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Geomorphic and River Channel Stability Assessment of the Merced River at the Ferguson Slide, Mariposa County, CA

Strudley, M.W., Guensch, G.R., Hastings, B.K., Thompson, K., Chartrand, S.M., Roberts, B., Hecht, B.

Abstract On April 29, 2006, the Ferguson Rock Slide covered California Highway 140 with approximately 70,000 cubic meters of material at Ferguson Ridge. Slide debris protrudes into the Merced River and continues to periodically accumulate in and along the river channel. Caltrans has installed temporary detour bridges and proposes to permanently install one of several alternative bridge designs. Balance Hydrologics, under subcontract to Parsons Transportation Group, has conducted a geomorphic and river channel stability assessment to examine the potential effects of the various bridge alternatives on river stability, channel migration, and scour and fill. Here we describe morphologic evaluation of the existing channel and a spatially-distributed incipient motion analysis keyed to geomorphic map units and simulated 2D hydrodynamic river behavior. This work represents a novel and useful approach to assess channel stability at engineered crossings, and provides a much clearer picture of river behavior than typical scour analysis calculations.

Introduction

The Ferguson Rock Slide is located on California State Highway 140, in between the towns of Mariposa and El Portal, a crucial local and regional transportation corridor. Freely-flowing traffic was first disrupted by reactivation of the Ferguson Rock Slide beginning on April 29, 2006. Conditions quickly deteriorated thereafter, and by the end of May 2006, a 600-foot long stretch of Highway 140 was buried in rockfall debris (Harp and others, 2006) and closed indefinitely. Balance Hydrologics, Inc. was asked by Parsons Transportation Group, Inc., on behalf of the California Department of Transportation, to prepare a River Geomorphology Study in support of environmental compliance for transportation restoration of Highway 140 at the Ferguson Rock Slide in Mariposa County, California. To restore reliable freely-moving traffic on Highway 140 Caltrans is considering nine (9) separate project alternatives, including the no build alternative. Six (6) of these alternatives (see Figure 5), Alternatives C, T, S, S2, A, and the No Build (two, one-lane bridges obliquely spanning the Merced River connected by a single-lane roadway opposite the slide mass), are examined in this paper because of their potential to impact Merced River form, function, and recreational whitewater characteristics.

Environmental Setting

The project site is in the Merced River canyon approximately 0.5 miles downstream of the mouth of the South Fork Merced River, a major tributary which has cut a valley with similar morphology to that of the main fork. Drainage area at the project site is 661 square miles (Cipponeri, 2007). Canyon walls composed predominantly of fine-grained phyllite are steep and generally mantled with a thin veneer of sediments that support mesic to xeric vegetation. The Merced River traces

a relatively straight path from the Yosemite Valley area to the Central Valley, and is bedrock controlled. Significant bends are likely a result of active or inactive faults and knickpoints, and changes in structure and lithology. The walls of the valley at the approximate level of the design flood are composed of (a) bedrock, (b) blast rock, (c) imported (and often cemented or fortified) rip rap, (d) vertically-cemented rock walls, and (e) slide debris and derivative talus. All wall types listed are generally stable, with the obvious exception of slide debris. Local intrusions of the Bass Lake Tonalite and the Pilot Ridge Quartzite supplement the predominantly granitic-boulder/cobble bedload of the Merced River derived from glacial deposits and eroded bedrock of the Sierra Nevada batholith farther to the east in the Yosemite area (Beck, 2007a,b; Bateman, 1992). The local climate at the project site is characterized by a wet winter season (October to March) during which approximately 90% of total precipitation falls, and a warm, dry season (May to September) with temperatures which can reach 100°F. Lows during the winter season are generally around 20°F. Mean annual rainfall for the entire Merced River watershed is 42 inches, although higher elevations receive closer to 60 inches annually in the form of snow, while lower elevation areas near the project site receive 37 inches.

Technical approach

Our comprehensive, inter-disciplinary analytical approach is designed to address a number of outstanding questions. First, what constitutes the present-day geomorphic characteristics of the Merced River at the project site? Second, what are the estimated hydraulic characteristics of flood flows at the project site under existing river conditions? Third, under what hydraulic conditions will existing river morphologic features be mobile and subject to adjustment? Last but not least, did the recent episode at the Ferguson Rock Slide affect river morphology and function, and how may subsequent re-activation phases interact with the river, and the potentially implemented transportation alternatives?

To address these queries, we employed several site-specific hydrologic, hydraulic, and geomorphic analyses, including (a) complete historic flow analysis of all locally available USGS gaging data including estimation of the peak flows for the recent floods of 1997 and 2005; (b) geomorphic facies mapping of alluvial deposits through the project reach (to describe present-day river-bed architecture); (c) surface and near-surface sediment grain-size analysis (to characterize the composition of alluvial deposits); (d) quantitative dating of flood deposits and geomorphically-significant surfaces utilizing lichenometry and dendrochronology with results placed in context of historic floods for results validation; (e) development of one- and two-dimensional hydraulic models to verify predicted water surface elevations and profiles against observed high water marks and simulate river hydrodynamics at design flows; and (f) incipient motion or bed mobility analysis.

Hydrologic Analysis

A total of 5 USGS gages with varying periods of record and proximity to the project reach were used to estimate peak discharge values so that design flows could be selected for calibrating simulations to observed high water marks from 1997 and 2005 events. Discharge estimations were complicated by the fact that the gages near

the site have short records ending in mid 1970s and that Pohono gage, with a long continuous record, is located 16 miles upstream. We estimated project reach discharges using ratios of the gage records from near the site to the concurrent data from the upstream Pohono gage. This produced an estimates of 16,500 cfs for the 2005 peak, and 43,250 to 49,250 cfs for the 1997 event.

Geomorphic Facies Mapping

The centerpiece of this study from a geomorphic perspective is our geomorphic facies map of the project reach (Figure 1). This map illustrates the suite of alluvial and colluvial deposits that mantle the bedrock floor and channel margins within the Merced River canyon. It depicts the relative age of each deposit, determined by stratigraphic and onlapping relationships, along with lichenometric and dendrochronometric sampling that provide an approximate absolute age. We also identified and mapped the location of trees and lichen used for absolute dating, large woody debris (LWD) left by flood flows, sediment sampling sites, knickpoints, riffles and pools, and cross section traces where we developed depictions of cross-valley surfaces and features. Geomorphic facies were identified based on grain size, texture, landscape position, degree and age of vegetation development, and topographic correlation across the channel.

Sediment Grain Size Analysis

We focused our grain size sampling at, and adjacent to, the locations of bridge piers in the proposed alternatives. The grain size analysis consisted of: (a) pebble count surveys along linear transects over bar and floodplain surfaces; (b) point-sampling of the bed surface on bars and within the submerged channel; and (c) point-sampling of subsurface (bed core) sediments on bars and within the submerged channel. Transects did not cut across different surfaces. Grains were measured with ruler and tape to half phi-size increments. Point sampling on subaerial and submerged surfaces consisted of placing a 1-meter square grid on the surface and sampling all particles within the grid square at the surface. Once surface particles were removed, subsurface particles were measured, or if the subsurface consisted of a large proportion of fines (gravels and finer, indicating a well-armored surface), an estimate of the modal percentage of fines was made relative to the remaining large particles. Grain size results at the medial bar across from the slide, on the right-side point bar 100 feet downstream and 200 feet upstream of cross section G, and on the left-side bar at cross section F yielded D_{50} values of 136, 256, 107, and 147 mm and D_{84} values of 244, 524, 249, and 318 mm, respectively (Figure 1).

Hydraulic Modeling

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used to conduct the one-dimensional hydraulic modeling for the project reach. Cross sections were extracted from the elevation contour map generated in ArcGIS using GeoRAS. Manning's 'n' values were estimated in the field based on substrate roughness and vegetation characteristics according to established guidelines (Chow, 1959; Haan and others,

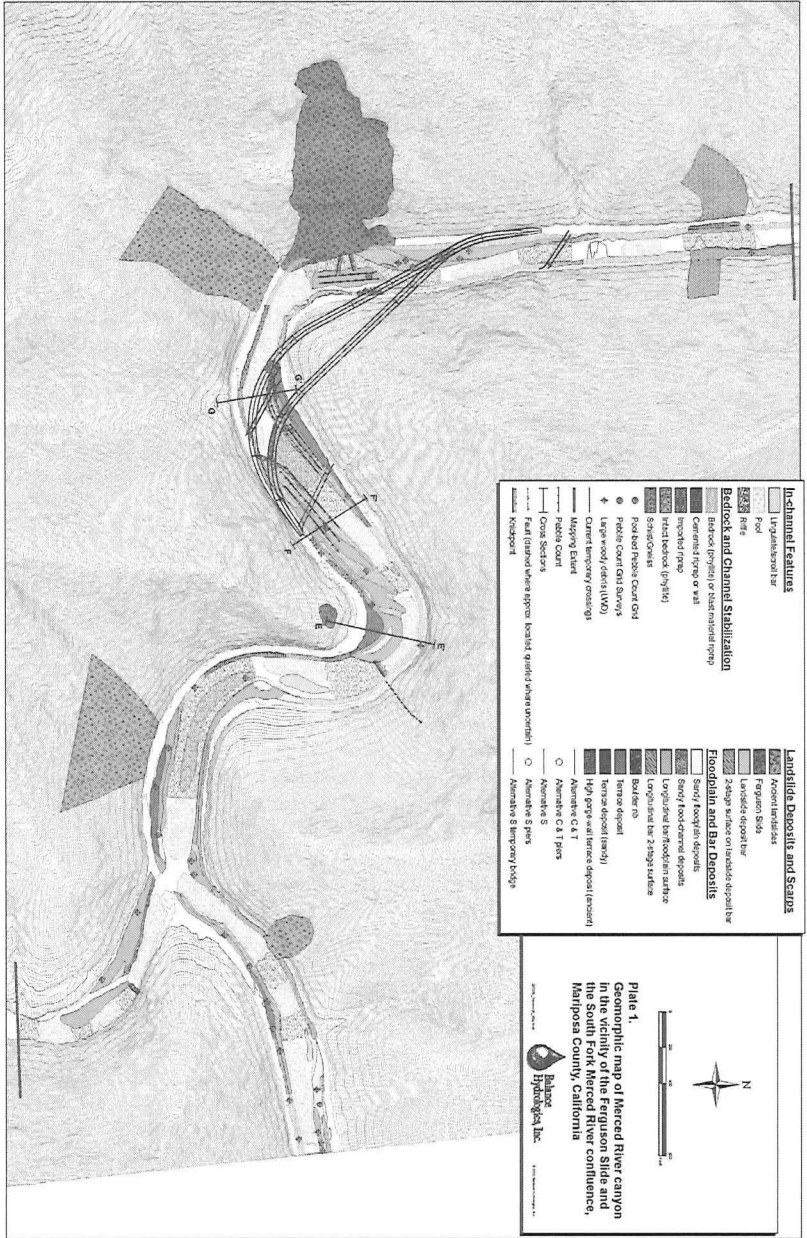


Figure 1. Geomorphic map of Merced River canyon in vicinity of the Ferguson Slide and South Fork Merced River confluence, Mariposa County, CA.

1994). 1D model performance was assessed by comparing the elevation of high water marks with water surface elevations simulated using the estimated flows from the 1997 and 2005 events (Figure 2). The calibrated 1D model was then run using design flows to be used in the two-dimensional hydraulic model. These flows were set at 42,000 cfs (the maximum flow estimated to pass under the downstream bridge soffit for Alternative S) and 8,800 cfs (the upper end of discharges suitable for recreational rafting). Results from these simulations were used to determine the downstream boundary condition for the 2D hydrodynamic model, and also as a check on water surface profiles developed using the 2D model.

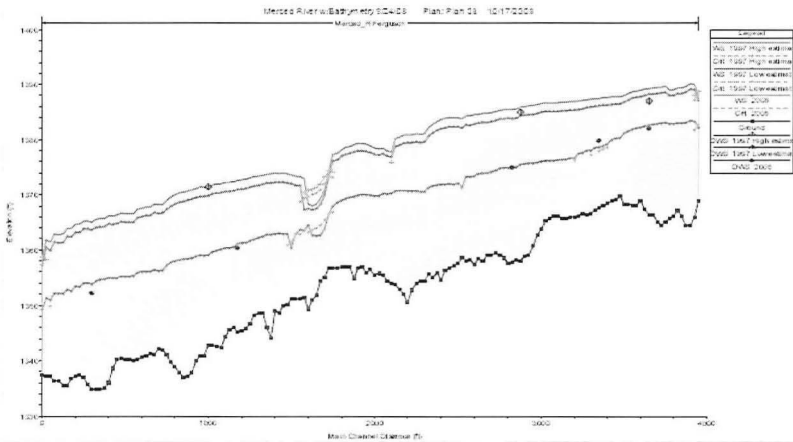


Figure 2. Water surface profiles generated using HEC-RAS for the 2005 peak flow (16,500 cfs) and the upper and lower estimates of the 1997 flood (43,250 and 49,250 cfs). Observed high water marks are show as black dots.

The two-dimensional (2D) modeling utilized the Finite Element Surface Water Modeling System – Two Dimensional Hydrodynamic Model (FESWMS-2DH) coupled with the Surface-water Modeling System (SMS) graphical pre- and post-processor software package (Environmental Modeling Research Laboratory, 1999). This model is recommended by Caltrans for use in modeling highway river crossings where complex hydraulic conditions exist (Caltrans, 2006) and has been used in other large studies of channel modifications such as Huizinga (2007). FESWMS-2DH applies the finite element method to solve a system of equations that describe two-dimensional depth-averaged surface water flow. Inputs to the model include a mesh representing the physical geometry of the river reach, conveyance parameters within the mesh, and upstream and downstream boundary conditions defining starting water surface elevations and flow rates, and numerous hydraulic and model execution parameters (Froehlich, 2002). A rectilinear mesh of relatively large cells was used to represent the channel bottom, with smaller cells used in the locations of the piers. A fine triangular mesh was used along the steep, irregular banks. Calibration was

performed by comparing water surface elevations in the 1D HEC-RAS model with those developed in the 2D model.

Sediment Transport

A bed sediment mobility analysis was used to evaluate how the different transportation alternatives may affect sediment mobility relative to existing conditions. The analysis involved determining the dimensionless critical shear stress of the median grain size (D_{50}), which is likely to be mobile under the different transport conditions. We used our 2D hydrodynamic modeling results to generate discrete distributions of boundary shear stress across the study reach, which we then used to calculate a critical median sediment diameter, D_c :

$$D_c = \frac{\tau_0}{\tau_c^* (\rho_s - \rho) g}$$

τ_0 is the applied boundary shear stress, given *a priori* values for the Shields' parameter (dimensionless critical shear stress), τ_c^* , and density of sediment, ρ_s , and water, ρ . (We assume a density of 2.65 g/cm³ for the quartz-rich granitic sediment supply.) We then compared D_c to the median diameter measured in our grain size pebble counts to ascertain stability of the surface. Applied boundary shear stress is calculated using output from the 2D hydrodynamic model:

$$\tau_0 = \frac{\rho \bar{u}^2}{[5.75 \text{Log}(12.27R/k_s)]^2}$$

where \bar{u} is the depth-averaged flow velocity and R is the hydraulic radius (here, flow depth is used as an approximation for R). The term k_s is the boundary roughness length scale, which is generally greater than D_{50} (Buffington and Montgomery, 1997); here we use $k_s = 3.5 * D_{84}$, consistent with HEC-18 (Richardson and Davis, 2001) and others (e.g., Whiting and Dietrich, 1990), where D_{84} is the sediment diameter below which 84% of the sampled grains are finer.

Results

A total of 7 scenarios were run in addition to the natural (no-bridge) condition. As a brief example of this analysis, we present results from the natural condition, and Alternatives C and T, which share the same bridge alignments.

Natural conditions under high flow

Under our modeled high flow condition of 42,000 cfs and with no bridges in place (the "natural condition") the velocity distribution shows high velocity flow through the thalweg, with the highest velocities, shown as dark areas occurring at the bend (Figure 3). The large region of high velocity flow just downstream of the bend is located at the toe of the slide where a rapid has been formed from slide debris. The shear stresses result in critical bed sediment size distributions generally much higher than median sediment sizes sampled on the three bars analyzed. As a result, we

would anticipate that most of the material along channel margins, on the river bed, and on bars not sampled, will be mobile under the simulated high-flow condition. On both the left-bank and right-bank bars upstream, the critical bed sediment sizes generally represent cobbles and boulders (up to ~2000 mm diameter), except along the outside margins of these bars just below adjacent roadways (Highway 140 on the left bank and Incline Road on the right bank). In contrast, critical sediment size distribution on the medial bar across from the slide is much higher, ranging between 1000 – 5000 millimeters. This is a product of the large predicted shear stresses which would be exerted over this bar during the modeled high-flow.

The above shear stress and critical sediment size distributions yield potential incipient motion conditions which would provide for complete mobilization of the river bed and banks within the project reach under high flow conditions with the exception of narrow geomorphically stable deposits along the periphery of the upstream bar deposits.

Alternatives C and T under high flow

Plots of the changes in flow depth, velocity, shear stress, critical grain size diameter, and incipient motion potential between natural conditions and Alternatives C and T under high-flow conditions are shown in Figure 4. The obliquely-oriented bridges for Alternatives C and T create up to 1-foot increases in flow depth upstream of the two crossings that dissipate gradually a few hundred feet upstream of each crossing. The results also show the isolated effects of the piers on water surface elevation and velocity.

Changes in flow velocity are the direct result of flow being channeled through bridge openings, between piers, and between piers and the river banks. Flow velocity increases of up to 1 ft/sec are predicted for flow zones between piers at both the upstream and downstream bridges, while decreases in flow velocity are created at the wakes or eddies downstream of all of the piers. The most significant velocity increase of approximately 3 to 4 ft/sec is shown between the left bank pier of the upstream bridge and the left bank.

The increase in shear stress associated with piers is most pronounced on either side of the right bank pier at the upstream bridge, but shear stress increases are also expected at the downstream piers and in the channel center in upstream reaches, as suggested by the changes to the velocity field in the project reach. Shear stress declines slightly in many locations on the left-bank bar at the upstream bridge, because the backwater effect of the upstream bridge is most pronounced along the left channel margin.

Fields of high critical sediment diameter have contracted slightly for Alternatives C and T, compared to natural conditions. This is a result of decreasing shear stress over much of the project reach under Alternatives C and T compared to natural conditions, except at locations of flow constriction between proposed piers. These reductions in critical sediment diameter yield contracted fields of potentially mobile sediment on bar surfaces, despite the increases in shear stress at localized areas between proposed piers. We still expect sediment in the channel center and around piers to experience enhanced mobilization compared to natural conditions,

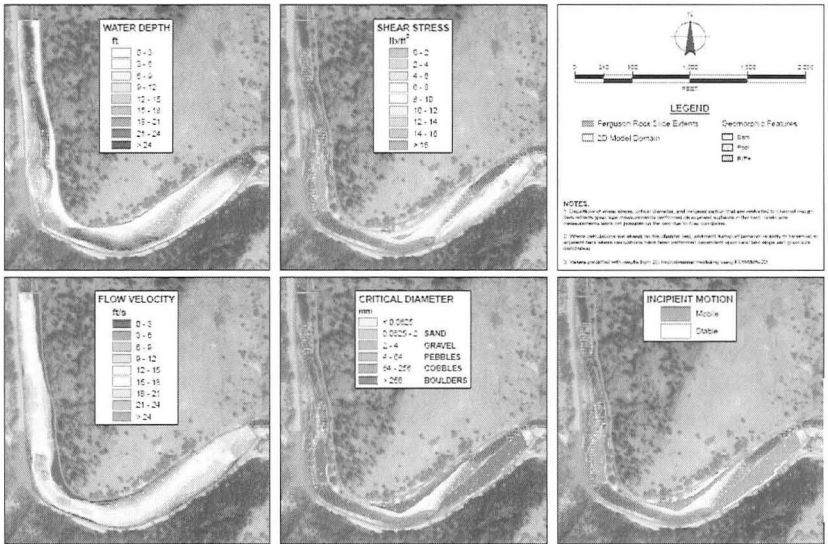


Figure 3. Distributions of depth, velocity, shear stress, critical sediment diameter and incipient motion for the natural condition at 42,000 cfs.

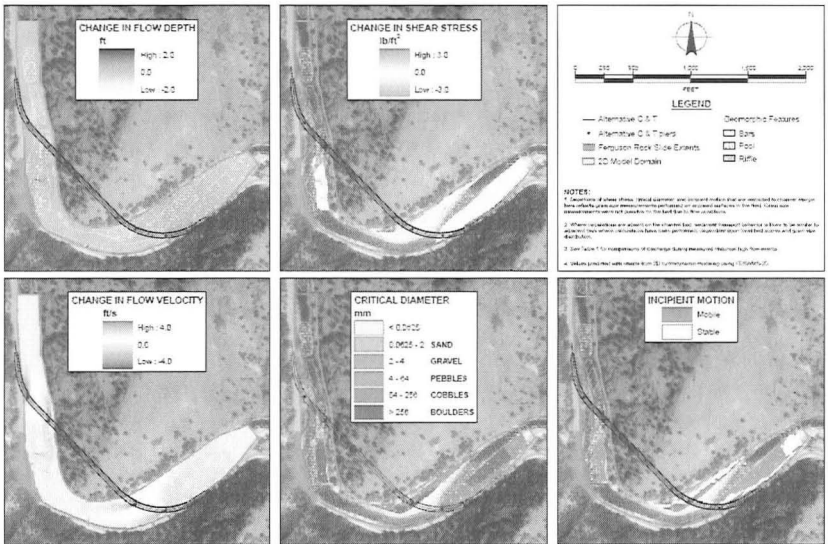


Figure 4. Distributions of change in depth, velocity, and shear stress relative to natural conditions for Alternatives C and T, and critical diameter and incipient motion.

whereas sediment mobility will be reduced in other locations that experience backwater effects and decreased flow velocities.

Synopsis of all modeling results

We performed the above analysis for all alternatives under both the low and high design flow conditions to assess river channel stability and whitewater recreational use. This resulted in a map of bridge pier feasibility zones (Figure 5). Our analysis goes far beyond a typical scour analysis and shows not only potential scour at pier locations but how the project reach as a whole may be modified under design flow conditions. In particular, our high flow analysis suggests that alternatives C, T, and S (results for S were not discussed) all pose some potential to permanently alter the nature of the existing river mostly in areas immediately adjacent to the bridges and piers, or in the high-flow channel and distal end of the bar mapped along the left bank, at the upstream bridges. These changes could include development of scour holes in bars, truncating the river side or downstream ends of these bars, erosion of the riffle mapped there, and perhaps upstream enlargement of the large pool mapped through the meander mid-way through the project reach.

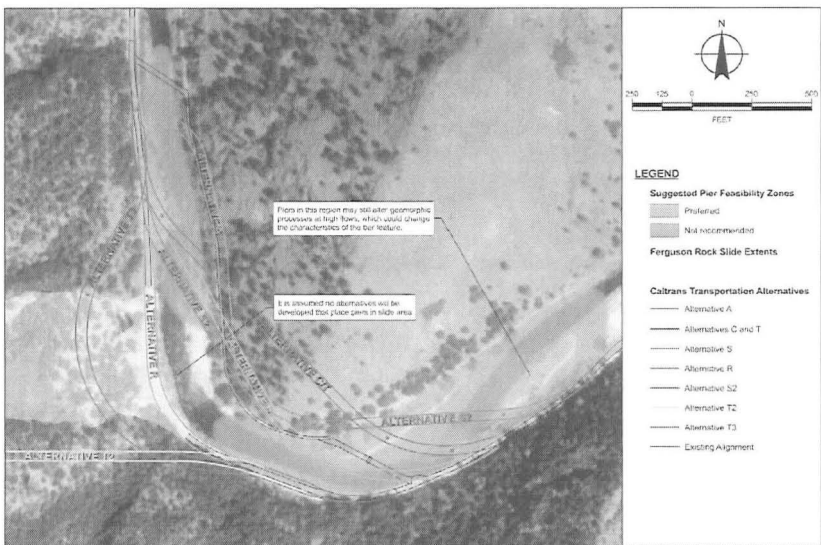


Figure 5. Suggested pier feasibility zones for continued planning and review of Ferguson Rock Slide Transportation Restoration Alternatives, Merced River, Mariposa County, California.

References

Bateman, P.C. (1992). "Pre-Tertiary bedrock geologic map of the Mariposa 1° by 2° quadrangle, Sierra Nevada, CA." *United States Geological Survey: Miscellaneous Investigations Series Map I-1960*.

- Beck, T.J. (2007a). "Preliminary Geotechnical Report." *Department of Transportation, Division of Engineering Services, Geotechnical Services – MS 5*, 13 p.
- Beck, T.J. (2007b). "Geotechnical Design Report." *Department of Transportation, Division of Engineering Services, Geotechnical Services – MS 5*, 11 p.
- Buffington, J.M. and Montgomery, D.R. (1997). "A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers." *Water Resources Research* 33(8): 1993-2029.
- Caltrans (2006). "Chapter 860, Open Channels." *Highway Design Manual*: p. 860-1 – 860-13.
- Chow, V.T. (1959). *Open-channel Hydraulics*, McGraw-Hill, St. Louis, MO, 678 p.
- Cipponeri, A. (2007). "Location Hydraulic Study, Merced River at Ferguson Slide area." *State of California Department of Transportation*, 8 p.
- Environmental Modeling Research Laboratory (1999). "Surface-water modeling system reference manual, version 9.2." Brigham Young University, Provo, UT, 315 p.
- Froehlich, D.C. (2002). "Two-dimensional depth-averaged flow and sediment transport model—Users manual for FESWMS Flo2DH." *Federal Highway Administration: FHWA-RD-03-053*, 203 p.
- Haan, C.T., Barfield, B.J., and Hayes, J.C. (1994). *Design Hydrology and Sedimentology for Small Catchments*, Academic Press, San Diego, CA, 588 p.
- Harp, E.L., Reid, M.E., and Godt, J.W. (2006). "USGS memorandum re: Ferguson Rock Slide, Mariposa County, California." *United States Department of the Interior, U.S. Geological Survey*, 6 p.
- Huizinga, R.J. (2007). "Two-dimensional hydrodynamic modeling and analysis of the proposed channel modifications and grade control structure on the Blue River near Byram's Ford Industrial Park, Kansas City, MO." *United States Geological Survey: Scientific Investigations Report 2007-5098*, 45 p.
- Richardson, E.V. and Davis, S.R. (2001). *Evaluating scour at bridges, 4th Edition: U.S. Department of Transportation, Federal Highway Administration: Publication FHWA NHI 01-001, Hydraulic Engineering Circular No. 18*, 378 p.
- Whiting, P.J. and Dietrich, W.E. (1990). "Boundary shear stress and roughness over mobile alluvial beds." *Am. Soc. Civ. Eng., J. Hydraul. Eng.* 116(12): 1495-1511.