Bridges and culverts reduced in size and cost by use of critical flow transitions

N. H. Cottman* and G. R. McKay*

C. van Beesten, *Fellow*

The Authors have succeeded admirably in presenting a Paper which sets out the concept of streamlined flows through constrictions in rivers by arranging the flow boundaries along lines that meet their requirement of a constant Froude number equal to unity. First impressions make the idea seem difficult to envisage in practical applications, as the developed geometry of structures appears to be too far removed from the natural shapes of river channels. Such views are accentuated by the calculations needed to establish the most appropriate streamlined shape in each case, where channel configuration, bridge discharge requirement and local site problems make each design a unique situation.

60. However, in suitable locations, the minimum energy principle can provide elegant and economical solutions, particularly when the idea can adapt an existing structure to flood flows exceeding the original 'conventional' design flows, and thus obviate the need to construct a new and much larger bridge. I am especially impressed by the flexibility of the system, as the designer can adjust the geometry to the peak flood flow selected for the river crossing, within the practical limits imposed.

61. The most difficult aspect of the design method lies in the acceptance of flow velocities in the order of 4–5 m/s. River engineering has, for many years, accepted a much lower limit on flows, in the order of 1.5 m/s, depending on the characteristics of the soils making up the bed and banks of the river. Protective measures are normally applied for higher velocities. In this case, the successful application of the minimum energy principle on some 100 structures provides convincing illustration that the normal scour and erosion criteria do not apply for the essentially turbulence-free flow at $F_N = 1$.

62. One problem mentioned in the summary but omitted from the Paper concerns floating debris. Such material can easily collect against bridge or culvert soffit, specially at sub-critical flows when the freeboard between soffit and water level is reduced to a marginal amount: e.g. 0.14 m is indicated in Fig. 6 of the Paper. In a case where debris gets trapped by a low soffit, the consequent surcharge level could change the bridge or culvert performance drastically and lead to flooding of bridge and road. In a report⁷ not mentioned by the Authors, McKay shows several photographs of debris collected at bridge piers and soffits for conventionally designed structures. Could Mr Cottman discuss this aspect in relation to minimum energy structures?

63. In conjunction with the question of freeboard, another difficulty arises when that freeboard is increased for the passage of debris, as it would also permit

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excessively large flood peak flows through, possibly resulting in downstream flooding. Mr Cottman's views in that respect would be appreciated in relation to his long experience with minimum structures.

64. The Authors' comments, in §§ 38 and 43 stress the need to adhere to the rigorous discipline of the calculation method as presented, in order to attain both the desired bridge performance and a thorough appreciation of the hydraulic principles involved. Before the minimum energy design is applied, I would recommend a study of the paper by Cottman² on floods and flood rating curves, which he uses to determine stage-discharge curves as observed by him.

65. Finally, attention is drawn to a couple of errors in the formulae in the Paper: formula (5) is § 7 should read $y = F_N y^{1.5} \sqrt{g}$; the last formula (critical velocity) in § 18 should read $V_c = \sqrt{gy_c}$.

M. J. Kenn, *Fellow (formerly Head of Hydraulics, Imperial College, London)*

The Authors' succinct account of their long experience with their innovative, efficient, effective and inexpensive 'maximum-discharge' flood-relief structures will be of great interest to all water engineers.

67. The quiet passage of large flood-flows through these elegant structures, with minimum energy, with negligible erosion, with insignificant wave undulations, and with essentially a Froude number of unity throughout, is most impressive.

68. Some years ago the Authors' enthusiasm for their well-tested structures became abundantly clear to those post-graduate students, and others, privileged to hear the Civil-Engineering Hydraulics Lectures given by Professor Gordon McKay, at Imperial College London, during a sabbatical year spent in England before his retirement. More recently, the Authors were being encouraged to present their ideas to a rather wider, receptive, audience.

69. This Paper should deservedly succeed with this objective. It is perhaps sad that the second Author did not survive to see the Paper appear in print. However, full appreciation should be accorded to Norman Cottman for completing the task and, incidentally, for ensuring a lasting tribute to Professor McKay, a long-standing friend and co-worker.

E. N. Cottman, *Construction and Maintenance Engineer with Ipswich City Council, Queensland**

In reply to *Mr van Beesten*, I agree that the drainage structures we see are usually in a form shape far removed from the ideal shape. My father used to comment that box culverts were much more efficient as water carriers than pipes, and I suspect that he would have rewarded a manufacturer who produced a modern pipe with the profile of the early egg shaped culvert.

71. In respect of the problem raised in § 62, I agree that debris can adversely affect the performance of any culvert structure, but I believe that the smooth inlet flow created by this design method allows more debris to pass through the culvert than through conventional drainage structures. In the Shire of Stawell, the rivers meander through gum-tree (eucalyptus) lined courses; during flood flows, the swollen waters carry many fallen branches (a curse of the gum) but this debris usually does considerably more damage to the sheep farmers' fences than to anything else. I recall, however, that it was my father's requirement that Shire

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maintenance crews on routine patrols should clear timber that had fallen within the inlet area and that, where practical, farmers' fences should not be permitted across the inlet transition section. Sometimes, farm fences that ran beside the roadway were taken over the head of the culvert rather than across the inlet, with special arrangements made to stop sheep from passing through the culvert in dry weather.

72. With regard to § 63, as suggested previously, increased freeboard for the passage of debris is not considered necessary with this design method, and flood flows beyond the design capacity of the culvert can be passed through and over the culvert structure with considerably less effect than at an overtopped conventional bridge. I believe this is because the overtopping flow is usually relatively broad, shallow and smooth; and, in cases I have observed, this flow is drawn into the smoothly flowing water downstream, creating minimal turbulence and erosion. The flood water level downstream from the culvert outlet transition is neither reduced nor raised by the existence of the culvert.

73. In § 7 of the Paper, the correct version of formula (5) is $q = \sqrt{(g)} F_N y^{1.5}$ derived from formulae (3) and (4) above it; and the formula for critical velocity in § 18 should read $V_c = \sqrt{gy_c}$, which is shown as formula (7) in § 8.

74. In response to the comments made by *Mr Kenn*, I wish to express my appreciation. My father was enthusiastic about his engineering work and, in particular, more recently with the hydraulics of bridges and culverts, where he had cause to reconsider the basic assumptions for previous designs. I believe we can all learn a lesson from that example.

Reference

7. MCKAY G. R. *Design of minimum energy culverts*. University of Queensland, Department of Civil Engineering, 1971, Oct.