LABORATORY STUDY ON STILLING BASIN AS AN INTEGRAL PART OF ENERGY DISSIPATOR SYSTEM

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ABSTRACT

Water flow from upstream to downstream will create to high energy at the time when it reaches the downstream. This situation will cause damage or critical erosion at spillways toe, weir bed and downstream of river. In order to overcome this problem, the water flow velocity has to be reduced. The solution for this problem is by constructing an energy dissipating structure at the effected areas. In this study, baffles were used as the experimental energy dissipating structure. Various size and arrangement of baffles at the downstream of the model were tested to determine the most effective result in reducing the water flow velocity. The relationship between the percentage of velocity decrease and the spacing between the baffles were determined by plotting graphs. The decreases in velocity depends on the size of baffles and the arrangement of baffles at the stilling basin.

ABSTRAK

Air yang mengalir dari hulu ke hilir akan menyebabkan tenaga air tinggi pada masa ia sampai di hilir. Keadaan ini boleh menyebabkan kemusnahan atau hakisan pada kaki alur limpah, dasar saluran dan hilir sungai. Untuk menyelesaikan masalah ini, halaju air yang mengalir hendaklah di kurangkan. Sebagai penyelesaian kepada masalah ini, struktur pelesap tenaga hendaklah dibina di kawasan yang mengalami impak halaju air. Dalam kajian ini, blok penghadang digunakan sebagai struktur pelesap tenaga. Pelbagai saiz dan susunan blok penghadang di dalam model besin limpah dikaji untuk memperoleh keputusan yang paling efektif dalam pengurangan halaju air. Hubungan antara peratus pengurangan halaju dengan jarak antara blok penghadang dapat diperolehi melalui graf lengkung yang diplot. Pengurangan halaju aliran bergantung kepada saiz dan cara susunan blok penghadang.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Outlet flow is water that flows out through a hydraulic structure. In this study, the water that flows out of the outlet flow spillways is outlet flow. To design a hydraulic structure, it requires its own design requirement, such as adequate capacity, depth and stability to ensure that the design for the outlet can accommodate the flow of water and energy velocity of water coming from upstream.

The outlet flow, whether it be form the world's largest dam or form a small drain, usually required some type energy dissipating structure to prevent downstream channel degradation. The design may vary from an elaborate multiple basin arrangement to a simple headwall design, depending upon the size and number of conduits involved, the erosion resistance of the exit channel bed material and the duration, intensity and frequency of outlet flows. Energy dissipator is any device that designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits. Energy dissipation at dams and weir is closely associated with spillways design, particularly with the chosen specific discharge, q, the difference between the upstream and downstream water level, (H) and the downstream condition. The magnitude of energy that must be dissipated at high dams with large spillways discharge is enormous. For example, the maximum energy to be dissipated at the Tarbala dam service and auxiliary spillways could be 40000MW, which is about 20 times the planned generating capacity at the site (Bureau of Reclamation, 1987)

The passage of water from a reservoir into the downstream reach involves a whole number of hydraulic phenomena such as the transition into supercritical flow, supercritical non-aerated flow and echoes of macroturbulence after the transition into the stream beyond the basin or plunge pool. It is therefore, best to the consider the energy dissipation process in five separate stages, some of which may be combined or absent (R.M.Khatsuria, 2005)

In the design of energy dissipation, sometimes environment factor play a decisive role in determining the type of energy dissipator. Environmental factors have to be considered, some of the most important ones are the effect of dissolves gases supersaturation on fish in deep plunge pools, and of spray from flip bucket jets which can result in landslides and freezing fog. In other words, deep seated stilling basins with highly aerated flows inducing nitrogen supersaturation would not be permissible where fish life is important consideration. (R.M.Khatsuria, 2005)

1.2 Problem Statement

Water flow from upstream to downstream will cause the water to have high energy at the time it reached the downstream. This situation also occurs in the spillways. Water flowing from the inlet to the outlet of spillways will cause the energy of water to increase due to the height of the spillways. The accumulated energy will cause the structure at the bottom of the spillways to damage and will sometimes result in failure of structure especially at the basin.

The typical energy dissipator for an outlet works structure required a stilling basin to produce a hydraulic jump. The stilling basin is joined to the outlet portal with a transition chute which has flared vertical sidewalls and a downward parabolic invert. (R.M.Khatsuria, 2005)

Study about stilling basin, the most related item with stilling basin is hydraulic jump. A hydraulic jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise occurs in the liquid surface. The most serious problem with the hydraulic jump dissipater is more of structure strength rather that hydraulic efficiency. Experiment in recent years gives many example of stilling basin suffering serious damages arising from uplift, vibration, cavitations, abrasion and hydrodynamic loading. To protect this hydraulic structure, it is sometimes necessary to employ an energy dissipater. (R.M.Khatsuria, 2005)

1.3 Objectives

The study aimed to design a suitable type of stilling basin, which is to minimize or reduce hydraulic jump that can cause damage of stilling basin. The specific objectives of study are:

i. To design a suitable size of baffle block that can dissipate the energy of water.

ii. To determine a suitable position of baffle for the dimension that chosen

1.4 Scope of study

This study includes design of stilling basin as energy dissipater to reduce energy of water at outflow. The scope is concentrated on design and analysis of the various sizes of chute block and baffle block. The suitable and new design that selected is subjected to the standard laboratory works. The specific tasks to achieve the objectives are:

i. Determine the dimension of stilling basin

ii. Fabricate model the various size of chute block and baffles block for stilling basin

iii. Installation by laboratory work

iv. Collect and analyze the data collected

Chapter 2

Literature review

2.1 Nature of the Hydraulic Jump

The hydraulic jump is a natural phenomenon which occurs when supercritical flow changes to subcritical flow. This abrupt change in flow condition is accompanied by considerable turbulence and loss of energy. Within certain flow ranges, the hydraulic jump is an effective energy dissipation device which is often employed to control erosion at hydraulic structures. The design and evaluation of stilling basins are based on these relationships. (Philip L. Thompson and Roger T. Kilgore, 2006)

When the upstream Froude number (Fr) is 1.0, the flow is at critical and a jump cannot form. For Froude numbers greater than 1.0, but less than 1.7, the upstream flow is only slightly below critical depth and the change from supercritical to subcritical flow will result in only a slight disturbance of the water surface. On the high end of this range, Fr approaching 1.7, the downstream depth will be about twice the incoming depth and the exit velocity about half the upstream velocity. When the upstream Froude number is between 1.7 and 2.5, a roller begins to appear, becoming more intense as the Froude number increases. This is the prejump range with very low energy loss. In this range, there are no particular stilling basin problems involved.

The only requirement is that the proper length of basin, which is rather short, be provided. The water surface is quite smooth, the velocity throughout the cross section uniform, and the energy loss in the range of 20 percent. The exit Froude number for many culverts falls within the range 1.5 to 4.5. An oscillating form of jump occurs for Froude numbers between 2.5 and 4.5. The incoming jet alternately flows near the bottom and then along the surface. This results in objectionable surface waves which can cause erosion problems downstream. (Philip L. Thompson and Roger T. Kilgore, 2006)

Hydraulic jump is a very common and effective way of dissipating energy at the downstream of the spillway toe. Energy dissipation and erosion control of the incoming flow is dependent on the available tail water depth (y_T) and the conjugate depth (y_2). (Bureau of Reclamation, 1987)

Figure 2.1 shows hydraulic jump with conjugate depth equal to tail water level: (a) simple horizon apron, and (b) stilling basin with lowered bed to achieve $y_2 = y_T$ while Figure 2.2 shows hydraulic jump with conjugate depth greater than tail water level: (a) hydraulic jump outside of the stilling basin when $y_2 > y_T$, and downstream prominent weir pushing hydraulic jump into the stilling basin.

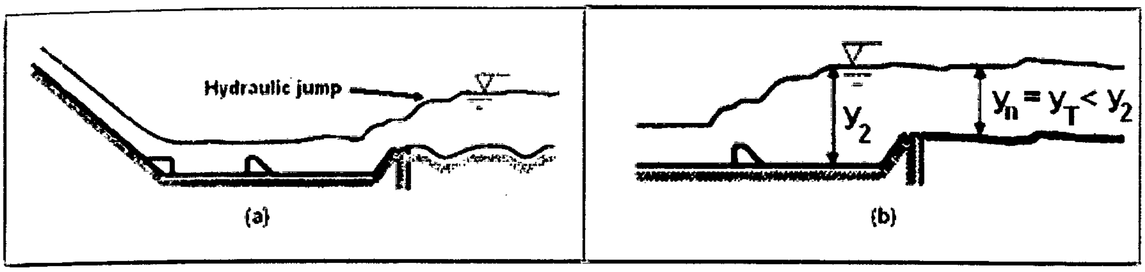

Figure 2.1: Hydraulic Jump with Conjugate Depth Equal to Tail Water Level (Blaisdell, Fred W, 1959)

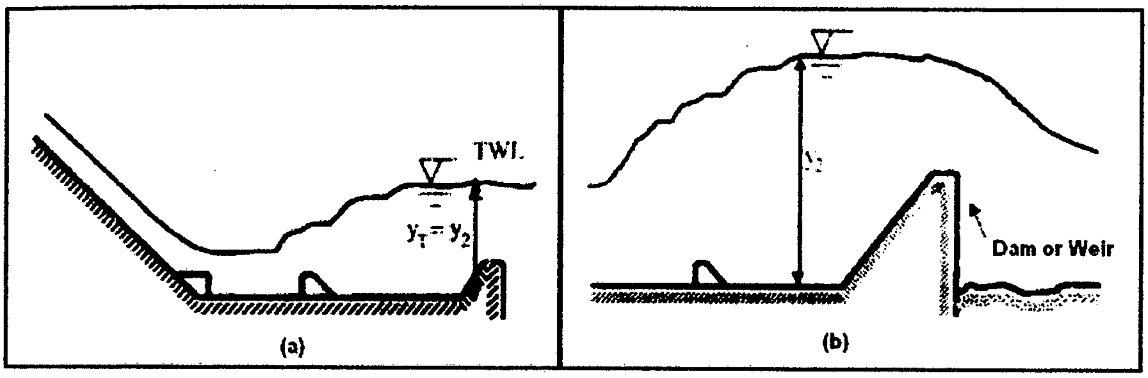

Figure 2.2: Hydraulic Jump with Conjugate Depth Greater Than Tail Water Level (Blaisdell, Fred W, 1959)

Figure 2.3 shows hydraulic jump with conjugate depth smaller than tail water level: (a) submerged jump at the dam toe when $y_2>y_T$, and (b) extension of the toe by a sloping apron free jump in stilling basin.

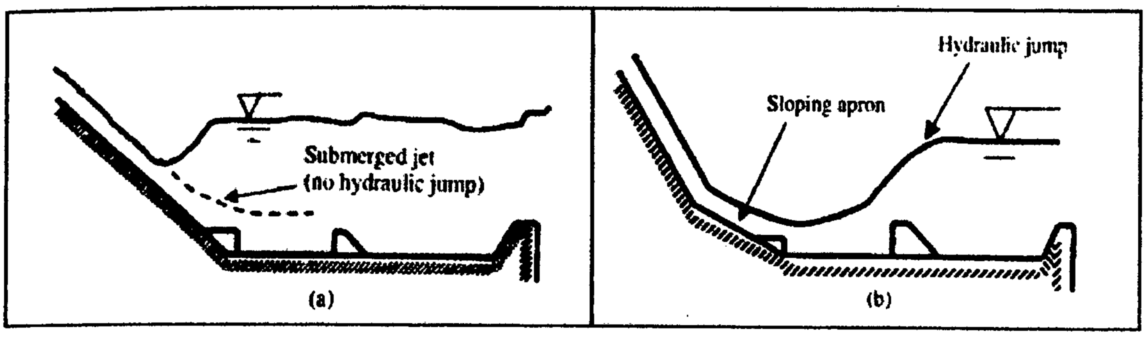

Figure 2.3: Hydraulic Jump with Conjugate Depth Smaller Than Tail Water Level (Blaisdell, Fred W, 1959)

The concrete apron of a channel function to prevent it from scouring but it is not practical to pave the entire length of the weir with concrete to accommodate the hydraulic jump as it is rather costly. Thus, accessories devices such as baffle piers and sills need to be installed in order to shorten the jump length and consequently reduce the size and cost of the stilling basin. The control through accessories installed also improves the dissipation function of the basin, stabilizes the jump action and increase the factor of safety (Ven Te Chow,1959). Figure 2.4 shows the control of jump by baffle piers (Bureau of Reclamation, 1987)

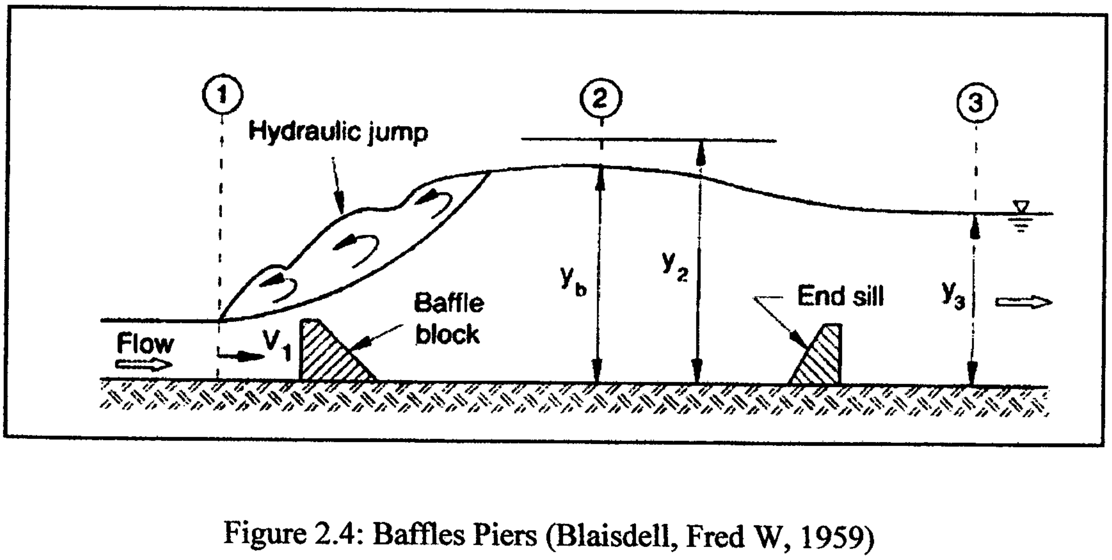

Figure 2.4: Baffles Piers (Blaisdell, Fred W, 1959)

Figure 2.5 show the hydraulic jump forms related to Froude number. Form A called prejump slage. The Froude number for this form of hydraulic jump is between 1.7 and 2.5. For the form B, this type of hydraulic jump called transition slage and the Froude number for this hydraulic jump is between 2.5 and 4.5. Froude number for form C hydraulic jump is between 4.5 and 9.0 while for form D is greater than 9. The name for form C is range of well balanced jump and for form D is effective jump but rough surface downstream. Table 2.1 shows the jump characteristics according to Froude numbers.

Table 2.1: Jump characteristic according to Froude number (Bureau of Reclamation, 1987)

Froude Number	Jump Characteristics
1.0 - 1.7	Surface waves (undular)
1.7 - 2.5	Weak jump. Low energy loss
2.5 – 4.5	Oscillating jump. Large irregular waves
4.5 – 9.0	Steady jump
>9.0	Strong jump

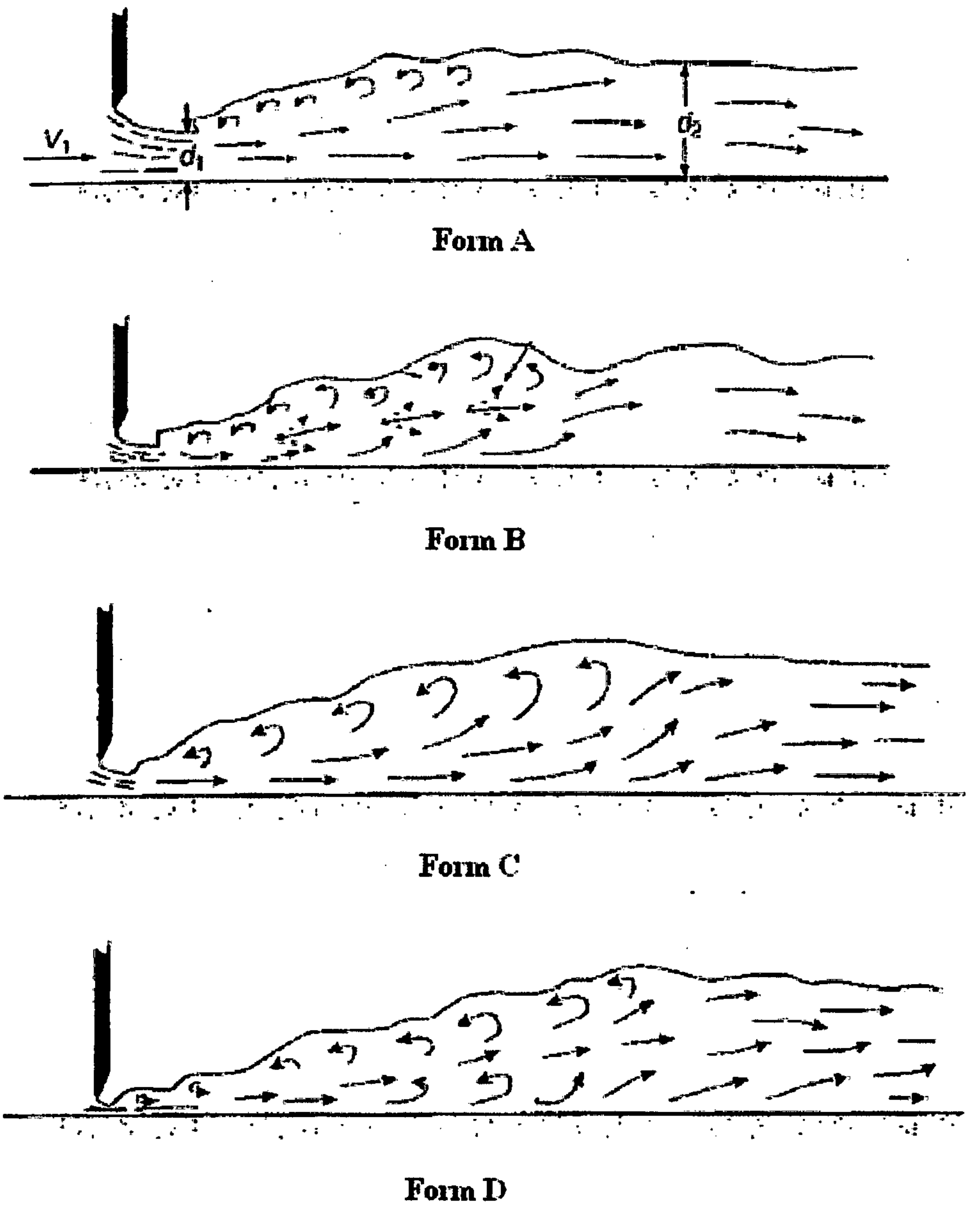

Figure 2.5. Hydraulic Jump Forms Related to Fr (Bureau of Reclamation, 1987)

2.2 Spillway

A spillway is nearly always required to pass flow by a dam. In the case of storage or hydroelectric dams, where large flow passes through hydraulic turbines, spillways may be used infrequently to pass the floods. For diversion dams, where the diversion represents a small portion of the total flow, the spillways may operate continuously.

The safe operation of spillways is the main objectives in design. Failure of the spillway to perform its design function can lead to failure of the dam with possible property damage and lose of life. The determination of the design flood flows is critical particularly for earth fill and rock fill dams, which cannot withstand overtopping. Because the dams raise the water level in a stream, spillways usually must be designed for high velocity flow, since this additional potential energy is transformed into kinetic energy. Not only the spillways must be designed to withstand these velocities but also the terminal structure, or dissipator, which must release flow at a small enough velocity and produce conditions so that the dam will not be endangered by excessive downstream erosion. (Blaisdell, Fred W, 1959)

Spillways for dams impounding water in reservoirs having little storage require a capacity that will nearly equal the peak of the inflow flood to the reservoir. However, if much of the flood volume entering, the reservoir can be temporarily stored, the spillway need not be designed for the flood peak (Blaisdell, Fred W, 1959)

2.2.1 Necessity of a spillways

A spillway is design to prevent overtopping of the dam at a place that is not designed for overtopping. Vischer et al. (1988) discuss the necessity of a spillway. A reservoir will overflow if its capacity is less than the difference between the volumes of inflow and outflow. If a dam can economically be made high enough to provide a retention space above Full Supply Level (FSL) to absorb the entire volume of inflow design flood, no spillways would be required and an outlet such as a turbine or sluice would only be needed for regulating or utilizing storage. There are indeed a few dams where spillways are dispensable or a nominal spillway facility was all that was needed; Moric (1997) has reported two such cases. However , in a majority of cases it is impractical to provided retention capacity above FSL large enough to absorb the inflow design flood and, hence, a special device to surplus the extra quantity of water is required, namely a spillway (R.M. Khatsuria,2005).

Whether a dam would fail due to overtopping depends largely on the type of the dam in equation. The most sensitive structure is earth-fill dams, which if not specially protected are destroyed by even a small overtopping. Masonry and concrete dams, as well as gravity and arch dams can withstand overtopping up to certain extent before they fail due to excessive stresses. However the indirect threat to their stability due to erosion from an immediate downstream, mainly by overflowing impinging jet, would be of more concern. Overtopping of a dam may also cause other damages to the nearby structures that are not designed for such overtopping (R.M. Khatsuria, 2005).

Considering the above, one can conclude that all dams should be constructed with a safety device, in the form of spillways, against overtopping.

2.2.2 Functions of spillway

While the principal function of spillway is to pass down the surplus water from the reservoir into the downstream river, there are precisely seven functions that can be assigned to spillway as discussed by Blaisdell, Fred W (1959).

i. Maintaining normal river water functions
ii. Discharging water for utilization
iii. Maintaining initial water level in the flood control operation
iv. Controlling the flood
v. Controlling additional flood
vi. Releasing surplus water
vii. Lowering water level

2.2.3 Classification of spillway

Spillways have been classified according to various criteria (R.M. Khatsuria, 2005).

1). According to the most prominent feature

i. Ogee spillway
ii. Chute spillway
iii. Side channel spillway
iv. Shaft spillway
v. Siphon spillway
vi. Straight drop or overfall spillways

vii. Tunnel spillways or culvert spillway
viii. Labyrinth spillway

2). According to function

i. Service spillway
ii. Auxiliary spillway
iii. Fuse plug or emergency spillway

3). According to control structure

i. Gated spillway
ii. Ungated spillway
iii. Orifice of sluice spillway

2.3 Energy Dissipator

Under many circumstances, discharges from culverts and channels may cause erosion problems. To mitigate this erosion, discharge energy can be dissipated prior to release downstream.

For some sites, appropriate energy dissipation may be achieved by design of a flow transition, anticipating an acceptable scour hole and allowing for a hydraulic jump given sufficient tail water. However, at many other sites, more involved in dissipator designs may be required. These are grouped as follows: (Philip L. Thompson and Roger T. Kilgore, 2006)

i. Internal Dissipators
ii. Stilling Basins
iii. Streambed Level Dissipators
iv. Riprap Basins and Aprons
v. Drop Structures
vi. Stilling Wells

The design of the energy dissipator probably includes more options than any other phase of spillway design. The selection of the type and design details of the dissipator is largely dependent upon the pertinent characteristics of the site, the magnitude of energy to be dissipated, and to a lesser extent upon the duration and frequency of the spillway. Good judgment is imperative to assure that all requirements of the particular project are met. Regardless of the type of dissipator selected, any spillway energy dissipator must operate safely at high discharges for extended periods of time without having to be shut down for emergency repairs. An emergency shutdown of the spillway facility during a large flood could cause overtopping of the dam and/or create unacceptable upstream flooding. The three most common types of energy dissipator used are as follows and figure 2.6 show the five actual phase of energy dissipation: (Philip L. Thompson and Roger T. Kilgore, 2006)

i. The stilling basin which employs the hydraulic jump for energy dissipation.

ii. The roller bucket which achieves energy dissipation in surface rollers over the bucket and ground rollers downstream of the bucket.

iii. The flip bucket which deflects the flow downstream, thereby transferring the energy to a position where impact, turbulence, and resulting erosion will not jeopardize safety of the dam or appurtenant structures