Chapter 1

Introduction

Hydraulic jump type energy dissipators are widely accepted methods of energy dissipation while designing the hydraulic structures like dams, weirs and barrages. They are popular for their simplicity and efficiency, but have certain limitations when there is variation in discharge conditions. The energy dissipators satisfactorily function at design discharge condition. But in case of varying discharge conditions they are not efficient as the location of hydraulic jump tends to shift on apron. This would result in percentage reduction in energy dissipation and in turn damage hydraulic structures and adversely affect tail channel conditions. Hence with an aim to resolve this problem, an attempt has been made to create a forced hydraulic jump at desired location for varying discharge conditions. A new technique is developed and studied in depth for designing hydraulic jump type energy dissipators with reference to tail water deficiency.

The forced hydraulic jumps are used for energy dissipation in stilling basins. It is a jump formed with the assistance of baffles and/or sill with or without sub critical tail water. In the recent past the contribution in this regard is due to Rajaratnam (1971, 1991, 1995, 2002), Bhowmik (1975), Hager (1989, 1992), Chaudhry (1991, 1995) et al. A hydraulic jump forms when a high velocity supercritical flow suddenly transforms into a relatively low velocity subcritical flow, accompanied by formation of eddies, rollers and turbulence along with air entrainment. Ultimately the energy is dissipated in the form of heat. The formation of hydraulic jump at the foot of spillway or under the sluice gate acts as an energy dissipator. The maximum energy dissipation occurs when a clear hydraulic jump forms at the section where the prejump depth is minimum. This is because when pre jump depth is minimum, as per Belanger equation (Vittal and Al-Garni 1992), its sequent depth i.e. post jump depth is maximum and thus the ratio of post jump depth to prejump depth is maximum and hence the initial Froude number is maximum. As energy dissipation is directly proportional to initial Froude number, for the given inflow condition the energy dissipation is maximum. It is well known that the length of the apron depends upon the length and location of the jump (for design discharge condition) which in turn depends on the pre jump depth \( y_1 \) and the relative magnitudes of post jump depth
(y₂) and tail water depth (yₜ) (Rajaratnam and Subramanya 1966; Jeppson 1970). As shown in Fig. 1.1, the pre jump depth (y₁) which is in supercritical state and post jump depth (y₂) which is in subcritical state are called as sequent depths and the tail water depth (yₜ) is the depth of water on downstream of the weir. In a rectangular channel with horizontal slope, hydraulic jump forms at a location where these sequent depths satisfy Belanger equation. The sequent depths are referred corresponding to the section at vena contracta as the ideal location of jump is at vena contracta of supercritical flow (Chow 1959). As the term vena contracta is normally used in connection with the gated flow, in case of spillway flows the vena contracta would be referred to a section where the prejump depth (y₁) is minimum. In case of tail water deficiency condition, the tail water rating curve lies below the jump height curve for all the discharges. Due to this the hydraulic jump may partially or fully sweep out of the basin and is not advisable as it would result in damage to stilling basin, tail channel and other downstream structures (Tung and Mays 1982; Moharami et al 2000). Thus it becomes very much significant to have the location of hydraulic jump in a stipulated zone (i.e. on apron), to successfully accomplish the task of energy dissipation (Rouse et al 1958). For this purpose the depth of water on the apron may be artificially raised to such a magnitude that it becomes sequent to the pre jump depth at vena contracta and form the jump at vena contracta (Leutheusser and Kartha 1972; Ohtsu et al 1991). That means by forming forced post jump depths on apron, the efforts can be made to match them with post jump depths given by Belanger equation for all the discharges (Vittal and Al-Garni 1992). This can be achieved by introducing an impediment in the form of weir at the end of the apron. (Pillai et al 1989; Gharangik and Chaudhry 1991; Rahman and Chaudhry 1995). In practice the rectangular broad crested weirs are considered for this purpose (Achour and Debabeche 2003). The weir with its height designed for design discharge condition, is not suitable under field conditions where discharges would vary and generally less than design discharge. Therefore to address this problem an attempt has been made to design an end weir geometry which would assure formation of clear jump at vena contracta for the design discharge as well as for the lower discharges. The main focus of the present study is to develop a mathematical procedure and computational technique to design an appropriate end weir to restrict location of hydraulic jump near sluice gate or toe of spillway for varying discharge conditions. The study is carried out in two stages. In the first stage weir section is designed considering free flow over weir crest. In the second stage three weir sections corresponding to three different tail
water submergence conditions are designed and tested in flume to confirm the location of jump at desired place.

In order to generalize the application, sloping apron is considered. The mathematical procedure is then applied to hydraulic jump on sloping apron. In this case three different slopes and corresponding to each slope, three different tail water submergence conditions are considered. For each of the nine cases, nine weir sections are designed and tested in flume to confirm the location of jump at desired place. A model study of single span of an existing spillway energy dissipator is carried out in laboratory to check the applicability of the weir. A CFD technique (fluent) is used to support the experimental findings numerically. A numerical model fluent is first validated with the help of results obtained through laboratory experiments. Finally, a pilot scale physical model study is carried out by using data of existing dam in India. The weir designed for this purpose is fabricated after testing its performance on fluent. Thus a new design of stilling basin in the form of horizontal apron with a rectangular broad crested stepped weir is proposed. The details of the study are reported herein.

Fig. 1.1 Definition sketch of hydraulic jump in a rectangular channel