Forces Acting on Gravity Dams:

Forces that act on a gravity dam (Fig.1) are due to:

- Water Pressure(Hydrostatic)
- Uplift Pressure
- Earthquake Acceleration
- Silt Pressure
- Wave Pressure
- Ice Pressure

>> Self Weight (W) counters the forces listed above.

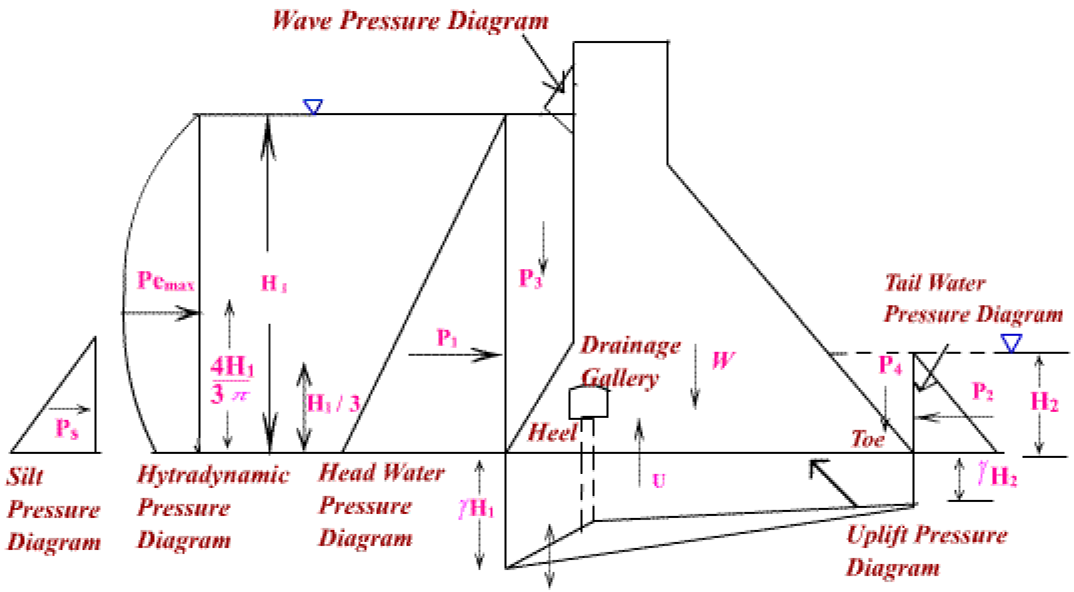


Fig.1 Forces on Gravity Dams

Force due to hydrostatic Pressure:

Force due to hydrostatic Pressure is the major external force on a gravity dam. The intensity of pressure from zero at the water surface to the maximum (γH) at the base. The force due to this pressure is given by γH^2, acting at $H/3$ from the base. In Fig.1, the forces P_1 and P_2 are due to hydrostatic pressure acting on the upstream and the downstream sides respectively. These are horizontal components of the hydrostatic force due to head water (upstream side) and tail water (downstream side) of the dam respectively.

The forces marked as P_3 and P_4 are the weight of water held over the inclined faces of the dam on the upstream slope and downstream slope respectively. These are the respective vertical components of the hydrostatic force on the two faces mentioned.

Force due to Uplift Pressure:

Water that seeps through the pores, cracks and fissures of the foundation material and water that seeps through the body of the dam to the bottom through the joints between the body of the dam and the foundation at the base, exert an uplift pressure on the base of the dam. The force (U) due to this acts against the weight of the dam and thus contributes to destabilizing the dam.

According to the recommendation of the United States Bureau of Reclamation (USBR), the uplift pressure intensities at the heel (upstream end) and the toe (downstream end) are taken to be equal to the respective hydrostatic pressures. A linear variation of the uplift pressure is often assumed between the heel and the toe. Drainage galleries can be provided (Fig.1) to relieve the uplift pressure. In such a case, the uplift pressure diagram gets modified as shown in Fig.1.

Earthquake Forces :

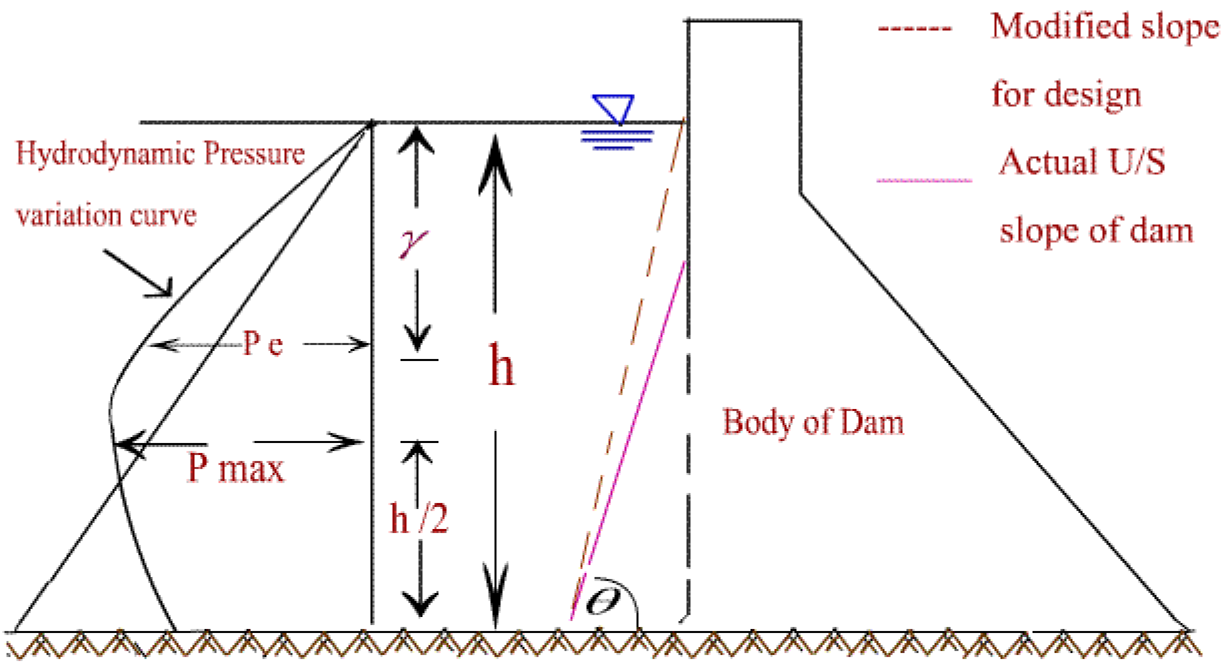
The effect of an earthquake is perceived as imparting an acceleration to the foundations of the dam in the direction in which the wave travels at that moment. It can be viewed (resolved) as horizontal and vertical components of the random acceleration.

Horizontal acceleration (α_h) is assumed to be equal to 0.1*g - 0.2*g, and the vertical acceleration (α_v) is assumed to be equal to 0.1*g (default values). Depending on the severity of the earthquake zone, these values will have to be modified.

Effect of Horizontal acceleration :

The horizontal acceleration may cause two forces: i) hydrodynamic pressure and ii) the horizontal inertial force into the body of the dam.

i) Hydrodynamic Force: The Hydrodynamic Pressure variation may be assumed to be **Parabolic**.



According to Von-Korman, the force due to the hydrodynamic pressure is expressed as: $P_e = 0.555\ (\alpha/g)\ (\gamma H_1^2)$, and acts at $(4H_1/3\pi)$ from the base.

Then, the moment due to the hydrodynamic force = $M_e = P_e * (4H_1/3\pi)$.

ii) Horizontal inertial force = $(W/g) * (\alpha_h)$

This force is generated so as to keep the body of the dam and the foundations together as one piece. Hence, the direction of this force will be opposite to that of the acceleration imparted by the earthquake.

The critical cases for the design will be:

For the reservoir full condition, the horizontal inertial forces due to earthquake being in the same direction as the horizontal force due to the hydrostatic water pressure (acting towards downstream). This means that the direction of the horizontal earthquake acceleration will be towards the upstream reservoir.

For the reservoir empty condition, the critical case will happen when the horizontal inertial forces due to earthquake being in the opposite direction to the horizontal force due to the hydrostatic water pressure (acting towards upstream). This means that the direction of the horizontal earthquake acceleration will be towards the downstream.

Effect of Vertical acceleration :

Upward : The effective weight of the dam increases and hence the stresses developed will increase.

Downward: This reduces the effective weight, in turn reducing the stability of the dam. ***This is a more critical case for the design.***

Hence, the net effective weight of the dam = W - W/g (α_v)

Force due to Silt Pressure:

Silt gets deposited against the upstream face of the dam. If 'h_s' is the height of the silt deposited, then the force exerted by the silt is given by Rankhine's formula):

$P_{silt} = \frac{1}{2}\gamma_s h_s^2 K_a$, acting at $\frac{h_s}{3}$ from base,

where $K_a =$ the coefficient of active earth pressure silt

$= \frac{1-\sin\phi}{1+\sin\phi}$ (Neglecting cohesion)

$\gamma_s =$ submerged unit weight of silt.

$\varphi =$ Angle of internal friction of soil.

If the upstream face is inclined, then, the weight of the silt supported on the slope is also to be considered.

In the absence of reliable data on silt type that would be deposited, the U.S.B.R. recommendations may be adopted:

In most of the gravity dam designs, silt pressure may be neglected – think about the possible reasons!!

Wave Pressure: Waves are generated on the reservoir surface because of the wind blowing over it. Wave pressure depends on the height of the wave developed. Wave height may be calculated from the following formula given by D.A. Molitor.

$$h_w = 0.032\sqrt{V.F} + 0.763 - 0.271\sqrt[4]{F} \quad \textbf{for F< 32 km}$$

$$h_w = 0.032\sqrt{V.F} \quad \textbf{for F > 32 km}$$

h_w = height of waves in meters, between trough and crest
V= wind velocity in km per hour; F = fetch or straight length of water expanse, in km.

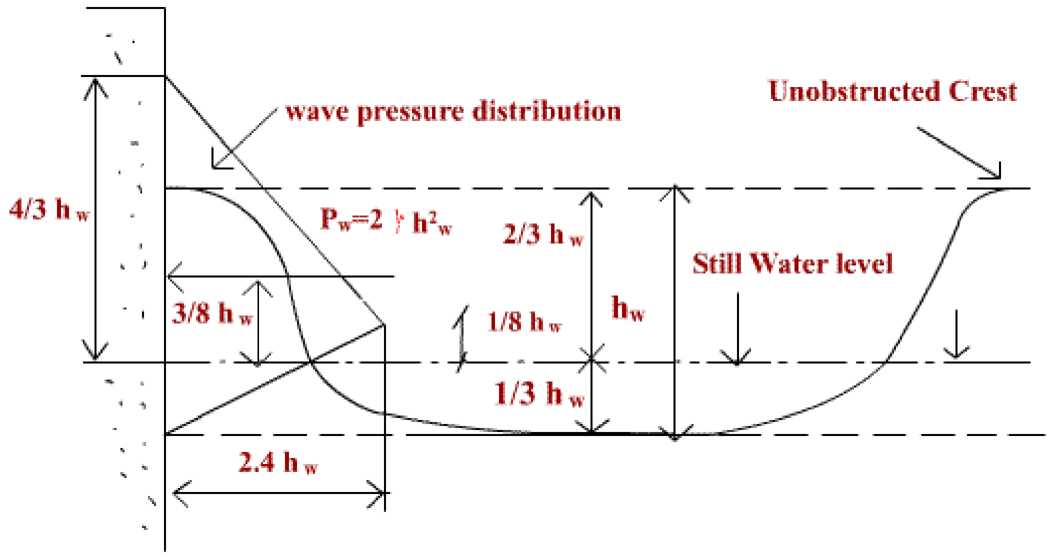


Fig. Wave Pressure.

The Pressure intensity due to waves is given by

$p_w = 2.4\ \gamma\ h_w$, where p_w is the maximum unit pressure which occurs at $(1/8)*h_w$ above the still water surface (denoted by dash and dot symbol in the Figure above). The pressure distribution is in fact curvilinear. However, for design purposes, the pressure distribution may be assumed to be represented by a triangle of height equal to $(5/3)*h_w$.

Hence the total force due to the wave pressure (P_w) is given by:

$$P_w = 0.5*(2.4\ h_w)*(5/3)h_w = 2\ \gamma\ h^2_w$$

and this acts at a distance of $(3/8)*h_w$ above the reservoir surface, as shown in the Fig. above.

<u>Ice thrust at reservoir level</u> :

Varies from 250 to 1500 kN/m^2, depending on temperature variations. Average value = 500 kN/m^2 acts along the length of the dam.