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HYDRAULIC STRUCTURES
DESIGN MANUAL

9

ENERGY DISSIPATORS

Daniel L. Vischer
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editors

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Hydraulic Design Considerations

ENERGY DISSIPATORS

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Photo on the binding: Tailrace outlet of Hongrin power scheme into Lake Geneva at Veytaux / Montreux, Switzerland. Discharge 20 m^3/s, jet inclination 10° and trajectory length 240 m.

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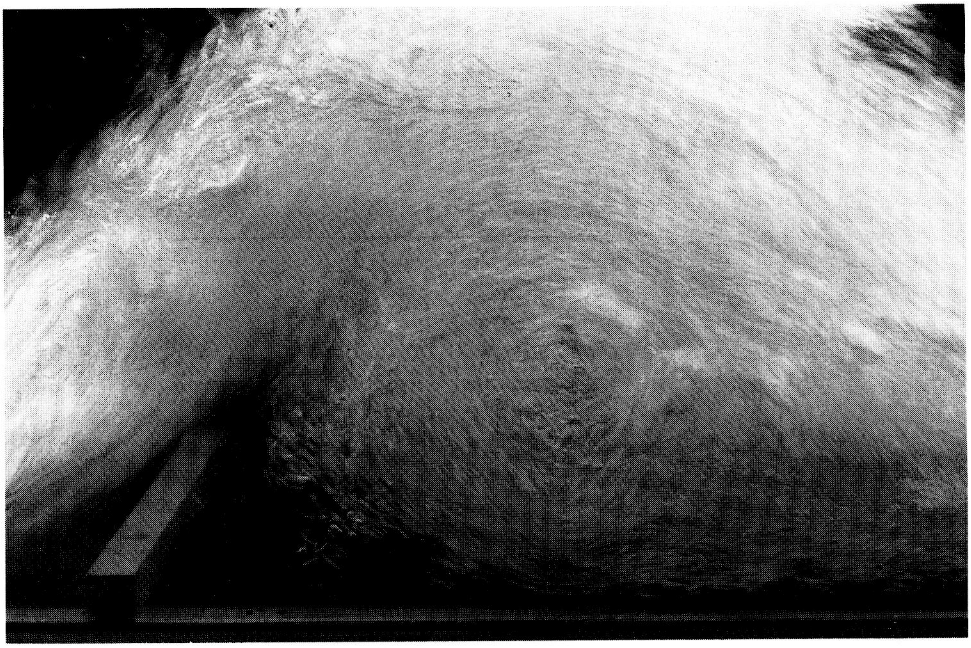
HYDRAULIC STRUCTURES DESIGN MANUAL

HYDRAULIC DESIGN CONSIDERATIONS

Hydraulic Structures Design Manuals:

1. J. Knauss (ed.), 1987. *Swirling flow problems at intakes.*
2. H.N.C. Breusers & A.J. Raudkivi, 1991. *Scouring.*
3. E. Naudascher, 1991. *Hydrodynamic forces.*
4. I.R. Wood (ed.), 1991. *Air entrainment in free-surface flows.*
5. M. Hino (ed.), 1994. *Water quality and its control.*
6. A.J. Raudkivi, 1993. *Sedimentation: Exclusion and removal of sediment from diverted water.*
7. E. Naudascher & D. Rockwell, 1993. *Flow-induced vibrations: An engineering guide.*
8. D.S. Miller (ed.), 1994. *Discharge characteristics.*
9. D.L. Vischer & W.H. Hager (eds), 1995. *Energy dissipators.*



Vortex flow and turbulence, the origin of energy dissipation.

Contents

CHAPTER 1

Introduction

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In hydraulic engineering numerous devices like stilling basins, baffled aprons, and vortex shafts are known under the collective term of energy dissipators. Their purpose is to dissipate hydraulic energy, i.e. to convert it mainly into heat. Dissipators are used in places where the excess hydraulic energy could cause such damage as erosion of tailwater channels, abrasion of hydraulic structures, generation of tailwater waves, or scouring.

1.1 ESSENCE OF HYDRAULIC ENERGY DISSIPATION

1.1.1 *The result*

If a particle of water falls into a basin and comes to rest, its entire plunging energy – i.e. its entire hydraulic energy – is dissipated. Under the defensible assumption that this mechanical energy is converted into heat that effects only the particle and not its surrounding, the increase in water temperature can be calculated. For a fall of 100 m it amounts to only 0.24°C. This is so small that it has no practical significance. Therefore, the term energy dissipator used by *hydraulic* engineers refers to devices that get rid of hydraulic energy. The important phenomenon is the annihilation of hydro-mechanical energy rather than the energy conversion.

1.1.2 *The mechanism*

Every moving fluid particle or drop of water loses some of its hydraulic energy along its trajectory. This loss is a result of friction or drag forces that are closely related to turbulence production in hydraulic energy dissipators.

The process of energy dissipation can be usefully divided into two cases:
1. A particle of water within a water current, and
2. A drop of water in an air current.

In the first case, the energy dissipation is related to energy consuming eddies. Such eddies are mainly generated in shear zones, i.e. in zones of large velocity gradients. To induce a considerable loss of energy, the creation of high turbulence zones is therefore important.

In the second case, the energy dissipation results from the air resistance exerted on the drop of water. It is large if the drop is small and the relative velocity between the drop and the ambient air is high.

Efficient energy dissipation is a matter of disturbing a water current either by increasing its turbulence or by diffusing it into spray. An *economical* energy dissipator is designed to effect such an impact within a comparatively small region.

1.1.3 *The methods*

Numerous methods are available for the *concentrated* dissipation of energy. According to the two mechanisms mentioned above, they can be divided into two process categories characterized by the following groups of phenomena:

1. Provoking large *velocity gradients* and thus increasing turbulence in the current with devices like
   - sudden expansions,
   - sharp deflections,
   - throttles,
   - sills and end sills,
   - chute blocks, baffle piers and beams,
   - counter flows,
   - rough boundaries, and
   - vortex chambers.

2. Creating extended and *turbulent interfaces* between the water and the surrounding air by devices that
   - create free jets, and
   - split free jets.

1.1.4 *The limits*

As stated previously, energy dissipation is achieved either by a strong disturbance or by an effective diffusion of the flow. Therefore, the designs of an energy dissipator and of a hydrodynamic element are opposed; the latter tends to produce a smooth current with only small disturbances. The large disturbances inevitably have strong consequences so that energy dissipators can cause

- pulsation,
- vibration,
- erosion,
- abrasion, or
- cavitation.

Energy dissipators must have the structural strength to resist these stresses. Unfortunately, no material exists that can endure strong and permanent cavitation. Nor is there a material which can withstand abrasion by flow that is heavily laden with silt or gravel and is not prohibitively expensive. Thus, there are limits to the contrast with hydrodynamic designs. Most energy dissipators are built of concrete or steel so that the properties of these common building materials set the limits.

1.2 PURPOSE AND SCOPE OF THE MONOGRAPH

1.2.1 *Delimitation of the topic*

In accordance with IAHR guide lines, this monograph deals with the hydraulic phenomena of energy dissipation in hydraulic structures. Since such phenomena exist in all turbulent currents, the topic must be delimited. As already mentioned, the focus is on currents with comparatively high rates of significant energy dissipation, i.e. flows in which significant quantities of energy are dissipated in a limited amount of space.

Energy dissipators are used in pressurized flows as well as in open channel flows. They provide a transition between flows of high and low hydraulic energy. Four such transitions can be distinguished:

- one pressure conduit to another,
- a pressure conduit to a channel,
- a channel to a pressure conduit, and
- one channel to another.

This monograph includes primarily those energy dissipators that link either pressure conduits to channels or one channel to another. A description of the other two types could be the subject of another monograph because these latter types comprise the rich variety represented by throttles, pressure valves, mixing tubes, etc.

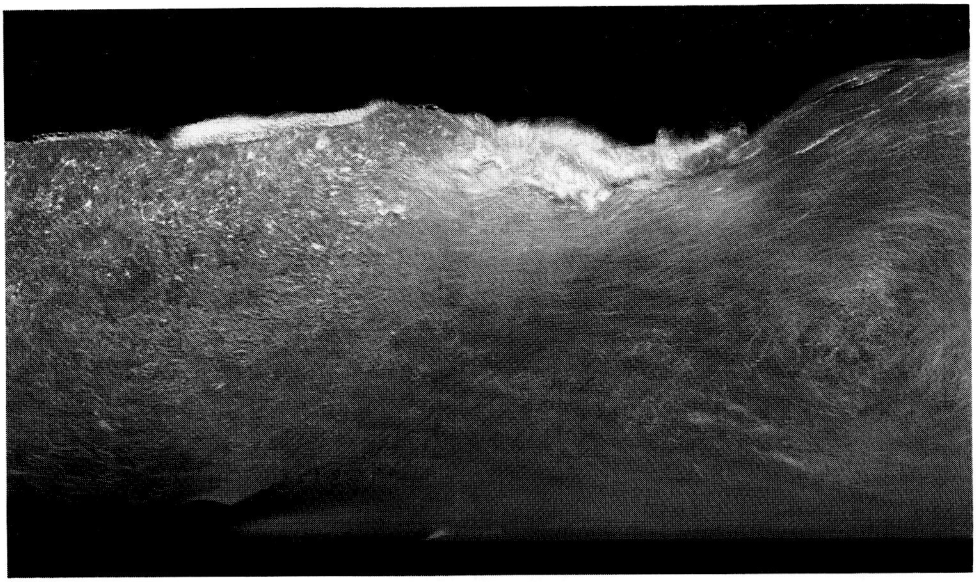
1.2.2 *Some definitions*

Aerator	Element to promote air entrainment in water flow.
Baffle	Impact element to promote energy dissipation.
Basin length	Length required to contain a jump without risk for tailwater scour.
Block	Cube type element used to disperse flow in stilling basin.
Boundary layer	Boundary flow where velocity gradients are developed due to shear stress.
Breakup of jet	Jet dispersion.
Bucket	Either solid or slotted deflector element, placed at beginning of energy dissipator.
Cascade	Series of drop elements to interrupt flow on a drop.
Cavitation	Collapse of vapour bubbles due to pressure reincrease over vapour pressure, associated with a cavity formation.
Cavitation damage	Structural damage due to cavitation.
Channel	Conveyance for a liquid with a free surface. Channel flow may also occur in partially filled pipes.
Chute	High speed channel, usually to convey excess water over a dam.
Classical hydraulic jump	Hydraulic jump in a prismatic rectangular and horizontal channel where effects of viscosity are negligible.
Counterflow	Reversal of flow direction towards main current.
Deflector	Bowl-shaped element that deflects a jet.
Densimetric Froude number	Froude number involving density ratio of two fluids.
Diffusion	Spreading of momentum, heat or sound in turbulent flow field.
Diffusor	Expanding conveyance of flow, involving pressure recovery and kinetic energy loss.
Disintegration	Phenomenon according to which a compact jet breaks up.
Dispersion	Mixing of any hydraulic quantity due to turbulence.

Dissipation	Transformation of mechanical energy, mainly into heat and sound energies.
Drag	Resistive force on element placed in a stream.
Drop	Structure at which bottom elevation reduces, with a take-off and an impinging portion.
Efficiency	Rate of energy dissipation relative to approach energy.
End element	Either blocks or sill to deflect bottom currents away from tailwater invert, used to reduce length of stilling basin.
Energy loss	Loss of hydro-mechanical energy.
Entrainment	Mixing of two or more separate phases by turbulent action.
Erosion	Removal of solid boundary material by flow.
Expansion	Increase of cross section to promote impact flow.
Flip bucket	Bucket type invert to deflect chute flow into the air.
Forced jump	Hydraulic jump assisted by baffle elements.
Friction	Force causing the loss of hydro-mechanical energy due to a surface interaction of flow.
Friction factor	Relating friction force to average velocity. Depends on surface roughness, surface shape, and Reynolds number.
Froude number	Index relating double kinetic energy to potential energy contents. For $\mathbf{F} = 1$ so-called critical flow occurs.
Gate	Movable hydraulic structure placed transverse to flow and used to control discharge.
Hydraulic jump	Transition from super- to subcritical flow without additional assistance. Basic phenomenon of turbulence production.
Impact flow	Jet impinging on solid or fluid interface flow. Concerns are dynamic pressures on impact bottom.
Jet	Source of fluid mass or momentum subject to entrainment and diffusion. A *submerged* jet is issued in a reservoir of a similar fluid, a *buoyant* jet occurs due to density difference of the ambient fluid and a *free* jet typically occurs with water issued in air.

Jet trajectory	Path of jet.
Jet-assistance	Disturbance of main flow by lateral jets.
Jump length	Length of hydraulic jump from toe to section where turbulence has greatly diminished, and the flow is practically undisturbed.
Overfall	Hydraulic structure involving a bottom drop.
Plunge pool	Location where a jet impinges on body of nearly stagnant water.
Pressure fluctuation	Dynamic component of pressure due to turbulence.
Reynolds number	Index relating viscous and inertial effects.
rms-pressure	Root-mean-square value of pressure, statistical property of turbulent pressure fluctuation.
Roller	Surface return flow zone.
Rotating jet	Jet with a swirl component.
Rotational flow	Current having finite vorticity, i.e. with circulation.
Roughness	Solid boundary characterisation. In fully rough turbulent flows, the effect of vicosity may be neglected.
Scale model	Reproduction of certain flow field according to a specific scaling law. Normally, the Froude similarity law is applicable to energy dissipation involving a free surface.
Scour	Local erosion due to flow concentrations.
Separation	Condition that occurs if the main stream of a viscous fluid flow stops following a solid boundary. The point of separation is located where the velocity gradient changes from positive to negative, or, alternatively, where the fluid shear on the wall falls to zero.
Sequent depths	Flow depths upstream and downstream of hydraulic jump.
Sill	Wall-type element, often placed in a stilling basin.
Ski jump	Bucket type terminal structure of a chute that causes water to form a jet in air.
Sloping jump	Abbreviation for hydraulic jump on a sloping invert.
Stagnation point	Point in flow field where velocity falls to zero.

Step	Element to change bottom elevation in stilling basin.
Stepped spillway	Chute with a cascade type bottom profile.
Stilling basin	Location of concentrated free surface energy dissipation located upstream from a receiving water.
Stilling chamber	Energy dissipator in pressurised flow, normally used for small discharges.
Submerged jump	Jump or outlet-type flow with pressurised approach, typically behind gates.
Submersion	Tailwater influence on hydraulic jump flow.
Swirl	Circular flow somewhat less intense than a vortex.
Toe of jump	Upstream end of hydraulic jump.
Trajectory basin	Impact area of a trajectory jet, either empty or filled with stagnant water.
Turbulence	Chaotic mixing of fluid flows, usually resulting from large-scale eddies.
Vortex	Coherent structure of rotational flow.
Vortex drop	Hydraulic drop structure by which fluid is conveyed tangentially in a vertical shaft spillway.
Wake	Region of disturbed flow downstream of a structure.
Wall jet	Jet along an adjacent wall, i.e. with a one-sided boundary layer and a diffusion layer on the other side.
Water cushion	Fluid layer between air and solid bottom in which impact jets may be diffused.
Weber number	Index accounting for effects of surface tension.



Jet flow in counter-current arrangement.

CHAPTER 2

Types of energy dissipators

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2.1 PRINCIPLE OF CLASSIFICATION

The author is not aware of any publications that present a complete morphology of energy dissipators. Hence, it would be tempting to elaborate a morphological grid here, for it would certainly allow for gaps to be detected such as types yet unknown or used out of hydraulic engineering. But that is beyond the scope of this chapter.

The following discussion of dissipators uses the keywords of Chapter 1 to give at least a certain classification:

Energy dissipation with
- sudden expansions,
- abrupt deflections,
- counterflows,
- rough walls,
- vortex devices,
- spray inducing devices.

This classification is based on the most striking features of the respective dissipators. Another classification could be based on the hydraulics of jets. Every inflow to an energy dissipator behaves like a turbulent jet, and its momentum is partly or entirely annihilated in a mixing process. Thus, the characteristics of a dissipator may be defined on the basis of its jet form (Fig. 2.1):

Type of jet
- free jet,
- submerged jet,

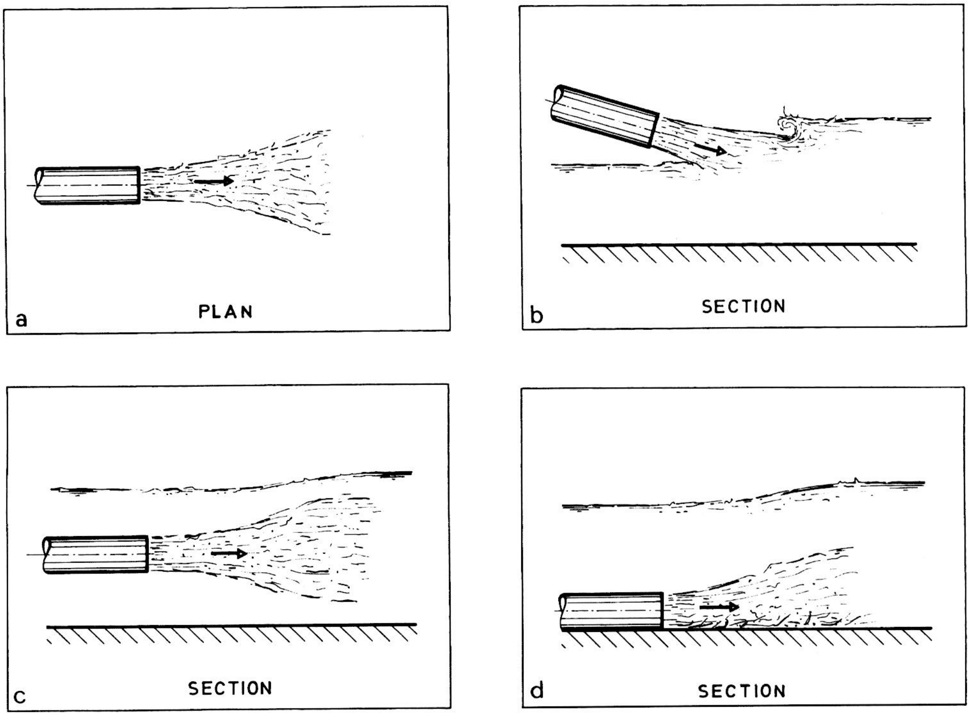

Figure 2.1. Types of jet flow.

– wall jet,
– surface jet,
– radial jet,
– oscillating jet,
– counter-current jet,
– split jet,
– rotating jet.

Entrained medium
– water,
– air.

But this principle of classification is perhaps too academic. Therefore, the author uses instead the most striking features of the dissipators.

2.2 ENERGY DISSIPATION BY EXPANSION AND DEFLECTION

A sudden expansion of a pipe induces the well known Borda-Carnot loss. It is often described as an impact loss: a faster current impacts with a