

coefficient of cohesion (c) and this product subtracted from the value of the trench load term.

FLUID LOAD

Fluid weight typically is about the same order of magnitude as pipe weight and generally represents a significant portion of the pipe design load only for large diameter pipe under relatively shallow fills. Fluid weight has been neglected in the traditional design procedures of the past, including the Marston Spangler design method utilizing the B and C beddings. There is no documentation of concrete pipe failures as a result of neglecting fluid load. However, some specifying agencies such as AASHTO and CHBDC, now require that the weight of the fluid inside the pipe always be considered when determining the D-load.

The Sixteenth Edition of the AASHTO Standard Specifications For Highway Bridges states: "The weight of fluid, W_f , in the pipe shall be considered in design based on a fluid weight of 62.4 lbs/cu.ft, unless otherwise specified."

DETERMINATION OF LIVE LOAD

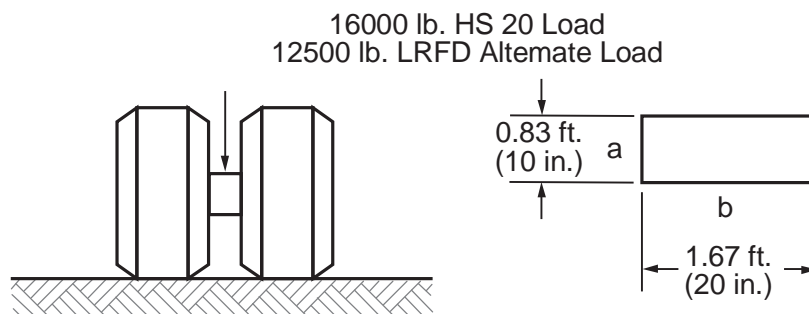
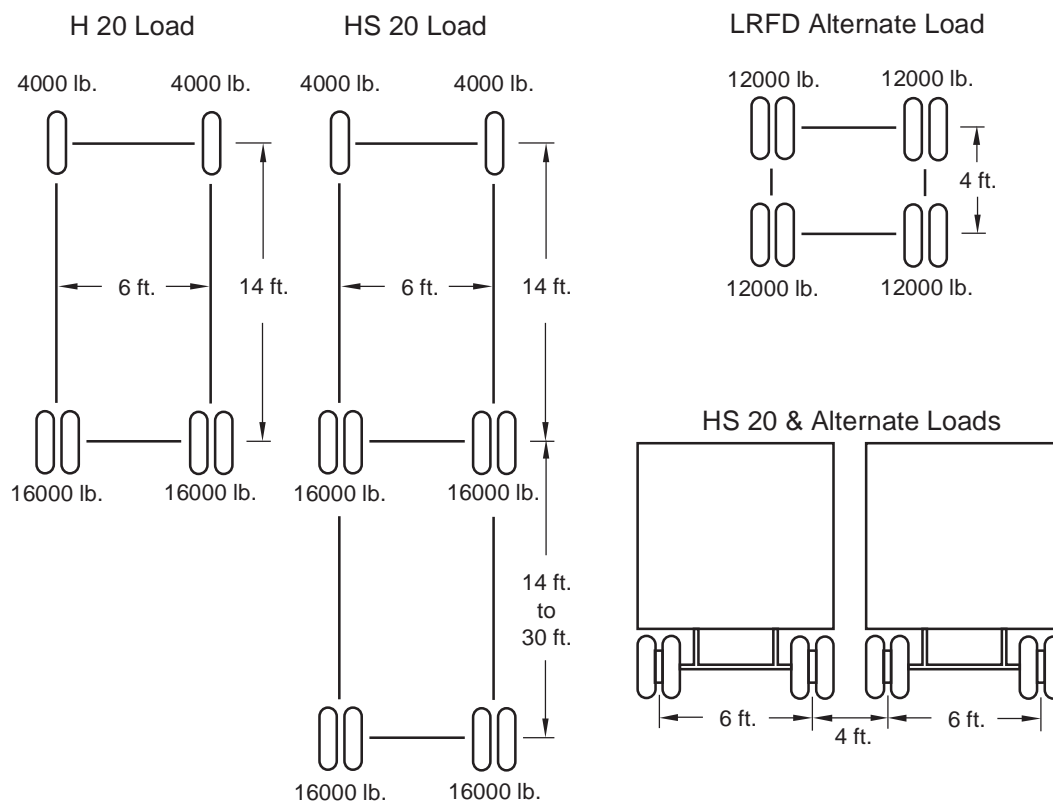
To determine the required supporting strength of concrete pipe installed under asphalts, other flexible pavements, or relatively shallow earth cover, it is necessary to evaluate the effect of live loads, such as highway truck loads, in addition to dead loads imposed by soil and surcharge loads.

If a rigid pavement or a thick flexible pavement designed for heavy duty traffic is provided with a sufficient buffer between the pipe and pavement, then the live load transmitted through the pavement to the buried concrete pipe is usually negligible at any depth. If any culvert or sewer pipe is within the heavy duty traffic highway right-of-way, but not under the pavement structure, then such pipe should be analyzed for the effect of live load transmission from an unsurfaced roadway, because of the possibility of trucks leaving the pavement.

The AASHTO design loads commonly used in the past were the HS 20 with a 32,000 pound axle load in the Normal Truck Configuration, and a 24,000 pound axle load in the Alternate Load Configuration.

The AASHTO LRFD designates an HL 93 Live Load. This load consists of the greater of a HS 20 with 32,000 pound axle load in the Normal Truck Configuration, or a 25,000 pound axle load in the Alternate Load Configuration. In addition, a 640 pound per linear foot Lane Load is applied across a 10 foot wide lane at all depths of earth cover over the top of the pipe, up to a depth of 8 feet. This Lane Load converts to an additional live load of 64 pounds per square foot, applied to the top of the pipe for any depth of burial less than 8 feet. The average pressure intensity caused by a wheel load is calculated by Equation 4.12. The Lane Load intensity is added to the wheel load pressure intensity in Equation 4.13.

The HS 20, 32,000 pound and the Alternate Truck 25,000 pound design axle are carried on dual wheels. The contact area of the dual wheels with the ground is assumed to be rectangle, with dimensions presented in Illustration 4.9.

Illustration 4.9 AASHTO Wheel Load Surface Contact Area (Foot Print)**Illustration 4.10** AASHTO Wheel Loads and Wheel Spacings

Impact Factors. The AASHTO LRFD Standard applies a dynamic load allowance, sometimes called Impact Factor, to account for the truck load being non-static. The dynamic load allowance, IM, is determined by Equation 4.11:

$$IM = \frac{33(1.0 - 0.125H)}{100} \quad (4.11)$$

where:

H = height of earth cover over the top of the pipe, ft.

Load Distribution. The surface load is assumed to be uniformly spread on any horizontal subsoil plane. The spread load area is developed by increasing the length and width of the wheel contact area for a load configuration as shown in Illustration 4.13 for a dual wheel. On a horizontal soil plane, the dimensional increases to the wheel contact area are based on height of earth cover over the top of the pipe as presented in Illustration 4.11 for two types of soil.

Illustration 4.11 Dimensional Increase Factor, AASHTO LRFD

Soil Type	Dimensional Increase Factor
LRFD select granular	1.15H
LRFD any other soil	1.00H

As indicated by Illustrations 4.14 and 4.15, the spread load areas from adjacent wheels will overlap as height of earth cover over the top of the pipe increases. At shallow depths, the maximum pressure will be developed by an HS 20 dual wheel, since at 16,000 pounds it applies a greater load than the 12,500 pound Alternate Load. At intermediate depths, the maximum pressure will be developed by the wheels of two HS 20 trucks in the passing mode, since at 16,000 pounds each, the two wheels apply a greater load than the 12,500 pounds of an Alternate Load wheel. At greater depths, the maximum pressure will be developed by wheels of two Alternate Load configuration trucks in the passing mode, since at 12,500 pounds each, the four wheels apply the greatest load (50,000 pounds). Intermediate depths begin when the spread area of dual wheels of two HS 20 trucks in the passing mode meet and begin to overlap. Greater depths begin when the spread area of two single dual wheels of two Alternate Load configurations in the passing mode meet and begin to overlap.

Since the exact geometric relationship of individual or combinations of surface wheel loads cannot be anticipated, the most critical loading configurations along with axle loads and rectangular spread load area are presented in Illustration 4.12 for the two AASHTO LRFD soil types.

Illustration 4.12 LRFD Critical Wheel Loads and Spread Dimensions at the Top of the Pipe for:

Select Granular Soil Fill

H, ft	P, lbs	Spread a, ft	Spread b, ft	Illustration
$H < 2.03$	16,000	$a + 1.15H$	$b + 1.15H$	4.13
$2.03 \leq H < 2.76$	32,000	$a + 4 + 1.15H$	$b + 4 + 1.15H$	4.14
$2.76 \leq H$	50,000	$a + 4 + 1.15H$	$b + 4 + 1.15H$	4.15

Other Soils

H, ft	P, lbs	Spread a, ft	Spread b, ft	Illustration
$H < 2.33$	16,000	$a + 1.00H$	$b + 1.00H$	4.13
$2.33 \leq H < 3.17$	32,000	$a + 4 + 1.00H$	$b + 4 + 1.00H$	4.14
$3.17 \leq H$	50,000	$a + 4 + 1.00H$	$b + 4 + 1.00H$	4.15

Illustration 4.13 Spread Load Area - Single Dual Wheel

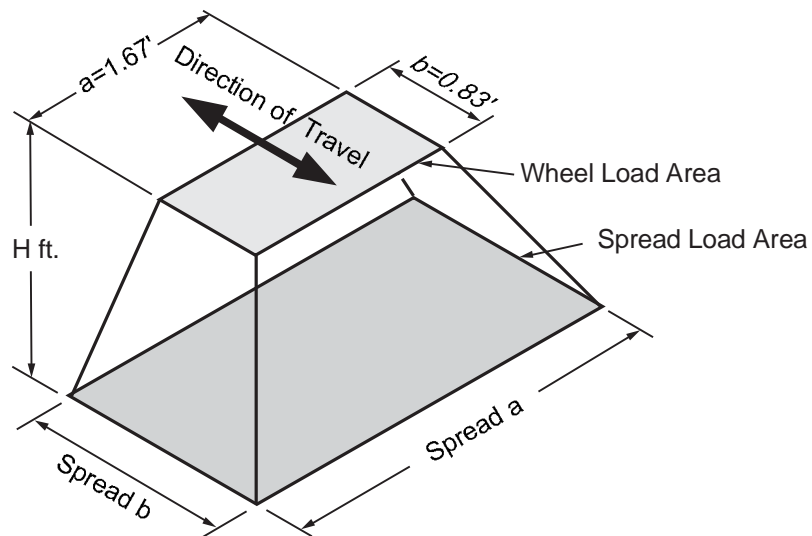


Illustration 4.14 Spread Load Area - Two Single Dual Wheels of Trucks in Passing Mode

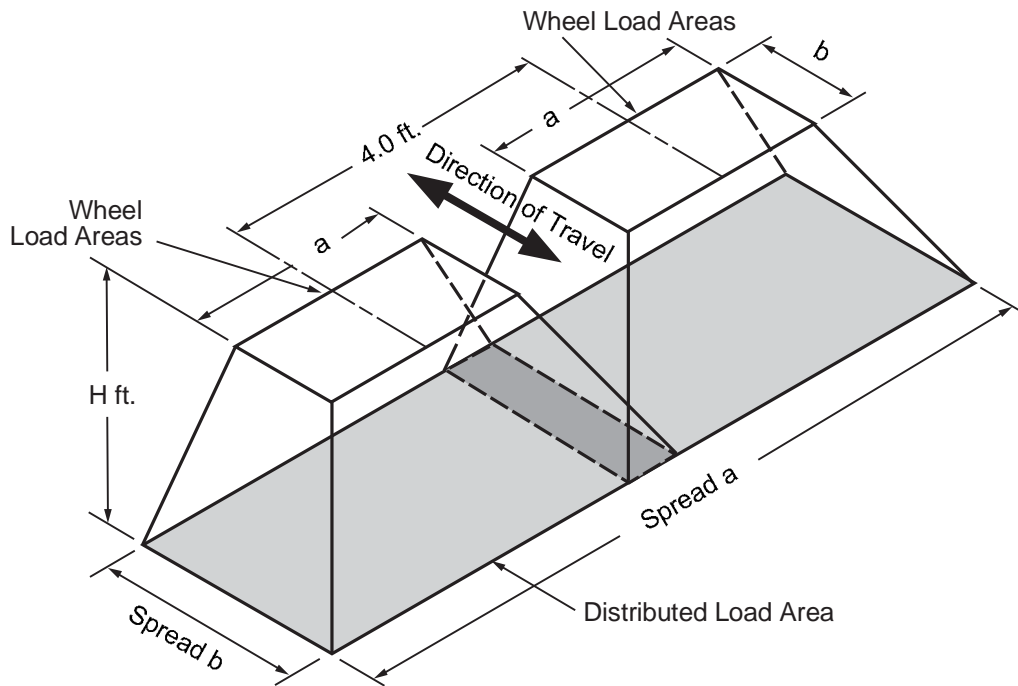
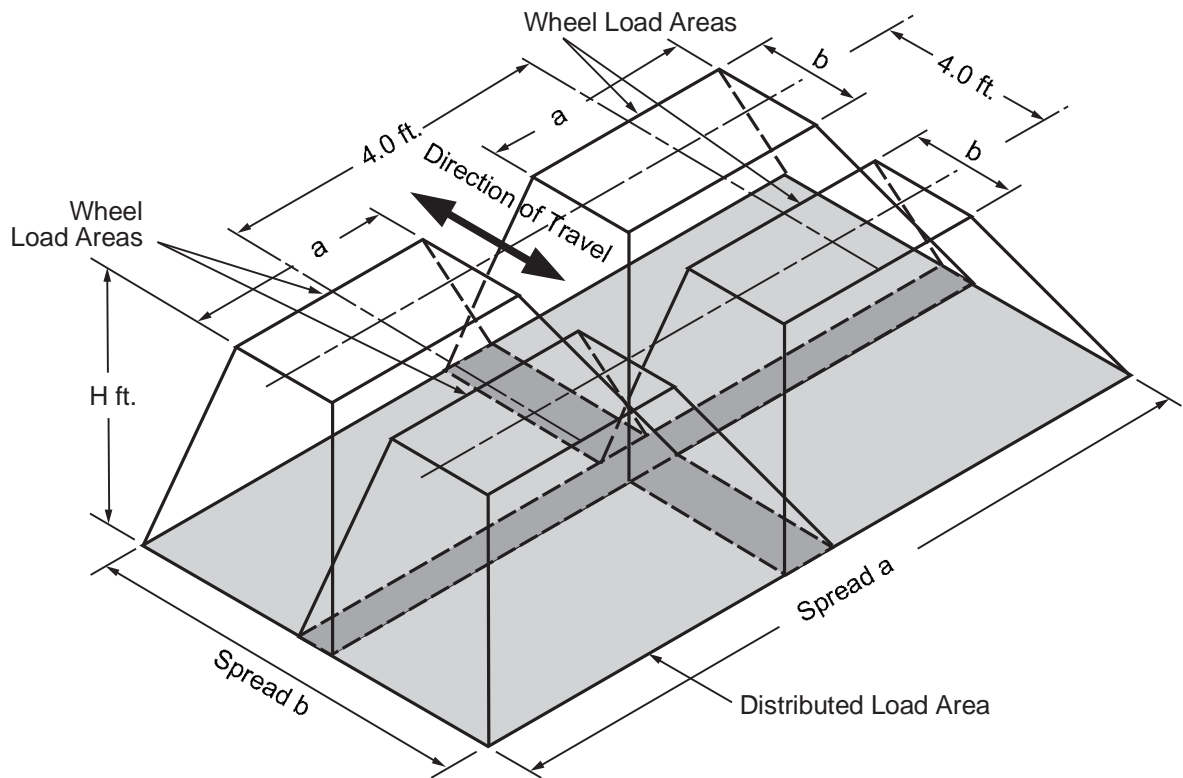


Illustration 4.15 Spread Load Area - Two Single Dual Wheels of Two Alternate Loads in Passing Mode



Average Pressure Intensity. The wheel load average pressure intensity on the subsoil plane at the outside top of the concrete pipe is:

$$w = \frac{P(1 + IM)}{A} \quad (4.12)$$

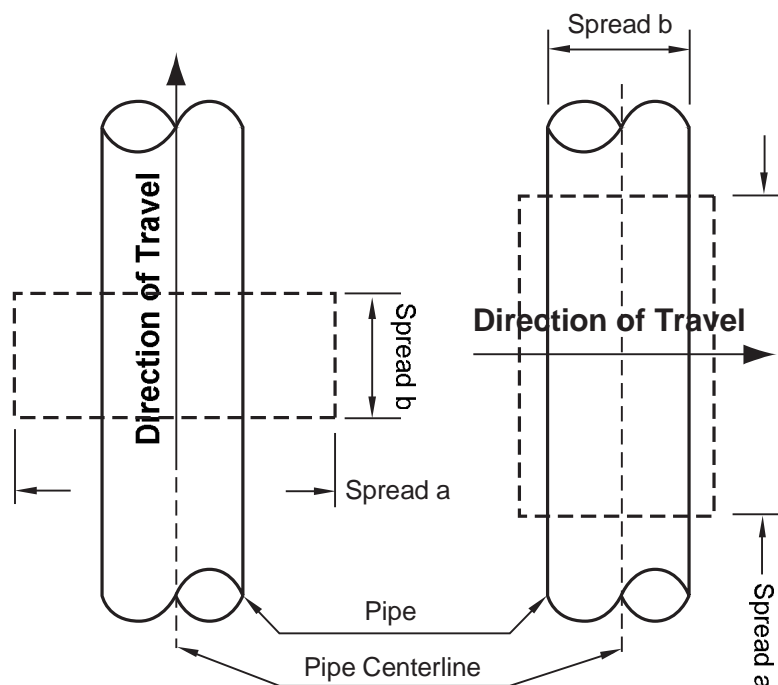
where:

- w = wheel load average pressure intensity, pounds per square foot
- P = total live wheel load applied at the surface, pounds
- A = spread wheel load area at the outside top of the pipe, square feet
- IM = dynamic load allowance

From the appropriate Table in Illustration 4.12, select the critical wheel load and spread dimensions for the height of earth cover over the outside top of the pipe, H. The spread live load area is equal to Spread a times Spread b. Select the appropriate dynamic load allowance, using Equation 4.11.

Total Live Load. A designer is concerned with the maximum possible loads, which occur when the distributed load area is centered over the buried pipe. Depending on the pipe size and height of cover, the most critical loading orientation can occur either when the truck travels transverse or parallel to the centerline of the pipe. Illustration 4.16 shows the dimensions of the spread load area, A, as related to whether the truck travel is transverse or parallel to the centerline of the pipe.

Illustration 4.16 Spread Load Area Dimensions vs Direction of Truck



Unless you are certain of the pipeline orientation, the total live load in pounds, W_T , must be calculated for each travel orientation, and the maximum calculated value must be used in Equation 4.14 to calculate the live load on the pipe in

pounds per linear foot.

The LRFD requires a Lane Load, L_L , of 64 pounds per square foot on the top of the pipe at any depth less than 8 feet.

The total live load acting on the pipe is:

$$W_T = (w + L_L) L S_L \quad (4.13)$$

where:

- W_T = total live load, pounds
- w = wheel load average pressure intensity, pounds per square foot (at the top of the pipe)
- L_L = lane loading if AASHTO LRFD is used, pounds per square foot
- $0 \leq H < 8$, $L_L = 64$, pounds per square foot
- $H \geq 8$, $L_L = 0$
- L = dimension of load area parallel to the longitudinal axis of pipe, feet
- S_L = outside horizontal span of pipe, B_c , or dimension of load area transverse to the longitudinal axis of pipe, whichever is less, feet

Total Live Load in Pounds per Linear Foot. The total live load in pounds per linear foot, W_L , is calculated by dividing the Total Live Load, W_T , by the Effective Supporting Length, L_e (See Illustration 4.17), of the pipe:

$$W_L = \frac{W_T}{L_e} \quad (4.14)$$

where:

- W_L = live load on top of pipe, pounds per linear foot
- L_e = effective supporting length of pipe, feet

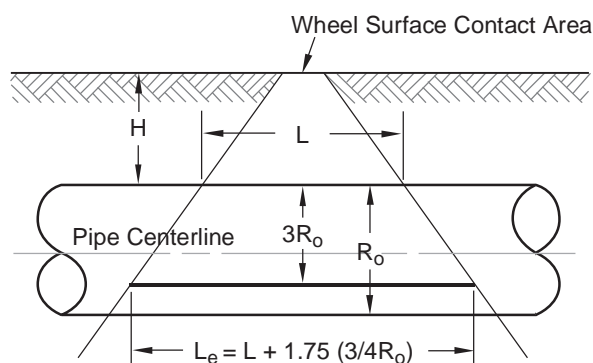
The effective supporting length of pipe is:

$$L_e = L + 1.75(3/4 R_o)$$

where:

- R_o = outside vertical Rise of pipe, feet

Illustration 4.17 Effective Supporting Length of Pipe



Airports. The distribution of aircraft wheel loads on any horizontal plane in the soil mass is dependent on the magnitude and characteristics of the aircraft loads, the aircraft's landing gear configuration, the type of pavement structure and the subsoil conditions. Heavier gross aircraft weights have resulted in multiple wheel undercarriages consisting of dual wheel assemblies and/or dual tandem assemblies. The distribution of wheel loads through rigid pavement are shown in Illustration 4.18.

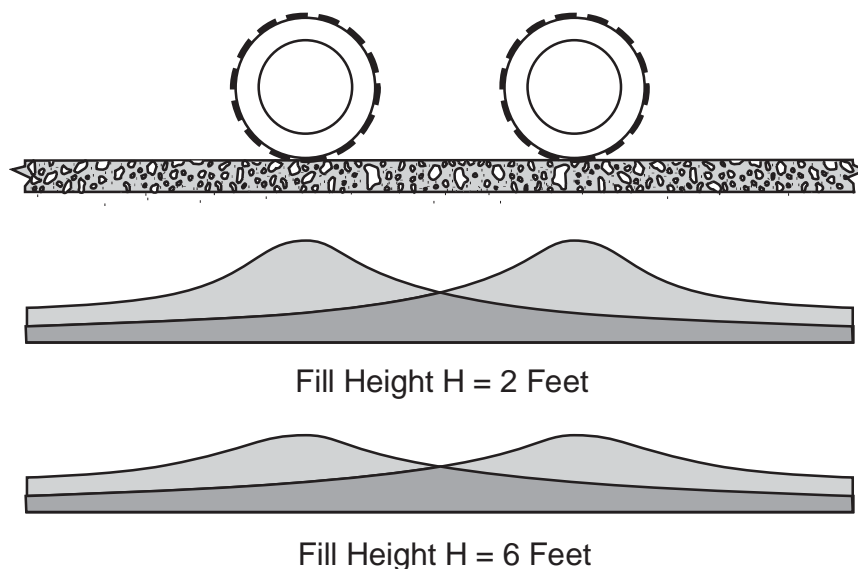
If a rigid pavement is provided, an aircraft wheel load concentration is distributed over an appreciable area and is substantially reduced in intensity at the subgrade. For multi-wheeled landing gear assemblies, the total pressure intensity is dependent on the interacting pressures produced by each individual wheel. The maximum load transmitted to a pipe varies with the pipe size under consideration, the pipe's relative location with respect to the particular landing gear configuration and the height of fill between the top of the pipe and the subgrade surface.

For a flexible pavement, the area of the load distribution at any plane in the soil mass is considerably less than for a rigid pavement. The interaction of pressure intensities due to individual wheels of a multi-wheeled landing gear assembly is also less pronounced at any given depth of cover.

In present airport design practices, the aircraft's maximum takeoff weight is used since the maximum landing weight is usually considered to be about three fourths the takeoff weight. Impact is not considered, as criteria are not yet available to include dynamic effects in the design process.

Rigid Pavement.

Illustration 4.18 Aircraft Pressure Distribution, Rigid Pavement



The pressure intensity is computed by the equation:

$$p(H,X) = \frac{CP}{R_s^2} \quad (4.15)$$

where:

- P = Load at the surface, pounds
- C = Load coefficient, dependent on the horizontal distance (X), the vertical distance (H), and R_s
- R_s = Radius of Stiffness of the pavement, feet

R_s is further defined as:

$$R_s = \sqrt[4]{\frac{(Eh)^3}{12(1-\mu^2)k}} \quad (4.16)$$

where:

- E = modulus of elasticity of the pavement, pounds per square inch
- h = pavement thickness, inches
- μ = Poisson's ratio (generally assumed 0.15 for concrete pavement)
- k = modulus of subgrade reaction, pounds per cubic inch

Tables 46 through 50 present pressure coefficients in terms of the radius of stiffness as developed by the Portland Cement Association and published in the report "Vertical Pressure on Culverts Under Wheel Loads on Concrete Pavement Slabs." 3

Values of radius of stiffness are listed in Table 52 for pavement thickness and modulus of subgrade reaction.

Tables 53 through 55 present aircraft loads in pounds per linear foot for circular, horizontal elliptical and arch pipe. The Tables are based on equations 4.15 and 4.16 using a 180,000 pound dual tandem wheel assembly, 190 pounds per square inch tire pressure, 26-inch spacing between dual tires, 66-inch spacing between tandem axles, k value of 300 pounds per cubic inch, 12-inch, thick concrete pavement and an R_s , value of 37.44 inches. Subgrade and subbase support for a rigid pavement is evaluated in terms of k, the modulus of subgrade reaction. A k value of 300 pounds per cubic inch was used, since this value represents a desirable subgrade or subbase material. In addition, because of the interaction between the pavement and subgrade, a lower value of k (representing reduced subgrade support) results in less load on the pipe.

Although Tables 53 through 55 are for specific values of aircraft weights and landing gear configuration, the tables can be used with sufficient accuracy for all heavy commercial aircraft currently in operation. Investigation of the design loads of future jets indicates that although the total loads will greatly exceed present aircraft loads, the distribution of such loads over a greater number of landing gears and wheels will not impose loads on underground conduits greater than by commercial aircraft currently in operation. For lighter aircrafts and/or different rigid pavement thicknesses, it is necessary to calculate loads as illustrated in Example 4.10.

Flexible Pavement. AASHTO considers flexible pavement as an unpaved

surface and therefore live load distributions may be calculated as if the load were bearing on soil. Cover depths are measured from the top of the flexible pavement, however, at least one foot of fill between the bottom of the pavement and top of the pipe should be provided.

Railroads. In determining the live load transmitted to a pipe installed under railroad tracks, the weight on the locomotive driver axles plus the weight of the track structure, including ballast, is considered to be uniformly distributed over an area equal to the length occupied by the drivers multiplied by the length of ties.

The American Railway Engineering and Maintenance of Way Association (AREMA) recommends a Cooper E80 loading with axle loads and axle spacing as shown in Illustration 4.19. Based on a uniform load distribution at the bottom of the ties and through the soil mass, the live load transmitted to a pipe underground is computed by the equation:

$$W_L = C p_o B_c I_f \quad (4.19)$$

where:

C = load coefficient

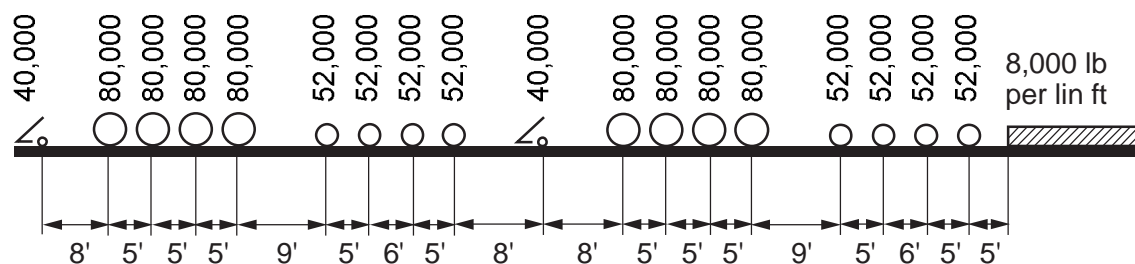
p_o = tire pressure, pounds per square foot

B_c = outside span of the pipe, feet

I_f = impact factor

Tables 56 through 58 present live loads in pounds per linear foot based on equation (4.18) with a Cooper E80 design loading, track structure weighing 200 pounds per linear foot and the locomotive load uniformly distributed over an area 8 feet X 20 feet yielding a uniform live load of 2025 pounds per square foot. In accordance with the AREMA "Manual of Recommended Practice" an impact factor of 1.4 at zero cover decreasing to 1.0 at ten feet of cover is included in the Tables.

Illustration 4.19 Cooper E 80 Wheel Loads and Axel Spacing



³ Op. cit., p. 28

⁴ Equation (21) is recommended by WPCF-ASCE Manual, The Design and Construction of Sanitary Storm Sewers.

Based on a uniform load distribution at the bottom of the ties and through the soil mass, the design track unit load, W_L , in pounds per square foot, is determined from the AREMA graph presented in Figure 215. To obtain the live load transmitted to the pipe in pounds per linear foot, it is necessary to multiply the unit load, W_L , from Figure 215, by the outside span, B_c , of the pipe in feet.

Loadings on a pipe within a casing pipe shall be taken as the full dead load, plus live load, plus impact load without consideration of the presence of the casing

pipe, unless the casing pipe is fully protected from corrosion.

Culvert or sewer pipe within the railway right-of-way, but not under the track structure, should be analyzed for the effect of live loads because of the possibility of train derailment.

Construction Loads. During grading operations it may be necessary for heavy construction equipment to travel over an installed pipe. Unless adequate protection is provided, the pipe may be subjected to load concentrations in excess of the design loads. Before heavy construction equipment is permitted to cross over a pipe, a temporary earth fill should be constructed to an elevation at least 3 feet over the top of the pipe. The fill should be of sufficient width to prevent possible lateral displacement of the pipe.

SELECTION OF BEDDING

A bedding is provided to distribute the vertical reaction around the lower exterior surface of the pipe and reduce stress concentrations within the pipe wall. The load that a concrete pipe will support depends on the width of the bedding contact area and the quality of the contact between the pipe and bedding. An important consideration in selecting a material for bedding is to be sure that positive contact can be obtained between the bed and the pipe. Since most granular materials will shift to attain positive contact as the pipe settles, an ideal load distribution can be attained through the use of clean coarse sand, well-rounded pea gravel or well-graded crushed rock.

BEDDING FACTORS

Under installed conditions the vertical load on a pipe is distributed over its width and the reaction is distributed in accordance with the type of bedding. When the pipe strength used in design has been determined by plant testing, bedding factors must be developed to relate the in-place supporting strength to the more severe plant test strength. The bedding factor is the ratio of the strength of the pipe under the installed condition of loading and bedding to the strength of the pipe in the plant test. This same ratio was defined originally by Spangler as the load factor. This latter term, however, was subsequently defined in the ultimate strength method of reinforced concrete design with an entirely different meaning. To avoid confusion, therefore, Spangler's term was renamed the bedding factor. The three-edge bearing test as shown in Illustration 4.20 is the normally accepted plant test so that all bedding factors described in the following pages relate the in-place supporting strength to the three-edge bearing strength.