 3.6.1.2.6 to determine distribution dimensions.

Since the traffic travels primarily perpendicular to the span, the patch dimension parallel to the direction of vehicle movement will be calculated according to Article 3.6.1.2.6 and Article 4.6.2.10.3 and the larger of the two dimensions will be used. The patch dimension parallel to the direction of vehicle movement according to Article 3.6.1.2.6 was calculated in Worked Example 4 and is equal to 7.73 ft.. The patch dimension parallel to the direction of vehicle movement according to Article 4.6.2.10.3 is:

$$l_p = 2.17 \text{ ft.} + 0.55S$$

$$S = 11 \text{ ft.}$$

$$l_p = 2.17 \text{ ft.} + 0.55(11 \text{ ft.}) = 8.22 \text{ ft.} > 7.73 \text{ ft.}$$

Article 4.6.2.10.3 controls; use $l_p = 8.22$ ft.

The patch dimension transverse to the direction of vehicle movement for one lane was previously calculated in Worked Example 4:

$$l_{t1} = 14.57 \text{ ft.}$$

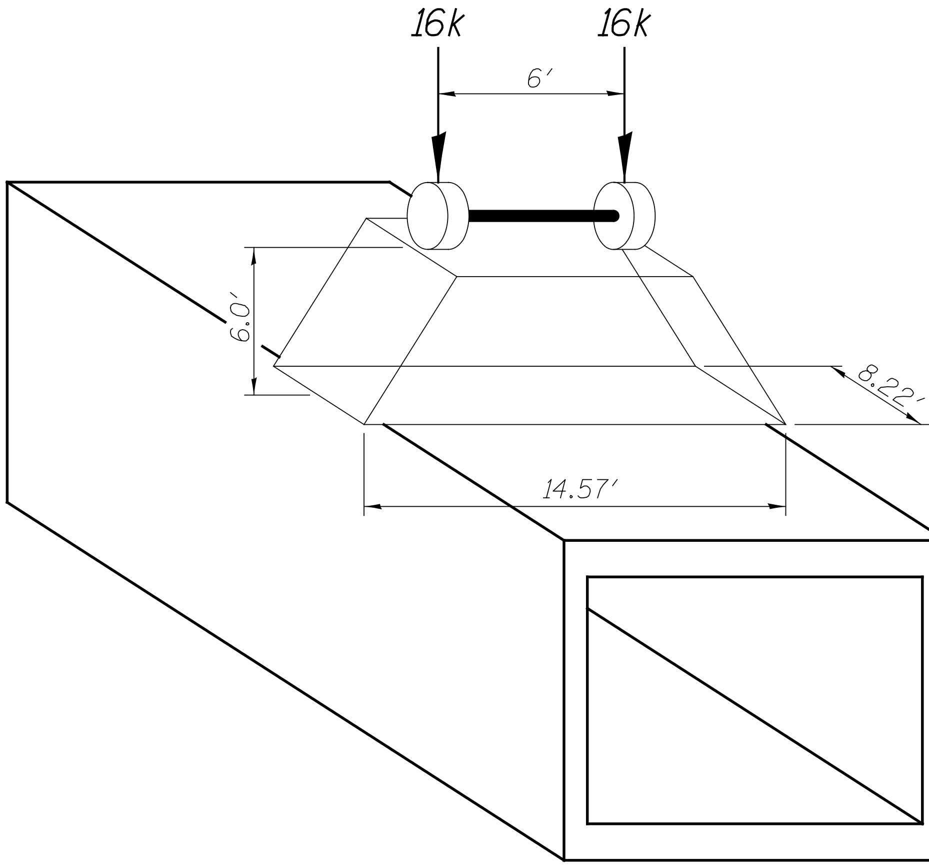

Figure 41 – Worked Example 5 – Isometric of Truck Load Distribution (1 Lane)

Live load pressure due to the Truck:

$$w_{LL_{truck}} = \frac{32\text{ k}}{l_p l_{t1}} = \frac{32\text{ k}}{(8.22\text{ ft.})(14.57\text{ ft.})} = 0.267\text{ kip/ft.}^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1+IM)MP = (0.267\text{ kip/ft.}^2)(1+0.083)(1.2) = 0.\ 347\text{ kip/ft.}^2$$

The one lane Truck load consists of a 0.347 kip/ft^2 pressure with a length of 14.57'.

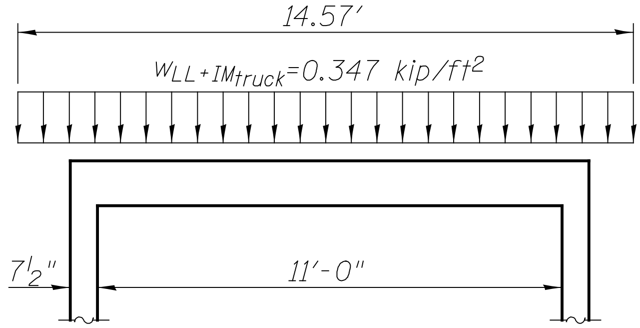

Figure 42 – Worked Example 5 – Truck Load (1 Lane)

Truck (Two Lane)

Since the length of the truck load for the one lane case exceeds the out to out width of the culvert, multiple lane cases will not control the truck load for this example. The calculations are included to illustrate the distribution of the live load for patch loads that overlap.

The patch dimension parallel to the direction of vehicle movement is the same as for the one lane case which was previously calculated and is equal to 8.22'.

The patch dimension transverse to the direction of vehicle movement for one axle was previously calculated and is equal to 14.57'. The spacing between the adjacent axles is according to Article 3.6.1.3.1 which states that the center of any wheel load may not be closer than 2' from the edge of the design lane. Therefore the minimum spacing between adjacent wheels of two axles in adjacent lanes is 4'.

Determine if the patch areas of two axles in adjacent lanes overlap. The clear distance between patch loadings from two axles in adjacent lanes is:

$$g_a = 4' - (l_{t1} - 6') = 4' - (14.57' - 6') = -4.57'$$

The patch loads from two axles in adjacent lanes overlap.

Patch dimension transverse to the direction of vehicle movement for two lanes:

$$l_{t2} = 2(l_{t1}) + g_a = 2(14.57') + (-4.57') = 24.57'$$

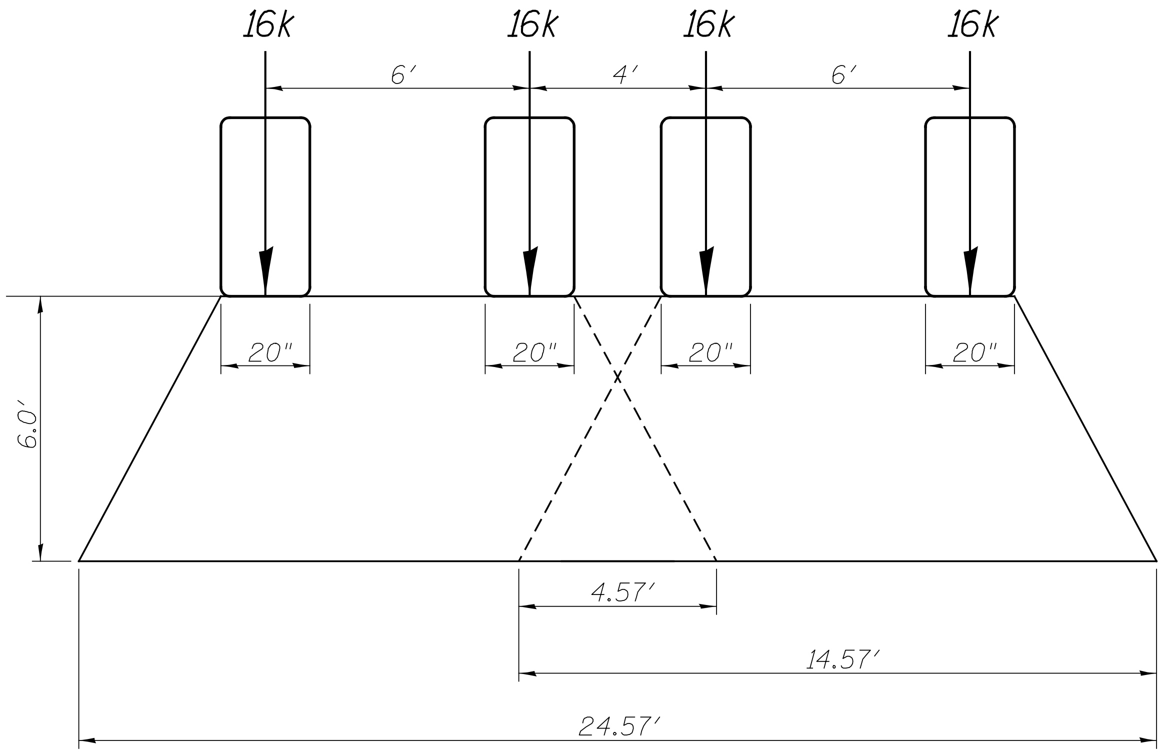

Figure 43 – Worked Example 5 – Truck Load Distribution Transverse to Movement (2 Lane)

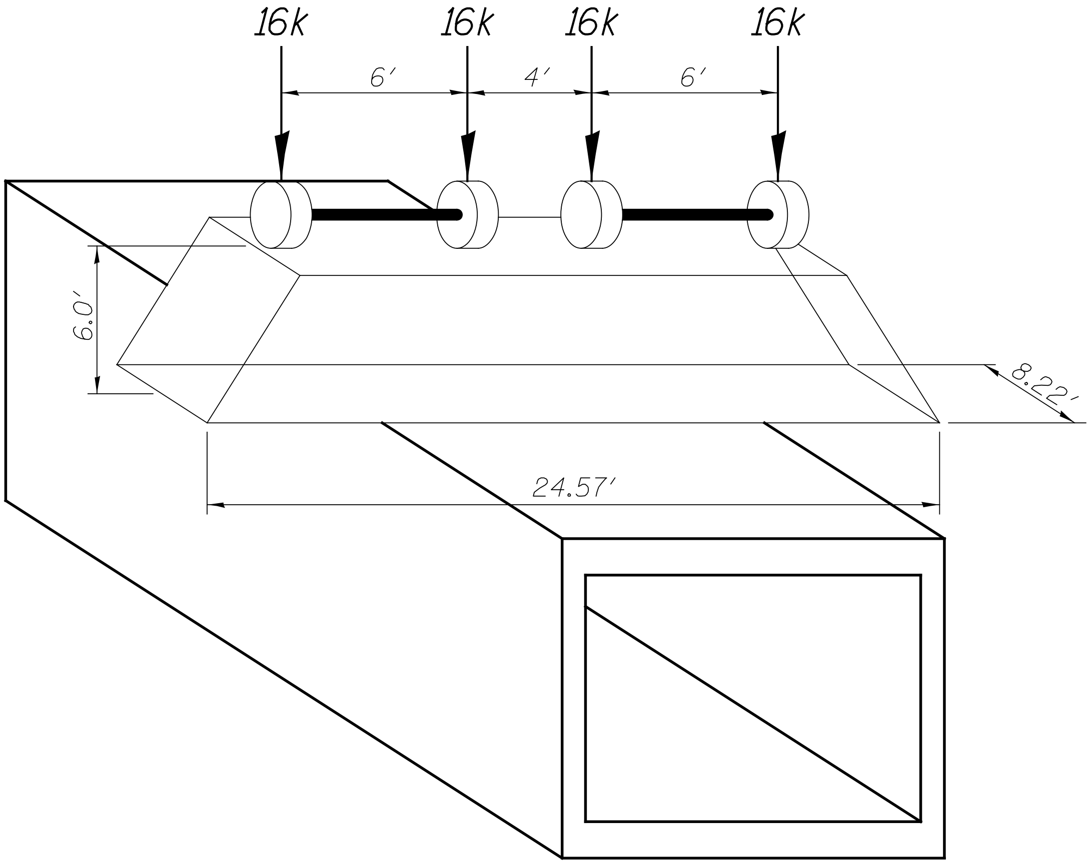

Figure 44 – Worked Example 5 – Isometric of Truck Load Distribution (2 Lane)

Live load pressure due to the Truck:

$$w_{LL_{truck}} = \frac{2(32\ k)}{l_p l_{t2}} = \frac{2(32\ k)}{8.22'(24.57')} = 0.317\ kip/ft^2$$

Live load pressure due to Truck with impact and multiple presence factor:

$$w_{LL+IM_{truck}} = w_{LL_{truck}}(1+IM)MP = (0.317\ kip/ft^2)(1+0.083)(1.0) = 0.343\ kip/ft^2$$

The two lane Truck load consists of a 0.343 kip/ft^2 pressure with a length of 24.57'.

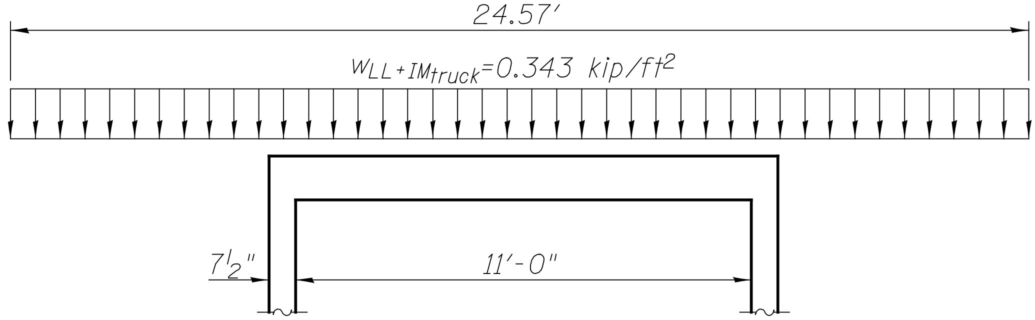

Figure 45 – Worked Example 5 – Truck Load (2 Lane)

Tandem (One Lane)

The two axles of the tandem are applied to the structure. The four individual wheels of the tandem are assumed to act together, therefore the pressures from the wheels are assumed to overlap whether or not they actually do. The fill height is greater than 2 feet, therefore use Article 3.6.1.2.6 to determine distribution dimensions.

Since the traffic travels primarily perpendicular to the span, the patch dimension parallel to the direction of vehicle movement will be calculated according to Article 3.6.1.2.6 and Article 4.6.2.10.3 and the larger of the two dimensions will be used. The patch dimension parallel to the direction of vehicle movement according to Article 3.6.1.2.6 was calculated in Worked Example 4 and is equal to 11.73'. The patch dimension parallel to the direction of vehicle movement according to Article 4.6.2.10.3 is:

$$l_p=6.17'+0.55S=6.17'+0.55(11')=12.22'>11.73'$$

Article 4.6.2.10.3 controls; use l_p = 12.22 ft.

The patch dimension transverse to the direction of vehicle movement for one lane was previously calculated in Worked Example 4 and is:

$$l_{t1} = 14.57 \text{ ft.}$$

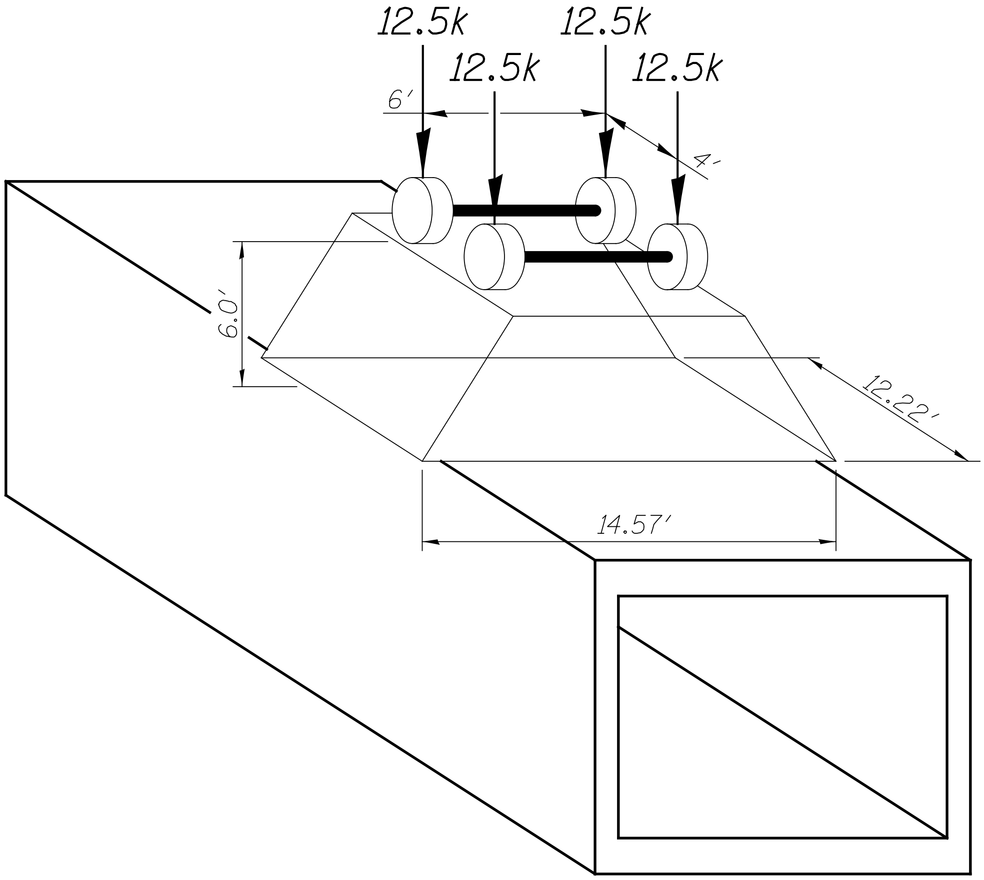

Figure 46 – Worked Example 5 – Isometric of Tandem Load Distribution (1 Lane)

Live load pressure due to the Tandem:

$$w_{LL_{tandem}} = \frac{2(25\ k)}{l_p l_{t1}} = \frac{2(25\ k)}{12.22'(14.57')} = 0.281\ kip/ft^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.281\ kip/ft^2)(1+0.083)(1.2) = 0.365\ kip/ft.^2$$

The one lane Tandem load consists of a 0.365 kip/ft.^{2} pressure with a length of 14.57 ft.

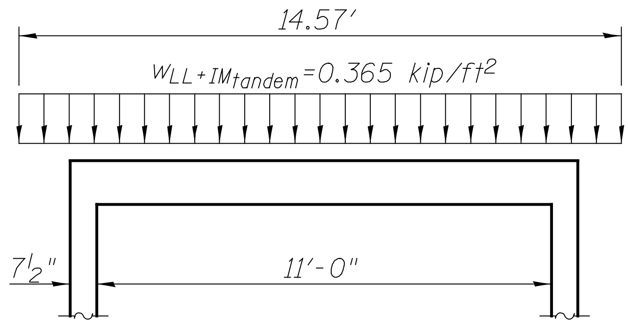

Figure 47 – Worked Example 5 – Tandem Load (1 Lane)

Tandem (Two Lane)

Since the length of the tandem load for the one lane case exceeds the out to out width of the culvert, multiple lane cases will not control the tandem load for this example. The calculations are included to illustrate the distribution of the live load for patch loads that overlap.

The patch dimension parallel to the direction of vehicle movement is the same as for the one lane case which was previously calculated and is equal to 12.22 ft.

The patch dimension transverse to the direction of vehicle movement for one axle and the distance between the patch areas for two axles in adjacent lanes is the same as for the truck which were previously calculated and are equal to 14.57 ft. and −4.57 ft., respectively. The patch dimension transverse to the direction of vehicle movement for two lanes is also the same as for the truck:

$$l_{t2} = 24.57 \text{ ft.}$$

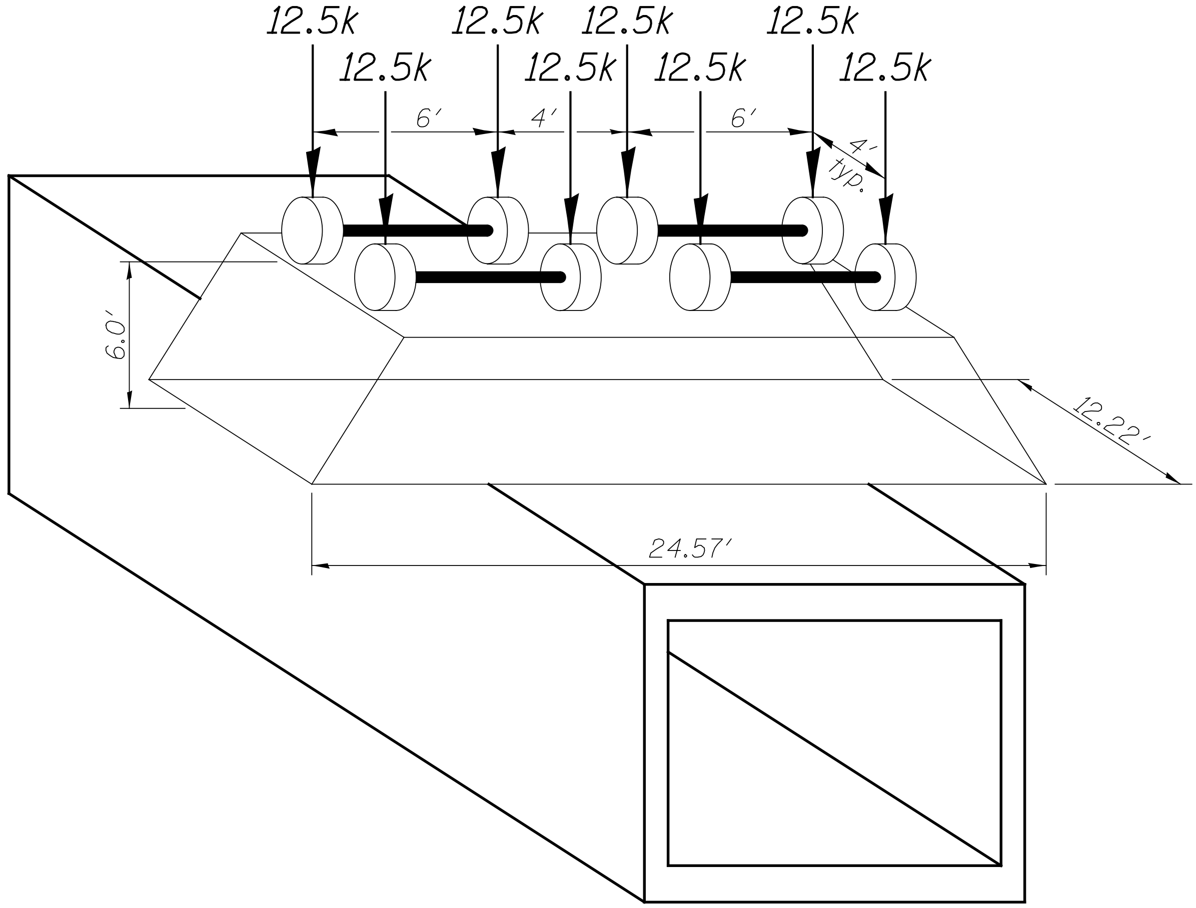

Figure 48 – Worked Example 5 – Isometric of Tandem Load Distribution (2 Lane)

Live load pressure due to the Tandem:

$$w_{LL_{tandem}} = \frac{4(25\text{ k})}{l_p l_{t2}} = \frac{4(25\text{ k})}{12.22\text{ ft.}\ (24.57\text{ ft.}\ )} = 0.333\text{ kip/ft.}^2$$

Live load pressure due to Tandem with impact and multiple presence factor:

$$w_{LL+IM_{tandem}} = w_{LL_{tandem}}(1+IM)MP = (0.333\text{ kip/ft.}^2\ )(1+0.083)(1.0) = 0.361\text{ kip/ft.}^2$$

The two lane Tandem load consists of a 0.361 kip/ft^2 pressure with a length of 24.57'.

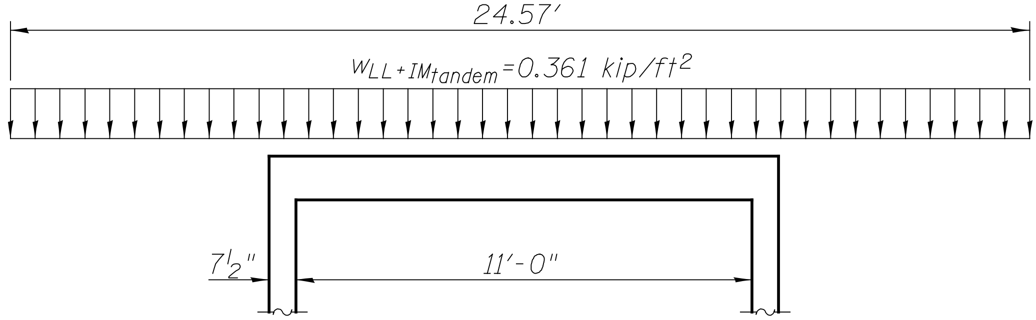

Figure 49 – Worked Example 5 – Tandem Load (2 Lane)

For single box culverts with skews of 90º or multiple box culverts with skews greater than 30º, live loads traveling parallel to the span should also be checked and the largest force effects from either direction of travel should always be used for design. Therefore, the force effects would be calculated for the loads in this Worked Example and compared to those calculated using the loads from Worked Example 4 and the larger values would be used to design the culvert.

Worked Example 6: Horizontal Loads

Determine the horizontal loads applied to the sidewall of a cast in place single 11 x 10 box culvert with 6 feet of fill. The top slab is 12" thick, the bottom slab is 13 in. thick and the sidewalls are 10 in. thick. The pavement thickness is 12" and the future wearing surface is 50 lb/ft.[2]. For this example, the "supports" for the sidewall design span are located 0.42' from the inside faces of the top and bottom slab. The culvert is not skewed.

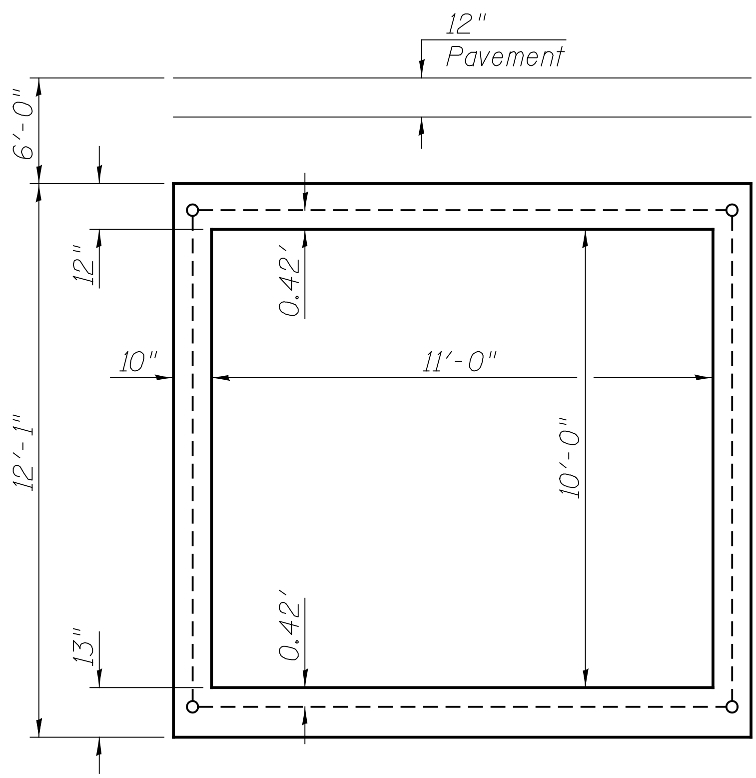

Figure 50 – Worked Example 6 – Culvert Cross Section

Horizontal Earth Pressure – EH

Determine the horizontal soil pressure at the top of the top slab and at the bottom of the bottom slab which would be used to determine the maximum and minimum axial forces in the top and bottom slab. Per Article 3.11.5.1, the general equation for the calculation of lateral soil pressure is:

$$p = k\gamma_s z$$

$$k = 0.5$$

$$\gamma_s = 0.120 \text{ kcf}$$

The depth of soil to the top of the culvert is:

$$H = F - t_{pavt} = 6.0 \text{ ft.} - 1.0 \text{ ft.} = 5.0 \text{ ft.}$$

The depth of soil to the bottom of the bottom slab is:

$$D_{bottom} = H + \frac{t_{topslab}}{12} + R + \frac{t_{bottomslab}}{12} = 5.0 \text{ ft.} + \frac{12 \text{ in.}}{12} + 10 \text{ ft.} + \frac{13 \text{ in.}}{12} = 17.08 \text{ ft.}$$

The maximum pressure at the top of the culvert and at the bottom of the culvert is:

$$p_{EH\ top(max)} = k\gamma_s H = (0.5)\left(0.120 \text{ kip/ft.}^3\right)(5.0 \text{ ft.}) = 0.300 \text{ kip/ft.}^2$$

$$p_{EH\ bottom(max)} = k\gamma_s D_{bottom} = (0.5)\left(0.120 \text{ kip/ft.}^3\right)(17.08 \text{ ft.}) = 1.025 \text{ kip/ft.}^2$$

Reduce the maximum pressure by 50% to calculate the minimum pressure per Article 3.11.7:

$$p_{EH\ top(min)} = p_{EH\ top(max)}(0.5) = (0.300 \text{ kip/ft.}^2)(0.5) = 0.150 \text{ kip/ft.}^2$$

$$p_{EH\ bottom(min)} = p_{EH\ bottom(max)}(0.5) = (1.025 \text{ kip/ft.}^2)(0.5) = 0.513 \text{ kip/ft.}^2$$

Determine the horizontal soil pressure at the “supports” which would be used to determine the shears and moments in the sidewall. These pressures are not used to determine axial forces, therefore minimum pressures are not calculated.

The depth of soil to the top “support” is:

$$z_{top} = F - t_{pavt} + \frac{t_{topslab}}{12} - l_{support} = 6.0 \text{ ft.} - 1.0 \text{ ft.} + \frac{12 \text{ in.}}{12} - 0.42 \text{ ft.} = 5.58 \text{ ft.}$$

The depth of soil to the bottom “support” is:

$$z_{bottom} = F - t_{pavt} + \frac{t_{topslab}}{12} + R + l_{support} = 6.0 \text{ ft.} - 1.0 \text{ ft.} + \frac{12 \text{ in.}}{12} + 10 \text{ ft.} + 0.42 \text{ ft.} = 16.42 \text{ ft.}$$

The maximum pressures at the top and bottom “supports” are:

$$p_{EH\ top} = k\gamma_s z_{top} = (0.5)\left(0.120 \text{ kip/ft.}^3\right)(5.58 \text{ ft.}) = 0.335 \text{ kip/ft.}^2$$

$$p_{EH\ bottom} = k\gamma_s z_{bottom} = (0.5)\left(0.120 \text{ kip/ft.}^3\right)(16.42 \text{ ft.}) = 0.985 \text{ kip/ft.}^2$$

Uniform Surcharge Load – ES

Apply pavement and FWS as a surcharge load. Since the pavement is 12 in. thick and the future wearing surface load is 50 lb/ft.^{2}, w_{DW} = 0.200 kip/ft.^{2}. Per Article 3.11.6.1, the general equation for the calculation of uniform surcharge pressure is:

$$\Delta_p = k_s q_s$$

$$k_s = 0.5$$

$$q_s = w_{DW} = 0.200 \text{ kip/ft.}^2$$

$$\Delta_{pES} = (0.5)\left(0.200 \text{ kip/ft.}^2\right) = 0.100 \text{ kip/ft.}^2$$

Live Load Surcharge – LS

Per Article 3.11.6.4, the general equation for the calculation of live load surcharge pressure is:

$$\Delta_p = k\gamma_s h_{eq}$$

$$k = 0.5$$

$$\gamma_s = 0.120 \text{ kip/ft/}^3$$

There is no skew therefore use Table 3.11.6.4-1. Enter the table with the distance from the top of the pavement to the bottom of the bottom slab. Distance from the top of pavement to the bottom of the bottom slab is 18.08 ft..

$$h_{eq}\text{=2.00 ft.} + \frac{(20 \text{ ft. - } 18.08 \text{ ft.})}{(20 \text{ ft. - } 10 \text{ ft.})}(3.00 \text{ ft. - } 2.00 \text{ ft.}) = 2.19 \text{ ft.}$$

$$\Delta_{pLS} = (0.5)(0.120 \text{ kip/ft.}^3)(2.19 \text{ ft.}) = 0.131 \text{ kip/ft.}^2$$

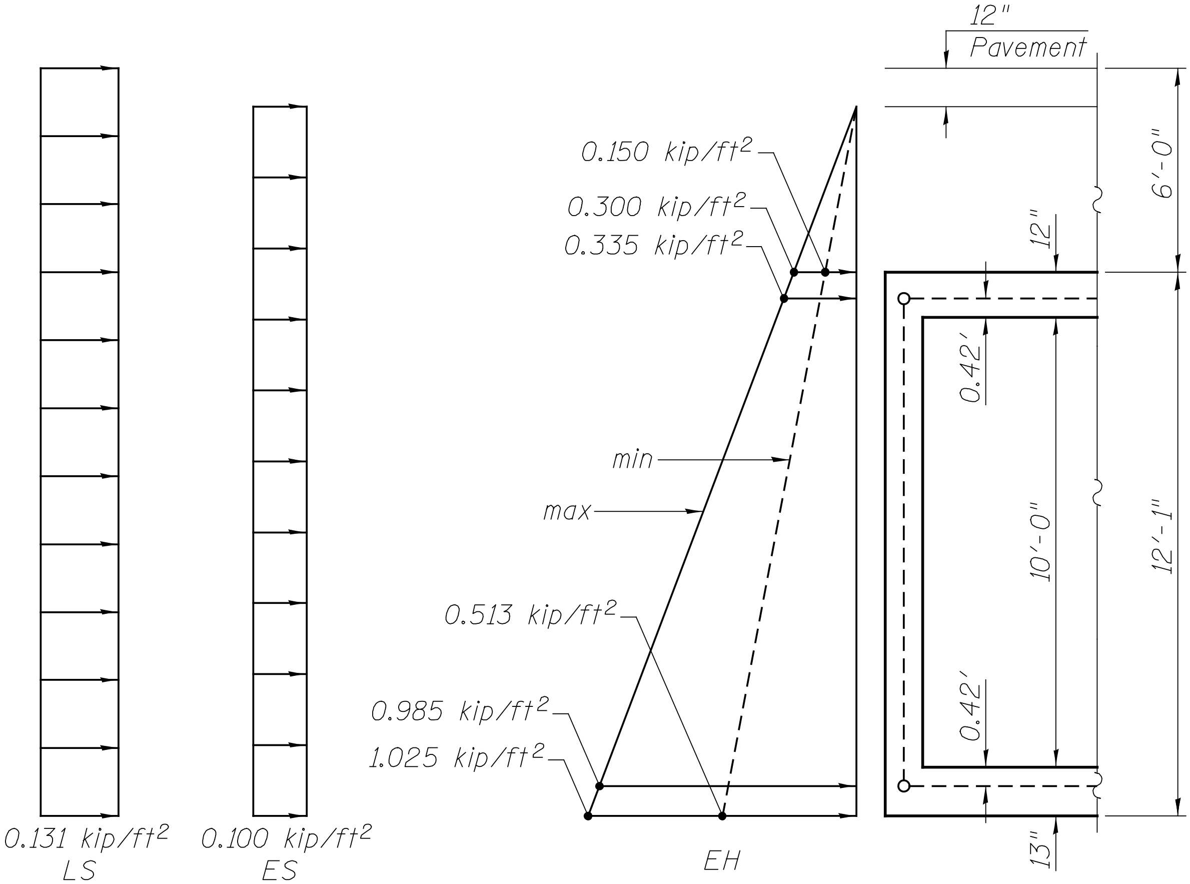

Figure 51 – Worked Example 6 – Horizontal Load Summary