Design Data 2M

American Concrete Pipe Association

Aircraft Loads

In 1958, the Federal Aeronautical Administration (FAA) adopted a policy of limiting participation in pavement design to airports who designed for airplanes with a takeoff weight of 158,760 kilograms. Pavements and buried structure designs were to adhere to those limits. Aircraft manufacturers have accepted and followed the 1958 rules while developing planes that greatly exceed the 158,760 kilograms limit by adding sufficient wheels to the landing gears. For instance, the Boeing 747 has a takeoff weight of as much as 394,632 kilograms and the Airbus 380 weighs up to 607,824 kilograms before takeoff. For both of these planes the landing gear has sufficient wheels with the proper spacing to prevent excessive pavement stress. The FAA Advisory Circular, Airport Pavement Design and Evaluation AC 150-5320-6E, published in 2009, is based on new geotechnical research and experience, and has completely revised the previous pavement design procedures. The new aircraft live load distributions recognize much heavier aircraft takeoff weights, but also do not overload existing runway designs.

Buried structures under airport runways and taxiways must be able to support the large aircraft live loads as well as the dead load from the soil and runway pavement. Additional wheels on the landing gear will spread the aircraft weight over proportionally more area to limit stress in the pavement, but the load on buried structures may increase because of the overlap of individual wheels or groups of wheel loads. The design of buried structures is dependent on the pavement material and thickness, distributed live load magnitude, shape and size of the structure and depth of fill over the top of the structures.

Live Loading

Appendix 3 of AC 150/5320-6E, Design of Structures For Heavy Airplanes, states, "Information concerning the landing gear arrangement of future heavy airplanes is speculative." It goes on to advocate building for those future yet undetermined loads when it states, "Strengthening of structures, however, may prove to be extremely difficult, costly, and time consuming". For design purposes of airfield drainage structures, the aircraft loading is represented by three landing gear configurations; a bicycle or tandem gear with fore and aft rectangular footprints and two tricycle patterns with either a longitudinal or transverse orientation of the footprint. For a given aircraft weight, each of the three basic gear configurations shall be used in the analysis of each drainage structure and the most conservative design selected for construction.

Figure 1 Type A Bicycle

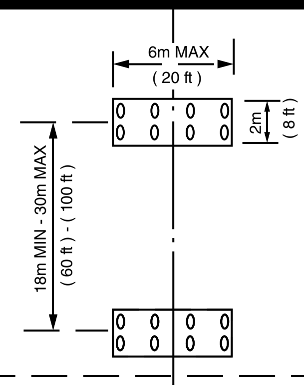


Figure 2 Type B Tricycle

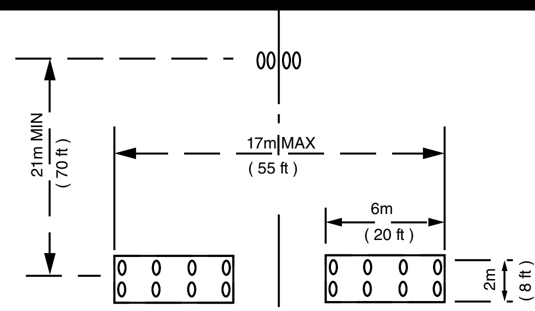
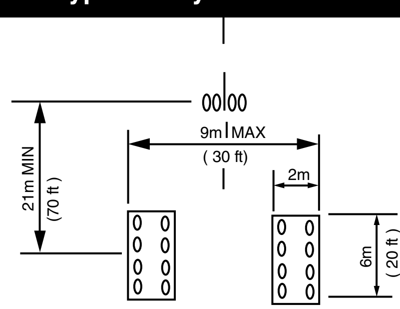


Figure 3 Type C Tricycle



Each of the three basic gear configurations is made up of two wheel groups of eight wheels each or a total of 16 wheels. Each configuration is 6.10 meters long and either 1.82 or 2.44 meters wide. Nose wheels are not considered in the basic design but must be considered as a point load for structures such as manholes. When the buried structure has 0.61 or more meters of cover, the load on the specified footprints shall be an area 1.75 times the depth of fill greater than the footprint. When the distributed loads lap, the load shall be distributed over the area defined by the outer limits of the individual areas.

Landing Gear Configuration for Design of Buried Structures

For a standard aircraft load, the highest loading stress is under the smallest footprint, all of the wheel footprints are 6.10 meters long but the narrowest is 1.83 meters wide. Appendix 3 states, "Wheel loads of 22,700 to 34,000 kilograms (50,000 to 75,000 lbs) should be considered," which can be as much as 272,108 kilograms for each gear footprint and over 544,216 kilograms for the entire aircraft. The weight on the nose gear is ignored for the Tricycle gear configurations, except when considering point loads at structures. The total load will be distributed over two 6.10 meter long and 1.83 meter wide footprints spaced 9.14 meter out-to-out. For buried structures, the live load is distributed over an area found by increasing each footprint dimension by 1.75 H, where H is the depth of cover in meters. For a single footprint of the Type C Tricycle gear, for example,

$w = 272,108 / (6.10 + 1.75 H)(1.83 + 1.75 H)$ kg/m^2

For fill depths greater than 3.14 meters, where the two wheel footprints overlap,

$w = 2 \times 272,108 / (6.10 + 1.75 H)(9.14 + 1.75 H)$

For buried structures such as concrete pipe and box culverts, this loading configuration will control.

Dynamic Load Effects or Impact

Dynamic load effects or impact is not often considered or even mentioned in discussion of buried structures under airfields. Arrival traffic is actually ignored when designing airport pavement, not only because airplanes typically arrive at an airport with less fuel and therefore less weight, but also because remaining lift on the wings helps alleviate the dynamic load effects of touchdown impact. Instead, the FAA recommends the use of the maximum anticipated take-off weight for design, adding that this even provides a degree of conservatism in the design. Lateral live loads do not have to be increased by the impact factor.

Horizontal Live and Dead Loads

The live load transmitted from the pavement through the soil will have a horizontal component to it especially because of movement of the planes. For structures that are subjected to direct wheel loads, horizontal braking forces are also applied. Horizontal forces are generally beneficial for circular shaped structures, but will affect the moment distribution in the walls of rectangular shaped structures. The ratio of horizontal pressure to vertical pressure of 40% is the Horizontal Arching Factor (HAF) for a SIDD Type 2 installation and will be used for all live and dead loading conditions in the design examples. The vertical soil pressure is the Vertical Arching Factor (VAF) times the pressure due to the weight of the vertical column of soil at that elevation. Because of the critical construction requirements under airfields, only SIDD Type 1 and Type 2 installations should be used because they include rigorous material specifications for the foundation and pipe soil envelop, soil compaction requirements, and onsite inspection. SIDD Type 3 and Type 4 installations have lower material and compaction requirements and onsite inspection is not required.

Dead Loads

Most drainage structures in airfields are installed without much cover. There are great areas of flat, paved surfaces that must drain quickly to permit uninterrupted airport operations. These hydrology conditions frequently require large pipe with minimum cover. The earth dead loads can be determined by multiplying the column of soil over the pipe by the unit weight of the soil and the vertical arching factor that is dependent on the type of installation. For a rectangular shape, the vertical soil column weight is multiplied by a soil structure interaction factor. For 453,515 kilogram aircraft live loads, the pavement, base, and sub-base typically will be 9.14 to 1.067 meters thick so most installations will have 1.22 meters of cover.

Design Methods

There are two common methods used to select the required pipe strength. They are the indirect design (Marston-Spangler method), and the Standard Installation Direct Design (SIDD method). The indirect method is a two-step process. First, the designer determines the loads on the pipe, and second, selects the pipe strength based on the relationship of the three-edge-bearing (TEB) strength of the pipe to and the bedding factor based on a standard installation. The direct design method calculates the pipe reinforcing based on physical characteristics of the pipe and the reactions of the aircraft live load and the reactions in soil envelop surrounding the pipe. The direct design method is more complex than the indirect design method but provides greater analytical detail for the engineer.

The American Concrete Pipe Association (ACPA) has developed two computer programs that simplify the computations for circular, arch and elliptical pipe designs. Pipepac can determine the live and dead loads on the pipe and directly select an ASTM C76 three-edge-bearing (TEB) strength class. Direct designs for pipelines installed under airfields are more complex than conventional direct designs. The Uniform/ Manual Load System input module of Pipecar may be used to calculate the moments, thrust, and shear forces in the pipe due to internal and external loads and determine the required steel reinforcing areas. Before using the program, the live and dead loads must be determined, resolved into their vertical and horizontal components, and increased by the proper load factor.

Load Factors

The FAA does not provide detailed structural design procedures such as load factors and capacity reduction factors. A good resource for appropriately designing buried structures is found in the American Association of Highway and Transportation Official's (AASHTO) LRFD Bridge Design Specification. The AASHTO LRFD vertical load factors and capacity reduction factors are used in the direct design example.

DESIGN EXAMPLES

Indirect Design

Select the class of a 2,438 millimeter (mm) B-wall reinforced concrete pipeline installed 1.22 meters below an airfield runway. The pipe will be installed with Standard Installations Direct Design (SIDD) Type 2 bedding. The indirect design uses six steps to select the required strength of the pipes:

1. Determine the earth load
2. Determine the live load
3. Select the bedding
4. Determine the bedding factor
5. Apply the factor of safety
6. Select the pipe strength

The earth load for a shallow fill may be taken as the prism of soil over the pipe and increased by the vertical arching factor for a SIDD Type 2 installation. For this installation, the average weight per cubic foot of the soil, w, in the base course and pavement over the pipe is w = w = 2,160 kgs/m³. A 2,438 mm diameter B-wall pipe has an outside diameter of 2.896 meters.

1. Earth load:

$$W_E = \left[\tfrac{1}{2} \left(\frac{D_O}{12}\right)^2 \left(1 - \frac{\pi}{4}\right) + \left(H \frac{D_O}{12}\right) \right] w\ VAF$$

$$W_E = \left[\tfrac{1}{2} \left(\frac{114}{12}\right)^2 (0.2146) + (9.5 \text{ X } 4) \right] 135 \text{ X } 1.4 = 9020 \ {}^{lb.}/_{ft.}$$

2. Live load:

$$P = \frac{600{,}000}{(6 + 1.75)(20 + 1.75H)}$$

$$P = \frac{600{,}000}{(6 + 7)(20 + 7)} = 1{,}709 \ {}^{lb.}/_{ft.}$$

$$W_L = D_O \text{ x } P = (9.5 \ ft.)(1{,}709 psf) = 16{,}236 \ {}^{lb.}/_{l.f.}$$

W_E = Earth Load / m
W_L = Live Load / m
D_O = outside diameter in meters

3. Bedding: Given as Type 2

4. Bedding Factors:

There are separate SIDD live load and dead load bedding factors. Since this pipe installation is constructed with only 1.22 meters of fill, the embankment bedding factor is appropriate and conservative. Trench installations generally develop beneficial friction between the trench walls and the backfill material that reduces the earth loads on the pipe. For a pipe of this size installed only four feet from the surface, no significant friction will develop. Generally, a designer may select the trench transition width for design purposes and use the SIDD embankments bedding factors for all but very deep installations.

From the ACPA Design Manual Chapter 4, the embankment dead load bedding factor is B_{fE} = 2.8 and the live load bedding factor is B_{fLL} = 1.9

5. Application of Safety Factor:

The factor of safety is defined as the relationship between the ultimate D-load strength and the 0.3-mm crack D-load strength. From ASTM C76, the relationship between the ultimate D-load and the 0.3-mm crack D-load is 1.5 for the 0.3-mm crack D-loads of D100 (N/m/mm) or less and 1.25 for 0.3-mm D-load cracks of D140 or more and a linear reduction from 1.5 to 1.25 for loads between more than D100 (N/m/mm) and less than D140. A factor of safety is included with to the required 0.3-mm D-load for this pipe.

6. Selection of Pipe Strength:

$$D\text{-}load = \left[\frac{W_E}{B_{fE}} + \frac{W_L}{B_{fLL}}\right] x \ \frac{F.S.}{D}$$

$$D\text{-}load = \left[\frac{9{,}020}{2.8} + \frac{16{,}236}{1.9}\right] \frac{1.0}{8}$$

D-load = 405 + 1,070 = 1,475 *pounds per linear foot per foot of diameter*

D = inside diameter, in feet

Use an ASTM C 76M Class IV design. A special design with stirrups will be required for an ASTM C76M Class IV pipe since there are no steel areas given in C76M for a 2,438 mm pipe. An alternative to the Class IV design could be an intermediate strength design manufactured to special design provisions of ASTM C 655M.

Direct Design

Use the direct design method to determine the reinforcing for a 2,438 mm B-wall reinforced concrete pipeline installed 1.22 meters below an airfield runway. The pipes will be installed with Standard Installations Direct Design (SIDD) Type 2 bedding. Use AASHTO LRFD load and capacity reduction factors. There are no manual methods of solving this direct design example, but the Uniform/ Manual Load System of PIPECAR may be adapted to provide a solution. Some of the live and dead load pressures found in the indirect design method may be factored for use in the direct design method. Use 41 mPa concrete strength and 483 mPa yield strength for the reinforcing steel.

Vertical loads:
Earth load at the crown of the pipe:
Load factor for vertical earth pressure L_{FE} = 1.3

$$W_u = L_{FE}\left[½(D_O)^2\left(\frac{1-\pi}{4}\right)+\left(\frac{D_O}{H}\right)\right] \text{w VAF}$$

W_u = 1.3 [½(9.5)^2 (0.2146) + (9.5 x 4)] 135 x 1.4 = 11,720 pounds per linear foot

$$P_u=\left(\frac{W_u}{D_O}\right)=\left(\frac{11{,}720}{9.5}\right) = 1{,}230 \text{ PSF}$$

Aircraft live loads at the crown of the pipe:
Live load with Impact:
Load factor for live load pressure, L_{fLL} = 1.75

$$P_u = L_{fLL} \ x \ \frac{600{,}000}{(6 + 1.75H)(20 + 1.75H)}$$

$$P_u = 1.75 \ x \ \frac{600{,}000}{(6 + 7)(20 + 7)} = 2{,}991 \text{ PSF}$$

At the invert of the pipe:
H = 4 + 8.75 = 12.75 feet.
The invert of the pipe is below 3.14 m so the double aircraft live load footprint distributions will apply.

$$P_u = L_{fLL} \ x \ \frac{1{,}200{,}000}{(30 + 1.75H)(20 + 1.75H)}$$

$$P_u = 1.75 \ x \ \frac{1{,}200{,}000}{(30 + 23.625)(20 + 23.625)} = 900 \text{ PSF}$$

Horizontal loads:
Horizontal live load at the crown of the pipe:
The horizontal live load is forty percent of the vertical live load. P_u (horizontal) = 0.4(2,991) = 1,196 PSF

Horizontal live load at the invert of the pipe:
P_u (horiz) = 0.4(900) = 360 PSF

Horizontal soil pressures: P_u = (K)(L_{fE})(w)(H), where K = 0.4, the same as the Horizontal Arching Factor (HAF) for a SIDD Type 2 installation.

Horizontal soil pressure at the crown of the pipe:
P_u (horiz) = 0.4 x 1.3 x 135 x 4 = 270 PSF

Horizontal soil pressure at the invert of the pipe:
P_u (horiz) = 0.4 x 1.3 x 125 x 13.5 = 930 PSF. (Use an average value of 125 PCF for w, the soil density at H = 13.5 feet.)

To use the Uniform/ Manual Load System of PIPECAR, the pipe designer must determine vertical and horizontal pressures, apply the proper load factors, and add all similar loads from each loading case. Because the designer has manually factored the input loads, all the live and dead load factors should be set to 1.0 and the fill height to zero on the Design and Loading screen. The PIPECAR program's Uniform/Manual Load System does not include the SIDD beddings but they can be approximated by selection of the proper width of pipe invert support. SIDD Class 2 bedding effectively spreads the bedding support to the pipe haunches or beyond 45 degrees from the invert. A bedding angle of 110 degrees, or 82 percent of Do, was selected for this example.

The inner reinforcing area of 1,304 mm^2/m found for the direct design example is somewhat less than the required reinforcing area for the 7.032 x 10^4 N/m^2 0.3-mm d-load indirect design example.