Update 1 Appendix A. Solved Problems and Figures with Additional Topics

Introductory Comments. Appendix A of report FHWA-CA-TL-95-10 is hereby updated, and it is referred to as "Update 1 Appendix A". It replaces all of Appendix A in the two printed editions (June 1996 and November 1997, none in stock) and in the third Internet edition (October 2000). Readers may notice some repetition, and that was intended for clarification.

"Update 1 Appendix A" is intended for Caltrans staff in hydraulics, project development (design), maintenance design, construction (resident engineers and inspectors), and by similar staff in the private sector. There are example problems and explanations of the California Bank and Shore (CaBS) rock slope protection (RSP) design method. Design staff should read all of "Update 1 Appendix A". Whether weight or volume is the method of measurement and payment for RSP, construction staff must inspect several dimensions related to RSP. Therefore, before RSP work begins, it is suggested that construction staff review pages A-17 through A-33.

To date, there are no standard plans for RSP (also called riprap). Figures A-7, A-8, and A-9 are updated generic design concept sketches. The sketches may be useful to construction staff, because they show relative dimensions and expressions, which were likely used to produce typical cross-sections and quantities of contract plans. Feedback is encouraged from construction to design for verifying estimates and for any quantity adjustments. Both design and construction are encouraged to report any errors in "Update 1 Appendix A" to the chair of the Bank and Shore Protection Committee, Office of Highway Drainage Design in Sacramento.

Figures A-1 through A-6 include **RSP-freeboard**, additional RSP above high water of the design event. In generic Figures A-7, A-8, and A-9, RSP-freeboard is a general dimension, and a common value is 2-feet in rivers, streams, and creeks. RSP-freeboard accounts for uncertainties in hydrologic and hydraulic calculations. The additional RSP shields erosive soil in bends due to the super-elevated water surface, guards against repeated wave attack due to wind and boating traffic, and buffers the uppermost bank from floating debris. The designer should contact the local flood control agency and ask if there is a value for channel freeboard (extra capacity), and then determine if that would also affect RSP-freeboard.

When Caltrans is requested to consider biotechnical techniques with nonliving and live components for bank and shore protection, designers typically first consider a CaBS layered RSP design by which to compare or contrast alternative techniques. The additional topic **A-5.2.1 Porosity** may be useful for estimating soil quantities for variations of vegetated riprap.

Summary of Changes.

1. In prior editions, Figure A-1 (embedded toe) of Problem 1 depicted a nonstandard design, so Figure A-1 and Problem 1 were changed to reflect a standard design. Also, the steps and expressions for changing dimensions of a mounded toe were revised in Figure A-2 and in section 6f of example Problem 1. Generic Figure A-8 (mounded toe) was changed to be consistent with Figure A-2. Relative dimensions in Figures A-2 and A-8 represent minimum dimensions of a mounded toe. Because rock gradations (RSP-classes) vary (within envelope curves of acceptable weights), and because gradations are inspected and accepted visually, it is possible that "out-of-spec" rocks can be delivered to a job. And, under normal conditions, some rocks wash away while most launch (drop) into the scoured zone and protect against undermining. Therefore, additional considerations are presented on RSP toe design and mounded toe dimensions in additional topic **A-6. RSP Toe. Scour and Embedded Depth, Mounded Toe, Bedrock** of "Additional Topics" (Item 7, next page lists all the Additional Topics).

2. Problems A-2 and A-3 retain most dimensions, expressions, and references as in prior editions, however, there are changes in Figures A-3 through A-6 that are consistent with the text.

3. The CaBS Equation 1 for determining a minimum stable stone weight, only indirectly accounts for river reaches on curves (also called bends, bendways), that is, the equation does not have separate input variables for the geometry of a river. Therefore, a brief paragraph, labeled **Impinging Or Parallel Flow** precedes the **Summary of Example Problems**.

4. RSP-fabric. All three problems retain the RSP-fabric designations "Type A" and "Type B", however, RSP-fabric is a generic label in figures, because changes are expected in specifications and material requirements. When changes are adopted, column entries for RSP-fabric in Table 5-2 (main report) should be updated. For nonstandard special provisions, for example, heavy duty RSP-fabrics, contact the Office of Highway Drainage Design in Sacramento.

5. Graded Gravel Filter Instead of RSP-fabric. After section 6e in Problem 2, a topic was added for designing a **Graded Gravel Filter Layer**. The recommended method is the Terzaghi method, which is valid when the bank soil is sand. When the bank soil is not sand, an alternative method, Cisten-Ziems, may be considered. The Cisten-Ziems method addresses a broad range of soil types, including sand. It is documented in Appendix C, section 7 "Filter Requirements", in the National Cooperative Highway Research Program (NCHRP) project 24-23 final report, "Riprap Design Criteria, Recommended Specifications, and Quality Control". The report can be purchased via the online Transportation Research Board (TRB) bookstore. Click on http://www.trb.org/bookstore/ enter NR568 as the search string, then click the GO button. A summary of project 24-23 and link to an electronic copy of the final report are available at http://www.trb.org/trbnet/projectdisplay.asp?projectid=722 .

6. In Problem A-3 (the example for concreted-RSP), terminology was updated to be consistent with Section 870 of the Caltrans **Highway Design Manual** dated May 2006. Also, Problem A-3 had no explanation for estimating concrete volume, so additional topic **A-5.3 Estimating Concrete Volume** was added. Figures A-5, A-6, and A-9 were modified accordingly.

7. Additional Topics. Based on discussions and consultations for about the last ten years with many engineers (some are listed in the Acknowledgments and Chapter 9 of the main report) several topics have come up repeatedly. The discussions were documented and are presented as **Additional Topics**. There are explanations, figures, and a few equations. Figure A-10 illustrates and describes the features of protruding and non-protruding revetments. Figure A-11 shows CaBS alternative dimensions for a mounded toe. When bedrock dips toward the center of a stream, Figure A-12 illustrates and suggests a possible toe design and construction techniques for a stable toe. Section designations and main topic headings are :

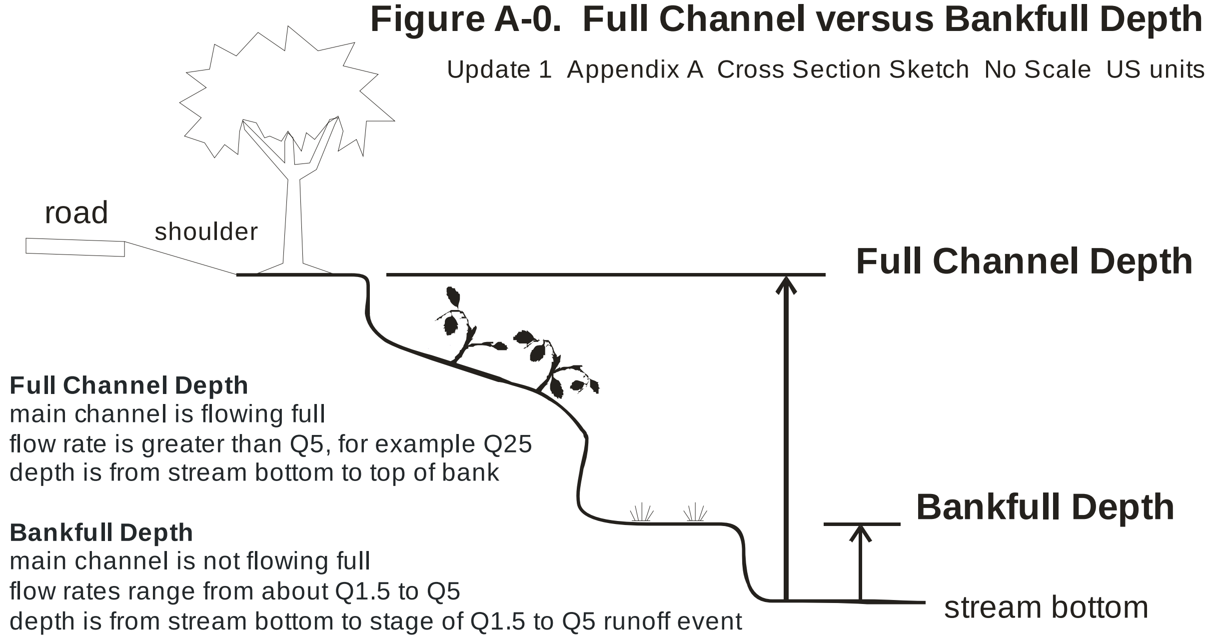
- A-4. Verifying Individual Rock Weights and RSP-Class (Gradation)
- A-5. Guidelines for RSP Volume and Weight (mass)
- A-6. RSP Toe. Scour and Embedded Depth, Mounded Toe, Bedrock
- A-7. RSP Tolerance
- A-8. Method A or Method B ?
- A-9. Notes on ASTM Riprap Guide.
- A-10. RSP (riprap) Monitoring   A detailed topic outline is on page A-20.

8. Significant correction of terminology. All readers need to know of this significant correction of terminology. Prior FHWA-CA-TL-95-10 reports incorrectly used the term *bankfull* in example problems. In "Update 1 Appendix A" *bankfull* is replaced with *full channel depth*. See Figure A-0 (A-zero) on the next page for clarification. In the example problems, *full* *channel depth* is measured from the stream bottom to the top of bank, and it is lower in elevation than the edge of roadway shoulder. The recurrence interval of an event flowing at or near *full channel depth* is greater than 5 years, for example, 25 years, and flow rate is greater than Q5, for example, Q25. This definition applies only to example problems in "Updated 1 Appendix A", whereas, in other reports and literature, *full channel depth* may be defined differently, if at all.

The term *bankfull* is not used in example problems of "Update1 Appendix A". *Bankfull depth* is a term used in discussions and descriptions of fluvial geomorphology, and it is defined as the local depth at a cross section during a *bankfull flow rate*. An exact elevation of *bankfull depth* can be difficult to determine in human-altered watersheds. Recurrence intervals of *bankfull runoff events* range from about 1.5 to 5 years, (*bankfull flow rates* may range from about Q1.5 to Q5). For clarification of *bankfull* and other water depths, see special topic number 1, *Bankfull Discharge*, in the NCHRP project 24-19 final report, "Environmentally Sensitive Channel and Bank Protection Measures". The report can be purchased via the online TRB bookstore. Click on http://www.trb.org/bookstore/ enter NR544 as the search string, then click the GO button. A summary of project 24-19 and links to an electronic copy of the final report and a CD-ROM are available at http://www.trb.org/trbnet/projectdisplay.asp?projectid=718 .

Figure A-0. Full Channel versus Bankfull Depth

Update 1 Appendix A Cross Section Sketch No Scale US units



Summary of Example Problems

The three example problems demonstrate how to design RSP (rock slope protection, also called riprap, and rock revetment) by the Ca Bank and Shore (CaBS) method, which results in a LAYERED design. In the following text and examples, the "bank" is roadway embankment, or it may be an embankment for other kinds of transportation infrastructure, like a railroad or a bikeway. The example problems are ideal, because velocity and scour data are given, and failure investigations and resource agency concerns are simplified. These simplifications helped to keep the focus on technical aspects of designing RSP. There is more to RSP design than exercising a stone-sizing equation. The problems illustrate step-by-step solutions, and guide the designer to arrive at a typical cross section and quantities and for a project PS&E (plans specifications and estimate). Inexperienced staff should consult with experienced staff.

Impinging Or Parallel Flow. Impinging flow is when the river current (velocity vector) is aimed directly, more or less, at a river/roadway bank, and parallel flow is when the current is aligned parallel with the bank. In plan view, impinging flow may range from greater than 5 degrees to 90 degrees (head on). Five degrees is a value based on flume studies for hydraulic skew effects on bridge piers (Hydraulic Engineering Circular Number 18, HEC-18). Regarding the CaBS equation 1, there is no exact “cutoff” angle for impinging flow versus parallel flow. It is a judgment call based on knowledge of the river, local flow patterns, and experience. At relatively low flows, some sites have flow which parallels the bank, and during a flood event as depth increases, the parallel flow may change and become impinging flow. The phenomenon of parallel flow becoming impinging flow may develop due to a temporary blockage in the channel from landslides, debris, or significant changes in local bedload.

Problem A-1 (with Figures A-1 and A-2) is a problem solution for impinging flow, and it shows two possible configurations of RSP for protecting the toe. Because undermining is a dominant failure mechanism of revetments, Figures A-1 (embedded toe) and A-2 (mounded toe) are presented. Impinging flow produces hydraulic forces on a bank which are greater than those of parallel flow. For impinging flow, the velocity in the stone sizing equation is increased. It is 4/3 times the average velocity in the approach (upstream) channel. The mounded toe is an option to the embedded toe. A mounded toe is an additional quantity of rock placed directly on the riverbed (streambed) in front of the revetment. A mounded toe is built when it is not feasible to dig a toe trench, or when digging in the riverbed is not allowed due to a permit condition, for example, as part of a Department of Fish and Game (DFG) streambed alteration agreement.

Problem A-2 (with Figures A-3 and A-4) is a problem solution for parallel flow. The velocity to use in the stone sizing equation is reduced, that is, it is 2/3 times the average velocity in the approach channel. The problem introduces the concept of placing soil among rock voids and on-top-of RSP. As contrasted to waiting for natural and variable deposits of silt, intentionally placing soil can help to accelerate plant growth for habitat, shade, and nutrients. Depending on the plant materials, a vegetated bank can increase hydraulic roughness, as contrasted to a rock-only surface. Introduced vegetation should blend with the upstream and downstream plants. Soil should not be placed where it would wash away during frequent events, that is, generally not below the stage of the Q1.5 to Q5 event. The vertical limit of soil cover is sometimes set as the stage of the Q2 event, however, the Q2 stage should not be used at all sites. Local hydrology, natural flow patterns versus releases from dams, whether or not there is in-stream aggregate mining, and long-term riparian vegetation patterns at adjacent and nearby sites should be field-investigated to determine a site-specific elevation below which soil should not be placed.

The cross sections of Figures A-1 through A-4 depict ***flexible*** RSP designs, where flexible means "only rock" with no binding material like concrete that would fill some voids and tend to restrict adjustment of rocks due to hydraulic, gravity, and/or seismic forces. Flexible RSP is considered as self-healing, that is, when limited movement and repositioning of rocks do not cause failure of the underlying bank.

Although rigid concreted-RSP was not the primary focus of the research, **Problem A-3** (with Figures A-5 and A-6) is a problem solution for ***rigid*** concreted-RSP. Concreted-RSP eliminates some inner layers of rock, which gives a thinner cross-section than a comparable flexible riprap cross-section. Concreted-RSP is used where hydraulic width is critical, that is, in narrow channels and on some bridge abutment fills. When only relatively small rock is available, concreted-RSP is an option that may be considered. Concrete binds several smaller rocks into a larger mass. While concreted-RSP is rigid, it is not intended to be impervious, and therefore water behind the revetment must have pathways back to the channel. Water pathways are provided with weep pipes or by intentionally omitting concrete at intervals from toe to top of the RSP. Scouring action and/or channel bed degradation (lowering of the channel elevation, and not necessarily a worsening of habitat), can remove streambed materials under the toe, and when the toe is not embedded deep enough, concreted-RSP may become cantilevered (perched) over relatively large voids. It should be possible for portions of cantilevered concreted-RSP revetments to fracture and fall into scoured zones at some time, behaving similar (but not equal) to flexible riprap revetments. Intentionally fracturing cantilevered sections of concreted-RSP with heavy equipment or with explosives may be necessary as part of a repair effort (consult with hydraulic engineering and maintenance staff). Soundless chemical demolition agents (SCDA) or other similar rapidly expanding chemical agents are alternatives to explosives. SCDA materials expand rapidly, and when placed in confined drill holes, sufficiently high pressures develop, which breaks rock and/or concrete. A valid California blasting license is required for using explosives or SCDA. Obtain the proper permits before using these techniques on any job.

Regarding concerns of environmental staff and requirements of resource agencies for restoring habitat, willows (and likely cuttings of other species) can be successfully grown through both flexible RSP and concreted-RSP revetments. See Photo C-48 in Appendix C, which demonstrates that willow cuttings can grow in a concreted-RSP revetment, when they are inserted before concrete is placed.

Problem solutions and figures are mostly in US customary units. SI (metric) units are in parentheses of problem explanations. As-built plans and district design files may be in either system. SI (metric) units were excluded from figures to present an uncluttered appearance. Figures A-1 through A-6 are problem-specific, and they are not standard plans or standard drainage details. Because there are many variations of layers, rock sizes, and geotextile (RSP-fabric) or granular filter, generic concept cross-sections are provided as Figures A-7 (embedded toe), A-8 (mounded toe), and A-9 (concreted-RSP). There are no standard plans of RSP.

For armoring banks, there are other materials and configurations with different degrees of flexibility and responses to scour. Some are: vegetated riprap, gabions, articulated concrete blocks (ACB) cabled and not cabled, interlocking concrete blocks, and concrete-filled fabrics. Example problems and discussions for such materials are beyond the scope of Appendix A.

Problem A-1 Impinging Flow. Along a rural highway 250 feet (76.2 m) of embankment length and portions of roadway shoulder were washed away. There was a landslide (nearby, upstream) during the runoff event. There are alternate routes, so the situation did not qualify as an emergency. A signal for one-way traffic was set up. Investigate and develop a design for the bank protection.

Solution.

1 (Chapter 5, Section 5-1-A). As-built plans show that the roadway/riverbank was armored with a layer of *Backing No. 1* RSP (Method B), 1.8 feet thick (550 mm), face slope angle 1.5H:1V. The toe was embedded 4 feet (1.2 mm) below the riverbed, and there was a graded gravel filter 8-inches (200 mm) thick under the Backing No. 1. In plan view, the river and road are on a large radius curve with tangent reaches upstream and downstream. Because of the landslide, a new river survey (cross sections, longitudinal slope) was done, and the data were used in a hydraulic model. Using a Q50 flow rate as the design event, the revised high water depth of the design event is 13 feet (3.96 m). The full channel depth is 15 feet (4.57 m), a few feet lower than the edge of shoulder. The new average velocity in the approach channel upstream of the curve and adjacent the landslide is 11.5 fps, feet per second (3.51 m/s). Calculated scour is about 5.5 feet (about 1.7 m).

2 (Chapter 5, Section 5-1-B).

2a Field review during low flow revealed the following information. The failed zone is opposite and downstream of the landslide on the outside of the curved reach (bend), where the Backing No. 1 and gravel filter washed away and are not visible. Both upstream and downstream of the failed zone, Backing No.1 is OK at 1.5 H:1 V. The exposed roadway embankment is sand and silty sand. Several silt-filled residual scoured zones along the toe of failed bank were probed with a 6-foot length of rebar. Rocks and gravel were felt about 4 feet (about 1.2) below the river bed, which suggests the remains of the revetment. In plan view, the flow will impinge at design depth. Silt stains on nearby trees and drift upstream (debris, mostly dead wood) show that the river crested at about 12 feet of depth.

2b The designer consulted with local residents and the Caltrans maintenance crew. The water depth rose gradually and then stayed steady at about 12 feet (3.65 m) for several hours. Then the landslide occurred and the bank failed shortly afterwards. The toe, middle, and upper bank and portions of road shoulder gradually sloughed into the river and washed away, along with some of the landslide material. Apparently, the velocity increased due to the landslide, such that the Backing No. 1 RSP throughout the bend and in the toe was not large (massive) enough to resist the erosive force of flowing water.

2c A Fish and Game biologist stated that the river has a fall salmon run. They advise no channel leveling and not removing any landslide material. The construction window (time frame for construction) is from July 1 to September 30.

2d Hydrologic and hydraulic records were checked and they show that flow is from spring snowmelt and rain runoff. There are no dams upstream.

3 (Chapter 5, Section 5-1-C). Find the minimum stable stone weight using Equation 1, US customary units. For an SI (metric) solution, first solve Equation 1 in US customary units, then soft-convert W to a metric value.

Equation 1. $$W = \frac{0.00002 \quad SG \quad V^6}{(SG - 1)^3 \quad SIN^3 (r - a)}$$

3a Increase the velocity for impinging flow: V = 4/3 x 11.5 fps = 15.33 fps

3b Assume rock specific gravity SG = 2.65

3c Angle a = arc tan (1/1.5) = 33.69 degrees. Angle r= 70 degrees.

3d Minimum stable stone weight W = 738 pounds (335 kg)

4 (Chapter 5, Section 5-1-D). See Table 5-1 "Guide for Determining RSP-Class of Outside Layer." Enter left side of table (row labels are standard rock sizes).

4a select ½ ton (450 kg), the closest heavier standard rock size greater than the minimum stable stone weight of 738 lbs (335 kg),

4b trace horizontally to the right and locate the "50-100" percent entry,

4c trace vertically upward and read column headings: 1/2 ton ***(1/2 T)***. Use this as the "first trial" RSP-Class.

4d District Hydraulic Engineer checks as-built plan, profile, and typical sections. A layered 1/2 ton RSP-Class facility was built on a nearby bend in the river with similar geometry about 7 years ago. That site was not seen during field-review, however, a call to the roadway Maintenance Engineer verified that it is OK and was not damaged during the recent event. So, the "first trial" outside layer RSP-Class is OK, and no further trials are needed.

5 (Chapter 5, Section 5-1-E). Using Table 5-2 "California Layered RSP", in column labeled OUTSIDE LAYER RSP-CLASS locate 1/2 ton entry. Read entries to right:

- 5a **NONE** in column labeled INNER LAYERS RSP-CLASS means no INNER LAYERS are required.
- 5b **1** in column labeled BACKING CLASS No. means a layer of *Backing No. 1* is required.
- 5c **B** in column labeled RSP-FABRIC TYPE means TYPE B RSP-fabric is required.

6 (Chapter 5, Section 5-1-F). Using Table 5-3 "Minimum Layer Thickness" in column labeled "RSP-Class Layer" notice there are two entries for 1/2 ton. Select **B** as "Method of Placement." The slope angle is not too steep for angular rock, and although Method B gives a thicker section, the unit cost is usually less by Method B than by Method A.

- 6a "Minimum Thickness" of 1/2 ton (1/2 T) is **4.3 feet (1.31 m)**.
- 6b next in column labeled "RSP-Class Layer" locate the only ***Backing No. 1*** entry. **B** is Method of Placement. Minimum Thickness is **1.8 feet (550 millimeters)**.
- 6c Add layers. Total RSP thickness normal to slope is **6.1 feet (1.86 meters)**. *Total base width (footprint)* is 11 feet (3.35 m). See Figure A-1 for cross section geometry and trigonometric expression for determining *total base width*.
- 6d The recommended vertical limit of RSP is 15-feet (4.6 m), the sum of calculated high water of the design event (13 feet, 4 m) and RSP-freeboard (2 feet, 0.6 m). The 2-feet (0.6 m) of RSP-freeboard is reasonable, due to likely super-elevated water surface around the bend (calculation not shown), surface waves, floating debris impacts at top of bank, and uncertainties in hydrology and hydraulic calculations. The recommended EMBEDDED depth is 6 feet (1.8 m) below the riverbed. This is reasonable, because the (rebar-probed) residual scour holes were about 4 feet (1.2 m) deep, and calculated scour was about 5.5 feet (1.7 m). Type B RSP-fabric (anchored at its top or pinned to slope) is recommended under the *Backing No. 1*. No RSP-fabric should be exposed in the riverbed.
- 6e An alternative for addressing toe scour is the MOUNDED toe. A toe trench is not excavated, and instead, a mound of rock is built directly on the riverbed, with only a short section of RSP-fabric underneath (see Figure A-2 or A-8). As the riverbed material is scoured away and transported downstream, some “mounded toe” rocks are also likely to wash away, while others will launch (drop) into the scour hole, thereby armoring the hole and arresting further scour. The minimum recommended thickness is 1.5 times the D50 of the RSP OUTSIDE layer, and the maximum height is DM, the embedded depth of Figure A-1. In this example, the mound of 1/2 ton *(1/2 T)* RSP is placed as shown in Figure A-2 with the same slope face angle as the RSP, 1.5H:1V. Figure A-8 has generic dimensions.
- 6f Different dimensions can be used for the MOUNDED toe.
  - (6f1) Maximum height of the mounded toe is DM, the EMBEDDED depth in step 6d above. A toe height greater than DM is not recommended. There must be enough rock in the mound that can launch, so that the main section of revetment does not launch. Minimum thickness of mounded toe is 1.5 D50 outside RSP layer.
  - (6f2) Initial base width = outside RSP layer thickness / sin (slope angle) and slope angle = arc tan (V/H), angle a in Figures 5-1 and 5-2.
  - (6f3) MOUNDED area = Initial Base Width x DM
  - (6f4) Establish minimum Toe Height = 1.5 D50 outside RSP layer.
  - (6f5) Establish a maximum Base Width = MOUNDED AREA / minimum TOE height
  - (6f6) Select a new Base Width or a new toe height, then divide the

MOUNDED AREA by the selected dimension, keeping within limitations of 6f1, 6f4, and 6f5. Maintain the as-designed slope face angle used in Equation 1.

The procedure of step (6f6) is repeated until the geometry of the MOUNDED toe is OK as demanded by river hydraulics (see step 10 of this problem) and by permit agencies. Monitor after large magnitude runoff events. Additional rock may be needed. See additional topic **A-6.2. Mounded Toe** and Figure A-11.

6g In this problem, the ends of RSP will be joined to existing RSP upstream and downstream, and the same cross sectional thickness is constructed for the entire length of the facility. That is, the reconstructed layer of Backing No. 1 layer will be flush with the existing upstream and downstream Backing No. 1 and the 1/2 ton layer will protrude (see Figure A-10, case 1, protruding revetment).

Flank treatments, also called cutoffs or leading and trailing edges, comparable to cutoff walls, might be needed in other situations. For the upstream flank (leading edge) HEC-11 (1989 edition, Reference 12 pages 42 and 43) suggests in longitudinal profile, a rock stub at least 5-feet deeper than T (total revetment thickness including backing layer) by 1T wide. An additional section of revetment is extended 3T upstream. The depth of the downstream flank (trailing edge) is 2T with a base width of 3T. Site-specific conditions may demand more or less of a cutoff with different geometry, for example, see Photo C-77 and caption. Where there is bedrock or an outcrop, build the revetment right up to the naturally stable material. For example, see Photos C-17, C-81, C-83 and their captions.

7 Materials engineer tests rock sources and finds specific gravity of rock is between 2.60 and 2.70, which brackets the assumed value of 2.65. Thus, it is OK to use Minimum Thickness values from step 6 (Table 5-3) above. For RSP-Classes larger than 1 ton *(1 T)*, the thickness values may need to be recalculated if specific gravity is much greater than 3.50, otherwise thicknesses in Table 5-3 should be OK, considering the 1-foot slope tolerance (see topic A-7, RSP Tolerance). Other quality requirements of Section 72-2.05 (1995 CA Standard Specifications) were found to be OK.

8 Recommended cross section is Figure A-1. In a letter to the pending resident engineer's file, state that the contractor can salvage clean *Backing No. 1* within plan view limits of failed embankment and proposed toe excavation, and not beyond.

9 There was no significant prior vegetation on the failed bank, nor immediately upstream or downstream. Therefore, no revegetation is required at this site.

10 (Chapter 5, Section 5-1-G). If the design of Figure A-1 is rejected, then Figure A-2 can be submitted. Re-calculate river hydraulics with appropriate cross section and future roughness values, assuming the alternate cross section of Figure A-2. Determine if the proposed alternate cross section would significantly increase channel velocity or reduce the hydraulic capacity. Discuss the proposed designs with engineers and biologists of the permit agency. Some sort of toe is needed. Emphasize that the bank originally failed because the riprapped toe was not adequate, due to altered river channel conditions (the landslide material redirected flow and impinged on the bank). Also, in the permit proposal, submit a sketch showing a temporary berm and geomembrane, or other dewatering scheme, which will keep any flowing, low-stage river water from getting into the construction zone. Clearly state in the permit application that the dewatering berm

will be removed to just slightly above the existing water elevation, such that no berm sediment is further stirred up by construction activities and washed into the river.

Problem A-2 Parallel Flow. In a suburban setting, formerly rural, flood waters carrying large amounts of natural debris caused the loss of 150 feet of riprapped streambank, shallow-rooted trees, and portions of road shoulder. Repairs and replanting are required. Investigate and recommend RSP designs.

Solution.

1 (Chapter 5, Section 5-1-A). As-built plans and design records show that the site has parallel flow. For the design event, mean channel velocity is 21.5 fps (6.55 m/s) and stage is near full channel depth of 20 feet.

2 (Chapter 5, Section 5-1-B)

- 2a Field review at site revealed coarse sand, gravel, and rounded cobbles as streambed. Calculated scour is 10 feet (3.05) meters. Flow is parallel to bank for full range of depths. Previous bank protection was *Facing* (same as *Backing No. 1*) and only extended 3/4 of the full channel depth (3/4 of 20 = 15 feet).
- 2b Consulted with residents, maintenance, wardens, biologists, and engineers of permit agencies. Stream flows year-round and is stocked with trout.

3 (Chapter 5, Section 5-1-C). Find the minimum stable stone weight using Equation 1, US customary units. For an SI (metric) solution, first solve Equation 1 in US customary units, then soft-convert W to a metric value.

Equation 1. $$W = \frac{0.00002 \quad SG \quad V^6}{(SG - 1)^3 \quad SIN^3 (r - a)}$$

- 3a Road embankments upstream and downstream of failed bank are OK at **1 vertical to 2 horizontal**. Replace RSP at same slope face angle.
- 3b Use decreased velocity for parallel flow condition: 2/3 x 21.5 = 14.3 fps
  - 3c Assumed rock specific gravity = 2.65
- 3d Minimum stable stone weight W = 310 pounds (141 kg)

4 (Chapter 5, Section 5-1-D). See Table 5-1 "Guide for Determining RSP-Class of Outside Layer." Enter left side of table (row labels are standard rock sizes).

- 4a Select 1/4 ton (220 kg), the closest heavier standard rock size greater than the minimum stable stone weight of 310 lbs (141 kg)
- 4b Trace horizontally to the right and locate the "50-100" percent entry,
- 4c Trace vertically upward and read column heading = 1/4 ton ***(1/4 T)***. Use this as the "first trial" RSP-Class.
- 4d Field information from nearby site indicates that 1/4 ton is OK there. District hydraulic engineer confirms 1/4 ton RSP-Class will be OK, based on nearby site that also failed recently due to undersized RSP-Class = *Facing*, (maintenance was doing frequent minor bank repairs). Use 1/4 ton for the OUTSIDE LAYER RSP-Class, no further trials are needed.

5 (Chapter 5, Section 5-1-E). Using Table 5-2 "California Layered RSP", in column labeled OUTSIDE LAYER RSP-CLASS locate 1/4 ton entry. Read entries to right:

- 5a **NONE** in column labeled INNER LAYERS RSP-CLASS means no INNER LAYERS are required.
- 5b **1 or 2** in column labeled BACKING CLASS No. means a layer of *Backing No. 1 or Backing No. 2* is required. Select *Backing No. 2*, available at quarry.

5c **A** in column labeled RSP-FABRIC TYPE means TYPE A RSP-fabric is required. Note: Consider specifying 200 mm of *Backing No. 3* instead of TYPE A RSP-fabric. See also **Graded Gravel Filter Layer** after section 6e on page A-10.

6 (Chapter 5, Section 5-1-F). Using Table 5-3 "Minimum Layer Thickness" in column labeled "RSP-Class Layer":

6a locate 1/4 ton entry, then read entries to right: **B** is "Method of Placement" and 3.3 feet (1.00 m) is "Minimum Thickness".

6b next in column labeled "RSP-Class Layer" locate the only ***Backing No. 2*** entry. **B** is "Method of Placement" and "Minimum Thickness" is **1.25 feet (380 millimeters)**.

6c Add layers, TOTAL THICKNESS normal to slope is **4.55 feet (1.38 meters)**.

6d See Figure A-3. Based on scour calculations, toe trench should be 10 feet (3.05 m) below streambed. One possible cross section is Type A RSP-fabric, *Backing No. 2,* and 1/4 ton RSP in toe trench, up roadway/streambank to full channel depth. Notice that additional RSP-fabric is included as a "soil brake" to limit the downward movement of cover soil and its possible leaching into the stream due to fluctuating water stages. The "soil brake" RSP-fabric should be placed no lower in elevation than "high water," and it may be placed higher. Note that “high water” is a term used relative to this problem and it more closely matches the elevation at which no (permanent) vegetation grows below. Some people may call this “annual high water” and it may vary from reach to reach on the same stream and among streams in similar but different watersheds, therefore, assigning or determining an exact design recurrence interval for this elevation is not recommended, as it tends to be copied for different streams.

6e To accommodate possible tree species higher up the bank with deeper root systems than typical riparian species, an alternative cross section with *Backing No. 3* is shown in Figure A-4. Specify 0.75 feet (230 mm) of angular to subangular *Backing No. 3* on typical cross section of contract plans. Write a note and place it in the pending Resident Engineer's file: "Reject *Backing No. 3* if it is rounded river-run, because the 1V:2H slope is too steep. Subangular rock shapes would be OK." See Reference 57 for standard description of particle shapes. A re-design would be needed using a slope of 2.5H:1V or flatter, which is a stable slope for rounded rock shapes. The "soil brake" RSP-fabric is still needed.

Graded Gravel Filter Layer (may also be called a granular filter). It is recommended that the designer use the Terzaghi filter design criteria (a set of mathematical inequalities), before Backing No. 3 or any other gravel mixture is specified as a graded gravel filter layer, instead of RSP-fabric. To design a graded gravel filter layer (or layers), the local bank soil (assumed to be sand or sandy soil) must be sampled and submitted to a soil testing lab. The bank soil, Backing No. 3, and proposed gravel source materials, must be sampled and submitted for mechanical analysis. Results are needed from Test Method Numbers CA 202 and CA 203, so particle size distribution curves can be drawn. For each material, key values of particle sizes are determined from its particle size distribution curve, and those values are substituted in the inequalities. Alternatively, experienced staff can field-determine particle sizes of the bank soil, Backing No. 3 and proposed gravel sources, and then estimate the key values required for the inequalities. For clarification, consult with District Materials and/or geotechnical engineering staff.

The mathematical inequalities establish whether the underlying sandy soil will "pipe", that is, pass through voids in the layer above it, or whether the soil will "bridge", that is, form a filter, so that water passes through voids and the (bank) soil particles (grains) are retained in a boundary layer. An unacceptable granular filter can lead to settlement and/or clogging of the soil, and ultimately, to the failure of the revetment.

From the particle size distribution curves of bank soil and Backing No. 3., the following values are needed : D15, D50, D85. These values are substituted in the mathematical inequalities (the Terzaghi filter criteria, or simply filter criteria), as documented in HEC-15 (1988 edition, pages 19 and 20 "Filter Design") or HEC-15 (2005 edition, pages 6-15 – 6-17, "Riprap Filter Design"). The 1988 SI (metric) edition shows the same inequalities and limiting values. Pay attention to the terminology. "Filter" and "upper" refer to the overlying material and "base" and "lower" refer to the underlying material, for each layer. The filter criteria are :

(D15 filter / D85 base) < 5
5 < (D15 filter / D15 base) < 40
(D50 filter / D50 base) < 40

The above criteria must be validated between the Backing No. 3 and the bank soil. If the mathematical inequalities are not satisfied, then "another layer" (of cohesionless granular material) must be located, and after its particle size distribution curve is established, the mathematical inequalities must be reformulated and tested, so that both sets of materials pass the inequality tests. For example :

(D15 another layer / D85 bank soil) < 5
5 < (D15 another layer / D15 bank soil) < 40
(D50 another layer / D50 bank soil) < 40

and

(D15 Backing No. 3 / D85 another layer) < 5
5 < (D15 Backing No. 3 / D15 another layer) < 40
(D50 Backing No. 3 / D50 another layer) < 40

7 Materials engineer tests sources and confirms assumed specific gravity of rock was OK, results ranged from 2.6 to 2.8. Actual shapes and other quality requirements are OK.

8 Recommended cross section is Figure A-4, toe trench 10 feet (3.05 m) deep.

9 (Chapter 5, Section 5-1-G). Re-calculate stream hydraulics. Discuss with permit agencies. For permit, propose building a temporary rock berm with a geomembrane for dewatering to facilitate excavation of the toe trench. Include removal of the dewatering berm to an elevation immediately above the existing water level.

10 Hydraulic calculations were redone for future mature vegetation and found to be OK. For the upper 8-foot zone of the reconstructed RSP above high water, fill voids and cover the 1/4-ton RSP with a layer of cover soil, minimum 4-inches (102 mm). Revegetate with grass, shrub, and tree species similar to those upstream and downstream. Consult with an erosion control specialist (licensed and experienced landscape architect) or botanist for appropriate species. None of the cover soil or plants are placed lower than "high water," roughly the annual observed elevation that persists from January through the end of March (**for this site in this hypothetical problem**), because even minor floods above the "annual event" would thereby create a sediment nuisance in spawning beds. At other sites there may be different definitions or ways of determining "annual high water."

Problem A-3 Concreted-RSP. At a stream crossing, both approach roadways washed out and an old spread footing centerspan pier foundation failed due to debris impact. A new bridge must pass 17,000 cfs (481.4 cubic meters / second) with Redwood debris. The roadway is "sole access" for law enforcement and emergency vehicles to several communities and ranches. The shortest duration alternate route would take 2 hours longer than if the road and bridge were passable. Although the new bridge will have deep pile foundations, the roadway must not be "sacrificed." Therefore, both abutment fills must be armored. The channel cross section under new bridge will be trapezoidal with 1V:1.5H side slopes. Design depth is 14 feet with 2 additional feet to pass debris (trees and shrubs) under the bridge. The channel bottom must be kept as a natural sandy bottom. Because the channel is on a bend, flow impinges, and with the likelihood of debris and an historically unstable thalweg, both abutment fills will get the same protection. Average approach velocity is 13 fps (3.96 m/s).

Solution. First follow steps 1 through 8, similar to Problem A-1. Determine the RSP-Classes for a layered flexible-RSP revetment. For this problem, suppose step 8 produced a cross-section similar to Figure A-3, with the following layers for one abutment fill :

RSP-Class and Method	thickness in feet (m)
1 ton (1T), B	5.4 (1.65 m)
Light (Light), B	2.5 (0.76 m)
Type B RSP-fabric	---
Total thickness normal to slope	7.9 (2.41 m)

Total base width 14.24 feet (4.34 m), and for both sides, 28.48 feet (8.68 m).

9 As recommended in Chapter 5, Section 5-1-G, a recalculation of stream hydraulics determined that the above layered cross section (for both abutments) constricts flow and increases velocity. Thus, the above flexible-RSP design is rejected. Concreting the rocks of the outside layer will reduce the total thickness of the revetment.

9a To arrive at a standard rock size for the outside layer of concreted-RSP, divide the standard rock size of the flexible-RSP outside layer by 4 or 5. The division factor 4 or 5 is based on observations, where concreted-RSP broke into sections that contained 4 or 5 individual rocks. Use the reduced standard rock size as the basis for selecting inner layers. Note that inner layers are not concreted.

9a1) flexible-RSP outside layer is 1 ton = 2000 lb.

9a2) 2000 / 4 = 500 lb, 500 lb = 1/4 ton.

9b Use Tables 5-2 and 5-3 for required layers and minimum thicknesses. Result is 1/4 ton (1/4 T), Backing No. 2 (Backing No. 2), both Method B, and Type A RSP-fabric. [The decreased channel width and velocity were found to be OK. Calculated scour depth is 12 feet (3.65 m)].

9c Figure A-5 is the recommended typical cross section.

10 See Figure A-6, Construction Notes for Concreted-RSP.

10a For concreted-RSP weep pipes are needed. Alternatively, concrete may be omitted at regular intervals. It is necessary to drain water from the backslope, especially in streams with rapidly rising and falling stages. Water filters through the RSP layers and gets into the bank soil during the rising limb of the hydrograph, and it seeps back into the stream during the receding limb.

10b Construction notes are presented in Figure A-6. Those or similar notes should be included in contract plans on a cross-section detail sheet. The following comments supplement notes A through G, respectively.

10b 1) Place Backing No. 2 and 1/4 ton RSP both by Method B. Construct rock in lifts that do not exceed 2 meters (6 feet) then place concrete (see also 10b 3) below).

Typical construction is from low-to-high elevation. Place weep pipes as the layered cross section is built. Just butt the weep pipes up against the RSP-fabric. Do not punch the weep pipes through the RSP-fabric, because bank soil will ultimately pipe away, leaving voids and the likelihood of bank failure.

10b 2) When perforated weep pipes are used, concrete must be prevented from passing through the perforations and clogging the pipes, so wrap newspaper or a piece of RSP-fabric around the pipe. Do not use waterproofed paper.

10b 3) The resident engineer has authority to control water content of the **concrete** mixture. Concrete is placed. If there is excess water, the mixture will pour or flow, in which case it is really grout. A common misnomer is "grouted- RSP". The contract pay item is **concreted-RSP**. Concrete will normally fill voids by gravity, however, it may need to be broomed, tamped, spaded, rodded, or vibrated. It is too wet if it slumps beyond the theoretical "concrete limit line" as shown in Figures A-5, A-6, and generic Figure A-9. To prevent concrete from oozing out at the bottom of the slope, limit concrete placement to 2 meters (6 feet) or less vertically. Until the Caltrans Standard Specifications section 72-5.04 is revised to show 6 feet instead of 10 feet, a special provision may be needed.

10b 4) Rocks of the outside layer must protrude beyond the "concrete limit line" so that rocks protrude about (1/5 Tout), thereby creating a rough surface for dissipating energy and decreasing velocity. When excess concrete is allowed past the "concrete limit line," it produces a smoother surface. Also, excess concrete can delay or preclude the cross-section from ever fracturing and creating large pieces of concreted-rock, as this kind of design originally intended. Alert the contractor that excess concrete will not be paid for.

10b 5) Similar to step 10b 1), placing concrete should progress from low-to-high elevation, roughly along contours. Section 72-5.04 (1995 Caltrans Standard Specifications) states: "In no case shall the concrete be permitted to flow on the slope protection a distance in excess of 3 m." Vertical progress should be limited to 2 meters (6 feet), while roughly following a contour. Cold joints are OK. Again, if the mixture really flows, it is too wet, and it is a grout, not concrete.

10b 6) After concrete has cured at least 1 day, cut the weep pipes on the stream-side so they are flush with the revetment, and so they do not protrude more than 1 foot.

10b 7) Whenever possible, it is important to replace the natural materials of the streambed, in a way that nearly replicates the prior condition. Fish passage must not be restricted by any aspect of the completed job. Any revegetation effort should be directed away from the "hydraulic opening" of the bridge, that is, do not plant on the abutment fills under the bridge and through the waterway cross sectional area limits. Typically, most vegetation that volunteers under bridges is transient, and it will be swept away during high stage, high velocity events, and subsequently, it will likely regenerate naturally.

Note. Problem A-3 omitted how to estimate concrete volume. See Additional Topic **A-5.3. Estimating Concrete Volume** and the updated generic Figure A-9.

Figure A-1 RSP Toe EMBEDDED Below Riverbed

Problem 1 Typical Cross Section No Scale US units Not a Standard Plan

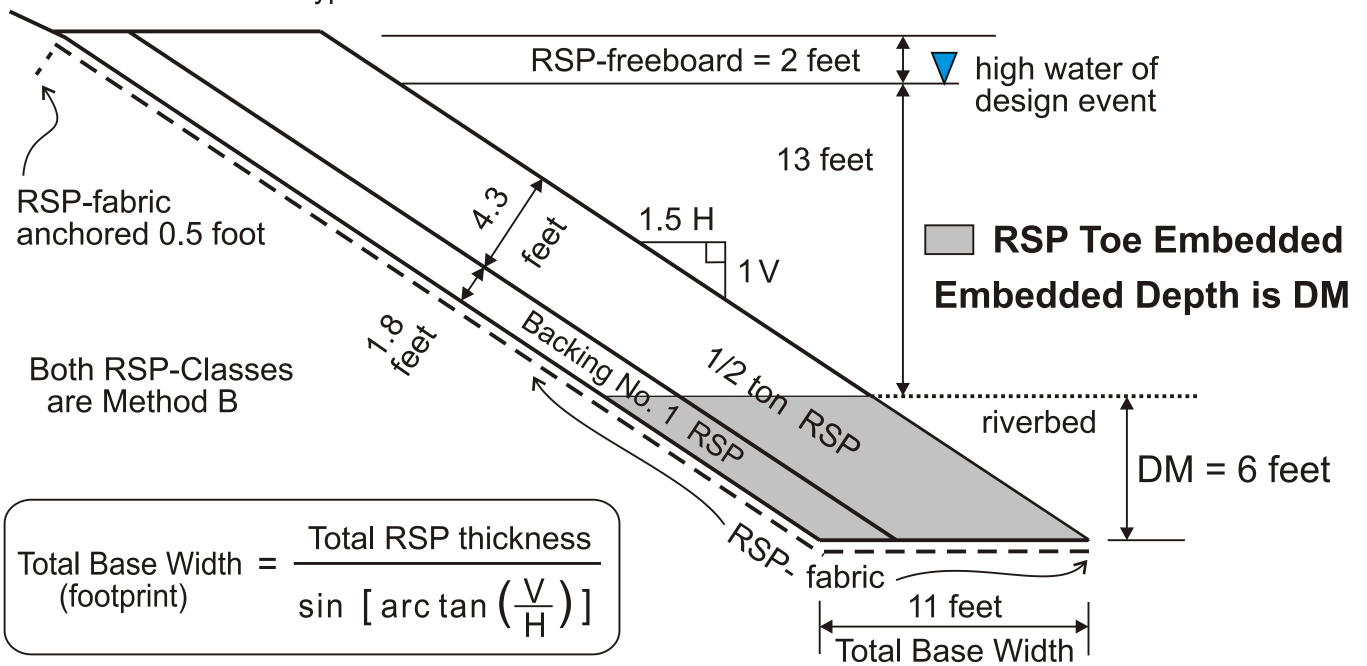
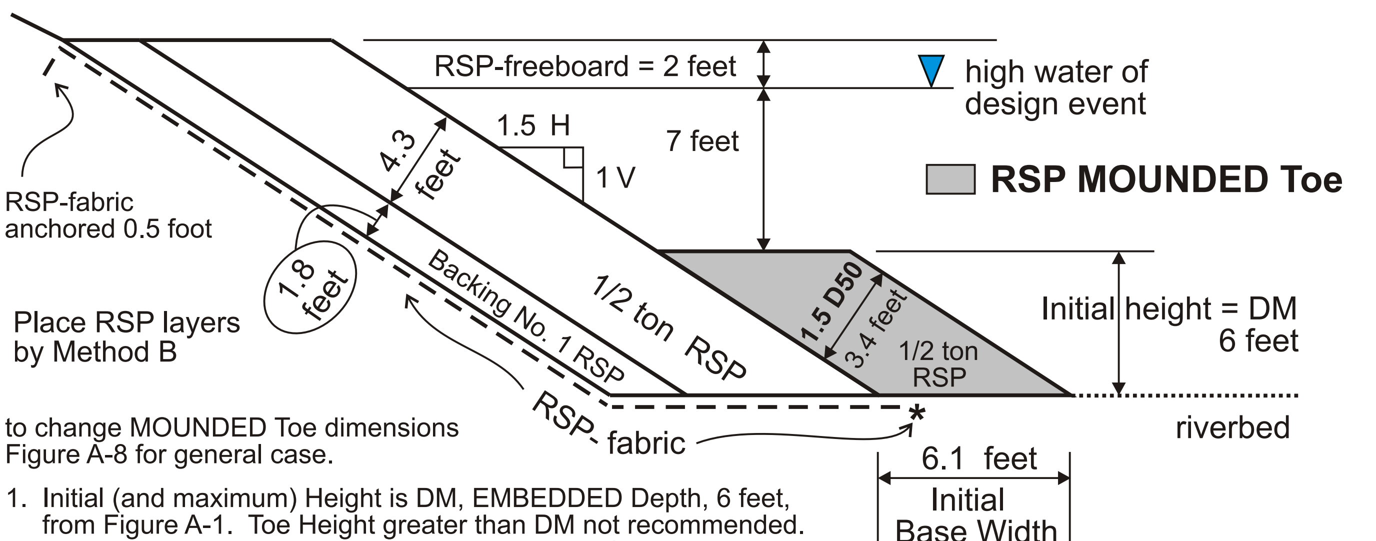


Figure A-2 RSP Toe MOUNDED on Riverbed

Problem 1 Alternate Cross Section No Scale US units Not a Standard Plan



to change MOUNDED Toe dimensions
Figure A-8 for general case.

1. Initial (and maximum) Height is DM, EMBEDDED Depth, 6 feet, from Figure A-1. Toe Height greater than DM not recommended. Minimum mound thickness is 1.5 D50 outside RSP layer.
2. $$\text{Initial Base Width} = \frac{\text{minimum mound thickness}}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]} = \frac{3.4}{0.555} = 6.1$$

* extend RSP-fabric about 10 to 20 % of Base Width under mounded toe

3. MOUNDED AREA = Initial Base Width x DM = 6.1 feet x 6 feet = 36.6 sqft
4. Establish minimum Toe Height = 1.5 D50 outside RSP layer D50 ½ ton = 2.26 feet 1.5 x 2.26 = 3.4 feet
5. Establish maximum Base Width = MOUNDED AREA / minimum TOE height 36.6 / 3.4 = 10.8 feet
6. Within limitations of steps 1, 4, and 5, select either a new Toe Height or a new Base Width, then divide MOUNDED AREA by selected dimension. Maintain slope face angle used in Equation 1. Example, select new Base Width = 7.0 feet, 36.6 / 7 = 5.2 feet as new Toe Height

Figure A-3 Layered RSP With Cover Soil

Problem 2   Typical Cross Section   No Scale   US units   Not a Standard Plan

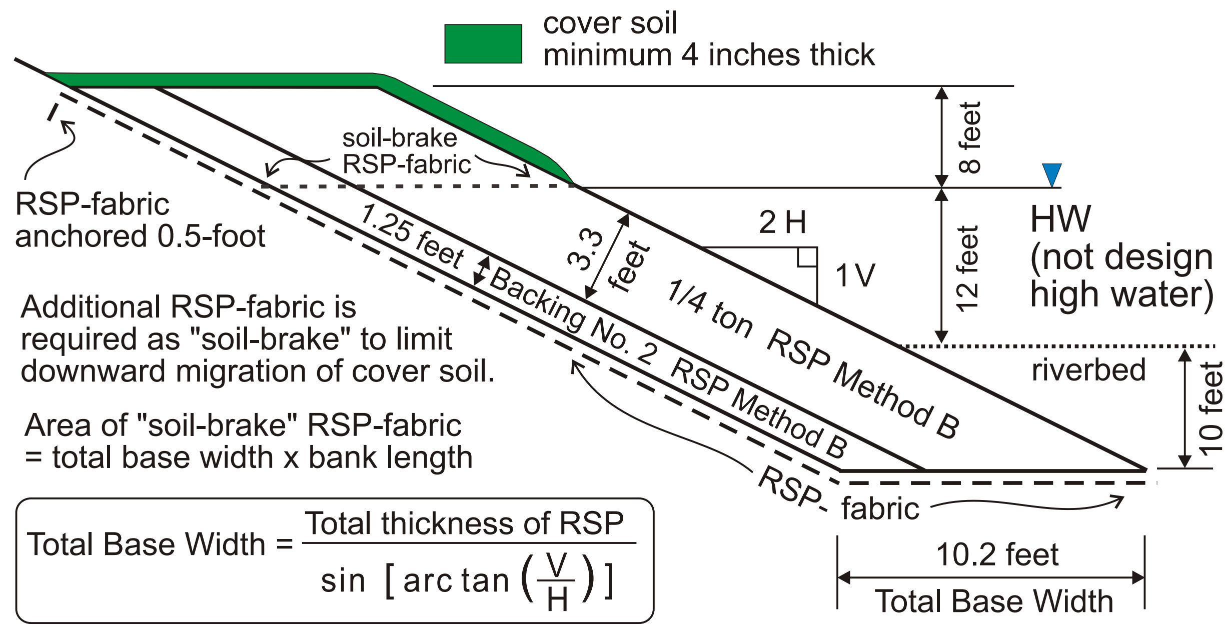


Figure A-4 Alternate Layered RSP With Cover Soil

Problem 2   Typical Cross Section   No Scale   US units   Not a Standard Plan

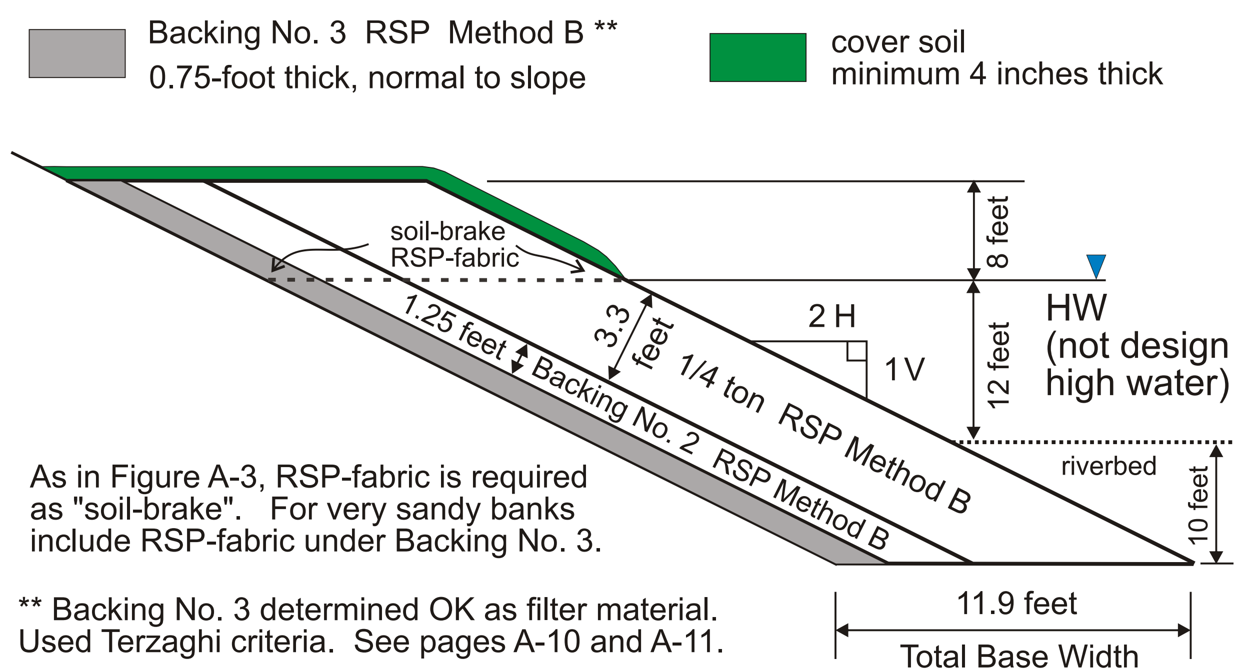
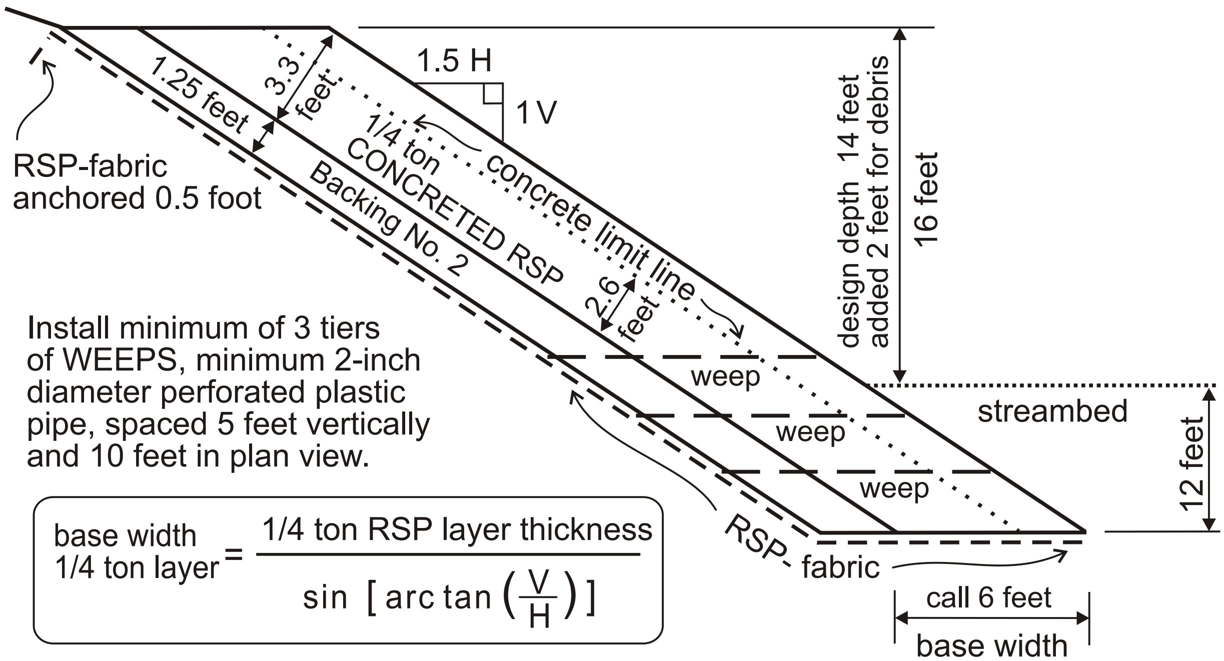


Figure A-5. CONCRETED-RSP with EMBEDDED Toe

Problem A-3   Typical Cross Section   No Scale   US units   Not a Standard Plan



$$\text{base width 1/4 ton layer} = \frac{\text{1/4 ton RSP layer thickness}}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$$

See Figures A-7 and A-9 and all the "Additional Topics" that are cited. Also see topic 5.3 "Estimating Concrete Volume".

Figure A-6 Construction Notes for Concreted-RSP

Problem A-3   Typical Cross Section   No Scale   US units   Not a Standard Plan

A. Backing No. 2 and 1/4 ton RSP both placed by Method B, see Figure A-5

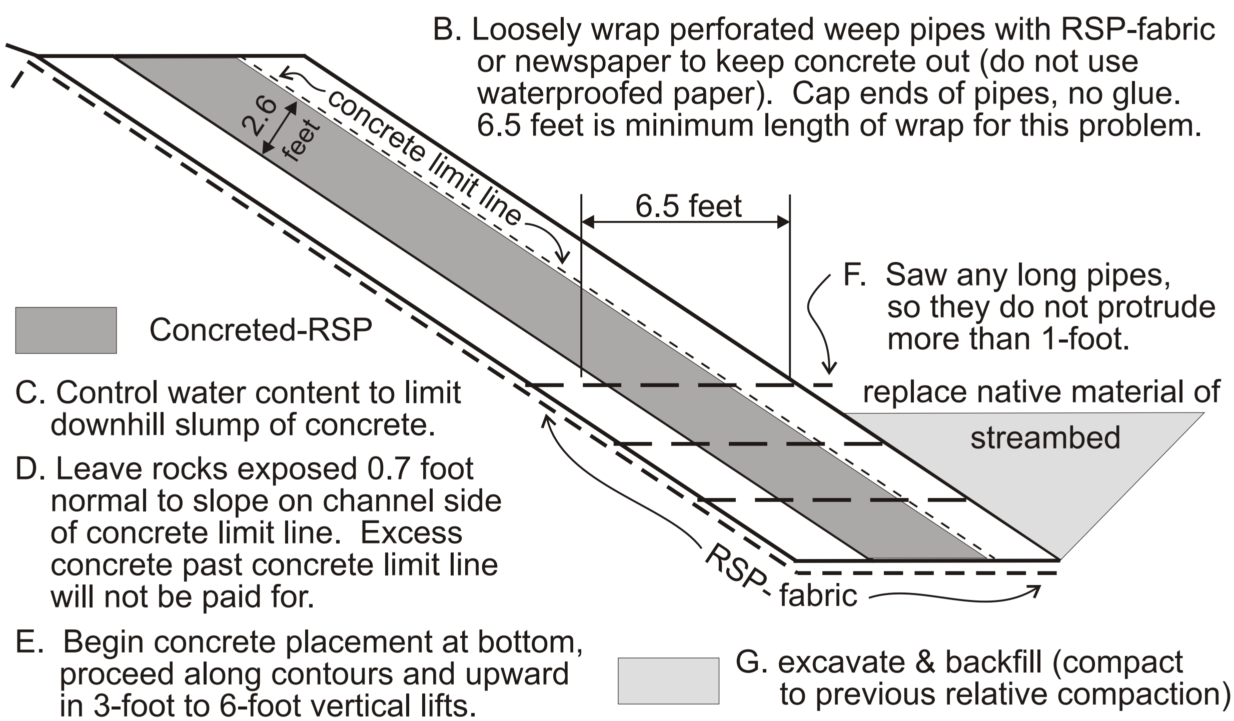
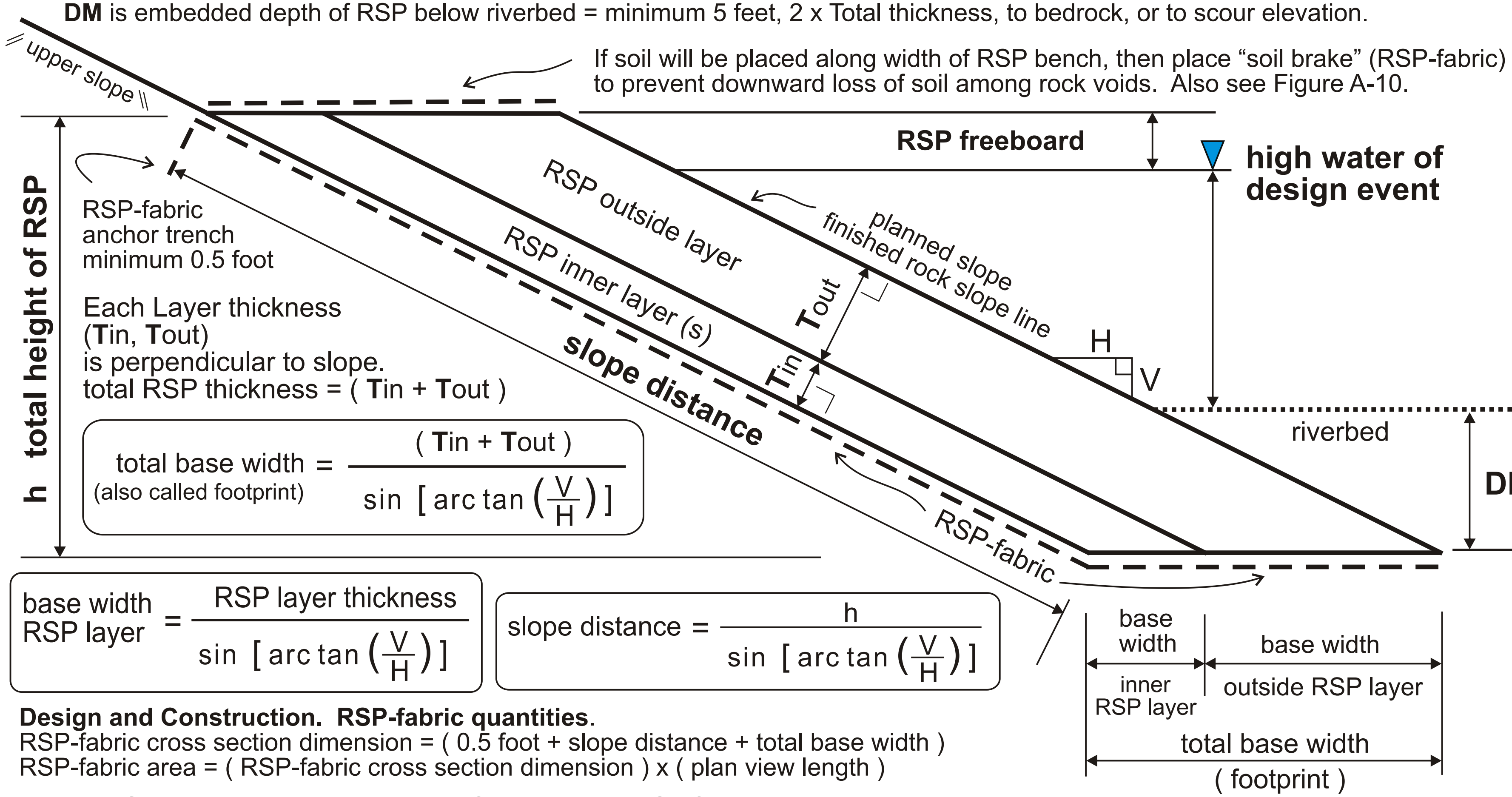


Figure A-7. CA Layered RSP with EMBEDDED Toe Cross-section No Scale US units Not a Standard Plan

Elevation limit of RSP = (calculated high water of design event + RSP freeboard) or site specific per hydraulic engineer.
Check with flood control district, bridge designers, and others about other freeboard dimensions and where measured.

DM is embedded depth of RSP below riverbed = minimum 5 feet, 2 x Total thickness, to bedrock, or to scour elevation.



total base width (also called footprint) $= \dfrac{(\text{Tin} + \text{Tout})}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$

base width RSP layer $= \dfrac{\text{RSP layer thickness}}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$

slope distance $= \dfrac{h}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$

Design and Construction. RSP-fabric quantities.
RSP-fabric cross section dimension = (0.5 foot + slope distance + total base width)
RSP-fabric area = (RSP-fabric cross section dimension) x (plan view length)

Design. Cross section has precise lines for calculating RSP-fabric area and rock volume.
To measure and pay by weight (mass), reduce volume (in-place, on slope) by void volume, see "Additional Topics" A-5.2.1 Porosity.

Construction. For laying-out and inspecting layer dimensions, see "Additional Topics" 5.1.2. Construction Notes on Volume.
For rock weight, collect weigh slips and tally. Verify RSP-class, see "Additional Topics" A-4 Verifying Individual Rock Weights and RSP-class (Gradation) and sub-topics, A-5.2.1 Porosity, and A-5.2.2. Construction Notes on Weight and sub-topics.

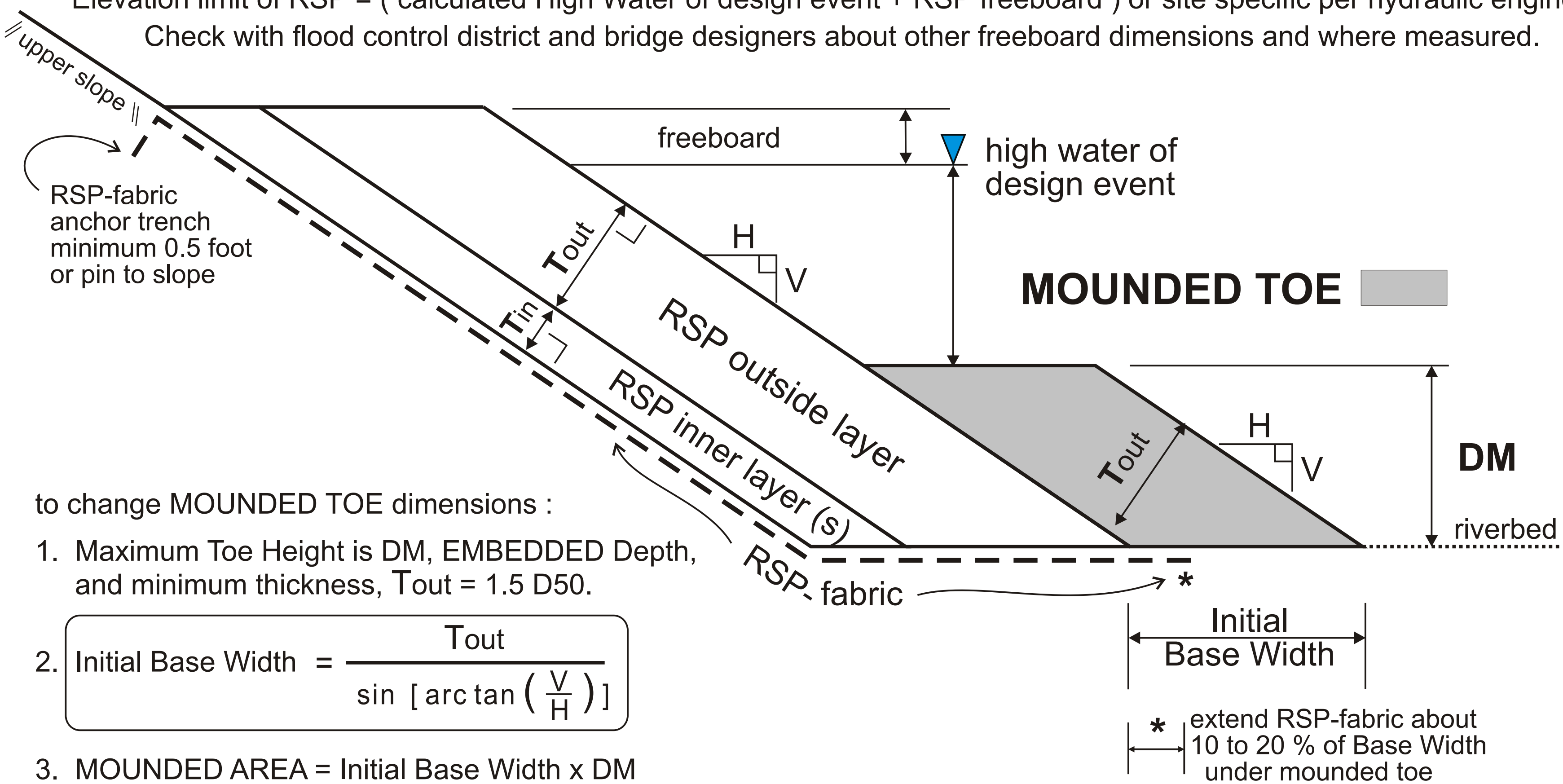
Flank treatments (RSP leading and trailing edges) have specific geometry per **design** or modified in **construction** to fit site conditions.
Need separate details and calculations for flank treatments. Tie to stable natural rock formations when possible. Also see Figure A-10.

Figure A-8. CA Layered RSP with MOUNDED Toe

Cross-section No Scale US units Not a Standard Plan

Design and construct a mounded toe when an embedded toe is not feasible or not permitted.
The magnitude of DM = minimum of 5 feet, 2 x Total thickness, riverbed to bedrock, or to scour elevation.

Elevation limit of RSP = (calculated High Water of design event + RSP freeboard) or site specific per hydraulic engineer.
Check with flood control district and bridge designers about other freeboard dimensions and where measured.



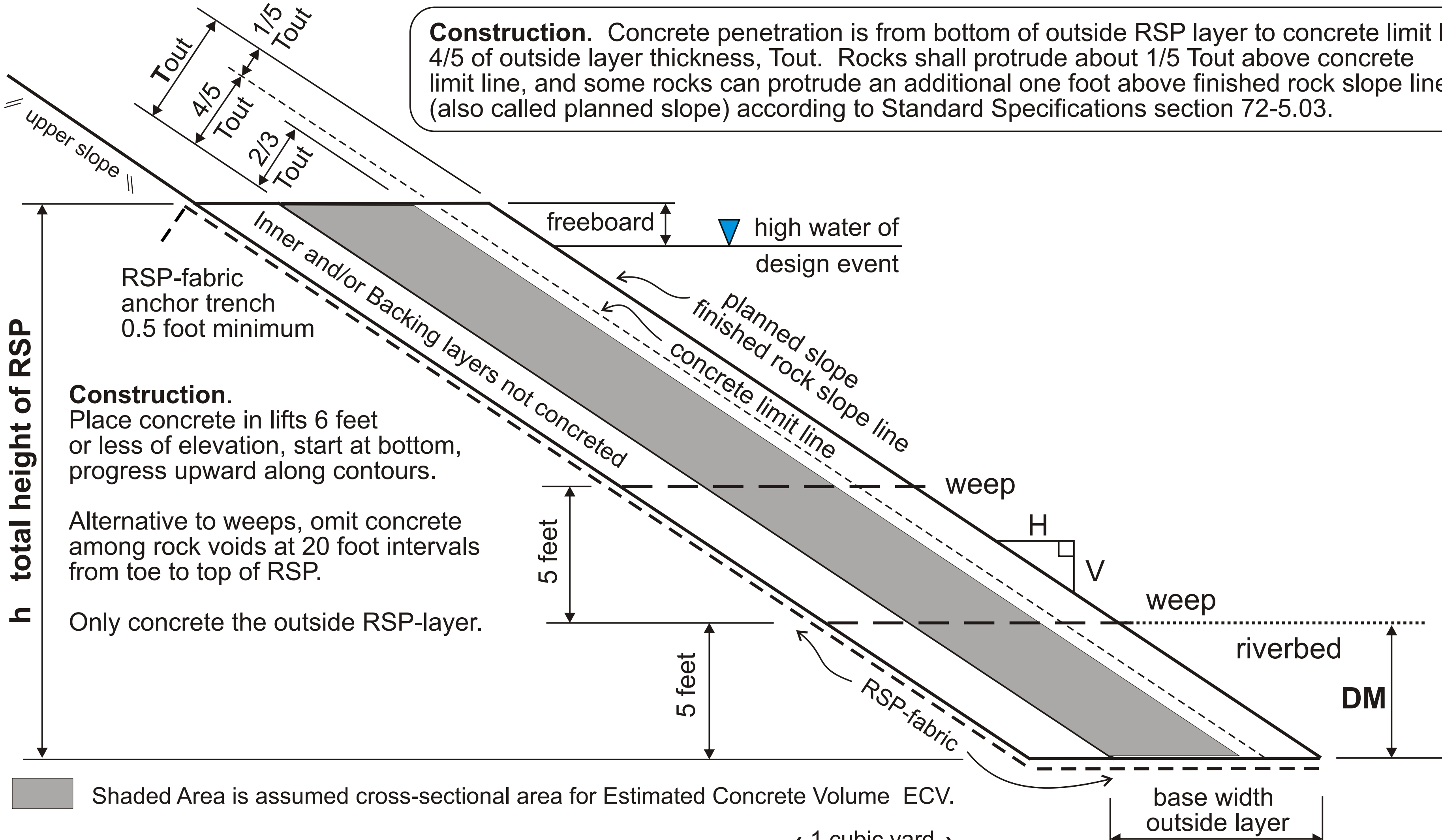
to change MOUNDED TOE dimensions :

1. Maximum Toe Height is DM, EMBEDDED Depth, and minimum thickness, Tout = 1.5 D50.
2. $$\text{Initial Base Width} = \frac{T_{out}}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$$
3. MOUNDED AREA = Initial Base Width x DM
4. Establish minimum Toe Height = or > 1.5 D50 outside RSP layer thickness, and < DM.
5. Establish maximum Base Width = MOUNDED AREA / minimum TOE height
6. Within limitations of steps 1, 4,and 5, select either a new Toe Height or a new Base Width, then divide MOUNDED AREA by selected dimension. Maintain as-designed slope face angle used in Equation 1.
7. Monitor periodically. More rock may be needed, as toe rocks launch. Above dimensions are considered minimum. See Additional Topics A-6.2 “Mounded Toe”, consider possible alternate dimensions and/or alternate gradation.

Figure A-9. CONCRETED-RSP Design Notes and Construction Details

Cross-section No Scale US units Not a Standard Plan

Construction. Concrete penetration is from bottom of outside RSP layer to concrete limit line, 4/5 of outside layer thickness, Tout. Rocks shall protrude about 1/5 Tout above concrete limit line, and some rocks can protrude an additional one foot above finished rock slope line (also called planned slope) according to Standard Specifications section 72-5.03.



Construction.
Place concrete in lifts 6 feet or less of elevation, start at bottom, progress upward along contours.

Alternative to weeps, omit concrete among rock voids at 20 foot intervals from toe to top of RSP.

Only concrete the outside RSP-layer.

Shaded Area is assumed cross-sectional area for Estimated Concrete Volume ECV.

$$ECV = \text{porosity} \times 2/3\ \mathbf{T}\text{out} \times \text{plan view length} \times \text{slope distance} \times \left(\frac{1\ \text{cubic yard}}{27\ \text{cubic feet}}\right)$$

Design and Construction.
See Figure A-7 for dimensions and see all the "Additional Topics" that are cited. Also see topic A-5.3 Estimating Concrete Volume.

Construction. Count concrete truck loads for concrete volume, enforce placement to concrete limit line, verify porosity and ECV.

Additional Topics

While a few additional topics are labeled “Construction Notes …”, it is suggested that both design and construction staff read all of the “Additional Topics ...”, especially topic A-5.4 “Sources of Confusion for Volume and Weight Calculations”. Whether volume or weight is the method of measurement and payment, several dimensions must be inspected and checked by construction staff for quality control and progress pay quantities.

A-4. Verifying Individual Rock Weights and RSP-Class (Gradation). Construction staff must verify individual rock weights and become familiar with their relative sizes, in order to assure that the as-designed RSP-Class (gradation) is delivered to the job and built. One technique, as indicated in the Caltrans Construction Manual, is to paint the weights on a few acceptable rocks. An alternative technique is to measure the volume of individual rocks and calculate their weights.

A-4.1. Painting Rock Weights. It is suggested that an experienced inspector, licensed geologist, or a materials staff person who is familiar with acceptable rock quality, visit the rock quarry or other source. Select three *visual indicator rocks* among the several rocks which are proposed for the job, and which are likely to pass the required material tests in section 72-2.02 of the Standard Specifications. Weigh and paint the weight on one of the minimum-size, median-size, (50 percent weight, W50), and maximum-size rocks of the RSP-Class. The required follow-up is for District Materials staff to randomly sample rocks which are proposed for the job, do the laboratory tests, and assure that test results meet the rock quality requirements. Leave the *visual indicator rocks* at the quarry. A loader operator can be directed to sort and stockpile the required gradation, for example, in lots of say 100 rocks per lot, for subsequent loading and transport to the job site.

For construction inspection staff, it may be convenient to place a similar set of *visual indicator rocks* at the job site, for ease of visual confirmation of rock that is delivered to the job.

A-4.2. Measure And Calculate Rock Weights. As an alternative to weighing, construction inspection staff can measure the 3 principal axes of selected *visual indicator rocks* (a= long, b= median, and c= short axis), estimate the specific gravity, and calculate the rock weights.

individual rock weight = (a x b x c) x specific gravity x 62.4 x unit conversion factors

Equation A-1 can be used, (see topic A-5.2 "Weight", page A-23), except DO NOT apply the factor, (1.00 - **n**). Thus, measured rock dimensions can be used to identify and select *visual indicator rocks*, and after a few trials, the weights can be painted on the appropriate rocks.

A-4.3. RSP-class (Gradation). The RSP-class (gradation) is still determined visually by counting the numbers of rocks for each standard rock size named of the RSP-class (gradation) and its range of "percentage larger than". Example. For 1/4-ton Method B, according to Standard Specifications section 72-2.02,

(95 to 100) percent of the rocks must be between 75 pounds and 1/4 ton,
so, only 5 percent can be smaller than 75 pounds,
(50 to 100) percent of the rocks must be between 1/4 ton and 1/2 ton,
and (0 to 5) none or 5 percent of the rocks can be heavier than 1/2-ton.

The *visual indicator rocks* are 75 pounds, 1/4 ton, and 1/2 ton. For example, among 100 rocks, count about 50 rocks between 75 pounds and 1/4 ton, count about 50 rocks between 1/4 ton and 1/2 ton, and allow about 5 rocks heavier than 1/2 ton.

For heavier RSP-classes, an estimating technique is to count the rocks in a legal truck load. For example, if the legal payload for the haul route is 20 tons, and the RSP-class is 1-ton Method A, a truck should have about 24 to 30 or so individual rocks. If a truck arrived with 40 or more rocks, then that load should be set aside, and later mixed with larger rocks to get an acceptable gradation for 1-ton, Method A. If there are 100 or more rocks in one truck, then that load should be used elsewhere on the job or sent back to the source, as it is out-of-spec or it is an overload.

A-5. Guidelines for RSP Volume and Weight (mass). Caltrans requires measurement and payment of each RSP layer by volume or weight (mass). Layers correspond directly to contract items in the engineer's estimate and the Standard Specifications Section 72. It is emphasized that volume or weight is for each layer of the completed RSP, in-place and on the slope. The topics of section A-5 rely on Figures A-7, A-8, and/or A-9 for dimensions and details. The figures show precise lines and shapes as the basis for quantity calculations, and for layout dimensions in the field. The figures and key dimensions may be useful for construction survey staff and the contractor's grade checker, for layout, measurement, inspection, and payment. There are no figures or calculations for flank treatments, also called leading and trailing edges or returns and keys, because those configurations are unique to each job and site.

A-5.1. Volume. The designer may elect to calculate the volume of each RSP layer (usually separate contract items) and stipulate payment by volume. For the designer, volume is somewhat easier than calculating the RSP layers by weight. To get volume for each RSP layer, multiply the as-designed layer thicknesses from the CaBS procedure by slope distance and length. Check by multiplying horizontal and vertical dimensions of the cross section by length. Generic dimensions and trigonometric expressions are in Figure A-7. Remember to include embedded depth of the RSP toe in slope distances and heights.

Design calculation. layer volume = layer thickness x slope distance x length
- thickness of RSP layer is measured perpendicular (normal) to the slope
- slope distance is measured from top to toe along backslope or face of underlying layer
- length is from station to station (arc distance if on a channel bend, curve)

Check (design and construction). layer volume = base width x height x length
- base width is the horizontal projection **(footprint)** of the RSP layer
- height is the vertical extent of the RSP layer, including embedded depth, DM
- length is from station to station (arc distance if on a channel bend, curve)

A-5.1.1. Footprint. The total base width, also called "footprint", is of interest when negotiating streambed alteration agreements with the California Department of Fish and Game (DFG) and permits with other agencies. Resource agencies consider footprint as the space available for stream functions and habitat. Depending on the RSP layering scheme and the RSP toe design, footprint can be a significant dimension. RSP footprint can be minimized, and maybe eliminated, by building the Case 2 cross section which is flush with up and downstream banks, as shown in Figure A-10 "Protruding and Non-protruding Streambank Revetments". Note that Figures A-1 through A-9 show Case 1, which requires flank treatments (transitions to natural banks), while Case 2 may or may not need flank treatments, also called leading and trailing edges, cutoffs, returns, and keys. To determine where cutoffs are needed, features to assess are bank soil(s), any rock formations, and the flow angles at various water stages during expected flow events, especially design high water. While excavating in streams can be detrimental, with precautions and techniques, short term construction impacts can be minimized, and these short term impacts should be weighed against likely long term gains. Stable banks tend to foster habitat and features like vegetation, whether planted or natural. An embedded toe (Figure A-7) should be considered, because it allows more width for natural stream functions and habitat, as contrasted to a mounded toe, which encroaches more on a riverbed (see Figure A-8). There are sites where a mounded toe is preferred, for example, at ocean shores where dewatering is not feasible and at sites where bedrock is very deep.

A-5.1.2. Construction Notes on Volume. For dewatered sites, stakes or lath can be set at the toe of slope to mark the base width of each RSP layer. The extent of the outside RSP layer approximates the RSP footprint (it is not an exact dimension due to irregular shapes of rocks and tolerances. Staking the footprint helps control the quantities of rock placed for each layer. Figure A-7 has general dimensions and expressions.

As the RSP cross section is being built, construction inspectors can verify the as-designed dimensions shown on the contract plans. Measure each layer thickness perpendicular to the backslope with a folding rule, rod, or other device, by sighting along a contour, about 25 feet beyond and through individual rock surface irregularities.

The rocks of any RSP-class (gradation) are usually not uniform sizes and shapes, and they do not stack into precise configurations on the slope. Actual deviations from the "finished rock slope line" (called "planned slope" in the Standard Specifications) will depend on the rock sizes and how they are arranged on the slope. As stated in sections 72-2.03 and 72-5.03 "PLACING" of the Standard Specifications, the current tolerance is 1-foot. This means that the planned slope is 1-foot lower than the outermost projecting rocks (called surface irregularities). The outermost projecting rocks should not be used as the limit of a layer thickness. Also, see topic A-7, "RSP Tolerance".

A-5.2. Weight. The designer may elect to measure and pay for each RSP item by weight. Simply converting in-place volume of an RSP revetment directly to weight will overestimate the rock weight of the revetment. The volume of air space among the rocks, that is, the voids, must be subtracted from the total volume before multiplying the rock volume by its unit weight and other factors. For RSP, it is not feasible or practical to measure the voids, so, the factor, porosity is introduced. To calculate weight (in US units), multiply the total volume of RSP from theoretical dimensions or as-built measurements by the factors in Equation A-1. Normally, there should be no weight adjustments due to water content.

Equation A-1

weight	= volume	x (1.00 - **n**) x specific gravity	x 62.4	x 27	x 0.0005
tons	yd^3		pound / ft^3	ft^3 / yd^3	ton / pound

Porosity, **n**, for RSP in-place and on the slope. For values of **n**, see topic A-5.2.1, "Porosity".
Specific Gravity of rock. Assume 2.65. Check against results of Test Method No. CA 206. Significant changes are not likely for specific gravities from about 2.50 to about 3.50, and it is rare that specific gravity is large enough to alter dimensions and hence quantities and payment.
Unit Weight of Water (62.4 pounds per cubic foot)
Unit Conversion Factors (cubic feet per cubic yard, and ton per pound)

A-5.2.1. Porosity. To calculate the weight of an RSP-layer, the designer must account for the volume of voids of the RSP, in-place and on the slope. While it is always the choice of the individual to use either porosity or void ratio in calculations, this document (Update 1, Appendix A) prefers and explains the use of porosity. However, Appendix XI of ASTM D 6825-02 seems to prefer and use void ratio in calculations. To learn why ASTM guidance was not followed or repeated here (Update 1, Appendix A) in its entirety, see topic A-9 "Notes on ASTM Riprap Guide" on page A-30. For gravel and relatively small RSP-classes, void ratio can be determined during construction, and thus, it may be a method for verifying design quantities (see last paragraph of topic **A-5.2.2.3. Review of Control Section Alternative**).

For consistency in estimating, recommended values and ranges of porosity are presented. Porosity values are based on the method of RSP placement (Method A or Method B). In addition to calculating the weight of RSP, porosity is needed to calculate Estimated Concrete Volume (ECV) for concreted-RSP. See Equation A-2 (topic A-5.3, "Estimating Concrete Volume", page A-25) which can also be used to estimate the volume of soil fill for vegetated riprap and other environmentally sensitive designs. The topic of soil fill for vegetated riprap is not covered in this document.

The standard definition of porosity which is presented in most soil mechanics text books is
porosity = volume of voids / total volume of sample
Porosity is a decimal between 0 and 1, or a percentage when multiplied by 100 %.

For staff who prefer to use void ratio, the standard definition of void ratio is :
void ratio = volume of voids / volume of solids
and the relationship between porosity and void ratio is
porosity = void ratio / (1 + void ratio)

Knowing the method of placement is the basis for estimating porosity. Again, for emphasis, the porosity is for the entire group of rocks, in-place and on the slope. First, visually assure that the as-designed gradation is built. The rocks in a mixture of RSP vary in size and are graded according to Section 72-2.02 of the Caltrans Standard Specifications. If contractors and quarry operators do not know that Caltrans RSP gradations are percentage LARGER than, give them a copy of pages 24-26 of section 5-1-D, found in the main text (report FHWA-CA-TL-95-10), and also suggest that they read topic A-4. "Verifying Individual Rock Weights and RSP-Class (Gradation)".

Next, assume a porosity for the RSP layer.
If rocks vary in size, and they are within gradation specifications, then it is recommended for :
Method B placement, the assumed porosity is 0.40 (range can be from 0.35 to 0.45)
Method A placement, the assumed porosity is 0.35 (range can be from 0.30 to 0.40).
However, if rocks within the RSP layer are nearly all the same dimensions and weight, that is, if they are uniform in size and shape, then the assumed porosity is 0.50.

To get in-place weight (mass), multiply volume by (1-porosity), specific gravity, and other factors as indicated in Equation A-1 (topic A-5.2, "Weight", page A-23).

A-5.2.2. Construction Notes on Weight. For accurate weight determinations, collect and tally all the weigh slips from the rock trucks. While weight can be the most accurate method for payment, the contractor's staff and resident engineer's inspection staff must still measure and ensure that the cross section dimensions shown on the plans are built, that is, each rock layer thickness (RSP-class), and the corresponding height, length, and slope face angle.

A-5.2.2.1. Control Section Alternative. Instead of collecting all the weigh slips for the rock trucks, for a large job, a control section 100 feet long may be randomly selected. For the control section, collect and tally all the weigh slips, then using an estimate of porosity, calculate the weight for each RSP layer.

Check what was placed in the field by doing the volume to weight conversion.
Assume 2.65 for specific gravity if the materials testing lab did not provide test results.
Determine the LENGTH limits of RSP with the same or nearly the same finished HEIGHT.

As the rock layer is being built, measure the layer thickness. For the smaller RSP gradations, LIGHT to Backing No. 3, there is less error associated with measuring the layer thickness, as contrasted to measuring a layer thickness for RSP-classes (gradations) that are LIGHT and heavier. For the larger gradations, the top-most projection of a rock that projects the farthest from the bottommost layer is generally NOT the layer thickness. Instead, the inspector must estimate the finished rock slope line of the layer, which will be below the top-most projecting rocks. As rock sources and shapes vary, there is no simple rule of thumb for this measurement. See topic A-5.1.2, "Construction Notes on Volume" for review.

A-5.2.2.2. Check. Calculate the Weight of RSP. For Method B, assume porosity = 0.40 and use the factor (1-0.40) = 0.6 to adjust for a "true weight". Similarly, for Method A assume porosity = 0.35 and use the factor (1-0.35) = 0.65 to adjust for a true weight.

Compare the calculated weight with the tally of weigh slips. If there is a difference greater than 25 percent, then recheck thickness of layer, gradation. If both layer thickness and gradation were accurate, then the recommended (per topic A-5.2.1) assumed porosity is in error. Share this data with the designer and with the chair of the Bank and Shore Committee.

A-5.2.2.3. Review of Control Section Alternative. Calculate a theoretical in-place volume of riprap (on the slope, not in a truck) by field measuring a finished "control section", which is large enough to minimize measurement errors. Be sure that the selected station-to-station RSP cross section has had good quality control of the rock sizes and gradation. Measure thickness of the layer (for example a 1/4 ton layer), perpendicular to the finished slope, as indicated on the typical cross section. Use the trigonometric expression in Figure A-7, calculate the BASE WIDTH of the 1/4 ton layer. The control cross section should have the same BASE WIDTH for the full height of RSP. Calculate :

in-place volume = BASE WIDTH x HEIGHT x LENGTH

Next, apply Equation A-1 (page A-23) and convert the volume to weight. Compare the calculated WEIGHT with the total WEIGHT of delivered of rock, as determined by collecting weigh slips for each truckload that was used to build the control section. Adjust the porosity if needed, and if it was not within the recommended ranges (topic A-5.2.1, "Porosity" page A-23), then report the new porosity to design staff and to the chair of the Bank and Shore Committee in Sacramento. Keep the WEIGH slips for the in-place rock of the control section in case of disputes.

ASTM D 6825 suggests that a "struck volume in a truck" may be used for estimating the porosity (or void ratio) for small riprap. In Caltrans, this may be possible for RSP-classes of Backing No. 2 and smaller. Getting an accurate struck volume is considered "not feasible nor practical" for the Backing No. 1 and heavier RSP-classes, due to typical truck sizes and bed configurations, the difficulty of loading and striking a level volume without damaging the truck bed, segregation, and repeatability (precision) of one truck load.

A-5.3. Estimating Concrete Volume. Design can use Equation A-2 for estimating concrete volume. See Figure A-9, for dimensions and terms.

Equation A-2

ECV = **n** x 2/3 Tout x plan view length x slope distance x (1 / 27) cubic yard per cubic feet
where ECV is estimated concrete volume in cubic yards

n is porosity
Tout is thickness of the outside RSP layer, as measured perpendicular (normal) to slope
slope distance is measured from top to toe of along backslope or face of underlying layer
length is from station to station (arc distance if on a channel bend, curve)

Construction should keep a tally of concrete truck loads delivered, and calculate :
as-placed porosity = concrete volume delivered / volume of control section of concreted layer
If all the trucks were counted, then a value for the total volume of rock used in the concreted-RSP should be calculated, based on field-measured dimensions (add toe depth to height or slope distance as appropriate).

Compare ECV to the yardage of concrete delivered and placed.
Report as-built porosity to design staff and to the chair of the Bank and Shore Committee in Sacramento.

A-5.4. Sources of Confusion for Volume and Weight Calculations. Contractors sometimes apply a weight or volume conversion factor for hauling riprap in their trucks, however, that factor is not a constant value, and therefore should not be used as the primary method for determining the amount of voids or the porosity of RSP classes, which are in-place and on the slope. Such "weight to volume haul factors" should not be used for payment of RSP.

People sometimes confuse porosity of an entire embankment with the absorption of individual rocks. Test Method No. CA 206 (apparent specific gravity and absorption), is done to either pass or fail quarry rock or excavated rock for use as RSP. Test 206 describes " … procedures for the determination of bulk and apparent specific gravity and absorption of coarse aggregate". In the context of the test method descriptions, the word "bulk" does not mean "of the whole RSP embankment", and instead, it means of the individual rocks that are being tested.

Individual rocks absorb water, and the weight of water is accounted for in test method 206. "Absorption" is the appropriate term for the amount (percentage) of water that a rock takes on, after it is immersed in water and then surface dried. The porosity "of the whole RSP embankment" which has length, width, and height is NOT analogous to the absorption values of individual rocks.

"Stone" materials (sandstone, silt-stone, mudstone) are generally rejected as suitable for RSP, due to their high values of absorption and their poor durability indexes.

A-6. RSP Toe. Scour and Embedded Depth, Mounded Toe, Bedrock. The choice of embedded or mounded toe may be constrained by permit or physical job-site conditions. An embedded toe limits the encroachment of the revetment footprint, and it requires excavation in the streambed. Figure A-7 indicates how deep to embed the RSP toe (to scour depth), and some limited guidance is provided in topic **A-6.1 Scour and Embedded Toe.** If no excavation is allowed in the streambed, then designers should develop a "mounded toe" alternative design. Some options are discussed for calculating the mounded toe dimensions and specifying rock gradations in topic **A-6.2 Mounded Toe.** Make sure it is understood by resource agencies that a mounded toe has a larger footprint than an embedded toe. The mounded toe is often preferred in ocean settings, where dewatering is challenging and costly. Written guidance for building in bedrock is sparse, so the additional topic **A-6.3 Bedrock Design and Construction** was included, and it is based mostly on practice in District 5.

A-6.1. Scour and Embedded Toe. There is limited guidance for estimating scour of revetments. When nothing is known about the bed materials, then a minimum of 5-feet is suggested as the embedded depth. HEC-11 suggests the embedded depth should be twice the revetment thickness. For the CaBS layered method, that could be excessive.

Dr. Steve Maynord of the US ACE (Vicksburg, MS - Waterways Experiment Station, WES) updated the "corps" method, and it is published in manual (USACE-EM-1110-2-1601). Dr. Maynord also produced a computer program called "CHANLPRO". There are some general limitations.

First, if you use CHANLPRO as a check method for a "rock size" comparison to the CA bank and shore layered method, then be aware that you may get different values for minimum stable rock sizes. The Corps standard rock gradations are different than the Caltrans standard rock gradations. Layer thickness are different. And selection of geotextile (RSP-fabric) is different. Be aware of the assumptions and limitations of the Corps method and of the CA method, and then use your engineering judgment. Revetments built by the both methods have been documented to function well under design conditions, that is, those revetments that were well-inspected, were built with suitable materials, and were built according to design.

The CHANLPRO Corps method is based on Dr. Maynord's "near-prototype" flume studies at WES. In models, be aware that grain size between riprap and channel bed material can not be precisely scaled. The Corps method is said to be valid for river and stream channels with a longitudinal slope of 2 percent or less. In addition to riprap sizes and gradations for channel side slopes and bottom, there is an option for **scour depth estimates in bends for sand channels**. Generally, the scour calculation is based on regression data that Dr. Maynord assembled from various sources. For more information, see "Toe Scour Estimation in Stabilized Bendways", 1996a, ASCE Journal of Hydraulic Engineering 122(8).

You can get the CHANLPRO program and a user guide at this Internet link.
(Internet link http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;3)
The user guide explains the design equation, variables, and charts along with the assumptions and limitations of inputs and outputs. There are some example problems.

> **Note**. The "gabion" option of CHANLPRO was based on work done by Maccaferri Gabions at Colorado State University, Fort Collins. It is among the references in the user guide by Dr. Steve Maynord. Caltrans does not recommend the "gabion" option of Channelpro. Caltrans guidelines and limited usage of gabions as downdrains are based on experience and field observations. The Caltrans standard special provisions (for channel lining) allow only 12 and 18 inch high mattress style gabions (0.3 and 0.5 meter high), and the rock size ranges in our standards were selected to prevent rocks from escaping through standard gabion mesh openings (either hexagonal or square). For Caltrans information on gabion design, there is a draft document at :
> http://onramp.dot.ca.gov/hq/esc/sd/bridge_design/ers/documents/gabion_dib.pdf

A-6.2. Mounded Toe. Generic dimensions are shown in Figure A-8 for a minimum quantity of rock that constitutes a mounded toe with thickness = 1.5 D50 (perpendicular to slope). Rocks of a mounded toe are expected to "launch", that is, drop into scoured zones of a riverbed, and this is likely to occur gradually, over the course of several events. Because some rocks will wash away not all the rocks will launch and stay in the scoured hole, providing more rock than previously recommended should be considered. The new thickness to consider is 3 D50, and Figure A-11 is a cross section with generic expressions for dimensions. When there is enough rock between the river currents and the erodible channel bed material, the fine bed particles will tend to remain in place and not be winnowed (sucked out through voids) and washed downstream.

The US Army Corps of Engineers suggests increasing the amount of launchable rock, based on the channel bed material (sand or gravel). For details on the Corps' suggested increased rock amounts for a mounded toe, see Chapter 3, topic 3-11, "Revetment Toe Protection Design", pages 3-10 and 3-11 in EM-1110-2-1601 **Hydraulic Design of Flood Control Channels**, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1601/toc.htm

A-6.2.1. Differences in Gradation, More or Less Rock ? The Corps' standard rock gradations usually have more ranges and quantities of smaller rock sizes than standard Caltrans RSP-classes (gradations). The Corps specifies "percent passing" while Caltrans specifies "percent larger than". Standard Corps gradations tend to be closer to "well-graded" mixtures of rock, so that when smaller-sized rocks launch, they may not remain nearby. Caltrans gradations (RSP-classes) tend to have larger and more "same sized" rocks, that is the rock sizes within an RSP-class tend to be uniform, as contrasted to well-graded. Furthermore, Caltrans does not allow "chinking the voids", that is, filling voids with small rock. The differences between Caltrans and Corps gradations imply that a mounded toe built with a standard Corps gradation could lose more rock volume than a standard Caltrans gradation. A comprehensive discussion of gradations is in the NCHRP project 24-23 final report NR 568. The discussion cites ranges of a quantity called "uniformity ratio", which is D85/D15. This should not be confused with the coefficient of uniformity, D60/D10, of the Unified Soil Classification System. Also discussed are similarities and implications for stability in riverine and ocean settings.

A-6.2.2. Example Nonstandard CaBS Mad River Launchable Gradation. An example, alternative and nonstandard launchable rock gradation was designed and built for the Mad River, on two contracts, 1992 and 1995. For the 1992 emergency contract, Caltrans District 1 hydraulics staff hired Dr. Darryl Simons (deceased) as a consultant to oversee the mounded toe design and rock gradation. Tom Hoover (deceased) and Jim Racin were the technical consultants for the Caltrans Bank and Shore Committee, and they designed a nonstandard launchable rock gradation for District 1. Dr. Darryl Simons concurred with the gradation. For the 1995 contract, the rock sizes were scaled down one RSP-class. See Table 7-2, page 55 in the main report, FHWA-CA-TL-95-10. Before copying the "Mad River launchable gradation" on any other jobs, designers should consult with the Bank and Shore Committee. Generally, for smaller rock sizes, it is suggested to consider the percent ranges, while making adjustments to rock sizes, possibly eliminating or adding some. A nonstandard gradation is not always needed.

Use engineering judgment and site-specific information for increasing, or not increasing, the amount of rock in a mounded toe.

A-6.3. Bedrock Design and Construction. Where bedrock dips downward and into the stream, a stable notch is needed, such that the toe rocks of the revetment will remain in place under hydraulic, gravity, sliding, and seismic forces. A cross-section similar to Figure A-12 is suggested. Consult with an engineering geologist or licensed geologist and get their input on the geometry of a stable notch in bedrock. They may also have suggestions for the contractor and the resident engineer on construction techniques, for example, chip-and-chisel with a hydraulic ram hoe, versus drilling and blasting with high explosives. The contractor may be familiar with the rock formation and may have developed an acceptable technique and knows the equipment required for constructing a notch in bedrock.

If repeated impacts from a hydraulic ram hoe will cause unacceptable, excessive vibrations (may also cause steep unstable material to slough), then check with a staff expert who has a valid California blast license, and who is experienced. Rapidly expanding compounds (soundless chemical demolition agents, SCDA) are available nowadays for splitting rocks, instead of using high explosives. SCDA usually do not create spectacular explosions and shock waves like high explosives. SCDA may do the job on some, but not all kinds of rock, and drilling is usually required, with orientation, number and depth of holes, etc. per recommendations of the geologist, engineering geologist, or the experienced blaster.

A major consideration of bedrock is to assess and determine what "competent bedrock" is. When excavated and exposed, shales and schists, certain kinds of stones, and chemically reactive rock formations may not be adequate as a long-term, stable foundation for RSP. Again, seek answers via field reconnaissance and findings from the geotechnical report, a special investigation by an engineering geologist, and/or licensed geologist.

A-7. RSP Tolerance. RSP tolerance means that individual rocks may protrude ABOVE the planned slope line. It does not mean "Plus or Minus", but instead "Plus", because a minimum design thickness is required for a stable revetment.

The existing Caltrans standard of 1-foot tolerance is likely :

a . too large for Backing No. 1 (also called Facing) and smaller RSP-classes (gradations),
b. OK for LIGHT, 1/4 ton, and 1/2 ton gradations,
c. too small for 1-ton, 2-ton, 4-ton and 8-ton gradations.

The tolerance as suggested by ASTM D 6825 is 1/2 D50 for each layer, however, that is not practical, considering the Caltrans gradations (RSP-classes). Additionally, ASTM D 6825 defines layer thickness as the average size of both a spherical and a cubical rock shape. This is not consistent with the CaBS layered design procedure, which bases dimensions on the spherical shape.

Until the RSP tolerance is formally changed by adequate documentation and approval by the Bank and Shore Committee, use the 1-foot tolerance for layer thicknesses of all RSP-classes.

A-7.1. Tentative Proposal for RSP Tolerances.
The Caltrans Bank and Shore Committee may (or may not) consider changing the 1-foot RSP tolerance. The values proposed below are loosely based on ASTM D 6825-02, that is, the dimensions are “near” the 1/2 D50 spherical sizes, and instead of naming a tolerance for each RSP-class, the proposed tolerances would apply to the stated range of RSP-classes.

RSP-Classes	Tolerance “Plus” from Planned Slope
a. Backing No. 1 and smaller	0.25 foot
b. LIGHT, 1/4 ton, and 1/2 ton	1 foot
c. 1 ton and 2 ton	1.5 feet
d. 4 ton and 8 ton	2 feet

A-8. Method A or Method B ?. For each layer, the construction method of placement is specified, as either Method A or Method B, which is based mostly rock size, as indicated in the tables of rock sizes and RSP-classes (gradations) in the Standard Specifications section 72-2 “Materials”. For 2-ton and larger RSP-classes, Method B is not practical. For ¼ ton and smaller, Method A is not practical. RSP-classes 1/2 ton and 1-ton can be either Method B or A, so design staff should investigate and inquire about site conditions, environmental constraints, and constructability, so the method that suits the site constraints can be selected.

A-8.1. Proposed Changes for Method of Placement in Caltrans Construction Manual.
Regarding RSP construction, there are at least two significant changes that are proposed, and these are based on the text of the ***California Department of Transportation Construction Manual July 2001*.**

The first proposed change to the Construction Manual is on page 4-72.2, topic 4-7203A, Rock Slope Protection, delete the phrase

“… and that the use of ‘chinking’ rocks is limited to filling voids.”

The sentence should read something like this :

“To ensure the success of Method A, ensure that the bearing of rocks from one to the other follows specifications.”

Since the Standard Specifications (PLACING, section 72-2.03) are somewhat vague, here is clarification. Do not chink voids with small rocks that are not part of the RSP-class for a respective layer. Before RSP construction begins, the RE (resident construction engineer), in conjunction with materials inspection staff, must ensure the correct gradations for each RSP layer, and when feasible, it is best to do this at the quarry or rock source. As a “Method A” RSP layer is being built, the inspector ensures that rocks have 3-point bearing, and that they interlock without wobbling or rocking of individual rocks. To accomplish this, instruct the machine operator to select and place a variety of the available rock sizes, that is, do not place all of the large rocks in the toe followed by all of the small rocks. Select and place rock sizes to the planned thickness so there is interlock among the rocks. An analogy to describe Method A is : "build a motarless wall".

The second proposed change to the Construction Manual is on page 4-72.4, topic 4-7203A, Concreted Rock Slope Protection, in the second paragraph, delete the phrase

"…or inadequate voids".

The paragraph should read something like this :

"To assure that concrete will bind to the rocks of the outside layer, the contractor may need to wash the rocks before placing concrete. If the outside layer of RSP contains a larger percentage of the smallest-sized rock than is stated for the RSP-class (gradation), then it is out-of-specification. An adequate void space is needed for concrete, so enforce the gradation specification and do not allow voids to be chinked or filled with small rock."

A-9. Notes on ASTM Riprap Guide. ASTM D 6825-02 "Standard Guide for Placement of Riprap Revetments" and its companion Appendix XI "Quality Control For Riprap" were carefully reviewed and appraised. As stated in their text, ASTM D 6825 is not a standard of practice. Instead, the ASTM discussions, opinions, and advice are based on riprap gradations, design assumptions, and procedures of the US Army Corps of Engineers (US ACE) and the Federal Highway Administration (FHWA). While there are similarities between US ACE and FHWA methods and the California Bank and Shore (CaBS) layered method of RSP, there are notable differences in rock gradations, design procedures, and some construction practices. Therefore, the guidelines (in this Update 1, Appendix A) were developed for staff who are using the CaBS layered method. For emphasis, the preceding discussions clarify Caltrans practice, they do not defend Caltrans practice, nor do they attack ASTM D 6825. Where applicable, ASTM guidance was incorporated.

A-10. RSP (riprap) Monitoring. Whether an RSP facility is successful or failed is discussed on page 35 of the main report (FHWA-CA-TL-95-10). An impending failure can be difficult to detect, however, with knowledge of the original design, and with some during construction and post-construction photographs, it is likely that an accurate status can be assigned. Without knowing the original design, some features of impending failure are degraded rock, dish (slump) in the slope, and undermined toe.

Periodic inspections should be done, especially after large magnitude runoff events. An inspection coding scheme (status) similar to the National Bridge Inspection Standards (NBIS) was proposed in the National Cooperative Highway Research Program (NCHRP) project 24-23 final report, "Riprap Design Criteria, Recommended Specifications, and Quality Control", Appendix C, Section **3.4 Inspection Coding Guide**. There are 11 distinct codes, which may result in 1 of 5 action items ranging from "continue monitoring" (no problem) to "notify law enforcement" (which may lead to a road closure). The report can be purchased via the online Transportation Research Board (TRB) bookstore. Click on http://www.trb.org/bookstore/ enter NR568 as the search string, then click the GO button. A summary of project 24-23 and link to an electronic copy of the final report are available at http://www.trb.org/trbnet/projectdisplay.asp?projectid=722 .

There is a comprehensive discussion with sketches and photographs of general situations and real-world case studies on riprap failure mechanisms. See pages 111 through 127.

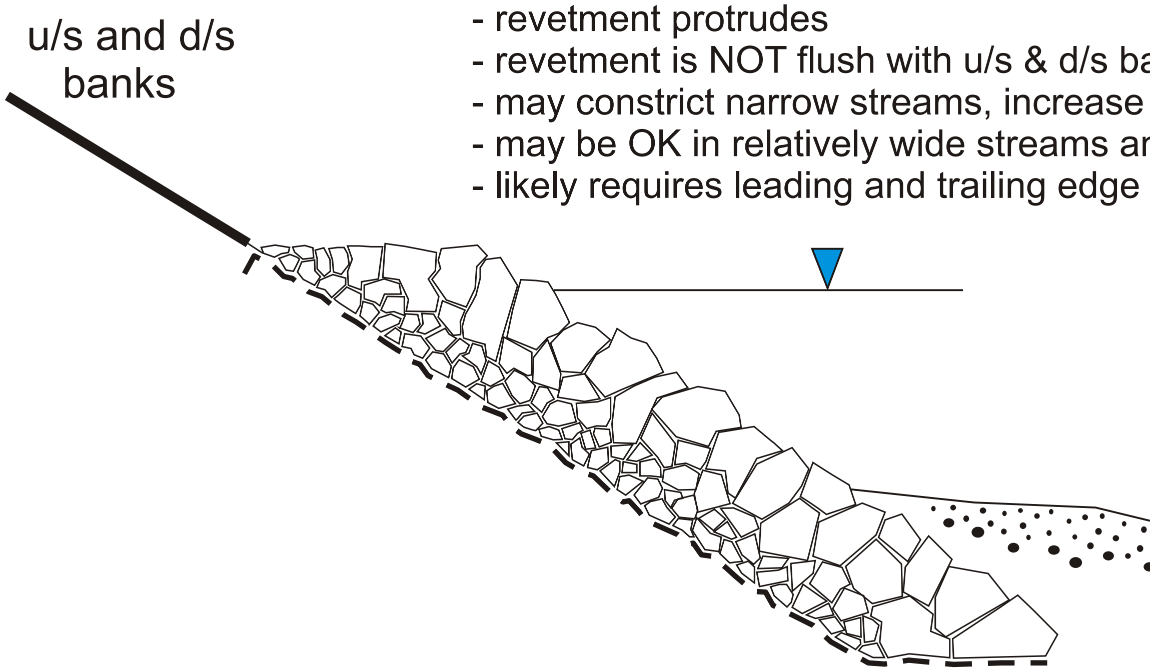
Figure A-10. Protruding and Non-protruding Streambank Revetments

Cross Section No Scale US units Not a Standard Plan

left bank looking downstream, may or may not be mirrored on right bank

case 1 protruding revetment

- revetment protrudes
- revetment is NOT flush with u/s & d/s banks
- may constrict narrow streams, increase velocity
- may be OK in relatively wide streams and rivers
- likely requires leading and trailing edge cutoffs



case 2 non-protruding revetment

- revetment does not protrude
- revetment is flush with u/s & d/s banks
- check roughness of banks and revetment
- does not constrict channel, so little or no change in velocity
- may be more challenging to build than case 1

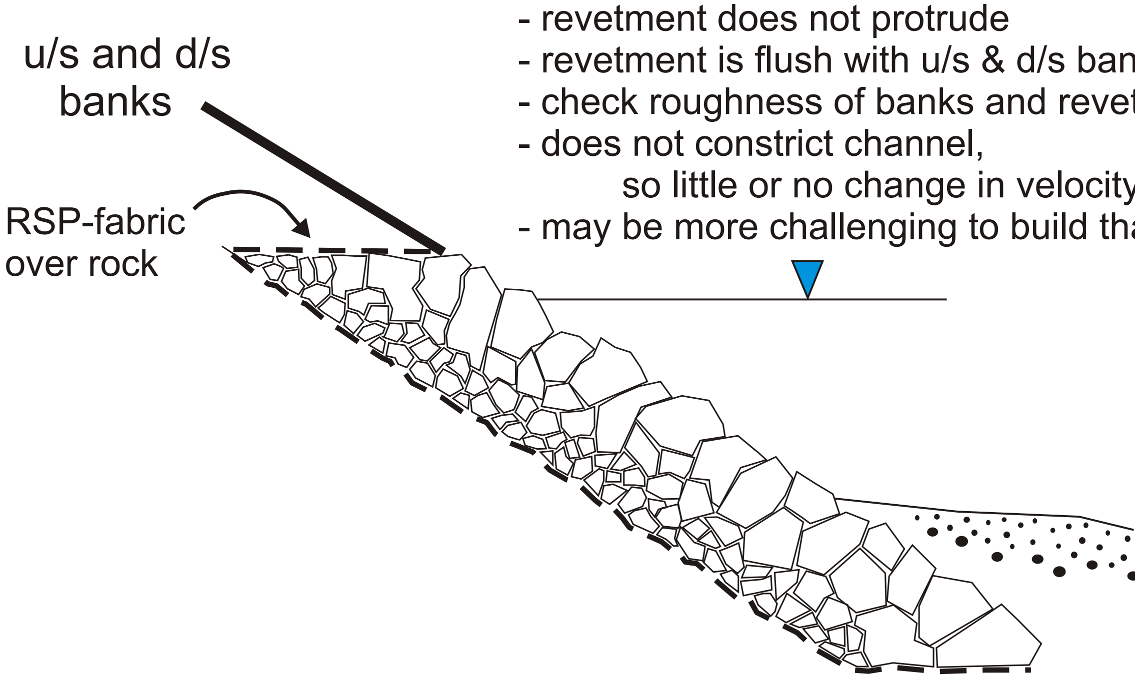
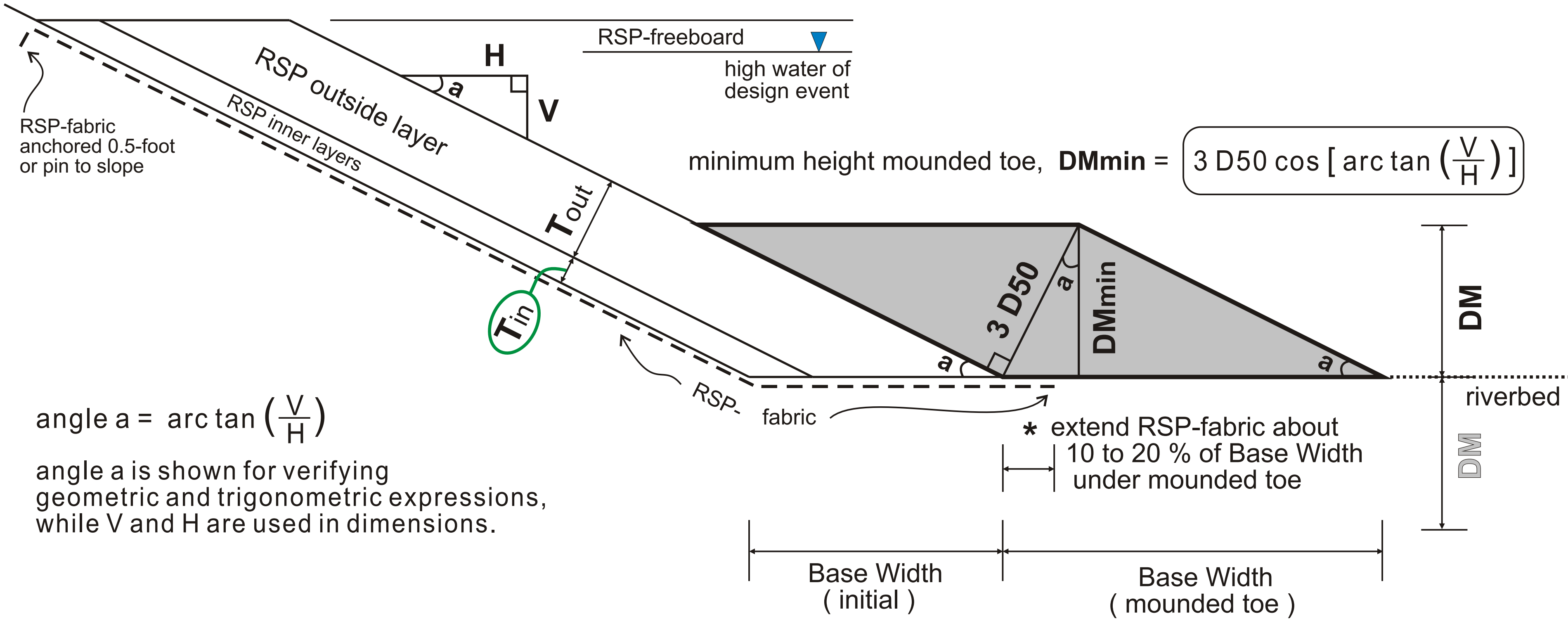


Figure A-11. CaBS Alternative Mounded Toe Dimensions

Typical Cross Section   No Scale   US units   Not a Standard Plan



minimum height mounded toe, **DMmin** = $3\ D50 \cos\left[\arctan\left(\frac{V}{H}\right)\right]$

angle a = $\arctan\left(\frac{V}{H}\right)$

angle a is shown for verifying geometric and trigonometric expressions, while V and H are used in dimensions.

1. Generally, minimum thickness of mounded toe = 2 x thickness of RSP outside layer.
   Set minimum thickness of Mounded Toe = 3 D50 of RSP outside layer.
   3 D50 minimizes Base Width (footprint of mounded toe).
   Contrast to Method B, Tout = 1.875 D50, and 2 x Tout = 3.75 D50.

Base Width (initial) = $\dfrac{\mathbf{T}out + \mathbf{T}in}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$

2. Compare embedded depth DM (calculated scour or empirical) and **DMmin**.

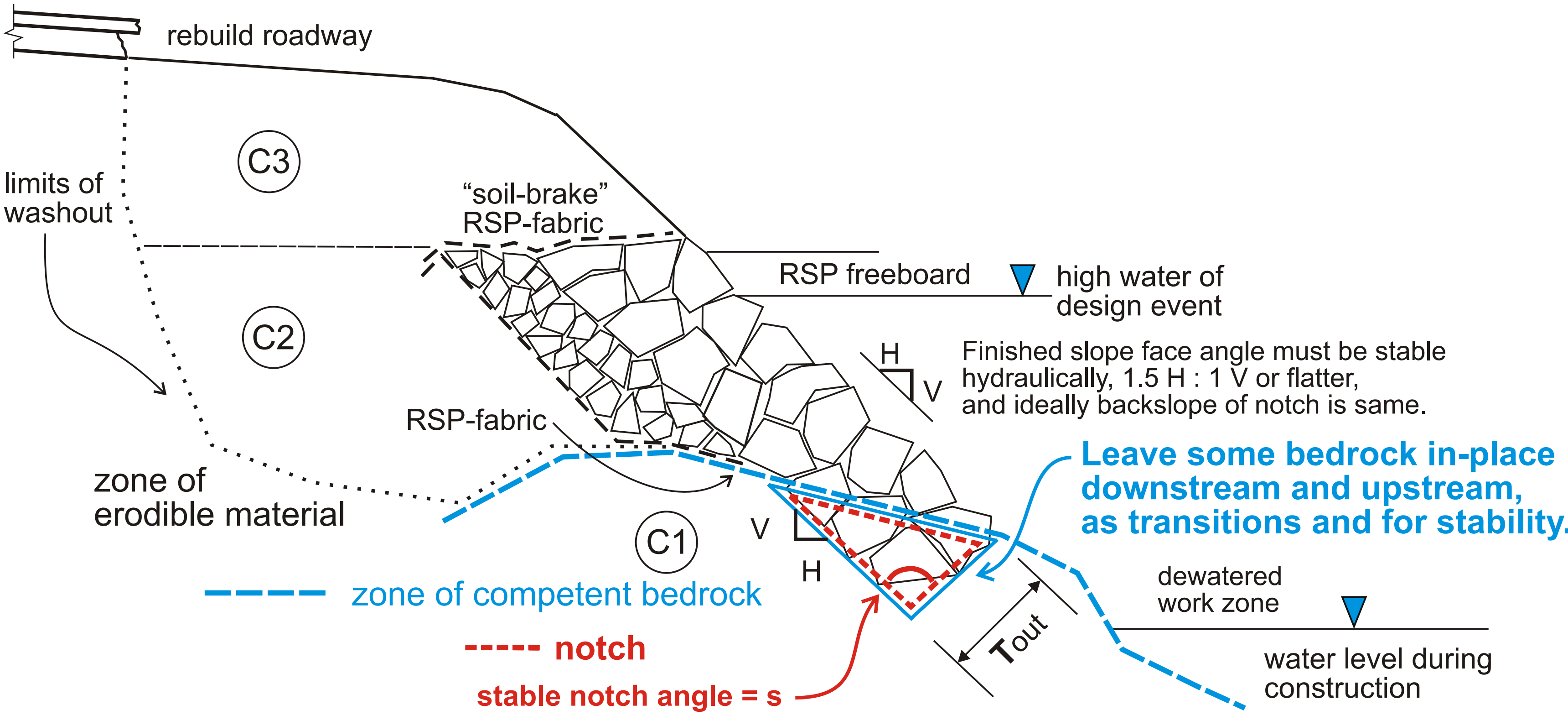
2A. If DM > DMmin, set DM = DM

2B. If DM < DMmin, set DM = DMmin

Minimum Base Width (mounded toe) = $\dfrac{3\ D50}{\sin\left[\arctan\left(\frac{V}{H}\right)\right]}$

Figure A-12. Stable RSP Toe in Bedrock

Cross-section No Scale US units Not a Standard Plan



1. When bedrock dips toward stream, construct notch for stable RSP toe in zone of competent bedrock C1.

1a. Consult with geologist or engineering geologist for recommended notch angle s, based on rock properties. Stable notch angle s = 90 degrees. Other notch geometry is possible based on bedrock and site constraints. Minimum notch thickness = **T**out, thickness of outside RSP layer

1b. Notch can be constructed with hydraulic ram hoe (chip-and-chisel), or by drilling hole patterns in bedrock and using either expansive chemical agents or explosives (blasting license required), or by other techniques and equipment. Obtain required permits.

2a. Place RSP toe (outside RSP-layer) in notch, zone of competent bedrock. Omit RSP inner layers in bedrock zone.

2b. Rebuild fill of zone C2

2c. Place RSP-fabric and layered RSP

2d. Place "soil brake" RSP-fabric at top of revetment

2e. Rebuild fill of zone C3 and roadway.