# HYDRAULIC SAFETY ASSESSMENT OF EXISTING DAMS

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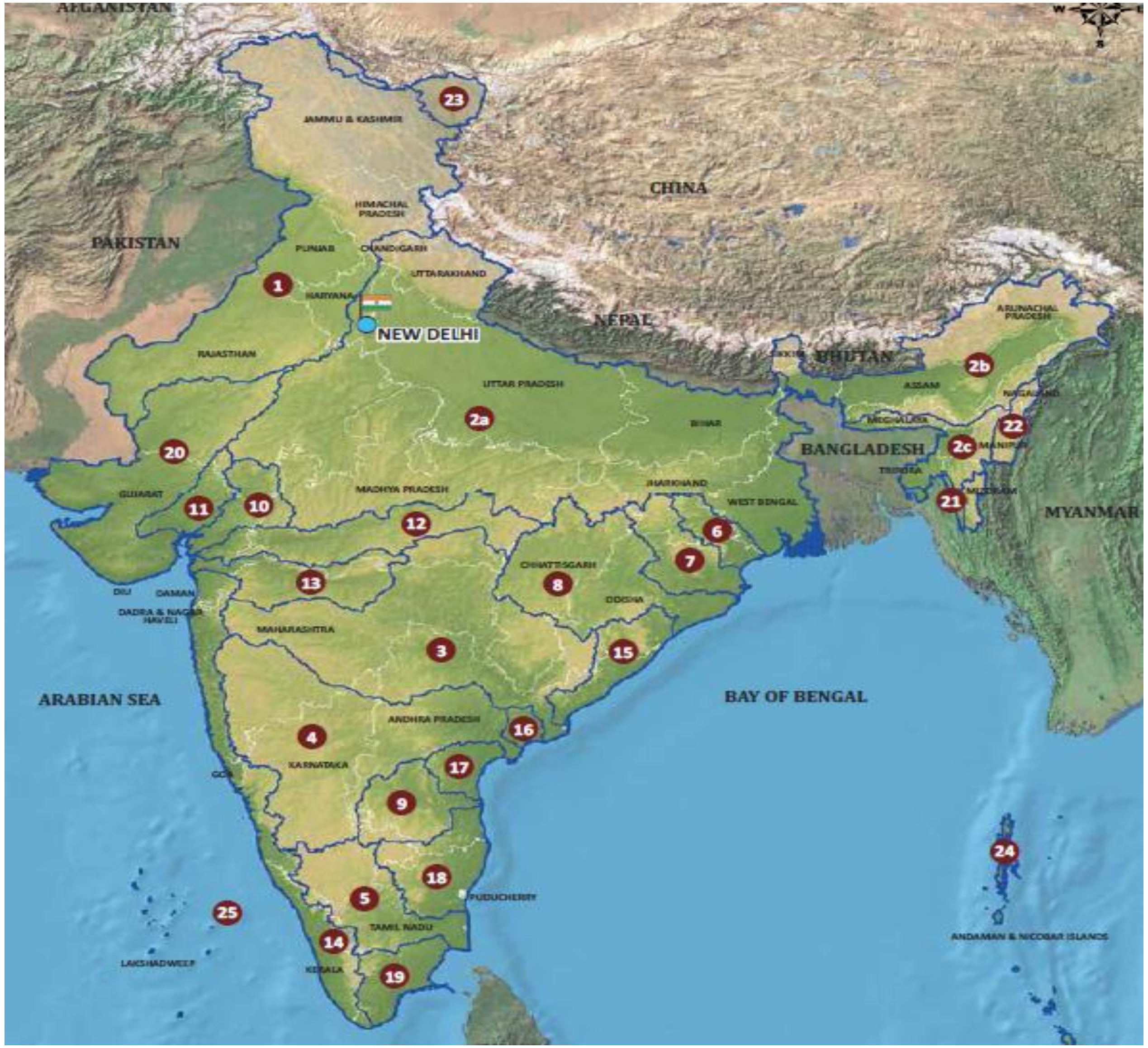
# Indian Water Resources Scenario

(Source: CWC and NRSC combined reassessment study report (2019))




## Share in World Resources

Land(2.4%)

Water(4%)

Human (17%)

Total Precipitation 3880 BCM

↓

Total water availability 1999 BCM

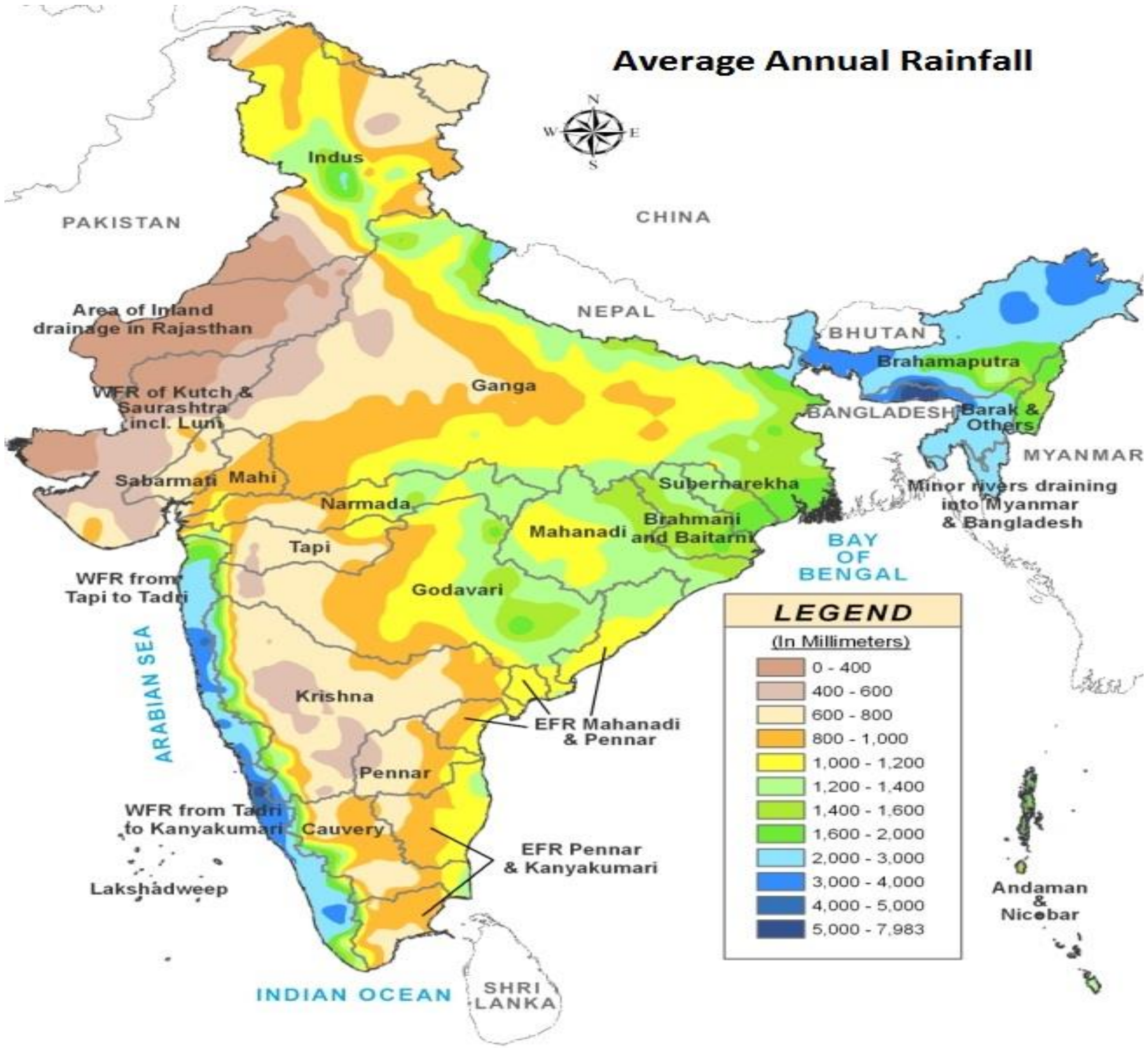
↓

Total Utilizable Water Resources 1137 BCM

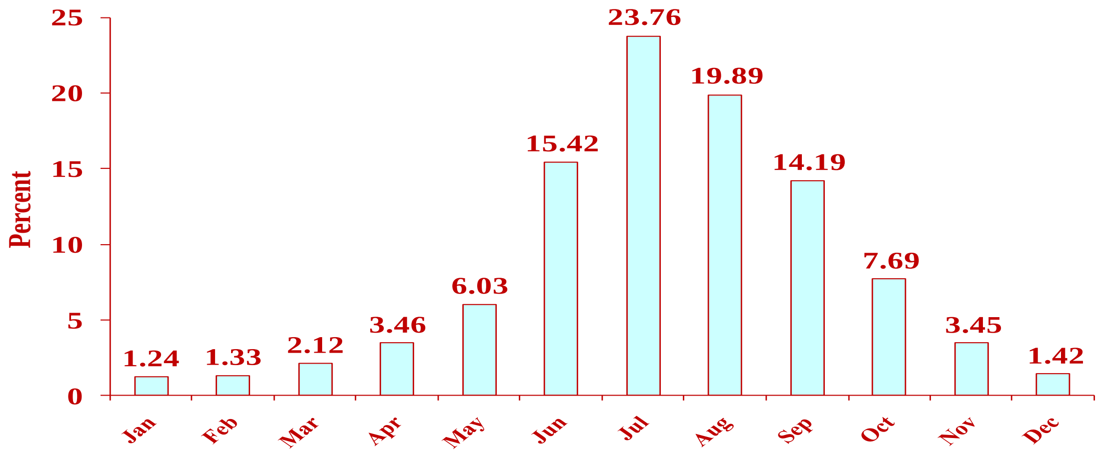
↓

| Surface Water 690 BCM | Ground Water 447 BCM |
|---|---|
| ↓ | ↓ |
| Current Utilisation 450 BCM | Current Utilisation 243 BCM |

# Spatial & Temporal Variation of Rainfall




**Precipitation during June to September 3000 BCM (75%)**




| Annual Rainfall in mm | | |
|---|---|---|
| Avg. | 1,170 | All India |
| Max. | 11,000 | Mawsynram, Meghalaya |
| Min. | 100 | Western Rajasthan |

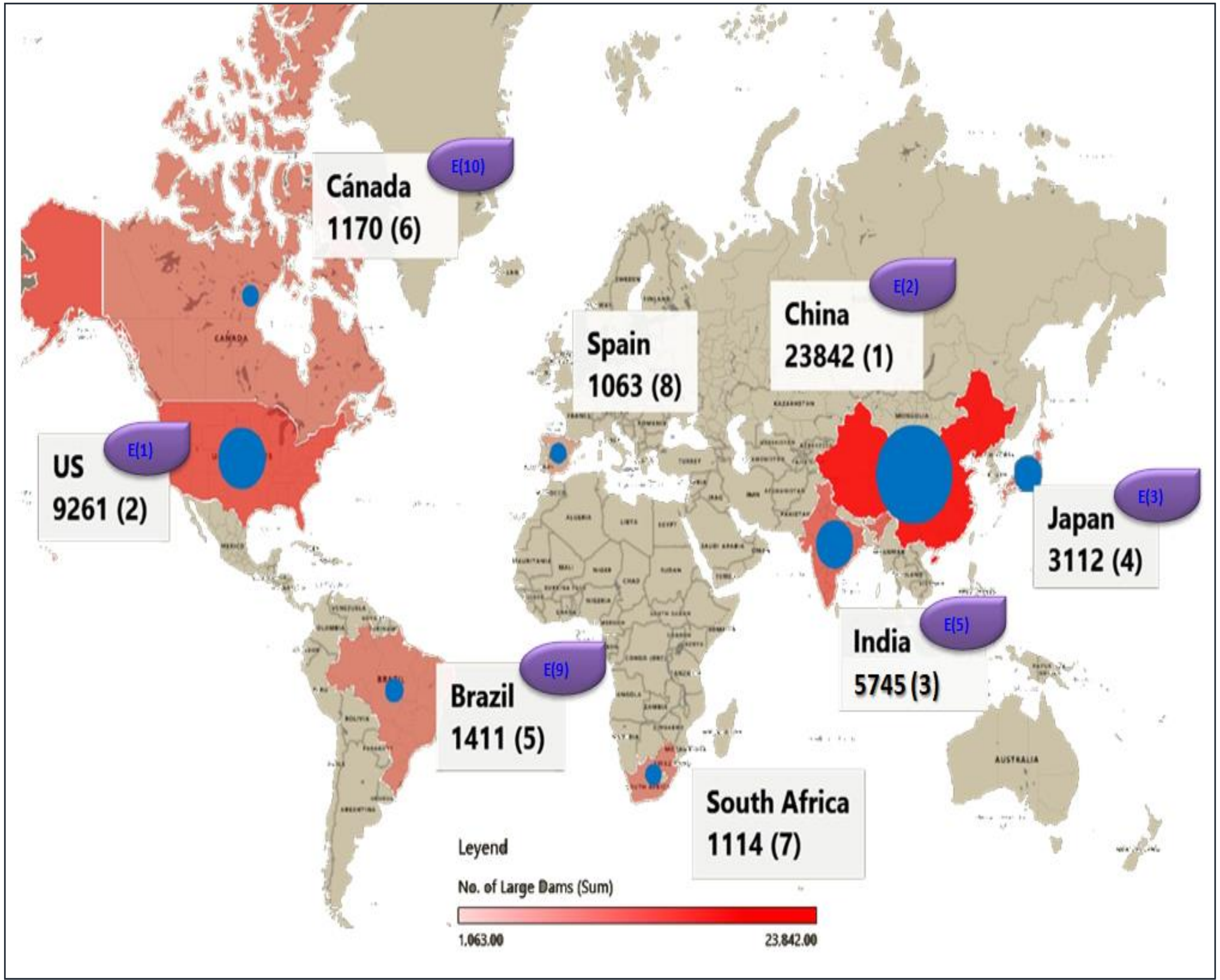
# LARGE DAMS

As per National Register of Large dams (2019)*, India has….

5334 existing large dams

411 dams under construction

*NRLD 2023 released this month wherein existing large dams have increased. (6138/143)




LARGE DAMS : WORLDWIDE

# SPECIFIED DAM

A specified dam in Dam Safety Act is classified as one with a maximum height of more than 15 meters from its deepest foundation to the crest.

A dam between 10 and 15 meters in height from its deepest foundation, provided it complies with one of the following conditions :

a) length of crest of the dam is not less than 500 meters or

b) capacity of the reservoir formed by the dam is not less than one million cubic meters or

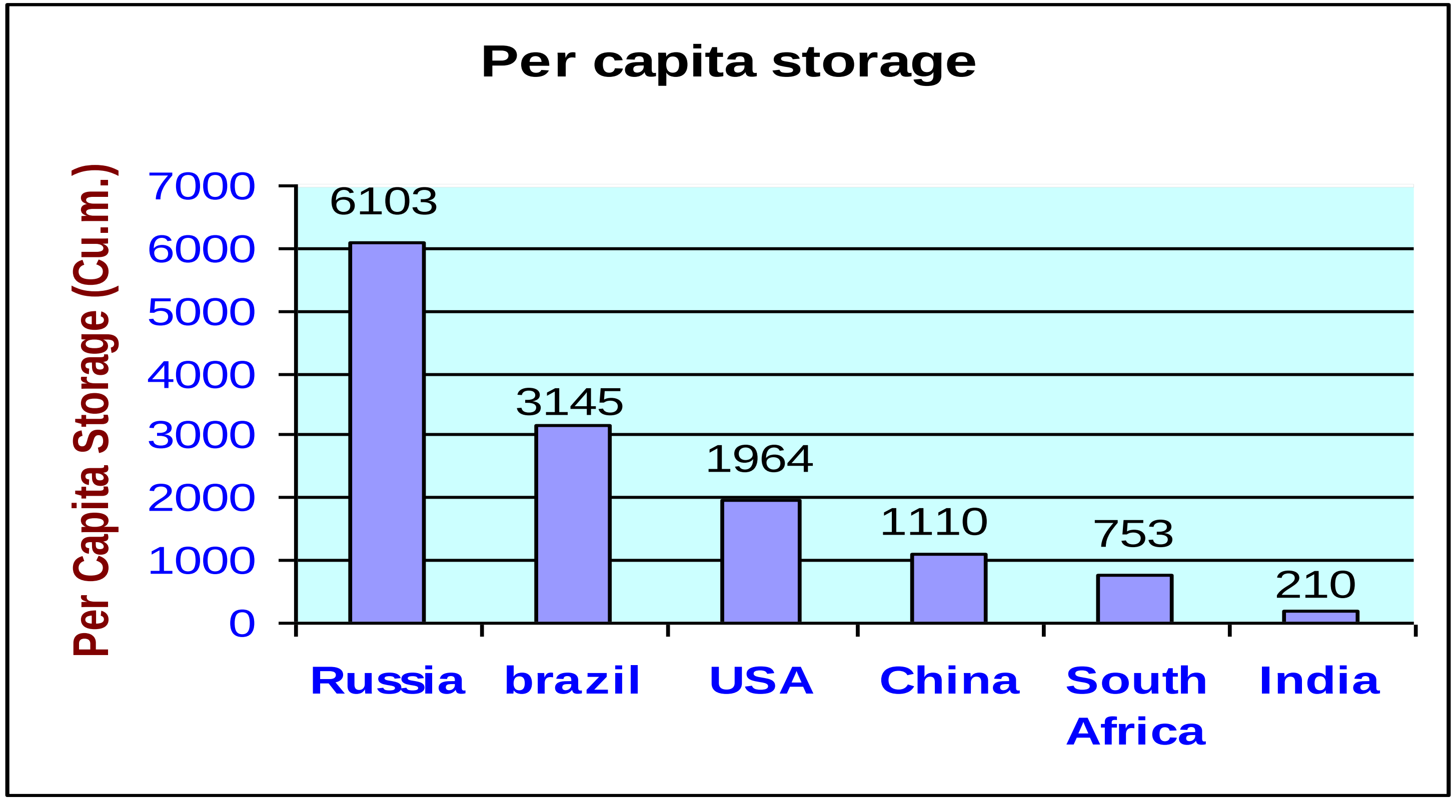
c) the maximum flood discharge dealt with by the dam is not less than 2000 cubic meters per second or

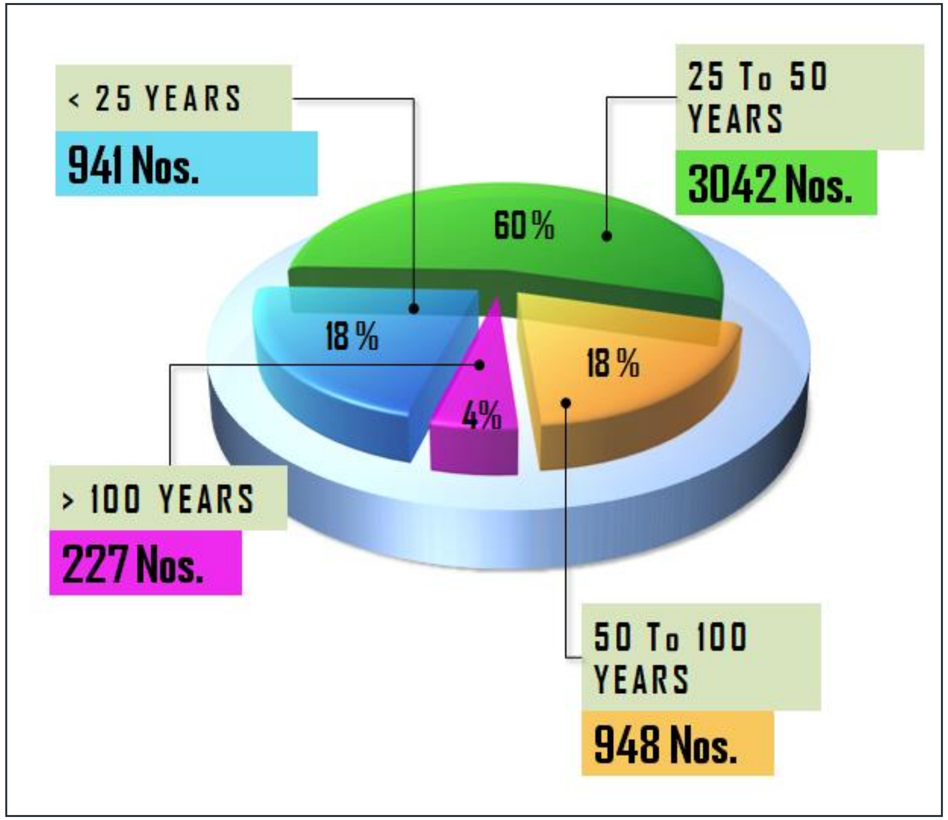
d) the dam has specially difficult foundation problems, or

e) the dam is of unusual design

| State/UT | NO. OF DAMS AS PER NRLD 2019 | |
|---|---|---|
| | Constructed | Under Construction |
| Maharashtra | 2117 | 277 |
| Madhya Pradesh | 899 | 7 |
| Gujarat | 620 | 12 |
| Chhattisgarh | 249 | 9 |
| Karnataka | 230 | 2 |
| Rajasthan | 204 | 8 |
| Odisha | 200 | 4 |
| Telangana | 168 | 16 |
| Andhra Pradesh | 149 | 17 |
| Tamil Nadu | 118 | 0 |
| Uttar Pradesh | 117 | 13 |
| Kerala | 61 | 0 |
| Jharkhand | 55 | 24 |
| West Bengal | 30 | 0 |
| Bihar | 24 | 2 |
| Himachal Pradesh | 19 | 1 |
| Uttarakhand | 17 | 8 |
| Jammu and Kashmir | 15 | 2 |
| Punjab | 14 | 2 |
| Other States/Uts | 28 | 7 |
| Total | 5334 | 411 |

| | | |
|---|---|---|
| 1 | Storages already created | 253.388 BCM |
| 2 | Projects under construction | 50.959 BCM |



# Sector-wise Future Demand Scenario (BCM)

| Sector | Probable Water Demand as Projected by NCIWRD (1999) | |
|---|---|---|
| | 2025 | 2050 |
| Irrigation | **611** | **807** |
| Domestic | **62** | **111** |
| Industry | **67** | **81** |
| Energy | **33** | **70** |
| Others | **70** | **111** |
| **Total** | **843** | **1180 *** |

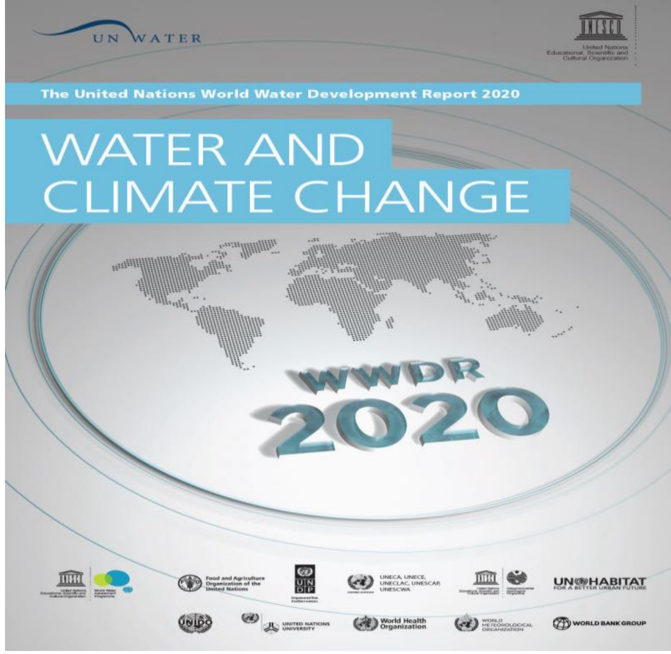
*** Against utilizable water resources of 1121 BCM**

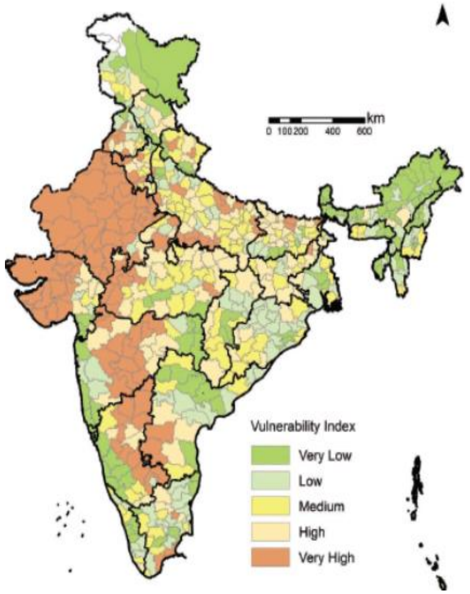
# CLIMATE CHANGE WILL INCREASE THE NEED OF STORAGES

- As per UN World Water Development Report 2020, Climate change will affect the availability, quality and quantity of water for basic human needs
- Climate change will make extreme events more severe by altering the timing, intensity and duration of their occurrences
- The alteration of the water cycle will also pose risks for energy production, food security, human health, economic development and poverty reduction

*What is needed ?*

***Storages are needed to increase resilience to impacts of Climate Change***




*Vulnerability of agriculture to climate change*

# Comparison

| Key Benefits | Large Storage | Small Storage | ArRe/RWH |
|---|---|---|---|
| Flood Moderation | Yes | Little or none | None |
| Spatial variability | Yes | Little or none | None |
| Temporal Variability | Yes | Little or none | Little |
| Cost per unit storage | Medium | High/ Medium | Low |
| Land per unit storage | Moderate | High/ Moderate | Low |
| Evaporation Loss (%) | Low | High | -- |
| Irrigation benefits | 2 or 3 crop | 1 crop | -- |
| Hydropower | Yes | No | None |
| Drought Resilience | High | Little | Little |
| Support for e-flows | Yes | Little | None |
| Infrastructure & employment | Yes | Little | None |
| Navigation | Yes | None | None |
| Recreation/ fisheries | Yes | Little | None |
| Expected Life | 150-200 years | 10-50 years | -- |

# Dam Design- Change in Approach

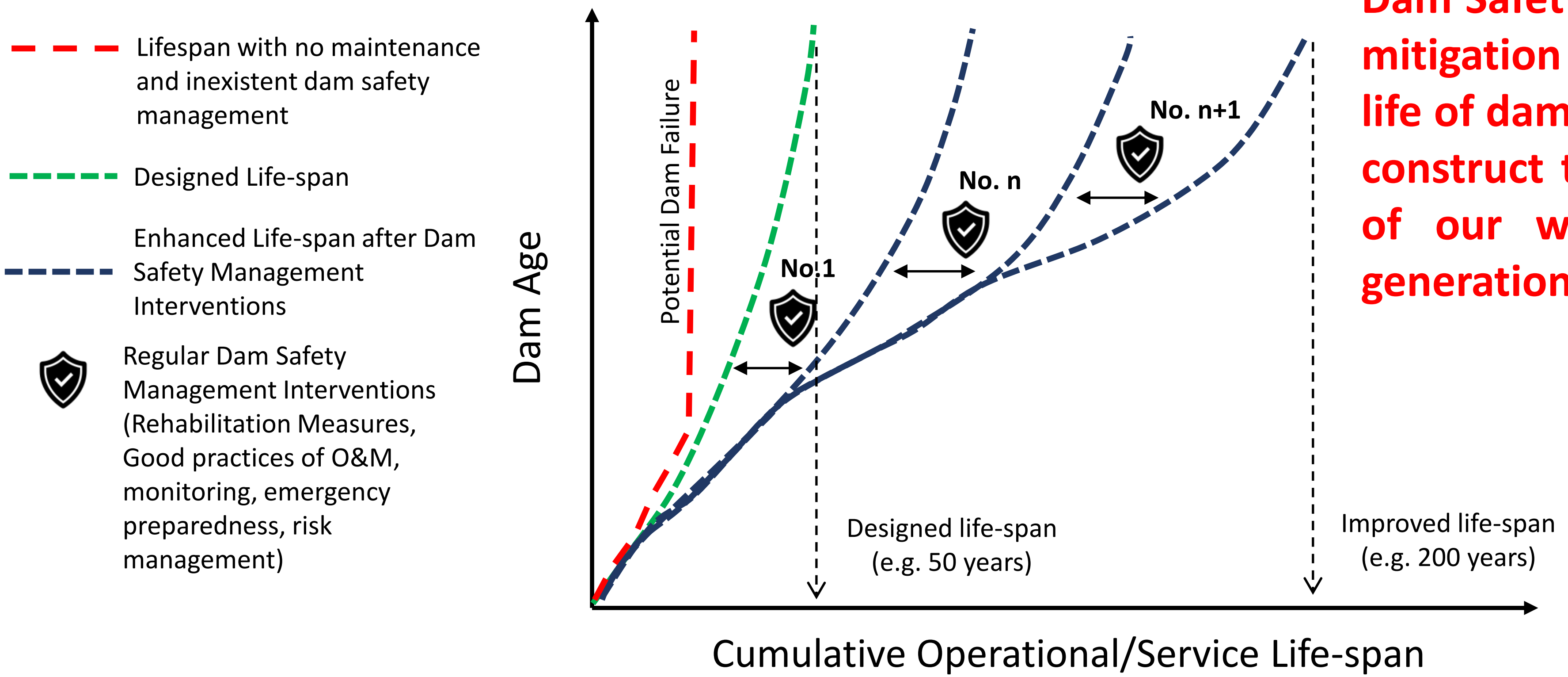
## A. Earlier Approach – "Design Life Approach"

This approach assumes a finite project life and gives superficial attention (if any) to what will happen to the dam at the end of its life. This results in substantial environmental, social, economic and safety considerations being left to subsequent generations.

## B. Earlier Approach – "Life Cycle Management Approach"

This approach advocates sustainable use, where the major functions of the dam are maintained, through good management and maintenance practices, in perpetuity.

# ARE AGEING WATER STORAGE INFRASTRUCTURE REALLY A THREAT ?



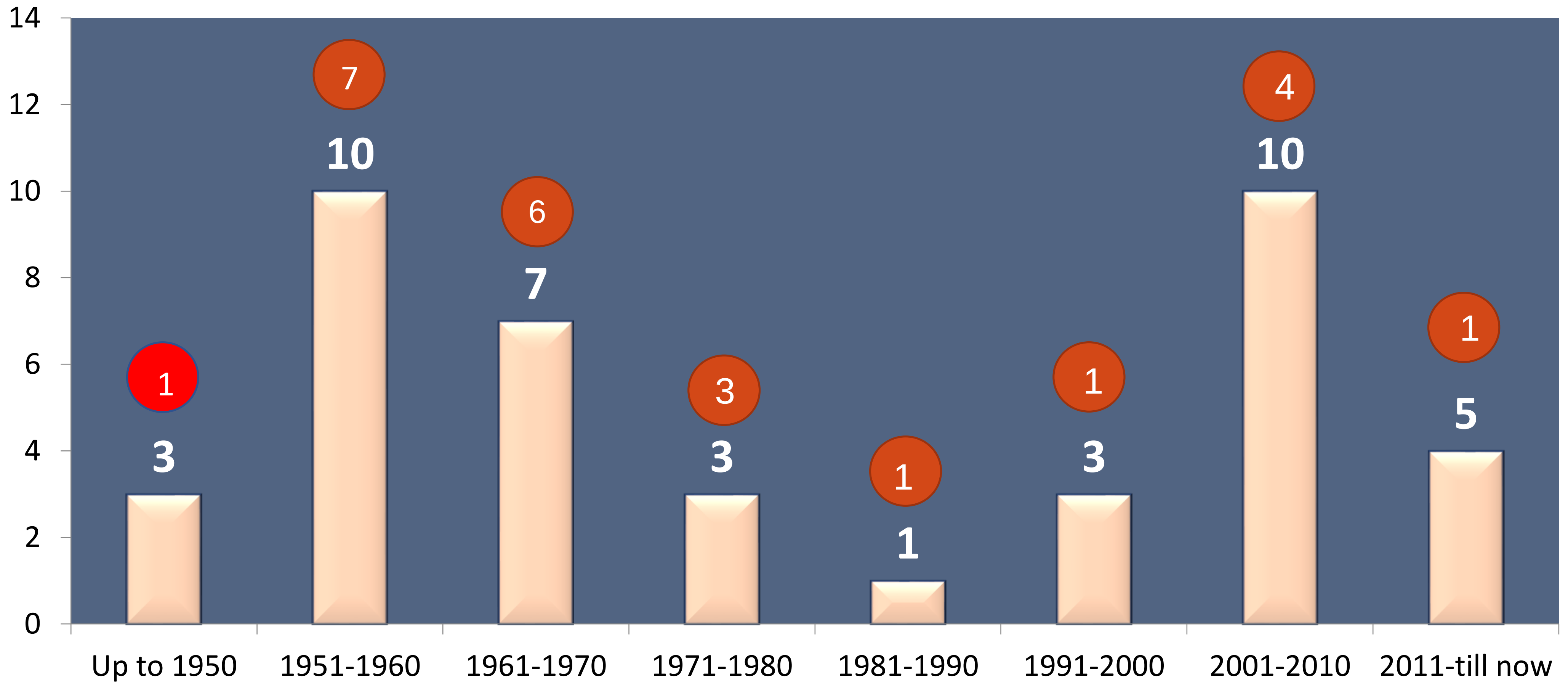

**Dam Safety Management and risk mitigation practices enhance the life of dams – what we design and construct today can serve people of our world for many, many generations**

Source: UN Report

Failed within 10 years

*42 reported dam failures in the last 100 years*
*Numerous dam incidents*

Decade-wise number of dam failures in India




Institutional Mechanism

Uniform dam safety procedures across the country

Machhu dam disaster of 1979 in Gujarat

Uttrakhand Dam Disaster

# Reported failure of dams in India by States/DSOs (Year wise)

| Sl. No | State | Name of Project | Type | Max. Height(m) | Year of Completion | Year of Failure | Cause of failure |
|---|---|---|---|---|---|---|---|
| **Up to 1950** | | | | | | | |
| 1 | Madhya Pradesh | Tigra | Masonry | 24.03 | 1914-17 | 1917 | Overtopping followed by slide. |
| 2 | Maharashtra | Ashti | Earth | 17.70 | 1883 | 1933 | Slope failure. |
| 3 | Madhya Pradesh | Pagara | Composite | 27.03 | 1911-27 | 1943 | Overtopping followed by breach. |
| **1951-1960** | | | | | | | |
| 4 | Madhya Pradesh | Palakmati | Earth | 14.60 | 1942 | 1953 | Sliding failure. |
| 5 | Rajasthan | Dakhya | Earth | N.A | 1953 | 1953 | Breaching. |
| 6 | Uttar Pradesh | Ahrura | Earth | 22.80 | 1953 | 1953 | Breaching. |
| 7 | Rajasthan | Girinanda | Earth | 12.20 | 1954 | 1955 | Overtopping followed by breaching. |
| 8 | Rajasthan | Anwar | Earth | 12.50 | 1956 | 1957 | Breaching. |
| 9 | Rajasthan | Gudah | Earth | 28.30 | 1956 | 1957 | Breached due to bad workmanship. |
| 10 | Rajasthan | Sukri | Earth | N.A | N.A | 1958 | Breached by leakage through foundation. |
| 11 | Madhya Pradesh | Nawagaon | Earth | 16.00 | 1958 | 1959 | Overtopping leading to breach. |
| 12 | Rajasthan | Dervakheda | Earth | N.A | N.A | 1959 | Breaching. |
| 13 | Gujarat | Kaila | Earth | 23.08 | 1955 | 1959 | Embankment collapsed due to weak foundation. |

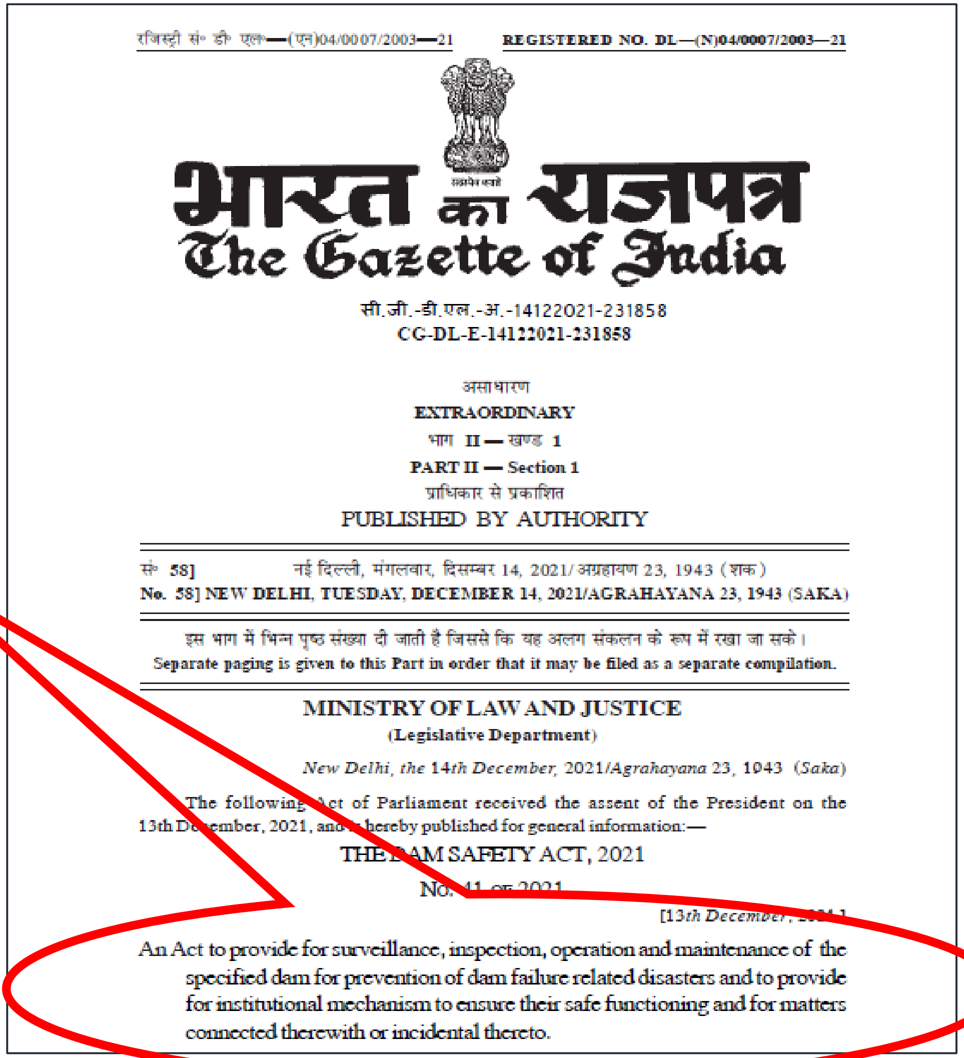
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1961-1970** | | | | | | | |
| 14 | Maharashtra | Panshet | Earth | 53.80 | 1961 | 1961 | Piping failure leading to breach. |
| 15 | Maharashtra | Khadakwasla | Masonry | 60.00 | 1875 | 1961 | Overtopping. |
| 16 | Rajasthan | Galwania | Earth | N.A | 1960 | 1961 | Breaching. |
| 17 | Rajasthan | Nawagaza | Earth | N.A | 1955 | 1961 | Breaching. |
| 18 | Madhya Pradesh | Sampna | Earth | 21.30 | 1956 | 1964 | Slope failure on account of inappropriate materials. |
| 19 | Madhya Pradesh | Kedarnala | Earth | 20.00 | 1964 | 1964 | Breaching. |
| 20 | Uttarakhand | Nanaksagar | Earth | 16.00 | 1962 | 1967 | Breached due to foundation piping. |
| **1971-1980** | | | | | | | |
| 21 | Gujarat | Dantiwada | Earth | 60.96 | 1965 | 1973 | Breach on account of floods. |
| 22 | Tamil Nadu | Kodaganar | Earth | 12.75 | 1977 | 1977 | Breached on account of floods. |
| 23 | Gujarat | Machhu-II | Composite | 20.00 | 1972 | 1979 | Overtopping due to floods. |
| **1981-1990** | | | | | | | |
| 24 | Gujarat | Mitti | Earth | 16.02 | 1982 | 1988 | Overtopping leading to breach. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1991- 2000** | | | | | | |
| 25 | Madhya Pradesh | Chandora | Earth | 27.30 | 1986 | 1991 | Breach. |
| 26 | Telangana | Kadam | Composite | 22.50 | 1958 | 1995 | Over topping leading to breach. |
| 27 | Rajasthan | Bhimlot | Masonry | 17.00 | 1958 | - | Breached due to inadequate spillway capacity. |
| | **2001-2010** | | | | | | |
| 28 | Gujarat | Pratappur | Earth | 10.67 | 1891 | 2001 | Breached on account of floods. |
| 29 | Madhya Pradesh | Jamunia | Earth | 15.40 | 1921 | 2002 | Piping leading to breaching. |
| 30 | Orissa | Gurilijoremip | Earth | 12.19 | 1954-55 | 2004 | The abutment structure along with wing and return walls got undermined with foundation scouring. |
| 31 | Maharashtra | Nandgavan | Earth | 22.51 | 1998 | 2005 | Excessive rain causing water flow over the waste weir. |
| 32 | Madhya Pradesh | Piplai | Earth | 16.73 | 1998 | 2005 | Breach |
| 33 | Rajasthan | JaswantSagar | Earth | 43.38 | 1889 | 2007 | Piping leading to breaching. |
| 34 | Telangana | Palemvagu dam | Earth | 13.00 | U/C | 2008 | Flash flood resulting in overtopping of the earth dam |
| 35 | Madhya Pradesh | Chandiya | Earth | 22.50 | 1926 | 2008 | Breach. |
| 36 | Rajasthan | Gararda | Earth | 31.76 | 2010 | 2010 | Examination for cause of failure by state authorities in progress. |
| 37 | Karnataka | Ankhamanhal | Earth | 21.29 | 1988 | 2010 | Overtopping by wave action and slip |

| 2011-2022 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 38 | Kerala | Peringalkuthu | Concrete & Masonry | 51.8 | 1957 | 2018 | - |
| 39 | Maharashtra | Tivare | Earth | 28.00 | 2004 | 2019 | - |
| 40 | Telangana | Sarala Sagar | Earth | 12 | 1959 | 2020 | - |
| 41 | Andhra Pradesh | Cheyyuru (Annamaya) Project | Earth | 25 | 2001 | 2021 | - |
| 42 | Madhya Pradesh | Karam dam | Earth | 52 | 2022 | 2022 | During first filling. |

# THE DAM SAFETY ACT, 2021 - PREAMBLE

An Act to provide for surveillance, inspection, operation and maintenance of the specified dam for prevention of dam failure related disasters and to provide for institutional mechanism to ensure their safe functioning and for matters connected therewith or incidental thereto.


रजिस्ट्री सं॰ डी॰ एल॰—(एन)04/0007/2003—21 REGISTERED NO. DL—(N)04/0007/2003—21

भारत का राजपत्र
The Gazette of India

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असाधारण
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PUBLISHED BY AUTHORITY

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No. 58] NEW DELHI, TUESDAY, DECEMBER 14, 2021/AGRAHAYANA 23, 1943 (SAKA)

इस भाग में भिन्न पृष्ठ संख्या दी जाती है जिससे कि यह अलग संकलन के रूप में रखा जा सके।
Separate paging is given to this Part in order that it may be filed as a separate compilation.

MINISTRY OF LAW AND JUSTICE
(Legislative Department)

*New Delhi, the 14th December, 2021/Agrahayana 23, 1943 (Saka)*

The following Act of Parliament received the assent of the President on the 13th December, 2021, and is hereby published for general information:—

THE DAM SAFETY ACT, 2021
No. 41 OF 2021
[13*th December*, 2021.]

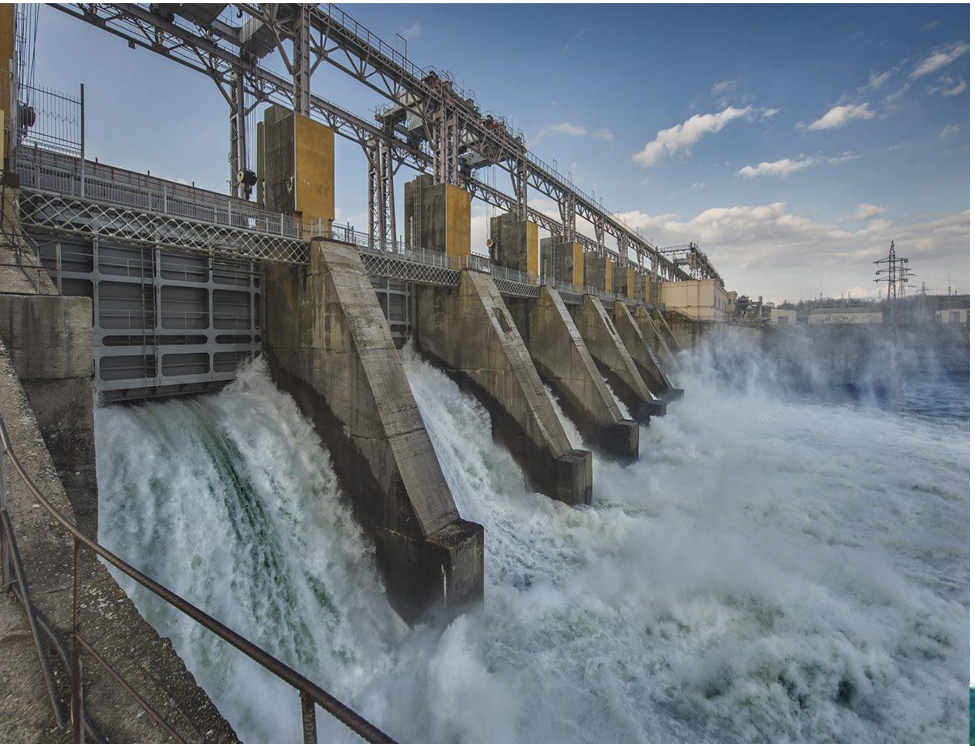
An Act to provide for surveillance, inspection, operation and maintenance of the specified dam for prevention of dam failure related disasters and to provide for institutional mechanism to ensure their safe functioning and for matters connected therewith or incidental thereto.

**IT EXTENDS TO THE WHOLE OF INDIA**

# MULTI-TIER INSTITUTIONAL MECHANISM

# THE ACT DEALS WITH THE SAFETY OF…..

**DAM or BARRAGE or WEIR STRUCTURE**



**SPILLWAYS, ENERGY DISSIPATION AND RIVER TRAINING STRUCTURES**

**HYDRO-MECHANICAL EQUIPMENT (GATES, VALVE, HOIST, ELEVATORS ETC.)**

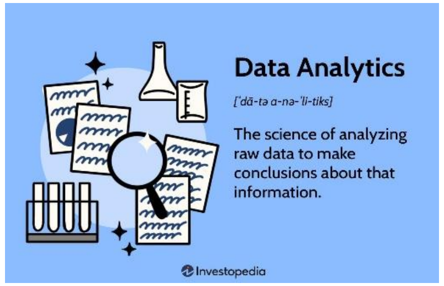
**WATER CONDUITS AND LOW LEVEL OUTLET STRUCTURES**

**Any other structure acting integrally with the dam or its reservoir or reservoir rim.**

**Life and property of the people, upstream & downstream of the dam, and the environment including flora, fauna and riverine ecology**

# COMPREHENSIVE DAM SAFETY EVALUATION

## Comprehensive Dam Safety Evaluation shall consist of, but not limited to;

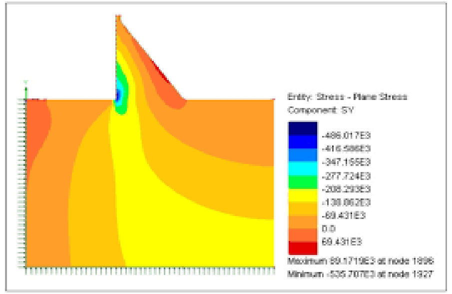



**Review and analysis of available data on design, construction, O&M and performance**

**Evaluation of inspection procedures**


**General assessment of hydrologic& hydraulic condition with review of design floods**

**Evaluation of operation & maintenance procedures**




**General assessment of seismic safety with site-specific seismic parameters**

**Evaluation conditions hazardous to integrity of the structure**

# HYDRAULIC SAFETY EVALUATION OF DAMS

1. Overview of hydraulic safety of dams
2. Dam and the reservoir, approach channel
3. Spillway, their control structure and conveyance structure
4. Outlet works, intake and conveyance structure
5. Energy dissipation arrangement, plunge pool and exit channel
6. Other appurtenant works

- **Approach or inlet channel and log boom:**

  It conveys water from the reservoir to the inlet structure or to the control structure if there is no inlet structure. Also, in some dams there is provision for retention and handling of floating debris (tree trunks, trash, other) to avoid obstruction.

- **Inlet structure:**

  It conveys water from the approach channel to the control structure and is intended to improve approach flow conditions to the control structure.

- **Control structure:**

  A crest structure or grade control sill, with or without hydro-mechanical elements viz. Gates, Bulkheads or Stop logs along with associated operating equipment. The hydraulics of the control structure establishes the discharging capacity for the spillway.

- **Conveyance features** (Chute, conduit, sluice, tunnel or in combination):

  It conveys water from the control structure to the terminal structure. The conveyance features may include combination of elements such as chutes with both mild and steep slopes, combinations of conduits, tunnels, and chutes.

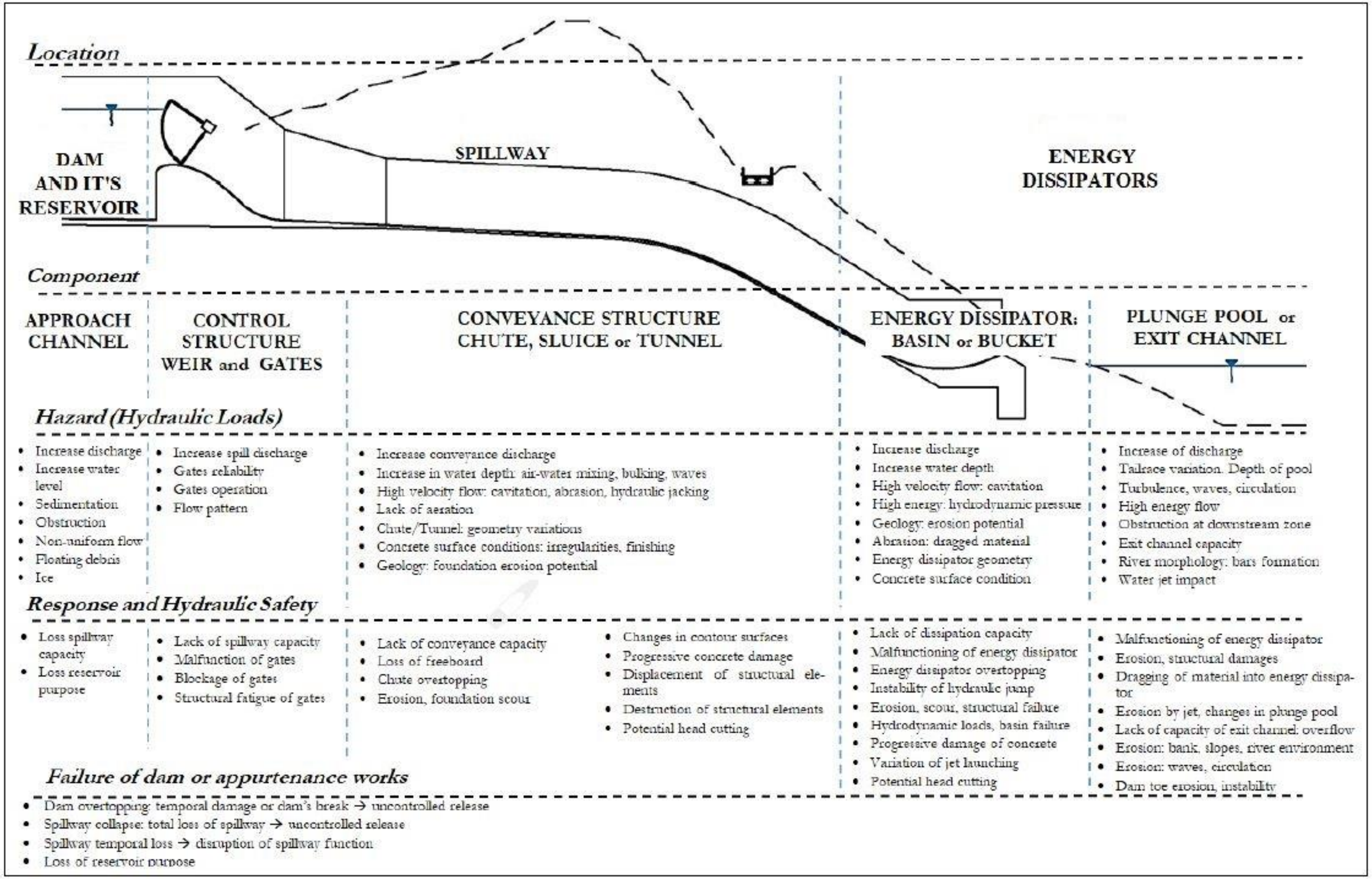
- **Terminal structure** (Energy dissipator such as a hydraulic jump stilling basin, flip bucket etc.):

  This structure dissipates most of the kinetic energy associated with moving water and leads waters to the exit channel.

- **Exit channel**:

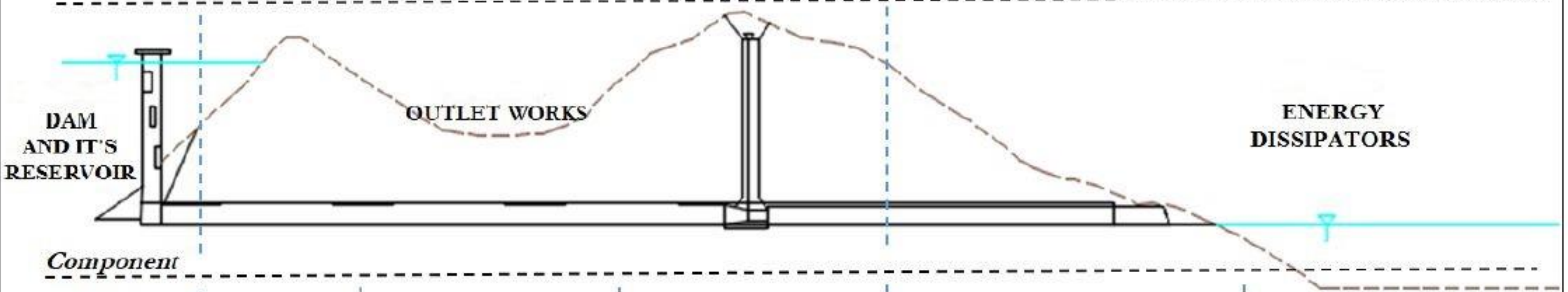
  Such channels are provided in some dams especially where the spillway is located in one of the flanks and not in the river bed to convey water from the terminal structure to the river or stream in the downstream.

# Various hazards/defects and their adverse responses/effects on hydraulic safety of dam



# Various hazards/defects and their adverse responses/effects on hydraulic safety of dam

*Location*




| *Component* | APPROACH CHANNEL | INTAKE | CONVEYANCE STRUCTURE | CONTROL STRUCTURE | ENERGY DISSIPATOR | PLUNGE POOL or EXIT CHANNEL |
|---|---|---|---|---|---|---|
| *Hazard (Hydraulic Loads)* | • Sedimentation<br>• Obstruction<br>• Floating debris<br>• Ice | • Gates/valves operation<br>• Floating debris<br>• Ice<br>• Human error | • High velocity flow<br>• Seepage/leakage form joints, cranks, etc.<br>• Weak foundation<br>• Sediments/debris laden flow<br>• Poor concrete quality<br>• Poor construction practice<br>• Poor aeration/ventilation (sluices) | • Gates/valves malfunctioning<br>• Sediments/debris laden flow<br>• Poor construction<br>• Poor aeration/ventilation (sluices) | • High velocity flow<br>• Drainage system deficient<br>• Poor hydraulic design<br>• Material draw in bucket/basing by back flow<br>• Poor construction practice | • Tail/spill channel-Bank and bend-unprotected especially if outlet is used for flood evacuation or if discharges are high |
| *Response and Hydraulic Safety* | • Loss of outlet capacity<br>• Loss of reservoir purpose<br>• Dam overtopping | • Cavitation<br>• Gates/valves vibration<br>• Gates/valves jamming<br>• Gates/valves impact<br>• Trashracks blockage | • Internal erosion/piping<br>• Damages on account of poor construction quality, cavitation, abrasion, etc.<br>• Foundation settlement | • Gates/valves vibration, jamming, etc.<br>• Electrical/mechanical failure<br>• Concrete damages due to poor construction/ cavitation/abrasion | • Bank instability due to residual energy/adverse d/s topography<br>• Overtopping of walls in casa the outlet is used for flood evacuation<br>• Undermining of foundation of energy dissipater<br>• Cavitation damages in flip bucket<br>• Damages due to abrasion | • Erosion due to sweep out of hydraulic jump<br>• Erosion due to poor protection of bank/bed<br>• Erosion due to inefficient energy dissipation<br>• Degradation in downstream reaches |

*Failure of dam or appurtenance works*

- Dam overtopping: temporal damage or dam's break → uncontrolled release
- Loss of reservoir purpose
- Temporal loss of gates/valves
- Loss of service, no water for irrigation or other water use

# DAM AND ITS RESERVOIR

**All types of defects or hazards that may be present in the reservoir falls into the following main effects:**

1. Effects that result in loss of reservoir storage by sediment driven by the river.
2. Effects that result in loss of reservoir storage by massive landslides
3. Effects that make the reservoir loose freeboard, such as waves, wave run up, etc.
4. Effects that make the spillway/ outlet/ intakes to loose discharge capacity, due to blockage by debris of diverse type.

# Dam and its Reservoir related hazards

| | HAZARDS / DEFECTS | CAUSES |
|---|---|---|
| 1 | Reservoir Instability/ Bank Sliding | Geology/seismic/ Reservoir Operation |
| 2 | Rim Erosion | Waves, Reservoir Operation /Drawdown, |
| 3 | Reservoir Sedimentation | Sediment production in the river basin |
| 6 | Bank Storage | Banks Geology |
| 7 | Reservoir Induced Seismicity | Seismic/geological |
| 8 | Back water flooding | Back water due to terrain landmarks |
| 9 | Ice | Low temperatures |
| 10 | Wind induced waves/Wave run up | Wind |
| 11 | Reservoir Operation | Policies/manmade errors |
| 12 | Rapid Reservoir Drawdown | Policies/ manmade errors |
| 13 | Reservoir Sedimentation/Delta formation | Sediment production in river basin |
| 14 | Reservoir Sedimentation/Bottom Deposits | Sediment production in river basin |
| 15 | Floating Debris | Debris production in the River Basin |
| 16 | Inflow Flood accommodation in the reser-voir | Poor estimation of Freeboard / Reservoir Operation |
| 17 | Slide Bank Erosion | Bank instability/Seismic effect |

Vajont Dam, Italy – Left bank sliding

Spencer Dam, USA – Gate operational problem due to ice

# Lessons learnt - Spillway clogging due to floating debris

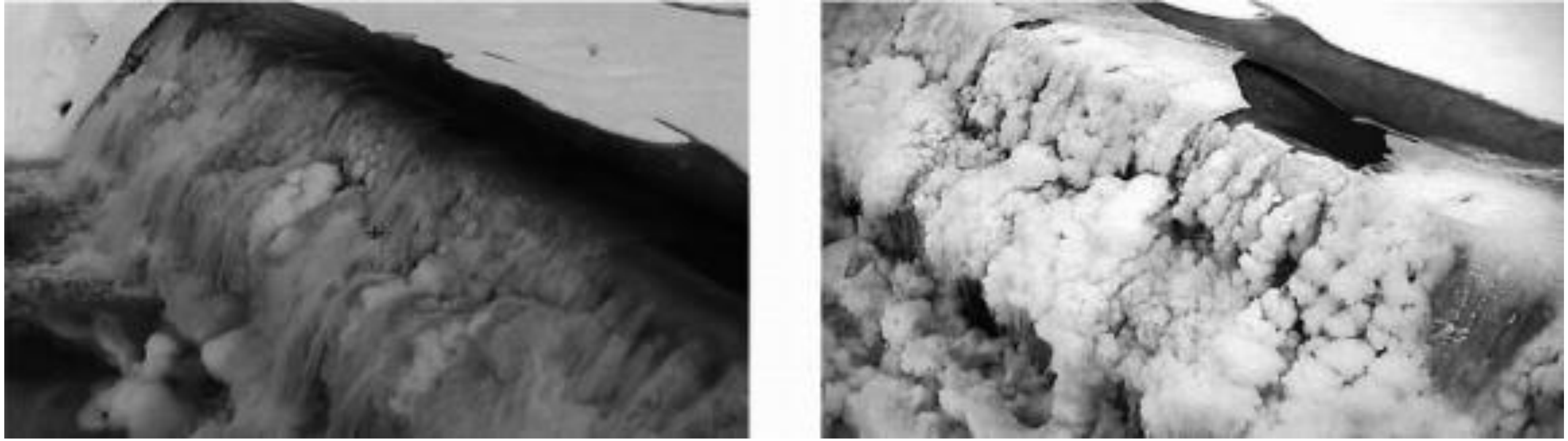
Palagnedra dam, Switzerland – Floating debris

| # | LESSON LEARNED |
|---|---|
| 1 | Debris and floating log, are capable of obstructing spillways, leading to dam overtopping during a flood scenario. |
| 2 | Some measures can be taken to prevent overtopping, for example, keeping a large bay width between spillway piers, removal of spillway bridge to provide a free passage for debris and logs to flow down the spillway along with flood waters. |
| 3 | Setting spillway piers about 12m apart, in order to keep reasonable free width for passing of flow with debris in a flood situation |
| 4 | Analysis of vegetative typologies of forestry practices in the watershed to understand and assess potential of the river watershed to produce debris loading |
| 5 | Pier spacing of the spillway should be at least 80 % of the maximum size of trees moved by the water current |
| 6 | Closed conduits are more vulnerable to clogging than open conduits |
| 7 | In free surface spillways, avoid flow contractions, sharp bends and rough walls |
| 8 | Drum, sector and flap gate should be preferably used to avoid gate clogging |
| 9 | Lift gates should be avoided unless there are a large number of openings due to the danger of trees being drawn below their lower edge during closure |
| 10 | Considering large size of water passages, for provision for large tree and other debris |
| 11 | It is usually impossible to remove all floating debris during a flood event because of the large volumes. In addition, if the dam spillway is activated, a partial discharge of floating debris via the dam spillway can hardly be prevented. |
| 12 | Increase hydraulic capacity of tunnels spillway to 5,000-year design flood with a minimum 5 m tunnel diameter. |
| 13 | Use open conduits when possible. If there are closed conduits, use smooth walls, no contractions or obstructions and no sharp bends |
| 14 | Concentrate the intake structure in one opening and make the invert of the intake as low as possible |
| 15 | Use radial gates in spillways; avoid vertical lift gates. |
| 16 | Avoid trash-racks at spillways as they compromise the design flood capacity |
| 17 | Try to intercept debris upstream of a reservoir, e.g. debris basins, debris retention posts |
| 18 | Use physical models in the design of spillways with high exposure potential to large amounts of floating debris |

# Hazards/Adverse response/Causes connected with Dam reservoir, Approach channel, Control section, Gates and valves

| | Hazard/Adverse Response | Causes |
|---|---|---|
| I | Reservoir Sedimentation | 1. Reservoir Sediment Inflow |
| | | 2. Bank Sliding |
| | | 3. Wind Induced Waves |
| | | 4. Wind Run Up |
| | | 5. Reservoir Operation |
| | | 6. Rim Erosion |
| | | 7. Reservoir rapid drawdown |
| | | 8. Delta Formation |
| | | 9. Bottom Deposits |
| | | 10. River Basin Deforestation |
| II | Dam Overtopping | 1. Wave Run Up |
| | | 2. Reservoir Operation |
| | | 3. Accommodation of Inflow Flood |
| | | **4. Blockage due to floating debris** |
| | | **5. Blockage due to ice** |
| | | **6. Insufficient spillway capacity** |

| | Hazard/Adverse Response | Causes |
|---|---|---|
| I | Overtopping of dam | 1. Blockage due to floating debris |
| | | 2. Blockage due to ice |
| II | Gate / Valves Malfunctioning | 1. Gate Vibration (in spillways) |
| | | 2. Gate Vibration (in sluice) |
| | | 3. Gate / Valve Jamming by Ice |
| | | 4. Gate / Valve Impact by floating debris |
| | | 5. Gate / Valve operation by human error |
| III | Concrete Damage | 1. Cavitation |
| | | 2. Abrasion |



SOLID ICE COVER ON THE SCREEN

ICE ACCUMULATION IN SPILLWAY

# Hazards/Adverse response/Causes connected with Conveyance structure

| | Hazard/Adverse Response | Causes |
|---|---|---|
| I | Wall Overtopping | 1. Increase in discharge |
| | | 2. Flow bulking |
| | | 3. Perturbed free surface |
| II | Chute Cavitation | 1. Poor concrete quality |
| | | 2. Flow velocity |
| | | 3. Low boundaries pressures |
| | | 4. Pressures pulsation |
| | | 5. Poor ventilation (Sluice) |
| III | Chute abrasion | 1. Sediment / Debris laden flow |
| | | 2. Side rock falling |
| IV | Concrete Chute Jacking | 1. Poor construction practice |
| | | 2. Drainage system deficient |
| | | 3. High velocity flow |

# Hazards/Adverse response/Causes connected with Energy dissipator

| | Hazards/adverse responses | Causes |
|---|---|---|
| I | Undermining of Energy Dissipater Foundation | 1. Poor protection at spillway toe |
| | | 2. Bank instability |
| | | 3. Asymmetrical flows |
| | | 4. Flow circulation |
| | | 5. High velocity flows |
| | | 6. Poor geology |
| | | 7. Poor construction practices |
| | | 8. Low tail water |
| | | 9. Flip bucket design |
| | | 10. Inefficient energy dissipation |
| | | 11. Poor construction practice |
| II | Cavitation | 1. Poor project layout |
| | | 2. High velocity flow |
| | | 3. Pulsating pressures |
| | | 4. Flow unitability |
| | | 5. Macro turbulence |
| | | 6. Due to return flows |
| III | Abrasion | 1. Material in basin |
| | | 2. Sediment laden flow |
| IV | Overtopping | 1. Increase in discharge |
| | | 2. Flow turbulence / waves |
| V | Concrete Jacking (Stilling Basin) | 1. Poor construction practices |
| | | 2. Sweep out of hydraulic jump |
| VI | Tailrace Channel -Bank and Bed Erosion | 1. Poor protection of bank/bed |
| | | 2. Energy dissipation inefficient |
| | | 3. Degradation in downstream reaches |
| | | 4. Flow circulation |

Sardar Sarovar Dam (India) during the monsoon flood.

Concrete overtopping protection for Santa Cruz Dam

Poringalkuthu Dam (India)
before, during and after the overflow.

# Structural and non-structural mitigation measures to take care of the increase in design flood in a dam

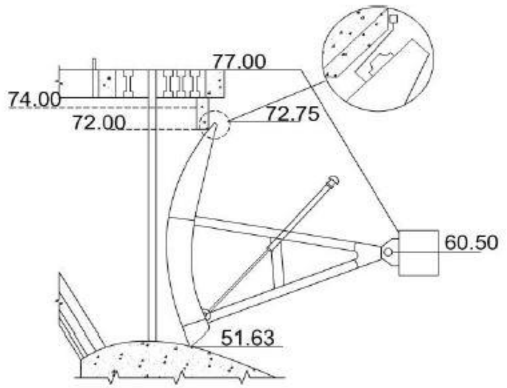
## Structural Mitigation Measures

- Raising the height of the dam to provide for freeboard necessary above the higher MWL.
- Raising the height of gates by lowering the spillway crest.
- Constructing one or more additional (auxiliary) spillways, fuse plugs with breaching section, flush bars, etc.
- Provision of a solid parapet wall on the upstream at the dam top (where not available) provided that it is able to provide for the revised freeboard requirement.
- Strengthening the crest and down-stream face of the embankment to al-low for some overtopping.

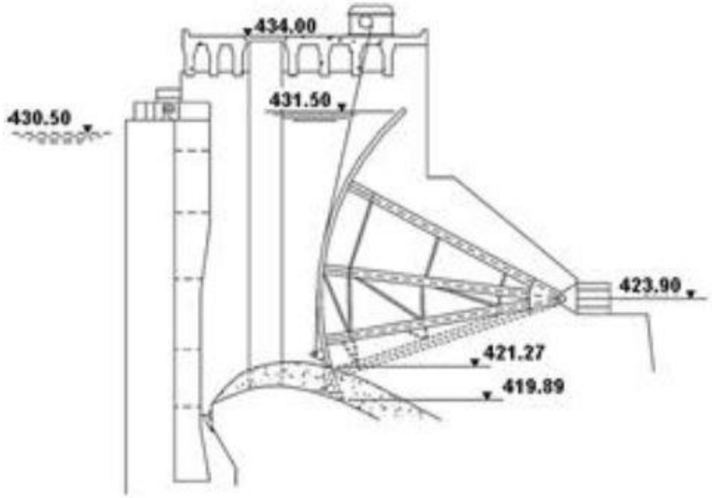
## Non-structural Mitigation Measures

- Improve methods of collecting data to give advance warnings of adverse conditions and to monitor the response of the dam and reservoir
- Improve operation of the reservoirs by lowering the reservoir level to increase flood control volume
- Modifying river basin flood characteristics by building flood detention devices or building an upstream dam
- For reservoirs in cascade, use upstream reservoir capacity to reduce flood peaks downstream.
- For cascade reservoirs, integrate operations of reservoirs.

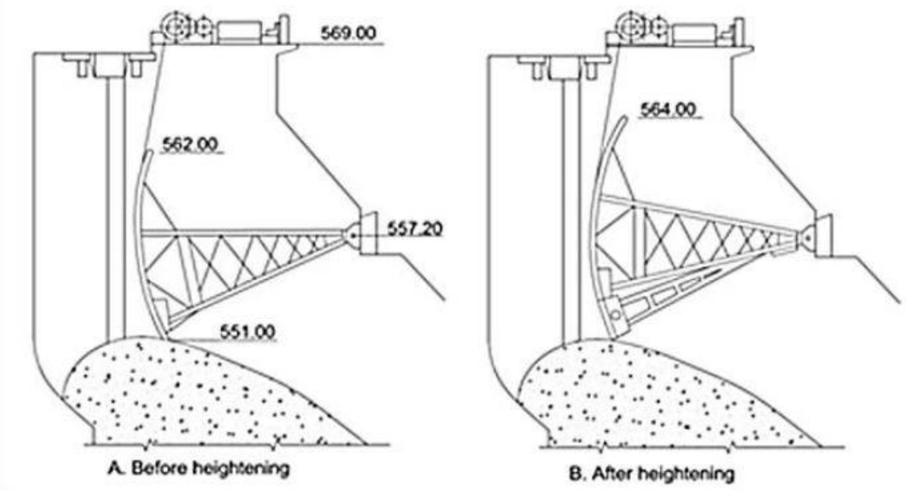
# MEASURES FOR INCREASING THE RESERVOIR STORAGE



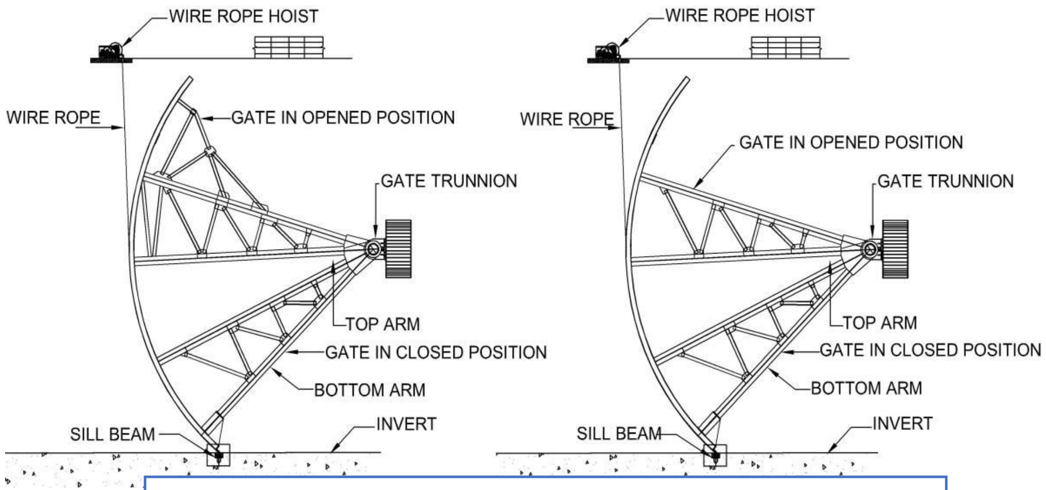

Mask beam used to raise by 2m the reservoir of Tucuri Dam, Brazil (Erbiste, P, 2004)




Spillway crest heightening at Cachoeira Dourada Dam, Brazil (Erbisti, 2004)




Bottom heightening of the Castro Dam radial gates, Spain. (Erbiste, P., 2004)




Top heightening of Furnas Dam, Brazil.

# SPILLWAY

# BROAD CLASSIFICATION

**Based on how the waters are carried to the downstream river**

- Surface spillways
- Tunnel spillways

**Based on the type of hydraulic control**

- Controlled
- Uncontrolled

**Based on the location**

-On the surface with free discharge with/without gates
-Submerged at Intermediate level
-At the bottom

**Based on the function**

-Service spillway
-Auxiliary Spillway
-Emergency Spillway

Service spillway, Controlled ogee crest

Service spillway, uncontrolled

Chute spillway

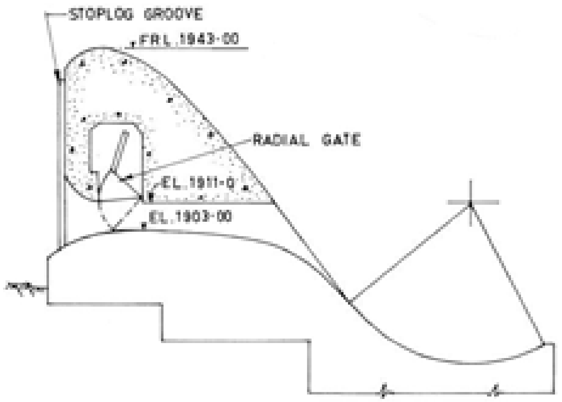
Service spillway, on left abutment of an embankment dam

Service spillway, Control structure - Morning glory and special weir

Service and auxiliary spillways located in dam and emergency spillway (fuse plug) located far away from the dam in reservoir rim

| N° | State listed by number of reservoirs | Number of reservoirs at state | SPILLWAY DESIGN CAPACITY ($m^3/s$) | | | | | | | Maximum design capacity ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Unknown | <1,000 | 1,000 to 3,000 | 3,000 to 10,000 | 10,000 to 20,000 | 20,000 to 60,000 | >60,000 | |
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | |
| 1 | MAHARASHTRA | 2394 | 108 | 1870 | 283 | 91 | 26 | 14 | 2 | 67,373 |
| 2 | MADHYA PRADESH | 906 | 30 | 826 | 21 | 13 | 7 | 5 | 4 | 106,000 |
| 3 | GURAJAT | 631 | 6 | 427 | 106 | 63 | 17 | 11 | 1 | 84,949 |
| 4 | CHHATTISGARH | 258 | 4 | 239 | 7 | 4 | 2 | 2 | 0 | 26,708 |
| 5 | KARNATAKA | 232 | 4 | 175 | 25 | 23 | 2 | 3 | 0 | 37,945 |
| 6 | RAJASTHAN | 212 | 2 | 138 | 43 | 19 | 3 | 7 | 0 | 32,411 |
| 7 | ODISHA | 204 | 2 | 167 | 18 | 11 | 3 | 2 | 1 | 66,676 |
| 8 | TELANGANA | 184 | 4 | 124 | 22 | 16 | 9 | 7 | 2 | 508,000 |
| 9 | ANDRA PRADESH | 166 | 26 | 81 | 25 | 21 | 8 | 4 | 1 | 91,400 |
| 10 | UTAR PRADESH | 130 | 2 | 91 | 18 | 8 | 8 | 2 | 1 | 111,328 |
| 11 | TAMIL NADU | 118 | 4 | 80 | 26 | 6 | 2 | 0 | 0 | 11,179 |
| 12 | JHARKHAND | 79 | 5 | 53 | 9 | 5 | 5 | 2 | 0 | 32,340 |
| 13 | KERALA | 61 | 10 | 26 | 17 | 7 | 1 | 0 | 0 | 14,200 |
| 14 | WEST BENGAL | 30 | 0 | 24 | 2 | 2 | 2 | 0 | 0 | 15,400 |
| 15 | BIHAR | 26 | 0 | 19 | 3 | 4 | 0 | 0 | 0 | 3,818 |
| 16 | UTTARAKHAND | 25 | 1 | 5 | 7 | 7 | 5 | 0 | 0 | 19,824 |
| 17 | HIMACHAL PRADESH | 21 | 0 | 3 | 3 | 10 | 3 | 1 | 1 | 26,500 |
| 18 | JAMMU AND KASHMIR | 17 | 1 | 6 | 3 | 4 | 1 | 2 | 0 | 22,500 |
| 19 | PUNJAB | 16 | 2 | 12 | 0 | 1 | 0 | 1 | 0 | 20,678 |
| 20 | MEGHALAYA | 10 | 2 | 1 | 4 | 2 | 1 | 0 | 0 | 10,440 |
| 21 | GOA | 5 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 1,450 |
| 22 | ARUNANCHAL PRADESH | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 9,216 |
| 23 | ASSAM | 4 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 37,500 |
| 24 | MANIPUR | 4 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 2,240 |
| 25 | ANDAMAN AND NICOBAR | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 405 |
| 26 | SIKKIM | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 12,500 |
| 27 | HARYANA | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 919 |
| 28 | MIZORAM | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4,450 |
| 29 | NAGALAND | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 5,977 |
| 30 | TRIPURA | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 481 |
| | TOTAL | 5745 | 213 | 4378 | 646 | 324 | 107 | 64 | 13 | |
| | RANK OF CAPACITY | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| | % | | 3.7% | 76.2% | 11.2% | 5.6% | 1.9% | 1.1% | 0.2% | |

**Spillways of reservoirs of India - Data from NRLD published by CWC - June 2019**




Bottom outlet in concrete dam

Wilson Dam, Alabama. Orifice spillway

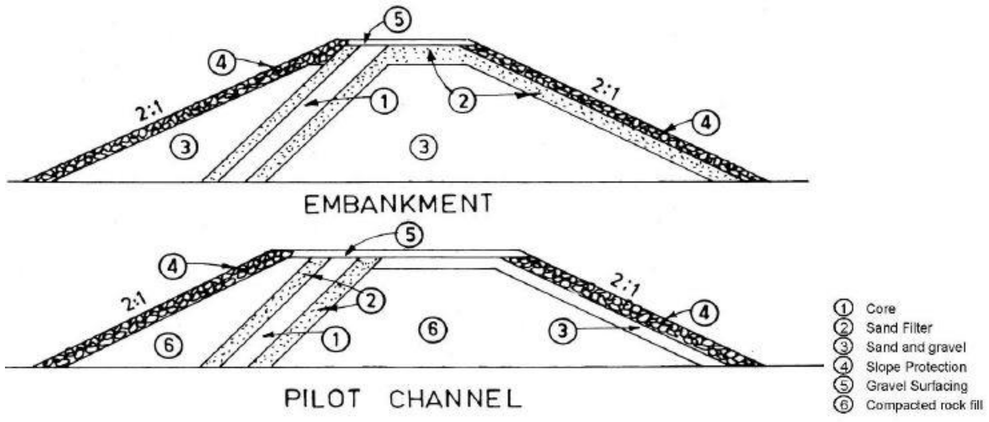
Typical bottom outlet in overflow dam section

| Sl. N° | Project | Hd (m) | Spillway Opening N° of bays(n) | W (m) | D (m) | Design Discharge (m³/s) | Specific Discharge (m³/s/m) | Cd |
|---|---|---|---|---|---|---|---|---|
| 1. | Chamera I | 30 | 8 | 10 | 12.8 | 20376 | 254.7 | 0.84 |
| 2. | Chamera III | 37 | 3 | 12.5 | 16.5 | 11400 | 304 | 0.78 |
| 3. | Dhauliganga | 38 | 2 | 6 | 10 | 2560 | 213.3 | 0.8 |
| 4. | Kurichu | 28 | 5 | 10.5 | 14 | 12200 | 232.4 | 0.83 |
| 5. | Nathpa Jhakri | 37.5 | 5 | 7.5 | 8.5 | 5660 | 150.9 | 0.88 |
| 6. | Nimobazgo | 28 | 5 | 7 | 9 | 4500 | 128.6 | 0.84 |
| 7. | Pandoh | 21.6 | 5 | 12 | 13.5 | 9939 | 165.7 | 0.73 |
| 8. | Parbati -II | 33 | 3 | 6 | 9 | 1850 | 102.8 | 0.77 |
| 9. | Parbati -III | 32 | 2 | 7.2 | 14 | 3300 | 229.2 | 0.74 |
| 10. | Sewa-II | 29.5 | 4 | 7 | 10.8 | 4020 | 143.6 | 0.76 |
| 11. | Subhansiri Lower | 60 | 9 | 11.5 | 14 | 3,500 | 338.2 | 0.8 |
| 12. | Tala | 43 | 5 | 6.5 | 13.2 | 10,490 | 322.8 | 0.89 |
| 13. | Teesta-V | 24 | 4 | 9 | 11.4 | 4,850 | 134.7 | 0.81 |
| 14. . | Uri-II | 24 | 4 | 9 | 11.4 | 4,850 | 134.7 | 0.81 |
| 15. | Myntdu | 30.5 | 7 | 8 | 12 | 10,440 | 186.4 | 0.78 |
| 16. | Pare | 29.2 | 3 | 10.4 | 14 | 5,000 | 160.3 | 0.78 |
| 17. | Punatsangchhu-II | 46 | 7 | 8 | 13.2 | 16,023 | 286.1 | 0.82 |
| 18. | Devasari | 29 | 5 | 8.5 | 12.5 | 6,969 | 163.9 | 0.77 |
| 19. | Mangdechhu | 45 | 4 | 10 | 16 | 8,500 | 212.5 | 0.72 |

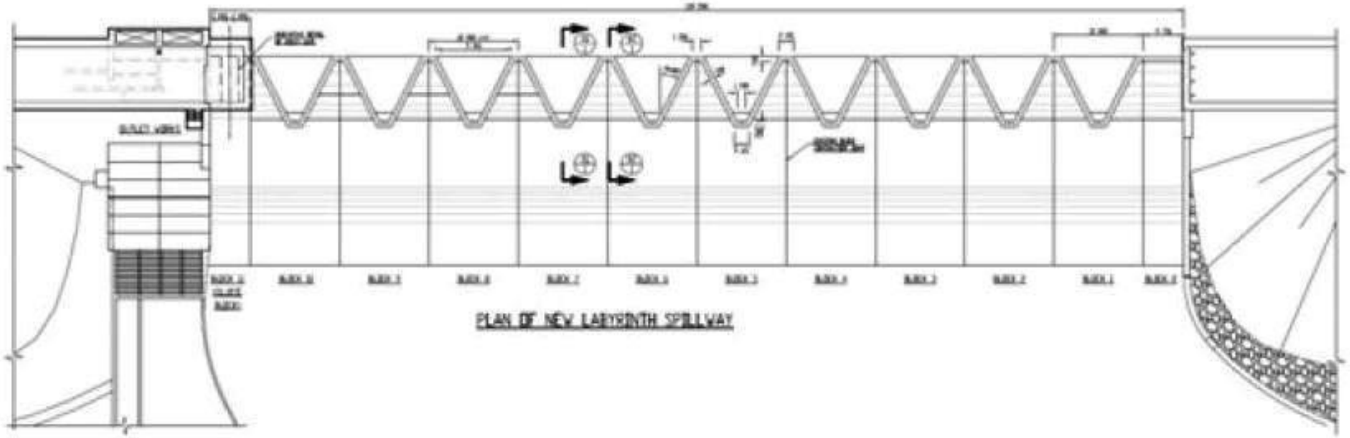
Select Orifice spillways

# NON-CONVENTIONAL SPILLWAYS

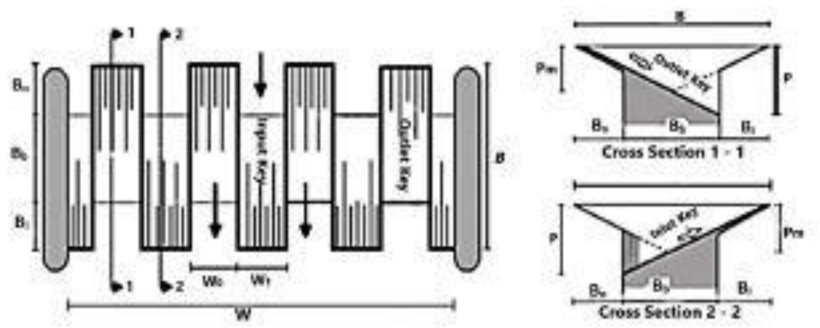
- ❑Fuse plug (erodible embankment or dyke)
- ❑Labyrinth weir
- ❑Piano Keys weir (PKW)
- ❑Fuse gates
- ❑Fuse plug (concrete blocks)
- ❑Overtopping of dam with protected section
- ❑ Unlined channels

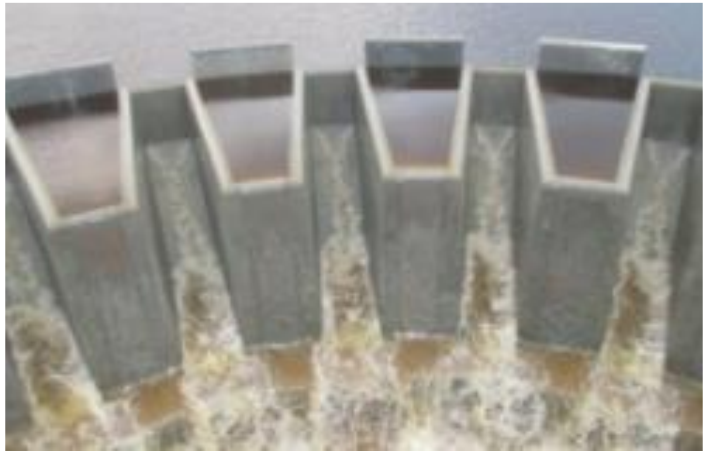



## Typical fuse plug section




## Labyrinth spillway layout



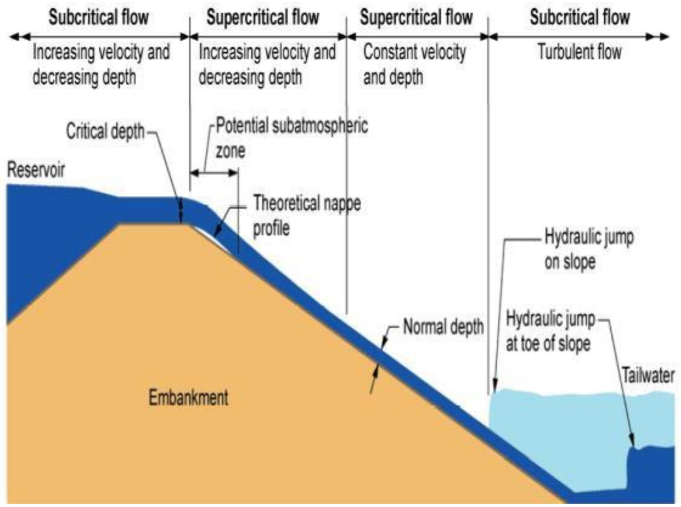
Piano Key Weir – Typical layout and section

Key Weir types with overhang and without them.

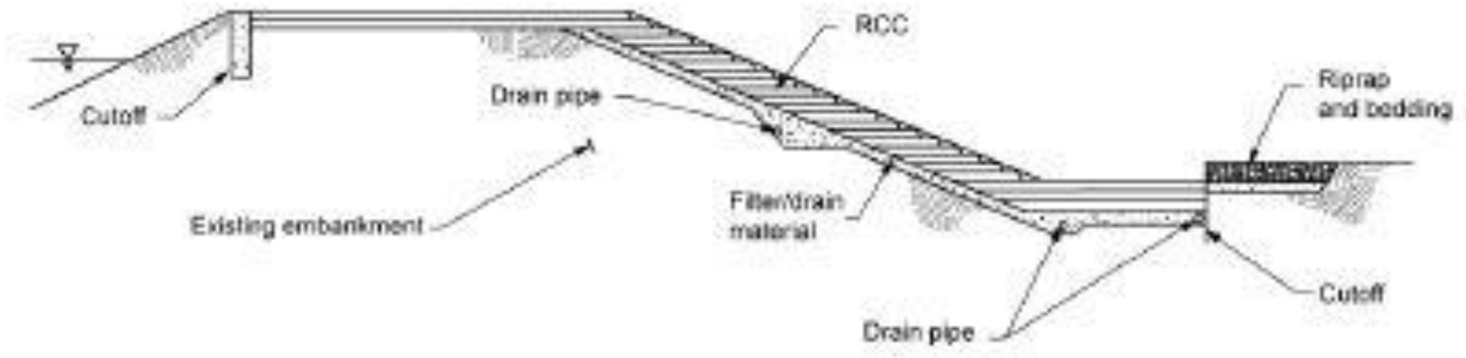
Piano Key Weir – Van Phnog Dam, Vietnam

Piano Key Weir on a Morning glory weir

# Overtopping of dam with protected section




Typical hydraulic conditions during embankment's overtopping (USBR, FEMA).




Typical Section: RCC overtopping protection (FEMA).

**-STEPPED CHUTE SPILLWAYS**

**- GATES FOR SPILLWAYS**

**OUTLET WORKS**

*A dam appurtenance that provides release of water from a reservoir.*

# Intake classification

Based on purpose

- Flood control
- Irrigation intake
- Hydropower intake
- Water supply
- Environmental flow
- Sediment management
- Reservoir depletion

Based on its location within the dam:

- Surface intake,
- Bottom intake
- Intermediate intake

Based on the characteristics of the Intake:

- Submerged intake
- Intake Tower or Multilevel Intake

Based on the discharging point/location:

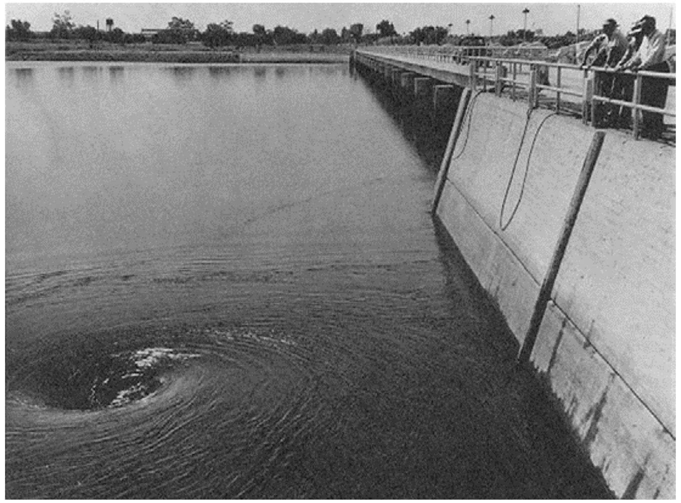
- River outlet
- Canal Outlet

Based on flow regime:

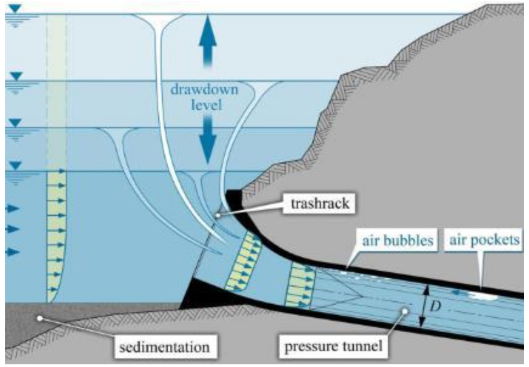
- Free surface flow
- Pressure flow
- Mixed flow

Internal erosion around conduit in embankment dam

Condition of sluice gates in 2018



Vortex at intake of hydropower plant




Schematic illustration of air entraining intake vortices.

# ENERGY DISSIPATORS

Two main aspects of particular importance in hydraulic performance of terminal works are:

a) Dealing with flow with high velocity and turbulence and high energy content.

a) Restoring the flow to the river without causing damages to the dam, and to close-by hydraulic works, river/ watercourse and to the nearby environment.

Typical flow with high energy content

# REHABILITATION MEASURES TO IMPROVE THE HYDRAULIC SAFETY OF SPILLWAYS

| Hydraulic Action | Adverse response of hydraulic or structural element |
|---|---|
| Obstruction in approach channel by floating debris | Loss of hydraulic area and increase of energy losses in approach channel |
| Obstruction of inlet work by floating debris, around piers and radial gates | Loss of hydraulic area at the inlet. Potential damages and clogging of gates and hoist equipment. |
| Ice blocking against radial gates | Loss of hydraulic area at the inlet. Potential damages, obstruction and limited movement of gates. Difficulty to operate hoist equipment. |
| Obstruction of approach channel by slipped material from banks | Loss of hydraulic area and increase of energy losses in approach channel |
| Non uniformity of flow in approach channel and | Reduction of effective length of spillway. Vortex formation. |

| Hydraulic Action | Adverse response of hydraulic or structural element |
|---|---|
| inlet | |
| Deterioration of concrete surface at inlet and control structure | Separation zones and turbulence. Reduction of effective length of spillway |
| Lack of reliability of gates due to structural, mechanical or electrical issues | Operative vulnerability. Lack of spill capacity. High potential hazard for the dam and spillway |
| Higher floods. Limited capacity of spillway. | Operative vulnerability. Significant hazard for the dam and/or spillway |

# Rehabilitation measures for improving hydraulic safety of conveyance structure

| Hydraulic Action | Adverse response of hydraulic or structural element | Rehabilitation measure |
|---|---|---|
| More discharge to be conveyed (for any option of upgrading the control structure) | Overtopping of chute's walls, Erosion of backfill, Instability of wall, Erosion and undermining of wall and slab - resulting in failure of chute, eventual head cutting. | For the new water surface profile, increase chute's wall height as needed. (See Manual "Assessing Structural Safety of Existing Dams" and "Manual of Rehabilitation of Large Dams") |
| Changes in geometry of the section of the chute (Horizontal transitions and vertical curves) | Local effects due to high velocity flow in changes of width and vertical curves, damages in local concrete joints. | See Abrasion and cavitation |
| Abrasion | Deterioration or damage to concrete flow surfaces, corrosion and/or loss of reinforcement, increase in roughness, irregularity of section of chute, potential source to trigger cavitation. | Concrete surface restoration or covering with appropriate material and technology. Structural restoration of sections of chute's slab. (See Manual "Assessing Structural Safety of Existing Dams" and "Manual of Rehabilitation of Large Dams") |
| Cavitation Low pressure section along the chutes and | Damage to concrete, surface of slab and reinforcement, Potential slab break, in extreme cases movement | Concrete surface restoration, finishing and protection with appropriate material and technology. Concrete |

| Hydraulic Action | Adverse response of hydraulic or structural element | Rehabilitation measure |
|---|---|---|
| surface irregularities that disturb flow | of fragments or collapse of slab, potential erosion of foundation material. | joints repair. Demolition and structural restoration of sector of slab, in extreme cases. Check for air in the water. Add aerator in sections of chute as needed. Restoration of erosion gully under the slab. (See Manual "Assessing Structural Safety of Existing Dams" and "Manual of Rehabilitation of Large Dams") |
| Stagnation pressure - Hydraulic jacking High pressure fluctuations along the chutes | Uplift and displacement of slab, foundation erosion, damages to underdrain system, piping, collapse of slab, gully formation. | Concrete surface restoration with appropriate material and technology. Concrete joints repair (seals). Demolition and structural restoration of sector of slab, in extreme cases. Restoration of erosion gully under the slab. Restoration of drain system (See Manual "Assessing Structural Safety of Existing Dams" and "Manual of Rehabilitation of Large Dams") |
| Foundation erosion Open joints or cracks | Scour of slab, piping, undermining and collapse of slab, damages to underdrain system, foundation erosion, gully formation. | Concrete surface restoration with appropriate material and technology. Concrete joints repair (seals). Demolition and structural restoration of sector of slab, in extreme cases. Restoration of erosion gully under the slab. Restoration on foundation material with selected and compacted soil or massive concrete. Restoration of drain system (See Manual "Assessing Structural Safety of Existing Dams" and "Manual of Rehabilitation of Large Dams") |

# Rehabilitation measures for increasing terminal structure capacity in spillways

| Rehabilitation measures for increasing terminal structure capacity in spillways<br>CASE 1: Limited increase | | |
|---|---|---|
| **Hydraulic Action** | **Hydraulic requirement / condition of structural element** | **Rehabilitation Measure** |
| Stilling basins<br>Increase in energy content at entry with changes in hydraulic jump's characteristics | Higher conjugate depth and TW level requirement.<br>Need of higher walls. | Accept partial encroachment in free-board of basin's walls. Increase of wall height with complementary concrete elements. Accept some wall's overtopping and use of fill surface protection. Check for hydrostatic uplift due to greater tail water and use structural measures to guarantee stability. |
| | Larger length of hydraulic jump. Need to increase the basin length | Accept movement of the hydraulic jump, possible sweep-out from basin. Incorporate a weir downstream with additional energy dissipation to increase tail water level. Improve protection downstream of basin. Modify ancillary elements if needed: chute blocks, baffle and end sill. |
| | New hydraulic conditions at stilling basin. Need to check potential hydraulic loads and concrete conditions. | Hydraulic evaluation of stilling basin. Hydrodynamic pressure fluctuations. Inclusion of performance or security measures as presented latter. |
| Flip buckets<br>Increase in energy content of entrance flow and changes in jet characteristics of the jet | Changes in jet trajectory. Displacement of impingement site. Larger depths and gravity effects, jets may fall near the concrete structures. | Adapt plunge pool area. Protection or reinforcement of impingement site. Protection of river banks and close-by installations. Test flip bucket performance for larger flows in physical models |
| | Higher tailwater depth, possible submergence of flip bucket | After hydraulic evaluation, accept some level submergence of deflector. Local protection downstream of flip bucket: concrete slab, heavy rip-rap, etc. Test operation rules of the spillway to operate the bucket free of submergence |
| | New hydraulic conditions at bucket. Need to check potential hydraulic loads and concrete conditions. | Evaluation of geometry (radius, throw angle, levels) and inclusion of performance or security measures as presented latter. |

| Rehabilitation measures for increasing terminal structure capacity in spillways<br>CASE 2: Significant increase | | |
|---|---|---|
| **Hydraulic action** | **Hydraulic requirement / condition of structural element** | **Rehabilitation measure** |
| Stilling basins<br>Increase in energy content of entrance flow and changes in hydraulic jump's characteristics | High conjugate depth and TW level requirement.<br>Need of higher walls. | Increase of wall height according to hydraulic loads. Check tail water level for new discharge. Incorporate a weir downstream with additional energy dissipation to increase tail water level.<br>Check for hydrostatic uplift due to greater tail water and use structural measures to guarantee stability. |
| | Larger hydraulic jump.<br>Need to increase the basin length | Lengthen the basin. Protection downstream of basin. Modify functioning of basin with ancillary elements: chute blocks, baffle and end sill. Adapt walls, transition discharge area and exit channel to new basin. Check for a cutoff element.<br>New stilling basin. |
| | New hydraulic conditions at basin. Need to check potential hydraulic loads and concrete conditions. | Evaluation and inclusion of performance or security measures as presented latter, especially, joint between structures, anchoring, under drainage system. |
| Flip buckets<br>Increase in energy content of entrance flow and changes in jet's characteristics | Changes in the trajectory of water jet.<br>Displacement of impingement site. | Adapt plunge pool area. Incorporate an excavated plunge pool. Protection or reinforcement of impingement site. Protection of river banks and close-by installations. |
| | Higher tailwater depth, possible flip bucket submergence | Check level of jet submergence and bucket performance. Increase wall height according to hydraulic loads. Protection of downstream of flip bucket: concrete slab, rip-rap, etc. |
| | New hydraulic conditions at bucket. Need to check potential hydraulic loads and concrete conditions. | Evaluation of geometry (radius, throw angle, levels) and inclusion of performance or security measures as presented latter. Inclusion of stability measures for structure as: anchoring, mass rock strengthening, cutoff, other. |

# Rehabilitation measures for improving performance and avoiding major damages in stilling basins and flip buckets

**Rehabilitation measures for improving performance and avoiding major damages**
**STILLING BASINS**

| Hydraulic action | Hydraulic requirement /condition of structural element | Rehabilitation measure |
|---|---|---|
| High velocity, rough flow in a stilling basin and its ancillary elements, with actual or upgraded discharge.<br>Entrance of solids as: sand, gravel, boulders, concrete fragments, trees, other debris, from downstream channel or other origin.<br>Abrasion | Damage to concrete, surface of slab/walls and steel bars reinforcement. Large abrasion damage. Potential slab break. In extreme cases partial or total loss of slab.<br>Increasing possibility of occurrence of cavitation. | Draining and emptying of stilling basin for inspection and to access and to work in dry environment.<br>Execute physical model tests<br>Repair concrete surfaces. Materials for repairs of surfaces: steel, high performance concrete, etc.<br>Investigate in Model tests, level of downstream surface (exit channel) required to guarantee that end sill is high enough to avoid material to get in the basin, due to any return flows (as required, depending on actual site conditions). Rehabilitate basin as appropriate.<br>For technical procedures and materials, see Manuals "Assessing Structural Safety of Dams", "Rehabilitation of Large Dams" and other technical references. |
| High velocity , rough flow in a stilling basin and its ancillary elements, with actual or upgraded discharge.<br>Irregularities in concrete surface.<br>Separation zones in ancillary elements<br>Cavitation | Damage to concrete, surface of slab/walls and steel bars reinforcement. Potential slab break. In extreme cases movement of concrete fragments and collapse of slab.<br>Potential erosion of foundation material. | Draining and emptying of stilling basin for inspection and to access and work in dry environment.<br>Execute physical model tests. Repair concrete surfaces: roughness, offsets, displacements, other. Repair structural details such as: joints, sealing of joints (waterstops or specific filling products).For technical procedures and materials, see Manuals "Assessing Structural Safety of Dams" and "Rehabilitation of Large Dams" and other technical references. |
| High Turbulent, high velocity flow in a stilling basin and its ancillary elements, with actual or upgraded discharge.<br>Hydrodynamic pressures fluctuations.<br>Openings in slab: cracks, joints, drains. Suction forces on slab Increase of uplift force due to propagation of hydrodynamic pressure fluctuations to foundation. | Loss of stability of slab and increased load on walls.<br>Cracking or breaking of slab panels. Sudden vertical movement of slab.<br>Collapse of parts or whole slab, especially at the upstream part of basin or end of chute.<br>Potential erosion of foundation material. | Draining and emptying of stilling basin for inspection and to access and work in dry environment.<br>Detailed structural evaluation of concrete elements under hydrodynamic pressure fluctuation. Concrete surface restoration: cracks, open joints, other damages. Restoration of stilling basin slab with increased concrete thickness. Anchoring of stilling basin slab as needed. For technical procedures and materials, see Manual "Assessing Structural Safety of Dams" and "Rehabilitation of Large Dams" and other technical references. |

**Rehabilitation measures for improving performance and avoiding major damages**
**Flip buckets**

| Hydraulic action | Hydraulic requirement /condition of structural element | Rehabilitation measure |
|---|---|---|
| High velocity flow in a flip bucket, with actual or upgraded discharge. | Damage to concrete surface of bucket/walls and reinforcement.<br>Increasing possibility of occurrence of cavitation. | Concrete surface restoration and protection with specific material and technology.<br>For technical procedures and materials, see Manuals "Assessing Structural Safety of Existing Dams" and "Rehabilitation of Large Dams" and other technical references. |
| High velocity flow in a flip bucket, with actual or upgraded discharge.<br>Irregularities in concrete surface.<br>Separation zones in ancillary elements at bucket lip<br>Cavitation. | Damage to concrete surface of bucket/walls and reinforcement.<br>Damage at end lip and dentate deflector.<br>Effect in shape of the jet or mass water distribution | Repair or improve concrete surfaces<br>Protect end lip with other materials: ~~steel~~<br>Check inclusion of forced aeration. For technical procedures and materials, see Manuals "Assessing Structural Safety of Existing Dams" and "Rehabilitation of Large Dams" and other technical references. |
| Turbulent high velocity flow in a flip bucket.<br>Hydrodynamic pressures. | Stability of concrete structure of bucket/walls under hydrodynamic pressure. | Check structural behavior of walls Improving stability of bucket by anchoring to the rock.<br>For technical procedures and materials, see Manuals "Assessing Structural Safety of Existing Dams" and "Rehabilitation of Large Dams" and other technical references. |

# Rehabilitation measures for improving performance and avoiding major damages in exit channel, plunge pool and river environment

| Rehabilitation measures for improving performance and avoiding major damages<br>Exit channel, plunge pool and downstream river environment | | |
|---|---|---|
| **Hydraulic action** | **Hydraulic requirement /condition of structural element** | **Rehabilitation measure** |
| Irregular , turbulent flow at the transition between stilling basin and exit channel for actual or upgraded discharge. | Extended erosion.<br>Back erosion and undermining of energy dissipator.<br>Drag of material into the basin. | Execute physical models<br>Geometry adjustment: shape according to eddies formation, adjust bed level at contact with end sill of basin, width and length. Bottom protection: rip-rap, concrete, others. Banks protection: rip-rap, gabions, others. |
| Actual or upgraded discharge vs. exit channel capacity. | Modification of tailwater elevation.<br>Overflow of exit channel.<br>Erosion at exit channel bottom | Occurrence of a downstream flow control section: evaluation and development of tail water rating curve.<br>Removal of obstructions or potential loss of area of exit channel, vegetation etc. To |

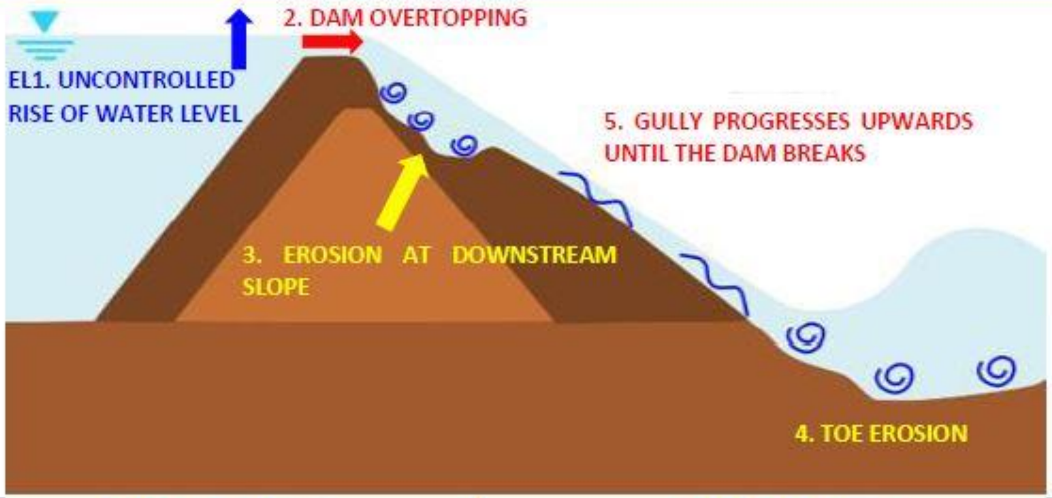
| Rehabilitation measures for improving performance and avoiding major damages<br>Exit channel, plunge pool and downstream river environment | | |
|---|---|---|
| **Hydraulic action** | **Hydraulic requirement /condition of structural element** | **Rehabilitation measure** |
| | and/or banks. | carry out slope stability as required, protection of local installations, etc. Increase of channel capacity by enlarging its section , use of lining, erosion protection: rip-rap, gabions, others. |
| Overflow of lip to foundation for low discharges | Local erosion and scour.<br>Potential scour of terminal structure/loss of stability. | Local protection with concrete slab.<br>Reinforce or strengthening of rock mass: anchors, filling of cracks, dental concrete, etc. |
| Impingement site with or without a plunge pool. | Local erosion and scour.<br>Back erosion towards the terminal structure and potential undermining.<br>River banks erosion and loss of slope stability<br>Deleterious water spray in the zone of discharge. | Protection of site from jet action: reinforced concrete(bed or slopes), closed to the bucket.<br>Aeration by splitting the jet with deflectors at bucket lip or with aerators at the chute. Air content reduces scouring capacity of the jet.<br>Excavate a plunge pool. Create a plunge pool by adding a tail pond dam downstream. Verify in physical model the efficacy of pool's level, Combination: excavated pool and tail dam Add a cutoff structure at the front face of flip bucket as anchored slab over rock. Reinforce or strengthening of rock: anchors, filling of cracks, etc. Geotechnical measures: river banks, slopes. |
| Transport and sedimentation of eroded material from impingement site or plunge pool. | Local changes in river morphology. Creation of bars of sediment, obstruction of the watercourse and effect in other installations. | River training and protection to avoid erosion of banks/bed by meandering channel. Channel with enough sediment transport capacity and excavated pool. |

| Failure Mode 1 | CONCRETE/MASONRY DAM OVERTOPPING DUE TO INSUFFICIENT CAPACITY OF SPILLWAY |
|---|---|
| **Description** | |
| The spillway has insufficient discharging capacity to pass the design flood or other extreme floods and inadequate safety free-board. Reservoir level overcomes dam freeboard and water passes over the crest. Flow on downstream face reaches the toe and causes backwards bed erosion and dam instability. Potential major damage to the dam, abutments and river channel or eventual dam break. | |
| Scenario | HYDROLOGICAL |
| **Graphical Scheme** | |


| More likely factors | Less likely factors |
|---|---|
| Inadequate freeboard or wave Wall (Parapet). | Dam toe protection. |
| Hydrology Flood Study not updated. | Large reservoir flood storage and freeboard. |
| Inadequate design capacity of spillway. | Massive good quality rock along the dam toe. |
| Gated spillway with inadequate gate operation rules. | Provision of emergency uncontrolled spillway. |

| Actions for Improving the Hydraulic Safety |
|---|
| Update Hydrology Flood Study. |
| Reevaluate Inflow Flood Accommodation criteria. |
| Evaluation of existing conditions at the dam toe. |
| Evaluation the reservoir operation rules during flood season. Including all outlets facilities. |
| Evaluate the increase of flow capacity by using additional/non-conventional spillways, auxiliary or emergency spillways. |
| Provision of flood forecasting system in the river basin. |

| Failure Mode 2 | EMBANKMENT DAM OVERTOPPING DUE TO INSUFFICIENT SPILLWAY CAPACITY |
|---|---|
| **Description** | |
| The spillway has insufficient hydraulic capacity to pass the design flood and maintain a safety free-board. This can result in overtopping of the dam´s crest. Flow over the crest washes out material in the downstream slope of the embankment and causes massive erosion that progresses leading to slope instability, breach formation and dam failure. | |
| Scenario | HYDROLOGICAL |
| **Graphical Scheme** | |




| More likely factors | Less likely factors |
|---|---|
| Inadequate freeboard. | Existing protection measures for overtopping in the downstream face. |
| Hydrology Flood Study not updated. | Large reservoir flood storage. |
| Inadequate design capacity of spillway. | Provision of emergency uncontrolled spillway. |
| Reservoir Flood control volume reduced. | |
| High erosion potential of downstream slope of dam. | |

| Actions for Improving the Hydraulic Safety |
|---|
| Update Hydrology Flood study. |
| Evaluate increase of the spillway capacity by using additional/non-conventional spillway. |
| Evaluation of existing conditions at the downstream face and dam toe. |
| Intensify protection measures along the downstream face and dam toe. |
| Adequate a reach of the embankment as a controlled overtopping section. |
| Establish a system of flood forecast in the river basin. |
| Evaluation of the reservoir operation rules during flood season including all outlets facilities. |

| Failure Mode 3 | DAM OVERTOPPING CAUSED BY GATE FAILURE |
|---|---|

**Description**

In the event of an extreme flood or even normal flow conditions, the spillway gate does not operate because of mechanical or electrical failure. That can result in increased reservoir level and eventual dam overtopping, deep erosion of Embankment dam on its downstream slope or toe of concrte/masonry dams and eventually, the dam failure.

| Scenario | HYDROLOGICAL - NORMAL |
|---|---|

**Graphical Scheme**


| More likely factors | Less likely factors |
|---|---|
| Non-trained operators /absence of standard operation manuals. | Operation is well defined. Proved rules for gate operation exists. Trained personnel. |
| Operation gate failure (Electromechanical). | Existence of surveillance and maintenance program. |
| No routinely inspection, or maintenance or testing of gates. | Redundancy in number of gates. |
| Deterioration and ageing of gates. | Downstream face and toe protection. |
| Poor maintenance of gates | Provision of parapet. |
| Power supply is non-dependable. No backup supply. | Provision of emergency uncontrolled spillway. |
| Occurrence of flash floods in the River basin | |
| Limited freeboard / Small reservoir. | |

| Actions for Improving the Hydraulic Safety |
|---|
| Update Hydrology Flood study. |
| Detailed evaluation of the electromechanical equipment / Include testing. |
| Installation of a backup power supply. |
| Training plans for the operation personal. |
| Evaluation of freeboard under limited spillway discharge. |
| Provide / update dam operation manual. |

| Failure Mode 4 | SPILLWAY BLOCKAGE BY DEBRIS ,GATES JAMMING AND DAM OVERTOPPING |
|---|---|

**Description**

During a flood, a significant load of floating debris gets into the spillway approach channel, causing a gate jamming, gates do not open, spillway is non operative and reservoir level rises leading to dam overtopping. Flow over the downstream face washes out material or eroded toe of concrete/masonry dam and causes massive erosion that progresses upstream. Water cuts the crest of the embankment eroded toe of concrete/masonry dam until the dam breaks.

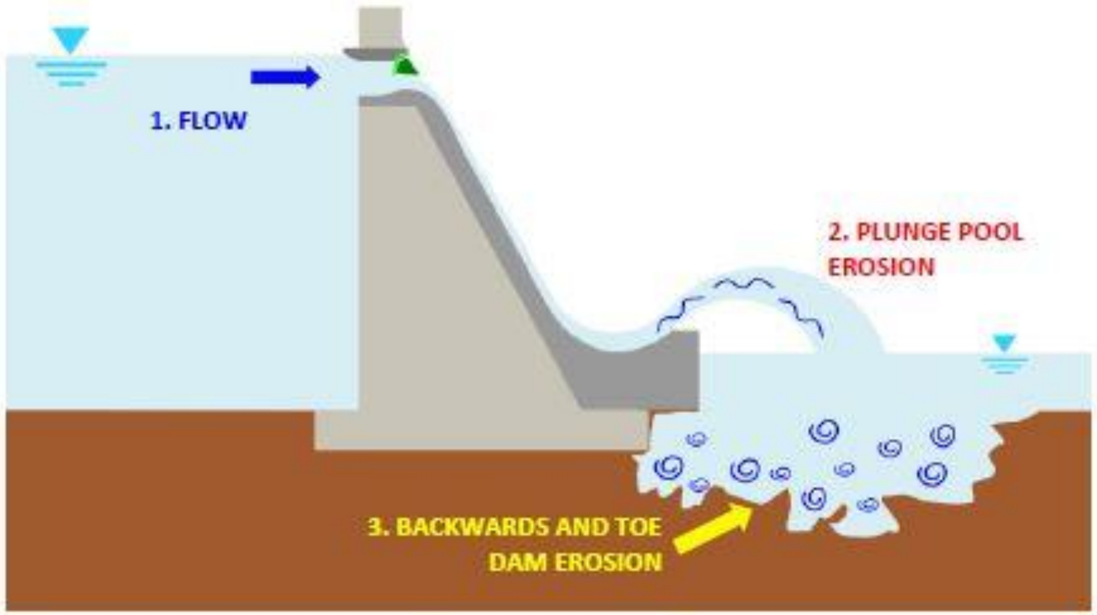
| Scenario | HYDROLOGICAL |
|---|---|

**Graphical Scheme**


| More likely factors | Less likely factors |
|---|---|
| Rapid increase in level of water in reservoir. | Provision of emergency uncontrolled spillway. |
| High production of debris/ice in river basin. | Existence of floating barriers in the reservoir (Tuff Booms). |
| Inadequate design/location of spillway. | Downstream face and toe dam protection. |
| Limited freeboard / Small reservoir. | Existence of dam parapet. |

| Actions for Improving the Hydraulic Safety |
|---|
| Conservation measures for the river basin. |
| Evaluate possibility of adopting an emergency spillway. |
| Develop / update reservoir operation rules. |
| Evaluate design against debris blockage. |
| Provision of debris dam upstream of the reservoir / dam. |
| Provision of floating barriers in the reservoir |
| Program of Supervision/Maintenance in the reservoir and river basin to control debris in the reservoir. |

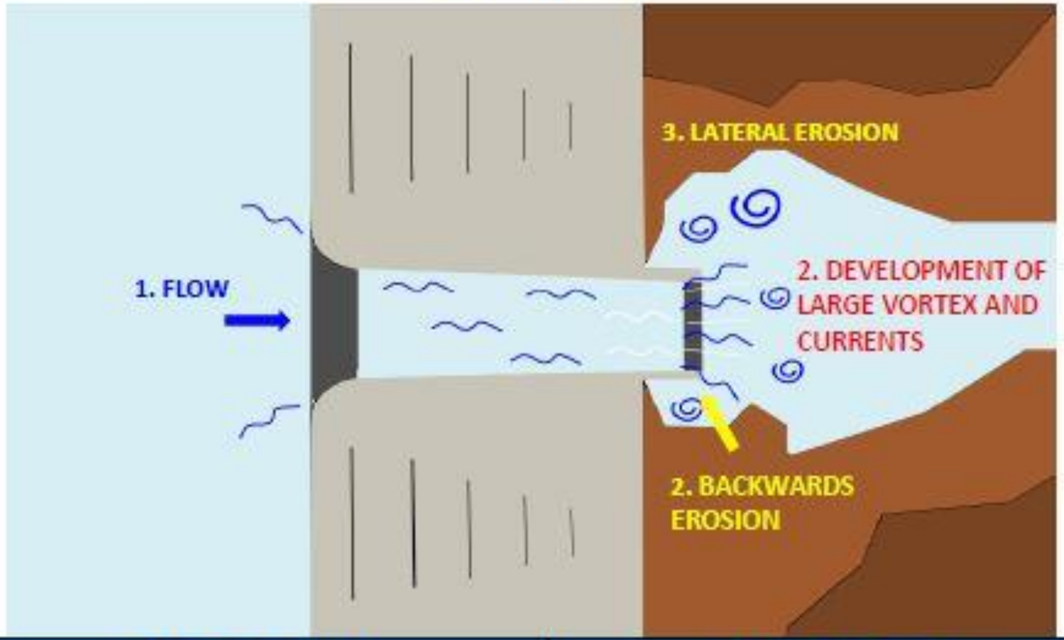
| Failure Mode 14 | PLUNGE POOL EROSION |
|---|---|
| **Description** | |
| Normal flow lower than design. Controlled or uncontrolled spillways. Excessive use of the spillway, during floods or normal hydrologic scenarios, cause problems as backward erosion and scour in the downstream channel or in the energy dissipation base structure. | |
| **Scenario** | NORMAL |
| **Graphical Scheme** | |




| More likely factors | Less likely factors |
|---|---|
| Incorrect design of energy dissipator. | Adequate protection in toe of spillway. |
| Overflow capacity exceeded. | Auxiliary or emergency spillway. |
| Prolonged use of spillway. | Good rock quality at plunge pool. |
| Difficult access to inspect the spillway and plunge pool. | |

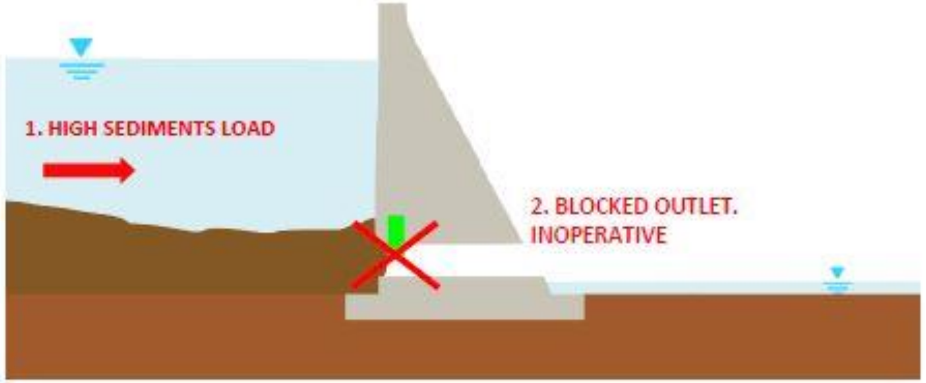
| Actions for Improving the Hydraulic Safety |
|---|
| Improve access of personal for inspections of the structure. |
| Intensify inspection and monitoring of the prototype pre and post monsoon season. |
| Construct an adequate protection for the spillway toe foundation. |
| Built a control weir type structure in the tailrace to guarantee enough water levels at plunge pool. |
| Evaluate excavation of a plunge pool to improve energy dissipation |

| Failure Mode 15 | BANK EROSION DUE TO POOR FLOW EXIT |
|---|---|
| **Description** | |
| In a hydrological scenario, either uncontrolled or gated spillways, a spillway equipped with a flip bucket energy dissipater, create large flow circulation forming at the receiving plunge pool, accompanied by large vortex formation, wave up rush causing large scour on banks, which may affect spillway / dam integrity. | |
| **Scenario** | HYDROLOGICAL |
| **Graphical Scheme** | |




| More likely factors | Less likely factors |
|---|---|
| Large flow spilled/narrow control section in tailrace channel. | Adequate protection of pool, banks and abutments of the main works (powerhouse/ spillway). |
| Non competent bank material. | Energy dissipated in a pre-excavated plunge pool. |
| Not detailed investigation in physical models. | Existing access to inspect plunge pool area. |
| Presence of loose material in the plunge pool. | Low frequency of spillway releases |
| Asymmetrical flows in the receiving pool. | |
| Not competent / protected bank material. | |
| Non symmetrical operation of spillway. | |
| Presence of bars in the downstream reaches. | |

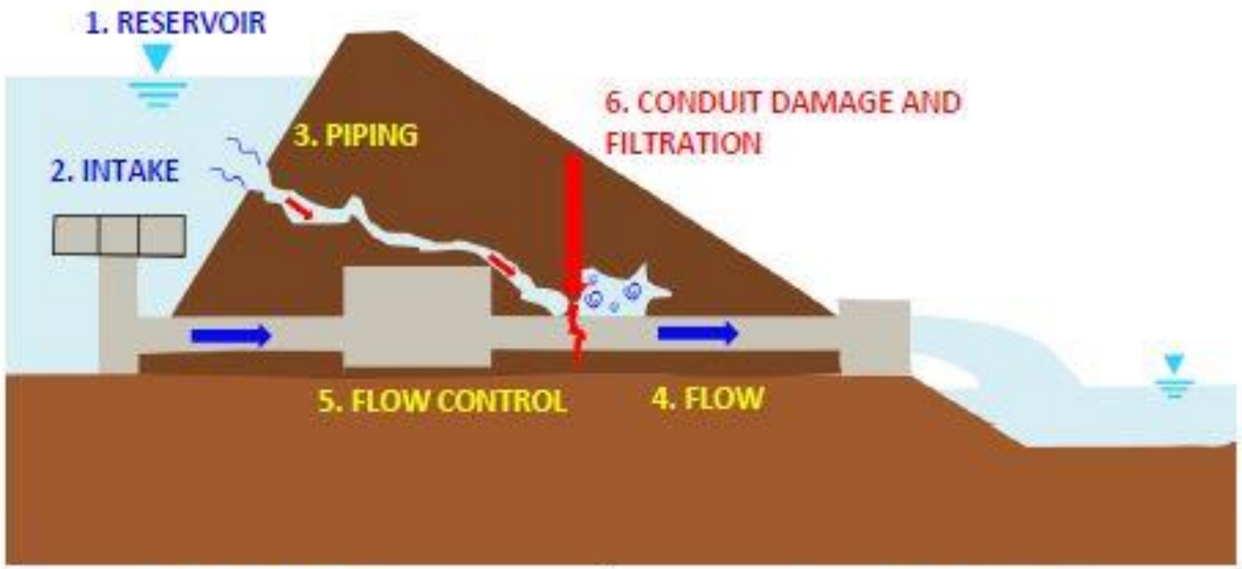
| Failure Mode 16 | BOTTOM OUTLET BLOCKAGE |
|---|---|
| **Description** | |
| Normal flow. As a consequence of the prolonged accumulation of sediments in front of the bottom outlets, they become blocked and inoperative, losing its capacities required for reservoir drawdown, flushing of sediments, environmental flows, and the reduced outflow capacities in the case of extraordinary floods. Partial or temporal loss of outlet operability. | |
| Scenario | NORMAL |
| **Graphical Scheme** | |



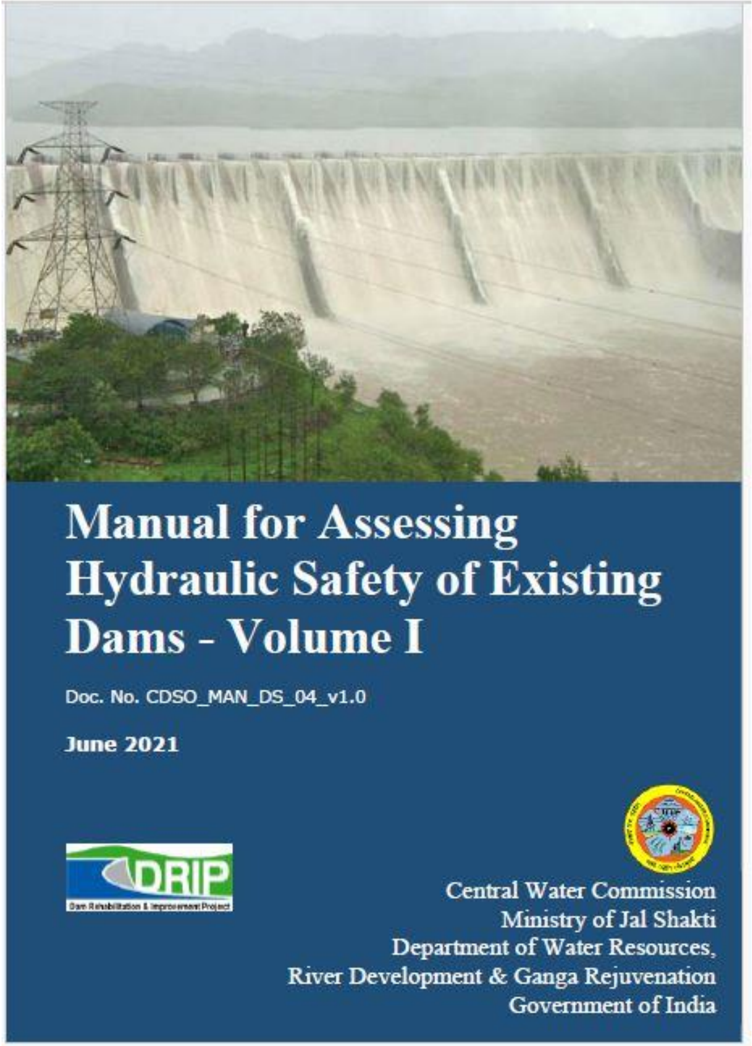

| More likely factors | Less likely factors |
|---|---|
| Uncontrolled use of soils in the contributing river basin. | Good geology of the reservoir rim and river basin. |
| Presence of high load of sediment. | Upstream dams for sediment trapping. |
| High trapping efficiency of the reservoir. | Monitoring of forest exploitation. |
| Inconvenient location of bottom outlet. | Restrictive use of land in river basin |
| Difficulty in access to its control room. | |
| Non existing documentation of the outlet design/operative experience. | |
| Bathymetric monitoring absent | |
| Fear of operators of using bottom outlet | |

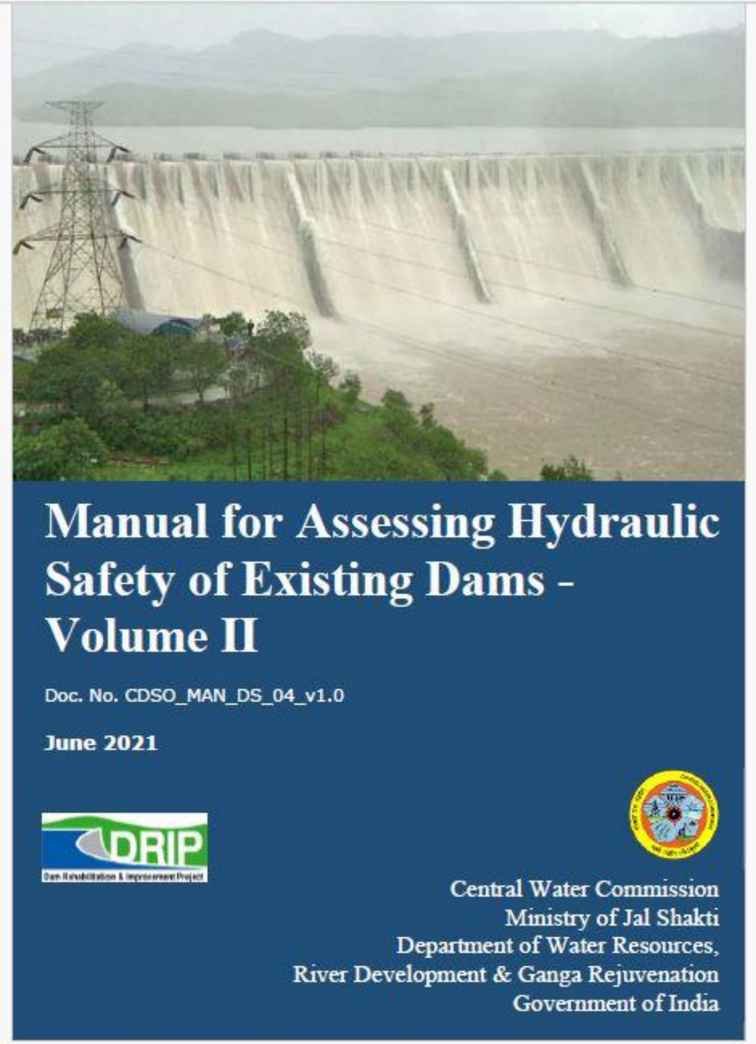
| Actions for Improving the Hydraulic Safety |
|---|
| Bathymetric survey in the reservoir and sub aquatic inspection nearby the outlet works. |
| Cleaning outlet intake. |
| Conservation and environmental measures in the river basin. |
| Elaborate operation manual of the bottom outlet. |
| Execution of sub aquatic inspections nearby the bottom outlet. |
| Improve access to the gates control room. |
| Maintenance program for all controls and electromechanical equipment. |
| Monitoring of sediment inflow. |
| Review performance of bottom outlet and program functional prototype tests annually |

| Failure Mode 21 | INTERNAL EROSION IN EMBANKMENT DUE TO STRUCTURAL FAILURE OF CONDUIT |
|---|---|
| **Description** | |
| Normal flow operation. Conduit located under the dam with flow control equipment close to intake. Due to the presence of a crack in the conduit downstream of the control section, there is a seepage flow from the dam to the conduit operating with free surface. This seepage will generate migration of materials and piping and will provoque the failure of the upstream slope and eventually of the dam. Partial or total loss of intake and outlet operability... | |
| Scenario | NORMAL |
| **Graphical Scheme** | |




| More likely factors | Less likely factors |
|---|---|
| Homogeneous earth dam. | Filter within the dam body or around conduit. |
| Poor construction practices. | Provision of external structural collar. |
| Difficult access to the outlet. | Provision of diaphragm filter at d/s end of conduit. |
| Age of dam. Deteriorated condition of conduit material. | Dam section equipped with instruments to detect in advanced the erosion process. |




# THANK YOU

## REF. MANUALS:

i) CWC MANUAL FOR ASSESSING HYDRAULIC SAFETY OF EXISTING DAMS – VOLUME I

ii) CWC MANUAL FOR ASSESSING HYDRAULIC SAFETY OF EXISTING DAMS – VOLUME II