**GEOLOGY**

TAUQEER AHMAD JAN

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Dams & Dam Site, Rock stability

DAMS

Introduction:

Dam is a hydraulic structure of fairly impervious material built across a river to create a

reservoir on its upstream side for impounding water for various purposes. A dam and a

reservoir are complements of each other. A distinction should be made between a weir and a dam. A weir is also a structure

built across a river; however, its purpose is not to store water but to divert it. Thus there is no reservoir on the upstream of a weir. If there is a small storage reservoir on its upstream, the weir is called a storage weir.

Sometimes, a pickup weir is constructed on the downstream of a dam quite away from it in the boulder reach or the alluvial reach of the river to divert the water released from the dam into canals for irrigation and other purposes. Dams are probably the most important hydraulic structure built on the rivers. These are very huge structure. Thousands of workers and engineers work for a number of years in the construction of a dam. Dams are structures designed by humans to capture water and modify the magnitude and timing of its movement downstream. A dam is a barrier that [impounds](http://en.wikipedia.org/wiki/Reservoir) [water](http://en.wikipedia.org/wiki/Surface_water) or underground streams. Dams generally serve the primary purpose of retaining water, while other structures such as [flood gates](http://en.wikipedia.org/wiki/Floodgates) or [levees](http://en.wikipedia.org/wiki/Levee) (also known as [dikes](http://en.wikipedia.org/wiki/Dike_(construction))) are used to manage or prevent water flow into specific land regions. [Hydropower](http://en.wikipedia.org/wiki/Hydropower) and [pumped-storage hydroelectricity](http://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity) are often used in conjunction with dams to generate electricity. A dam can also be used to collect water or for storage of water which can be evenly distributed between locations

Purpose

1. **Irrigation:**

Water requirements for irrigation in India are mostly seasonal. The maximum demand of water for irrigation is during the winter months for Rabi crops. However, there is usually a small demand of water for Kharif crops during the summer months just prior to the onset of the monsoon. Water requirements for irrigation are generally higher in a year of low rainfall. But the average demand does not vary greatly from year to year if the irrigated area remains the same. Because irrigation is a sort of insurance against drought, it is desirable to reserve as much storage as possible for irrigation use.

1. **Meeting the agricultural demand for food supply**

One of the biggest uses of water on a worldwide scale is agricultural irrigation. This will account for about 1147 liters per day per capita by the year 2000. Since the early 1990s, less than 1/5 of the land suitable for agriculture in the world has been irrigated, and it has contributed about 1/3 of world food production. It is estimated that 80% of additional food production by the year 2025 will come from irrigated land. Most of the areas in need of irrigation are in arid zones, which represent a major portion of the developing countries. Even with the widespread measures to conserve water by improvements in irrigation technology, construction of more reservoir projects will be required.

1. **Flood control**

Dams and reservoirs can be effectively used to regulate river levels and flooding downstream of the dam by temporarily storing the flood volume and releasing it later.

The most effective method of flood control is accomplished by a number of multipurpose dams strategically located in a river basin. The dams are operated by a specific water control plan for routing floods through the basin without damage. This not only eliminates flooding, but provides other benefits such as water supply, irrigation, and hydropower and water quality. The number of dams and their water control management plans are established by comprehensive planning for economic development and with public involvement. Flood control is a significant purpose for many of the existing dams and continues as a main purpose for some of the major dams of the world currently under construction.

1. **Hydropower**

The availability of energy is essential for the socio-economic development of a nation. It is advantageous to use energy that is clean, efficient, dependable and renewable. Hydropower meets all of these requirements. In countries, where a vast amount of

1. **Navigation:**

Requirements for inland navigation are that there should be adequate flow in the river to maintain the required water depth. Water is released from a storage reservoir to sustain downstream flow for navigation. There is a marked seasonal variation in the demand. Generally, peak releases are required during the summer months when the

natural flow is low.

Factors affecting Dams Design

* Topography
* Geology and soils
* Bearing capacity of the underlying soil
* Foundation settlements
* Permeability of the foundation soil
* Material availability
* Spillway position
* Earthquakes
* Safety
* Height
* Aesthetic view
* Qualified labour
* Cost
* Rainfall
* Climate
* Ground water
* Terrain
* Sediments
* Reservoir function
* Probable wave action

Types of Dams

1. **With Respect to Structure:**

Based on structure and material used, dams are classified as easily created without materials, [arch-gravity dams](http://en.wikipedia.org/wiki/Arch-gravity_dam), [embankment dams](http://en.wikipedia.org/wiki/Embankment_dam) or masonry dams etc.

* **Arch** **Dam:**
* In the arch dam, stability is obtained by a combination of arch and gravity action. If the upstream face is vertical the entire weight of the dam must be carried to the foundation by gravity, while the distribution of the normal [hydrostatic pressure](http://en.wikipedia.org/wiki/Fluid_pressure) between vertical [cantilever](http://en.wikipedia.org/wiki/Cantilever) and arch action will depend upon the [stiffness](http://en.wikipedia.org/wiki/Stiffness) of the dam in a vertical and horizontal direction. When the upstream face is sloped the distribution is more complicated. The [normal](http://en.wikipedia.org/wiki/Normal_(geometry)) component of the weight of the arch ring may be taken by the arch action, while the normal hydrostatic pressure will be distributed as described above. For this type of dam, firm reliable supports at the abutments (either [buttress](http://en.wikipedia.org/wiki/Buttress) or [canyon](http://en.wikipedia.org/wiki/Canyon) side wall) are more important. The most desirable place for an arch dam is a narrow canyon with steep side walls composed of sound rock. The safety of an arch dam is dependent on the strength of the side wall abutments, hence not only should the arch be well seated on the side walls but also the character of the rock should be carefully inspected
* Two types of single-arch dams are in use, namely the constant-angle and the constant-radius dam. The constant-radius type employs the same face radius at all elevations of the dam, which means that as the channel grows narrower towards the bottom of the dam the central angle subtended by the face of the dam becomes smaller. [Jones Falls Dam](http://en.wikipedia.org/wiki/Jones_Falls_Dam), in Canada, is a constant radius dam. In a constant-angle dam, also known as a variable radius dam, this subtended angle is kept a constant and the variation in distance between the abutments at various levels is taken care of by varying the radii. Constant-radius dams are much less common than constant-angle dams. [**Parker Dam**](http://en.wikipedia.org/wiki/Parker_Dam) is a constant-angle arch dam



* A similar type is the double-curvature or thin-shell dam. Wild- horse Dam near Mountain City, Nevada in the United States is an example of the type. This method of construction minimizes the amount of concrete necessary for construction but transmits large loads to the foundation and abutments. The appearance is similar to a single-arch dam but with a distinct vertical curvature to it as well lending it the vague appearance of a concave lens as viewed from downstream.
* The multiple-arch dam consists of a number of single-arch dams with concrete buttresses as the supporting abutments, as for example the [**Daniel-Johnson Dam**](http://en.wikipedia.org/wiki/Daniel-Johnson_Dam), Québec, Canada. The multiple-arch dam does not require as many buttresses as the hollow gravity type, but requires good rock foundation because the buttress loads are heavy.
* **Gravity Dam:**
* In a gravity dam, the force that holds the dam in place against the push from the water is Earth's gravity pulling down on the mass of the dam. The water presses laterally (downstream) on the dam, tending to overturn the dam by rotating about its toe (a point at the bottom downstream side of the dam). The dam's weight counteracts that force, tending to rotate the dam the other way about its toe. The designer ensures that the dam is heavy enough that gravity wins that contest. In engineering terms, that is true whenever the resultant of the forces of gravity and water pressure on the dam acts in a line that passes upstream of the toe of the dam.
* Furthermore, the designer tries to shape the dam so if one were to consider the part of dam above any particular height to be a whole dam itself, that dam also would be held in place by gravity i.e. there is no tension in the upstream face of the dam holding the top of the dam down. The designer does this because it is usually more practical to make a dam of material essentially just piled up than to make the material stick together against vertical tension.
* Note that the shape that prevents tension in the upstream face also eliminates a balancing compression stress in the downstream face, providing additional economy.



* The designer also ensures that the toe of the dam is sunk deep enough in the earth that it does not slide forward.
* For this type of dam, it is essential to have an impervious foundation with high *bearing* strength.
* When situated on a suitable site, a gravity dam can prove to be a better alternative to other types of dams. When built on a carefully studied foundation, the gravity dam probably represents the best developed example of dam building. Since the fear of [flood](http://en.wikipedia.org/wiki/Flood) is a strong motivator in many regions, gravity dams are being built in some instances where an arch dam would have been more economical.
* Gravity dams are classified as "solid" or "hollow" and are generally made of either concrete or masonry. This is called "zoning". The core of the dam is zoned depending on the availability of locally available materials, foundation conditions and the material attributes. The solid form is the more widely used of the two, though the hollow dam is frequently more economical to construct. Gravity dams can also be classified as "overflow" (spillway) and "non-overflow." [Grand Coulee Dam](http://en.wikipedia.org/wiki/Grand_Coulee_Dam) is a solid gravity dam and [Itapúa Dam](http://en.wikipedia.org/wiki/Itaipu_Dam) is a hollow gravity dam.
* **Arch-Gravity Dam:**
* A gravity dam can be combined with an arch dam into an [arch-gravity dam](http://en.wikipedia.org/wiki/Arch-gravity_dam) for areas with massive amounts of water flow but less material available for a purely gravity dam. The inward compression of the dam by the water reduces the lateral (horizontal) force acting on the dam.
* Thus, the gravitation force required by the dam is lessened, i.e. the dam does not need to be so massive. This enables thinner dams and saves resources



With Respect to Use:

* **Saddle dam**
* A saddle dam is an auxiliary dam constructed to confine the reservoir created by a primary dam either to permit a higher water elevation and storage or to limit the extent of a reservoir for increased efficiency. An auxiliary dam is constructed in a low spot or *saddle* through which the reservoir would otherwise escape. On occasion, a reservoir is contained by a similar structure called a [dike](http://en.wikipedia.org/wiki/Dike_(construction)) to prevent inundation of nearby land. Dikes are commonly used for *reclamation* of arable land from a shallow lake. This is similar to a [levee](http://en.wikipedia.org/wiki/Levee), which is a wall or embankment built along a river or stream to protect adjacent land from [flooding](http://en.wikipedia.org/wiki/Flood).



* **Underground dam**
* Underground dams are used to trap groundwater and store all or most of it below the surface for extended use in a localized area. In some cases they are also built to prevent saltwater from intruding into a freshwater aquifer. Underground dams are typically constructed in areas where water resources are minimal and need to be efficiently stored, such as in deserts and on islands like the [Fukuzato Dam](http://en.wikipedia.org/wiki/Fukuzato_Dam" \o "Fukuzato Dam) in Okinawa, Japan. They are most common in northeastern Africa and the arid areas of Brazil while also being used in the southwestern United States, Mexico, India, Germany, Italy, Greece, France and Japan.



* There are two types of underground dams: a *sub-surface* and a *sand-storage* dam. A sub-surface dam is built across an aquifer or drainage route from an impervious layer (such as solid bedrock) up to just below the surface. They can be constructed of a variety of materials to include bricks, stones, concrete, steel or PVC. Once built, the water stored behind the dam raises the water table and is then extracted with wells. A sand-storage dam is a weir built in stages across a stream. It must be strong as floods will wash over its crest.

With Respect to Material:

#### Steel dams:

#### A [steel dam](http://en.wikipedia.org/wiki/Steel_dam) is a type of dam briefly experimented with in around the start of the 20th century which uses steel plating (at an angle) and load bearing beams as the structure. Intended as permanent structures, steel dams were an (arguably failed) experiment to determine if a construction technique could be devised that was cheaper than masonry, concrete or earthworks, but sturdier than timber crib dams

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#### Timber Dam:

* [Timber](http://en.wikipedia.org/wiki/Timber) dams were widely used in the early part of the industrial revolution and in frontier areas due to ease and speed of construction. Rarely built in modern times because of relatively short lifespan and limited height to which they can be built, timber dams must be kept constantly wet in order to maintain their water retention properties and limit deterioration by rot, similar to a barrel. The locations where timber dams are most economical to build are those where timber is plentiful, [cement](http://en.wikipedia.org/wiki/Cement) is costly or difficult to transport, and either a low head diversion dam is required or longevity is not an issue. Timber dams were once numerous, especially in the North American west, but most have failed, been hidden under earth embankments or been replaced with entirely new structures.
* dams were the  Other types



#### Coffer dams:

#### A [coffer dam](http://en.wikipedia.org/wiki/Cofferdam) is a (usually temporary) barrier constructed to exclude water from an area that is normally submerged. Made commonly of wood, concrete or [steel](http://en.wikipedia.org/wiki/Steel) sheet [piling](http://en.wikipedia.org/wiki/Deep_foundation), cofferdams are used to allow construction on the [foundation](http://en.wikipedia.org/wiki/Foundation_(architecture)) of permanent dams, bridges, and similar structures. When the project is completed, the cofferdam may be demolished or removed. See also [causeway](http://en.wikipedia.org/wiki/Causeway) and [retaining wall](http://en.wikipedia.org/wiki/Retaining_wall).

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#### Common uses for cofferdams include construction and repair of off shore oil platforms. In such cases the cofferdam is fabricated from sheet steel and welded into place under water. Air is pumped into the space, displacing the water allowing a dry work environment below the surface. Upon completion the cofferdam is usually deconstructed unless the area requires continuous maintenance

#### Beaver dams:

[Beavers](http://en.wikipedia.org/wiki/Beaver) create dams primarily out of mud and sticks to flood a particular habitable area. By flooding a parcel of land, beavers can navigate below or near the surface and remain relatively well hidden or protected from predators. The flooded region also allows beaver’s access to food, especially during the winter.



EFFECTS OF JOINT

A three-dimensional curved surface isoperimetric interface element is used to model the parietal joints in the contact area of dam body and foundation and the vertical joints between the cantilevers of an arch dam. During an earthquake these joints may open and close cyclically and affect the seismic response of the dam. In this paper the nonlinearity of dam body material combined with nonlinearity due to presence of joints and discontinuities at predefined sections of the dam are investigated. Although the mechanism of both system of joints are the same but their effects on the response of the dam are different. Non-linear parietal joint opening releases the Cantilever tensile stresses at the contact area of dam body and foundation and increases the compressive arch stresses at the mid height of crown cantilever. Non-linear vertical joint opening between the cantilevers of the dam releases the arch tensile stresses. In this case the arch action is partially lost and the cantilever action resists the forces by bending toward upstream face which Results an increase in the cantilever compressive stresses at the base of upstream face. Considering the parietal and vertical joint opening combined with the material nonlinearly of concrete to some extent fills up the gap between linear analysis results and actual behavior of the dam.

**INTRODUCTION**

Concrete arch dams are not monolithic structures and contain variety of joints and discontinuities. Some of these Joints are unintentional zones of weakness such as horizontal and vertical construction joints, concrete rock Interface joints (Fig. 1) and others are designed to accommodate thermal strains, differential displacements and Structural movements of the dam. During an earthquake these joints may open and close cyclically and affect the Response of the dam. Linear dynamic analysis of concrete arch dams neglecting the effect of joints may result high tensile stresses that cannot be interpreted easily. The importance of joint modeling in dam engineering has motivated several analytical and experimental researches.

[**Dowling and Hall, 1989]** developed a discrete joint model represented by non-linear springs. The earthquake analysis of Pacoima dam demonstrated that contraction joint opening, particularly in the upper portions of the joint, could occur even under moderate earthquake ground motions. The analysis of Morrow Point dam by

**[Fenves et. al, 1992]** showed that the joint opening of the contraction joints has a significant effect on the stress Developed in maximum credible earthquake. During an earthquake the contraction joints may open and close which result in arch tensile stress release and redistributing the internal forces between the arch action and cantilever action. They also investigated the effects of the number of joints on the seismic response of the dam and showed that arch stress reduce, as the number of joints in the model increase. They also demonstrated that modeling only a few numbers of joints in the arch dam is practical and can provide a realistic estimate of the stresses and displacements.

The results of the shaking table test with and without joints done by [H.Q. Chen et. al, 1996] and comparison with theoretical analysis using ADAP-88 program showed that opening of contraction joints under seismic loading reduces the arch tensile stresses and increases the cantilever compressive stresses and there is a good agreement between the experimental and theoretical results on this phenomena.

There are many factors that contribute in the non-linear response of a concrete arch dam. Even if we model the joints and discontinuities at predefined sections of the dam, the assumption of linear stress-strain relationship for concrete under such a condition is not realistic and the material nonlinearity should be taken into account.

In this paper a three-dimensional curved isoperimetric interface element is used to model the vertical joints between the cantilevers of the dam and the circumferential joint in the contact area of dam body and foundation.

In order to model the material nonlinearity of concrete during loading and failure under three dimensional stress state, a comprehensive elastic-plastic fracture stress-strain relationship based on the theories of elasticity and plasticity is used and the response of a concrete arch dam considering the material nonlinearity combined with nonlinearity due to presence of joints and discontinuities at predefined sections of the dam is investigated.

**CURVED INTERFACE SURFACE ELEMENT:**

Because of the complicated shape of contact area between the cantilevers of the dam and also the concrete-rock interface area, the quadratic isoperimetric surface element [Buragohain D.N., Shah V.L., 1978]has been used to model the parietal and vertical joints in a concrete arch dam. The element develops resisting forces due to relative displacements but it doesn’t develop inertial or damping forces.

Conclusion:

Dynamic behavior of concrete arch dams during occurrence of strong motion was clarified by considering the joints and discontinuities at predefined sections of the dam and modeling the material behavior of dam body. After joint opening, arch dam redistributes the internal forces by converting the cantilever action to arch action or vice versa. This process results in a stable stress state which is consistent with actual behavior of the dam.

1. Theoretical investigations confirmed considerable opening of the contact joint both in no overflow and especially in powerhouse sections of the Bratsk dam. Other conditions being equal, the length of the zone of opening of the contact joint in the powerhouse sections is 2–3 m greater than in the no overflow sections.
2. Opening of joints has a seasonal character. In the winter the zone of opening in the powerhouse sections reaches the grout curtain (9–10 m from the upstream face), in the summer it is about half as much.
3. Such opening of the contact joint together with the phenomenon of decompression of the foundation leads to an increase of the uplift pressure, increase of seepage discharges, and decrease of safety against shearing. In turn, an increase of uplift pressure can lead to an increase of the zone of opening of the joint by 1–2 m.
4. A decrease in the winter of the upper pool level from the NPL (402 m) to 398 m brings the contact zone into about the same state as in the summer at the NPL.
5. Calculations showed that the zone of opening of the contact joint can be followed by a closed joint zone with displaced surfaces (sliding zone) and only then does the remaining part of the joint have an undisturbed initial strength. The size of the sliding zone depends on many factors and requires further refinement, but in any event this zone can completely enter the second column.
6. In the future we must refine the state of the contact zone in various sections with a more accurate consideration of the characteristics of the contact joint (friction with the initial strength) and with consideration of decompression of the foundation or the formation of cracks in it, seepage in the foundation, and effect of opening of the column joints.

**Suitability of Igneous rocks**

To determine the suitability, we will first have to have a look at the physical properties of igneous rocks. We all know that igneous rocks can:

* Crystalline in nature
* Signified having high compressive strength
* Impermeability
* Less porous to achieve optimum stability
* Have large crystal structure like granites
* Well grained intrusive rocks
* Have small crystal structure like basalts
* Be denser than other rock types
* Have an interlocking crystalline structure
* Appear to be peppered with black specks
* Be light enough to float (pumice).



Now depends on their use in dams. If these rocks are to be used in concrete, then they might not be such a good alternative for the commonly used aggregate.

If they are to be used in fill along with earth, they might be used. Because they are denser than other rock types, have an interlocking crystalline structure. But if water reaches them some of the rocks have the capability to flow and can be porous then this could lead to some disastrous effects.

But as in case of Hoover dam, igneous rocks are present as magmatic enclave in black canyon dacite. And still it is a wonder in dams. So they from a good rock bed and foundation.

However granite and other igneous rock are also used as armor stone or rip rap in sea defenses, on embankment dams and in pier walls.

So their use in dams and their suitability depends upon the given conditions and properties of igneous rocks present in reachable and economically fit distance within the site.

**Suitability of Sedimentary rocks**

Some characteristic features of sedimentary rocks are that:

* Most rocks do not have a crystalline structure and their surface is matt.
* They are soft and easy to scratch or crush;
* If a given rock contains calcium carbonate, it releases bubbles of gas on contact with dilute hydrochloric acid.
* They form visible layers.
* They consist of separate particles.
* They may contain fossils.



But again sedimentary rocks as the igneous rocks are, quite a branch of rocks. Some of them can be used or are heavy and dense enough along with high crushing strength and low porosity to be used for the desired purposes and some of them can’t be.

As speaking of an example is gravels found in the river bed. They have been used by early civilizations for the water bearing purposes or blocking the way of water forming a dam. Not so promising but still quite effective.

As in the above picture, a technician is checking the effectiveness of a gravel dam. So such dams have existed and are quite something to work with.

Other examples are,

[Glennies Creek Dam:](http://members.optusnet.com.au/~engineeringgeologist/page14.html) A 10 meter thick layer of completely weathered, non-welded tuff (a soil type material) at the dam site had a controlling influence on the choice of type of dam and the siting of the dam, diversion tunnel and the spillway; in fact, the whole project layout was determined by the outcrop and weathering pattern of the non-welded tuff.  
  
[Windermere Dam:](http://members.optusnet.com.au/~engineeringgeologist/page8.html) The embankment dam was built on a weathered, sedimentary rock foundation. The rock fill construction material to build the dam was obtained from an unlined rock cut spillway in untethered andesite about 1 km from the dam site. If a spillway had been built adjacent to the dam in the weathered sedimentary rocks it would have had to have been lined with concrete to prevent erosion, at a greatly increased cost.

**Suitability of Metamorphic rocks**

Metamorphic rocks are to an extent unpredictable.

Where the rock is weathered at the surface, an investigation is usually required since weathered formations may prove exceptionally difficult when the foundations are dug out.



*Example*: The Lavaude-Gelade dam in the Central Massif, Creuse, France was founded on altered granulite. The alteration in the granulite was found to persist to a depth of 20m, in addition to being broken and fissured. The site required an extensive grouting injection with cement, clay and bentonite.

Foliated rocks possess prominent directional properties. The strength is much weaker in the direction of the foliation than in other directions. Care should be taken that loads (bridges, dams, and buildings) are not transferred to foliated directions. In tunnel construction, foliated metamorphic rocks are generally more costly because of more steel supports.