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CHAPTER 5: MAJOR STRUCTURE DESIGN AND CONSTRUCTION

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5.1 CHAPTER GOALS

The goal of this chapter is to describe opportunities and concerns for the design, construction and maintenance of bridges and box culverts in order to best integrate them into the existing landscape.

Major structures as described by ADOT include bridges, box culverts and retaining walls. In this chapter, major structures are termed “structures.” This chapter addresses the design, construction and maintenance of bridges and box culverts. Retaining walls are discussed in Chapter 4. Pipe culverts are addressed in Chapter 6.

Riparian areas are extremely important resources to both BLM and USFS. As defined in this manual and used in this chapter, riparian areas include natural perennial, intermittent and ephemeral streams and the habitats associated with them.

5.2 SCOPING AND NEPA PROCESSES

For highways constructed on BLM or USFS lands, the project team should seek to provide Context Sensitive Solutions. That is, the team should integrate the highway corridor with the surrounding landscape. The value of the environmental, wildlife and aesthetic resources that will be impacted must be taken into account when considering the costs of various structure alternatives. With respect to major structures, this directive translates into the following considerations:

Riparian Areas
The protection of riparian areas is of critical importance. The proposed alignment should minimize impacts to existing drainage patterns, *Figure 5.1*, both within and outside of the right-of-way.

Where the preferred alignment will impact riparian habitat, changes to that habitat should be minimized as follows:

- The use of bridges. Bridges are typically less environmentally disruptive than are drainage culverts.
- The type of bridge. Impacts to the surrounding landscape will vary with bridge structure types, as will be discussed in greater detail later in this chapter.
- The relationship of the alignment of the proposed roadway to that of the existing natural drainage. Typically, unless extensive reconstruction of the natural drainage is required, the most cost-effective and least damaging approach is at a perpendicular angle to the direction of stream flow.
- Soil types and stream bank stability at the proposed site. Preferably, soils on either side of the drainage should be stable. Rock is ideal since it offers high stability for support of the new structure and resistance to erosion. In general, the banks of straight reaches of the drainage are more stable than those where the drainage turns.

Figure 5.1 Roadway alignments should minimize impacts on drainage patterns.

- The character of the adjoining areas: the proposed structures should integrate with nearby natural and cultural resources.

Where damage to existing riparian areas is unavoidable, the project team should consider mitigation measures such as the restoration or enhancement of other riparian areas.

Visual Impacts
Where the NEPA process reveals that large cut and/or fill slopes will have significant and undesirable visual impacts, the project team should consider bridges in place of those fills. Bridge structures do not typically appear as natural features in the landscape. However, in general they are more attractive than large slopes.

Geotechnical Investigations
Geotechnical investigations for major structures will typically be initiated during the scoping process and will require subsurface investigations involving excavation and/or drilling. Natural drainages may need to be cleared and graded to prepare for this activity. The project team should attempt to limit the necessary disturbance for this and subsequent bridge construction activities to one area. In addition, the design team should be aware that NEPA, biological and archaeological clearances, Storm Water Pollution Prevention Plans and possibly other clearances will be required prior to the onset of the geotechnical investigation in the field.

Right of Way
Easement acquisition should not be a limiting factor in the design of major structures. Both BLM and USFS will consider a larger than typical right of way easement where necessary in order to design and construct a major structure.

5.3 DESIGN

NEPA Documents
As discussed in Chapter 2, the NEPA process may make recommendations regarding the types of structures. During the design process, the project team should regularly review NEPA documents to ensure that these recommendations are reviewed and included in the construction documents.

Sections 404 and 401 of the Clean Water Act
Section 404 of the Clean Water Act regulates the discharge of fill or dredged materials into the waters of the United States and establishes a program to issue permits. In Arizona, the U.S. Army Corps of Engineers (Corps) administers this program. In addition, the U.S. Fish and Wildlife, the National Marine Fisheries Service and State resource agencies (Arizona Department of Environmental Quality, Arizona Game and Fish Department, Water Resources) have important advisory roles. The 404 program has considerable impact on the design, construction and maintenance of Arizona's highways in general and on highway structure design in particular. Essentially, any proposed work in washes, rivers, streams, lakes and wetlands requires ADOT's Environmental Protection Group (EPG) to obtain a permit from the Corps.

Section 401 of the Clean Water Act enables the State to provide certification that the draft 404 permit is in compliance with State law regarding water quality standards. ADOT EPG obtains 401 certification during the design process.

Riparian Areas
The project design team should seek to protect riparian areas in all cases. Bridges and box culverts affect both local and downstream riparian environments. These structures are also typically a major component of the corridor budget. Therefore, they are of central concern to all parties involved with the highway corridor. Their cost must be weighed against the value of the environmental, wildlife and aesthetic resources that will be impacted. Impacts to riparian areas may be minimized by consideration of the following during the design process:

- Changes to natural stream channel dynamics should be minimized. In general, the less the geometry of the natural drainage is altered, the smaller the impact to the dynamics of the natural flows.
- Avoid or minimize armored bank protection.
    - Installed primarily to control damage to structures, bank protection can take several forms including rock rip rap, *Figure 5.2*, gabion baskets, rail bank, revetment systems, concrete, shotcrete, soil cement and metal sheet piling.
    - Even where installed over relatively short

Figure 5.2 Bank protection of rip rap to control damage to bridge structure and embankment.

stretches of streamside, bank protection can have far-reaching impacts to the dynamics of channel flows both up- and downstream.
    - Bank protection can also act as a barrier to wildlife movement.
    - Alternatives to bank protection include changes in structure alignment and longer-span bridge structures that completely avoid the floodplain.
- Riparian areas typically act as wildlife corridors. Seek input from wildlife experts to determine those species that may be negatively impacted, where those impacts are anticipated to occur and what preventive measures might be taken. Refer to Chapter 3 for more information concerning highway corridors and wildlife habitat.
- For streams designated as important fisheries by Arizona Game and Fish, restrict construction activities that will affect streamflow to appropriate times of year as determined by Game and Fish.
- Anticipate requirements for access during construction:
    - Temporary roads should not degrade water quality, damage streams, disturb channels nor impede fish passage.
    - Ensure that equipment is not allowed to operate in actively flowing streams.
    - For perennial streams designated as important fisheries by Arizona Game and Fish, design temporary access that allows the passage of fish and other riparian wildlife.
    - Evaluate options regarding temporary road construction. Potential techniques include culverts, coarse rock fills, hardened fords, low water crossings and temporary bridges.
    - Minimize the number of temporary crossings.
    - Design temporary crossings to be as perpendicular to natural drainages as possible.
    - Minimize excavation at the stream banks.
    - Remove temporary crossings when permanent crossings become operational and reclaim the affected areas.
- Anticipate requirements for maintenance access by coordinating with local ADOT maintenance districts during design.
- Minimize sediment transport into riparian areas from excavated areas within the natural drainage:
    - Identify staging areas for stored materials that are clear of the floodplain.
    - Divert water flows around construction sites.
- Minimize sediment transport into riparian areas caused by erosion of disturbed soils adjacent to riparian areas. Ensure proper design and installation of both temporary and permanent erosion control measures.
- Reclaim areas disturbed by construction. Successful reclamation incorporates permanent erosion control and establishment of perennial native vegetation.

Structure Type

The type of structure selected is important for

several reasons:

- Structures are among the most expensive items to construct in a given project. Bridges are typically more expensive than box culverts.
- Where structures serve to convey off-site runoff flows, they can dramatically affect the characteristics of that runoff. In general, box culverts collect a given flow into multiple channels, each of which is smaller than the natural drainage. Channeling flows into smaller and usually straighter courses typically increases flow velocities. Increased flow velocities increase the potential for downstream erosion and subsequent environmental degradation. Bridges typically affect natural flow patterns least. Longer-span bridges have less impact than shorter bridges with higher retaining wall abutments.
- Where crossings over perennial streams are anticipated, structures should allow for continued near-natural stream conditions, *Figure 5.3*.
- Natural drainages are frequently associated with high natural resource value. In general, drainages contain greater plant variety and numbers and therefore offer greater habitat value. They also typically serve as conduits for wildlife movement. As discussed in Chapter 3, bridges are less disruptive to natural resources and wildlife movement than are box culverts.
- The NEPA review and documentation process may provide direction for the design team with respect to structure type. The design team should carefully review NEPA requirements and integrate these into the project contract documents. In addition, other state and federal agencies (e.g., Corps of Engineers) may have specific requirements.
- The design of the structure should include consideration of aesthetic values as applied to both the highway and surrounding areas.

Bridge Design

As discussed above and in Chapter 3, bridges typically offer the least environmentally disruptive type of drainage structure. Designers should review the following considerations:

- Locations of permanent bridge supports. In general, these should be minimized within the flood plain.
- Bridge abutments and embankment slopes:
    - These should remain outside of drainages in order to reduce disturbances to natural stream channel dynamics and to wildlife movement. Longer-span bridges, *Figure 5.4*, have less impact than shorter bridges with higher retaining wall abutments.
    - Embankment slope materials (concrete, riprap, gravel, soil) and grades (vertical versus battered) may impact wildlife movement and should therefore be carefully reviewed. Some wildlife species (e.g., bighorn sheep) prefer to migrate along the sides of drainages. Refer to Chapter 3 for more information.
    - Bridges form waterproof “roofs” to the areas below. Therefore, once disturbed, embankment slopes under bridge decks tend to remain bare and subject to erosion from runoff originating outside of this area. Designers should consider the use of rock mulch or other permanent, inert material to control erosion in these areas. The type and placement of these materials should

Figure 5.3 Bridge design allows for near-natural stream conditions.

Figure 5.4 Longer bridges have less impact to waterways.

  be coordinated with anticipated wildlife movement and aesthetic considerations.
  - Bridge abutments that encroach into drainages can be eroded by storm water runoff flows, thereby damaging nearby riparian areas. As described in the ADOT Erosion Control Manual, designers should address this abutment/storm water runoff interface with permanent erosion control measures.
- Geotechnical investigations at bridge sites typically require subsurface investigations involving excavation and/or drilling. Natural drainages will need to be cleared and graded to prepare for this activity. The design team should attempt to limit the necessary disturbance for this and subsequent bridge construction activities to one area.
- Storm water runoff. Bridges typically concentrate rainfall into gutters which daylight through scuppers. Where bridges are superelevated and/or sloped, the runoff from an entire bridge may flow through a small number of scuppers at a relatively high velocity. These fast concentrated flows can be erosive. In addition, the bridge runoff may carry pollutants that had been deposited on the bridge deck. Both of these issues become more critical in sensitive riparian areas. To address these concerns, designers should consider the installation of features to control storm water runoff. Designers should also provide maintenance access to these features.
- Bridges frequently offer valuable habitat for bats, typically in the narrow joints between vertical elements such as girders. For this reason, the design team should consider providing alternate habitats for soffit fill bridges (bridges with no exposed girders or other structural elements).
- Because aesthetics are of concern to both BLM and USFS, consider the appearance of the proposed bridge. Among others, trapezoidal box girders, concrete segmental bridges and arch bridges are attractive options. Consider both through and deck arches.
- Bridges, columns, abutment structures, parapets, rails, etc., should incorporate appropriate context sensitive and cultural design elements and features such as icons, textures, patterns, rustication finishes and colors.
- Bridges require some form of roadside barrier. ADOT typically installs F-barriers (Jersey barriers), *Figure 5.5*, because they require little maintenance and are relatively inexpensive to construct. However, it is difficult for motorists to see over these barriers. Since highway corridors through BLM and USFS lands are frequently constructed in scenic areas, consider the use of more transparent barriers, *Figure 5.6*.
- During construction, all bridge structures require staging areas near the installation sites. Because subcontractors typically construct bridges, these staging areas will need to be independent of (or in addition to) staging areas required for other purposes. The design team should include provisions in the project contract documents for the recontouring and reclamation of these staging areas.
- Bridges typically require regular maintenance and inspection following construction. Access for these purposes should be coordinated during design with ADOT Bridge Inspectors and maintenance staff. Review the need for access roads; if required, access roads should minimize impacts to riparian environments. The design of pullout parking areas, *Figure 5.7*, beyond the

Figure 5.5 F-Barrier (Jersey barrier).

Figure 5.6 F-Barrier with semi-transparent headlight screening.

Figure 5.7 Pullout parking area.

Figure 5.8 Steel arch bridge with concrete deck.

Figure 5.9 Concrete I-Beam construction.

guardrail or barrier should be considered.

Bridge Type

- Steel. Because of its relatively low mass in relation to its strength, steel girders offer the greatest flexibility in terms of bridge design, *Figure 5.8*. However, steel construction is typically expensive.
- Concrete I-beam construction, *Figure 5.9*. Pre-cast concrete beams (also known as AASHTO girders) are typically the least expensive type of construction method based on transportation, time for construction and site access. This form of design poses several challenges:
  - The girders come in a variety of lengths, typically from 100 to 140 feet. Road access for construction is critical. Maximum allowable grades range from 8 to 9%. A 14- to 20-foot access road width is usually required in addition to generous widening at the curves. 70- to 80-foot radius turns are typical.
  - Suppliers usually like to have loop access, entering the bridge site by one road and continuing across the site to exit by a second road. Passing girders from crane to crane is possible in extremely tight or critically sensitive areas if loop access is not feasible.
  - Cranes require cleared, level pads, *Figure 5.10*, (approximately 50 by 50 feet) adjacent to the bridge alignment and outside of the access road. All tall objects (e.g., trees) need to be removed in order to swing the girders into place.
  - Crane pads are required at every bridge site, but usually only on one side of the bridge.
- Cast-in-place post-tension box girder design, *Figure 5.11*. This type of construction includes a variety of designs and considerations:
  - Longer spans are possible (200 feet is typical) than can be used for pre-cast concrete girder design. Therefore, supporting structures may be installed outside of the drainage, reducing long-term disturbance to riparian resources.
  - Temporary scaffolding is necessary the entire length of structure; therefore short-term disturbance to the riparian environment under the bridge alignment will occur. Where the height of the bridge deck is limited and/or where earth is readily available, it may be that soil can be used as a temporary support during construction.
  - Access roads to the bridge site are required for drilling equipment and concrete trucks. However, these roads can be steeper and narrower than are the roads required for transporting pre-cast concrete girders.

- Cast-in-place segmental box, *Figure 5.12*. This type of design and construction poses the least disturbance to adjacent environments but is expensive. Concrete piers are constructed first, then the bridge superstructure is constructed from the tops of the piers, counterbalancing in both directions. Disturbance in the drainage is limited to that required to construct the piers.

Construction and Access Requirements
Access during construction should be clearly identified early in the review process. Clearing limits, including those required for access, should be reviewed in the field at the Stage II (30%) level. Temporary stream crossings and erosion control measures should be identified and described. Where not obliterated by finished slopes, temporary access roads should typically be reclaimed to pre-construction conditions. Therefore, separate plans documenting construction access and mitigation and reclamation of that access may be required in the contract documents. Restrictions on access should be specific in the construction documents: it should be made clear to the contractor his obligations to work within the right-of-way or other approved areas. Identify and make provisions for maintenance that will be required following completion of construction.

Figure 5.10 Pads for cranes.

Figure 5.11 Cast-in-place post-tension box girder design.

Figure 5.12 Cast-in-place segmental box bridge design.

ADOT Structure Design and Review Process
The development of major structure plans, including design criteria, consideration of alternatives, and final design of structures for a project occur throughout the ADOT project development process. The following are typical planning and design stages that offer opportunities for agency review.

Project Scoping
During the project scoping process, the need for new structures is identified as follows:

- Structure Site Identification: Includes site topography, possible structure size, existing hydrological data, existing geotechnical data, and rough cost estimate.
- Agency Coordination: Review of BLM or USFS management plans, environmental data and cooperative agreements; review of appropriate environmental regulations.
- Feasible Alternatives:
  - Review of possible structure types, including issues relating to natural resource damage, constructability, construction access, public detours and removal and obliteration of existing structures.
  - NEPA requirements should address pedestrian access and/or protection of natural or cultural resources.
  - Documentation of the Condition of Existing Major Structures: Evaluation of existing major structures including current National Bridge Inspection Standards (NBIS) inspection report, photos, existing structure plans, existing hydraulic reports, and existing geotechnical reports.
- Structure Planning Report:
  The report includes detailed studies of the more promising sites within the limits of the selected corridor. The report should address the following concerns:
  - Site identification and reconnaissance: Site analysis including current site photos, existing hydraulic and geotechnical data, information regarding existing structures, field notes as well as traffic, safety and environmental considerations.
  - Site requirements and concerns: US FS Forest Plan, BLM or environmental requirements, construction and public detour limitations, utility requirements, easement needs and abandonment and removal of existing structures.
  - Design requirements: Applicable AASHTO and ADOT design standards.
  - Structure alternatives and costs for rehabilitated existing or new alternatives. New structures should include number and locations of piers and abutments.
  - Site Selection:
    The Site Selection process should provide detailed studies of the more promising sites. Consider the following:
    - Skew angle relative to existing stream; an approach that is perpendicular to the drainage produces less impact.
    - Analysis of bank soils types; stable rock is desired.
    - Stream channel condition; avoid drainages where channels are shifting or eroding or where proposed structures will require changes to the natural drainage channel.
    - Respond to adjacent natural, cultural and aesthetic resources.
    - Visibility of proposed structure both from within and outside of easement.
    - Construction access.
  - Site Surveys:
    Site surveys should be conducted for each major structure. The Site Survey should be commensurate with the complexity of the site and the proposed structure. Sufficient environmental analysis should be completed at this point to allow access for geotechnical investigation, if required. This analysis could be part of the final environmental document or could be addressed separately as a preliminary environmental study.
    - Preliminary Foundation Investigation:
      - Review known information, including biological evaluation, archaeological data, and visual information.

- Conduct site visit to classify soil and rock type, evaluate their stability, and obtain information on topographic features, natural flora and fauna, and any built features.
- Conduct preliminary foundation investigation based on proposed layout for structure.
- Prepare preliminary bridge foundation report.

◊ Topographic Map
The site topographic map should be prepared using conventional or photogrammetric methods. The area covered must be sufficient to design and detail the drainage structure and related improvements such as dikes, channel improvements, bank protection measures, detour structures and overflow channels.

The successful integration of the highway with the surrounding landscape depends largely on the project scoping process which will, in turn, inform much of the design process. Therefore, the project team should carefully and fully explore implications to design that are contained in the project scoping document.

Stage II (30%)
Stage II documents should include a preliminary selection for bridge type(s), a preliminary geotechnical report (for structures) and the preliminary foundation investigation (if not completed earlier).

The Initial Drainage Report is submitted with the Stage II review. The Report describes existing natural drainage conditions and specifies the initial sizes and locations of structures (described in greater detail in Chapter 6).

As part of the Stage II (30%) review, the design team should conduct field reviews of proposed structure types, locations and extent of resources impact.

Stage III (60%)
Stage III documents should include the final foundation investigation. Bridge design should be complete.

The Structure Selection Report is prepared for each major structure at this stage. The purpose of the report is to document the evaluation used in determining the recommended structure type and to present criteria for proceeding with final design. The report typically includes the following information as required:

- Structure geometrics including roadway and structure cross-sections, alignment, grade, location, minimum vertical and horizontal clearances and provisions for future expansion.
- Drainage concerns including hydrology and hydraulics for natural and man-made drainages and identification of bank protection needs.
- Bridge superstructure alternatives including cast-in-place concrete, pre-cast concrete or steel girders.
- Bridge substructure alternatives including piers, abutments, foundations and scour protection.
- Natural and cultural resource protection issues.
- Utility concerns.
- Aesthetic concerns and architectural treatments including rustication, railing details, and color.
- Availability of structural materials and components.
- Construction issues including phasing, traffic detours, falsework, erosion control and disruption to the site.
- Construction cost comparisons.
- Suggested alternatives based on comparisons made above.
- Supporting data including calculations and plans for various alternatives.

5.4 CONSTRUCTION

- Since construction may take place in a particularly sensitive environment, maintain strict controls over contractor access.
- Prior to any earth-disturbing activities, the contractor shall prepare and deliver to ADOT proposed erosion control plans for approval by ADOT in consultation with BLM or USFS.
- Prior to allowing earth-moving equipment to operate on BLM/USFS lands, the equipment will require washing as described in the ADOT Erosion and Pollution Control Manual.
- Remove temporary access and restore disturbed areas in compliance with project plans and specifications.

5.5 ADDITIONAL RESOURCES

Illustrations of barrier options are shown at:
http://www.fhwa.dot.gov/bridge/bridgerail/

ADOT Infrastructure Delivery and Operations Division: Bridge Design Service:
http://www.azdot.gov/business/engineering-and-construction/bridge