CIRCULAR BRIDGE PIERS AND RIPRAP DESIGN

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Scour at bridge piers may be prevented by riprap placement. The latter is an addition to a pier to increase its performance against scour. Most of the present research works account only for selected parameters mainly the hydraulic load (Chiew 1995). This research presents (1) three basic scour mechanisms associated with circular-shaped bridge piers in rivers, (2) introduces a number of selected experiments and (3) describes a novel procedure for assessing the safety of bridge piers against failure. The procedure is based on an extended Shields' approach accounting for the presence of a circular-shaped pier that is protected by a circular-arranged riprap layer of equal size elements. For equal riprap and sediment sizes this design degenerates to the entrainment condition of a pier, and to the Shields entrainment condition when the pier is removed.

The Shields' diagram relates the Shields' parameter to the grain Reynolds number. The entrainment (subscript i) of sediment in the rough turbulent regime follows with $\sigma=(d_{84}/d_{16})^{1/2}$ as the bed sediment non-uniformity parameter and $R_{ho}=Bh_o/(B+2h_o)$ as the hydraulic radius with B as channel width (Hager and Oliveto 2002)

$$\sigma^{-1/3}V_i/(g'd_{50})^{1/2}=1.65(R_{ho}/d_{50})^{1/6} \qquad (1)$$

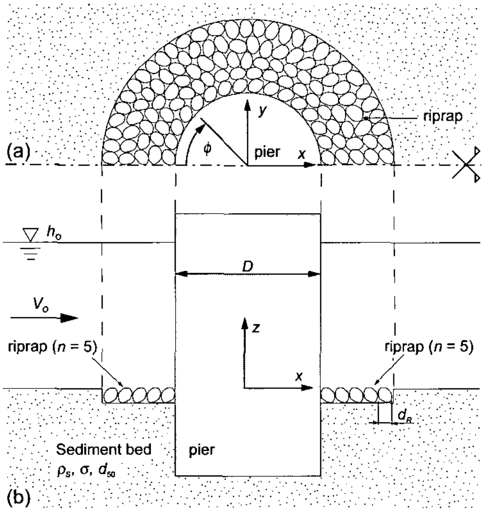

Fig. 1 Definition sketch for riprap arrangement (a) Plan, (b) Section

Equation (1) applies also for a sediment bed in which a pier diameter $D \rightarrow 0$ is placed. As the latter increases, an additional effect of relative pier size $\beta = D/B < 1$ results whereas all other parameters are included in (1). Adding a riprap to the pier involves additional parameters to the entrainment condition made up by the relative riprap (subscript R) diameter $\delta = d_R/d_{50}$ and the aerial extent of riprap expressed with the number n of riprap rows placed around a pier.

Experiments were conducted in a channel B=1.0 m wide, 5 m long working section, with discharges up to Q=130 l/s. In total 35 experiments were conducted with two bed sediments of d_{50}=5.0 mm and 1.1 mm, and $\sigma = (d_{84}/d_{16})^{1/2}$=2.29 and 1.18, respectively. The uniform riprap sediment had diameters d_R=8.4, 12, 13, 19, 23.6, 30 and 50 mm, resulting in diameter ratios $\delta = d_R/d_{50}$ from 2.4 to 45. Conditions with n=1 to 10 riprap rows were investigated, pier diameters D ranged from 110 to 457 mm. A total of 104 tests were conducted.

Fig. 1 is a definition sketch. The approach (subscript o) flow depth is h_o and the approach velocity V_o. The sediment (subscript s) bed is described with the parameters ρ_s, d_{50} and σ, whereas the riprap layer is characterized with d_R and n. All tests involve one riprap layer whose surface was exactly level with the bed sediment surface. This was considered critical for riprap failure.

Three failure modes are proposed as (Unger and Hager 2005):

(1) *Rolling* as observed by Shields involving a small sediment size ratio $\delta = d_R/d_{50}$ for a riprap whose size is close to the bed sediment.

(2) *Undermining* as the typical failure mode occurring for riprap diameters much larger than the bed sediment, with riprap members sinking into the bed sediment.

(3) *Sliding* as the intermediate case once an interface scour has developed along the riprap periphery.

A design diagram on which the relative hydraulic load is plotted versus the relative riprap diameter and the riprap row number allows simple application to practice, for both the riprap design procedure and the assessment of failure probability of an existing riprap placement. Failure modes Rolling, Sliding and Undermining were identified to depend exclusively on the so-called riprap load parameter R, the relative riprap size δ and the riprap extent n. The performance of the riprap failure equation was experimentally assessed to ±15% for the Sliding and the Undermining failure modes, and to some ±30% for the Rolling failure mode. Except for two recent riprap design approaches, large deviations occur mainly because a variety of parameters were not considered. The limitations of the present failure criterion are listed and practical issues of riprap application are discussed.

REFERENCES

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