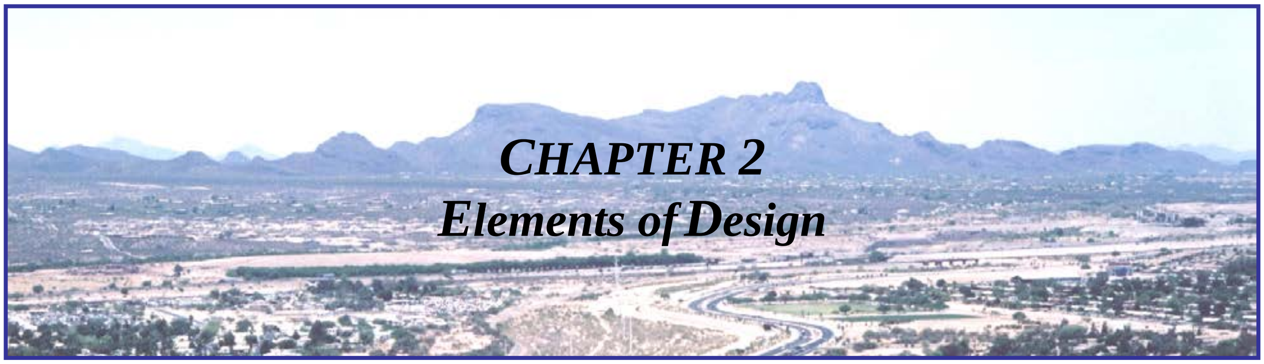


CHAPTER 2
Elements of Design

2.1 INTRODUCTION

This chapter highlights the important considerations and requirements in designing and reviewing plans for new and improved Pima County roadways. The chapter sections present the elements of roadway design and include references to other documents for additional guidelines and specifications. These latter documents are also listed in the Appendices of this chapter.

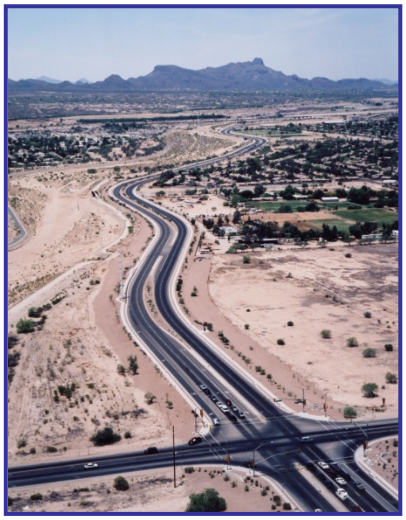
In addition, this chapter is based on the principles of "Complete Streets" which looks to incorporate use by all existing and future users, and not be limited to just motor vehicles. This expansion of thought associated with the roadway design, includes a responsibility to the public health, safety and welfare in order to design, operate, and maintain the right of way in a manner that enables safe and efficient access for drivers, transit users, vehicles, pedestrians, and bicycles; along with children, the elderly and those with disabilities. It is essential to recognize that all modes of travel need to be analyzed, evaluated and accommodated to the maximum degree practicable.

Note that these documents are revised periodically; therefore users should double check that they have either the specific version of the document specified in this chapter, or, that they have the most recent version if the reference is updated.

Pima County recognizes that each roadway project is likely to have some conditions that require special and/or unique treatment. This chapter, therefore, is not intended as a "cookbook." That is, this chapter is not a substitute for experience, professional judgment, and ongoing communication between the designers and reviewers. In those cases, however, where the application of a particular standard **is required**, the words "must" or "shall" have been used. In other cases, "may" or "should" are used to imply some flexibility at the discretion of Pima County. Figures referenced within this chapter are included consecutively at the end of the chapter, but preceding the chapter's appendices. Tables are presented near their point of reference within the text.

Finally, if a project is designated an "environmentally sensitive roadway" by Pima County or meets the criteria of such a roadway, designers and reviewers must also take into account the County document entitled *Environmentally Sensitive Roadway Design Guidelines*, which is included as Chapter 4 of this manual.

2.2 HORIZONTAL ALIGNMENT



The horizontal alignment of a roadway is comprised of horizontal curves and tangent sections. Superelevation is introduced into the alignment to provide appropriate balance between centrifugal forces and side friction on the tires of the vehicle moving through the curved section.

Two primary factors that provide the framework for horizontal alignment are design speed and stopping sight distance. The design must also consider the functional classification, topography, vertical alignment, environmental factors, right-of-way width, access locations and project costs, etc. Sight distance must be considered concurrently with topography since it will often require a greater curve radius than what is required solely by design speed.

Design Speed

The design speed is based on the physical features and functional classification of the roadway. Horizontal and vertical alignment, sight distance and superelevation are features directly related to the selected design speed. Pima County will specify a design speed for each project, with the maximum design speed being 60 miles per hour (mph).

Stopping Sight Distance on Horizontal Curves

The sight distance available to drivers across the inside of horizontal curves is an important element in the design and review of horizontal alignment. When sight obstructions such as walls, outside curbline barriers, cut slopes, buildings, and continuous median barriers exist on the inside of curves, the distance to the obstruction from the center of the nearest travel lane must be checked. This distance, M, is termed the middle ordinate of the curve. Guidelines for the middle ordinate are given in the latest edition of the *American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets* (*AASHTO Policy)*, based on the stopping sight distances that should be provided.

Horizontal Curves

Values for design elements, including minimum curve radii, design speed, and superelevation, are found in the *AASHTO Policy*. When designing the horizontal alignment of new or improved roadways, the following factors should be considered:

- The design of horizontal and vertical alignments should be well coordinated in order to avoid undesirable driver reactions. For more information on this topic, refer to the latest edition of the *AASHTO Policy*.
- Differences in design speed between successive horizontal curves should be avoided.

- For small deflection angles, horizontal curves should be sufficiently long to avoid the appearance of a kink. Curves should be at least 500 feet for a central angle of 5 degrees, and the minimum length should be increased 100 feet for each 1-degree decrease in the central angle (*AASHTO Policy*).
- An angle point is acceptable for breaks in tangent alignments of less than 1°08'.
- Horizontal curves, meeting minimum radii as defined by the latest edition of the *AASHTO Policy*, should be avoided at points where driver expectation is low, such as at the ends of long horizontal and vertical tangent sections.
- Median openings along horizontal curves are generally discouraged.
- Broken-back curves (i.e., two horizontal curves in the same direction separated by short tangent sections) should be avoided.

<u>Superelevation</u>

Superelevation refers to cross slope introduced into the cross section of a roadway in order to compensate for the centrifugal forces created by horizontal curves. In Pima County, 0.06 ft/ft and 0.04 ft/ft are the maximum rates for rural and urban/suburban roadways, respectively.

Examples of design superelevation rates based on the design speed, the radius of curve, and the superelevation rate can be found in *AASHTO Policy*.

Typical superelevation sections are presented in Appendix 2-B (Figures 2-8 and 2-9), at the end of this chapter.

<u>Axis of Rotation</u>

When superelevation is introduced to account for horizontal curvature and to provide a stable turning motion for vehicles traveling at or below the design speed, the rotation of the pavement section must be designed along a given axis. The location of this axis of rotation has impacts on the length required to transition from a normal crown section to a superelevated section. The location can also impact drainage patterns, driver perception of the transition area, and aesthetics. Within a given project, the axis of rotation should remain constant for all horizontal curves and for a given type of cross section.

Regardless of the location of the axis of rotation, "flat" areas shall be avoided and the change in cross slope between the roadway and its intersecting driveways and cross streets shall be carefully reviewed. Designing narrow medians is particularly challenging since the cross section slope across the width of the median (from outer curb face to outer curb face) should be flatter than 10:1. Median openings should conform to a maximum grade differential of 5%.

<u>Superelevation Transitions</u>

Superelevation transitions refer to the lengths of highway that are used to bring a normal crown section up to the superelevation rate that is being designed. Transitions are also used to bring a superelevated section back to the normal crown section. There are two components that make up the total transition for a superelevated section. The first component is the tangent runout, which denotes the length of highway needed to bring a normal crown section to a section with an adverse crown removed (zero cross slope), or vice versa. The second component is superelevation runoff, which denotes the length of highway needed to bring a section with the adverse crown removed (zero cross slope) up to a fully superelevated section, or vice versa. Guidelines for the minimum length of superelevation runoff and tangent runout for a variety of design speeds and superelevation rates are given in *AASHTO Policy*.

Refer to the latest edition of the *AASHTO Policy* for a complete discussion of superelevation transitions, including proportion of runoff length on the tangent, the use of spiral transition curves, and maximum relative gradients.

Spiral Curves

Spiral curves are used in Pima County projects only when required to coordinate and be compatible with roads designed by other agencies, particularly the Arizona Department of Transportation (ADOT).

Compound and Reverse Curves

The use of compound circular curves should be avoided. In special cases, where topography or right-of-way constraints require the use of compound curves, the radius of the flatter curve should not exceed 1.5 times the radius of the sharper curve.

Where topographic or right-of-way constraints require the use of reverse simple curves, a minimum tangent separation between the curves equal to at least 4/3 of the longer of the two superelevation runoff lengths shall be used. Special attention to roadway drainage requirements must be given when using reverse curves.

Broken back curves, which consist of two curves in the same direction connected by a short tangent section, should be avoided in the design of horizontal alignment. Pima County will review requests for permission to use this type of curve.

For curvature and superelevation transitions near bridges, the beginning and end of horizontal curves should occur sufficiently beyond the bridge limits so that the superelevation transition sections do not fall on the bridge or its approach slabs.

2.3 ROADWAY SECTIONS

The typical cross sections for Pima County roadways are shown in Appendix 2-B (Figures 2-1 through 2-7), at the end of this chapter. For roadways that may be annexed in the near future by a city or town, Pima County may elect to incorporate none, some, or all of the city's or town's standards into the design.

Lane and Shoulder Width

The preferred lane widths to be used for Pima County roadway design are presented in Table 2-1 at the end of this section. Proposed lane widths that will exceed the preferred lane width shall be reviewed to determined if a wider lane is justified based on roadway geometry, traffic conditions, volume, vehicle mix (percentage of trucks), bicycle use, driver age/demographics for the location, along with design and posted speed limits.

Clear Zone and Cross Slope

Standards for other cross section features are presented in Table 2-2 at the end of this section. Drainage structures should extend beyond the clear zone limits. Noise walls and retaining structures should be installed beyond the clear zone limits. However, there may be circumstances which require the location of these types of features within the clear zone due to functionality or for other reasons/requirements (e.g. – available right-of-way, constraints associated with project construction, impact on other roadway features/components, costs, etc.). Therefore, when these types of features are constructed within the clear zone, a further review for appropriate clear zone mitigation shall occur.

Refer to the latest edition of the *AASHTO Roadside Design Guide* for further discussion on clear zone, crash attenuation, traversable and recovery slopes, and barriers.

Side Slope

Figures 2-1 through 2-7 illustrate required side slopes, both in cut and fill sections. The Pima County standard for cut and fill sections is a 4:1 slope on urban roadways, and a 6:1 foreslope and 4:1 backslope on rural roadways. Embankments and excavations steeper than 4:1 and heights greater than 10 feet must be in compliance with the Pima County Hillside Development Overlay Zone.

Medians

The standard median width for Pima County designed projects is 22 feet. The minimum median width is 20 feet. A maximum median width of 24 feet may be included as part of the design, subject to a review of documentation and justification for the increased width, and with approval of Pima County prior to it being included as part of the design.

Pedestrian Walkways

Pedestrian walkways (sidewalks and paths) should be incorporated in a roadway cross-section design based on a review and analysis of existing and projected pedestrian use, unless otherwise directed by Pima County. The standard width for sidewalks is 5 feet unless the sidewalk is placed abutting the back of curb; then the standard width is 6 feet. Pedestrian facilities are furhter discussed in Section 2.6. Sidewalks, paths, and all ramp connections shall be designed and installed to be compliant with the Americans with Disabilities Act.

Roadside Barriers

Roadside barriers are systems used to shield motorists from natural or man-made obstacles located along the traveled way and may be used to protect pedestrians and bicyclists from vehicles under special conditions. The primary purpose of all roadside barriers is to prevent an errant vehicle from striking a fixed object or terrain feature that is less forgiving than striking the barrier itself. Roadside obstacles and embankments within the clear zone may warrant shielding by a roadside barrier and require evaluation in accordance with the barrier warranting process identified in the latest edition of the *AASHTO Roadside Design Guide*. Roadside obstacles and embankments located outside the clear zone should be reviewed for potential barriers based on engineering judgment relative to the risk and severity of an incident.

Barrier warrant analysis documentation shall be included in the project files and submitted to the department for review and approval. Documentation shall include the location and description of the obstacle, evaluation, and final approved disposition of all existing and proposed improvements and obstacles.

Regardless of the location of the obstacle, the preferred placement for barrier and/or guardrail treatment should be at the face of the curb for curbed roadways and back of shoulder for uncurbbed roadways. The length shall meet the reocmmendations presented in the latest edition of the *AASHTO Roadside Design Guide.* The guiding principal in barrier selection is its' funcitonality and proven performance. The barrier chosen shall have been crash tested and approved byFHWA, with its' use compatible with the testing performed.

Utilities

The formally adopted Pima County *Design Guide for Constructing and Relocating Utilities within Public Right-of-Way* is provided in Appendix 2-D of this chapter. The guideline requires that all new overhead and above-ground utilities be constructed outside of the roadway clear zone. Also, underground utilities should be placed outside the paved areas of the roadway section. See Figure 2-11 in Appendix 2-B for standard locations of overhead and underground utilities.

Table 2-1 Lane Width Standards – Pima County Design

Lane Type	Preferred Width (Ft)
Travel	11
Travel (inside), with median curb	12[1]
Right-turn	13[2]
Left-turn, with median curb	13[1]
Left-turn, no curb	12
Two-way, left-turn lane	12
Paved Shoulder (urban)	6
Shoulder (2 lane rural), paved + unpaved	10

Notes: Widths measured from center of stripe to center of stripe unless otherwise noted.
1. Width is inclusive of the median yellow edgeline offset of one foot
2. Width is inclusive of the edge of pavement white edgeline/curb offset of one foot.
See Typical Section figures 2-1 through 2-9

Table 2-2 Cross Section Standards – Pima County Design

Element	Standard	Minimum
Median width	22 feet	20 feet
Cross slope (travel lanes)	2%	2%
Cross slope (paved shoulder)	2%	2%
Cross slope (turn lanes)	2%	1%
Cross slope (pedestrian walkway)	2% (toward road)	1% (toward road)
Cross slope (graded shoulder)	2%	2%
Cut slope	4:1	3:1
Fill slope	4:1	3:1
Clear zone	6:1	4:1

Note: See the latest edition of the AASHTO Roadside Design Guide, for clear zone values.

2.4 VERTICAL ALIGNMENT (PROFILE)

The vertical profile gradeline is the reference line by which the elevation of the pavement and other roadway features are established. The profile gradeline of a roadway is defined by a series of tangent grades and vertical curves. The vertical curve used for roadway design is a parabola. Consistency of the vertical alignment is important in order to provide safe stopping sight distance at all points along the roadway. Also, the vertical alignment must be coordinated with the horizontal alignment during the design effort.

Grades

Pima County guidelines for maximum and minimum profile grades are:

- 3% maximum grade in flat terrain
- 7% maximum grade in foothill or mountainous areas
- 0.5% minimum grade in all areas
- 4% maximum grade break at side-street intersections
- 8% maximum grade break at driveways without using vertical curves
- A minimum 18 foot level landing should be placed at driveways and side streets

Vertical Curves

Pima County uses vertical curves based on the simple parabola and with the vertical axis centered on the point of intersection. Vertical curves generally should be made as long as possible to provide greater stopping sight distance and more pleasing aesthetics. In some cases, however, a minimum length vertical curve may be required to reduce the amount of excavation in rolling or hilly terrain.

The formulas used to establish the length of a vertical curve for crest situations are:

for $S < L$ $\quad L = AS^2/2158$
for $S > L$ $\quad L = 2S - 2158/A$

where

L = length of crest vertical curve (ft)
S = sight distance (ft)
A = algebraic difference in grades (percent)

Pima County's design control criterion for both crest and sag vertical curves is the provision of adequate safe stopping sight distance (refer to the next section for a discussion on stopping sight distance). A minimum length of vertical curve of three times the project design speed is desirable for Pima County roadways. Most project designs should use a longer than minimum vertical curve length. Specific values for crest vertical curves, both tabular and graphical, can be found in the latest edition of the *AASHTO Policy*.

The following equations apply for the design of sag vertical curves:

for $S < L$ $L = AS^2/400+3.5S$

for $S > L$ $L = 2S - (400+3.5S)/A$

where

L = length of sag vertical curve (ft)
S = sight distance (ft)
A = algebraic difference in grades (percent)

In Pima County, the sight distance value for designing sag vertical curves is taken as the minimum safe stopping sight distance. The design will approximate the condition of headlight distance on the pavement at nighttime by using the stopping sight distance. The assumption for the design of sag vertical curves is that no continuous street lighting will exist, and that headlight distance will govern. For design values for sag vertical curves for Pima County projects, see the latest edition of the *AASHTO Policy*.

Some of the important design considerations for both crest and sag vertical curves are:

- A smooth grade line with longer tangent grades and fewer vertical curves should be a design objective.
- Grade breaks in the profile of 0.5% or less do not require a vertical curve.
- Broken-back grade lines (i.e., two vertical curves in the same direction separated by short sections of tangent grade) should be avoided.
- For long upgrades, it is preferable to place the steepest grade at the bottom and reduce the grades at the top. Roller coaster and hidden dip profiles should be avoided.
- Drainage and flow patterns at the top of the crest and at the bottom of sag curves.

Stopping Sight Distance

The principal design control for both crest and sag vertical curves is the provision of adequate stopping sight distance along the entire length of the curve. All portions of the profile gradeline shall meet sight distance requirements for the design speed of the roadway. In computing and measuring stopping sight distance, the height of the driver's eye is estimated to be 3.5 feet and the height of the object to be seen by the driver is 2.0 feet. The equation used to calculate stopping sight distance (SD) is:

$$SD = 1.47\ Vt + 1.075\ V^2/a$$

where

SD = stopping sight distance (ft)
V = design speed (mph)
t = brake reaction time, 2.5 sec
a = deceleration rate, ft/sec^2 (use 11.2 ft/sec^2)

Refer to the latest edition of the *AASHTO Policy* for information about the effects of grade on stopping sight distance.

Values for stopping sight distance for Pima County roadway design are given in Table 2-3. These values assume wet pavement and a 2.5 second brake reaction time.

Table 2-3
Stopping Sight Distance – Pima County Design

Design Speed (mph)	SD (ft)
30	200
40	305
45	360
50	425
55	495
60	570

Source: AASHTO 2011 Policy, Chapter 3
Note: Verify with the latest edition of the AASHTO Policy. Use the more restrictive length

Passing Sight Distance

On two-lane highways, provision of passing sight distance can be an important consideration. Generally, for crest vertical curves, the passing sight distance is substantially longer than the stopping sight distance, and the latter is used as the design control. Appropriate no-passing zones and markings must be in place in order to enforce the no passing criterion. For multilane highways, the stopping sight distance is again used as the design control for vertical alignment. Refer to the latest edition of the *AASHTO Policy* for a discussion of passing sight distances for various design speeds. Note that the AASHTO standard is based on a driver's eye height of 3.5 feet and an object height of 3.5 feet (passing) or 2.0 feet (stopping).

Coordination of Vertical and Horizontal Alignments

The combined effect of vertical and horizontal alignments along a given section of roadway is an important factor to consider. Although there are no specific design values or specific criteria, the following considerations should be addressed:

- A design that balances horizontal and vertical alignments in the middle range of values is preferable to allowing either the horizontal or vertical alignment to become extreme in order to optimize the other.
- Crest vertical curves should not be coincident with or immediately precede sharp horizontal curves.
- Sharp horizontal curvature near the low point of a sag vertical curve should be avoided.
- Horizontal curvature and vertical profiles should be as flat as possible at intersections, where vehicles have to decelerate, stop or accelerate. Refer to the latest edition of the *AASHTO Policy*.

2.5 INTERSECTIONS

The goal of intersection design should be to provide layouts that allow for safe and efficient crossing, merging, and diverging of conflicting vehicle streams. These conflicts can be significantly reduced through the provision of adequate sight distances and efficient traffic control devices. Providing safe sight distances and effective control will depend on human factors related to the drivers, bicyclists, and pedestrians; the traffic volumes to be accommodated; and the geometric and topographical characteristics of the intersection itself.

Design Elements

<u>Human Factors</u>

Two of the most important human factors that impact the design of intersections are the perception reaction time of drivers and the walking speed of pedestrians. The perception reaction time affects required intersection sight distances and also affects traffic signal timing. Pedestrian walking speed affects traffic signal timing, as well as placement of channelization and islands. The values appropriate for Pima County design are a driver perception reaction time of 2.5 seconds and a pedestrian walking speed of 3.5 feet per second. In areas where the proportion of older drivers or pedestrians is greater than average, these human factor values should be reviewed and may be revised upward in the case of the perception reaction time, and downward in the case of pedestrian walking speed. For projects in the Green Valley area of Pima County, a slower pedestrian walking speed of 3.0 feet per second should be used.

<u>Traffic Demand</u>

There are two key items relative to traffic demand that must be identified early in the design process. First, a design hour volume must be established. In Pima County, typical practice is to use the 20-year traffic forecasts prepared by the Pima Association of Governments (PAG). These forecasts provide average daily traffic (ADT) over a 24-hour period on the major roadway system in the County. Pima County may also provide a set of recent traffic volume and turning volume counts at major intersections. Using the 20-year forecasts and existing data, a set of volumes for both through and turning traffic is established for the design. All of this material is reported in the Traffic Engineering Report required by the Pima County design process (see Chapter 3, Section 3.15). See below for a general indication of the ranges of values that are often encountered for intersection design. Note, however, that for each design effort, the specific values documented in the Traffic Engineering Report may vary from these ranges significantly.

- K-factor - 0.08 to 0.10 (Ratio of the design hour traffic volume to the average daily traffic volume)
- D-factor - 55/45 to 65/35 (Directional distribution of peak hour traffic)

- Peak-hour factor - 0.80 to 0.90 (Ratio of the peak hour volume to four times the highest 15-minute volume during the peak hour)
- Heavy vehicles - 2% to 6% of total volume (Percent of heavy vehicles in the design traffic volume)

Design Vehicles

Design vehicle selection is an important geometric design component for roadway projects. The design vehicle should be selected based upon the roadway functional classification and the existing and anticipated vehicle type and volume. The standard design vehicle to be used for Pima County projects is the large semi-trailer denoted as WB-62. Dual left and right turn lanes should be designed for the SU-30 in the inside lane and the WB-62 in the outside lane. The standard bus vehicle may also be considered in areas with school bus activity.

The dimensions and turning templates for design vehicles may be found in the latest edition of the *AASHTO Policy*. All turning movements shall be contained within the pavement for the design vehicle, and shall not cross into the opposing lane of travel. Consideration must be given to accommodate the largest vehicle that may use the intersection/segment. Turning template diagrams shall be made available upon request by Pima County.

Traffic Control

The requirements for two-way stop control, all-way stop control, or traffic signal control will be analyzed in the Traffic Engineering Report for the project. Selection of a specific form of control will have significant impact on design elements, such as length of storage for exclusive turn lanes, warning and regulatory signs, sight distance, and the need for acceleration and deceleration lanes. Also, the type of control to be implemented will affect how pedestrians and bicycles are managed and controlled at the intersection.

Roadway/Driveway Location and Configuration

The establishment of locations for cross street intersection locations is often constrained by existing street patterns. Intersections shall be created or revised according to the following general guidelines:

- 90-degree intersections are almost always preferable to skewed intersections
- Skews greater than 20 degrees are to be avoided
- Intersections should be located along tangent sections of the roadway
- A minimum of 200 feet of tangent is recommended for the approach and departure into each intersecting roadway
- Signalized intersections should be spaced no closer than 0.5 miles
- Intersections with more than four entering approaches should not be used.

Roadway and driveway tie-ins, on the same or opposite sides of the street, shall be spaced at the minimums shown in Tables 2-4 and 2-5, and shall not be located within the functional limits of an intersection, unless otherwise approved by Pima County. Functional limits are defined as the beginning and ending of tapers for right- and left-turn lanes and acceleration and deceleration lanes, the redirection tapers for through lanes, or from the near curb line of an intersection street to the end of such tapers. New construction that encompasses existing roadways/driveways that do not meet the minimum spacing requirements are subject to Pima County approval. A variance to these minimum requirements shall be requested in writing from the Department.

Table 2-4: Minimum Spacing between Consecutive Roadways & A Roadway and Driveway

Posted Speed on Adjacent Street (MPH)	Minimum Corner Clearance (FT)
≤35	150
40	185
45	230
50	275

The minimum corner clearance denoted in Table 2-4 shall be measured from the nearest pavement edge of the roadway/driveway to the curbline of the nearest intersecting roadway/driveway. Pima County may request increased spacing in rural areas, or when warranted by field conditions such as significant weaving or insufficient left turn peak period queue storage.

Table 2-5: Minimum Spacing between Consecutive Driveways

Posted Speed on Adjacent Street (MPH)	Minimum Driveway Spacing (FT)
25	105
30	125
35	150
40	185
45	230
50	275

The minimum driveway spacing denoted in Table 2-5 shall be measured from driveway centerline to driveway centerline. Pima County may request increased spacing in rural areas, or when warranted by field conditions such as significant weaving or insufficient left turn peak period queue storage. Driveways near median openings should be centered with the center of the median opening or should be a minimum of 100 feet from the center of the median opening. If return radii are used for the driveway, the returns shall be located within the extension of the property line, to ensure that they do not interfere with the adjacent property.

Sight Distance

In the design of street, driveway and access point intersections, three types of sight distance shall be considered: (1) stopping sight distance, (2) intersection sight distance, and (3) as needed, decision sight distance.

Stopping Sight Distance

Stopping sight distance shall be provided at all intersections and driveways. The standard values are given in Section 2.4, Table 2-3, of this chapter.

Intersection Sight Distance

Adequate intersection sight distance and traffic controls significantly reduce potential vehicle conflicts at intersections. An unobstructed and continuous view of both the intersection and the intersecting roadway help drivers to avoid conflicts. Pima County has developed a procedure to calculate the required intersection sight distance for unsignalized intersections (not for multiple residential roadways). The required intersection sight distance shall be calculated in accordance with Appendix 2-C. For the required intersection sight distance at signalized intersection, refer to the latest edition of the *AASHTO Policy*.

The sight triangle at each intersection quadrant should provide a continuous and unobstructed view for the major and minor road vehicle at the eye/object height denoted in the latest edition of the *AASHTO Policy*. The sight triangle must be clear of any visual obstructions including structures, cut slopes, vegetation, and mounds of natural earth or rock. Intersection sight distance triangles are required to be shown on the design plans. Also, obstructions in both the horizontal plane and the vertical plane must be reviewed when designing the intersection. *The Pima County Department of Transportation Landscape and Irrigation Guidelines* (http://dot.pima.gov/transeng/landscape/) contain additional information regarding sight triangle planting configurations.

Decision Sight Distance

Decision sight distance is defined as the distance required for a driver to detect an unexpected or difficult to perceive source of information in a complex roadway environment such as found along urban and suburban roadways. If such a combination of characteristics exists, refer to the latest edition of the *AASHTO Policy*. Decision sight distances can be significantly greater than intersection sight distance. It is important, therefore, to review the overall design to determine if the application of decision sight distance at critical points is appropriate.

Exclusive Turn Lanes

Exclusive left-turn lanes shall be provided on all Pima County roadways classified as arterials or collectors. Design values for the length of the left-turn tapers and storage are provide in the latest edition of the Pima County Department of Transportation and City of Tucson Department of Transportation *Pavement Marking Design Manual.*

The provision of exclusive right-turn lanes and the associated additional right-of-way should be considered at major intersections and at locations where safety is significantly improved by providing a deceleration area for vehicles moving from the major roadway and turning right into a cross street or driveway. Exclusive right-turn lanes generally improve both safety and efficiency of operation at both signalized and un-signalized intersections. Where a right-turn slip-lane (with a separation island) is being considered, the latest edition of the FHWA

PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System should also be reviewed to assure pedestrian needs are appropriately addressed.

Curb Radii

A standard curb radius of 35 feet should be used for arterial/arterial intersections, 30 feet for arterial/collector intersections, and 25 feet for intersections with residential streets. The design radii can be modified as necessary for special conditions, such as large volumes of truck traffic and/or skewed intersection angles. Consideration must be given to accommodate the design vehicle and the largest vehicle that may use the intersection/segment. Three center curves should be considered to accommodate the need for a larger radius. The minimum turning radius for the design vehicles is shown in the latest edition of the *AASHTO Policy*. Variations to curb radii proposed shall be reviewed and approved by Pima County prior to being included as part of the design.

Median Openings

Median openings along Pima County arterials and collectors should be spaced one-quarter mile apart, but generally no closer than 660 feet to other median openings and major intersections. Median openings shall not be allowed within the functional limits of an intersection without prior Pima County approval. Functional limits are defined as the beginning and ending of tapers for right- and left-turn lanes and acceleration and deceleration lanes or of redirection tapers for through lanes, or from the near curb line of an intersection street to the end of such tapers.

Driveways

<u>Residential Driveways</u>

Driveways providing access to residential properties shall comply with the following standards unless otherwise approved by Pima County:

- Access to residential property that has frontage along a major arterial and a collector/local road should access off of the collector/local road.
- Access onto major arterial roadways should be limited to one driveway.
- Driveway entrances should be constructed perpendicular to the roadway.
- Driveways should provide sufficient maneuvering area within the property to allow a vehicle to exit the property in a forward direction.
- Paved driveways on rural uncurbed roadways should consist of a minimum 25 foot radius fitted with a 6-inch by 12-inch concrete header.
- On curbed roadways, a driveway apron with curb cuts is preferred to return radii. See Section 8.1.2 of the Pima County Subdivision and Development Street Standards for more information and exception criteria and can be found at the following location:

  http://dsd.pima.gov/Dev_Review/PDFs/SubDevStreetStandards.pdf

- Maintenance and repair of driveways shall be the responsibility of the property owner. Pima County will reconstruct existing driveways located within the right-of-way with standard construction material applicable to the project.
- Driveway widths should be placed in accordance with the following Table:

Table 2-6 Driveway Widths

Single residential	14 ft
Joint Use Residential (Maximum 4 joint use properties)	20 ft
Commercial & Industrial (See Pima County Subdivision and Development Street Standards)	24 ft to 30 ft

Commercial and Industrial Driveways

Except as provided for herein, Commercial and Industrial driveways shall be placed in accordance with the requirements of the Pima County Subdivision and Development Street Standards, Section 8.1.2, Driveway Aprons and Return Radii, and can be found at the following location: http://dsd.pima.gov/Dev_Review/PDFs/SubDevStreetStandards.pdf.

It should be noted that driveways that have one entry and one exit lane shall be a maximum of 30 feet in width. Driveways having three or more lanes should follow the design standards for street intersections. Where more than two lanes are provided, a raised median island with a width between 6 and 16 feet shall be installed and each side of the median divided driveway shall be a minimum of 16 feet.

On curbed roadways, driveways should be depressed curb driveways unless turning movement requirements dictate the use of return radii as prescribed in section 8.1.2 of the Pima County Subdivision and Development Street Standards.

Refer to the Roadway/Driveway Location and Configuration section for further driveway information.

Lane Tapers

Lane tapers are used along roadways for two purposes. First, a lane taper is used when the number of lanes is going to be reduced in a given direction of travel. A lane width reduction taper can also be used to reduce the widths of travel lanes. Second, when the number of lanes or the width of the existing lanes is going to be increased, a lane addition taper is appropriate. Lane taper standards can be found in the Pima County and City of Tucson *Pavement Marking Design Manual* identified in Section 2.8.

2.6 BICYCLE, PEDESTRIAN AND TRANSIT FACILITIES

Bicycle Lanes and Paths

Bicycle facilities and activities within Pima County are an important part of the overall transportation and a key component for a complete street type of system. The Pima County *Community Participation and Mitigation Ordinance* (Appendix 1-A Pima County Code - 10.56.240 D.1.) sets forth the requirements to include bicycle lanes and paths. On curbed roadways, 6 feet are to be added to the typical width of outside travel lanes to accommodate bicycles. This 6-foot width is designated as a paved shoulder. For roadways considered rural and uncurbed, the typical width of outside travel lanes shall also be increased by 6 feet for the same purpose. Refer to the AASHTO *Guide for the Development of Bicycle Facilities*, and to the latest Federal Highway Administration (FHWA) *Manual on Uniform Traffic Control Devices,* Part IX, for further direction regarding design of bicycle features.

Other design features that shall be considered when major roadways are being planned and designed, including:

- Appropriate striping and signing along roadway sections and at intersections to identify proper bicycle/vehicle interactions, including the potential to use pavement coloring (green) in special situations.
- Location of pushbuttons and vehicle detectors at signalized intersections to accommodate bicycle and pedestrian activity.
- Design of curb inlets, catch basins, drainage grates, and locations of manhole covers such that they do not impede bicycle activity.

When a paved shoulder is being added to an existing roadway (typically for bike lane purposes), considerations to be used in determining an appropriate pavement section shall include a review of the intersecting cross streets/driveways to assess any special or unusual turning movements, the existing pavement section, and the potential for other shoulder crossing uses (e.g. – parking associated with adjacent parcels). Should this review not identify the need for an enhanced structural section, then an analysis of the condition and makeup of the subgrade adjacent to the roadway shall be made. If the evaluation determines that the sub-grade is suitable (e.g. - uniformly graded gravel/sand with no predominant layers of silt or clay), then the pavement design will consist of 2½” AC placed directly on subgrade (compacted to 100%). If the evaluation determines that the sub-grade contains unsuitable material, then the unsuitable materials will be over excavated and replaced with 4” of compacted AB.

Pedestrian Sidewalks

Based on the *Community Participation and Mitigation Ordinance (*Appendix 1-A 10.56.240 D. 1.), and the incorporation of a complete street system, pedestrian sidewalks shall be provided along major roadways where warranted by pedestrian travel. Determination of pedestrian travel shall be based on a visual inspection that notes an absence of sidewalks and evidence of pedestrian traffic, as well as an assessment of pedestrian demand/travel generators. Additional guidelines regarding pedestrian facilities can be found in the AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* and the FHWA *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System.*

The standard sidewalk width is 5 feet, but may be increased to accommodate special conditions taking into account the characteristics i.e. age, mobility, etc. of the primary users. When the sidewalk is designed to be flush with the back of the raised curb, the standard width is 6 feet. Pedestrian considerations shall also include pedestrian crosswalks, mid-block crossings, accessible median openings, overpasses, underpasses, and school zones. Additionally, the design shall meet appropriate American with Disabilities Act (ADA) requirements. Useful web sites include www.ada.gov and www.access-board.gov. The report published by the Public Rights-of-Way Access Advisory Committee (PROWAAC), entitled *Special Report: Accessible Public Rights-of-Way: Planning and Designing for Alterations*, also discusses possible ADA solutions to pedestrian mobility. This report can be accessed at the following site:

http://access-board.devis.com/guidelines-and-standards/streets-sidewalks/public-rights-of-way/guidance-and-research

Multiuse Paths

Multiuse Paths are another component of a complete streets system and shall be considered based on a review of pedestrian traffic/activities. These facilities shall be designed to meet all applicable codes and other requirements. Asphalt should be considered as the primary material for these types facilities due to its longevity and maintainability, with other materials being considered as conditions warrant.

Trails

Trails shall be considered based on a review of the *Eastern Pima County Trail System Master Plan* (http://www.pima.gov/nrpr/geninfo/masterplan.htm), a review of pedestrian traffic, equestrian traffic, and other activities. These facilities shall be designed to meet all applicable codes and other requirements.

Transit Facilities

Transit facilities within Pima County are another important part of the overall complete streets transportation system. The Pima County *Community Participation and Mitigation Ordinance* (Appendix 1-A Pima County Code - 10.56.240 D.2 & D. 3.) sets forth the requirements to consider and include facilities for transit vehicle pullouts if service is available or planned along the proposed improvement. In addition, should the proposed improvement project be located in the vicinity of major intersections, consideration should also be made regarding the potential for the development of park and ride facilities. Additional guidelines for Transit Facilities are found in the Pima County Department of Transportation *Transit Guidelines for Roadway Design and Construction*. The link is as follows:

http://dot.pima.gov/transeng/transitguidelines/PCDOT_BusStopTransitGuidelines.pdf

2.7 TRAFFIC SIGNALS AND ROADWAY LIGHTING

Roadway and intersection design plans for Pima County projects include plan sheets for traffic signal installations or upgrades and for roadway and intersection lighting. The County follows specific standards for the equipment to be used and for installation details.

Warrants for Traffic Signals

A Traffic Engineering Report will be prepared for new signal installation based on the warrants presented in the most current *MUTCD*. There are eight warrants that relate to the volume, delay, and accident experience of the intersection. Satisfying one or more of these warrants may be an indication that installation of signals is appropriate.

Traffic Signal Design Criteria

Refer to the Pima County Department of Transportation *Traffic Signal Design Manual* for specific design direction. This manual can be found at the Traffic Engineering website: http://dot.pima.gov/trafeng/

Roadway Lighting Design Criteria

Refer to the Pima County Department of Transportation *Street Lighting and ITS Conduit Design Manual* for specific design direction. This manual can be found at the Traffic Engineering website listed above.

Other Traffic Control Devices

Emergency Vehicle Access - Roadways which connect and provide access to facilities which house emergency response vehicles (e.g. fire stations) shall be identified, with a review being made in accordance with Traffic Engineering Division Procedure 15.1 which identifies the process to be followed to determine if additional traffic control devices should be incorporated into the project.

Photo Enforcement Camera (PEC) Installations - Pima County Department of Transportation Traffic Engineering Division shall be consulted regarding efforts associated with the inclusion of PEC installations into the project.

2.8 TRAFFIC SIGNS AND PAVEMENT MARKINGS

Roadway and intersection design plans for Pima County projects include separate plan sheets for traffic sign installations, upgrades or modifications (Signing Plans), and for roadway and intersection marking (Pavement Marking Plans). The County has developed specific standards for the material to be used and for installation details associated with signing and pavement marking, along with a standard roadway naming process.

Traffic Sign Design Criteria

Refer to the latest edition of the Pima County/City of Tucson Department of Transportation *Traffic Design Signing Manual* for specific design direction. This manual can be found at the Traffic Engineering website: http://dot.pima.gov/trafeng/

Pavement Marking Design Criteria

Refer to the latest edition of the Pima County Department of Transportation and City of Tucson Department of Transportation *Pavement Marking Design Manual* for specific design direction. This manual can be found at the Traffic Engineering website listed above.

Roadway Naming

Pima County Development Services shall be contacted and coordinated with, should a section of roadway require naming (e.g. – newly created roadway segment, segment not previously named or renaming of an existing roadway). The links to initiate these efforts are as follows:

http://www.pimaxpress.com/Addressing/PDFs/Naming%20A%20Street.pdf

http://www.pimaxpress.com/Addressing/PDFs/Changing%20A%20Street%20Name.pdf

2.9 RAILROAD GEOMETRY

The most important document for railroad design standards is the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering*, which is updated and published on an annual basis in April of each year. Section 5 of the manual focuses on the design of horizontal and vertical aspects of the rail line.

2.10 DRAINAGE

Drainage is a complex subject and no one set of guidelines can address every circumstance. The guiding principle of roadway drainage design is to maintain existing flood plain limits, depths, and velocities; and convey and control stormwater in a safe and responsible manner. An important part of roadway drainage is storm water control facilities that perform the vital functions of conveying, diverting, and removing stormwater from the roadway surface and right-of-way. The design of stormwater control facilities are based on criteria and guidelines that are generally defined in this section and illustrated in Figures 2-8 through 2-10. When the designer encounters design issues that are not clearly described by these guidelines, consultation with Pima County is necessary.

Drainage structures such as bridges, box culverts, other large drainage structures and headwalls shall be structurally designed using the load and resistance factor design (LRFD) methodology. Bridge designers should reference the latest version of AASHTO bridge specifications.

Drainage design requires application of the principles of hydrology and hydraulics. In Pima County, hydrology for roadway design generally involves surface water rather than groundwater. The design of roadway drainage will require the determination of the quantity and frequency of surface water runoff impacting the roadway project, and the design of stormwater control facilities to intercept, divert, or convey stormwater runoff along, under, or over the roadway within drainage structures such as culverts, bridges, channels, ditches, and storm drains.

Hydrology

<u>Offsite</u>

Offsite hydrology pertains to stormwater runoff from upstream tributary areas that discharge across, under, or over the roadway by way of culverts and at-grade and weir crossings. Offsite design discharges shall be based and calculated for the 100-year storm frequency unless the County Engineer has provided prior approval for a design using a lesser storm frequency.

Pima County Regional Flood Control District's Technical Policy, TECH-015 *Acceptable Methods for Determining Peak Discharges* shall be used as the basis for determining peak discharges.

<u>Onsite</u>

Onsite hydrology addresses stormwater runoff from watersheds within the road right of way that discharge to stormwater control facilities such as storm drains, roadside ditches, culverts, and spillways.

Onsite discharge design shall be determined using the Rational Method. A maximum 5 minute time of concentration shall be used. When both on and offsite flow are directed to a stormwater control facility, the design discharge shall be calculated using PC-Hydro with the offsite flow added to the pavement drainage values.

Hydraulics

Open Channel

Pima County Regional Flood Control District's Technical Policy, TECH-016 *Acceptable Mthods for Floodplain Delineation* shall be used to determine open channel flow in engineered channels and floodplain flow in natural washes. At the direction of RFCD, two-dimensional modeling may be required in distributary flow areas. When open channels are proposed to intercept flows approaching the right-of-way, open channel flow modeling is also necessary

Computations for channel design elements, such as bank protection and channel alignment, and for outlet protection shall be in accordance with the Pima County *Drainage and Channel Design Standards for Local Drainage, 1984*, the *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona, 1989, revised 1998,* and the Pima County *Floodplain and Erosion Hazard Management Ordinance*.

Flood limits, depths and velocities shall be kept unchanged unless mitigation options such as the following are exercised: (1) Drainage improvements are provided to prevent flood damage (2) Flood limits are contained within the road right-of-way and the structural roadway components are not subject to infiltration and (3) Drainage easements are acquired to encompass the increased flood limit when outside the road right-of-way. In no case shall a habitable structure be subjected to increased flood limits due to improvements. Computations and exhibits shall be provided to the extent that pre-developed and post-developed flood limits, depths and velocities are equal

The potential for erosion or sedimentation occurring in the channel should be considered. The design shall be in accordance with the *Pima County Floodplain and Erosion Hazard Management Ordinance*. Energy dissipators for channel outlets should be designed in accordance with FHWA, *Hydraulic Design of Energy Dissipators for Culverts and Channels - Third Edition (2006)*, HEC-14, or other applicable methodology approved by the Pima County.

Cross Drainage

When cross-drainage structures are located within natural washes or major watercourses, open channel hydraulic modeling is required to evaluate the pre-developed and post-developed floodplain and flow characteristics of the natural wash.

Every effort shall be made to design drainage crossings and associated channels to convey the 100-year storm under the roadway unless the County Engineer approves a design to convey a lesser storm event under the roadway. The depth of flow crossing the roadway in the 100-year storm shall not exceed one foot in depth at any point within the paved section regardless of the design discharge under the roadway. In addition, the 100-year storm must not be allowed to overflow to adjacent drainage basins.

Flood limits, depths and velocities shall be kept unchanged unless mitigation options such as the following are exercised: (1) Drainage improvements are provided to prevent flood damage (2) Flood limits are contained within the road right-of-way and the structural roadway components are not subject to infiltration and (3) Drainage easements are acquired to encompass the increased flood limit when outside the road right-of-way. In no case shall a habitable structure be subjected to increased flood limits due to improvements. Computations and exhibits shall be provided to the extent that pre-developed and post-developed flood limits, depths and velocities are equal.

Hydraulic calculations for pipe and box culvert flow shall be in accordance with methodologies contained in the latest edition of the *Federal Highway Administration Hydraulic Design Series Number 5 Hydraulic Design of Highway Culverts*, or other programs or methodologies accepted by RFCD and Pima County.

End sections or headwalls shall be provided on all pipe culverts. For pipe diameters 30 inch or greater or for multiple pipes, the end treatment shall be headwalls with wingwalls. Straight headwalls without wingwallls are discouraged. The use of traversable designs for culvert end sections, such as ADOT Safety End Sections, is encouraged whenever feasible.

Where an inlet headwall and/or wingwall are proposed, the top of the inlet headwall and/or wingwall shall, at a minimum, be placed above the design headwater elevation. Where no headwall and/or wingwall is proposed or flows from drainage crossings and associated channels occur adjacent to embankments, an impervious treatment shall be placed at or above the design headwater elevation. Erosion protection shall be provided at the top of and around headwalls, wingwalls, retaining walls and other similar drainage structures.

Storm drains and open channels discharging into or adjacent to culverts or bridges shall be designed to prevent harmful erosion or damage to the structure. Where possible, storm drain outlets should be located on the downstream side of the roadway through the outlet wingwalls.

An evaluation of the outlet scour potential shall be made at all culverts. While the outlet velocity is the predominant factor in determining the potential need for and type of outlet protection, the ratio of the outlet velocity to the natural stream velocity can be used as a guide in determining the actual need for protection. Outlet protection shall be in accordance with the Pima County *Drainage and Channel Design Standards for Local Drainage, 1984*, the *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona, 1989, revised 1998*, and the Pima County *Floodplain and Erosion Hazard Management Ordinance.*

Energy dissipators for culvert outlets, when required, shall be designed in accordance with HEC-14, *Pima County Drainage and Channel Design Standards for Local Drainage, 1984*, the *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona, 1989, revised 1998*, and the Pima County *Floodplain and Erosion Hazard Management Ordinance*, or other applicable methodology approved by RFCD and Pima County.

The potential for sedimentation within the culvert or at the inlet or outlets shall be considered.

Culverts must be suitably protected with traffic and pedestrian barriers. Adequate distance should be provided for pedestrian access within the roadway Typical Section. (See Section 2.3 of the *Pima County RDM*, Roadway Sections - Clear Zone and Cross Slope, for further information.) Refer to the latest edition of the *AASHTO Roadside Design Guide* for further discussion on clear zone, crash attenuation, traversable and recoverable slope and barriers.

At-Grade Crossings

At-grade crossings are acceptable in rural typical sections due to low frequency of stream flow, provided that the 100-year flow traversing the roadway is less than 500 cfs and all-weather criteria are met.

At-grade crossings in which the transverse flow during the 100-year event is less than or equal to 50 cfs, shall at a minimum be fitted with 6-inch by 12-inch concrete headers.

If the 100-year flow ranges from 50 to 500 cfs, concrete ford walls (cut-off walls) shall be installed to maintain the integrity of the roadway pavement. Ford walls shall be designed 1 foot deeper than the scour, as determined by use of approved general and local scour equations, with sliding and overturning moments also requiring analysis for at-grade crossings protected by walls deeper than 6 feet. The roadway pavement width shall be increase at the locations of the ford walls such that the total pavement width is 4' wider, both upstream and downstream, than the typical roadway section. Concrete walls and headers shall extend to the developed 100-year flow width.

If the flow rate of the 100-year event exceeds 500 cfs, or the 100-year event will cross the road at a depth greater than one foot, a culvert or a culvert dip section combination shall be used to assure drainage over the roadway meets all-weather access criteria. These design thresholds are illustrated in the following Table 2-7:

Table 2-7 Design Thresholds for At-Grade crossings

100-year peak flow	**Minimum Treatment**
≤ 50 cfs	Concrete headers
50-500 cfs	Concrete ford walls (Cut-off walls)
≥ 500 cfs	Culvert or Culvert plus at-grade crossing

In order to improve safety and to reduce maintenance, all at-grade crossings shall be designed to be self-cleaning by providing an appropriately designed superelevated section at the at-grade crossing, installing a sediment trap, or by other means. The method shall be approved by RFCD and Pima County.

Erosion protection must be provided at the culvert outlets of at-grade crossings and shall be in accordance with Pima County *Drainage and Channel Design Standards for Local Drainage, 1984*, the *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona, 1989, revised 1998,* and the Pima County *Floodplain and Erosion Hazard Management Ordinance.*

Bridges

Bridge Hydraulic Design

HEC-RAS shall be used to analyze the hydraulic conditions at bridges. Transitions and friction head losses as well as pier head losses should be considered.

The bridge waterway opening shall be designed to meet the 100-year design storm frequency with the extreme storm event as the check storm criteria. The extreme event is defined as the flood resulting from a storm having a flow rate in excess of the design flood, but in no case a flood with a recurrence interval exceeding 500 years. The waterway opening should be sized and situated such that:

- Backwater is limited, as noted below;
- Erosion of banks is limited;
- Progressive sedimentation is not encouraged;
- General and local scour are minimized; and
- Minimal bank protection is needed.

Backwater computations for a bridge shall be based upon approved methodology and on the design conditions which result in the highest value of backwater. Backwater shall be computed with no allowance for scour (i.e. with rigid channel boundaries).

Bridge piers and abutments should be located to provide the following benefits:

- Minimize hindrance to the passage of water and debris;
- Be compatible with the location of piers and abutments of adjacent structures;
- Minimize the depth of local scour; and
- Minimize upstream and downstream bank erosion.

Bridge piers should be round or have the upstream end rounded. Solid wall piers should only be used where the direction of flow is well controlled and will remain so in the future. Piers should not be used to align the flow.

Bridge Deck Drainage

Bridge deck drainage systems shall not allow surface drainage to encroach into any traffic lane(s) on the bridge deck, and must be free of ponding or flowing water in each direction of travel during the 10-year storm event. Drainage that collects in pools or sheet flow across the travel lane can slow traffic, plug deck drains, cause hydroplaning, and may form ice, making the roadway slick and dangerous to motorists.

Deck drainage on railroad overpasses should be conveyed in a piping system from deck drain inlets to a properly designed drainage outfall system. The use of piping systems on other bridges or overpasses may also be required, depending upon project requirements. Design methods provided in the latest edition of HEC-21, *Design of Bridge Deck Drainage*, or other alternate methodology approved by Pima County shall be used in determining the size and location of bridge deck drainage openings and details. At a minimum, deck drainage must be provided at the quarter points of all spans using standard ADOT deck drains or other approved methods or details. Particular care must be taken regarding bridge deck drainage at the beginning and end of the bridge deck in order to prevent erosion of the approach roadway embankment.

Bridge Scour and Freeboard

Bridge scour and freeboard shall conform to the guidelines presented in the latest edition of the Pima County Department of Transportation and Pima County RFCD *Guidelines for Establishing Scour and Freeboard for Bridges in Pima County*.

Pavement Drainage

Storm Frequency

Storm drains shall be designed to convey intercepted offsite and onsite flows. Design storm frequencies for pavement drainage and storm drain systems are as follows:

- 10-year for pavement drainage.
- 100-year for depressed roadway with a sag vertical curve such as an underpass.

Spread Criteria

In a 10-year storm, the following spread criteria shall be met:

Table 2-8 Spread Criteria

Number of Lanes	**Number of lane equivalent width pavement to be left clear of flowing or ponded water in each direction of travel ***
2 to 5	One-lane equivalent
6	Two-lane equivalent

***** Clear lanes shall be kept within normal thru travel lanes but may cross between lanes through superelevated transitions. Turn lanes shall not be used as clear lanes.

For urban sections with curbing, the following criteria shall be utilized in order to limit the spread of flow and prevent runoff from crossing travel lanes:

- On superelevated roadways, drainage interception structures, such as catch basins and scuppers, etc., shall be installed at the approximate locations, as shown in Figure 2-12, and on the upstream side of intersections, driveways and median openings
- Storm water should be intercepted at side curbs in order to prevent curb flow and side street flow from crossing travel lanes
- Drainage inlets are not permitted within crosswalks or within 10 feet of a curb access ramp.

Sizing of Inlets

The safety factors presented in Table 2-9 below shall be used for sizing inlets.

Table 2-9 Capture Ratios for Inlets

	On Grade	In Sump
Standard Inlets		
– Grate	0.50	0.50
– Curb Inlet	0.80	0.80
Combined Curb and Grate		
– Grate	0.50	0.50
– Curb Inlet	0.80	0.80
Combined Slotted Drain and Grate		
– Grate	0.50	0.50
– Slotted Drain	0.67	0.50

Source: ADOT Roadway Design Guidelines. May 2012, Table 606.2

All storm drain grates shall be ADA compliant and bicycle safe on roadways with a pedestrian access route.

Calculation of Spread and Inlet Capacity

Methods presented in the latest edition of *HEC-22, Design of Urban Highway Drainage, Federal Highway Administration* or other methodology approved by Pima County shall be used to calculate the capacity of inlets and pavement spread.

100-year Check Storm Pavement Drainage Evaluation

A check storm evaluation of the pavement drainage and storm drain system shall be provided using the 100-year design discharge. Flowing or ponded water shall not exceed one foot in depth within the pavement and the 100-year storm shall not overflow to adjacent drainage basins or increase the floodplain limit in any area.

Flood limits, depths and velocities shall be kept unchanged unless mitigation options such as the following are exercised: (1) Drainage improvements are provided to prevent flood damage (2) Flood limits are contained within the road right-of-way and the structural roadway components are not subject to infiltration and (3) Drainage Easements are acquired to encompass the increased flood limit when outside the road right-of-way. In no case shall a habitable structure be subjected to increased flood limits due to improvements. Computations and exhibits shall be provided to the extent that pre-developed and post-developed flood limits, depths and velocities are equal.

Pavement Surface Flow

Non-curbed Sections

The pavement surface should have a cross slope that directs flow away from the roadway. A minimum 2% cross-slope is recommended. The shoulder cross slope should match the pavement cross-slope. See Typical Sections Figures 2-5 through 2-8. Roadways with steep longitudinal slopes may require steeper cross-slopes, since drainage will tend to flow along the longitudinal pavement surface. When sidewalks are located adjacent to and along the outside edge of the shoulder, the shoulder cross-slope should be continued through the sidewalk.

Shoulders should direct water flow to roadside ditches. Roadside ditches should be designed with a minimum longitudinal slope of 1%. Steep longitudinal slopes may require erosion protection. Side slopes of 4:1 are desirable. Roadside designs that are traversable and recoverable are preferred. Steeper side slopes shall be evaluated for erosion protection requirements and for barrier warrants. See the latest edition of the *AASHTO Roadside Design Guide* for guidance and additional information.

Curbed Sections

Pavement drainage within a curbed roadway shall be directed to drainage structures by way of curb or curb and gutter as approved by the County Engineer. Most major roadway designs will include a storm drain system to accept flow from the pavement; however, in some cases, flow may be directed off the pavement through a curb opening structure into an open natural or engineered channel adjacent to the roadway. These structures shall be located and spaced in a manner to ensure that the spread criterion is met and that design considerations shown in Figure 2-8 thru 2-10 are followed.

Storm Drain

Design

The latest edition of FHWA, *Urban Drainage Design Manual*, HEC-22 shall be a reference document for pressure and non-pressure flow designs. The recommendations shall be considered in the design within Pima County roadway systems. Non-pressure flow design may only be used with the prior approval of the County Engineer.

When off-site flows along curbed roadways are directed into and through the pavement drainage system, that length of the pavement drainage system (point of introduction of off-site flow until point of discharge) should be designed to accommodate the 100-year storm frequency. However, when this is being considered as the proposed design, it shall be reviewed and discussed with Pima County prior to being finalized, as it may be impacted by other considerations.

Pressure flow design shall include the following design criteria:

- Storm drain mainlines shall be routed through catch basins rather than manholes. When manholes cannot be avoided, they shall be kept outside the pavement either behind curb or within the median, unless otherwise approved by the County Engineer.
- Calculation of the hydraulic grade lines, including the water surface elevation, from junction to junction. The hydraulic grade line shall be a minimum of 1 foot below curb inlets, grates, slotted drains, area inlets, manhole rims, or other free-surface openings in the pavement drainage system, unless otherwise approved by the County Engineer.

- Standard calculations for pipe losses due to friction and "minor" losses at manholes, junctions, bends, transitions, and entrances.
- A normal full-flow velocity of at least 3.0 feet per second for storm drains. It is generally desirable to maintain a minimum slope of at least 0.3 % unless precluded by utility conflicts or other constraints. The minimum allowable slope is 0.1 %.
- A check of discharge velocities to determine if outlet protection and/or energy dissipation is required.
- Presentation of all storm drainage system elements on the final project plan and profile sheets, including proposed culvert type, stationing, size, discharge value, hydraulic grade line, pipe slope from junction to junction, proposed finished grade at the pipeline center line, and all catch basins, manholes, junction structures, bends, transition structures, connectors, inlets and outlets, and inverts.
- Calculations of head losses through junctions, bends, manholes, and catch basins, using the procedures of HEC-22 or other reference(s) approved by the County Engineer. Junction losses do not need to be considered when the incoming lateral flow is less than 10% of the combined mainline outflow.
- Soffits of adjoining pipes in a transition or junction structure shall be placed at the same elevation, unless other constraints such as utility conflicts exist and are approved by the County Engineer.

Where storm drains discharge into an open channel, the frequency of storm for determining tail water depth in the channel is not necessarily that for which the storm drain is being designed. Rather, it should be based on the comparative size of the tributary areas of the channel and the storm drain as indicated in Table 2-10 as follows:

Table 2-10 Frequency of Coincidental Occurrence

Area Ratio	**10-Year Design**		**100-Year Design**	
	Main Stream	**Tributary**	**Main Stream**	**Tributary**
10,000 to 1	1 10	10 1	2 100	100 2
1,000 to 1	2 10	10 2	10 100	100 10
100 to 1	5 10	10 5	25 100	100 25
10 to 1	10 10	10 10	50 100	100 50
1 to 1	10 10	10 10	100 100	100 100

Source: HEC-22, Table 7-3, pp. 7-9
Note: This table may also be used for channel design.

Pipe size

The minimum pipe size for storm drain mains is 24 inches and 18 inches for laterals. Slotted drains shall be a minimum of 18 inches in diameter and sized using the same hydraulic procedures as for normal storm drains.

Manhole placement

Manhole placement within the pavement is not allowed unless otherwise approved by the County Engineer. Storm drains shall be routed through catch basins rather than manholes wherever possible. Catch basin geometry may require adjustment in order to accommodate a varying number and size of storm drains. Manholes shall be spaced according to the following parameters:

300 feet for pipe diameters ≤ 30 inches
400 feet for pipe diameters > 30 inches to 42 inches
500 feet for pipe diameters > 42 inches

Note: Catch basins with frame and covers and accessible grates are considered manholes for manhole spacing requirements.

Drainage Structure and Pipe Material, Pipe Joint Connection, and Service Life

Drainage structures such as bridges, box culverts, other large drainage structures and headwalls shall be structurally designed using the load and resistance factor design (LRFD) methodology. Bridge designers should reference the latest version of AASHTO bridge specifications.

Joint Connection

Water tight joints are required for storm drains and cross culverts under the roadway prism and recommended for areas outside the roadway prism. Water resistant joints may be used for storm drains and cross culverts outside of the roadway prism when approved by the County Engineer. Testing procedures shall conform to the most current ADOT, PAG and Pima County Specification.

Service Life

All drainage structures and pipe shall have a service life of 100 years within arterial roads and 75 years within all other roadways

Storm Drains

Reinforced concrete pipe shall be used for storm drain systems under public arterial roadways, unless an alternative material is approved by the County Engineer.

Reinforced concrete pipe or polypropylene pipe may be used under local roads and residential/commercial collectors. Polypropylene pipe shall be limited to 36 inches in diameter unless otherwise approved by the County Engineer. Specific backfill requirements apply to plastic pipe including bedding and shading material and cover requirements.

Cross Culverts

Reinforced concrete pipe or box culverts shall be used for cross drainage under public arterial roadways, unless an alternative material is approved by the County Engineer. Box culverts should have a minimum height of 3 feet and a minimum width of 6 feet. Pipe culverts shall have a minimum diameter of 24 inches in diameter unless otherwise approved by the County Engineer.

Reinforced concrete pipe or polypropylene pipe may be used under local roads and residential/commercial collectors. Polypropylene pipe shall be limited to 36 inches in diameter unless otherwise approved by the County Engineer. Specific backfill requirements apply to plastic pipe including bedding and shading material and cover requirements.

Cross Culverts under driveways

The material for cross-drainage pipe under driveways shall be reinforced concrete pipe or polypropylene pipe.

Alternative Pipe Materials

The County Engineer may allow alternative storm drain and cross culvert materials and will consider alternatives on a case-by-case basis. The following items shall be considered in evaluating the use of storm drain and cross culvert materials:

- The Arizona Department of Transportation (ADOT) Pipe Selection Guidelines and Procedures manual and related guidelines shall be used as a guide in determining the product type and thickness/gauge for the service life desired. The County Engineer shall approve the final pipe selection.
- The pipe shall be on ADOT’s approved products list.
- The use of alternative pipe, such as plastic pipe and steel pipe, may be allowed within enclosed storm drain systems, except where storm drains will convey runoff from tank farms, sites that are at risk for spills (such as gas stations, refueling locations, certain warehouse or manufacturing facilities), and locations where hazardous or flammable liquids can flow into the system.
- Soil Corrosivity.
- Specific backfill requirements apply to plastic pipe including bedding and shading material and cover requirements. All pipe shall meet the requirements set forth in the specifications, special provisions and the manufacturer’s recommendations.
- A 36 inch diameter pipe will generally be considered the maximum diameter alternative storm drain or cross culvert pipe. The County Engineer may allow larger pipe on a case by case basis.
- All evaluations shall include a flammability risk assessment.
- All evaluations shall show that the alternative material is equivalent to reinforced concrete pipe or reinforced concrete box culverts in terms of loading, performance and service life.

APPENDIX 2-A
Chapter 2 References

Note: These documents, including standards, regulations, and guidelines, are revised periodically. Users, therefore, should double check that they have the specific version of the document specified in this chapter, or, if the reference is undated, that they have the most recent version.

- American Association of State Highway Transportation Officials. 2004. *Guide for the Planning, Design, and Operation of Pedestrian Facilities.* 1st ed.
- ———. 2011. *Policy on Geometric Design of Highways and Streets*. 4th ed.
- ———. 2011. *Roadside Design Guide*. 4th ed.
- ———. 2012. *Guide for the Development of Bicycle Facilities.* 4th ed.
- American Railway Engineering Association. *Manual for Railway Engineering*.
- Pima County. 1984. *Drainage and Channel Design Standards for Local Drainage*.
- ———. 1992. *Community Participation and Mitigation Ordinance*.
- ———. 2011. *Procedures & Checklist for Landscape & Irrigation Plans*
- ———. *Eastern Pima County Trail System Master Plan*
- ———. *Floodplain and Erosion Hazard Management Ordinance* 2010-FC5 (Title 16)
- Pima County Department of Transportation/City of Tucson Department of Transportation.
- ———. *Guidelines for Establishing Scour & Freeboard of Bridges in Pima County*.
- ———. *Pavement Marking Design Manual*.
- ———. *Street Lighting and ITS Conduit Design Manual.*
- ———. *Traffic Signal Design Manual.*
- ———. *Traffic Signing Design Manual.*
- U.S. Army Corps of Engineers. *HEC-1/HEC-HMS.*
- ———. *HEC-2/HEC-RAS.*
- U.S., Department of Justice. 2010. *ADA Standards for Accessible Design*
- ———. 2011. *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right of Way*
- U.S., Department of Transportation. Federal Highway Administration. 1993. *Design of Bridge Deck Drainage.* HEC 21.
- ———. 2006. *Hydraulic Design of Energy Dissipators for Culverts and Channels.* HEC-14
- ———. 2009. *Manual on Uniform Traffic Control Devices*
- ———. 2009. *Urban Drainage Design Manual*. HEC – 22. 3rd ed.
- ———. 2012. *Evaluating Scour at Bridges.* HEC 18. 5rd ed.
- ———. 2012. *Hydraulic Design of Highway Culverts.* HDS No. 5. 3rd ed.
- ———. 2012. *Hydraulic Design of Safe Bridges.* HDS No. 7.

APPENDIX 2-B
Typical Sections

Figure 2–1 Typical Section for 3 Lane Road (Urban)

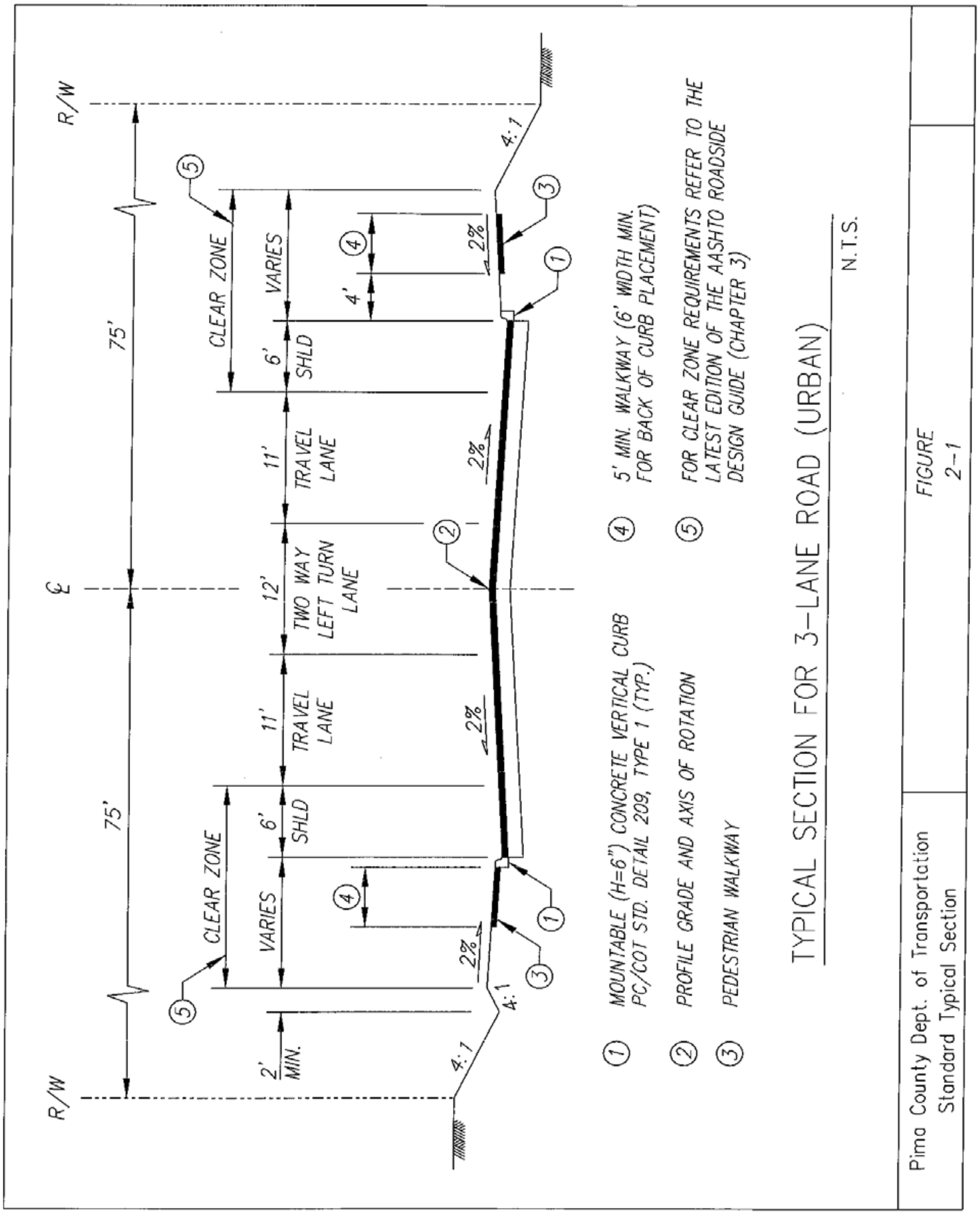


Figure 2–2 Typical Section for 5 Lane Road (Urban)

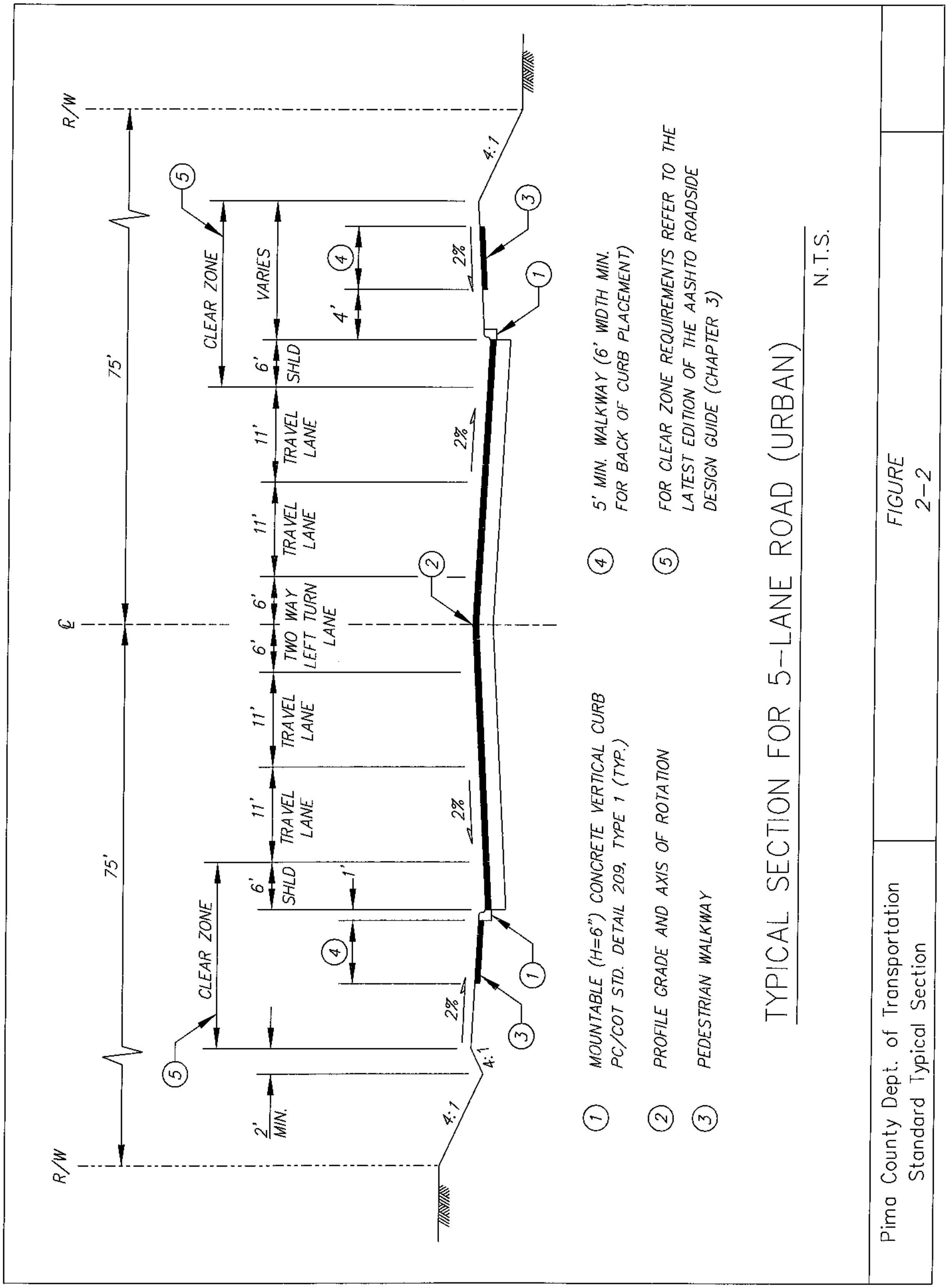


Figure 2–3 Typical Section for 4 Lane Divided Road (Urban)

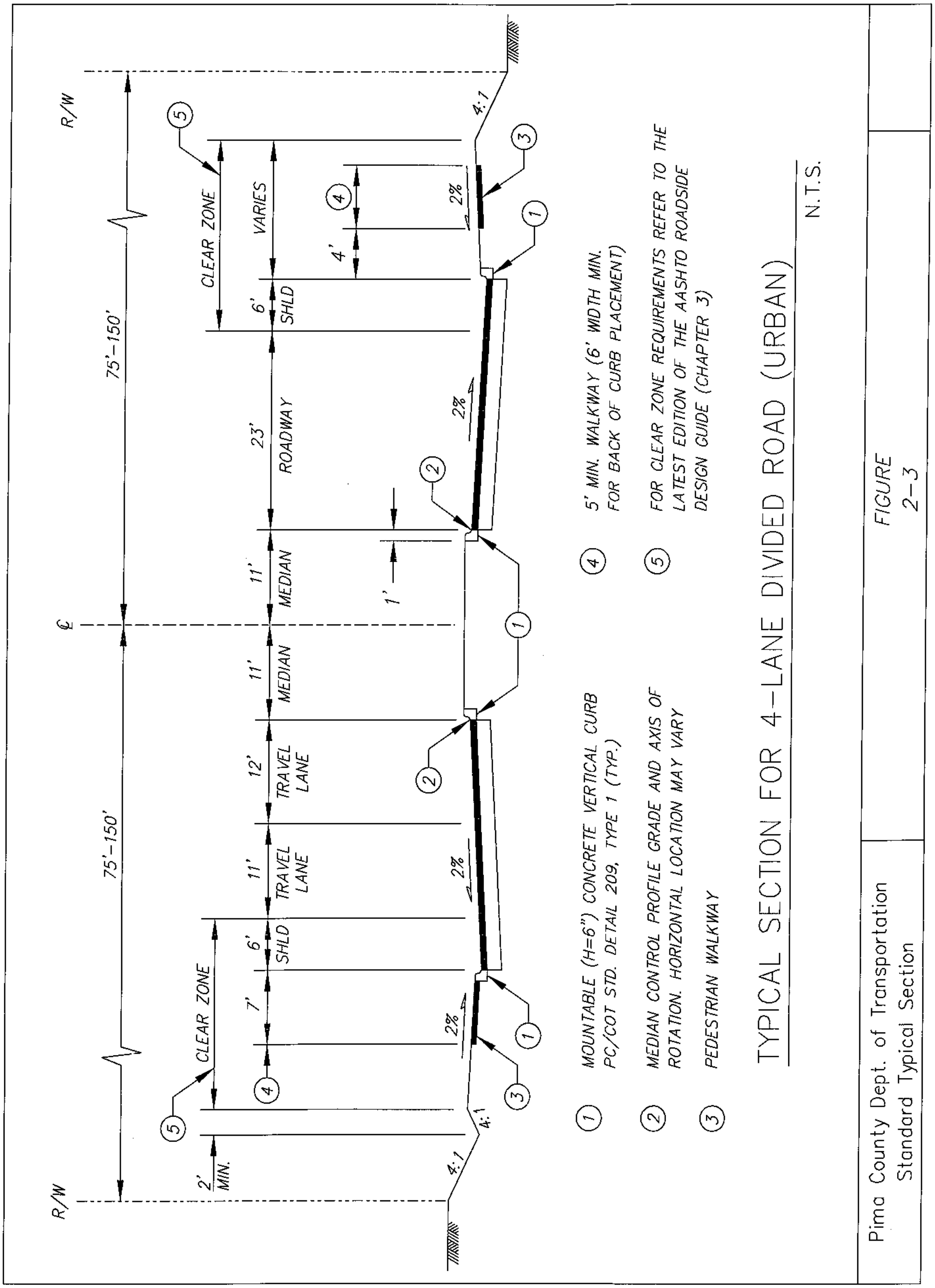


Figure 2–4 Typical Section for 6 Lane Divided Road (Urban)

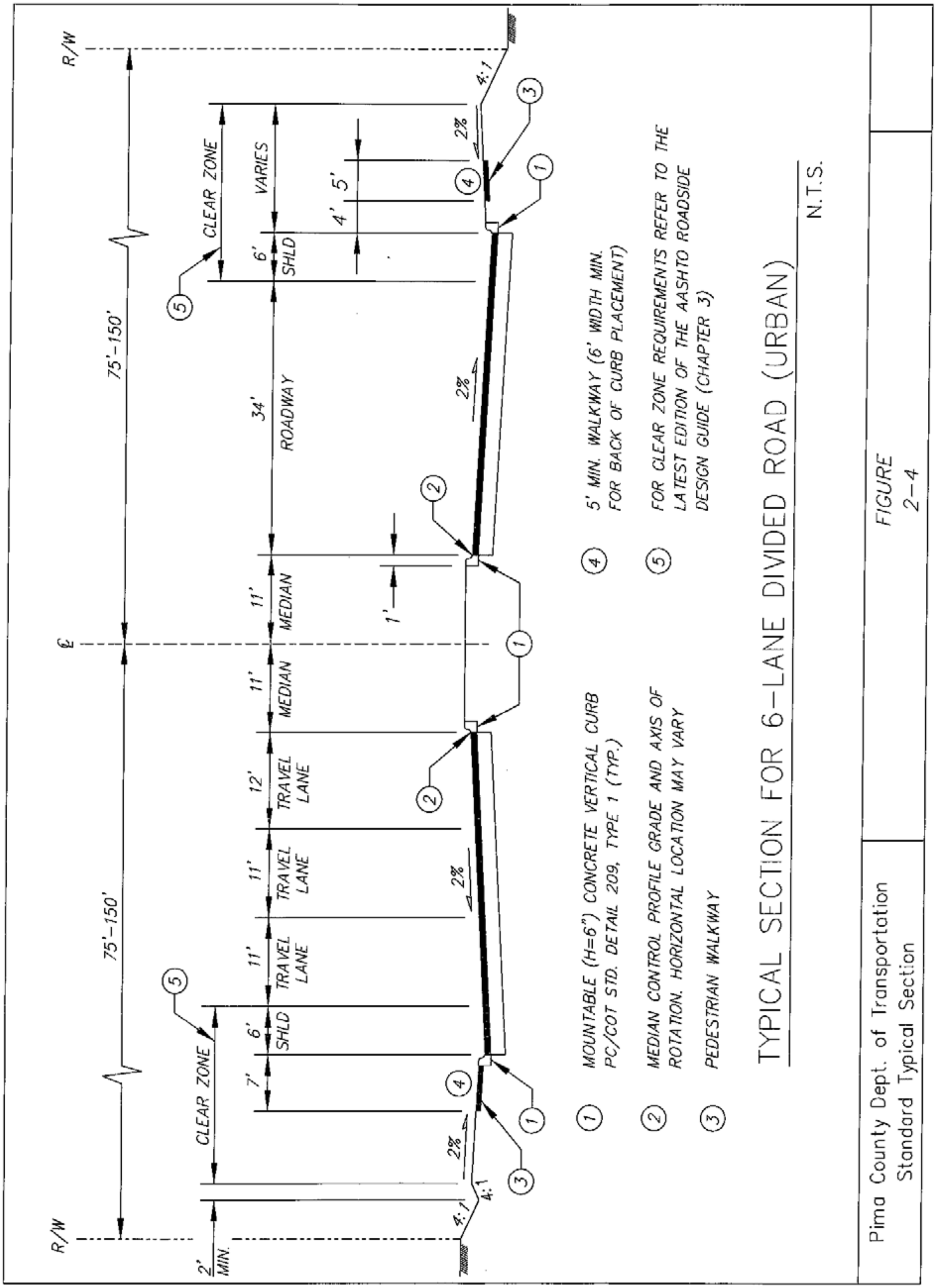


Figure 2–5 Typical Section for 2 Lane Road (Rural)

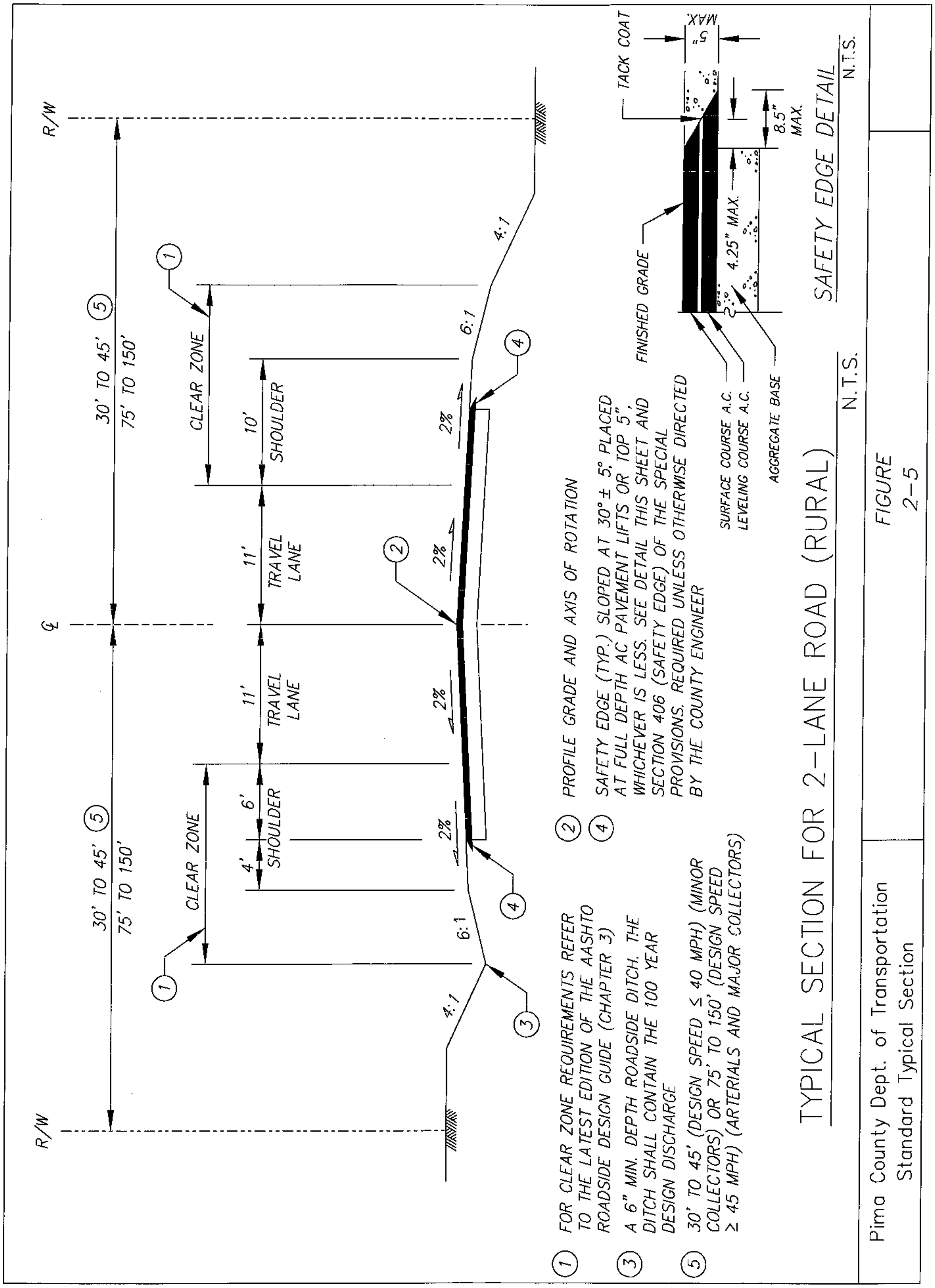


Figure 2–6 Typical Section for 3 Lane Road (Rural)

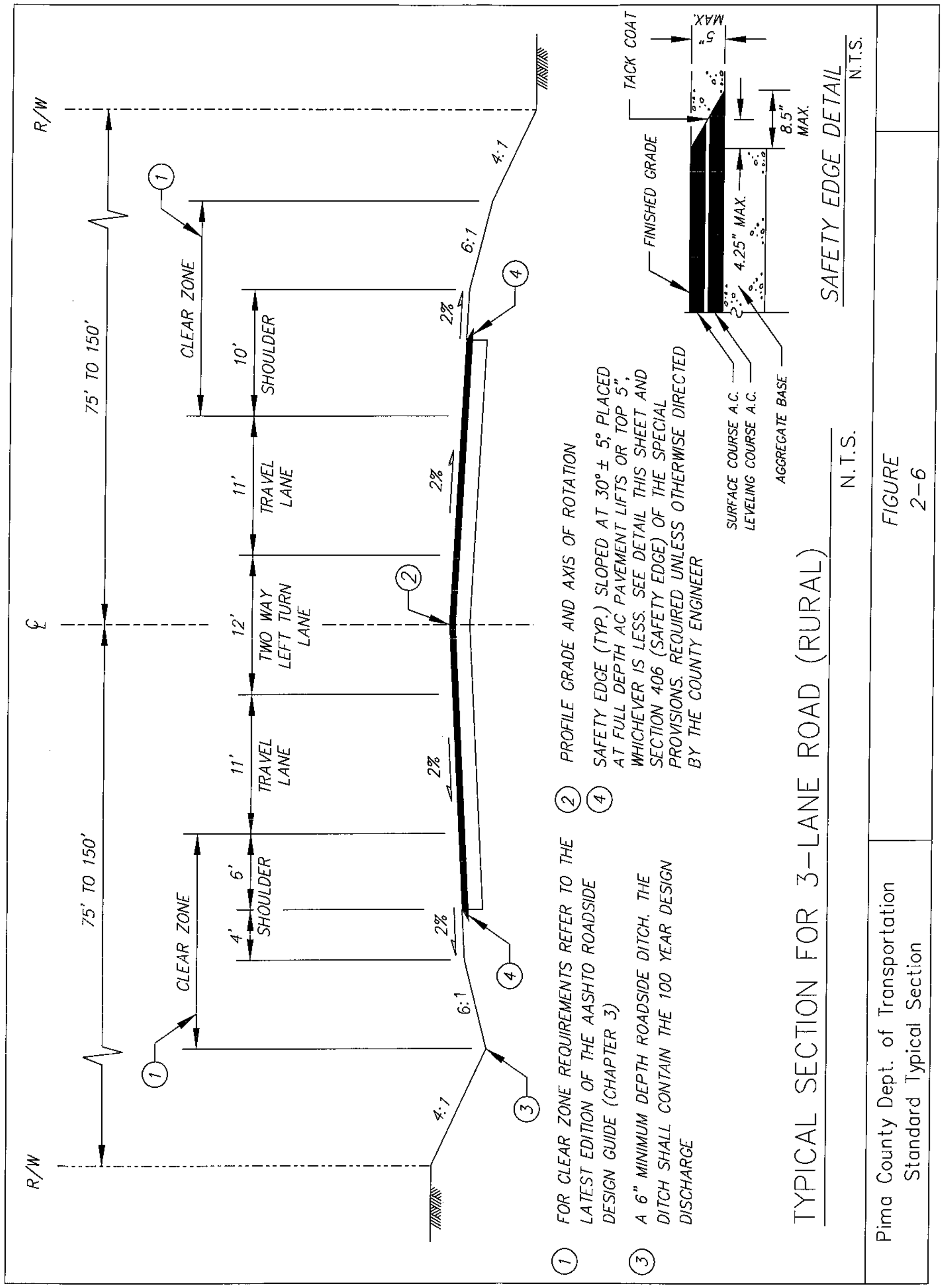


Figure 2–7 Typical Section for 5 Lane Road (Rural)

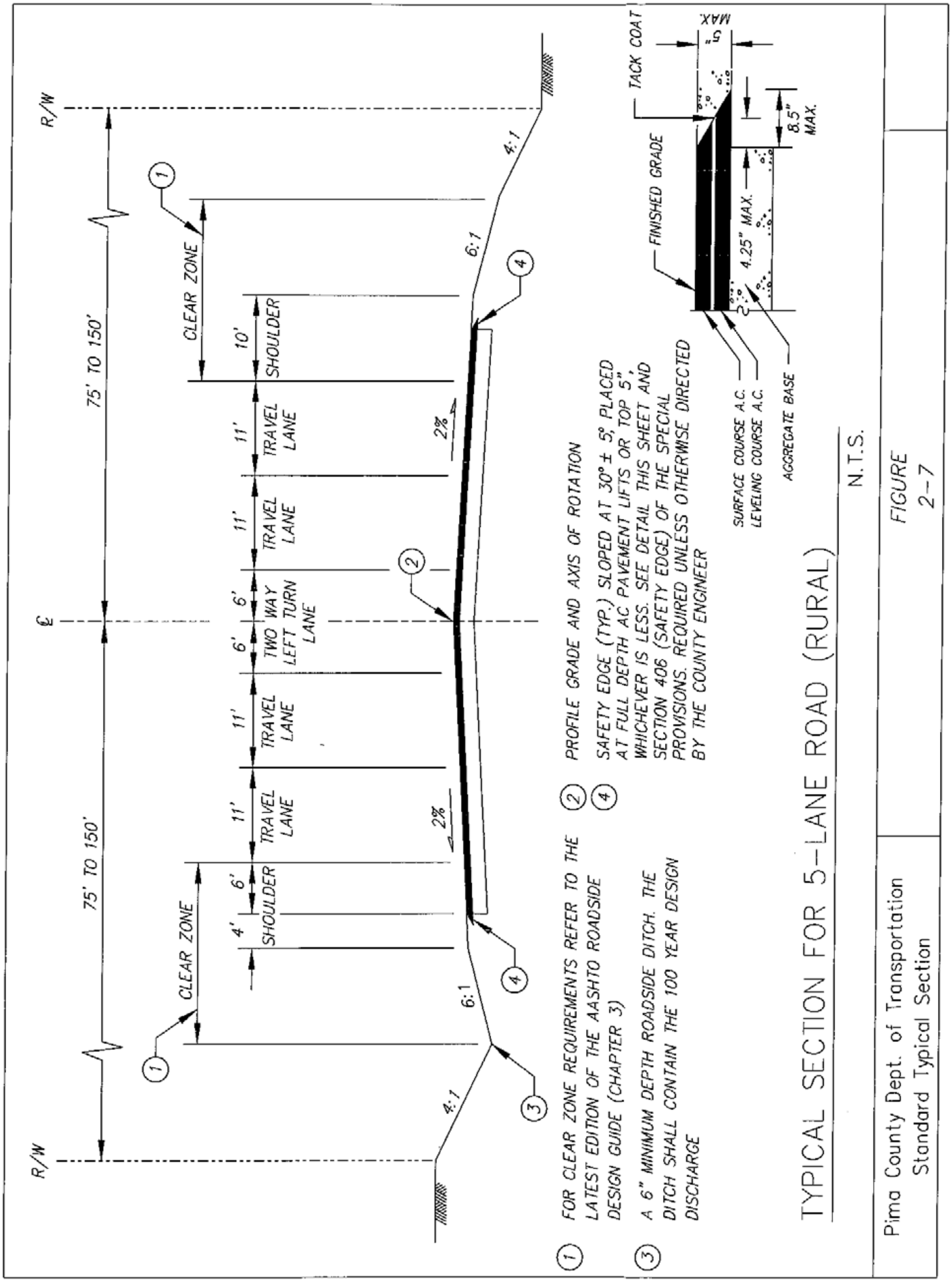


Figure 2-8 Pavement Drainage – Typical Superelevated Section on a 4 Lane Roadway

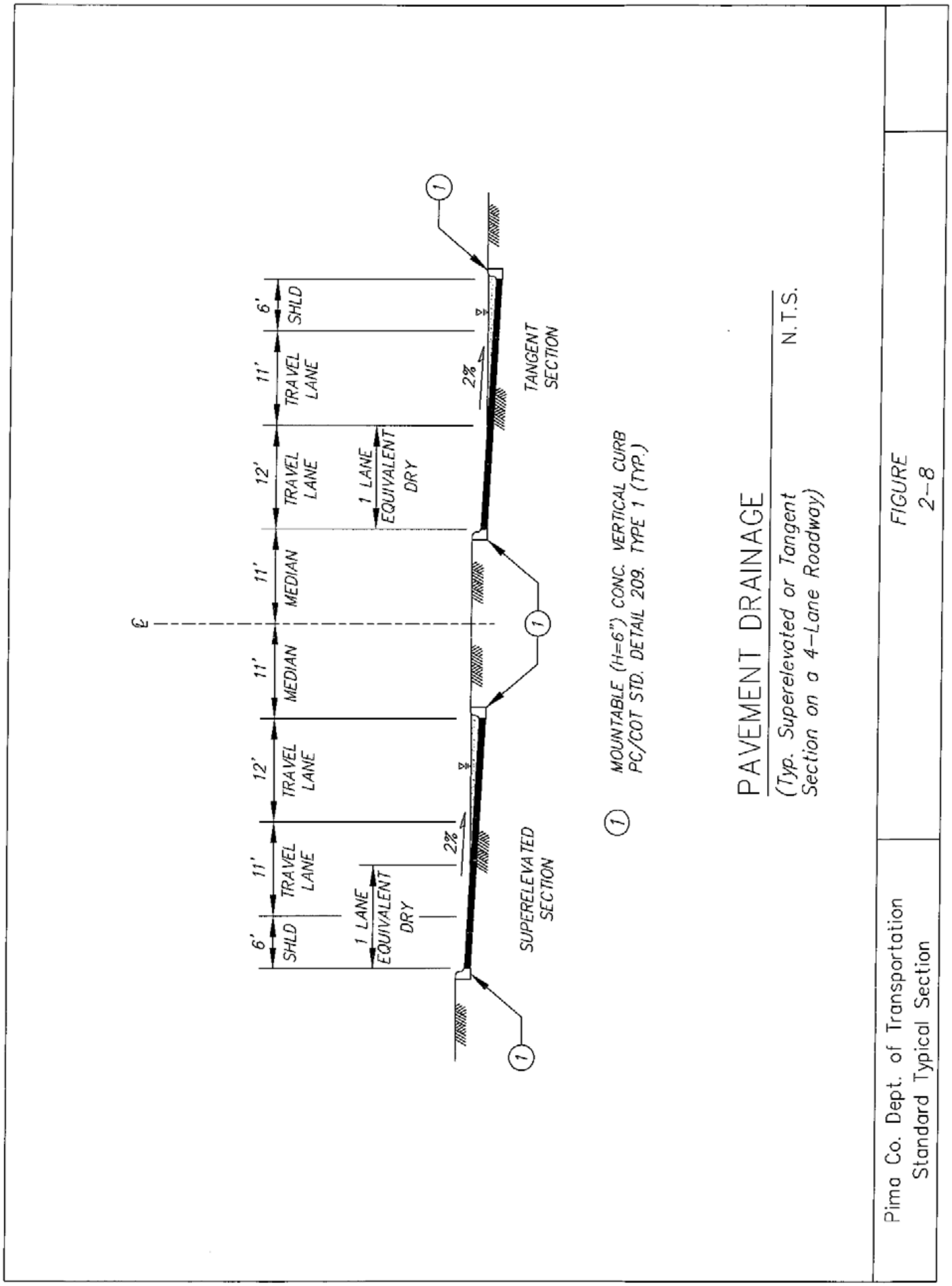


Figure 2-9 Pavement Drainage – Typical Superelevated or Tangent Section on a 6 Lane Roadway

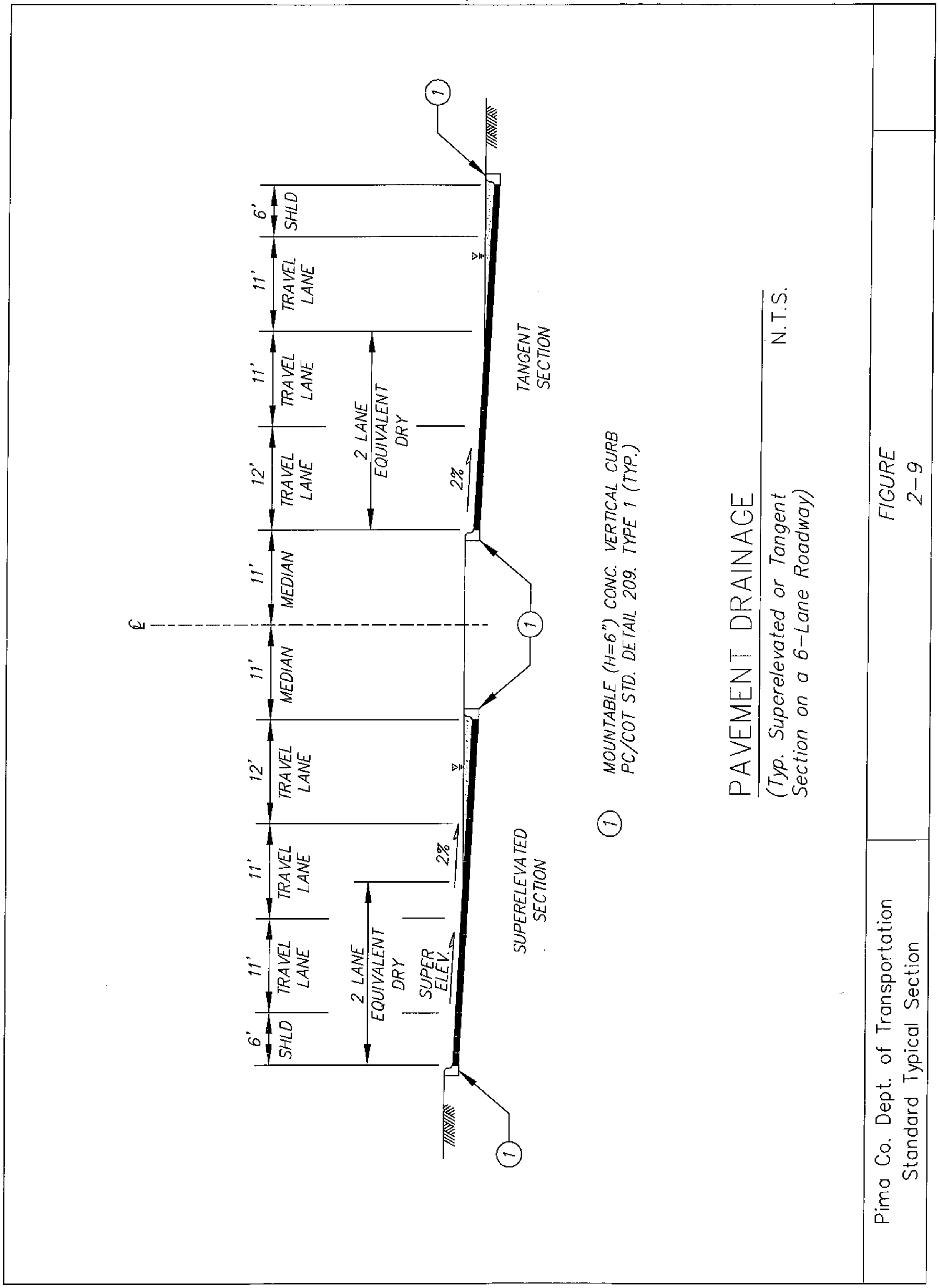


Figure 2–10 Catch basin Typical Locations

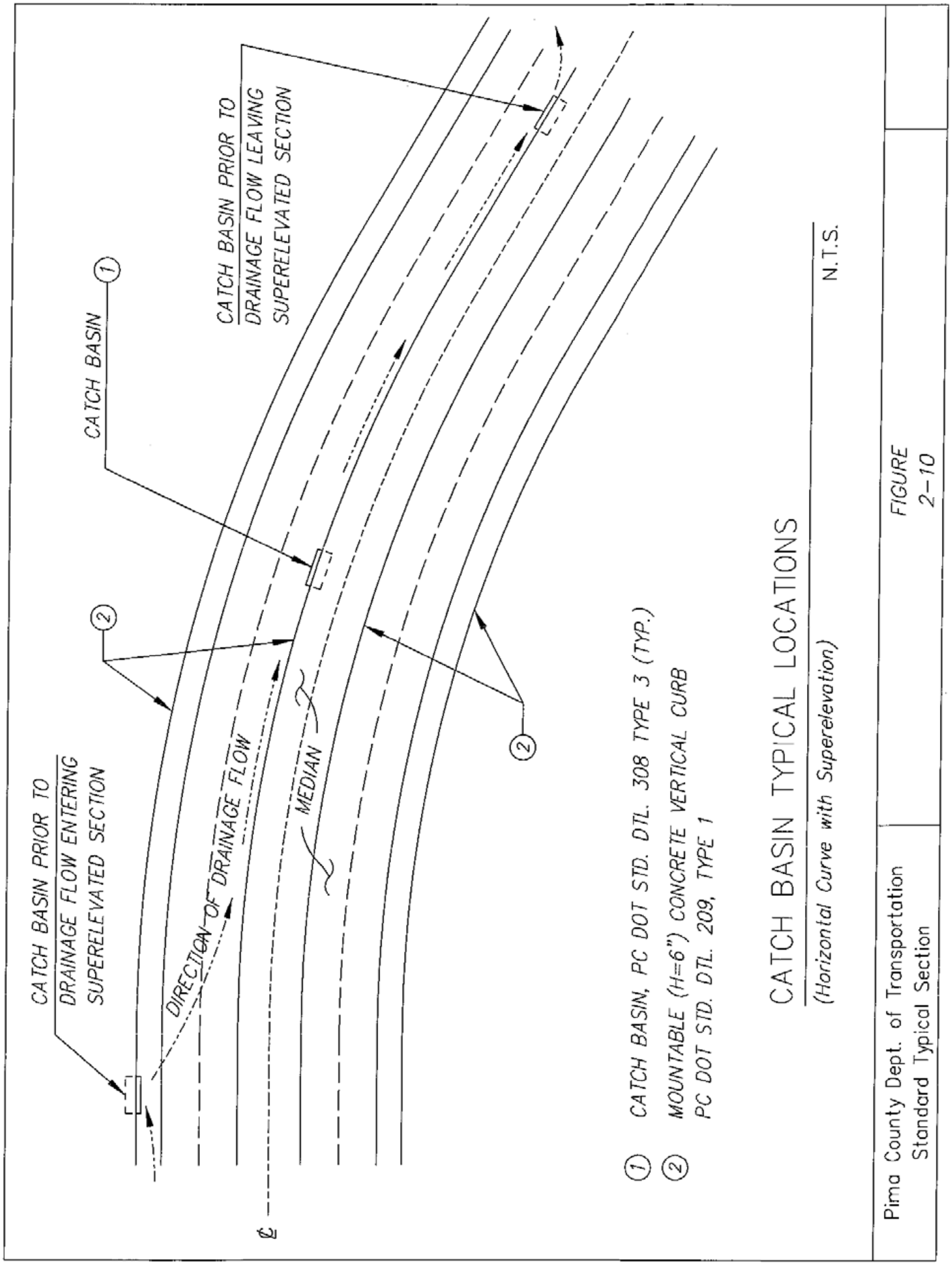


Figure 2–11 Typical Section for Divided Roadway (Urban)(Utility Corridor)

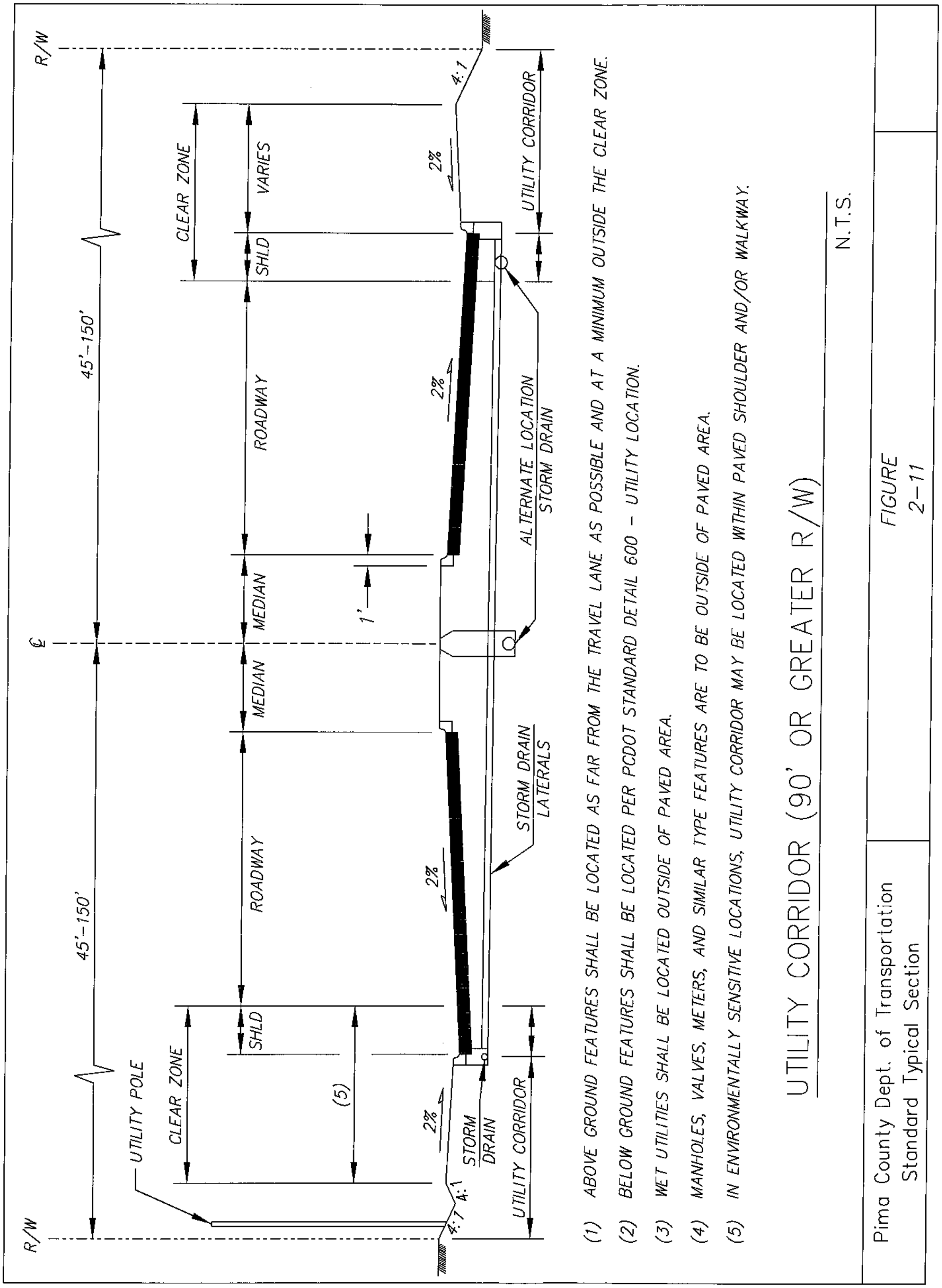


Figure 2–12 Utility Impact Zone

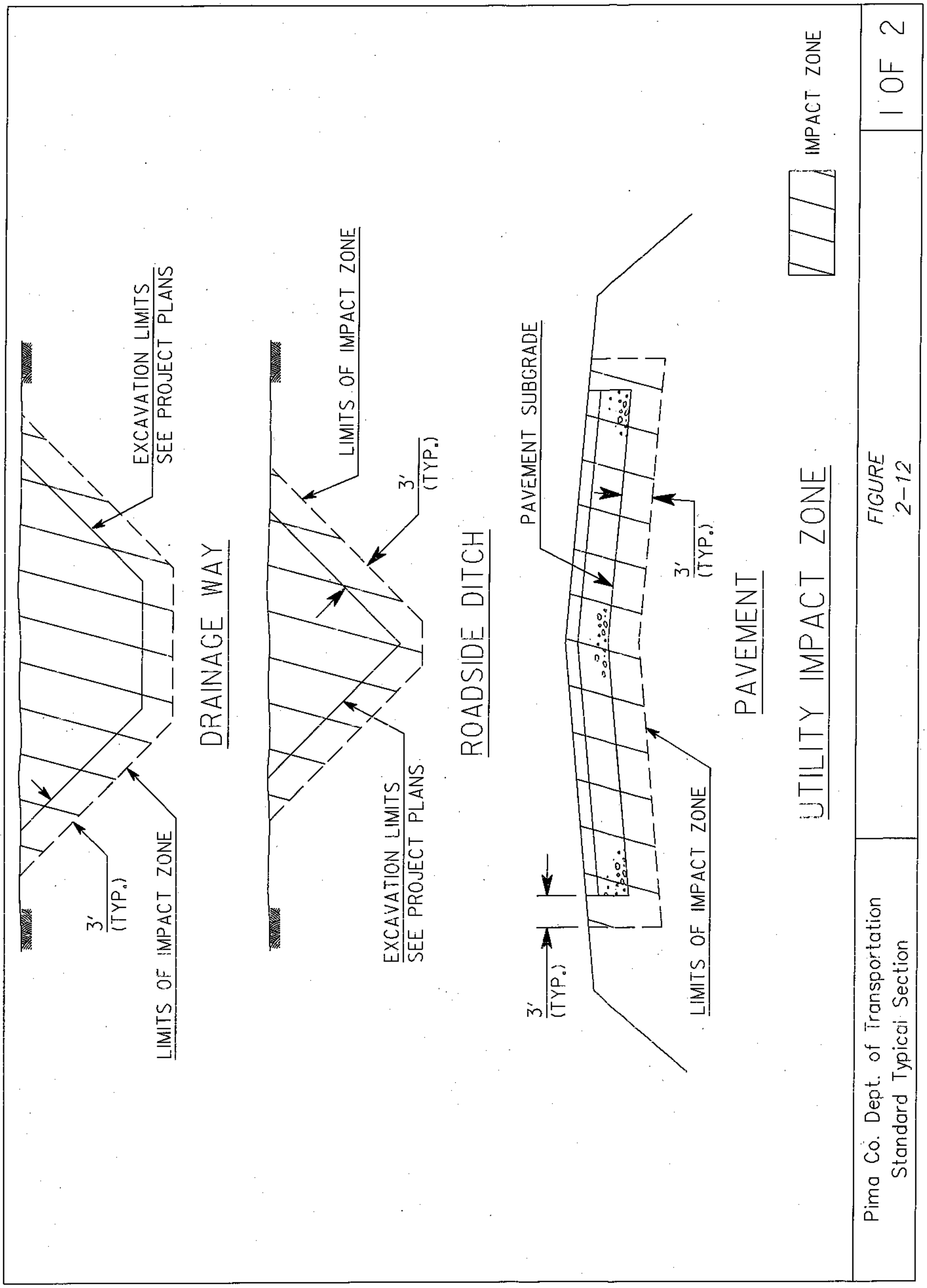
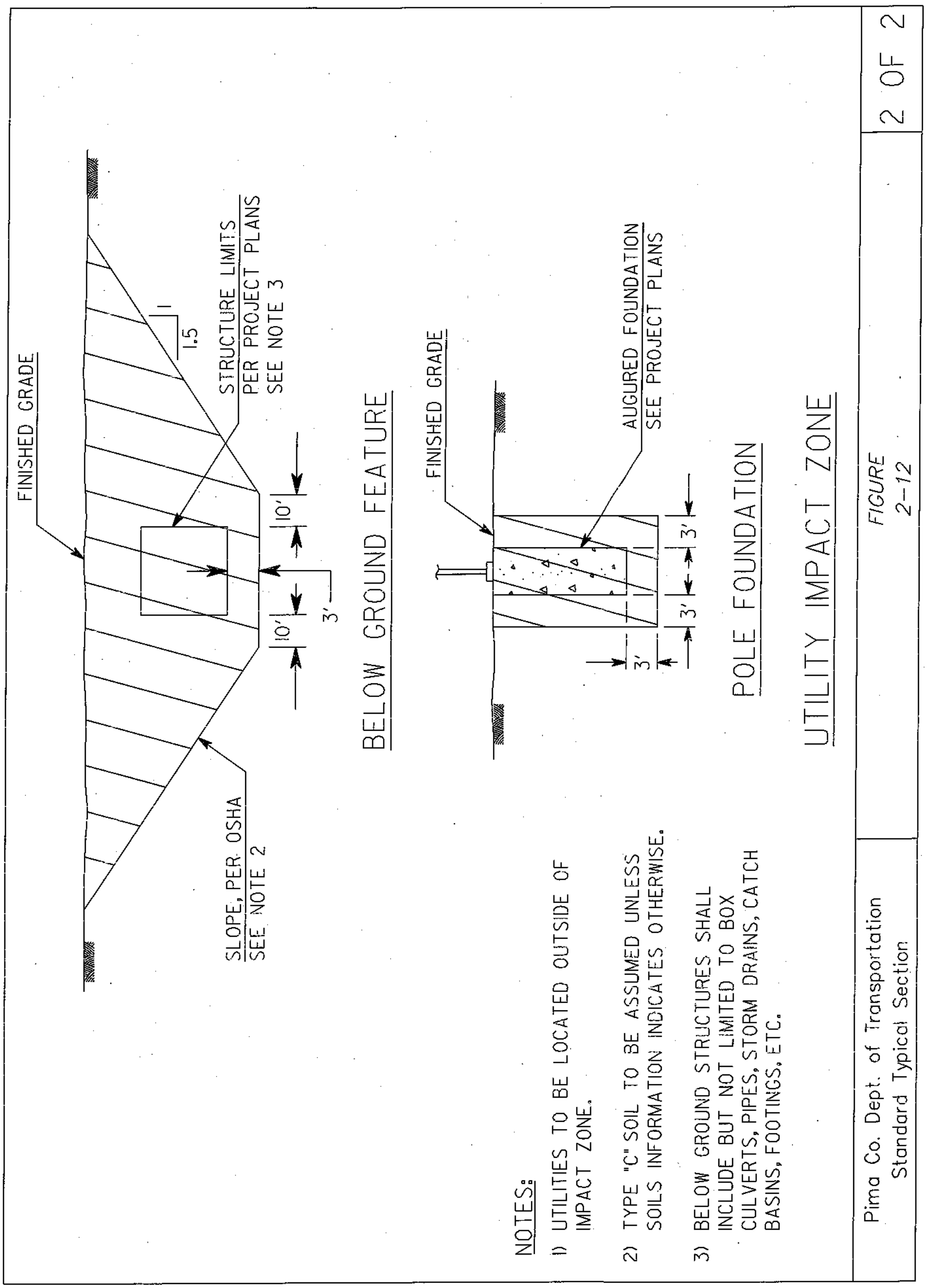
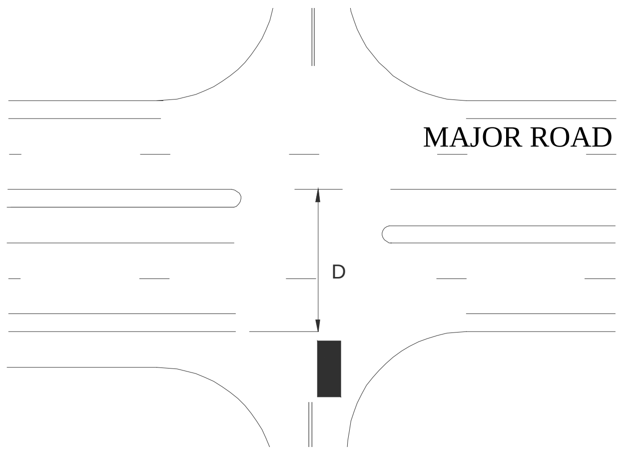


Figure 2–12 Utility Impact Zone

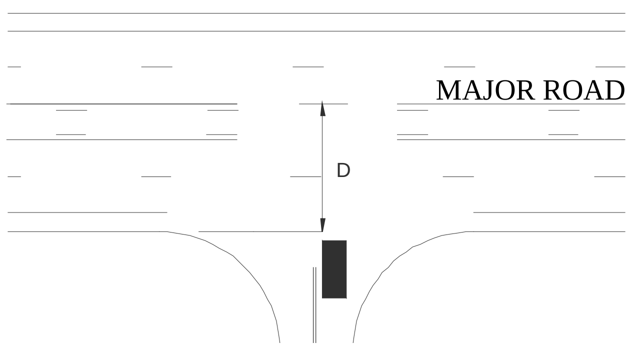


APPENDIX 2-C
Required Intersection Sight Distance Calculation Procedure

Measure the distance on the major road from the edge of pavement to the first lane the vehicle can turn into for a left-turn. If a right-turn lane (on the major road to turn onto the minor road being studied) is present, the width of the right-turn lane is not included in the distance measurement. This distance is indicated as "D," with examples given below.



Distance "D" Example 1:
Four Lane Divided Roadway with Left-Turn Lanes, a Right-Turn Lane and
Bike Lanes/Paved Shoulders/Multi-Use Lanes



Distance "D" Example 2:
Five Lane Roadway with Bike Lanes/Paved Shoulders/Multi-Use Lanes

Utilize the following equation to calculate the ISD required for each approach to the minor road:

$$ISD = 1.47 V_{major} t_g$$

Equation 1: Intersection Sight Distance (ISD) Calculation

ISD = intersection sight distance required for a left-turn from stop (ft)

V_{major} = posted speed limit on the major road (if new construction use the design speed) (mph)

t_g = time gap for the minor road vehicle to enter the major road and make a left-turn (s)

If $D \leq 12\, feet$, then $t_g = 7.5$. If $D > 12\, feet$, use Equation 1 below.

$$t_g = 7.5 + \left(\frac{D}{24} - 0.5\right)$$

Equation 2: Time Gap (t_g) Calculation for $D > 12$ feet

$D =$ distance on the major road from the edge of pavement to the first lane the vehicle can turn into for a left-turn. If a right-turn lane (on the major road to turn onto the minor road being studied) is present, the width of the right-turn lane is not included in the distance measurement.

Equation 1 above is based on *AASHTO Policy* Case B1 and should be utilized to determine the time gap for each approach on the major road. For cases other than Case B1, (ex: Crossing Maneuver from the Minor Road, Right-Turn From Stop), if grades are involved, and if a design vehicle other than a passenger car is to be studied, utilize the same methods indicated above, along with the time gap value adjustments provided in the *AASHTO Policy*. For the required intersection sight distance at signalized intersection, refer to the *AASHTO Policy*.

ISD Triangles should be created from the information calculated above, and are required to be depicted on the design plans. The major and minor road vehicles should have an unobstructed and continuous view within these sight triangles at the eye/object height denoted in the latest edition of the *AASHTO Policy*.

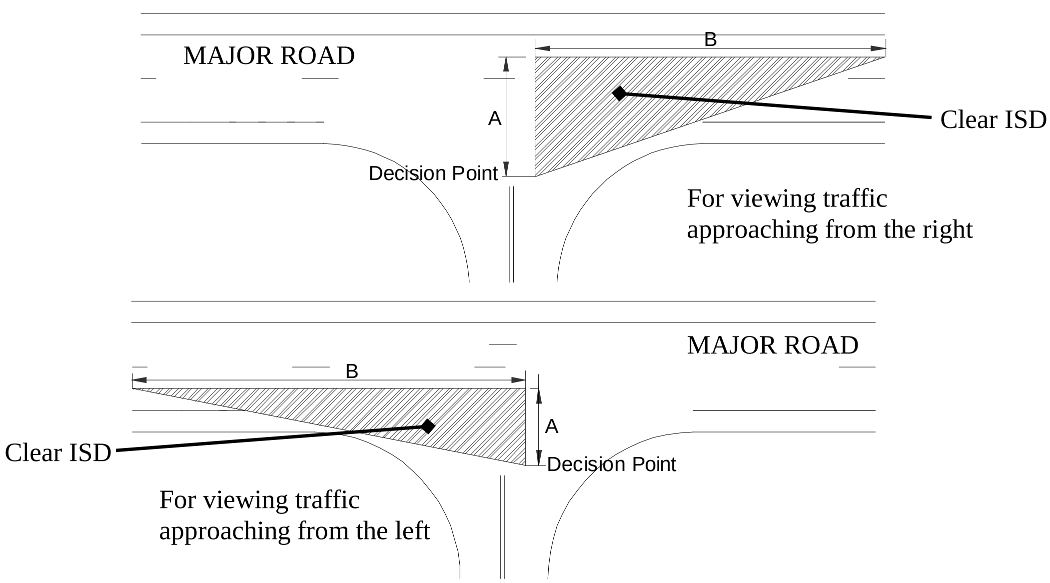


Figure 2: Intersection Sight Distance Triangle Examples

Decision Point = driver's eye offset (15 feet from the edgeline or edge of pavement in absence of an edgeline) at the center of the exiting minor road lane

A = The distance from the Decision Point to the center of the closest approach lane to the minor road from the left or right (per Figure 2 examples)

B = Intersection Sight Distance along the major road (per Equation 1)

Appendix 2-D
Design Guide for Constructing and Relocating Utilities within Public Right-of-Way

Introduction

Pima County Department of Transportation is mandated by Arizona Revised Statutes to construct and maintain roads and streets for safe and efficient transportation of people and goods. It is, therefore, the intent of the department to strive to provide safety and convenience to the motoring public by eliminating and minimizing driving hazards on arterial and major collector roadways.

This guide applies to all public and private utilities including but not limited to communication, electric power, gas, water, sewer, cable television, telephone, fiber optics, irrigation, and similar facilities that are located on, over, and under arterial roads and major collectors within Pima County public right-of-way.

Statement of Guidelines

All overhead utility lines, utility poles, and other above ground utility structures shall be constructed outside the clear zone in accordance with the latest edition of the AASHTO *Roadside Design Guide* and as specified by the Pima County *Roadway Design Manual*. Pole guys are not permitted within the functional limits of an intersection and discouraged within road right-of-way, especially when adjacent to sidewalks, equestrian paths, and along property frontage where existing and future access may be affected. The use of guys should be brought to the attention of the department's utility coordinator for review. Overhead lines are not permitted within the operational limits (i.e. fifteen feet vertically and horizontally) of overhead traffic signals, lighting, signing, and other similar type features.

All underground utility lines, manholes, valves, risers, and other appurtenant structures should be located outside of the through travel lanes of the roadway section, and preferably outside of pavement, sidewalks, and paths between the existing right-of-way line and the outer travel lane edge. Specific locations of each utility within the corridor will be determined by overall project design criteria, including environmental considerations; and be coordinated with the respective utility provider. Service meters, backflow preventers, private service lines and all features identified by a utility as private, shall be placed outside of public right-of-way.

Additionally, all above ground utility facilities (AGF) such as, but not limited to, transformers, splice cabinets, and pressure relief valves shall be placed away from roadways, driveways, alleys, and sidewalks/pedestrian facilities. AGF shall not block safe cross corner sight distance, impede or hinder pedestrian access, or block viewsheds, existing signage, businesses, or homes. Whenever possible, aesthetic as well as practical considerations shall be studied prior to locating AGF. Air pressure relief valves, natural gas regulators, water backflow prevention assemblies, and other similar facilities should be placed subsurface.

Where it is necessary for underground utility lines to cross a roadway, the trench for such utility lines shall be constructed per specifications for utility trench construction approved by the Pima County Department of Transportation.

Final disposition of utility facilities shall be coordinated with the Department's utility coordinateor for conformance with latest department directives, regulations, and requirements. The designer is directed to the Department of Transportation's website for the latest directives and policies related to utility occupany within public right-of-way.

All existing utilities that do not adversely affect the safety, design, or construction of proposed roadway improvements and are not identified by the County as in need of relocation may remain. Abandon utilities are to be remvoed from public right-of-way per County Ordiance 10.50.150 Abandonment of Facilities.

Location Details and Construction

Utility corridors along roadways shall be adjacent and parallel to the outer right-of-way limits of the roadway. Appendix 2-B, Figure 2-11 of the Pima County *Roadway Design Manual*, while reflecting a typical section for a divided roadway, also identifies the locations for these types of corridors and also provides suggested locations of overhead utilities relative to the clear zone of the roadway. Figure 2-12 delineates the underground utility impact zone for minimum utiliity clearances for typical roadway improvements.

These design guidelines are intended to supplement existing nationally accepted design criteria. Professional Engineering judgment is expected to be exercised in generating the design of major arterial and collector roadways. If, in the course of preparing the design, it is necessary to deviate from these guidelines, approval from the Pima County Department of Transportation must be obtained.