SUPERSEDES MEMO TO DESIGNERS 1-23 DATED OCTOBER 2003

16-1 HYDRAULIC DESIGN FOR STRUCTURES OVER WATERWAYS

Introduction

This memorandum provides direction for the hydraulic design of structures over waterways on the State Highway System (SHS). The intent is to assist the structure designer in understanding the recommendations provided in the Bridge Hydraulics Reports.

The hydraulic design of a bridge must include the scour condition. Generally, scour is increased with high flow velocities in the waterway. Other factors such as turbulence, complex flow patterns around the abutments, or a bridge location on a bend in the stream can contribute to the scour condition. The hydraulic design of the bridge should aim to accommodate waterway conveyance with the least amount of impact to velocities and water surface levels.

Policy Statement

Structures over waterways on the SHS shall be designed in accordance with the AASHTO LRFD Bridge Design Specifications, current California Amendments (AASHTO LRFD-BDS-CA) and the Highway Design Manual (HDM). Design Flood is defined in the Highway Design Manual (HDM 818.1) as:

Design Flood - The peak discharge (when appropriate, the volume, stage, or wave crest elevation) of the flood associated with the probability of exceedance selected for the design of a highway encroachment.

Design flood frequencies adopted as a standard for design and their application are listed below:

- 50-year or 100-year flood used for adequate waterway conveyance OR as specified by any flood control agency.
- 100-year flood used for scour analysis.
- Minimum of 200-year flood or a maximum of 500-year flood used for check flood.

The general criteria for setting the soffit elevation is to pass the greater of (1) Design Flood (typically Q50 + freeboard), or (2) Base Flood (Q100 without freeboard). Per HDM 818.2 & 821.3, design practice recommends that a range of peak flows be considered and that the Design Flood be established which best satisfies the specific site conditions and associated risks. There will be rare situations where the risks of a lower water crossing is acceptable, but typically the highways shall not be inundated by the Design Flood. At low water crossings subject to inundation as an accepted risk, the overtopping flood will be used as the Design Flood. Deviation from the standard design criteria requires project-specific design criteria to be included in the hydraulic reports.

In accordance with the Local Assistance Procedures Manual (LAPM), Chapter 11, local-agency-funded projects with bridges on the SHS must be designed in accordance with current SHS standards outlined in the Caltrans bridge design manuals and the HDM. All local bridge and structure projects off the SHS and either on or off the National Highway System (NHS) must use similar design criteria. For all state or local bridges, the effects of objectionable backwater conditions must be considered.

Certain regions throughout the state are regulated by local flood control agencies and bridge structures within their jurisdiction must satisfy their design requirements. Certain local agencies have established higher design standards than Caltrans requires. Local agencies that choose to require higher standards of design may complicate the ability to receive federal funding. There may be circumstances where the risks of a lower water crossing are acceptable. The hydraulic studies must provide justification for deviating from the standard design criteria.

The AASHTO LRFD-BDS requires scour at bridge foundations to be investigated for two conditions: (1) design flood and (2) check flood. Scour for the design flood is based on the 100-year event or from an overtopping flood of a lesser recurrence interval. Scour for the check flood is based on a higher flood discharge; typically a 200-year event.

For all capital projects, a hydraulic study report is required for any bridge over a waterway to address adverse flood risk potential. Environmental approvals often hinge on compliance with local flood control agencies or other regulatory agencies. The hydraulic study reports must comply with the requirements set forth in this document. Reports may not be necessary for structure maintenance projects.

Scour of Geologic Material

The geologic material underlying a waterway may be either: (1) granular or fine material, (2) cohesive or non-cohesive, (3) erodible or non-erodible rock. Various geologic materials erode at different rates. Non-cohesive materials scour more readily than cohesive materials, while cohesive or cemented soils typically are less scour-resistant than some rocks. The geotechnical analysis studies the in-situ soil properties and the hydraulic conditions of the flow to determine the erosional susceptibility of the foundation material during a single flood event or long-term erosion.

The geologic properties and hydraulic conditions of water flow may vary during the life of the bridge. The geologic and soil factors include the sediment or rock type, its porosity and permeability, hardness, cementation, fracturing, degree of weathering, etc. Scour prediction methods assume that scour may reach predicted depths given sufficient time, regardless of the type of foundation material and its properties. Geologic materials erode when the resistance of material is less than the erosive force of water in motion.

Hydraulic Summary Table

A Structure Hydraulics Report must be prepared for all bridge projects over waterway crossings including: (1) new bridges, (2) bridge widening projects, (3) bridge retrofit projects, and (4) structural scour mitigation projects. The Structure Hydraulics Report shall address, but is not limited to: flooding history of the site, waterway adequacy at the bridge opening, bank stability and erosion, streambed stability, and issues leading to continuous maintenance due to scour. For a new alignment, the location of the drainage structures and the hydrology analysis should be finalized during the scoping stage. For more information, refer to Attachment 2, Hydraulics Reports.

A Final Hydraulic Report (FHR) will provide a Hydrologic Summary Table similar to Table 1:

Table 1 - Hydrologic Summary Table

Hydrologic Summary for Bridge No. xx-xxxx			
Drainage Area:_____ mi^2			
Frequency	**Design Flood**	**Base Flood**	**Flood of Record**
	50-year	100-year	x-year
Discharge	_____ cfs	_____ cfs	_____ cfs
Water Surface Elevation at Bridge	_____ ft	_____ ft	_____ ft
Floodplain data are based upon information available when the plans were prepared and are shown to meet federal requirements. The accuracy of said information is not warranted by the State and interested or affected parties should make their own investigation.			

The Hydrologic Summary Table shall be placed on the Foundation Plan, and will be available on the As-Built Plans.

Components of total scour at a bridge foundation are needed for foundation design. Scour depths are reported in various formats in the body of the report. A sample table for reporting scour is shown in Table 2:

Table 2 - Scour Summary Table

Long Term & Short Term Scour Depths Bridge Name, Br. No. xx-xxxx			
Support No.	Degradation Scour Depth (ft)	Contraction Scour Depth (ft)	Short Term (Local) Scour Depth (ft)
Abutment 1			
Pier 2			
Pier 3			
Abutment 4			

Table 2 reports scour depths that a designer can use for foundation design without referencing the specific site survey information. Another very similar table identified as the Scour Data Table (see Table 3) must also be provided. The difference is that the Scour Data Table must identify the long-term scour elevations (not scour depths) at the bridge foundation elements that will assist bridge inspectors to make a very quick scour condition assessment by referencing the As-Built Plans. The format and column descriptions of the Scour Data Table must not be changed.

Scour Data Table

A Final Hydraulic Report (FHR) will provide a Scour Data Table in similar format to Table 3:

Table 3 - Scour Data Table

Support No.	Long Term (Degradation and Contraction) Scour Elevation (ft)	Short Term (Local) Scour Depth (ft)
Abut 1*		
Pier 2		
Pier 3		
Abut 4*		

*Scour at support location; not at Abutment embankment toe.

The Scour Data Table shall be placed on the Foundation Plan. This data will be useful to Structure Maintenance & Investigations (SM&I) during routine inspections to determine if noted scour is within the limits of the original design.

Hydraulic Design Considerations:

New Bridges:

1. Every effort must be made, if structurally and economically feasible, to have a bridge layout that improves and enlarges the waterway flow area to avoid conditions that may lead to foundation scour (*AASHTO LRFD 2.6.4.3, C2.6.4.3*).
2. The elevation of the bridge soffit typically needs to be set to provide the minimum freeboard required above the Design Flood (typically Q50) water surface elevation. Minimum freeboard will be provided in the hydraulic reports. Also, the bridge soffit must be high enough to pass the Base Flood (Q100) without freeboard.
3. The bridge substructure needs to be designed to satisfy any permit requirements as well as all the limit state design requirements using the latest AASHTO LRFD codes, CA Amendments and commentaries relating to scour for the given design flood, overtopping flood, and check flood. Currently under California Amendments (*AASHTO LRFD-BDS-CA 3.7.5*), the Strength limit state is used in lieu of a check flood evaluation.
4. The orientation of multi-column bents and pier walls must match, as closely as structurally feasible, the natural channel skew angle relative to the bridge alignment to minimize stream flow obstruction. Obstructions create conditions that may lead to foundation scour. Fenders and other similar pier protection systems such as a pier nose extensions may be recommended in the hydraulic report to deflect and prevent debris from collecting on the piers (*AASHTO LRFD C2.6.4.3, C2.6.4.4.1, 2.6.4.4.2*).
5. Traditional pier walls are not a preferred option for new structures due to seismic considerations. For new construction where debris between columns is a concern, guide walls are recommended to be placed between columns in lieu of traditional pier walls.
6. The Structure Hydraulics Engineer will recommend when the abutment may need to be protected with scour countermeasures (*AASHTO LRFD C2.6.4.4.1*). Commonly recommended countermeasures are abutment side walls and/or rock slope protection (RSP) armoring. RSP designs for countermeasures should be based on procedures presented in FHWA HEC-23. For gradation specifications, use the recently updated Grading Specifications.
7. The potential effects of channel degradation or aggradation, contraction scour and local scour must be investigated in the different scour condition limit state load combinations (LRFD-BDS-CA Table 3.7.5-1). It is important to note that scour per se is not a force effect, but by changing the conditions of the substructure it may affect resistance of the substructure elements and lead to instability of the foundation system. The structure designer will need to consider the change in column or pile stiffness due to the loss of streambed material caused by scour or long term degradation.

8. The top of a spread footing must be placed at or below the anticipated total scour (Degradation + Contraction + Local) elevation (*LRFD 2.6.4.4.2 and LRFD-BDS-CA Figure C2.6.4.4.2-1*) unless founded on competent, scour-resistant bedrock.
9. The top of a pile cap footing must be placed at or below the estimated degradation plus contraction scour depth (*LRFD 2.6.4.4.2 and LRFD-BDS-CA Figure C2.6.4.4.2-2*). The bottom of a pile cap footing should be placed at or below the anticipated Total Scour elevation. Figures C2.6.4.4.2-1 & C2.6.4.4.2-2 show a typical bent or pier location.
10. The effect of scour on increasing top of pile displacement under the Service Limit State shall be discussed during the Structure Type Selection meeting.
11. Stream pressure must be considered in combination with scour for the bridge substructure including any pile support that is exposed based on predicted scour for the given limit state load combination (*AASHTO LRFD 3.4.1-1, 3.7.3, and C3.7.5*). If debris accumulation is a known problem, the designer must account for debris loads as a transient load WA (water load and stream pressure). A drag coefficient of 1.4 must be assumed for debris loads.
12. Exposed piles must be checked for buckling and lateral stability (*AASHTO LRFD 2.6.4.4.2 and 10.7.1.5*).
13. When requesting a Foundation Recommendation from Geotechnical Services, include all anticipated short and long term scour information supplied by Structure Hydraulics. Soil springs for seismic analysis (Extreme Event I limit State) shall be requested for two scenarios: 1) current condition; i.e., no long term degradation has occurred and 2) the channel has fully degraded. If the difference in streambed elevation between the two scenarios is significant, analysis may yield different shear and moments in the design of the columns or pile shafts.
14. AASHTO LRFD-BDS requires all bridge foundations to be assessed for scour under the check flood, also known as the superflood event (*LRFD 2.6.4.4.2*). Currently under California Amendments (*AASHTO LRFD-BDS-CA 3.7.5*), the Strength Limit State is used in lieu of a check flood evaluation.

Existing Bridges:

Typical scour related projects for existing bridges are as follows:

1. <u>Scour mitigation without bridge modification</u> – Scour mitigation can be accomplished by a combination of waterway improvements such as: channel realignment, installation of countermeasures such as streambed or foundation armoring (RSP), or installation of check dams. The recommendations for scour mitigation or countermeasures shall be provided by Structure Hydraulics, through consultation and coordination with SM&I Hydraulics.

2. Scour mitigation with bridge modification – commonly called "Bridge Scour Retrofit". Bridge modification may be required when the total potential scour depth can result in pile exposure, potentially leading to structural instability. Bridge modification may be required when scour mitigation by channel improvement is not hydraulically and/or environmentally feasible. New piles are typically retrofitted onto the existing foundations either through the use of outrigger bents, pile footing enlargement, or entire bent replacement.
3. Bridge Widenings – The foundation for the widened portion of the bridge must comply with the design criteria for a new bridge. Existing foundation, if scour critical, shall be mitigated using a combination of items 1 and 2 listed above.
4. Complete bridge replacement – SM&I, through their own internal peer review process for scour critical assessment, typically recommends and identifies complete bridge replacement as the scope of work for a scour-critical bridge on the long-term SHOPP plan. Complete bridge replacement is necessary when the combined cost of a bridge scour retrofit and bridge maintenance costs over the remaining service life of the bridge (i.e. life cycle cost) is competitively close to the replacement cost of the existing bridge. An early meeting with the District and Offices of Structure Design, Structure Hydraulics, and SM&I during the APS or Design phase to discuss this option is critical to have the proper funding programmed and approved. A life cycle cost analysis prepared by SM&I could be requested by the District to justify replacement over rehabilitation.

Regulatory Flood Control & Other Regulatory Agencies

Regulatory agencies require hydraulic model results for all bridge project alternatives including any temporary structures. If impacted by Sea Level Rise, the regulatory agencies require that analysis to consider tidal flow. If a project is within a FEMA regulatory floodway, the hydraulic analyses must be compared to their regulatory flood elevations.

Certain regulatory agencies such as the Central Valley Flood Protection Board (CVFPB) will require certain information to be reported. Hydraulic data for comparison of existing and proposed conditions are reported in a summary table. Required data includes: design flow, velocity, water surface elevation (WSE), soffit elevation, and freeboard as well as change in WSE and velocity. A sample table of common data is listed as follows:

Table 4 -CVFPB Table

Design Information		Existing (Pre-Construction)				Future (Post-Construction)				Δ Existing to Future	
Bridge No.	Design Flow cfs	Soffit Ft*	WSE Ft*	Velocity ft	Freeboard ft	Soffit Ft*	WSE Ft*	Velocity ft	Freeboard ft	Δ WSE ft	Δ Velocity fps

All bridge projects located in the CVFPB jurisdiction must meet specified design criteria in order to be granted a permit. Per Title 23, Code of California Regulations, Article 8-128, bridges across streams under the jurisdiction of the CVFPB shall follow the criteria below:

(A) The bottom members (soffit) of a proposed bridge must be at least three (3) feet above the design flood. The required clearance may be reduced to two (2) feet on minor streams at sites where significant amounts of stream debris are unlikely.

(B) When an existing bridge being widened does not meet the clearance requirement above the design flood, the bottom structural members of the added section may be no lower than the bottom structural members of the existing bridge, except as may be caused by the extension of existing sloped structural members.

Unlike Caltrans' standard design criteria, projects in the CVFPB jurisdiction often must meet a 200-year flood protection standard for urban development in the Sacramento River and San Joaquin River watersheds. Senate Bill 5 (2007) tasked the Department of Water Resources (DWR) with developing "Urban Level of Flood Protection" criteria. "Urban area" means a developed area in which there are 10,000 residents or more. "Urbanizing area" means a developed area or an area outside a developed area that is planned or anticipated to have 10,000 residents or more within the next 10 years. The 200-year flood protection criteria may apply to both urban and urbanizing areas.

An encroachment permit from the CVFPB is likely to be required. It is the responsibility of the District PE to prepare the permit application, with assistance from the District Hydraulic Engineer. Thg District Hydraulic Engineer is the signee of the permit application and is the responsible unit to communicate with the Board. Districts 2, 3, 4, 6, and 10 may potentially be impacted by these regulations.

Summary

A bridge superstructure must be designed to pass or freely clear the design flood plus freeboard or the base flood without freeboard. For low water crossings where a bridge superstructure cannot be placed to satisfy this standard design criteria, a bridge must be designed to endure fully submerged flow conditions.

Scour at bridge foundations must be assessed for two conditions: (1) design flood and (2) check flood in which, under California Amendments (AASHTO LRFD-BDS-CA 3.7.5), the Strength limit state is used in lieu of a check flood evaluation.

Effective communication early in the project delivery process is essential for managing a successful project.

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