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CRACK OPENING OF EMERGENCY GATE :
REAL FACTS

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ABSTRACT

Emergency gates are installed on Sluices/ Conduits/ Penstocks in dams for controlling water flow. In most of the cases emergency gate is operated by wire rope hoists. Due to water head on upstream side only, emergency gate remains in unbalanced condition when closed. At the time of opening of emergency gate, it is desirable that it should be lifted in balanced condition. To create balanced condition, along with other practices, crack opening of gate is done very often.

Crack opening leads to many uncalled for deficiencies in gate and system. Some of which may be severe enough to damage gate and installation entirely.

The issue of crack opening, and deficiencies due to it, is discussed in present paper. By putting forth relevant facts; remedial measures are suggested for safety of gate and installation.
1 INTRODUCTION

The outlet from dam wall closed Conduit for embankment dams, Sluices for concrete gravity dams. It is Penstock in case of power outlet for Hydro power generation systems.

To regulate flow through sluice or conduit, Service Gate (SG) and Emergency Gate (EG) is installed, locations depending on design and situation requirements. Thus some space (3 to 4 m) is available between EG and SG. In case of penstock this space is up to turbine scroll case and is of much more length.

This space is essential but becomes root cause of source of problems to EG. SG with stem rod being positively and direct driven is capable of opening against existing water head. SG can be lifted positively in any odd situation against existing water head. Partial opening can also be made easily.

EG being operated by wire rope hoists, descends due to self-weight hence it is not positively closed to its seat. It simply parks by gravity to its bottom position in slot against all odds. The sealing action is obtained by addition of water head on gate leaf.
2. ORIGIN OF UNBALANCED CONDITION

When EG is lowered into slot, it is subjected to pressure differential in closed condition. EG slot is open to reservoir, hence always there is water on upstream side of EG. Downstream side remains empty and open to atmosphere. This creates pressure differential on both sides of EG creating unbalanced condition on gate.

For lifting and lowering operation of EG, due to use of wire rope, the mechanism is not positively driven, becomes flexible and unsteady and not much sufficient to cater for load due to unbalanced condition.

Thus while opening EG unbalanced condition on gate becomes a potential threat to safety of entire installation. EG is kept in either fully closed or fully opened condition, partial opening is not favoured.
3. MEANS OF EG BALANCING

Different arrangements are made to balance pressure differential on EG when both gates are closed and only EG needs to be opened.

- Use of sluice valve
- Baby gate
- Crack opening of gate
- Leakages

3.1 Sluice Valve

At suitable place sluice valve is fitted on pipes, intake of which is taken from dam itself and outlet is kept open in chamber between EG and SG. By opening sluice valve water can be allowed into chamber. Thus balanced condition on EG is easily created by filling the chamber. The valve is usually positioned at just above the top of the conduit. However, number of shortcomings and practical deficiencies are observed in this system. Hence, even if erected, sluice valve arrangement becomes useless.
For penstock this arrangement cannot be made due to space constraints. It is found that the valve becomes fully rusted, jam because of non-use and lack of regular maintenance.
3.2 Baby Gate

Another practice is that; a small opening is kept in EG leaf itself. This opening, like baby gate can be opened by suitable means and balanced condition can be obtained. The opening in gate is provided with a valve which can be opened manually conveniently. This arrangement is rarely used for EG and also suffers from number of inherent shortcomings, like difficult operation from top with levers and maintenance, etc.
3.3 Crack Opening

If both of the above arrangements are not made; or in view of practical difficulties in using the available arrangements, or to tackle real conditions at site on time, third method is used almost unasked and mandatorily. **It is crack opening, also sometimes called as cracking of EG.** The gate is initially slightly lifted; say 3 cm, with hoisting mechanism. The opening created allows water to fill chamber and create balanced condition, wait for some time to fill chamber and then lift EG in balanced condition.

However, crack opening method is associated with its potential dangers. With only single advantage of creating balanced condition in difficult situations, all other are disadvantages of this method. It is seen that **this method is used practically almost at all places, on many locations, number of times.**
3.4 Leakages

For many EG the seals do not remain truly effective. Always leaks. There is also good amount of leakages through construction. This leaked water many times becomes sufficient to fill up the chamber. If seals of SG are more effective, leaked water accumulates in chamber and it is always found filled with leaked water when both gates are in closed condition. This situation is never desired. In some cases, even if both gates are closed there is good amount of leakage seen through sluice.

4. THE ACTION OF CRACK OPENING

When closed with full reservoir level EG leaf is subjected to maximum load and stresses. Now, if gate is crack opened in unbalanced condition, excessive and sudden load is applied to gate through wire ropes. Water starts flowing through narrow opening with turbulence.
The opening beneath gate is small and chamber size is comparatively large. Due to sudden increase in downstream area the continuity equation forces the downstream flow to be slower than the upstream flow resulting decrease in velocity and corresponding increase in pressure. This causes flow to separate at boundaries. Actual flow area becomes smaller than area of crack opening forming vena contracta. The flow transforms from sub-critical to super-critical to hydraulic jump to sub-critical again, and from steady to unsteady flow while passing through crack opening.
The flow is restricted at another end by SG. Hence water tries to flow back resisting further incoming flow, resulting in increase in head at SG. When level of crack opening is achieved in chamber, flow gets converted from open channel to submerged flow due to stagnation. In this manner water is accumulated and chamber is then filled up gradually from SG to EG.
Since EG is normal to flow, vortex forming at edges and shredding at flow past EG in chamber occurs. Circulation occurs below EG, after rubber seal and backing plate. Eddies set in flow in chamber. Air bubbles in large amount get entrapped in flow, originating and collapsing very often. The entire air column in air vent pipes vibrates instantaneously due to dynamic changes in chamber with expelling air out.

At EG opening, bottom and both sides of sluice are in continuity with upstream and downstream. There is abrupt change in cross section from gate tip to chamber. Water goes for sudden expansion. Downside to EG there is sudden enlargement in section, causing head loss at enlarged section. As such, water decelerates from section 

\[ h_l(1-2) = \frac{(V_1-V_2)^2}{2g}, \]

2-2.

Hence the developed boundary layer at gate tip separates at upper edges of the expansion at chamber, resulting formation of annular region at the expansion. In this region water does not flow immediately, but re-circulates as turbulent eddies causing energy loss. There shall be marginal temperature increase of water. The flow action
Pressure distribution over EG leaf and on crack opening area of slot is not uniform but differs. Applying Bernoulli’s theorem between section 1-1 and 2-2, the increase in pressure and corresponding head loss can be found out. Also we can find out,

Net force acting on EG towards reservoir,
Rate of change momentum,
Hydraulic jump losses,
Energy being lost at crack opening,
Discharge through gate at the time of crack opening

\[ p_2 - p_1 = \frac{\rho V_1^2}{A_2} \left( 1 - \frac{A_1}{A_2} \right) \]

\[ h_1 = \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{V_1^2}{2g} \]

\[ F_n = (A_2 - A_1)(p_2 - p_1) \]

\[ \rho (A_2 V_2^2 - A_1 V_1^2) \]

\[ h_j = \frac{(y_2 - y_1)^3}{4y_1 y_2} \]

\[ N = \frac{1}{2} \rho V_1^2 A_1 \left( 1 - \frac{A_1}{A_2} \right)^2 \]

\[ Q = \frac{2}{3} C_d \sqrt{2g} w \left\{ \left( H_2 + \frac{V_1^2}{2g} \right)^{\frac{3}{2}} - \left( H_1 + \frac{V_0^2}{2g} \right)^{\frac{3}{2}} \right\} \]
Operating hydrodynamic forces on gate are maximum when gate crack opening is 20%. This is true both for opening as well as closing of gate.

Thus crack opening is associated with decrease in velocity, pressure rise, energy loss in eddies, turbulence, circulation, uplift and thrust on gate, standing waves, hydraulic jump, violent agitation in roller of hydraulic jump etc., and as such is linked with their respective consequent detrimental effects on the system. Size of crack opening, head available and frequency of use of crack opening determines the amount of these adverse effects. Representative flow at crack opening of SG is seen as
5. PERILS AND CONSEQUENCES OF CRACK OPENING

The perils and consequences of crack opening on gate, hoist, and entire installation are;

5.1 Gate Leaf

When gate is crack opened, all of the welded, riveted joints and nut bolts are initially subjected to sudden excessive load and subsequent vibrations. Since the gate is always in proximity of water it is already subjected to corrosion regularly and continuously, which weakens its strength. Therein this excessive load, push-pull reduces strength and weakens the structural integrity of EG component parts to a great instant. EG is held in slot against tremendous water pressure and in this condition is pushed up and pulled down with impulse. Welded, bolted, and riveted joints of gate structural plates are subjected to this load which may initiate cracks or enhance crack propagation in future.
5.2 Rubber Seal

Seals do their work against full load at full reservoir level. In gate closed condition seals are compressed to their maximum extent and remain in that state. In such condition the impulsive shear load is applied to side rubber seals. This load is usually beyond the safe compressive bearing capacity of rubber. Bottom rubber seal is subjected to changes in velocity and pressure with scouring effect of turbulence. Thus permanent set, deformation, cracks and damage is imparted to rubber seals. Sometimes, cracking or physical break up of seal can be observed. The Brass or Teflon cladding on seal becomes loose or gets removed. Due to downstream sealing of EG water load on gate is transmitted to concrete through rubber seals. This action gets hampered and leakage of water starts from EG. The clamping nut bolts and backing plates of rubber seals also suffer from these disturbances of cavitation’s and turbulent flow. They start accelerated corrosion.
5.3 Sill Beam
Damages due to turbulence, cavitation, and gate hammering leads to leakages through sill beam. Sill beam holding concrete is subjected to cracks and scoring. Accelerated corrosion and erosion corrosion of sill beam takes place.

5.4 Rollers
EG rollers are also subjected to jerking action and vibrations. Instead of smooth rolling action rollers slip and tend to follow chatter path, endangering the bearings and shafts. Permanent damage spots are made on roller surface as well as wall plates.

5.5 Guide Brackets
The guide brackets of gate may get damaged or removed completely. Sometimes they hang in distorted position along with gate. Due to this gate becomes jam, locked up or may leave its position from the slot.
5.6 Wall Plates

Wall Plates becomes loose, also leave their position. The shape is also distorted. Wall plate adherence to concrete and hence sealing action becomes less effective. Wall plates become wavy and forms pockets. Welded joints crack. Sometimes wall plate gets torn from bottom. Damaged wall plates obstruct next downward movement of EG in slot. Damages and cavitation leads to leaks through wall plates.

5.7 Wire Rope

Wire rope is momentarily subjected to sudden, high impulsive loads. If load exceeds yield limit, wire rope may get permanently strained. Permanent plastic deformation may occur, and in future will provide weak spot for failure.
5.8 Hoisting Arrangement
The hoist and its structure are subjected to this sudden load through wire ropes. Elements subjected to load are shafts, gears, keys, bearings, foundation, wire rope drum and clamps, etc. consequently they show signs of peculiar failure due to this type of loading.

5.9 Hoist Supporting Portal
Hoist supporting portal is subjected to additional compressive load and may lead to failures. The crushing of portal concrete is an example of this type of failure. Further, sudden load on wire rope and hoist assigns load as one end of cantilever on portal. In extreme positions this load may uproot the portal.
5.10 Air Vents and Sluice Valve Pipes

The chamber between EG and SG does not have any other opening or passage except air vent and sluice valve pipes. Both EG and SG seals are facing each other. In this case when chamber is filled with water, due to further incoming flow during crack opening, turbulent flow of water starts rising up through air vents and sluice valve pipes. This damages both pipes in gate slot. If sluice valve pipe is damaged, subsequent leakage of reservoir starts through it in SG slot. This pipe damage and leakage is always risky, dangerous, and objectionable.
5.11 Conduit Opening and Flow

It is desired that the flow should be laminar at the conduit opening. Due to crack opening of EG, the flow inevitably becomes turbulent. The turbulent flow at conduit opening is associated with its own characteristics and problems such as, vacuum creation, cavitation, cracking, scoring, surge, etc.

5.12 Gate Catapulting

As the space between EG and SG becomes full with water, further incoming water may rise through an opening between the downstream side of the EG and gate slot. This opening area is smaller than the gate opening area. Hence it restricts the vertical flow of water into gate slot. Under these conditions sufficient hydraulic forces on the gate can occur, which would abruptly raise or "catapult" the gate up in slot. Due to use of wire rope there will not be much obstruction to this unwanted and uncontrolled upward movement of EG. Thus catapulting may damage both EG and gate slot. During this up and down movement EG may get dangled in slot. Sometimes gate comes out of its position from guide brackets in slot and hangs in inclined position. Similar effect is
5.13 Cavitation

Cavitation at gate bottom edge, side walls and surrounding area of bottom portion of conduit starts and increase when gate is crack opened. It leads to damaging the respective part and area to a great extent. On concrete and metal part surfaces cavitation leads to crack initiation and erosion corrosion. Damage to concrete becomes permanent and goes beyond repairable stage.

5.14 Vibrations and Resonance

Since EG is wire rope suspended the magnitudes and frequencies of the exciting hydraulic forces are important at the time of crack opening. These exciting hydraulic forces have high natural frequencies, compared to low frequencies of various elements of the structure. The gate may have one or more natural frequencies. At the instant of crack opening entire system vibrates, its displacement amplitude increases without bound and is governed by the available amount of damping in system. There is equal chance of self-excited coupled mode vibrations to set in at the time of crack opening. Gate may behave as simply hanging mass free to oscillate in any direction. The amplitude increases rapidly if there is marginal difference between the forcing and natural frequencies. Resonance may result in gate and structural failure.

For EG two possible sources of disturbing frequencies are the vortex trail shed from the bottom edge of a crack open gate and the pressure waves that travel upstream to reservoir and reflected back to the gate. The vortex trail originates from vortex region of EG.
6 REAL OBSERVATIONS OF CONSEQUENCES ON GATES

Some practical observations are made about above discussed effects of crack opening on dams. These cases may not be the direct effect of crack opening but it is sure that crack opening of respective gates has definitely contributed to these deficiencies.

- Power outlet EG, POEG **supporting portal** is in distressed state at **Manik Doh** dam. Concrete is cracked. Inside steel bars have become open and are visible and rusting. EG is dismantled.
- EG got dislodged from gate slot and is in hanging position in slot, it remained under water for some years at **Bhama askhed** dam. Heavy **leakage** is seen from conduit even if both EG and SG are in closed position.
- **Leaking and damaged air vent pipes, bottom seal damaged** at number of dam EG.
- **Brake failure** of irrigation sluice EG is observed for Manik Doh, Chaskaman, and Dimbhe dam.
- **Wire rope sling** to gate is in broken state at Mula dam.
- Top and bottom guide bracket is broken Waghad, Chaskaman dam.
- EG leaking when closed at Temghar, Vadaj, and Mula dam.
- There is no other provision on any dam for filling penstock when POEG is closed. Pump provided only at Pavana dam is not in working condition.
7 REMEDY

It is observed that before opening EG, if sluice valve is provided, one has to go down in well to the level of sluice valve and open it. Due to heavy leakages in well and bad condition of ladders, it is very difficult to reach to bottom level. Down the slot natural condition is very bad, there is total darkness, absence of light, sunlight, and fresh air, presence of bats, snakes, reptiles, crabs is seen, algae and moss growth is observed everywhere, danger of falling debris and loose construction lumps if touched, is always there. There is total loss of communication to top and outside world from slot and bottom.

Another difficulty is that the operation of sluice valve is very rare; as such it remains in very dismal condition and without any maintenance for most of the dams.

Due to non-use and non-maintenance it becomes jam and cannot be opened when need arises. No provision is available on any dam to ensure the volume quantum of filling of chamber.
In prevailing distressed condition for operation of EG, it is also observed that there is a psychological barrier for the operating crew that to go down slot and operate sluice valve before opening EG. Hence sluice valve opening is always relinquished. Same is true of baby gate also.

Hence, it is suggested that the gap between EG and SG should be filled directly from dam top itself. For this purpose another pump may be used. Very often number of pumps are available on dam top, e.g. for radial gate water lubrication, or for drinking water supply, or for numerous other applications. Only additional piping is required. Not much additional cost is involved. When need is felt the available system can be effectively used to fill the chamber. At suitable location after sluice valve feeding pipe from top can be joined and used without hindrances.

Thus we can totally abandon the practice of crack opening of EG and the detrimental consequences on system from its use. The leakages in slot through inlet pipe can also be avoided.

Thanks..