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Verification on physical model of the erosion downstream of an asymmetrical stream flow

G. Ciaravino , L. Ciaravino

In the present paper a particular laboratory experience carried out by means of a physical model (in accordance with Froude's law of similitude) is shown; such experience has pointed out that the study of the three-dimensional effects is fundamental for the identification of technical solutions producing the reduction of scours that can be verified downstream of a stilling basin. In particular the works analyzed by means of model, even if in theory correctly designed, are characterized by a strong asymmetry both from the geometric point of view and from the point of view of hydraulic working; such asymmetry, giving rise to casual phenomena of stream flow concentration, determines an anomalous working of the stilling basin and deep scours in the mobile river bed subject to erosion reproduced in model. The experimental study on model has led to variations of the design scheme for the stilling basin that, through the elimination of concentration and asymmetry in the stream flow, have produced the effect of a drastic diminution of the scours. Therefore the present study, in spite of its specificity and particularity, has allowed to achieve some considerations that can be held of general validity.

1 Introduction

Frequently for free surface streams the theoretical framework of the hydraulic phenomena can not be easily represented. For the more complex schemes (three-dimensional), to which it is not always possible and correct to apply the simplifications that have allowed the singling out of the design rules, it seems necessary to fall back on experimental studies. Among these schemes it is possible to enumerate works as stilling basins of energy dissipation which have been studied by Nebbia some decades ago (Nebbia, 1940, 1941). In such basins water discharges (endowed with a considerable kinetic energy) derived, usually, from outlet works of storage reservoirs, disperse large part of the energy possessed by the stream through the formation of a hydraulic jump. The mathematical models that are used for the design of a stilling basin are, generally, based on the hypothesis to have hydrodynamic processes not conditioned by side walls: therefore the unitary rate flow $q = Q/B$ is taken as fundamental parameter, where Q is the flow rate discharged and B is the width of the stilling basin (Nebbia, 1941). Moreover it is known that frequently downstream of the stilling basins localized scours are verified (due to the residual energy possessed by the stream) particularly in the passage from the paved floor of the basin to the mobile river bed. It is possible to notice that the assessment of such scours is generally effected, once more, on the basis of mean parameters of the stream as the above mentioned unitary flow rate q. A first really systematic research concerning erosion on mobile bed has been carried out by Schoklitsch (1935): such research, besides the simplifier hypothesis of plane motion, is founded on the hypothesis that the maximum scour depth is independent of mobile bed material characteristics. Subsequently many Authors have proposed experimental formulas and/or formulas with analytical origin for the evaluation of the maximum scour, such formulas take into account, in some cases, both the characteristics of the mobile bed material submitted to erosion and three-dimensional hydrodynamic schemes, even if simplified (Adami, 1971; Rajaratnam & Macdougall, 1983; Nola & Rasulo, 1989; Graf & Altinakar, 1998; Kurniawan et to the., 1999; Karim & Wings, 2000). Generally, however, the hypothesis of constant flow rate for unit of width q is confirmed. Actually, in the practice, often the boundary conditions diverge from the ideal conditions of motion on which the usual mathematical or experimental models are based (Ciaravino, 2004). Therefore a laboratory experience will be shown, which points out as the three-dimensional study is determinant in the identification of solutions that bring to the reduction of the scours downstream of a basin for energy dissipation.

2 The study on model

The study is based on the verification by means of physical model of the operation of the outlet works of the storage reservoir of Farneto del Principe on the Esaro River (Southern Italy). The outlet works (with reference to the prototype) are synthetically constituted by: an spillway n.1, formed by a weir crest set 136.30 m over sea level divided in four parts each of them 6.10 m wide and regulated by automatic gates; an spillway n.2, formed by a weir crest set 139.70 m over sea level and 101.00 m long, conveying the discharges in a manifold side channel with variable trapezoidal cross section; two bottom outlets constituted by two tunnels each of them having circular cross section of diameter d = 4.95 m, before the interception gates of discharges whereas polycentric (horseshoe) cross section of diameter d = 4.80 m is adopted after interception gates; a stilling basin for energy dissipation with depressed apron, 112 m long and 60 m wide, in which the flow rates of discharged water are concentrated both from the spillways, by means of a unique linking free flow channel, and from the bottom outlets. The part of the study on model that will be reported aims to clarify the working of the basin for energy dissipation foreseen in order to reduce, within tolerable limits, the scours in the downstream mobile river bed submitted to erosion. With regard to this, the mobile river bed downstream of the stilling basin has been reproduced in model (for separate series of tests) by means both of sand (2 mm < d_s < 4 mm), and of gravel (6 mm < d_g < 10 mm). Apart form the erosion phenomena in the mobile river bed downstream, keeping negligible the effects of viscosity, surface tension, elasticity and cavitation and being the stream regulated by the gravity, the Froude's similitude law has been held valid. Therefore the physical model has been reproduced in geometric similitude with scale of reduction 1:50. First of all it is important to observe that just a few of the several tests concerning the stilling basin will be reported (that have involved some hundred working hours of the experimental installation) and particularly the conclusive tests will be reported that allow, besides, the deduction of some results held of general validity. Moreover only the tests related to the contemporary working of the two spillways will be reported (maximum flow rate in model Q_{m1-2} = 64.20 l/s corresponding to the maximum flow rate in prototype Q_{p1-2} = 1135 m^3/s) in which gravel has been used for the reproduction of the mobile river bed: such material has allowed a remarkable simplification in the way of execution of the tests and a quick comparison of the scour entity in the different solutions adopted. The early experimental tests, conducted on the outlet works as foreseen by the designers, have pointed out an asymmetry which is geometrical and of hydraulic working; such asymmetry causes a concentration of flow making the stream thickened sometimes toward one side, sometimes toward the other side of the stilling basin. In fact, in consequence of the circumstance that the two spillways have different levels of weir crests, different ways of inlet to the linking channel and different flow rates of water discharged, the stream is already meandering and asymmetrical in the linking free flow channel between the weir crests and the stilling basin. Particularly, when the central part of the stream, endowed with larger water depth and velocity, moves toward of one side of the basin either toward the other side, large vortexes with vertical axis are determined. Such vortexes also affect the outflow over the sill placed on the downstream end of the basin. The possibility that such part of the stream moves at random under one side either the other side also influences downstream scour phenomena which are localized sometimes on a side of the river bed, sometimes on the other one, in a substantially unpredictable way. In effects, in correspondence of the above mentioned maximum flow rate, also for tests in which mobile bed is reproduced with gravel, scours reach remarkable values (10 ÷ 11 cm in model). In Figure 1, with reference to the originally designed device, the results are shown concerning scours occurred in one of such early experimental tests. The tests have definitely pointed out that the asymmetry of stream makes difficult the application of dimensioning mathematical models founded on the hypothesis of constant flow rate for unit of width q. Therefore a solution has been sought that, renouncing to achieve the dissipation of surplus of hydraulic head possessed by the stream at the basin inlet only by means of hydraulic jump, is able to reach the aim through the action of a series of baffle piers. Particularly a solution has been sought in order to achieve dissipation of superabundant head and elimination of stream asymmetry at the same time.

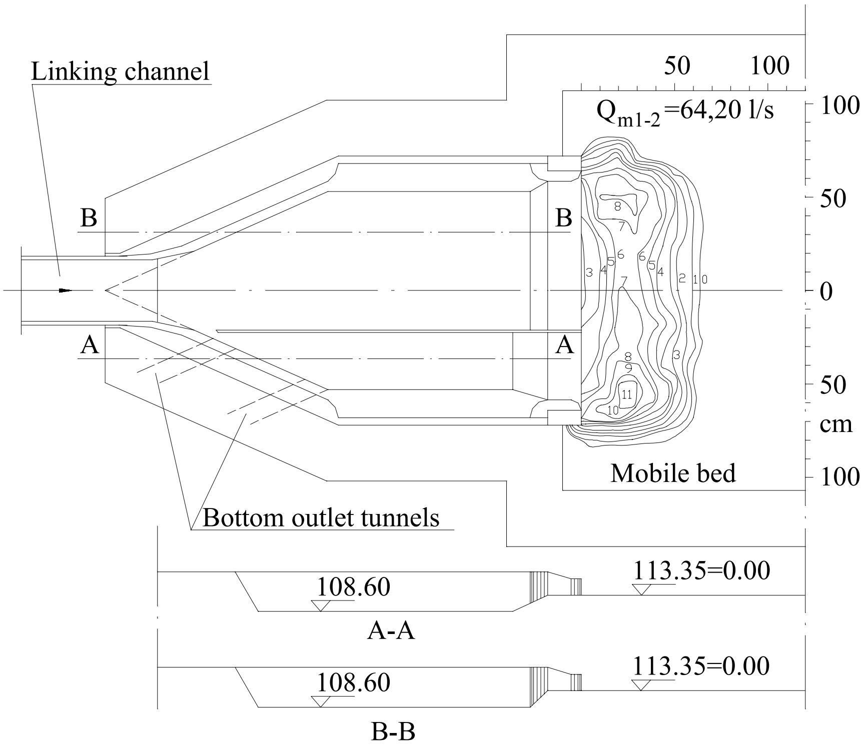

Figure 1 Preliminary test with originally designed basin (Q_{p1-2} = 1135 mc/s)

The first solution adopted, represented in Fig.2, slightly changes the geometry of the stilling basin, being the variant limited to the insertion of baffle piers near the inlet of the basin and to a different profile of the downstream sill. Particularly the variant consists of: two lines of prismatic shaped baffle piers 2.00 m wide (in prototype) and with triangular longitudinal section, whose dimensions are 7.50 m, as it regards the base length and 1.50 m, as it regards the cathetus - height set downstream; two lines of cubic shaped baffle piers whose side is 2 m long. The tests show (Fig.2) that maximum scour is slightly decreased (8 cm in model) and that the asymmetry, observed in the early tests, is still present and therefore it is not possible to establish steady and predictable working conditions. Consequently the experimenters has definitely worked on the elimination of the asymmetry.

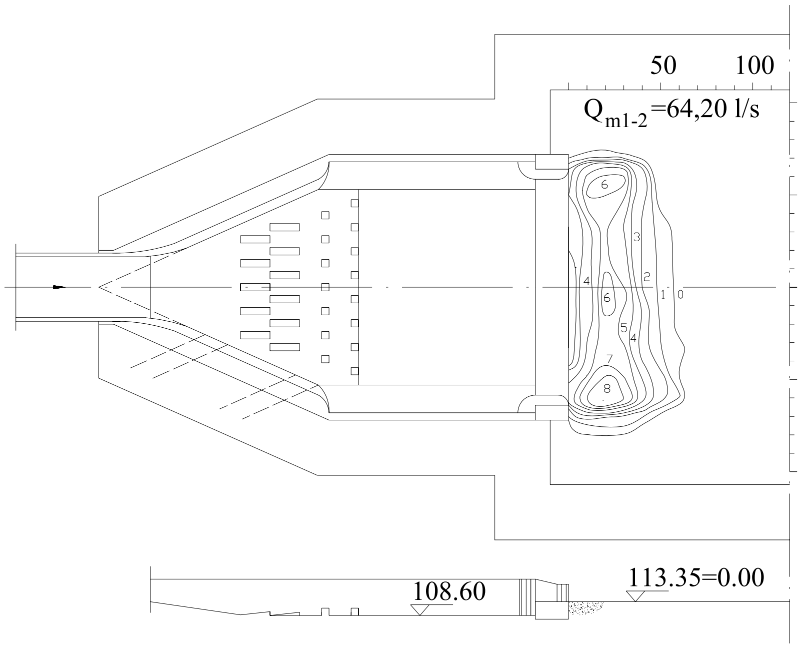

Figure 2 Test with modified basin - First solution (Q_{p1-2} = 1135 mc/s)

Therefore in the second solution reported in Fig.3 more radical variations have been carried out and particularly: the zone, where baffle piers have been situated, has been extended; baffle piers have been set on seven lines, two lines with triangular longitudinal section and five lines with cubic shape.

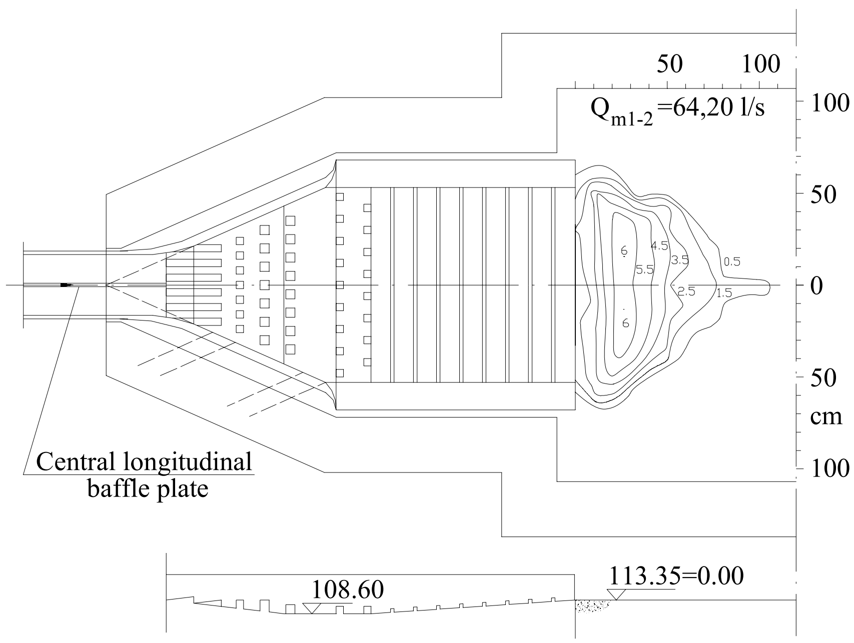

Figure 3 Test with modified basin - Second solution (Q_{p1-2} = 1135 mc/s)

Moreover the final sill has been eliminated giving to the longitudinal configuration of the basin a shape of inverse scalene trapezium; on the adverse slope linking with the downstream river bed a series of small sills across the basin has been set; such sills have a square transverse section with side 1 m long (in prototype); a central longitudinal baffle plate has been placed in the channel linking spillways and stilling basin, such baffle, with variable height, aims at decreasing the stream meandering already before the basin inlet. The tests, with the so modified basin, point out (Fig. 3) a limitation of the meandering phenomena of the stream (also owed to the presence of the longitudinal baffle placed in the linking channel) and a decrease of the maximum scour (6 cm in model). Scours occur always in the same areas, also having repeated the tests over and over again. Taking into account the former experimental tests stilling basin has been definitively modified as shown in Fig. 4 and in particular:

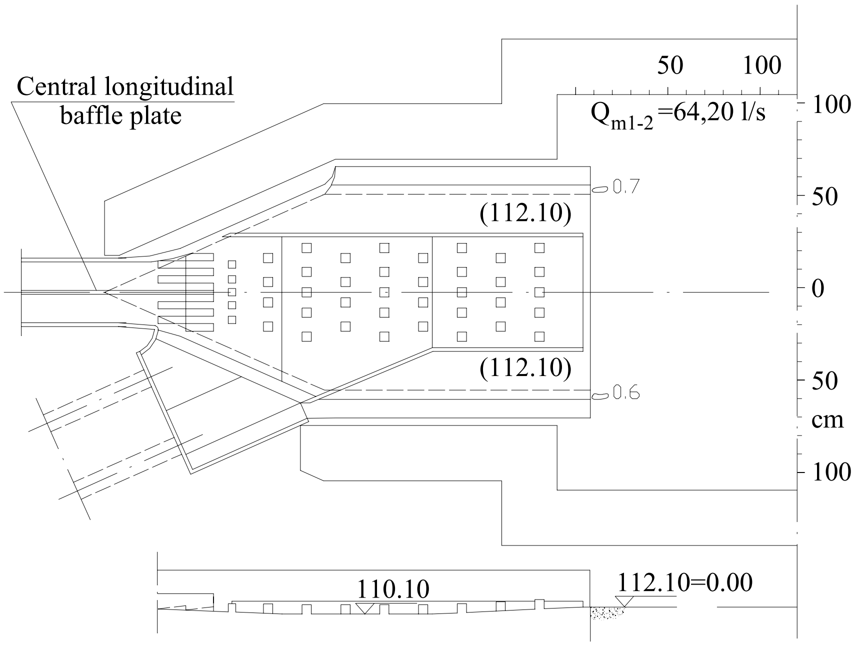

Figure 4 Test with modified basin – Final solution (Q_{p1-2} = 1135 mc/s)

the horizontal part of the apron of the basin has been raised, from the originally designed quota of 108.60 m over sea level, to quota 110.10 m over sea level (measures of prototype); the bottom quota of basin end section has been lowered, from the originally designed quota of 113.35 m over sea level, to quota 112.10 m over sea level; baffle piers have been placed in the basin concentrated, however, only in the central zone of the basin where the stream is endowed with larger kinetic energy; the basin bottom is raised, in the two remaining parts at the two sides of the central zone with baffle piers, also to quota 112.10 m over sea level; the central baffle with variable height has been made slightly longer, in the channel linking spillways and stilling basin. The baffle piers consist of structures set in lines endowed with increasing height and staggered in order to avoid excessively “prancing” stream and in particular: the first two lines are still prismatic shaped, 2.00 m wide in prototype and with triangular longitudinal section whose dimensions are 7.50 m, as it regards the base length and 1.50 m, as it regards the cathetus - height set downstream; the third line is cubic shaped with side 2.00 m long; the remaining lines are cubic shaped with side 2.50 m long. The so modified basin accomplishes its function of dissipation and it almost completely eliminates the phenomena of asymmetry, of meandering and of thickening of the stream thus providing scours, with tests repeated over and over again, which are very small and even measurable only with the maximum flow rate. Indeed the maximum scour under such conditions is equal to 0.7 cm.

3 Conclusions

The present research, even if characterized by intrinsic specificity and particularity, also achieving results substantially qualitative, confirming the importance of the physical models, has produced some considerations that can be held of general validity. Experimental tests have pointed out that in the case of asymmetrical (and three-dimensional) streams the mathematical models commonly used in order to dimension stilling basins for energy dissipation, failing the hypothesis of constant flow rate for unit of width q, provide results which are strongly approximate and therefore not acceptable for the purpose of practical applications. Therefore a good rule seems to study in a more careful way, already in the preliminary design phase, the geometry of the outlet works of the storage reservoir, not excluded the weir crests. Moreover, when the asymmetry of the inlet works of the stilling basin is actually not removable, it must be ruled with a suitable conformation of the stilling basin: from experimental tests it can be deduced that it is even convenient to reduce the volume of the stilling basin provided that this allows the elimination of stream meandering and a larger efficiency of baffle piers (in such case baffle piers are necessary). As a consequence of the elimination of the meandering it is easier to place baffle piers in such a way that they always collide with the part of water flow endowed with the larger quantity of kinetic energy. Moreover the control of the asymmetry can be achieved in a larger way by adopting inverse scalene trapezium as a shape of longitudinal section of the stilling basin with the longer oblique side linking with the downstream end section. In effects such better shape is rather complying with the geometric shape of scour which occurs in a river mobile bed that, in correspondence of a vortex, tends to produce a quasi-steady configuration.

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