PIP CVE02350
Roadway Design Guide
(U.S. Customary)
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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1. **Scope**

This Practice describes roadway classifications and provides guidance for design of right-of-ways, access to public roadways, use of local materials, climate effects, traffic loading, layout and traffic control, design of paving and roadways, providing drainage, and providing railroad and pipeline crossings for roadways within plant boundaries. This Practice uses United States standards for roadway design. User should research regional standards for variations from this design guide.

2. **References**

Applicable requirements of the following Practices, industry guides, codes and standards, should be considered an integral part of this Practice. The edition in effect on the date of contract award should be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP CVS02350 - Roadway and Area Paving Construction Specification
- PIP CVS02700 - Underground Gravity Sewers Specification
- PIP PNE00003 - Process Unit and Offsites Layout Guide
- PIP CVI02350 - Roadway and Area Paving General Notes and Typical Details

2.2 **Industry Guides, Codes and Standards**

- American Association of State Highway and Transportation Officials (AASHTO)
  - Guide for Design of Pavement Structures (GDPS)
  - A Policy on Geometric Design of Highways and Streets (GDHS)
  - Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400) (VLVLR)
- American Concrete Institute (ACI)
  - ACI 325.12R - Guide for Design of Jointed Concrete Pavements for Streets and Local Roads
  - ACI 350-06 - Code Requirements for Environmental Engineering Concrete Structures and Commentary
  - ACI 504R - Guide to Sealing Joints in Concrete Structures
- American Concrete Pipe Association (ACPA)
  - Concrete Pipe Design Manual
  - Design Data 1 (DD 1) - Highway Live Loads on Concrete Pipe
- ASTM International (ASTM)
  - ASTM C14 - Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
  - ASTM C76 - Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
  - ASTM D1195/D1195M - Standard Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
3. Definitions

base course: A layer of well-graded granular material that supports the paving and distributes wheel loads over a greater area of the subgrade.

full contraction joint: A full contraction joint has no reinforcement crossing the joint (except for load transfer devices).

gri: High tensile strength polymer material designed with transverse and longitudinal grids. Laid directly on the subgrade, the grid geometry provides a mechanism for interlocking aggregate base or subbase material placed on the geogrid. Interlocking prevents lateral movement of aggregate and improves load distribution to subgrade.

gi: Polyester fabric material laid over subgrade materials directly below an aggregate subbase. It maintains separation of subbase from subgrade. Geotextile is permeable, allowing pore water to pass vertically through fabric.

HS20: A truck with a 32,000 lbs. axle load. If higher loads must be considered, HS25 axle loading is 40,000 lbs.

owner: Party who has authority through ownership, lease, or other legal agreement over site wherein roadways will be installed.

partial contraction joint: A partial contraction joint has 50% or less reinforcement crossing the joint.

paved surface: Cementitious or asphaltic concrete that distributes the load to base and subbase, seals against penetration of surface water or liquids, resists abrasion, and provides traction.

plant boundaries: Delineation between areas accessible to public and areas where access is controlled by owner.
subbase: A compacted layer of well-graded fill that may be required under base course. Typically provided over fine grained subgrade soils to improve drainage, resist frost heave, provide structural support by distributing loads, and to prevent pumping of finer grained soils into base material at paving joints and edges.

subgrade: Foundation soil placed and/or compacted during rough grading work. Typically consists of natural soils found on site, unless soil strength is inadequate and imported soils are required.

4. **Roadway Classifications**

4.1 **General**

4.1.1 All major plant areas should be accessible by primary roadways from two opposite sides minimum and preferably all around to provide adequate access for firefighting and other emergency equipment. As a minimum, a tertiary roadway around the plant should be considered.

4.1.2 Plant areas containing process equipment should be accessible for plant maintenance activities. Roadways to these areas should be designed to permit access for the largest required maintenance equipment.

4.1.3 Roadway design requirements within plant boundaries should be specified by owner and are typically unregulated by governmental agencies.

4.1.4 Type of roadway pavement is defined based on traffic, load, climate, environmental regulations, existing subgrade, cost, etc. It includes paved roadways such as asphaltic concrete and portland cement concrete, and unpaved roadways such as gravel. Primary focus of this Practice is on paved roadways.

4.2 **Primary Roadways**

4.2.1 **Within Plant Boundaries**

4.2.1.1 Primary roadways provide access to product shipping and receiving points and sufficient space for major maintenance vehicles to pass. Primary roadways include all roadways typically used by large trucks and cranes.

4.2.1.2 Vehicle speed limits are normally set by owner.

4.2.1.3 Roadways designated for heavy haul truck traffic may require a greater than typical radius and lane width. These roadways should also be designed for loadings in accordance with AASHTO GDPS, and the local state highway design manuals for applicable locale.

4.2.1.4 Primary roadways typically have two 10- to 12-ft wide lanes with 3- to 3.5-ft shoulders.

4.2.1.5 Primary roadways are typically paved.

4.2.2 **Urban and Rural Areas (Outside Plant Boundaries)**

4.2.2.1 AASHTO, GDHS, categorizes functional systems for travel movement. Although rural and urban areas differ in travel volumes and percentage of roadway length comprising each functional system, the broad categories share common traits. Public primary roadways generally are
included in the arterial functional category – either principal or minor. There can be some component of the lower hierarchy collector functional category included also.

4.2.2.2 Typically, primary roadways in urban and rural areas include principal state highways, interstates, and routes providing higher levels of mobility between major population centers.

4.2.2.3 Roadways are characterized by strict design and safety standards. Typically, states limit vehicle widths to 8 ft without permit. Vehicle height restrictions typically range from 12.5 to 14 ft. A nominal 12-ft wide lane is typical for general use. A 6- to 10-ft shoulder can be required depending upon surrounding terrain.

4.2.2.4 Design of public primary roadways is seldom required for plant facilities. However, a project may include connecting a plant roadway to one of these roadways. Appropriate AASHTO and state documents should be consulted for further guidance.

4.3 Secondary Roadways

4.3.1 Within Plant Boundaries

4.3.1.1 Secondary roadways provide access to equipment within plant areas by maintenance vehicles and personnel vehicles.

4.3.1.2 Typically, vehicle speed limits are set by owner and posted 15 mph or less.

4.3.1.3 Secondary roadways typically have one or two 10-ft wide lanes.

4.3.1.4 Secondary roadways may or may not be paved depending on loading conditions and other considerations such as dust control and drainage.

4.3.2 Urban and Rural Areas (Outside Plant Boundaries)

4.3.2.1 AASHTO functional classifications included in public secondary roadways are collector roadways, local roadways and streets, and roadways that provide access between a primary roadway system and land use.

4.3.2.2 Typically, secondary roadways have lower traffic volumes and vehicle velocities and provide access to a facility.

4.3.2.3 Pavement structures and geometric considerations are not as stringent as for primary roadways and can provide limited through-traffic accessibility.

4.3.2.4 Design of public secondary roadways should be in accordance with local, state, and federal requirements. Appropriate AASHTO and state documents should be consulted for further guidance.

4.4 Tertiary Roadways

4.4.1 Typically, tertiary roadways (also known as accessways) provide occasional access to areas of a facility for maintenance, security, and firefighting vehicles.

4.4.2 Tertiary roadways may have one or two 8- to 10-ft wide lanes with or without shoulders.
4.4.3 Tertiary roadways may or may not be paved.

4.5 **Construction and Heavy Haul Roadways**

4.5.1 Construction and heavy haul roadways provide greater than typical load capacity and have specialized service conditions.

4.5.2 These roadways may be temporary or permanent.

4.5.3 Composition of these roadways can range from a stabilized earth surface prepared by reshaping and compacting native soil to a high-quality subgrade with several layers of engineered base and subbase courses and pavement.

4.5.4 Service life, maximum grade, clearances, turning points, load and unloading points, drainage, and environmental impact on the surrounding areas (e.g., surface drainage, noise, dust, etc.) should be considered in the initial layout of these roadways.

5. **General Design Considerations**

5.1 **Right-of-Way**

5.1.1 **Within Plant Boundaries**

5.1.1.1 Right-of-way considerations are defined by owner.

5.1.1.2 If owner has sold or leased part of a plant facility to another entity, an easement condition can exist that includes sharing plant roadways.

5.1.2 **Outside Plant Boundaries**

5.1.2.1 Local, state, and federal right-of-way requirements apply to plant boundaries that border roadways outside plant boundaries and access points to the roadways.

5.1.2.2 Right-of-way is acquired by governmental authority through direct purchase or eminent domain with compensation.

5.1.2.3 Right-of-way width is typically sufficient to accommodate ultimate planned roadway including traveled way, shoulders, drainage ditches, medians and borders.

5.2 **Access to Public Roadways**

5.2.1 **General**

5.2.1.1 Design of roadways within plant property boundaries is typically unencumbered by regulation and should be performed and executed with good engineering practices specific to a plant’s mobility needs and safety requirements.

5.2.1.2 Movement of people, products and material across plant property boundaries requires interaction with adjacent property owners or authorities and entities vested with the power to regulate or control waterway usage, rail and pipeline systems, utilities, and roadways.
5.2.1.3 Consideration of access to public roadways is important for design of a new plant and can also be important for a major project at an existing plant.

5.2.2 Effects of Plant Activities

5.2.2.1 Plant facilities can be heavy traffic generators and adequate access to a local roadway system during normal operating/production periods and for major onsite construction projects is important to a plant’s success.

5.2.2.2 Plant shift changes can place a heavy, short-term demand on a local roadway system two or more times a day.

5.2.2.3 Outbound and inbound shipping of products, supplies and feed stocks by truck requires special consideration regarding access to local roadway systems.

5.2.2.4 Because of additional transportation for craft workers and other project team members, increased truck traffic for delivery of equipment and materials, and traffic from permit loads for equipment and construction material, plant construction projects can affect local traffic conditions. Controlled and adequate access to local streets and highways during major construction projects requires early team planning and may require investment in new roadway access points.

5.2.3 Regulation of Access

5.2.3.1 Control of access points is a method used by regulators to manage the quality of a roadway’s mobility, capacity, potential for collisions, and access for adjacent land use.

5.2.3.2 Methods used by governmental authorities for controlling access points to public streets and roadways include the following:

a. Regulations and Permits - Ordinances at the local level

b. Eminent Domain - A way for government to purchase property for public roadways. Property owners are compensated for the property taken; however, property owners may donate land for right-of-way if they can benefit from a roadway project or from having new or additional access to a roadway.

5.2.3.3 Long-term planning is an essential aspect of access management and the principles and policies adopted by regulators are defined for an entire system that includes roadways and local land use that generates travel.

5.2.3.4 Regulators are typically required to provide reasonable access, although not necessarily direct access, to roadways from adjacent property.

5.2.4 Design of Access Points

5.2.4.1 An owner typically employs a consultant with expertise in traffic impact studies to perform necessary studies, prepare reports required by regulating authority, and assist owner with the permitting process.
5.2.4.2 A consultant may also be engaged to design the traffic controls and improvements at the access points.

5.2.4.3 Roadway design from the access point interface to plant boundary can then be performed. Connection from a public access point to a plant boundary can vary from a parking lot driveway to a multi-lane roadway with length measured in miles. The connection typically occurs on the owner’s land.

5.2.4.4 Depending on which public entity has jurisdiction at the access point, local, state, or federal regulations should be consulted for design of alignment, acceleration/deceleration lanes, signage, roadway markings, etc.

5.2.4.5 Expected plant traffic volume and generated loads should be determined to complete pavement and drainage design to plant boundary.

5.2.5 Plant Entry

5.2.5.1 Parking facilities for plant employees, contractors and visitors are typically located outside the plant fence.

5.2.5.2 Security facilities to enter a plant from parking area are typically required and may consist of badge controlled turnstiles for pedestrians and checkpoint shelters occupied by security staff for vehicular access. Homeland Security requirements must be considered. See https://www.dhs.gov

5.2.5.3 Truck staging areas and weigh stations are often required at plant vehicular entrances.

5.2.5.4 Temporary parking and security facilities for construction projects may be required to be located on available plot space within plant fence.

5.2.6 Easements

5.2.6.1 Plant boundaries may be adjacent to or include dedicated easements or right-of-ways for drainage, utilities, pipelines and railroads. New plant roadways can be required to cross or run parallel to these easements.

5.2.6.2 Design interfaces with one or more entities that own or regulate easements may be required in order to protect their facilities from new traffic loads. If more than one entity is involved, it can be challenging to resolve multiple requirements.

5.2.6.3 Resolutions of easement concerns can involve the following items that are typically paid for by the plant owner:

a. Raising or rerouting overhead lines
b. Providing protective sleeves for pipelines
c. Installing culverts or bridges for ditches
d. Improving traffic crossings for railroads
5.3 Materials

5.3.1 Suitability of locally available materials for roadway construction should be investigated. A good source of information is a geotechnical consultant with knowledge of materials in the area.

5.3.2 A geotechnical consultant can provide recommendations regarding the following:
   a. Stabilization of in situ soils
   b. Replacement of in situ soils with suitable borrow materials
   c. Economical specifications for base, subbase, and roadway materials

5.4 Climate

5.4.1 Rainfall and temperature extremes should be considered for both design and construction phases of roadway projects.

5.4.2 Rainfall determines drainage design. Rainfall may also affect construction schedule.

5.4.3 Extreme temperatures affect installation of concrete and asphaltic concrete surfaces and may require special provisions for construction. Asphaltic concrete materials may not be available in certain climates during the colder times of the year.

5.5 Traffic Loading

5.5.1 Design loading criteria should be established for a roadway project.

5.5.2 Normal loading for roadway design should consider expected types of vehicles and frequency of use.

5.5.3 Unusually heavy loads from maintenance vehicles, equipment, and delivery transporters should be considered, but this may not necessarily control design of roadway if temporary matting or improvements can be provided.

5.5.4 Highway pavement design variables and design procedures are provided in AASHTO GDPS, Part II. The design is focused on obtaining a specific pavement thickness (including sub base and base thicknesses) that can withstand cyclic loading, based on pavement failure due to fatigue. Pavement design is primarily based on cumulative heavy axle load application, Equivalent Single Axle Load (ESAL), which represents all different traffic axle loads and configurations as equivalent 18-kip axle loads. It is then necessary to determine the cumulative loading to be used for design of roadways regardless of the amount of traffic level or the distribution.

5.5.5 AASHTO GDPS, Part II, Chapter IV addresses pavement design for low-volume roadways which is applicable to most plant roadways. Procedure and design variables for low-volume roadways are basically the same as for highway design, except that a lower reliability percentage is recommended. Reliability defines the certainty of a designed pavement to complete the design period before failing. If a lower reliability percentage is used for design, then a smaller pavement thickness will result.
6. Layout and Traffic Control

6.1 General

6.1.1 Layout for a roadway within a plant should be in accordance with plant grid system and the established plant coordinate system for horizontal and elevation control (e.g., Horizontal Control Plant Datum and Plant Elevation).

6.1.2 Layout for a public roadway should be in accordance with governing guidelines.

6.1.3 Grading plans should minimize quantity of earthwork. If only on-site materials are used for grading, cut and fill volumes should be calculated to try to achieve a reasonable balance after the initial clearing, grubbing and stripping.

6.2 Traffic Flow

6.2.1 Traffic flow within plant boundaries is typically limited to low volume, low speed vehicles, trucks, and construction and maintenance equipment.

6.2.2 Emergency vehicles (e.g., fire truck and ambulance) access and flow to most critical sites of a plant should be considered.

6.2.3 If truck loading/unloading is an essential part of day-to-day plant operations, daily delivery traffic flow should be considered in roadway layout. Security, truck staging space, and loading/unloading operations should be considered.

6.3 Plant Roadway Turning/Layout/Grades

6.3.1 Minimum Turning Radius

6.3.1.1 Minimum turning radii at roadway intersections and curves should be based on turning requirements of vehicles that are expected to use the roadway regularly.

6.3.1.2 Figure 1 is a simplified diagram showing critical turning dimensions for common types of vehicles. See AASHTO GDHS for more detailed diagrams.

6.3.1.3 For turning dimensions of other types of vehicles, see AASHTO GDHS and/or commercially available turning radius software.

6.3.2 Roadway Cross Section

6.3.2.1 To prevent major process spills from flowing into adjacent areas, consider setting centerline elevations of roadways within plant boundaries 6 inches minimum above high points of adjacent finished grades or high points of adjacent process units.

6.3.2.2 Surface slope from crown of a roadway section is typically 1.5% to 2% for paved roadway lanes, 2% to 6 % for unpaved roadway lanes, and 2% to 6% for paved or unpaved roadway shoulders.

6.3.2.3 For parking or wider areas, minimum slope should be 1%.

6.3.2.4 Typical lane and shoulder widths are shown in Table 1. Shoulder widths should be added to lane width(s) to obtain total roadway width. Some owners prefer widths in excess of values listed, for example, to accommodate wide loads or locations with heavy snow which can require room for snow storage after plowing.

6.3.2.5 See drawing CVE02350-01 for typical details of roadway sections at cut and fill.
**Figure 1 – Turning Radius for Passenger Car and Common Trucks**

<table>
<thead>
<tr>
<th>VEHICLE DIMENSIONS (FEET)</th>
<th>&quot;A&quot;</th>
<th>&quot;B&quot;</th>
<th>&quot;C&quot;</th>
<th>&quot;D&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTOMOBILE (19' LONG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.8’</td>
<td>21.0’</td>
<td>25.4’</td>
<td>14.4’</td>
</tr>
<tr>
<td>2-AXLE-TRUCK OR BUS (30' LONG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>41.8’</td>
<td>38.0’</td>
<td>43.3’</td>
<td>28.4’</td>
</tr>
<tr>
<td>SEMI-TRAILER COMBINATION (45.5' LONG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>39.9’</td>
<td>36.0’</td>
<td>40.8’</td>
<td>19.3’</td>
</tr>
<tr>
<td>SEMI-TRAILER COMBINATION (69' LONG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.8’</td>
<td>41.0’</td>
<td>46.3’</td>
<td>7.4’</td>
</tr>
</tbody>
</table>
### Table 1 – Typical Lane and Shoulder Widths

<table>
<thead>
<tr>
<th>Plant Roadway Type</th>
<th>Lane Width</th>
<th>Shoulder Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Roadways</td>
<td>10 to 12 ft</td>
<td>3 to 3.5 ft</td>
</tr>
<tr>
<td>Secondary Roadways</td>
<td>10 ft</td>
<td>3 to 3.5 ft</td>
</tr>
<tr>
<td>Tertiary Roadways</td>
<td>8 to 10 ft</td>
<td>2.5 ft</td>
</tr>
</tbody>
</table>

#### 6.3.3 Turnouts and Turnarounds

6.3.3.1 Section of roadway at fire hydrants shall have a minimum width of 22 ft for a length of 50 ft to allow fire trucks to be parked clear of traffic. Turnouts shall be provided for roadway sections that do not meet these minimum dimensions.

6.3.3.2 A turnaround shall be provided for dead-end roadway when the distance from centerline of access road to farthest point of the dead-end roadway exceeds 150 ft. Design of the turnaround shall meet the turning requirements of the fire truck.

#### 6.4 Vertical Alignment

##### 6.4.1 Gradients

6.4.1.1 Maximum and minimum vertical gradients along a roadway alignment or across a paved area are shown in Table 2.

6.4.1.2 If possible, vertical gradients should be kept near the minimum value shown in Table 2.

6.4.1.3 For areas subject to ice and snow conditions, vertical gradient should be 5% maximum.

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Roadways</td>
<td>6.0%</td>
<td>-</td>
</tr>
<tr>
<td>Secondary Roadways</td>
<td>7.5%</td>
<td>-</td>
</tr>
<tr>
<td>Tertiary Roadways</td>
<td>10.0%</td>
<td>-</td>
</tr>
<tr>
<td>Access ways (Ramps)</td>
<td>10.0%</td>
<td>-</td>
</tr>
<tr>
<td>Paved Parking / Paved Setback Areas</td>
<td>3.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Paved Areas</td>
<td>6.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Unpaved Areas</td>
<td>1.5%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

##### 6.4.2 Curves

6.4.2.1 Vertical curves provide a gradual transition between two intersecting tangent grade lines.

6.4.2.2 The types of vertical curves are sag and crest. Each curve type has three subsets depending on signs and relative magnitudes of tangent
gradient lines. Typical sign convention is positive for grades ascending forward and negative for grades descending forward.

6.4.2.3 Algebraic change in gradient and stopping sight distance are important parameters for vertical curve design at typical plant vehicle speeds. For example, at 20 mph, AASHTO recommended stopping sight distance is 115 ft. Minimum recommended curve length for a 5% change in gradient is 35 ft for a crest curve and 85 ft for a sag curve. These lengths include factors for height of eye and object sighted that would permit 115 ft stopping sight distance.

6.4.2.4 Vertical curves should be provided for hard surfaced roadways having a change in vertical alignment greater than 3% at typical low plant speeds.

6.4.2.5 Vertical curves are designed parabolic with length measured as horizontal projection of the curve, and are typically designed symmetrical with tangents of equal length.

6.4.2.6 See AASHTO GDHS, and AASHTO VLVLR or a route design textbook for additional geometric design information.

6.5 Horizontal and Vertical Clearances

6.5.1 A horizontal clearance of 5 ft minimum should be maintained between edge of roadway or face of curb and any structure projecting above adjacent grade including parallel fence lines and pipe rack columns. Minimum clearance to equipment should be 13 feet.

6.5.2 Owner should be consulted for special requirements that can dictate specific clearances.

6.5.3 Typical minimum vertical clearances are shown in Table 3. See drawing CVE02350-02 for roadway design clearance envelope.

6.5.4 See PIP PNE00003, Table 4, for additional minimum clearance requirements.

<table>
<thead>
<tr>
<th>Description</th>
<th>Minimum Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance over primary access roadways where major maintenance vehicles are expected to pass</td>
<td>18'-0&quot;</td>
</tr>
<tr>
<td>Clearance over secondary and tertiary access roadways</td>
<td>13'-6&quot;</td>
</tr>
<tr>
<td>Clearance to electrical transmission and distribution lines (22 kV or less)</td>
<td>18'-6&quot; (See Note)</td>
</tr>
</tbody>
</table>

Note: For clearance to electrical transmission and distribution lines greater than 22 kV refer to NFPA 70 (NEC), increase clearances by 0.4 inch per KV.

6.6 Guardrails and/or Guard Posts

6.6.1 Guardrails and/or guard posts should be provided to protect equipment and/or structures that are not provided with minimum horizontal clearance.
6.6.2 Horizontal clearances for guardrails and guard posts should preferably be 2 ft minimum from outer edge of shoulder.

6.6.3 Special hazards that have minimum clearances may still require protection with guardrails or guard posts.

6.6.4 See PIP CV102350 for typical details for guardrail and guard posts that are used inside plant boundaries with low speeds limits.

6.7 Pavement Marking/Signage

6.7.1 Pavement marking and signage within plant boundaries are typically limited to roadway names, speed limits, stop signs, clearance signs, railroad crossings, and evacuation routes.

6.7.2 For designating traffic control devices, pavement markings and signage within and outside plant boundaries, see FHWA Manual on Uniform Traffic Control Devices (MUTCD).

6.8 Railroad Crossings

6.8.1 Railroad facilities within a process plant are typically owned by plant owner but may be subject to one or more local railroad operating company specifications.

6.8.2 To cross railroad tracks with a new plant roadway, an acceptable crossing detail should be developed in coordination with railroad operating company. Typical details can range from asphaltic concrete infill between rails to proprietary concrete, rubber or plastic panels.

6.8.3 An owner may have a preferred railroad contractor that performs the plant’s rail construction and maintenance. Specialty vendors may also be consulted for rail crossing materials and traffic control signage and devices.

6.9 Miscellaneous Information

Consider truck jack stand heights and low clearance vehicles when designing containment roll over curbs or ramps.

7. Paving/Roadway Design

7.1 Paving System Selection

7.1.1 Types

7.1.1.1 Typically, two types of paving systems are used for roadways: flexible and rigid. See example configurations in Figure 2.

7.1.1.2 Flexible paving is composed of material such as asphaltic concrete, and relies on a relatively thin paving (e.g., 2 to 4 inches thick) in combination with layers of base and subbase material to distribute vehicle loads.

7.1.1.3 Rigid paving is composed of material such as portland cement concrete which has low flexibility and is capable of distributing wheel loading over a wide area of subgrade.
7.1.4 Relative costs of asphaltic concrete and portland cement concrete paving vary considerably between geographic locations. Typically, initial cost of portland cement concrete is higher (30 to 50% in some cases) than asphaltic concrete paving. Life cycle costs should be considered when choosing materials.

Figure 2 – Examples of Flexible and Rigid Paving

7.1.2 Advantages/Disadvantages

7.1.2.1 Flexible Paving

1. Advantages of flexible paving may include the following:
   a. Surface can be more easily shaped to specified slopes.
   b. Greater flexibility permits adjustments to subgrade changes.
   c. Repairs can be made more easily.
   d. Subsurface lines can be accessed more easily.

2. Disadvantages of flexible paving may include the following:
   a. Hydrocarbons can damage paving.
   b. Heavy concentrated wheel loads can more easily damage surface.
   c. During hot weather conditions, heavy wheel loads can cause surface distortion.
   d. Less durable, requiring more maintenance over time

7.1.2.2 Rigid Paving

1. Advantages of rigid paving may include the following:
   a. Surface is more durable.
   b. Hydrocarbon leaks or spills typically do not damage paving.

2. Disadvantages of rigid paving may include the following:
   a. Unstable subgrades can cause poor performance of paving.
   b. Differential settlement can cause cracking of pavement.
   c. Repairs can be more expensive.
   d. Special joints are required to control location of cracks, provide relief from expansion, and provide for construction joints.
7.2 Flexible Pavement

7.2.1 Asphalt Terminology

Following are definitions of terms used for various aspects of asphalt paving components and construction:

a. Asphalt cold mix: Mixture of unheated mineral aggregate and emulsified asphalt. May be produced in stationary plants with close control of production process or mixed in place. Spreading and compaction is performed with conventional equipment.

b. Asphaltic concrete: High-quality, thoroughly-controlled hot mixture of asphalt and well-graded, high-quality aggregate, thoroughly compacted into a uniform dense mass.

c. Asphalt paver: A paving machine, sometimes referred to as an asphalt finisher, used to spread and level asphalt paving mixtures.

d. Asphalt pavement compaction: Usually accomplished with special rolling equipment that may include vibrating drums, this is a critical component of a successful asphaltic concrete paving operation.

e. Asphalt pavement structure: Combination of asphalt courses and asphalt-aggregate or untreated aggregate courses, placed above subgrade. A properly designed and constructed surface or wearing course should be smooth, durable, prevent water penetration, and resist both deformation and vehicle skidding. Asphalt binder quality and proper selection and gradation of course aggregates and mineral fillers contribute to a well-designed wear course mix. For pavements installed in two or more lift courses, a base or binder course with a somewhat less stringent aggregate gradation may be specified for the first lift. This may have some economic benefit on larger paving projects.

f. Asphalt prime coat: Spray application of low-viscosity asphalt emulsion to an untreated base to bind the granular material to asphalt layer.

g. Asphalt seal coat: Thin asphalt surface treatment used to waterproof and improve the durability of an existing surface.

h. Asphalt tack coat: Spray application of asphaltic material to existing pavement (e.g., portland cement or old asphaltic concrete) to insure bond between superimposed material and existing surface.

i. Binder course: For a multi-layered paving system, a layer directly below wearing course, and composed of intermediate-sized aggregate with a lesser amount of asphalt than wearing course.

j. Emulsified asphalt: Fine droplets of asphalt suspended in water used for roadway construction, sealing and surface treatments, and patching mixes. Droplets are held in suspension for a long time because of emulsifying agents. The material can be handled with little or no heat. The following types are available: rapid setting, medium setting, and slow setting.

k. Full-depth asphaltic concrete pavement: Pavement in which asphaltic concrete mixtures are used for all courses above the subgrade.
1. Liquid asphalt or cutback asphalt: Uses solvents to thin asphalt to enable handling at lower temperatures. Naphtha-type, kerosene-type, and light oil solvents are used to produce rapid, medium, and slow curing asphalt materials, respectively. Because of environmental concerns, federal and state regulations either severely restrict or prohibit use of liquid asphalt. Liquid asphalts have typically been replaced by emulsified asphalts.

m. Wearing course: A layer of fine aggregate or course sand held together by an asphalt binder and designed to resist wear from traffic.

7.2.2 Basic Design Concepts for Asphaltic Concrete Paving

7.2.2.1 General

1. Industry-wide standard design criteria cannot be applied to asphaltic concrete paving because of the following reasons:
   a. Major environmental characteristics can impact strength and performance of subgrade materials. AASHTO has subdivided continental U.S.A. into six climatic regions for various combinations of environmental characteristics (e.g., freeze/thaw cycling, wet, dry, hard freeze, and no freezing).
   b. Materials of construction vary widely. In some locations the highest quality aggregate is readily available, whereas it may be prohibitively expensive in others.
   c. Asphaltic concrete mixes should be based on local and state highway department specifications. Locally specified mixes are what local asphalt mixing plants are prepared to provide, and local mixes are expected to be designed in accordance with local requirements. For additional asphalt design guidance, refer to Asphalt Institute Design Manuals.

2. Knowledge of local paving practices can be developed from the following sources:
   a. District office for state department of highways
   b. County or city offices responsible for public roadways
   c. Local geotechnical engineers
   d. Asphalt plant operators and paving contractors
   e. Personal observation of local roadways under equivalent service

These sources should provide a sound basis for making decisions about materials, design criteria, and installation procedures for achieving quality paving at reasonable cost.

3. Most state DOT’s have adopted all or part of requirements of the Superpave System developed by the Strategic Highway Research Program (SHRP). The Superpave system is a performance-based specification where tests and analyses have a direct relationship to field performance. Specifying Superpave system adds significant cost to smaller plant projects.
a. Binders are categorized by a Performance Graded specification ASTM D6373. Various binder grades must meet high and low pavement temperature requirements. High and low temperature designations are specified in degrees Celsius and six-degree increments. The first temperature designation represents the average seven-day maximum pavement temperature. The second temperature designation represents the minimum pavement design temperature likely to be experienced. A binder classified as PG64-22 means that binder must meet high temperature requirements up to 64°C and low temperature requirements down to -22°C. Higher high temperature designations are more resistant to high temperature distress such as rutting and shoving. Lower low temperature designations are more resistant to low temperature cracking.

b. Aggregate should be specified using a Dense Graded mix and by Nominal Maximum Size aggregate or Maximum Size aggregate. Dense Graded mixes are considered the workhorse of Hot Mix Asphalt because they may be used effectively in all pavement layers. It is important to state if Nominal Maximum Size aggregate or Maximum Size aggregate is being specified. Superpave defines the Maximum Size aggregate as one sieve larger than the Nominal Maximum Size aggregate. Superpave defines Nominal Maximum Size aggregate as one sieve size larger than the first sieve to retain more than 10 percent of material.

7.2.2.2 Subgrade Strength Evaluation

1. General

a. Thickness requirements for asphaltic concrete pavements depend mainly on strength requirements of the finished subgrade.

b. For a project with significant paving requirements, with heavy vehicle loading, and no directly relatable paving experience for the site, subgrade evaluation should be included as part of other geotechnical studies. Because stability of subgrade is closely related to its density and moisture content, subgrade soil testing should be performed as near as possible to anticipated in-service conditions.

c. Frequently, because of typical nature and intended use of a specified paving and available knowledge and experience with local subgrade materials, paving design can be performed with confidence without a site-specific subgrade evaluation.

d. If testing is required to evaluate strength of subgrade, the following tests can be used for determining in-place base and subbase strengths:

(1) Plate Bearing Test

(2) California Bearing Ratio Method

(3) Resistance Value Method
(4) Resilient Modulus Method

Results from any of the four testing methods cannot be directly converted to equivalent values of another method. However, Figures 2.6 and 2.7 in AASHTO GDPS provide average correlations of (2), (3), and (4) above.

2. Plate Bearing Test
   a. The Plate Bearing Test, in accordance with ASTM D1195, can be used for subgrade evaluations, and for strength measurements for subbase, base, or finished pavement.
   b. Test procedure involves loading a 6- to 30-inch diameter test plate on top of the surface of the materials. Deflection and rebound are measured at the plate and at distances up to 1.5 times the diameter from the edge of the plate.

3. California Bearing Ratio (CBR)
   a. The CBR test, in accordance with ASTM D1883, consists of measuring the load required to cause a plunger of standard size to penetrate a soil specimen at a specified rate.
   b. The CBR rating is the resultant of the CBR test expressed as a percentage of load for the same test performed on a standard sample of crushed rock.

4. Resistance Value (R-Value) Method
   a. The R-Value Method, in accordance with ASTM D2844, is a two-test procedure as follows:
      (1) A resistance value test determines thickness of a pavement structure required to prevent plastic deformation of soil under imposed wheel loads.
      (2) An expansion pressure test determines thickness or weight of cover required to maintain compaction of the soil.
   b. The design R-Value is determined from moisture content and density where thicknesses from the two tests are equal.

5. Resilient Modulus (Mr) Method
   a. The Mr Method, in accordance with FHWA Protocol P46, determines the resilient modulus of untreated fine-grained subgrade soils for conditions that are representative of stresses in pavements subjected to moving wheel loads.
   b. The Mr Method involves testing of soils in a triaxial chamber, subjected to repeated loads of fixed magnitude, frequency, and load duration.

7.2.3 Paving, Base, and Subbase Thicknesses

7.2.3.1 See Table 4 for guidelines for estimating paving and base and subbase thicknesses for three types of subgrade materials, and five types of
service and traffic requirements for roadways. Asphalt pavement thicknesses shown in Table 4 are for total depth of all courses.

7.2.3.2 Guidelines in Table 4 are based on untreated aggregate bases. An alternative design, using asphaltic concrete mixtures for base or subbase courses, can resist pavement stresses better than un-bonded aggregate layers which have no tensile strength. Consequently, wheel loads are spread over broader areas using the alternative design and less pavement thickness is required.

Table 4 – Thicknesses for Untreated Aggregate Bases

<table>
<thead>
<tr>
<th>Subgrade Soils</th>
<th>Approximate Thickness (in)</th>
<th>Typical Evaluation Values</th>
<th>Traffic Volume (Daily)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CBR</td>
<td>Resilient Modulus (M_r)</td>
</tr>
<tr>
<td>Relative Quality</td>
<td>Pavement</td>
<td>Base &amp; Subbase</td>
<td>Pavement</td>
</tr>
<tr>
<td>GOOD Coarse-grained soils (well-graded)</td>
<td>40-60</td>
<td>12,000 psi</td>
<td>Pavement (Note 1)</td>
</tr>
<tr>
<td>Gravel, sand w/limited clay binder</td>
<td>Pavement (Note 1)</td>
<td>Base &amp; Subbase (Note 2)</td>
<td>6</td>
</tr>
<tr>
<td>FAIR Coarse-grained soils (poorly-graded)</td>
<td>20-40</td>
<td>5,000 psi</td>
<td>Pavement (Note 1)</td>
</tr>
<tr>
<td>Sands, and sand/clay mixtures</td>
<td>Pavement (Note 1)</td>
<td>Base &amp; Subbase (Note 2)</td>
<td>8</td>
</tr>
<tr>
<td>POOR Fine-grained soils Plastic, high shrinkage and expansion, low-permeability</td>
<td>4-20</td>
<td>3,000 psi</td>
<td>Pavement (Note 1)</td>
</tr>
<tr>
<td></td>
<td>Pavement (Note 1)</td>
<td>Base &amp; Subbase (Note 2)</td>
<td>12</td>
</tr>
</tbody>
</table>

Notes:
(1) Paving thicknesses are based on asphaltic concrete (hot-mix). Alternative paving materials (cold-mix) may require additional thickness or additional base/subbase.
(2) A minimum of 6 inches of higher quality base materials should be placed over lower quality subbase materials.

7.2.3.3 Guideline thicknesses shown in Table 4 are based on a relatively dry and non-freezing location. See Table 5 for a relative comparison of roadbed soils that shows impact of various climates on design requirements.

7.2.3.4 Relatively poor subgrade soils can be treated in about the same manner regardless of climatic conditions at a particular site.
7.2.3.5 For fair subgrade soils, additional base and/or subbase thicknesses are probably required for more severe climates.

7.2.3.6 For good subgrade soils, climate becomes a more important consideration. Good subgrade soils in locations subject to hard freezes can be expected to perform no better than fair subgrade soils in areas without freezing. For example, good subgrade soils in Wyoming should be downgraded to fair if using Table 4. Subbase and base thicknesses should be adjusted accordingly.

7.2.3.7 If depth of frost penetration is greater than the total thickness of a subbase, base, and pavement system, subbase thickness should be increased until the total system thickness equals frost depth or 18 inches whichever is less.

7.2.3.8 Considering total pavement structure, it should be understood that there is not a single unique design solution. Instead, there are many combinations of paving, base, and subbase that can provide satisfactory results. Combination selected should be based on cost, construction, and maintenance considerations.

Table 5 – Impact of Climate on Various Roadbed Soils

<table>
<thead>
<tr>
<th>Climate Description</th>
<th>Examples</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry, no freeze</td>
<td>S California, S Texas</td>
<td>12,000</td>
<td>5,500</td>
<td>3,000</td>
</tr>
<tr>
<td>Wet, no freeze</td>
<td>W Oregon, N California, Gulf States</td>
<td>9,500</td>
<td>5,000</td>
<td>2,800</td>
</tr>
<tr>
<td>Wet, freeze/thaw cycling</td>
<td>Midwest and East Central States</td>
<td>7,300</td>
<td>4,500</td>
<td>2,700</td>
</tr>
<tr>
<td>Wet, hard freeze, spring thaw</td>
<td>Great Lakes to New England</td>
<td>5,700</td>
<td>4,000</td>
<td>2,700</td>
</tr>
<tr>
<td>Dry, freeze/thaw cycling</td>
<td>E Washington, N Texas</td>
<td>8,200</td>
<td>5,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Dry, hard freeze, spring thaw</td>
<td>Wyoming, Montana</td>
<td>5,700</td>
<td>4,100</td>
<td>2,800</td>
</tr>
</tbody>
</table>

7.2.4 Base, Subbase, and Subgrade Compaction

Compaction of base, subbase, and subgrade is critical for performance of roadway. See PIP CVS02350 for requirements.

7.2.5 Subbase and Base Materials

7.2.5.1 Subbase

1. For a subbase with a CBR of 20 (R-Value 55) minimum, the following materials may be used:
   a. Coarse sand
   b. Poorly graded gravel
c. Sandy loam  
d. Decomposed granite with fines  
e. Gravel containing fines  
f. Sand/shell mixtures  

2. Subbase material should contain not greater than 20% by weight of particles finer than 200 mesh.  
3. Very fine sand or silty sand should not be permitted as a base or subbase material.  
4. Maximum size of stone should not be greater than one-third the lesser thickness of the base course or subbase course.  

7.2.5.2 Base  

1. For a base with a CBR of 70 (R-Value 80) minimum, the following materials may be used:  
   a. Crushed rock  
   b. Pit run gravel (well-graded)  
   c. Well-graded sand (asphalt stabilized)  
   d. Coarse decomposed granite (well-graded)  
2. Base material should contain not greater than 7% by weight of particles finer than 200 mesh.  
3. Maximum size of stone should not be greater than one-third the thickness of the base course.  

7.2.5.3 Frost Considerations  

1. For areas subject to frost damage, base and subbase materials should contain not greater than 8% by weight of particles finer than 200 mesh. This helps to maintain good drainage through materials and reduce frost heave potential.  
2. If low-quality subgrade soils are present, consideration should be given to the use of geotextiles (see Section 7.5). Cost of using geotextile fabric over the weak subgrade may be offset by reduction in base and subbase costs.  

7.2.6 Types of Asphalt Paving  

7.2.6.1 Plant Mix – Asphalitic Concrete (Hot-Mix)  

1. Asphalt paving mixtures prepared in a central mixing plant are known as plant mixes. Asphalitic concrete is considered to be the highest-quality plant mix.  
2. Asphalitic concrete consists of well-graded, high-quality aggregate and asphalt. Asphalt and aggregate are heated separately from 250 to 325°F, carefully measured and proportioned, then mixed until aggregate particles are coated with asphalt.
3. The hot mixture, kept hot during transit, is hauled to construction site, where it is spread on roadway by an asphalt paving machine at temperatures greater than 240°F. Uniform layer of asphaltic concrete mix is spread by a paver, motor grader, or by hand followed by compaction with rollers to specified density before asphalt cools.

4. Asphaltic concrete may be placed in lifts from 2 to 4 inches compacted thickness.

5. Advantages of asphaltic concrete include the following:
   a. Produces a high-quality paving surface suitable for heavy traffic
   b. Good quality control can be achieved at mix plant
   c. Can be installed in a wide range of ambient temperatures provided quality control is maintained
   d. Because the aggregate is heated the moisture can be controlled

6. Limitations of asphaltic concrete include the following:
   a. Paving placement requires careful monitoring to assure that compaction procedures and equipment are providing specified compaction before the mixture cools.
   b. If hot-mix plants are too far from the work site, mix temperature considerations and economics can preclude use of hot-mix.
   c. Hot-mix plants in cold regions typically shut down during winter months.

7.2.6.2 Plant Mix – Cold-Mix

1. Cold-mix paving is a mixture of unheated mineral aggregate and emulsified asphalt that may also be produced at a central mixing plant.

2. Cold mix may be placed in lifts of 2 to 3 inches compacted thickness.

3. Advantages of cold-mix include the following:
   a. Similar to a hot-mix, production can be closely controlled
   b. Does not require stringent control of mix temperature during placement and compaction
   c. Can be used for patching during cold temperatures when hot mix is not available
   d. Can be pre-mixed and stockpiled for subsequent small quantity repair jobs

4. Cold-mix cannot provide high-quality, long-wearing paving that is attainable with hot-mix.

7.2.6.3 Roadway Mix (Mixed-in-Place)

1. Roadway mix paving is emulsified asphalt sprayed onto and mixed into aggregate at moderate-to-warm ambient temperatures. Mixed-in-place construction may be used for surface, base, or subbase courses.
2. If used as a surface or wearing course, roadway mix is typically satisfactory for light and medium traffic. However, mixed-in-place layers covered by a high-quality plant mix surface course can provide a pavement suitable for heavy traffic.

3. Advantages of roadway mix include the following:
   a. Can use aggregate already on the roadbed or available from nearby sources, and without extensive processing
   b. Eliminates need for a central mixing plant
   c. Placement can be performed with a variety of machinery often readily available (e.g., motor graders, rotary mixer with revolving tines, and traveling mixing plants).

4. Limitations of roadway mix include the following:
   a. Should not be installed if ambient temperatures is less than 50°F because proper mixing of asphalt and aggregate is difficult
   b. If surface moisture on aggregate is not properly controlled, excessive moisture causes problems in mixing, curing and compacting. Typically, surface moisture should not be greater than 3%.
   c. Quality of mixed-in-place paving is more difficult to control than plant mixes.

7.2.7 Asphalt Coatings

7.2.7.1 Prime Coat

1. Typically for untreated granular bases, when base course has been properly compacted and loose material removed, an asphalt prime coat should be applied.

2. A pressure distributor is normally used to spray low-viscosity asphalt on the prepared surface of base.

3. Asphalt prime coat should be fully absorbed by the base and permitted to set and cure before placing overlying asphaltic concrete course.

7.2.7.2 Tack Coat

1. If asphal tic concrete overlay is to be applied over a surface of existing asphaltic concrete or concrete, an asphalt tack coat should be applied to achieve proper bonding.

2. A tack coat should be very thin and uniformly cover the area to be paved.

7.2.8 Joints in Flexible Pavement

7.2.8.1 Jo ins occur in flexible pavement between new and existing pavements, between successive day’s work, and when a pavement under construction has a break in continuity of placing operations, where last mix placed becomes cold relative to next delivered batch.
7.2.8.2 Vertical joints in new asphaltic concrete pavement between lanes and between cold and hot paving will typically require special trimming or shaping and may require application of an asphalt coating.

7.3 Rigid Paving

7.3.1 General

7.3.1.1 There are two main types of rigid paving that are commonly specified:
   a. Jointed Plain Concrete Paving (JPCP) has no reinforcing and uses closer spaced joints to control cracking and joint movement. Dowels may be used for load transfer across joints for heavy traffic.
   b. Jointed Reinforced Concrete Paving (JRCP) is reinforced to control cracking and extend spacing between joints. Dowels may be used for load transfer across joints for heavy traffic.

7.3.1.2 Comparative studies as reported by the American Concrete Paving Association (ACPA) have shown that when JPCP is placed on a properly prepared subgrade, initial installation and long-term maintenance costs may be reduced.

7.3.1.3 JRCP is beneficial if probability of transverse cracking is high due to such factors as soil movement and/or stresses caused by temperature and moisture changes.

7.3.2 Subgrade

7.3.2.1 General

1. Subgrade is defined as top surface of a roadbed upon which pavement structure and shoulders are constructed. The most important consideration for a subgrade for rigid pavement is its ability to provide uniform support.
2. Concentrated wheel loads are distributed over a large supporting area of subgrade because of the rigidity of the concrete slab. The effectiveness of slabs on grade to distribute loads has been demonstrated by tests conducted by Portland Cement Association and others.
3. If subgrade is non-uniform, with abrupt changes from hard to soft, cracking can occur where slab bridges over soft spots or rides on hard spots.

7.3.2.2 Modulus of Subgrade Reaction

1. Typically design references for thickness of portland cement concrete paving evaluate subgrade support on the basis of modulus of subgrade reaction (i.e., Westergaard’s “k”).
2. The modulus is intended to measure temporary (elastic) properties of the subgrade, rather than long-term soil bearing properties.
3. The modulus is calculated in accordance with ASTM D1196 using the loading pressure to make a rigid 30 inch diameter bearing plate deflect 0.05 inch into subgrade material.
4. Value of the modulus of subgrade reaction, k in pounds/cubic inch, is calculated in accordance with the following equation:

\[ k = \frac{\text{load (psi)}}{\text{deflection (inch)}} \]

where:

deflection = actual measured deflection (approx. 0.05 inch)

5. Typical values for subgrade materials are shown in Table 6.

<table>
<thead>
<tr>
<th>Relative Quality</th>
<th>K Value (pci)</th>
<th>Examples of Subgrade Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>&gt;550</td>
<td>Crushed Rock</td>
</tr>
<tr>
<td>Good</td>
<td>400-550</td>
<td>Well-graded gravel</td>
</tr>
<tr>
<td>Fair</td>
<td>250-350</td>
<td>Sand/Clay Mixture, Well-graded</td>
</tr>
<tr>
<td>Poor</td>
<td>150-250</td>
<td>Gravel/Clay, Poorly Graded</td>
</tr>
<tr>
<td>Very Poor</td>
<td>&lt;150</td>
<td>Silts and Clays</td>
</tr>
</tbody>
</table>

### 7.3.3 Subbase

#### 7.3.3.1 General

A subbase is not mandatory for rigid paving, but should be considered for the following conditions:

a. The subgrade lacks uniformity because of minor soil variations. However, a subbase layer cannot correct major subgrade defects. Major defects should be corrected by excavating poor material.

b. A significant number of vehicles with axle loads exceeding AASHTO Design Truck HS20 are expected routinely.

c. To provide a stable working surface during paving construction

d. The subgrade materials are known to be problem soils (e.g., differential shrinkage and expansion or excessive frost heave).

#### 7.3.3.2 Thickness

1. If a subbase is provided, AASHTO GDPS recommends 4 to 6 inches for rigid pavement (See Chapter IV, Low Volume Road Design).

2. A subbase thicker than 4 inch should only be used for large wheel loads on poor material. When subbase depths are increased beyond 4 to 6 inches, there is an increasing risk of poor pavement performance due to subbase consolidation from heavy traffic. Consider using a geotextile instead of increasing subbase thickness beyond 6 inches. See Section 7.5 for additional information.
7.3.3 Material Characteristics

1. Dense-graded material
2. Maximum aggregate size, 1/3 subbase thickness
3. Particles finer than 200 mesh, 15% maximum
4. Plasticity Index, 6% maximum

7.3.4 Paving Thickness

7.3.4.1 For light traffic areas, walkways, and areas designed for automobiles or pick-up trucks, paving should be 4-inch minimum thickness. Consider potential for the occasional heavy load which could control pavement thickness design.

7.3.4.2 For typical plant roadways, a simplified design could be based on AASHTO GDPS Rigid Pavement Design Catalog. For example, for roadways intended to serve low traffic volume (range of 30,000 to 50,000 ESALs during a design life of 20 years), fair drainage conditions, and for all six climatic regions found in the United States (Table 5) and provide a 50% reliability percentage, rigid pavement thicknesses of 5 inch if a granular sub-base is provided and of 5.5 inch if no sub-base is provided. In this case a 6-inch thickness would probably be specified.

7.3.4.3 For typical plant roadways, rigid paving thicknesses typically range from 6 to 10 inches.

7.3.4.4 For areas designed for heavier loads (e.g., large mobile cranes, forklifts or heavy storage), an alternate paving analysis should be considered.

7.3.5 Joints in Rigid Pavement

7.3.5.1 Rigid roadway pavements will require joints for one or more of the following reasons: to control thermal effects (expansion joints), to control shrinkage cracking (contraction joints), ceasing concreting operations for more than a specified time period (construction joints) and to prevent interference of pavement with another structure, such as an abutment or utility structure (isolation joint).

7.3.5.2 Contraction joints may be formed partial depth, or created with a shallow saw cut. Other joints are usually formed for full depth of the pavement section.

7.3.5.3 Joints in rigid pavement will usually require vertical load transfer between adjacent sides of joint, the notable exception being isolation joints. Load transfer can occur by aggregate interlock, continuation of reinforcing across joint, dowels or other transfer devices. Construction, contraction and expansion joints for roadways typically use smooth dowels for load transfer projecting into both sides of the joint and centered in joint filler material. Load transfer dowels for expansion joints will require an expansion sleeve or cap on one side of joint. See PIP CV102350 for typical details of rigid pavement joints.
7.3.5.4 Joints in rigid pavement require sealing primarily to protect concrete reinforcing from corrosion, prevent water infiltration into subgrade and to prevent incompressible items from entering the joint that could create a spall in the concrete. Important joint sealant properties when specifying are their flexibility, chemical resistance, durability and their ability to bond to other materials. Sealants may be hot or cold applied and may be one or more parts that require on-site mixing. See ACI 504R for joint sealants information.

7.3.6 Joints Spacing in Rigid Pavement

7.3.6.1 Joint spacing should be tempered with judgment. Local materials and geographic conditions can have an effect on thermal properties of the concrete mix (e.g., changes in coarse aggregate type can change thermal coefficient). See ACI 325.12R for guidance with joint spacing.

7.3.6.2 Contraction joint spacing is typically determined by expected interval of cracking due to contraction generally expected for plain concrete. Pavement thickness, base stiffness, and climate affect maximum anticipated joint spacing beyond which transverse cracking can be expected. A general relationship has been developed between ratio of slab length (L) to radius of relative stiffness (ℓ) as defined by Westergaard and transverse cracking. When ratio of L/ℓ is greater than 4.44, there is tendency for an increase in transverse cracking. Based on this relationship, joint spacing would increase with concrete thickness and decrease with stiffer foundation support.

\[ ℓ = \left( \frac{Et^3}{12k(1-\mu^2)} \right)^{0.25} \]

- \( ℓ \) = Radius of relative stiffness (in)
- \( \mu \) = Poisson’s ratio for pavement material (≈ 0.15)
- \( E \) = Modulus of elasticity for concrete (psi)
- \( t \) = Pavement thickness (in)
- \( k \) = Modulus of subgrade reaction (pci)
- \( L \) = Joint spacing (in)

\[ L \text{ (Maximum)} = 4.44 \ell \]

Maximum joint spacing provided above is recommended in lieu of the general rule that contraction joint spacing should not exceed 24 times thickness with a non-stabilized base and 21 times thickness with a stabilized base. Maximum spacing should not exceed 15 ft.

7.3.6.3 For reinforced pavement, longer contraction joint spacing can be considered. With joint spacing greater than 30 ft, there is a greater tendency for cracks to develop between joints, an increase in faulting, and a decrease in joint sealant performance. However, if longer joint spacing is desired, guidance can be obtained in ACI 350-06, Table 7.12.2.1. See Table 7 for contraction joint spacing/minimum reinforcement guidance. Although these values are for environmental concrete structures, they are applicable for use in pavements not related to containment. It should be noted that longer contraction joint spacing
will increase crack width at joint and may affect load transfer at the joint that depends on aggregate interlock such that dowels may be required at the joint.

### Table 7 – Minimum Shrinkage and Temperature Reinforcement

<table>
<thead>
<tr>
<th>Length Between Full Contraction Joints</th>
<th>Minimum Shrinkage and Temperature Reinforcement Ratio – Grade 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 30 ft</td>
<td>0.0030</td>
</tr>
<tr>
<td>30 ft to less than 40 ft</td>
<td>0.0040</td>
</tr>
<tr>
<td>40 ft and greater</td>
<td>0.0050</td>
</tr>
</tbody>
</table>

7.3.6.4 Construction joint locations are generally field determined. If they need to be determined by engineering and design, they normally replace contraction joints and should be located within the parameters for contraction joints.

7.3.6.5 Expansion joints should be used at fixed objects such as structures, intersecting roadways, and other permanent objects. Current practice is to avoid installation of expansion joints at regular interval spacings.

7.3.6.6 Longitudinal joints are used to relieve warping stresses and are used when slab widths exceed 15 ft. Slab widths 15 ft and less have performed satisfactorily without longitudinal joints.

7.3.6.7 Concrete panels should be as nearly square as possible. Ratio of the slab width to length should not exceed 1.25 with a stabilized base and 1.5 with a non-stabilized base. Joint spacing requirements are the same as stated above.

### 7.4 Alternative Surface Treatment for Vehicle Traffic Area

#### 7.4.1 General

7.4.1.1 Paving with asphaltic concrete or portland cement concrete is typically limited to areas where, because of traffic loads or other considerations, the cost of paving is justified.

7.4.1.2 Other surface treatments that have application for limited vehicle traffic include the following:

a. Crushed rock
b. Gravel
c. Stabilized soil

7.4.1.3 Walking on these alternate surfaces can be difficult unless suitable material gradations are used and compacted to 90 to 95% of their maximum density.
7.4.2  **Compacted Crushed Rock**

7.4.2.1  Depending on quality of the subgrade, adequate support for occasional vehicle loads can be provided using crushed rock approximately 4 inches thick.

7.4.2.2  Crushed rock surfacing is typically used for the following conditions:

   a. An all-weather, well-drained surface is specified.
   b. Neat appearance is important.
   c. Heavy vehicle traffic is not expected.

7.4.2.3  For the best wearing, well-compacted surface, a well-graded crushed rock material with gradation (e.g., grain-size distribution) shown in Table 8 should be provided.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Amount Passing Sieve, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>100</td>
</tr>
<tr>
<td>3/4 inch</td>
<td>90-100</td>
</tr>
<tr>
<td>1/2 inch</td>
<td>25-60</td>
</tr>
<tr>
<td>3/8 inch</td>
<td>10-15</td>
</tr>
<tr>
<td>No. 4</td>
<td>0-3</td>
</tr>
</tbody>
</table>

7.4.2.4  To limit growth of vegetation through the rock surface, a weed killer approved by owner should be applied to the area before spreading crushed rock.

7.4.3  **Gravel**

7.4.3.1  Gravel is defined to be the wide variety of soil mixtures that have a significant portion of gravel (e.g., grain size .08 inch to about 3 inches) and/or coarse sand. Gravel surface course aggregates vary by region. If project specific geotechnical guidance is not available, consult local suppliers for available gradations that are commonly used.

7.4.3.2  Gravel can be found naturally at the site, or imported from a borrow pit.

7.4.3.3  Gravel can be well-graded (e.g., relatively uniform distribution of grain-size particles) to poorly graded (e.g., excessive percentages of certain grain sizes and absence of others). Some gravels have some plasticity, whereas others are non-plastic.

7.4.3.4  Well-graded gravels provide better and longer-lasting surfaces, and tend to perform better if they have a small percentage of clay which acts as a binder.

7.4.3.5  Poorly-graded gravels can become soft during wet weather and loose and dusty in dry weather.

7.4.3.6  Wearing properties of gravel surfaces can be improved by applying emulsified asphalt to bind the gravel.
7.4.3.7 For well-graded gravel, the gradation of fines shown in Table 9 should be provided.

<table>
<thead>
<tr>
<th>Designated Sieve</th>
<th>Amount Passing Sieve, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 10</td>
<td>20-100</td>
</tr>
<tr>
<td>No. 40</td>
<td>10-70</td>
</tr>
<tr>
<td>No. 200</td>
<td>3-25</td>
</tr>
</tbody>
</table>

### 7.4.4 Stabilized Soil

**7.4.4.1** In addition to typical compaction techniques for strengthening soils, chemical additives including the following can enhance soil properties:

a. Portland cement
b. Asphalt
c. Lime
d. Calcium chloride

**7.4.4.2** Chemical additive treatments can accomplish the following:

a. Upgrade strength of very poor subgrade materials under roadways
b. Decrease permeability of soils
c. Act as a palliative to control dust problems
d. Provide a surface for areas not subject to heavy vehicle loads

**7.4.4.3** The quantity of additive required and the expected stabilization gain depends on properties of the natural soil and depth of soil to be stabilized. Laboratory testing may be performed to assess the value of using chemical additives.

**7.4.4.4** Following is a typical procedure for stabilizing soils:

a. Scarify existing surface
b. Spread chemical additives
c. Mix with motor grader using windrow mixing or alternative procedure
d. Spread mixture
e. Compact surface as required

### 7.5 Paving over Low-Strength Soils

#### 7.5.1 General

Traditionally, where low-strength soils are encountered, soils are either excavated and replaced, or excavated and recompacted, or overlaid with thicker subbase materials to reduce unit loading to the subgrade. However, with development of geogrid and geotextile products, other alternatives are available for working with problem soils.
7.5.2 Geogrids

7.5.2.1 Geogrids are manufactured from high tensile strength polymer, and designed with transverse and longitudinal ribs.

7.5.2.2 Laid directly on subgrade, geogrid geometry provides a mechanism for interlocking aggregate base or subbase material placed on geogrid. Interlocking prevents lateral movement of the aggregate and improves load distribution to subgrade.

7.5.2.3 Geogrid materials are inert to typical chemical and biological conditions in soils and are not expected to degrade.

7.5.3 Geotextile

7.5.3.1 Geotextile is manufactured from various polymers in rolls up to about 16 ft wide and 300 to 1000 ft long.

7.5.3.2 Laid over subgrade materials directly below an aggregate subbase, geotextile is designed to perform any or all of the following functions:
   a. Maintains separation between subbase and subgrade. Coarse aggregate cannot move downward, and fine soil particles in subgrade cannot rise into subbase.
   b. Is permeable and permits pore water to pass vertically through fabric
   c. Tensile strength of geotextile material provides tensile reinforcement for subbase
   d. Permits lateral water flow within the plane of geotextile material and dissipates excess pore water pressure

7.5.3.3 Geotextiles are resistant to freeze-thaw and soil chemicals.

7.5.3.4 Geosynthetic Institute is a source of additional information related to geotextiles.

8. Drainage Considerations

8.1 Roadway Drainage

8.1.1 Proper drainage design is critical to long term performance of roadways. Roadway drainage should be considered in two categories, surface and subsurface, each of which is treated separately.

8.1.2 Roadway drainage systems consist of collection, conveyance, removal, and disposal of surface water runoff from the traveled way, shoulders, and adjoining roadside areas. Culverts, headwalls, ditches, swales, curbs and gutters are typically integral parts of roadway drainage systems.

8.1.3 Subsurface water should also be drained away from roadbed for a sufficient depth below roadway surface to prevent frost troubles, and maintain a layer of stable material thick enough to distribute pavement pressure successfully to less stable layers beneath. Subgrade sloped to ditches is normally used to provide subsurface drainage. If ditches are not appropriate, subdrains may be used.
8.2 Curbs, Gutters and Inlets

8.2.1 Sidewalks and curbs may be specified along a roadway. Change in elevation from curbs along a roadway edge channels surface water runoff, forming gutters.

8.2.2 Gutter grades should be 0.3% to 0.4% minimum.

8.2.3 Inlets and/or catch basins should be placed along curb and gutters to remove surface runoff.

8.2.4 Catch basin spacing should be determined based on the following conditions:
   a. Flatness of the grade
   b. Volume of rainfall typical for the location
   c. If applicable, firewater flow

8.2.5 Inlets should be ample to receive full flow of water.

8.2.6 Maximum spacing of catch basins is typically 250 ft.

8.2.7 Water should not be permitted to cross surface of an intersecting street.

8.3 Ditches

8.3.1 General

8.3.1.1 Roadside ditches should prevent water from pooling on roadway surface, penetrating base or subbase, and prevent overland runoff from reaching roadway.

8.3.1.2 Design considerations for roadside drainage ditches include ditch shape, slope, lining considerations, and capacity requirements.

8.3.2 Shape

8.3.2.1 Typically, ditch shape is either V-shaped or trapezoidal.

8.3.2.2 For mild side slopes, ditch shape tends to approach a parabolic shape, which is the most hydraulically efficient shape.

8.3.2.3 Because V-shaped ditches are more susceptible to erosion, trapezoidal ditches may be preferred for certain soil conditions.

8.3.2.4 Size and depth of ditch should be set by volume of water that needs to be channeled.

8.3.2.5 Roadbed may need to be elevated to permit depth of ditch to be sufficient for good drainage.

8.3.2.6 Special design features (e.g., drop structures, check dams, etc.) should be considered to minimize shear stresses exerted on ditch boundary or lining, and avoid occurrence of supercritical flow.

8.3.3 Slope

8.3.3.1 Side slopes of an unlined or grass lined ditch should not exceed the angle of repose of soil comprising the ditch side slope, or be provided as specified in geotechnical report. A shallow slope such as 3:1 (horizontal:vertical) may be required to allow safe operation of ditch maintenance equipment.
8.3.3.2 For typical surface drainage over pavement to a ditch, the roadway side slope of an unlined or grass lined ditch should be 4:1 to minimize erosion. The other side of ditch should be in accordance with Section 8.3.3.1.

8.3.3.3 Linings as described in Section 8.3.4 or retaining walls will permit the use of steeper ditch side slopes and will mitigate slope stability and erosion issues.

8.3.4 Linings

8.3.4.1 Linings can be either rigid or flexible. Lined ditches generally allow for steeper slopes and can provide protection against erosion caused by high velocities at ditch and culvert outlets.

8.3.4.2 Rigid linings include concrete, paved, or other low permeability linings. Rigid linings may be specified where ditches are designed to carry runoff from process areas adjacent to roadway.

8.3.4.3 Flexible linings include asphalt, vegetation, riprap, or geotextile material.

8.4 Culverts

8.4.1 General

8.4.1.1 Culverts are used to channel water under roadways and driveways or to remove drainage from ditches.

8.4.1.2 A wide variety of standard shapes and sizes are available for most culvert materials. Because equivalent openings can be provided by a number of standard shapes, selection of shape may not be critical in terms of hydraulic performance.

8.4.1.3 Factors governing culvert shape selection may include some of the following:
   a. Depth of cover
   b. Limited headwater elevation where a low profile shape may be required
   c. Potential for clogging by debris
   d. Requirement for a natural stream bottom
   e. Structural and hydraulic requirements

8.4.2 Culvert Materials

8.4.2.1 Selection of a culvert material may depend upon structural strength, hydraulic roughness, durability, resistance to corrosion and abrasion, cost and availability.

8.4.2.2 Pipe materials used for culverts are typically classified as either rigid or flexible according to pipe material stiffness. By definition, deflection of rigid pipe should be limited to no more than 1% of its diameter whereas flexible pipe may deflect 3% or more of its diameter.
8.4.2.3 Concrete (reinforced and non-reinforced) is the most common type of rigid pipe material used for culverts. Corrugated aluminum, corrugated steel, and solid wall and profile wall plastic are the most common types of flexible pipe materials used for culverts.

8.4.2.4 Culverts may be lined to inhibit corrosion and abrasion, or reduce hydraulic resistance (e.g., corrugated metal culverts may be lined with asphaltic concrete).

8.4.2.5 Concrete

1. Concrete culverts may be made from either precast or cast-in-place reinforced concrete depending on size and complexity of the culvert design.

2. Precast culvert sections are uniform in size and shape and are made in sections that can easily be transported, lifted, and installed.

3. Precast concrete culverts may be made with high strength concrete.

4. Cast-in-place culvert construction is typically used if ready-mix concrete is available and a culvert is specified to be constructed without joints.

5. Cast-in-place concrete culverts may have special reinforcement at critical locations to resist high loads and stresses.

8.4.2.6 Corrugated Metal

1. Corrugated metal culverts are made from factory-produced corrugated sheet steel or aluminum.

2. Corrugated culvert pipes are made with factory-produced corrugated pipe sections.

3. Large corrugated culverts are typically field-assembled using structural plate products.

8.4.2.7 Plastic

1. Many types of materials may be used to produce plastic culvert pipe. Two commonly used materials for these gravity or low-pressure applications are polyvinyl chloride (PVC) and polyethylene (PE).

2. Physical properties of plastic pipe materials typically depend on the type of base resin and blend or formulation of chemicals in the final resin material. Different wall treatments are available - solid wall smooth, corrugated and profile wall. Profile wall pipe typically has smooth internal pipe surfaces with stiffening ribs, corrugations or other shapes fused or extruded in manufacturing of the pipe. Fabricated elbow, wye, tee, and reducer fittings are usually available from plastic pipe manufacturers.

3. Plastic culvert pipes are typically joined by couplings or bell and spigot ends with elastomeric gaskets. PE pipe can also be joined by extrusion welding or heat fusion methods, but this is usually
employed for sewer applications. Solvent weld joining of PVC pipe is common for small diameter smooth wall (up to 8 inches), but is not recommended for the larger pipe diameters normally encountered in culvert applications.

8.4.2.8 See Section 9.3 of this Practice for design of culvert pipes for dead and live loads imposed on top of the culvert pipe.

### 8.4.3 Culvert Coatings

#### 8.4.3.1 General

1. A variety of coatings may be used either singularly or in a combination of layers to protect culverts from chemical and/or abrasion attack.

2. Type of coating to use depends upon type of culvert material and types of deterioration or distress to be resisted.

3. Need for protective coatings depends upon the following factors:
   a. Chemistry and acidity of adjacent soil
   b. Chemistry and acidity of water passing through culvert
   c. Particle size and velocity of solid material being transported through culvert
   d. Environmental effects including freezing and thawing

#### 8.4.3.2 Metal Culverts

1. Corrugated steel culverts may be protected with metallic coatings of zinc (e.g., galvanized) or aluminum.

2. Protective coatings for metal culverts may also include bituminous coatings, bituminous paving, fiber-bonded bituminous coatings, polymer, concrete paving, and concrete coatings. These protective coatings may be applied in addition to a metallic coating for serious corrosion or abrasion conditions.

3. Inverts of larger corrugated metal culverts may be specified as paved to extend life of the culvert by protecting the invert against corrosion and abrasion. Paving smooths the inside of culvert and improves hydraulic capacity.

#### 8.4.3.3 Concrete Culverts

1. Typically, concrete culverts are not coated when constructed.

2. If installed in aggressive chemical environments, concrete culverts may be coated with epoxy resins or special high density, low porosity concrete materials that have a high resistance to chemicals and chemical attack.
8.5 Headwalls

Headwalls control and direct transitional flows in and out from a culvert to an open ditch or creek. Headwalls may be cast in place or pre-cast units. See *PIP CVI02350* for typical details for headwalls.

9. Culvert, Pipeline, and Pipe Crossings

9.1 Pipeline and Pipe Protection at Crossings

9.1.1 Transmission pipelines and process pipe crossing under roadways with depth of cover generally less than three feet should be protected from external loads or shock during or after construction of the roadway. Pipe protection should be capable of supporting expected overhead traffic. Protection can be provided by enclosing in an encasing pipe, embedding in or covering with concrete, or routing in a conduit trench to protect pipe.

9.1.2 Unlined roadway drainage ditch flow lines should be placed 2 foot minimum above buried pipes where practical to prevent damage from ditch cleaning operations or flow scour.

9.1.3 Use “One Call (811)” during design phase to avoid problems during construction that involve excavation around commercial pipelines.

9.2 Pipe Loading

9.2.1 General

9.2.1.1 For designing underground culverts and piping, earth loads and live or transmitted loads should be considered. Data on dead and live loads can be obtained from many different handbooks available and from pipe manufacturer’s guidelines.

9.2.1.2 Load from both dead and live loads transferred to below grade varies as a function of depth of cover as shown in Figure 3. Dead load is based on unit weight of soil of 120 pcf times depth of cover, i.e., no surcharge load due to other circumstances is accounted for in Figure 3. Live load is based on AASHTO Design Truck HS20 axle load and a dynamic load allowance derived using *ACPA DD 1*. Figure 3 is conservatively based on a pipe parallel to traffic and neglects installation conditions and backfill materials that can reduce load transferred to pipe. For a more rigorous approach, engineer should consult pipe design literature.

9.2.1.3 If the area above piping is paved with flexible pavement, a higher percentage of load will be transmitted to pipe; whereas, rigid pavement (e.g., concrete) will bridge pipe transmitting more load to surrounding soil and therefore live load transferred to pipe below grade is significantly less and therefore generally considered negligible at any depth.

9.2.1.4 For piping under a roadway, depth of cover should be based on rough grade elevations for roadway if underground piping will be subject to significant truck traffic (i.e., heavy construction loads) before any paving is applied.
9.2.1.5 If greater loads are expected, calculations should be based on actual loads. Heaviest wheel load that would be expected from a large unladen truck crane is 32,000 pounds (1/2 axle load of 64,000 pounds). Wheel load may be on dual tires but is still considered one wheel. Heavier loads could be possible during equipment handling or lifting activities and this point should be reviewed with owner. Generally, load sensitive existing pipe is protected with timber mats or other methods.

![Figure 3 – Loads on Buried Pipe](image)

9.3 Culvert Design

9.3.1 Culvert Pipe Bedding and Backfill

9.3.1.1 Culvert pipe bedding is material placed on top of native soil at bottom of excavation on which pipe rests to provide uniform support for pipe. Some types of bedding extend to spring line of pipe.

9.3.1.2 Backfill is compacted soil that is filled in excavation for pipe, after bedding and pipe are installed, on the sides of and above pipe.

9.3.1.3 Culvert pipe bedding and backfill have a direct impact on ability of pipe to support imposed dead and live loads on top of pipe.

9.3.1.4 Unusual conditions (e.g., extraordinary loads or very deep or shallow depths of bury) require special consideration.

9.3.1.5 Refer to *PIP CVS02700* for typical bedding and backfill requirements for culvert pipe.

9.3.2 Rigid Culvert Pipe Design

9.3.2.1 Rigid culvert pipe (i.e., concrete) either cracks or ruptures if imposed dead and live loads exceed the inherent circumferential strength of the
pipe, also known as crushing strength of the pipe. Crushing strengths for concrete culvert pipes are determined by use of three-edge bearing tests.

9.3.2.2 Non-reinforced concrete culvert pipes must meet minimum three-edge bearing test strengths specified in ASTM C14, which are based on testing pipes to the point of rupture (ultimate strength).

9.3.2.3 Reinforced concrete culvert pipes must meet two separate minimum three-edge bearing test strengths specified in ASTM C76, which are based on testing pipes to the point that a 0.01-inch crack is produced and to the point of rupture (ultimate strength). Load strength of pipe, either the 0.01-inch crack or ultimate in lb/ft of pipe, divided by nominal internal diameter of pipe in feet is called the D load strength. These D load values are constants for each Class of reinforced concrete culvert pipes.

9.3.2.4 Typical factors of safety used for design of concrete culvert pipes are 1.5 if designing to ultimate strength for non-reinforced or reinforced concrete pipe and 1.0 if designing to a 0.01-inch crack load for reinforced concrete pipe.

9.3.2.5 ACPA Concrete Pipe Design Manual provides detailed procedures for design of non-reinforced and reinforced concrete culvert pipes with imposed dead and live loads on top of pipe.

9.3.2.6 Minimum required earth cover for non-reinforced and reinforced concrete culvert pipes subject to imposed dead and live loads on top of pipe are presented in Table 10 based on the following:

a. Dead loads are calculated based on a unit weight of soil backfill of 120 pcf.

b. Live loads are based on an HS20 wheel load determined in accordance with the ACPA Concrete Pipe Design Manual, for pipe running parallel to the roadway, and assuming conservative pipe bedding and backfill conditions.

c. Required earth cover for non-reinforced concrete pipe is calculated based on minimum three-edge bearing strength (crushing strength), in accordance with ASTM C14, using a factor of safety of 1.5.

d. Required cover for reinforced concrete pipe is calculated based on specified class strength for D-load to produce a 0.01-inch crack, in accordance with ASTM C76, using a factor of safety of 1.0.

9.3.3 Flexible Culvert Pipe Design

9.3.3.1 Design of flexible culvert pipe (e.g., aluminum, steel and plastic) is usually controlled by deflection due to imposed dead and live loads on top of culvert pipe.

9.3.3.2 Flexible culvert pipe resists deflection due to vertical loading using pipe material stiffness combined with lateral support provided by compacted soil at side fills. See manufacturer’s literature for design procedures.
9.3.3.3 Maximum external vertical load that can be applied to a coated flexible culvert pipe is the load that produces the following deflection:

a. For flexible coating, 5% of nominal pipe diameter
b. For rigid coating, 2% of nominal pipe diameter

Table 10 – Minimum Required Earth Cover for Underground Concrete Culverts

<table>
<thead>
<tr>
<th>Culvert Inside Diameter (inch)</th>
<th>Minimum Required Earth Cover (inch)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Reinforced Concrete Culvert Pipes</td>
<td>Reinv.</td>
</tr>
<tr>
<td></td>
<td>Class I</td>
<td>Class II</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>6</td>
<td>26</td>
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</tr>
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<td>8</td>
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<td>10</td>
<td>46</td>
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</tr>
<tr>
<td>12</td>
<td>50</td>
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<td>15</td>
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<td>NP</td>
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<td>NP</td>
<td>48</td>
</tr>
<tr>
<td>24</td>
<td>NP</td>
<td>52</td>
</tr>
</tbody>
</table>

Notes:
N/A = Reinforced Concrete Culvert Pipes are not manufactured in these diameters
NP = Not Permitted; Pipe Strength Exceeded
(1) Minimum cover usually specified as 12 inches

10. Typical Roadway Details

See drawings CVE02350-01 and 02 for typical details for roadway sections and roadway clearances.
NOTES:

1. DEVELOP DESIGN DRAWING AND SPECIFICATIONS FOR:
   - Type of roadway construction
   - Base and subbase requirements
   - Cut and compacted fill requirements
   - Subgrade preparation requirements
   - Drainage and ditch requirements

2. Secondary and tertiary roadways may be single lane and may be one way traffic.
NOTE:
SECONDARY AND TERTIARY ROADWAYS MAY BE SINGLE LANE AND MAY BE ONE WAY TRAFFIC.