Paper No. 6369

Storm-water overflows: the operation and design of a stilling pond†

by

Derrick Ernest Sharpe, A.M.I.C.E.

and

Thomas William Kirkbride, B.Sc., Grad.I.C.E.

Discussion

Mr Peter Ackers (Principal Scientific Officer, Hydraulics Research Station) said that the Paper would be welcomed by sewerage engineers, for previously little information had been published about the design of stilling-pond overflows. He hoped that this example would encourage other drainage authorities to adopt an experimental approach, as the Authors had done when faced with a lack of established design data. It was a pity that the Authors had not been able to make a more comprehensive investigation of larger basins, and of other variations of the basic design they had chosen. Perhaps other establishments with greater facilities would fulfil this need in due course.

93. The Authors had had limiting chamber dimensions in mind when planning their research: they had thought it "unnecessary to investigate chambers which were unlikely to be constructed because of excessive cost or site limitations", and so had regarded a length of six diameters and a width of four diameters as the maximum size acceptable. However, a reappraisal of the proportion of the cost of a sewerage scheme to be allocated to overflow structures might not be amiss, and, if research were to demonstrate the need for even larger chambers, surely the call for a reduction in pollution would warrant the expenditure. The Authors' outlook had also been restricted by their failure to appreciate the possible advantages of continuous disposal of light solids, although they had accepted continuous disposal of heavy solids as a normal procedure. Much of their research hinged on the provision within the chamber of storage volume for scum, which was obviously necessary with a drowned pipe at the foul sewage outlet, but which might have been avoided by the adoption of a free-surface form of outlet control, e.g. a side-contracted flume or a vortex drop.

94. The introduction of the Boussinesq Number, which was a variant of the Froude Number using the hydraulic mean depth as the length dimension, had presumably been based on Engel's 1933 Paper on non-uniform flow⁷. However, Engel had since modified his ideas and now said¹⁶: "The Boussinesq Number does not represent a genuine law of dynamic similarity." Mr Ackers confirmed that the Froude Number, and not the Boussinesq Number, represented a proper comparison of dynamic and gravitational forces in open channel flow, but he doubted if either of these parameters was really appropriate to what was essentially a problem of sedimentation. Some further explanation of § 52 would be appreciated.

95. The use of balls of various sizes and densities in determining the effectiveness of the model basins had been ingenious, but, although the investigation had had the practical aim of deducing design recommendations, the Authors did not appear to have considered how closely prototype solids would follow the performance of the arbitrary model solids. Some comment on this aspect would be valuable. The properties of the material to be separated must affect the efficiency, and should therefore have been included in the list of variables in § 47.

96. Turning next to the actual experimental results, there could be no doubt of their

† Proc. Instn civ. Engrs, vol. 13, p. 445 (Aug. 1959).

value in the design of stilling-basin overflows of the pattern chosen, since no information at all was available before, but it should be realized that rather different results might have been obtained if the representation of solids had not involved discontinuities in the properties of the sample. Consequently, Mr Ackers was not convinced that a Boussinesq Number of 0.867 and a weir level of 0.9D above invert were necessary and sufficient criteria for efficient operation. In Fig. 11, for instance, the plotted points did not justify the shape of graph drawn, and did not indicate a limiting Boussinesq Number. Moreover, although the data of Fig. 12 showed a sharp drop in efficiency, the approximate agreement between the Boussinesq Numbers in the large and small chambers might nevertheless be fortuitous. Would the Authors not agree that the stepped form of the efficiency curve in certain tests might have arisen from the discontinuities in the properties of the solids injected, rather than from abrupt changes in the true performance of the chambers?

97. The Authors' interpretation of their data on the variation of water depth with discharge was not very convincing. The points shown in Fig. 11 for a sill at 0.84D did not really support the suggested "two distinct laws which are linked by an abrupt transitional region", although one might anticipate a gradual transition from weir-type discharge to orifice-type discharge as the head increased and the influence of the scum boards became more pronounced. Might not the "two critical values" mentioned in § 71 have again been due to discontinuities in the sample of solids, rather than to subtle changes in the discharge function?

98. The brief description of a model of a typical side-weir overflow was very enlightening: it was now generally realized that an overflow of this type, with controlled outlet and scum boards, did not perform in "text-book" manner, and this had now been demonstrated convincingly. The Authors had confirmed that this type of overflow was not a selective device; it was quite ineffective in separating light solids when downstream control forced a standing-wave back into the chamber. The investigation of a siphon spillway in the stilling basin was obviously of limited scope, and it was to be hoped that the Authors' recommendation for further research would be noted by universities with suitable facilities. Mr Ackers would recommend the use of full-width air-regulated siphons giving a discharge continuously adjusting itself to suit inflow, in place of the usual form of siphon running intermittently to "black-water", which led to undesirable discontinuities in flow conditions.

99. The design of stilling-basins for storm overflows was probably more akin to sedimentation tanks than to the energy-dissipating hydraulic structures bearing the same name, and so present-day ideas on the efficiency of sedimentation tanks might repay study. These ideas stemmed largely from Hazen's theory¹⁷ that settlement depended primarily on the surface area of the basin, as might be derived by considering particle trajectory¹⁸. Several American investigators had recently lent support to this concept^{19, 20} and the suggestion was made that the primary basis of correlation for comparing efficiencies was the Hazen Number, which might be defined as:

$$H_n = \frac{\text{the mean settling velocity of the solids}}{\text{the discharge per unit of surface area}}$$

100. Further factors of importance were the momentum of the incoming flow, and the turbulence in the basin by which settled solids might be re-entrained. These factors might provide pointers to a better understanding of stilling-basin design.

Mr R. S. Tymms (Abingdon Borough Council) observed that the design method for stilling-pond overflows appeared both thorough and workable on the basis of the experimental findings. Could the Authors give their views on the question of design of the throttle pipe? Having fixed the chamber dimensions according to their recommendations, the last stage in the design of the overflow was the selection of the type of throttle to be used and the calculation of its dimensions. Perhaps the first question that arose was the selection of the head to act on the throttle; it was not clear from Fig. 17 whether the value of H_w was intended to serve or whether some larger value might be chosen.

If the latter was the case, had the effect on performance of deepening the chamber to gain the desired head been considered? Similarly, what might be the effect on operation if, say, a level invert throughout were adopted?

102. The throttle device would almost invariably be a pipe of suitable diameter laid to a suitable fall, but there was probably a lower limit to this straightforward method of control. If the flow demanded it, should a 6-in.-dia. pipe be adopted in view of the fact that many engineers considered a foul sewer should not be less than 9 in. in diameter? In such a case it would be preferable to limit the length of the 6-in.-dia. pipe to that necessary to give the required control and to continue the sewer run below this point as a 9-in.-dia. pipe. Such an arrangement would reduce the potentiality for blockage and also locate a possible blockage within a relatively short distance from the overflow chamber so that it could be rodded clear more easily. Did the Authors consider that a 4-in.-dia. throttle pipe might be used safely?

103. Mr Tymms questioned whether the transverse fall chosen for the experimental chamber floor would be steep enough for practical use. The Authors had stated that generally the balls of greater specific gravities than unity passed through the throttle pipe but, in fact, would not sewage grit and lighter solids be left high and dry on a floor of this slope during the gradual fall of water level at the conclusion of a storm? If a steeper slope, say of 30° or more (as high as the weir permitted) was chosen, better clearing of the floor would result, but would the Authors' conclusions as to the ideal dimensions still be valid if such a modification were to be made?

The Authors, in reply, agreed that a comprehensive investigation into the performance of stilling-pond overflow chambers of larger dimensions would be of considerable academic interest, and they would have welcomed the opportunity to undertake such research. The investigations described in the Paper had been carried out to obtain design information and were undertaken with a sound background of practical main drainage experience. The minimum chamber dimensions advocated were more generous than many designs recently constructed. Wide experience in the practical design, location, and construction of storm-water overflow chambers had indicated that site conditions normally precluded the construction of chambers of large horizontal dimensions. The highway building lines imposed an outer limit which was normally greatly reduced by a maze of existing underground services. It was essential that the benchings of stilling-pond chambers were constructed to a self-cleansing gradient since mechanical or manual cleaning would present unreasonable operational problems and expenses. In very large chambers the provision of self-cleansing benchings would require a large differential head between the incoming and outgoing sewers. This head would seldom be available. Overflows in actual operation indicated the tendency for grit and floating solids to be deposited on the chamber benchings. A floor slope of 1 in 4 had been found to be reasonably self-cleansing.

105. Observation of a full-scale overflow indicated that the volume of solids was unlikely to exceed the volume available for storage. By setting the weir at 0.9D maximum use was made of storage within the sewer, and the overflow came into operation infrequently. Heavy storms were required to produce precipitation over the weir and they were usually of short duration. Thus, there was little likelihood of large volumes of floating matter collecting on the surface in those short periods. The volume of solids in sewage was very small in relation to dry-weather flow and even smaller in relation to storm flow. The volume of solids was not a function of storm discharge: more nearly, it was a function of time.

106. The advantages of the continuous disposal of floating solids were fully appreciated but the Authors were not aware of a suitable outlet control that would provide that facility. Designs had been prepared using side-contracted flumes but they had been abandoned as impracticable. The volume of sewage passed forward down the sewer, its ratio to the volume of storm-water overflowed, and the relatively large differential head between the incoming and outgoing sewer normally resulted in a deep flume with an unreasonably narrow throat. The throat would trap sewage solids and rapidly

obstruct. The exact application of a vortex drop to those conditions was not fully appreciated. It was, however, considered that such an outlet would preclude the continuous disposal of heavy solids, resulting in sedimentation with attendant obstruction and septic conditions in the sewer and chamber during dry-weather periods. In addition the vortex inlet would collect rags and the volume of sewage passed forward would rapidly increase as the water level in the chamber rose. The use of a venturi flume as an outlet control was not advised. Large sewage solids would tend to obstruct the taper approach to the throat and consolidate into a serious obstruction under water pressure.

107. The Authors did not know of a form of outlet control that was superior to the submerged throttle pipe. Hydraulic design presented some indeterminate problems. It was difficult to calculate the pipe inlet losses. The importance of those losses would be reduced if the pipe was made as long as possible. Under those conditions the more accurately calculable friction losses dominated. It was unwise to use pipes of less than 6 in. dia. The danger of obstruction was reduced if the approach channel extended up to the level of the soffit of the throttle pipe. Large solids then collected across the adjacent benchings above the outlet pipe. The submerged throttle pipe had disadvantages but it provided a reliable outlet control of reasonable dimensions. In addition the volume of sewage passed forward down the sewer would not be greatly increased as the hydraulic head rose from H_w to $H_{\max}$. That resulted in the overflow not operating until the downstream sewer was nearly charged to capacity, and prevented surcharge of the sewer at periods of maximum overflow discharge.

108. Storm-water overflows were normally designed to operate at a predetermined degree of dilution. The outlet control should pass that volume of sewage forward to the sewer with the design head H_w . In addition the downstream sewer should be of adequate size to pass the discharge from a head of $H_{\max}$. The most suitable throttle pipe diameter and length was usually selected by a process of mathematical trial and error.

109. The Boussinesq Numbers quoted in the Paper referred to the flow in the inlet pipe. They were calculated from the formula:

$$\text{Boussinesq Number} = \frac{v}{\sqrt{gr}} \quad \text{where } r = \frac{2A}{p}$$

Since it was a condition of flow that the inlet pipe must always flow full (i.e. $\frac{2A}{p} = \frac{D}{2}$) the formula resolved into:

$$\text{Boussinesq Number} = \frac{v}{\sqrt{gD/2}}$$

which bore a constant relation to the Froude Number $\left(= \frac{v}{\sqrt{gD}} \right)$. In that case, there

was no inconsistency in using the Boussinesq Number.

110. In 1933, Engel⁷ referred to five conditions of flow, three of which were:—

- (1) Turbulent (Boussinesq Number between 0.4 and 0.85).
- (2) Intermediate range (Boussinesq Number between 0.85 and 0.95).
- (3) Rapid flow (Boussinesq Number 1).

Referring to Fig. 10, it was possible to consider the shape of the graph in relation to those flow conditions. First there was the range up to a Boussinesq Number of 0.867 in which efficiencies were high, but reducing slightly as the energy of the incoming water increased. That was the "turbulent range". At a Boussinesq Number of 0.867 a dramatic change occurred and it was obvious that a new regime of flow in the pipe had taken control of happenings in the chamber. The flow in the pipe was then in the "transitional stage" and approaching the region of "rapid flow". Reference to Boussinesq Number therefore provided an effective means of describing the entry

flow in terms which had a direct bearing on efficiency and for that reason the use of the Boussinesq Number was perpetuated.

111. The efficiency tests were designed as a standard or yardstick for the comparison of the performance of various chambers. The tests performed that function most satisfactorily. Prototype solids had indeed been used in a few tests and their performance had been similar to that indicated by the model test solids. The use of prototype solids did not lend itself to experimental measurement and could not readily be expressed in quantitative form. In § 85 the full-scale observation of actual overflows was advocated. Such observations would do much to relate the theories indicated in the Paper to actual site operation.

112. It was agreed that the operational performance of any chamber depended on the properties of the sewage entering the overflow. For the purpose of comparing the efficiency of different chambers those sewage properties must be assumed constant and were therefore omitted from § 47.

113. When the preliminary tests were undertaken it was visibly obvious that an upper critical inlet velocity existed. Above the critical inlet velocity increases in the chamber dimensions had very limited effect upon the turbulence in the chamber. The subsequent efficiency tests made it possible to measure and define conditions that were already observably apparent.

114. Mr Ackers had suggested that discontinuities of the sample solids might account for the "two critical values", mentioned in § 71. A wide variety of tests had been undertaken, and the use of balls with continuity of size and density had indicated critical values of the same order as those recorded in the Paper.

115. It was normal to compare the operation of a stilling-pond overflow chamber with that of a sedimentation tank. That theory was instanced in the Code of Practice on Drainage (Sewerage) referred to in § 6. To suggest that the problem was essentially one of sedimentation indicated a lack of practical knowledge and a complete rejection of the basic operational conditions observed and recorded in Fig. 6. The research undertaken indicated that stilling-pond overflow chambers as at present constructed seldom resembled a sedimentation tank in their mode of operation. Their primary function was the dissipation of the energy of the incoming sewage and the creation of flow patterns favourable to the separation of the more offensive lighter and heavy solids. In many existing stilling-pond overflow chambers the incoming water would at times of storm shoot through the chamber and over the storm weir unimpeded, and it certainly would not resemble a sedimentation tank in operation. The designs advocated in the Paper were intended to dissipate the energy of the incoming sewage and effect separation of sewage solids.

116. The Authors fully realized that considerably more model and full-scale investigation was required to obtain more detailed information for the design of stilling-pond overflow chambers. It was hoped that more extensive research would be undertaken into that important and interesting aspect of sewerage design.

REFERENCES

16. F. V. A. Engel and W. Stainsby, "Weirs for flow measured in open channels". *Wat. & Wat. Engg.* vol. 62 (April, May, June 1958), pp. 142, 190, and 238.
17. Allen Hazen, "On sedimentation". *Trans Amer. Soc. civ. Engrs.* vol. 53 (1904), p. 45.
18. C. B. Townend and G. W. Wilkinson, "Some hydraulic aspects of sewerage and sewage disposal". *Proc. Instn civ. Engrs.* Pt III, vol. 4, p. 662 (Dec. 1955).
19. D. E. Bloodgood, W. J. Boegly, and C. E. Smith, "Sedimentation studies". *Proc. Amer. Soc. civ. Engrs.* vol. 82, SA5 (Oct. 1956).
20. A. C. Ingersoll, J. E. McKee, and N. H. Brooks, "Fundamental concepts of rectangular settling tanks". *Trans Amer. Soc. civ. Engrs.* vol. 121 (1956), p. 1179.