CHAPTER - VI

SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF THE PRESENT STUDY

The salient features of the investigation made by the writer is summarised as follows, with the suitable comments wherever necessary.

(1) The flow characteristics below a sluice can be described completely by the diffusion characteristics of the jet, the growth of boundary layer with distance, velocity distribution law, the development of boundary shear stress and its variation with time, and the critical shear stress at the location of maximum scour.

(2) The diffusion of two dimensional horizontal wall jet can be described following the procedure as proposed by Albertson et.al. The reduction of maximum velocity with distance from the sluice (jet efflux section), cannot be expressed as a simple function of the efflux velocity and the thickness of the jet ; it is rather expressed as a function of the efflux velocity and the thickness of the jet, the length of the rigid apron and the representative grain size of the erodible bed, in the more general form.

(3) The growth of the boundary layer along the rigid apron is not similar to that along the erodible bed; this growth , rather , is faster along the erodible bed as compared to that along the rigid apron and obviously there exists a transition zone in between. However, the growth of the boundary layer thickness has been found to depend on the distance from the sluice (jet efflux section), the length of the rigid apron, the tailwater depth and the characteristic grain size of the erodible bed.

(4) The velocity distribution along the vertical (i.e., normal to the bed) on the rigid apron is different from that on the erodible bed. The velocity distribution over the rigid apron deviates considerably from that due to the classical wall jet and that due to the submerged wall jet flowing over a rigid apron and then on to an erodible bed, specially in the region beyond the boundary layer. The vertical velocity distribution within the boundary layer on the erodible bed can be expressed in the polynomial form as well as in the form of power law for different ranges of η.

(5) The expression for the critical shear stress at the location of maximum scour at the state of equilibrium, has been developed from the solution of Vón Kármáns momentum intergral equation, and it has been obtained as the function of the efflux velocity and the thickness of the jet, the tailwater depth, the length of the rigid apron, the distance of maximum scour point from the sluice and characteristic grain size. The critical shear stress as computed using the expressions developed with Sheild's Criteria, shows good agreement in case of the gravel bed, whereas a great deal of discrepancy exists in case of the sand bed.

(6) The time variation of the boundary shear stress at the location of the maximum scour has been obtained with the help of a Preston tube, for which relevant expression for the pressure-shear relationship has been developed using appropriate velocity distribution law (power law). The functional relationships of the shear values, non-dimensionalized with respect to the critical shear values (i.e., τ_t / τ_{oc}), in term of non-dimensional time ratio (i.e., t/T), have been developed for the appropriate ranges of validity for both the sand bed and the gravel bed. The use of the Preston tube in case of the gravel bed has been found to give satisfactory results, whereas in case of the sand beds the agreement is rather unsatisfactory.

(7) The overall scour characteristics have been found to be adequately described through the development of functional relatioships to evaluate the maximum depth of scour at any time and its location from the end of rigid apron, the length of the scour hole at any time, the volume of scour at any time, the time required to reach the state of equilibrium and the maximum scour depth at the equilibrium stage the volume and weight rate of sediment transported at any time.

(8) The nature of scour profiles shows similarity in character, being independent of time of scour but dependent on the grain size of the bed materials. In the present study, it is very interesting to note that at any instant of time, the product of the length of scour hole and the maximum scour depth of corresponding scour profile, bears a constant ratio to the volume of scour per unit width for a particular type of bed material and thereby confirming the similarity of scour profiles. The scoured bed profile, in the non-dimensional form, for its major part, follows the "Sine Curve" in case of the sand beds ; but it deviates from that in case of the gravel bed.

(9) The time period required to be elapsed to reach the state of equilibrium, varies exponentially with the efflux velocity of the jet for a particular length of the rigid apron and for a particular bed material and hence, the equilibrium time can be expressed as a function of the efflux velocity of the jet, the length of the rigid apron and the representative grain size of the bed material. The maximum scour depth at the equilibrium stage has been found to be expressible in terms of the efflux Froude number of the jet, the efflux thickness of the jet and the characteristic grain size of the bed material.

(10) It has been observed that the rate of scour is significantly higher during the first one-third of total time of scouring (i.e., time required to attain the state of equilibrium) and comparatively gets slower at the later stage and as such two different relationships are necessary to express the time variation of the volume of scour for two different time limits, for the whole period of scour. Volume of scour at any time instant, however, can be expressed in terms of the efflux velocity and thickness of the jet, the tailwater depth, the length of rigid apron, the representative grain size of the bed material and the time elapsed upto that instant.

(11) From the similarity in geometry of the scour profiles, it is obvious that the maximum depth of scour at any time and its location from the end of the rigid apron and the length of scour hole at any time are directly related to the volume of scour at the corresponding time instant and as such those parametrs can be expressed as functions of the volume of scour only. While expressing each of these parameters as function of time, two different relationships obtained for two different time limits as applicable to the expression for time variation of the volume of scour.

(12) The expressions for the volume rate of sediment transport have been developed by differentiating the expression for volume of scour (at any time), with respect to time and obviously , two different relationships are obtained - one being valid for the first one-third of the equilibrium time and the other for the remaining period of scour . Subsequently , the expressions for the weight rate of sediment transport have been developed from the corresponding volume rate of transport and characteristics of the materials of erodible bed, separately, for each representative grain size.

(13) Finally, the similarity criteria for the sediment transport has been investigated following the famous stream power concept of Bagnold, used in the conventional river transport. It has been found that a generalised transport equation correlating the weight rate of sediment transport with the fluid power of the jet and the transport stage $(u_*/u_{*o}-1)$, alongwith the non-dimensional parameters concerning the diffusion characteristics of the jet can be formulated ; the parameter "transport stage" being analogous to the "excess sediment number", $(N_s^2-N_{sc}^2)$ after Carstens. Herein a single relationship describes the transport law applicable to both the sand bed and the gravel bed for the whole range of the scouring process. It is, however, observed that apart from the flow parameters and the sediment properties , the diffusion characteristics of the jet, the length of the rigid apron and the tailwater depth play very important role in the sediment transport below a sluice.

6.2 PRACTICAL APPLICATION OF THE PRESENT STUDY

In the present study, apart from developing various functional relationships to describe the flow characteristics and the scour phenomena , the similarity criteria for the sediment transport has been formulated , which will be useful to the professionals seeking simulation of sediment transport in the model or for predicting the behaviour of the prototype with the help of model studies. Moreover, various empirical relationships developed in this study are useful in the design of the scour protecting structures downstream of sluices, spillways etc.

6.3 SCOPE OF FUTURE WORK

In the present study it has been observed that the critical shear stress values obtained from Shield's criteria do not agree with those obtained from the solution of Vón Kármán's momentum integral equation, specially in the case of sand beds. It seems that the criteria for incipient motion in the case of scour due to jets may be different and further investigation is required to study the phenomenon.

The boundary shear stress during the development of scour hole has been estimated from the pressure-shear relationship for a Preston tube using the values of dynamic pressure drop recorded by the tube at different time instants. The use of the Preston tube for the estimation of shear stress seems to be satisfatory in case of the beds composed of coarser particles only. To extend the use of Preston tube to the case of the beds composed of finer particles, further study is necessary.

In the formulation of the similarity criteria for the sediment transport, it has been noted that the length of the rigid apron, the tailwater depth and the sediment properties have a great influence on the scouring process. Hence, it is suggested that, for the general applicability of the expressions developed in this study, further investigation is required with large range of variation of those parameters to explore their complete effect on sediment transport below a sluice.