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8511 DISCUSSION

Devon floods and the waterways of bridges

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It is interesting to compare some of the Author's comments with recommendations in the *Guide to bridge hydraulics*.[11] Regarding flood frequency standards, the Author suggests a return period of 150 years for motorways and trunk roads, reducing to 30 years in some rural areas, and 5 years for submersible bridges. For bridges crossing valleys immediately downstream of a community, he suggests 1000 years. Table 7 suggests a range of from 200 years for long motorway bridges to 25 years for short rural bridges, but it is also recommended that due consideration be given to the maximum historical flood (whether measured or estimated indirectly), and to the possibility in certain regions of unusual types of flood that do not agree with frequency experience. Such floods occurred in Southern Ontario in 1954 as a result of a tropical hurricane; glacial-lake outbursts constitute another example.

41. With regard to bridge waterways, the Author does not give specific methods for determining waterway area for a given design flood discharge. The accompanying Fig. 5 shows a relationship between net surface width and discharge, based on the well-known Lacey relationship for alluvial channels; it is surprising how good a chart this often is as a check for adequate bridge widths on all kinds of channels. Another relationship for mean velocity through the waterway is given in Fig. 6, for cohesionless materials, and Table 4.1 of the *Guide to bridge hydraulics* gives suggested velocities for cohesive materials; these data can be used to check liability to general waterway scour. Detailed methods are given for estimating scour caused by waterway constriction of flood flows and by local vertex effects at piers.

42. When the Canadian guide was prepared, it was recognized that these guidelines were of a tentative nature and would need to be revised in the light of further experience.

R. B. Bulman, Consultant

Apart from its ambiguity, there are advantages in avoiding the use of the term 'mean annual flood'. 'The median value of annual maximum floods' is a much more stable starting point for the comparison of floods of differing probability.

44. Accuracy in the measurement of the highest floods often leaves much to be desired and this is reflected in instability in the determination of the average value.

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Table 7. Suggested frequency guidelines to assist in selection of design high-water level and discharge*[11]

Type of roadway†	Type of bridge‡	Frequency of flood conditions, %	Corresponding recurrence interval, years
Freeway	Long	0·5	200
	Short	1	100
Arterial	Long	1	100
	Short	1	100
Collector	Long	1	100
	Short	2	50
Local	Long	2	50
	Short	4	25

* These guidelines are not to be taken as necessarily defining design values.

† As classified in *Geometric design standards for Canadian roads and streets.*[12]

‡ Minimum dimensions to qualify as long bridge
(*a*) on freeway: clear span 35 m, handrail length 60 m
(*b*) on arterial road: clear span 30 m, handrail length 50 m
(*c*) on collector road: clear span 25 m, handrail length 40 m
(*d*) on local road: clear span 20 m, handrail length 30 m.

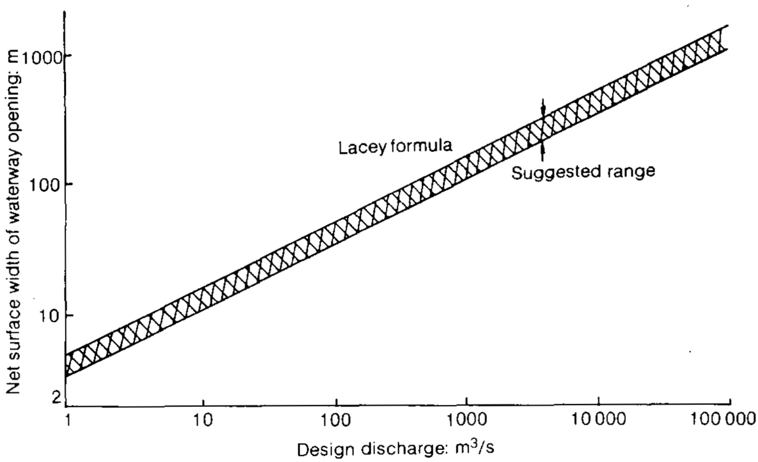

Fig. 5. Chart for selecting a trial waterway opening width based on Lacey's regime formula for alluvial channels

However, the stability of the median value is virtually independent of the accuracy of the few highest values in the sample.

45. Paragraphs 26–29 discuss the use of various equations for the determination of peak discharge, and §22 discusses regional growth curves. These may be considered suitable for the design of a submersible bridge on the basis of a non-

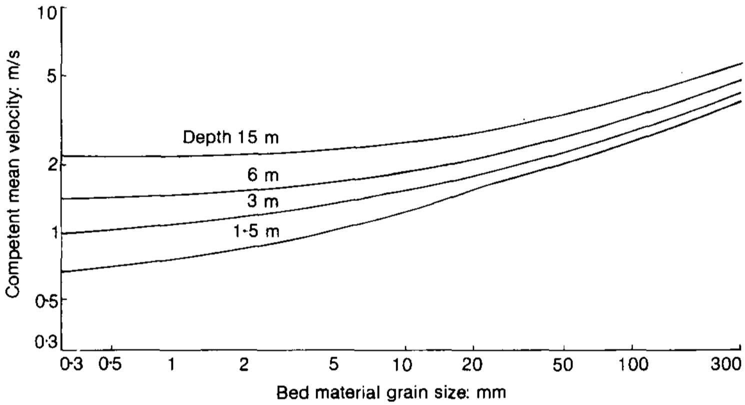

Fig. 6. Suggested competent near velocities for significant bed movement of cohesionless materials, in terms of grain size and depth of flow

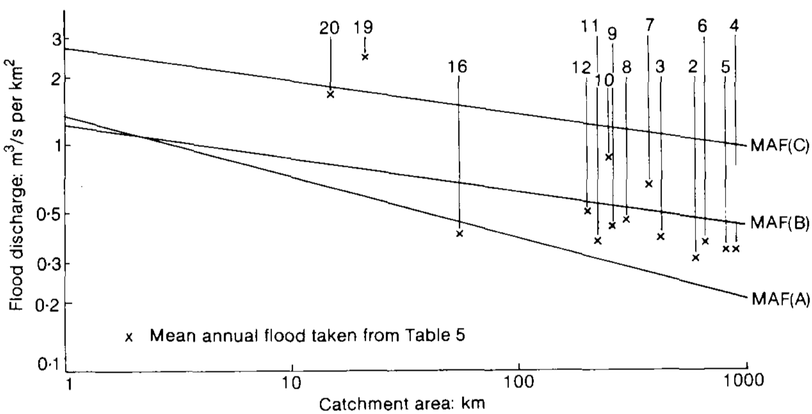

Fig. 7. Comparison of mean annual flood values for sites with records with values obtained from formulae in the **Flood studies report**

exceedance probability of, say, 0·80. Otherwise these equations and curves should be considered as no more than first approximations.

46. Where life is at risk the design merits, in the first place, a rigorous analysis of catchment and channels to determine the variation of critical duration with intensity of run-off. Following this the best available rainfall data must be analysed to determine the appropriate intensity in relation to critical duration at the required probability. All these calculations must be specifically related to the catchment in question and not merely reflected from surrogate data in other parts of the region.

Mr K. T. Bass, Rofe, Kennard & Lapworth

In Table 5 the mean annual flood is quoted for a number of sites with records and Fig. 1 gives curves obtained from formulae in the *Flood studies report*.[1] These are compared in Fig. 7. The errors of estimate resulting from adopting MAF(B) for

Table 8. Comparison of estimates of 150 year flood

Gauging station	Table 5 with growth factor of 2·6, m^3/s	MAF (B) with growth factor of 2·6, m^3/s	Quick method,[13] m^3/s	Using average height of catchment,[14] m^3/s
1	—	1253	1376	622
2	494	734	769	482
3	424	536	588	353
4	809	1036	1172	431
5	720	945	991	405
6	645	784	849	258
7	530	489	532	384
8	364	399	—	—
9	299	358	303	121
10	577	340	430	449
11	229	314	271	146
12	273	289	242	149
13	—	160	145	344
14	—	161	147	195
15	—	150	147	183
16	60	95	95	106
17	—	77	67	168
19	133	42	42	55
20	65	32	32	42
21	—	17	14	17

Devon could amount to a factor of 2, and will be compounded by applying any growth factors, for rarer floods, which themselves may have similar errors.

48. The minimum standard recommended is the provision for the 150 year flood, which is also the minimum recommended standard for reservoirs.[13] However, it is necessary to provide a margin and for bridge and culverts this takes the form of headroom to allow floating debris to pass.

49. Without a good record of river gaugings the estimates of the 150 year flood are liable to serious error. Table 8 shows the differences in various estimates for the 150 year flood. Unfortunately one cannot say which is the best estimate for any site as each involves the application of an average to the particular, but the difficulties are clear. Perhaps the highest estimate should be adopted to cater for the margin of headroom required.

Mr George

The information on Canadian practice provided by Mr Neill is valuable not only for his reminder that the designer must seek evidence or warning of unusual causes of flooding but for his indication of methods of ascertaining waterway area and particularly waterway width. In Devon where over 1000 masonry arch bridges remain, the provision of adequate waterway width has been seriously inhibited through the centuries by the method of construction. Consequently in Devon only modern bridges reach the waterway width standards shown in Fig. 5.

51. Nevertheless many ancient structures survive because they are founded in hard rock. Such a bridge is Staverton near Totnes which dates from 1413. It comprises seven arches of about 6 m span each, totalling 41·8 m of waterway width separated by piers 3·4 m wide. The distance from the river bed to the crown of the slightly pointed arches is approximately 5 m. This bridge lies on the River Dart and passed 550 m^3/s on 27 December 1979. Arch bridges in the soft rock regions of Devon have to be examined below waterline frequently as the river flows scour the river bed producing an inverted arch effect with the piers and abutments on the pinnacles.

52. The depth of bed movements shown in Fig. 6 explain the collapse of old arch structures founded too high on cohesionless soils where the scour effects of a flood are masked by the deposit of loose material under and around piers as the flood recedes. This leads to pier settlement and subsequent collapse some time after a flood has passed.

53. Mr Bulman has rightly drawn attention to more rigorous methods of assessment that are available and the exceptional care that must be taken where life is at risk. As time spent in the determination of the design flood is usually small compared with time spent on structural design, I consider that this reinforces the need for discussion of less rigorous but sound estimating procedures that can be available in the bridge design office. The use of these will lead to a more careful assessment of methods of providing adequate waterway for the minimum cost. Fig. 2 shows the logarithmic increase of return period compared with increase in waterway capacity. The increase in capacity need not lead to a *pro rata* increase in cost.

54. Mr Bass notes that the errors of estimate resulting from adopting the curve MAF(B) for Devon could amount to a factor of 2. This curve was drawn to explain, with MAF(C), how particular information is used and would not be applied as a design curve. Rather the particular values of (soil) and (RSMD) would be used in conjunction with the area to obtain $\bar{Q}$ as in equation (2). For this reason

the extension of curve MAF(C) in Fig. 7 to cover areas in the range 50–1000 km^2 is not applicable to Devon, because (RSMD) of 70 and (soil) type 5 do not occur together over these large catchments.

55. Table 8 shows the range of values that can be obtained for a 150 year flood using four different methods. For the bridge engineer the second column depends on access to records of MAF for the site he is considering, hence there are some dashes. For the reasons I have given the third column should be compiled using data for the particular catchment rather than the curve MAF(B) which is only for (soil) type 3 and an (RSMD) of 50. The quick method[13] has been found to be useful in Devon since the guide[13] was published because it was then possible to produce curves of 150 year floods for varying (RSMD) values as a design aid. As Mr Bass observes, the wise course is to assemble as much information as possible and include a margin for headroom before making a waterway estimate.

References

11. Roads and Transportation Association of Canada. *Guide to bridge hydraulics.* University of Toronto Press, 1973. Metric revision supplement, 1980.
12. Roads and Transportation Association of Canada. *Geometric design standards for Canadian roads and streets.* Roads and Transportation Association of Canada, Ottawa, 1976.
13. Institution of Civil Engineers. *Floods and reservoir safety: an engineering guide.* Institution of Civil Engineers, London, 1978.
14. Kennard J. and Bass K. T. *The effect of the average height of a catchment on the estimation of the intensity of flood discharge.* International Association for Hydraulic Research, Congress Lunch, 1963, Paper 2.22.