41.2 History of Dam Failures

A few case histories of dam failures in India and in USA are described briefly below. The details regarding other failures are reported by Mahesh Kumar (1992) and Singh.

Kaddam Project Dam, Andhra Pradesh, India

Built in Adilabad, Andhra in 1957 - 58, the dam was a composite structure, earth fill and/or rock fill and gravity dam. It was 30.78 m high and 3.28 m wide at its crest. The storage at full was 1.366 * 108 m^3. The observed floods were 1.47 * 104 m^3/s. The dam was overtopped by 46 cm of water above the crest, inspite of a free board allowance of 2.4 m that was provided, causing a major breach of 137.2 m wide that occurred on the left bank. Two more breaches developed on the right section of the dam. The dam failed in August 1958.

Kaila Dam, Gujarat, India

The Kaila Dam in Kachch, Gujarat, India was constructed during 1952 - 55 as an earth fill dam with a height of 23.08 m above the river bed and a crest length of 213.36 m. The storage of full reservoir level was 13.98 million m^3 . The foundation was made of shale. The spillway was of ogee shaped and ungated. The depth of cutoff was 3.21 m below the river bed. Inspite of a freeboard allowance of 1.83 m at the normal reservoir level and 3.96 m at the maximum reservoir level the energy dissipation devices first failed and later the embankment collapsed due to the weak foundation bed in 1959.

Kodaganar Dam, Tamil Nadu, India

This dam in the India, was constructed in 1977 on a tributary of Cauvery River as an earthen dam with regulators, with five vertical lift shutters each 3.05 m wide. The dam was 15.75 m high above the deepest foundation, having a 11.45 m of height above the river bed. The storage at full reservoir level was 12.3 million m^3, while the flood capacity was 1275 m^3/s. A 2.5 m free board above the maximum water level was provided. The dam failed due to overtopping by flood waters which flowed over the downstream slopes

of the embankment and breached the dam along various reaches. There was an earthquake registered during the period of failure although the foundation was strong. The shutters were promptly operated during flood, but the staff could only partially lift the shutters, because of failure of power. Although a stand-by generator set was commissioned soon, this could not help and they resorted to manual operation of shutters. Inspite of all efforts, water eventually overtopped the embankment. Water gushed over the rear slopes, as a cascade of water was eroding the slopes. Breaches of length 20 m to 200 m were observed. It appeared as if the entire dam was overtopped and breached.

Machhu II (Irrigation Scheme) Dam, Gujarat, India

This dam was built near Rajkot in Gujarat, India, on River Machhu in August, 1972, as a composite structure. It consisted of a masonry spillway in river section and earthen embankments on both sides. The embankment had a 6.1 m top width, with slopes 1 V : 3 H and 1 V : 2 H respectively for the upstream and downstream slopes and a clay core extending through alluvium to the rocks below. The upstream face had a 61 cm small gravel and a 61 cm hand packed riprap. The dam was meant to serve an irrigation scheme. Its, storage capacity of 1.1 * 108 m^3. The dam had a height of 22.56 m above the river bed, a 164.5 m of crest length of overflow section, and a total of 3742 m of crest length for the earth dam.

The dam failed on August 1, 1979, because of abnormal floods and inadequate spillway capacity. Consequent overtopping of the embankment caused a loss of 1800 lives. A maximum depth of 6.1 m of water was over the crest and within two hours, the dam failed. While the dam failed at a peak discharge of 7693 m^3/s, the figure was revised to 26,650 m^3/s after failure, with a free board of 2.45 m given, providing also an auxiliary spillway with a full capacity of 21,471 m^3/s. The observed actual flood depth over spillway crest was 4.6 m with an observed 14,168 to 19,835 m^3/s, while the design depth over spillway crest was 2.4 m.

Nanaksagar Dam, Punjab, India

Situated in Punjab in northwestern India, the dam was constructed in 1962 at Bhakra, with a reservoir capacity of 2.1 * 106 m3. An estimated maximum discharge of 9,711 m^3/s had occurred on August 27, 1967, due to heavy monsoon rains that were heaviest in twenty years. This caused dam to fail. The water that gushed through the leakage created a 7.6 m breach, which later widened to 45.7 m. The condition of the reservoir had worsened, causing a 16.8 m boil downstream of toe, which was responsible for the settlement of the embankment. As the dam was overtopped, causing a breach 150 m wide. A downstream filter blanket and relief wells were provided near the toe but were insufficient to control the seepage. The relief wells each 50 mm in diameter were spaced at a distance of 15.2 to 30.4 m.

Panshet Dam: (Ambi, Maharashtra, India, 1961 - 1961)

The Panshet Dam, near Pune in Maharashtra India, was under construction when the dam had failed. It was zoned at a height of 51 m and having an impervious central core outlet gates located in a trench of the left abutment and hoists were not fully installed when floods occurred at the site of construction. The reservoir had a capacity of 2.70 million m^3.

Between June 18 and July 12, 1961, the recorded rainfall was 1778 mm. The rain caused such a rapid rise of the reservoir water level that the new embankment could not adjust to the new loading condition. The peak flow was estimated at 4870 m^3/s . Water rose at the rate of 9 m per day initially, which rose up to 24 m in 12 days. Due to incomplete rough outlet surface the flow through was unsteady which caused pressure surges. Cracks were formed along the edges of the right angles to the axis of the dam causing a subsidence of 9 m wide. An estimated 1.4 m of subsidence had occurred in 2.5 hours, leaving the crest of the dam 0.6 m above the reservoir level. Failure was neither due to insufficient spillway capacity nor due to foundation effect. It was attributed

to inadequate provision of the outlet facility during emergency. This caused collapse of the structure above the outlets.

Khadakwasla Dam (Mutha, Maharashtra, India, 1864 - 1961)

The Khadkawasla Dam, near Pune in Maharashtra, India was constructed in 1879 as a masonry gravity dam, founded on hard rock. It had a height of 31.25 m above the river bed, with a 8.37 m depth of foundation. Its crest length was 1.471 m and had a free board of 2.74 m. The dam had a flood capacity of 2,775 m^3/s and a reservoir of 2.78 * 10^3 m^3. The failure of the dam occurred because of the breach that developed in Panshet Dam, upstream of the Khadkawasla reservoir. The upstream dam released a tremendous volume of water into the downstream reservoir at a time when the Khadkawasla reservoir was already full, with the gates discharging at near full capacity. This caused overtopping of the dam because inflow was much above the design flood. The entire length of the dam spilling 2.7 m of water. Vibration of the structure was reported, as the incoming flood was battering the dam. Failure occurred within four hours of the visiting flood waters.

Tigra Dam: (Sank, Madhya Pradesh, India, 1917 - 1917)

This was a hand placed masonry (in time mortar) gravity dam of 24 m height, constructed for the purpose of water supply. A depth of 0.85 m of water overtopped the dam over a length of 400 m. This was equivalent to an overflow of 850 m^3s^{-1} (estimated). Two major blocks were bodily pushed away. The failure was due to sliding. The dam was reconstructed in 1929.

Teton Dam, Teton river canyon, Idaho, USA, NA - 1976

The construction began in April, 1972, and the dam was completed on November 26, 1975. The dam was designed as a zoned earth and gravel fill embankment, having slopes of 3.5 H : 1 V on the upstream and 2 H : 1 V and 3 H : 1 V on the downstream, a height above the bed rock of 126 m, and a 945 m long crest. The dam had a height of

93 m, a crest width of 10.5 m, and had side slopes of 1 V : 3 H on the upstream side and 1 V : 2.5 H on its downstream side. It had a reservoir capacity of 3.08 * 108 m^3. The embankment material consisted of clayey silt, sand, and rock fragments taken from excavations and burrow areas of the river's canyon area. It had a compacted central core. Narrow trenches 21 m deep, excavated in rock and compacted with sandy silt and a deep grout curtain beneath a grout cap the central zone were the measures taken to control the foundation seepage.

The dam failed on June 5, 1976, releasing 308 million m3 of reservoir water. A flood at an estimated peak discharge in excess of 28,300 m3/s had occurred. The peak outflow discharge at the time of failure was 4.67 * 104 m^3/s. A breach 46 m wide at its bottom and 79 m deep had formed. The time of failure was recorded as four hours. The cause of failure was attributed to piping progressing at a rapid rate through the body of the embankment. The two panels that investigated into the causes of failures were unanimous in agreement that the violence and extent of failure completely removed all direct evidence of the details and sequence of failure. However, the main findings suggested that erosion on the underside of the core zone by excessive leakage through and over the grout curtain was the cause of destruction. "Wet seams" of very low density in the left abutment extended into the actual failure area. These caused local deficiencies in the compaction of the fill, and might have been the locus of the initial piping failure.

Earlier on the day of failure, leaks were observed about 30 m below the top of the dam. After four hours, efforts to fill the holes failed and the dam breached by the noon time. The fundamental cause of failure was regarded as a combination of geological factors and design decisions, which taken together allowed the failure to occur. Numerous open joints in abutment rock and scarcity of more suitable materials for the impervious zone were pointed out by the panel as the main causes for the failure of the dam. Futhermore, complete dependence on deep dry key trenches that developed arch action, cracking and hydraulic fracturing as a measure adopted against seepage and

reliance on compacted material for impervious zone were also attributed as possible causes of failure.

Malpasset Dam

An arch dam of height 66 m, with 22 m long crest at its crown. When the collapse occurred, the dam was subjected to a record head of water, which was just about 0.3 m below the highest water level, resulting from 5 days of unprecedented rainfall. The failure occurred as the arch ruptured, as the left abutment gave away. The left abutment moved 2 m horizontally without any notable vertical movement. The water marks left by the wave revealed that the release of water was almost at once. The volume of water relieved was 4.94 Mm^3 of water. 421 lives were lost and the damage was estimated at 68 million US dollars.

Vaiont Dam

This is an arch dam, 267 m high. During the test filling of the dam, a land slide of volume 0.765 Mm^3 occurred into the reservoir and was not taken note of. During 1963, the entire mountain slide into the reservoir (the volume of the slide being about 238 Mm^3, which was slightly more than the reservoir volume itself). This material occupied 2 km of reservoir up to a height of about 175 m above reservoir level. This resulted in a overtopping of 101 m high flood wave, which caused a loss of 3,000 lives.

Baldwin Dam

This earthen dam of height 80 m, was constructed for water supply, with its main earthen embankment at northern end of the reservoir, and the five minor ones to cover low lying areas along the perimeter. The failure occurred at the northern embankment portion, adjacent to the spillway (indicated a gradual deterioration of the foundation during the life of the structure) over one of the fault zones. The V-shaped breach was 27.5 m deep and 23 m wide. The damages were estimated at 50 million US dollar.

Hell Hole Dam

The Hell Hole (lower) dam was a rock fill dam of height 125 m, failed during construction, when the rains filled the reservoir to an elevation of 30 m above the clay core. The capacity of this multipurpose reservoir after completion was 2.6 M m^3.

Summary of a few other Dam failures

Dam / Reservoir	Year of accident	Year of construct	Accident / Failure	Lives lost
Puentes dam, Spain	1802	1785 - 1791	Dam break caused by a foundation failure. Gravity dam with overflow spillway.	608
Minneapolis Mill dam, USA	1899	1893 - 1894	Dam break during a small spill (q_w = 0.04 m^2/s) caused by cracks resulting from ice pressure on the dam. Gravity dam with overflow spillway (H_{dam} = 5.5 m, W = 51.8, 9 steps, h = 0.61 m)	-
Arizona Canal dam	1891 and 1905	1887	Partial destruction of the dam during a flood (q_w = 11.3 m^2/s) caused by foundation problems and timber deterioration. Timber crib dam (H_{dam} = 10 m, W ≈ 245 m, 3 steps, qdes = 33 m^2/s)	-
Warren dam, Australia	1917	1916	Dam overtopped (Q_w = 128 m^3/s) without damage. Concrete gravity dam (H_{dam} = 17.4 m, 4 steps, h = 0.37 m, Q_{des} ≈100 m^2/s)	None
St. Francis dam, USA	1928	1926	Dam break caused by foundation failure. Arched gravity dam (H_{dam} = 62.5 m, h = 0.4 m)	450
Kobila dam, Slovenia	1948	1586	Dam break caused by a flood caused by lack of maintenance. Timber crib dam (H_{dam} = 10 m)	-
New Croton dam, USA	1955	1892 - 1905	Spillway damage during flood releases (Q_w ≈ 651 m^3/s). Masonry gravity dam (H_{dam} = 90.5 m, W ≈ 305 m, h = 2.1 m, Q_{des} ≈ 1,550 m^3/s)	None
Lahontan dam, USA	1970 s	1915	Damaged spillway concrete caused by freezing and thawing. Earth dam with concrete spillway (H_{dam} = 90.5 m, Q_{des} ≈ 742 m^3/s)	None
Goulburn weir, Australia	1978	1891	1 - Gate failure caused by corrosion and 2 - foundation stability problem. Concrete gravity dam (H_{dam} = 15 m, W = 126 m, h = 0.5 m, Q_{des} = 1,980 m^3/s)	None

Moscovite earth dams, Russia (former USSR)	1978 - 80	1978	Failure of two overflow earth dams caused by incorrect drainage layer construction. Earth fill embankments with overflow stepped spillway made of pre-cast concrete blocks (H_{dam} = 7 to 15 m, $Q_{des} \approx$ 30 to 60 m^3/s)	-
Binda weir, Australia	1986	1953	Weir destroyed (blown) because unsafe (lack of maintenance). Timber crib piled weir (H_{dam} = 5.2 m, 5 steps)	None
Silverleaf weir, Australia	1995	1951	Weir overtopping during refurbishment works (no damage). Timber crib piled weir (H_{dam} = 5 m, 4 steps)	None
Dartmouth dam, Australia	1996	1977	Unlined rock steps damaged by flow concentration during low spill ($Q_w \approx$ 225 m^3/s). Earth rock fill embankment with unlined rock cascade spillway (H_{dam} = 180 m, W = 91.4 (concrete crest) and 300 to 350 m (cascade), h = 15 m, $Q_{des} \approx$ 2,755 m^3/s).	None

Notes: (-) unknown information.