SECTION 5

STRUCTURES

5.01 MAJOR STRUCTURE – BRIDGE

This section provides guidance for preliminary engineering plan submittal and approval for buildings, bridges, snow sheds, tunnels, geotechnical structures featuring wall systems or ground improvement systems, and hydraulic structures.

Major structures are bridges and culverts with a total length of 20 feet or greater and retaining walls with both a total length greater than 100 feet and a maximum exposed height at any section of over 5 feet. The length is measured along the centerline of roadway for bridges and culverts, and along the top of the wall for retaining walls. Overhead sign structures (sign bridges, cantilevers and butterflies extending over traffic), tunnels and high mast light standards also are major structures.

Refer to the *CDOT Bridge Design Manual*, Section 3, for minimum design loading. Major structures should be analyzed individually for the optimal design. Any substantial costs for deviations from the most economical design need to be considered in the structure selection process and must be agreed to by the Resident Engineer. The construction of a bridge rather than a large culvert is determined from estimated construction and maintenance costs, structural aesthetics, hydraulic needs, and environmental considerations.

For bridges over waterways requirements, please refer to the CDOT Drainage Design Manual. Hydraulic design of the bridge opening shall be completed by a licensed hydraulic engineer, or by a hydraulic engineer under the supervision of a hydraulic engineer with a P.E. license.

The Resident Engineer is responsible for submitting to the Project Structural Engineer the preliminary information including the following:

1. Current and proposed roadway and waterway plans, profiles, and cross-sections for both upper and lower features, with alignment data.
2. Bridge situation sheet with all topography including contours, utilities, and railroads (bridge site data).
3. Any hydraulics report, right-of-way restrictions, and selected guardrail types.
4. Any region design recommendations, including deviations from M Standards.
5. Requirements for electrical conduit, lighting, and utility locations.
6. Corridor aesthetics, environmental consideration, and architectural concepts, if applicable.
7. Request a foundation report from the Geotechnical group and arrange for access, traffic control, and the locations for drilling to be surveyed.

Any subsequent revisions to the roadway alignments or profiles shall be transmitted to the Project Structural Engineer without delay.

The Project Structural Engineer's responsibilities include:

1. Review preliminary alignments and bridge site data.
2. Prepare structure concept study, including appropriate engineering and economic studies.
3. Prepare structure layouts and specific details that reflect a specific structure type, size, and location.
4. Prepare structure selection reports and/or wall selection reports.
5. Request foundation report from the Resident Engineer. See Section 5.06.

For a complete description of responsibilities, see Section 19.1 of the *CDOT Bridge Design Manual*.

The following is a brief overview of the bridge design process outlining the responsibilities of the Project Structural Engineer:

1. Structure concept study
   a. Attend Design Scoping Review meeting.
   b. Obtain and review bridge site data.
   c. Review preliminary alignment to determine structure location.
   d. Determine conceptual structure layout and alternative structure types.

2. Preliminary bridge design
   a. Review bridge site data.
   b. Prepare engineering and economic recommendations.
   c. Prepare general layouts and special details.
   d. Prepare selection report.
   e. Prepare drawings for foundation investigations.
   f. Attend Field Inspection Review (FIR) and make required revisions to layout.

3. Final bridge design
   a. Design all structural elements.
   b. Prepare all structural plans and specifications.
   c. Provide independent design, detail, and quantity check.
   d. Attend Final Office Review and make required revisions to Plans and Specification. At the discretion of the Resident Engineer, a separate structure Final Office Review or a structure advance plan review meeting may be held prior to the overall project Final Office Review.
   e. Provide final structural submittal (i.e., the final detail letter, final design notes, independent design check notes, field package and rating package), see Subsections 19.1.4D and 19.1.4E of the *CDOT Bridge Design Manual*.

f. Provide revised plans and specifications as per the FOR comments for construction.

The Resident Engineer should compare the roadway and bridge plans to verify grade, alignment and clearances.

Additional References:

1. CDOT *Bridge Design Manual*
2. AASHTO LRFD *Bridge Design Specifications*
3. AASHTO *Manual for Bridge Evaluation*
4. CDOT *Bridge Rating Manual*
5. *CDOT Drainage Design Manual*

5.02 MAJOR STRUCTURE – CULVERT

A culvert is used in lieu of a bridge based on estimated construction and maintenance costs, when either alternative is viable hydraulically.

A culvert is considered a major structure if it has an opening measured along the center of the roadway of 20 feet or more between the inside faces of the outside walls or spring lines of arches. It may also include multiple pipes, where the clear distance between the centerlines of the exterior pipes plus the radius of each of the exterior pipes is 20 feet or more.(See CDOT *Bridge Detail Manual*, Section 1.4 Structure Number, Figures 1.4-3, -4, -5 & -6.)

http://www.coloradodot.info/library/bridge/bridge-manuals/bridge-detail-manual/01_general_instructions.pdf/view

For structures equal to or exceeding 20 feet, the Resident Engineer must contact the Project Structural Engineer for a structure selection report if the M Standard Plans can't be used. If the M Standard Plans do apply, it is up to the Resident Engineer to determine if a structural selection report would be beneficial.

All culverts not included in the *CDOT M&S Standard Plans* shall be designed by the Project Structural Engineer. The Project Structural Engineer will request a foundation exploration and foundation report.

For culverts over the waterways requirements, refer to the *CDOT Drainage Design Manual*.

Hydraulic design of a drainage structure, such as a concrete box culvert, shall be completed by a qualified engineer with knowledge of hydrology and hydraulics. However, this knowledge requirement varies according to the complexity of design. Larger drainage structures, for example, concrete box culverts, storm sewers and channel improvements, shall be designed by an engineer specialized in that field.

The following procedures and documentation are required when designing a culvert or concrete box culvert on the project:

1. When selecting pipe material, designers shall use the recommendations of the *CDOT Pipe Material Selection Policy*.
2. For major structures, the hydraulic designer will provide adequate designs for both a culvert or bridge alternatives. The roadway and structural designers will determine the most economical alternative.

3. A cost comparison should be made to determine what structure alternative is the best choice to be constructed. Project grade adjustments should be included in the cost comparison alternatives.

Additional References:

1. CDOT *Roadway Design Guide*
2. CDOT *Drainage Design Manual*
3. CDOT *Bridge Design Manual*
4. AASHTO *LRFD Bridge Design Specifications*
5. CDOT Pipe Material Selection Policy.

5.03 MAJOR STRUCTURE – UNUSUAL

An unusual bridge is one involving: (1) difficult or unique foundation characteristics, (2) new or complex designs with unique operational or design features, (3) exceptionally long bridge spans, or (4) designs with procedures that depart from currently recognized acceptable practices. Examples of unusual bridges include cable-stayed, suspension, arch, segmental concrete, movable, or truss bridges. Other examples are bridge types that deviate from AASHTO bridge design standards or AASHTO guide specifications for highway bridges such as: bridges requiring abnormal dynamic analysis for seismic design; bridges using three-dimensional computer analysis; bridges with spans exceeding 500 feet; and bridges with major supporting elements of “ultra” high strength concrete or steel.

Unusual structures are:

1. buildings;
2. snow sheds;
3. tunnels;
4. geotechnical structures featuring new or complex wall systems or ground improvement systems;
5. hydraulic structures that involve complex stream stability countermeasures, designs, or design techniques that are atypical or unique; or
6. unusual hydraulic structures, such as those serving large storm drainage systems, stormwater pumping facilities, dams or levees.

FHWA Washington Headquarters shall approve all movable bridges and unusual bridges, tunnels, hydraulic structures, and geotechnical structures. A Structure Selection Report should be submitted to the FHWA for review and approval. On federal-aid projects, the FHWA Divison Office shall approve all other bridges (not included in the previous sentence) that have an estimated total deck area greater than 125,000 square feet and all bridges on the National Highway System, major hydraulic structures, and major geotechnical features.

The Resident Engineer shall submit a Structure Selection Report as well as the Field Inspection Review and Final Office Review plans to the FHWA. The Project Structural Engineer will provide the Resident Engineer with plans for bridges, earth retaining structures, and tunnels. The local FHWA Division will review those submittals and may forward them to the Washington Headquarters for approval as appropriate.

The Resident Engineer must coordinate the required submittals with the Project Structural Engineer. The Structure Selection Report submitted with the initial request for review and approval shall include environmental concerns and suggested mitigation measures, and studies of alternate spans and bridge types.

Additional References:

1. CDOT *Bridge Design Manual*
2. AASHTO *LRFD Bridge Design Specifications*

5.04 PEDESTRIAN OVERPASSES AND UNDERPASSES

Pedestrian facilities should be provided where pedestrian volume, traffic volume, or other conditions merit their use. These facilities are usually located in central business districts, factory areas, school zones, athletic fields, parks, and other major activity centers.

Pedestrian separation, either over or under the roadway, is usually desirable at freeways or expressways where cross streets are terminated or where conditions impose an extreme inconvenience or safety hazard to pedestrians due to heavy vehicle traffic. They are also desirable at locations where the need for a pedestrian crossing is otherwise warranted and the separation is economically and environmentally feasible.

When designing pedestrian overpasses and underpasses, the requirements should be the same as for any other highway structure where the same geometric and architectural considerations should be considered (see Section 5.01 of this manual). The Resident Engineer is responsible for providing the Project Structural Engineer with the preliminary geometric layout, vertical profiles, and cross sections for the location of the structure. Additionally, topography of the surrounding area should be provided in electronic format.

The Project Structural Engineer is responsible for reviewing and commenting on the proposed alignments submitted and preparing a structure selection report including a general layout for the selected structure with appropriate widths, clearances, and accommodations for the physically handicapped. The Project Structural Engineer shall request that the appropriate foundation investigations be completed.

The design of pedestrian overpasses and underpasses should accommodate accessibility for the physically handicapped, and bicycle traffic, where warranted.

Public safety features such as vertical clearance, fencing and lighting should be included in the design of the structures. Design criteria for overpasses and underpasses are in the *CDOT Roadway Design Guide*.

Additional References:

1. AASHTO *Policy on Geometric Design of Highways and Streets*
2. CDOT *Bridge Design Manual*
3. *Design of Pedestrian Overpass and Underpass to Accommodate the Handicapped*, Publication N5040.38, FHWA

4. *Pedestrian and Bicycle Accommodations and Projects*, Code of Federal Regulations, Title 23, Highways, Part 652
5. AASHTO *LRFD Bridge Design Specifications*
6. AASHTO *Guide for the Planning, Design and Operation of Pedestrian Facilities*
7. AASHTO *Guide Specifications for Design of FRP Pedestrian Bridges*
8. AASHTO *LRFD Guide Specifications for the Design of Pedestrian Bridges*
9. CDOT Roadway Design Guide

5.05 ARCHITECTURAL AND AESTHETIC TREATMENTS

Aesthetically pleasing structures should be compatible with their surroundings and include features and treatment that prove to be enduring. Care must be exercised when incorporating architectural features and aesthetic treatment in a structure because some structures could be in service 50 to 75 years.

Corridors typically have an existing architectural-aesthetic theme developed during the NEPA Process or from a local entity preference. The Project Structural Engineer and Resident Engineer will determine the structure specific architectural treatment guidelines. An architect may be consulted for ideas on features and treatments.

Preliminary design and architectural details must be documented in the Structure Selection Report (see Section 5.07 of this manual.)

Visually appealing structures should be adopted and developed early before final design commences because inclusion of these details is not easily accomplished after the structure design has begun. Some aesthetically pleasing features can be incorporated in a structure at low cost while others increase cost significantly. New or untried features and treatments must be thoroughly investigated before they are incorporated into a structure. Aesthetics are important in high-profile, frequently viewed structures.

Additional References:

1. CDOT *Bridge Design Manual*
2. *Bridge Aesthetics Around the World*, Transportation Research Board (TRB) National Research Council, 1991
3. *Bridgescape – The Art of Designing Bridges*, Frederick Gottemoeller, 1998

5.06 FOUNDATION INVESTIGATION AND RECOMMENDATION

The foundation investigation gathers data and provides foundation recommendations based on existing subsurface conditions. Typical requests include foundation studies for bridges, major concrete box culverts, high-mast lighting, sign structures, sound walls, and retaining walls. Investigation requests should be made at the conceptual stage of structure design so that preliminary foundation recommendations are available for inclusion in the Structure Selection Report prepared by the Project Structural Engineer.

When a boring or a geotechnical study is required, the Project Structural Engineer will send a foundation investigation request, including the proposed General Layout, to the Resident Engineer. A copy of the request and the general layout with approximate locations for the structure borings will be sent to the Geotechnical Program Manager.

The Resident Engineer will be responsible for obtaining access. The Resident Engineer or survey crew will arrange for traffic control. When the Resident Engineer has completed the access and traffic control has been arranged, he shall notify the Geotechnical Engineer and the Project Structural Engineer in writing. The Resident Engineer will have the final boring locations surveyed for inclusion in the report.

Any questions the Geotechnical Engineer may have related to the boring locations shall be addressed to the Project Structural Engineer. The Geotechnical Engineer is responsible for examining the site and scheduling utility locates, as required.

The Geotechnical Engineer will analyze subsurface data and provide an engineering geology plan sheet and geotechnical report.

The Geotechnical Engineer should be included in the Design Scoping Review and should participate in the follow-up and resolution of any structural problems identified.

Additional References:

1. CDOT *Bridge Design Manual*
2. AASHTO *LRFD Bridge Design Specifications*

5.07 STRUCTURE SELECTION REPORT

A structure selection report documents the important factors that lead to the recommended selection and establishes the basis upon which the final structure design will proceed.

During the conceptual and preliminary design stages of a project, the Project Structural Engineer shall develop a structure selection report for all major structures in accordance with Section 19 of the *CDOT Bridge Design Manual*. For a structure selection report for major culverts, see Section 5.02.

Selection of the best structure type alternative may be based in part on the lowest cost, but other requirements to be considered include:

1. Site requirements (topography, alignment)
2. Safety (during construction, traffic, detours)
3. Structural (future widening, foundation conditions)
4. Environmental (appearance, wetlands, public exposure)
5. Construction (ease of construction, false work, season)
6. Hydraulics (stream flow, bank and pier protection, culvert alternates, scour)
7. Life cycle costs (maintenance, durability)
8. Other (commitments to officials and community, team studies)

The Resident Engineer will provide the Project Structural Engineer the information required to prepare a structure layout, structure selection report, and final design. See Section 5.01 of this manual.

Prior to commencing the final structure design, the Project Structural Engineer will prepare and distribute a structure selection report, including an economic analysis, to the Resident Engineer. The Resident Engineer shall make distribution within the Region and to the FHWA. The structure selection report should be reviewed and approved prior to the Field Inspection Review meeting.

5.08 RETAINING WALLS

Retaining walls are used primarily for retaining soils or roadway cuts and fills to create a grade change. They are also used when it is necessary to contain the roadway fill within the available R.O.W, as well as other applications.

Retaining walls are classified into three categories according to basic mechanisms of retention and source of support:

1. An externally stabilized system uses a physical structure to hold the retained soil.
2. An internally stabilized system uses soil reinforcement to make the retained soil self-supporting.
3. A hybrid or mixed system combines elements of both externally and internally stabilized systems.

Factors affecting the selection of a retaining wall are:

1. Spatial constraints -- Functions of a wall, space limitations, proposed profile.
2. Behavior constraints -- Earth pressure, water table, foundation pressure.
3. Economic considerations -- Environmental, aesthetic.

Retaining walls should be designed to resist corrosion, deterioration, and other environmental factors compromising the durability of the wall. Permanent retaining walls should be designed for a minimum service life of 75 to 100 years.

The Project Structural Engineer in cooperation with the Resident Engineer will be responsible for the selection and design of the best-suited wall type. Where appropriate, alternative wall designs may be developed. The Project Structural Engineer will request a foundation investigation and foundation report.

The required documentation for the wall selection report is outlined in the *CDOT Bridge Design Manual*, Section 5.

The default wall design and design alternative documentation provided by the Project Structural Engineer will include:

1. Default design -- Defined to mean the best wall obtained from the selection process (see the *CDOT Bridge Design Manual*, Subsection 5.6).
2. Design alternatives -- The products of the design selection process (see the *CDOT Bridge Design Manual,* Subsections 5.4 and 5.5).

For a proprietary wall, refer to Section 2.24 Proprietary Items in this manual.

Additional References:

1. CDOT Bridge Design Manual
2. AASHTO LRFD Bridge Design Specifications

5.09 NOISE WALLS

The Resident Engineer, in cooperation with the Project Structural Engineer, will be responsible for the selection of the best-suited wall type. Based on the noise analysis, the Resident Engineer will provide the Project Structural Engineer with the alignment, height, and configuration. The Project Structural Engineer will be responsible for the structural design and requesting the foundation investigation. The Resident Engineer will need to review the structural plans for any potential conflicts with buried utilities.

Additional References:

1. CDOT *Bridge Design Manual*
2. AASHTO *LRFD Bridge Design Specifications*
3. AASHTO *Guide Specifications for Structural Design of Sound Barriers*

5.10 ANALYSIS OF STRUCTURES TO BE RESURFACED

A structural analysis is performed before a structure is resurfaced because resurfacing may affect the load carrying capacity of the structure, its vertical clearance, its bridge rail height, its bridge expansion devices, or a combination thereof. Additional pavement can be placed on a structure if there is adequate load carrying capacity. The total thickness of asphalt after resurfacing shall be limited to 3 inches on the structure.

The Resident Engineer will request recommendations from the Project Structural Engineer for resurfacing of structures.

The Project Structural Engineer will send a surfacing recommendation memo to the Resident Engineer. The memo will include conditions related to the structure resurfacing, recommended repairs to maintain the integrity of the riding surface, existing water proofing membrane, and bridge rail upgrades to maintain roadway safety.

The Resident Engineer will inform the Project Structural Engineer of the final proposed resurfacing method.

Additional References:

1. CDOT *Bridge Design Manual*

5.11 DETERMINE EXISTING STRUCTURAL ADEQUACY

An existing structure must meet criteria as established by FHWA and CDOT, if it is to be left in place.

The Resident Engineer will furnish the Project Structural Engineer pertinent data involving the existing structures and proposed design.

The Resident Engineer shall request recommendations from the Project Structural Engineer regarding the adequacy of the existing structure and recommendations and documentation according to the CDOT Bridge Design Manual for repair or replacement.

The Resident Engineer shall compare the bridge width with the requirements shown on the Form 463, Design Standards, to determine adequacy of the bridge width.

The decision to leave bridges that are narrower than the proposed roadway should be documented.

Additional References:

1. For forms, see CDOT on-line forms library http://www.coloradodot.info/library/forms
2. CDOT Bridge Design Manual

5.12 CRASHWORTHY BRIDGE RAIL

FHWA approved crashworthy bridge rail must be provided on all new bridges. Rehabilitated bridges on all projects, regardless of funding, shall use crashworthy bridge rail unless a variance is approved. The variance shall include an analysis based on criteria presented in the *CDOT Bridge Design Manual*, Section 2.

Crashworthy rail is defined as crash tested in accordance with the *National Cooperative Highway Research Program Report 350*, *AASHTO Manual for Assessing Safety Hardware* (MASH), or rail which has been approved by the FHWA as being equivalent to crash-tested rail.

The Project Structural Engineer will provide a recommendation to the Resident Engineer regarding the replacement of existing bridge rail. The Resident Engineer is responsible for determining whether to install new bridge rail or to leave the existing bridge rail in place.

Approved documentation for variances and design decisions shall be in the project file.

The following bridge rails are required for new or rehabilitated bridges on the following roadway classifications:

1. Type 7 or Type 10M on National Highway System (NHS) and non-NHS state highways projects.
2. Type 3 or any approved crash tested bridge rail on local roads. Type 3 has limited applications because of its 27-inch height. Therefore, CDOT has elected to use type 10M for all new construction requiring a steel bridge rail on the state highway system.

When a bridge also serves pedestrians or cyclists and the posted speed limit is greater than 45 mph, a barrier to shield them from the traveled way and a pedestrian rail at the bridge edge may be warranted as determined by the Resident Engineer or Staff Bridge.

Working drawings with currently approved bridge rail are available from the Bridge Design and Management Branch.

Detailed drawings of bridge rail with revisions or modifications are to be included in the Construction Plans as determined by the Resident Engineer.

Additional References:

1. 23 CFR Part 625, *Design Standards for Highways*
2. AASHTO *Guide for Selecting, Locating, and Designing Traffic Barriers*
3. AASHTO *LRFD Bridge Design Specifications*
4. AASHTO *Roadside Design Guide*
5. AASHTO *Standard Specifications for Highway Bridges*

5.13 VERTICAL CLEARANCE OF STRUCTURE

All highway projects shall meet or exceed minimum vertical clearances according to guidelines set by the FHWA and CDOT. These clearances shall pertain to all overpasses, underpasses, railroad and transportation facilities, bicycle and pedestrian facilities, overhead lines, sign bridges, signal mast arms, navigational streams, channels, and canals. The Resident Engineer is responsible for determining the appropriate clearances.

Vertical clearance applies to the full pavement width, including provisions for future widening and overlay. A formal variance is required if less clearance than the minimum is achieved.

Minimum vertical clearances are listed in the CDOT *Roadway Design Guide*, Chapter 6.

The Resident Engineer must verify vertical clearances for all phases on detours and traffic shifts. Clearances to false work and shoring during construction should be considered. If minimum clearances cannot be maintained during construction, appropriate signing shall be included in the plans. Vertical clearances shall be shown on the highway construction plans for all structures.

Additional References:

1. 23 CFR Part 625, *Design Standards for Highways*
2. AASHTO *Policy on Geometric Design of Highways and Streets*
3. AASHTO *Guide for the Development of Bicycle Facilities*
4. AASHTO *LFRD Bridge Design Specifications*
5. AASHTO *Standards Specifications for Highway Bridges*
6. CDOT *Bridge Design Manual* (Section 2)

5.14 ACCELERATED BRIDGE CONSTRUCTION (ABC)

For construction projects that include one or more bridges, CDOT has developed a tool for evaluating Accelerated Bridge Construction (ABC) techniques, to determine whether or not they are appropriate for any given project.

The materials for ABC evaluation can be downloaded at the internet link given below. The materials are compressed in a Zip file. Download the materials, unzip the files, and save the files to your local computer.

http://intranet/engineering/staff-bridge/accelerated-bridge-construction/view

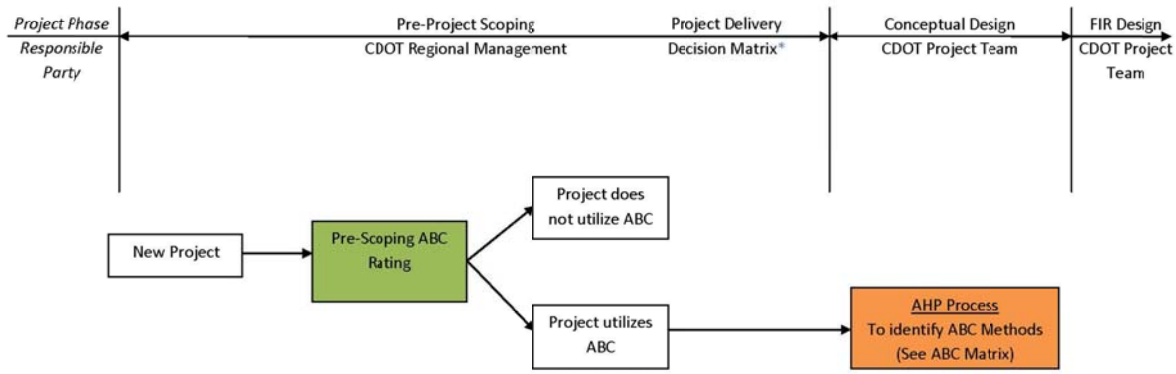
The accelerated bridge construction methodology is to be evaluated for all projects that will contain one or more bridges. After completion of the evaluation, a justification letter must be written and added to the project file explaining why or why not an ABC technique will be used on the project. The justification letter should include materials completed during the ABC evaluation. The design team may choose to work with the designated Staff Bridge Engineer for guidance and information regarding the use of the ABC materials.

The document "CDOT_ABC_Selection_Overview" contains an overview of the ABC process. The process is a two-phase approach. One phase is a cursory evaluation as to whether or not ABC is appropriate for a given project. The second phase is an in-depth evaluation as to what type of ABC technique will be employed.

This cursory evaluation is to be done during the scoping phase using the spreadsheet "CDOT_Prescoping_ABC_Rating_Attachment_B." If the results of the cursory evaluation show that an ABC technique is appropriate for the project, the design team may move on to a more in-depth evaluation using the "ABC Decision Making Software" to determine which ABC method best meets the project's goals and constraints. If the in-depth evaluation is required, the design team shall schedule a meeting with all specialty groups including but not limited to: Staff Bridge, Utilities, Environmental, Traffic, Hydraulics, etc. to execute the ABC Decision Making Software. The results of the software are to become part of the project files.

The above information is represented graphically in Figure 5-1. This is the same diagram that is included in the document titled, "ABC_Workflow_Attachment _A."

ABC Evaluation and Decision Matrix Workflow



**Contracting methods can work hand in hand with ABC delivery. Depending on the particular goals of the project and complexity of the ABC method some contractual tools maybe more beneficial than others. For each project, the Delivery Decision Matrix should be completed after the Pre-scoping ABC Rating form has been completed. Some contractual tools are listed below:*

Innovative Contracting Tools	A+B Contract Provision	Contract in Calendar Days	Fixed Completion Date Contract	Incentive-Disincentive Provision	Lane Rental Provision	Value Engineering Specification	Design Buid Contract Delivery Method	CM/GC Contract Delivery Method

Figure 5-1
ABC Evaluation and Decision Making Matrix Workflow