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Detection of underwater weak zones of dam seepage, using remote operated vehicle-an emerging underwater technology

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Abstract

The detection of underwater weak zone of the dam seepage is an important aspect for the dam safety monitoring. In unconsolidated or weak zone when seepage velocities reach critical values, internal erosion takes places, as a result the affected areas collapse and weakening the foundation of the dam. The internal erosion is one of the main reasons for the dam failures. Therefore seepage detection plays an important role in the dam safety monitoring. The visual detection of underwater weak zones of upstream face of the dam surface is difficult by conventional methods. Therefore, there is a need for new or improved technology of underwater inspection and investigation. The advanced development of remote operated vehicle in the underwater robotic technology increasingly adopted as efficient and effective tools for underwater inspection, evaluation and investigation. Furthermore, the use of a remote operated vehicle for obtaining an easily and quickly visual image recorded of underwater damage structure along the upstream face of the dam. In this study remote operated vehicle was used for the assessment of underwater weak zones prone of seepage in the upstream face of Mullaperiyar dam, Kerala, India. The analysis of the results revealed water seepage through a certain locations of unconsolidated or weak zones are presents and development of openings on the underwater upstream face of the dam.

Keywords: Detection, dam safety, dam seepage, weak zone, remote operated vehicle.

Introduction

The life of many peoples all over the world depends on the dams for domestic, industrial and agricultural water supply, production of electricity and flood protection. Most of the dams existing in India were constructed long back, with limited technical resources. Information relating to dam foundations and structural components is essential in the evaluation, stability assessment and retrofitting of existing dams[1]. Distress in concrete and gravity dams is observed with time. The improper foundation material characterization, poor quality of concrete, deterioration in concrete, lack of maintenance, alkali-aggregate reactions, washing of mortar in masonry dams may be some of the probable reasons of distress and problems in old concrete and masonry dams. Therefore, regular visual inspection and adequate monitoring is required for the dam safety and efficient performances. The instrumented data serves and regular analysis serves as a tool for assessment of the health of the dam and to suggest the remedial measures at the right time to avert any failure[2].

Safety and structural integrity of the dam is needed to be ensured, therefore, well designed and executed instrumentation plan is needed to record the variations in structural displacement, piezometric/pore/uplift pressure, deformation and stresses. Visual inspection, regularly instrumented data, analysis and the surveillance exercise, play a key role in ensuring structural safety. A number of geotechnical, geophysical, engineering and others techniques or tests are used to evaluate the conditions of the existing dams, associated structures and detection and monitoring of dam leakage/seepage[3-10]. These techniques are generally providing information on the internal quality of the dam and associated structures and unable to visual detection of weak zones or degraded zones underwater in the upstream face of the dam body. Visual inspections can be done for the dam sections above the reservoir level whereas for inspections and monitoring of any cracks below the reservoir level or any sort of damages in the submerged zones, we need to take help of divers. In the event of limitations of depth by divers, remote operated underwater vehicles (ROV) may be employed for cost effectiveness and safety, real-time video recordings of the upstream submerged face of the dam. ROV can help in recording the structural damages, cracks or any other defects through visual observations. Apart from this, distressed zone, the defective section or corrosion in metallic elements can be exactly located. Moreover, the risk associated with divers is eliminated. Some of the locations like sluice inlets/outlets, where use of divers is risky and life threatening, ROV can be used for visual inspections for assessment of silt depositions or any other flow restrictions. In case of very high dams, ROV is the only option for inspections. Dams require significant investment to build and maintain and yet their usefulness and integrity are constantly threatened by seepage and sedimentation. The use of ROV for underwater inspection and videography of the submerged structures is a cost-effective tool to reduce such threats.

Remote operated underwater vehicles are presently used for the scientific, commercial and military submerged applications[11,12]. Underwater portions of the dams that impound water for the production of hydroelectricity have a number of challenges, when it comes to operations and maintenance. Until the 1980s, when the commercially available remotely operated vehicle started to come into use, the only options for inspecting and maintaining these parts of dams to use commercial divers wherever safe and possible. The use of ROVs was restricted to military or academic objectives in early 1960s in United States and Western Europe, but due to safety and cost effectiveness, ROVs are replacing the operations that were being performed by the divers. The applications of ROV extended to several areas for underwater inspection and videography of the submerged structures i.e. upstream face of the dam, intake, trash racks, guides of penstocks, river outlets, steel gates, concrete, masonry, etc.[13,14]. The important used of ROV to see the underwater repair and remedial measures under taken and to assess the quantity and quality of work done by the contractors[15,16]. It is also used for diver support, supervision and monitoring for all underwater activities like, civil and marine engineering, hydroelectric, environmental, archeological, port authorities, safety and rescue agencies, coastal survey, offshore oil industry, subsea cabling, fisheries and aquaculture[17- 21].

The principal aim of the survey was to assessment of underwater weak zones prone of seepage in the upstream face of the Mullaperiyar dam. Identify and locate any incidences of structural damage in the concrete or steel linings using video image recorded in VHS cassettes and compact disk. Delineate the foundation soundness and health of the dam and appurtenant structures.

Site Description

The Mullaperiyar dam was constructed during 1887 to 1895 across Periyar River in Kerala. The composite dam constructed using lime surkhi and masonry is 1200 ft. long and 155 ft. in height. Lime was used as binding material at the time of construction of the dam. Uncoursed rubble masonry in lime, surkhi and sand mortar was used in upstream and downstream faces whereas lime surkhi using broken stones was used in hearting of the dam. The dam is being owned and operated by Government of Tamil Nadu under lease agreement for 999 years with Government of Kerala. The filling of reservoir was commenced in July 1896. The dam under full reservoir level (FRL) up to 152 ft. irrigates 68558 ha of the Vaigai basin in Tamil Nadu. As per agreement in 1970, Government of Tamil Nadu is also generating hydropower. Total water storage of the dam is 443.23 million cubic meter. During filling the reservoir up to its full reservoir level, slight amount of water seepage was noticed on the downstream face. Dam grouting was resorted twice to address the seepage issue. Strengthening works like RCC capping on the top of the dam, cable anchoring of upstream face and widening the base of the dam through backfill concrete were carried out[22] (Figure-1). With the time the seepage of water are increasing and also notice seepage of water in the gallery of the dam, which affects the safety and stability of the dam structure. A review of the structural safety committee of the dam was constituted and his recommendation of testing the strength of the dam materials and inspection of upstream face of the dam was decided using remote operated vehicle.

Table-1: Salient features of the dam.

Type of Dam	Masonry Dam
Length of the Dam	1200 ft.
Maximum Height of the Dam (from deepest foundation)	176 ft.
Top of the Dam	155 ft.
Full Reservoir Level	152 ft.
Maximum Water Level (MWL)	155 ft.
Top of solid parapet	158 ft.
Storage capacity	443.23 M Cu M
Length of the Baby Dam	240 ft.
Hydro-power (installed capacity)	4x35 = 140 Mw

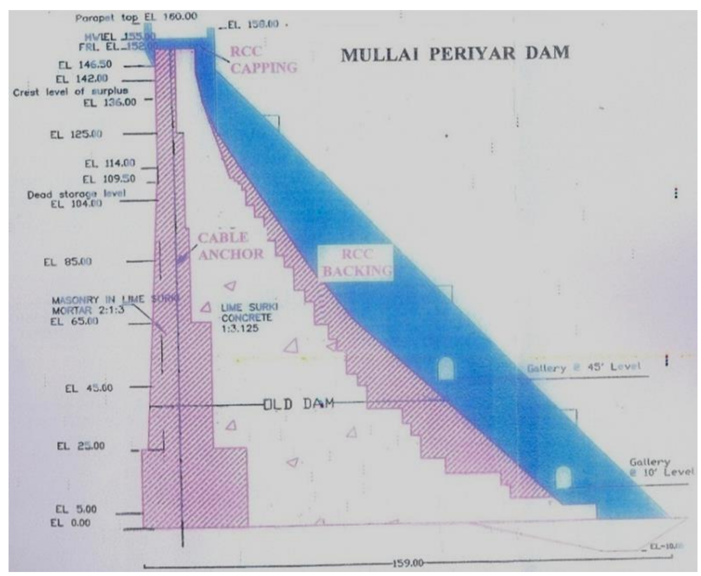

Figure-1: Cross section of Mullaperiyar dam after strengthening[22].

Remote Operated Vehicle (ROV)

Remote operated vehicle is vehicle that is controlled by an operator who is not site in the vehicle. This vehicle controlled by a cable or line connecting the vehicle to the operator location. The ROV is configured with a high-definition (HD) video camera, high intensity LED illumination, sonar mapping system and other tools to navigate and collect valuable information in conditions unsafe for diver entry[23,21]. A remotely operated underwater vehicle (ROUV), more commonly called an ROV. Over the last few decades, ROV used as essential part of basic toolkits for sub-sea inspection and observation system for variety of underwater work and capable for operating up to a specified depth. An ROV is used for underwater inspection of construction work, intervention or other tasks.

The remote operated vehicle H-300 model, M/s. Hytec Hydro Tectechnologie, France was used for under water inspection of upstream face of dam surface. The H-300 ROV is a sub-sea inspection and observation system, capable of operating down to a depth of 300m. Remote operated vehicle comprises of a submersible vehicle, surface control unit (SCU), an umbilical cable connecting the control console to the submersible vehicle, Joysticks, multimedia recording system, VCR and other accessories. Joysticks help to controlling the vehicle and its movement underwater[24]. The video signal of underwater object is brought to control console for online viewing and can be recorded in recording system. The ROV system comprises two video cameras viz. one DTR 100Z colour camera and other black and white to capture the video of the underwater portion of the dam. The black and white camera which is a silicon intensified target (SIT) camera is fitted with an auto-iris, auto focus lens and can operate in very low light intensities. These cameras mounted on ROV was used for underwater scanning of the upstream face of the dam including concrete blocks, block joints and trash racks of river outlets and penstocks. The SONAR system fitted in the ROV is used for navigation aid and to capture acoustic image of the structure[25]. The area of interest was scanned through the video cameras mounted on the underwater vehicle and recording the image on the video-cassettes (VHS) and compact disk (CD) simultaneously. The captured image with depth and heading informations of the ROV is displayed on operator's screen in SCU. The technical specifications of ROV system are mentioned in Table-2[26].

Table-2: Technical specifications of ROV Performance.

Motion	3 axes (horizontal, vertical, lateral) and rotating around axis
Speed	3 knots forward speed.
Maximum working depth	300 m
Storage Device	CD, HDD and VHS

ROV Dimensions: Length 84cm, width 60cm, Height 47cm. Length when adding the CECH300 clear water cylinder: 90cm to 102cm according to bumpers position.

Weight in air with ballast weights for freshwater: i. W/O CECH300 clear water cylinder: 77Kg. ii. With CECH300 clear water cylinder: 82kg.

Vehicle operating conditions: Operating temperature 0^0C to + 50^0C, Storage temperature -10^0C to + 60^0C.

Equipments: The picture of ROV with number markings as mentioned in Table-3 is shown in Figure-2.

Methodology

The ROV was deployed at specific points for assessing the condition of underwater dam surface. The vertical grid was marked at 10 feet interval on the upstream face of the Mullaperiyar dam surface as shown in Figure-3. The grid marking was starting from the left bank as zero RD and 1200 RD at the end of right bank on the dam surface. The 300 feet (RD 0-RD 300) at left bank and 180 feet (RD 1020-RD 1200) at the right bank scanning was neglected due turbid water and very shallow depth Figure-4. The scanning of bank portions are generally avoid due to the presence of floating objects, oil etc., which tends to come to banks and may interfere with the normal functioning of thrusters which may result in the breakdown of ROV. Initially it was planned to scan at each 100 feet grid as a preliminary survey then to reduce the spacing to 50 feet and then to 20 feet and 10 feet. For inspection of particular RD, a rope with a weight attached to its bottom was lowered along with the dam body for the reference of scanning area/path. The ROV was deployed to the respective RD vertically lowered down and seeing the rope hung from the top of the dam along the corresponding RD as a marker. The trim switch for downward movement of ROV is set at a desired speed and the ROV is bring close to the upstream face of the dam surface with the help of forward thrusters. Once the image could be captured satisfactory the forward thrusters are released and the ROV is allowed to go down slowly then immediately the forward thrusters are activated to make the ROV to take the closer view by touching the upstream face of the dam. This process is repeated till the maximum possible depth is reached by ROV. Once the maximum possible depth was reached, then the ROV was bring back from the dam surface by releasing the trim switch for upward movement and the same procedure is repeated. The scanning was carried out vertically down and vertically up at all the RDs. Video recordings were carried out at both the upward and downward movement of ROV. The data was acquired in CD and VHS cassettes at the same time.

Results and discussions

The analysis of the video images captured from grid points corresponding to the RD's helped to divide the scanned upstream surface area into five zones, based on the relative scale of deterioration and presence of weak zones. The first zone divided from 0-3m depth from water level, second zone from 3-5 m depth, third zone from 5-7m depth from water level was classified as deteriorated plaster zone, partially deteriorated zone and deteriorated zone respectively. The fourth zone from 7-9m depth and fifth zone below 9 m up to the maximum depth of scanned area by ROV was classified as intact zones as show in Figure-5. The interpretation has been done in the terms of plaster peeled off or plasters getting crushed due to the impact of bumpers of the ROV or mortar missing seen/deteriorated mortar in masonry and extent of cavities present. The details of interpreted results of all the classified zones are given in Table-1 The interpreted results are based on the analysis of all images scanned by ROV. The some images related to each classified zone are presented for simplicity (Figures-6-10).

Table-3: Number markings as shown in Figure-2.
0: Frame assembly: Frame pressed polypropylene, Fittings 316 L stainless steel, Buoyancy: PVC foam 0,25Kg/dm^3.
1: Horizontal thrust: 2 x 435 W thrusters, thrust 200 N
2: Vertical thrust: 1 X 435 W thrusters thrust 100 N
3: Lateral thrust: 1 x 435 W thrusters thrust 100 N
4: Electronic housing: Opto isolated serial link with piezoresistive depth sensor.
5: Camera: colour, zoom, manual or automatic focus, tilt and rotation movements, model DTR100ZC3S and SIT, black and white camera for low visibility inspection and navigation.
6: Lights: 2 halogen lights, 120V/75 W, variable intensity, VSE 360 SS version
7: High sensitivity camera: Osprey Camera
8: Additional lights: 2 halogen lights, 75 W, variable intensity, VSE 360 SS version
9: Sonar: STENMAR SONAVISION 2392 Mercury Sonar in 300m depth acetal housing, full 360º continuous rotation, 600 KHz to 1200 KHz for navigational aid and acoustic scanning of the front, bottom and around.
10: Hydrophone: To assess the safety of ROV
11: Compass: To know bearing of the equipment
12: CECH300: Clear water cylinder. In the case of ROV use in turbid water, it must be equipped with a CECH300 clear water cylinder which permits the integration of the DTR100ZC3S camera with two VES360SS lights.
13: Bumpers.

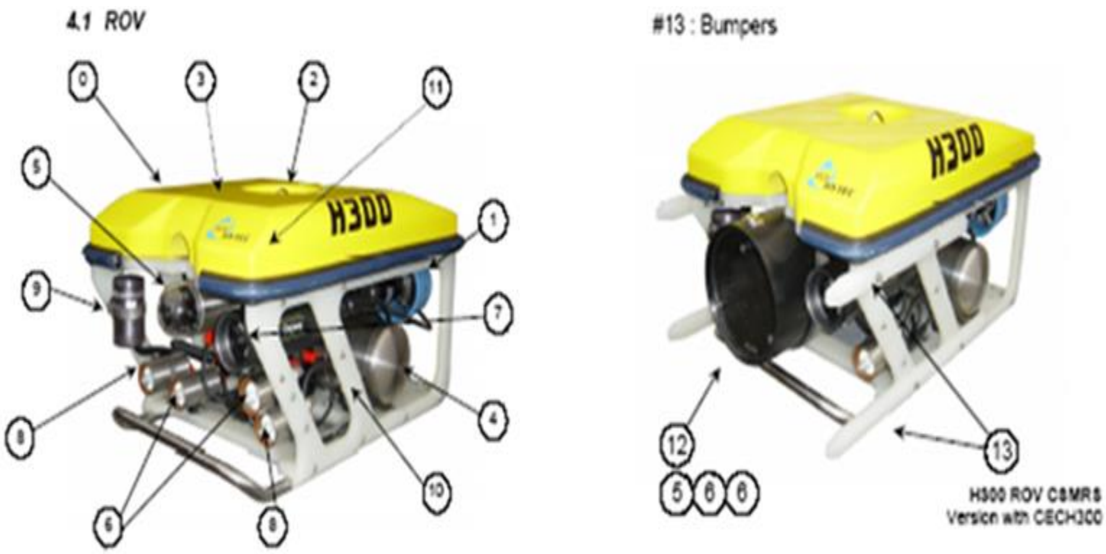

Figure-2: ROV shows its parts with number markings and with CECH300 clear water cylinder[13,26].

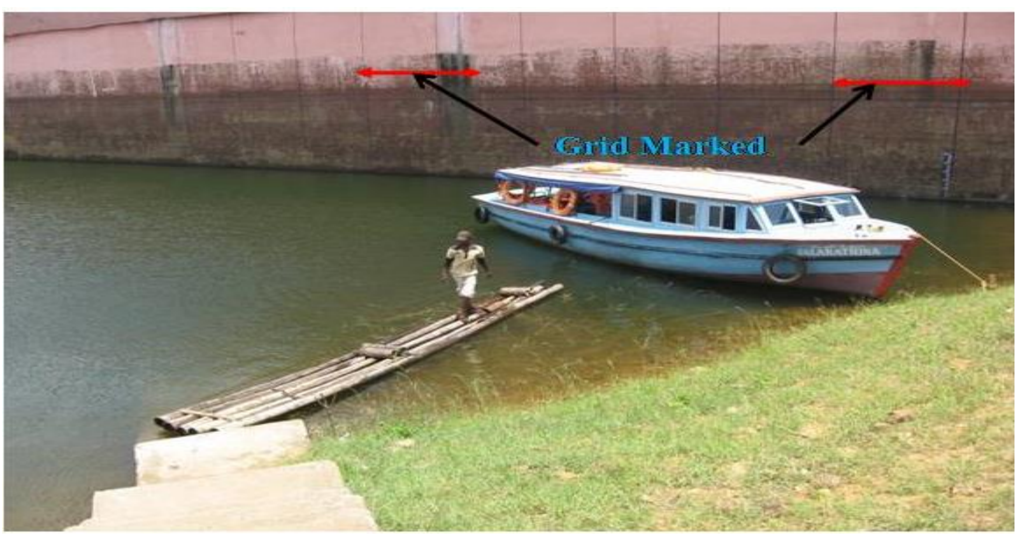

Figure-3: Vertical grid marked at 10 feet interval on the dam.

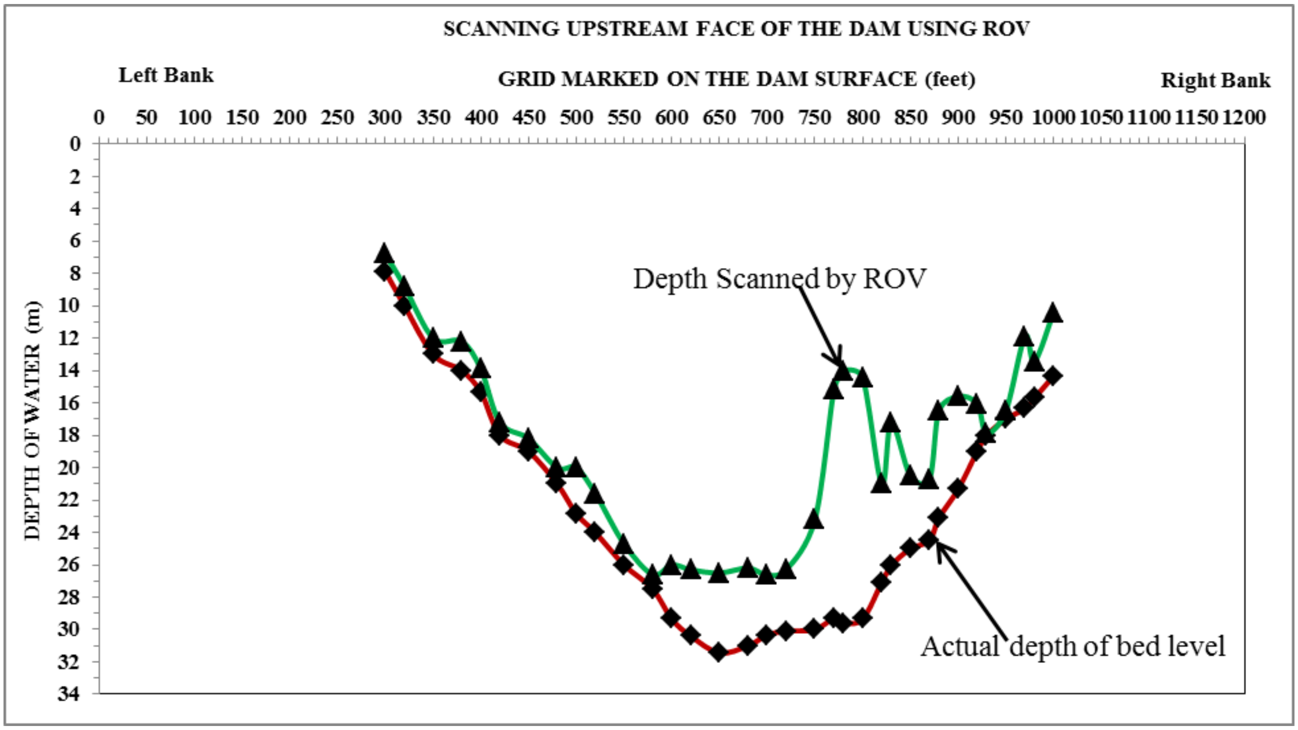

Figure- 4: Longitudinal section of the Mullaperiyar dam.

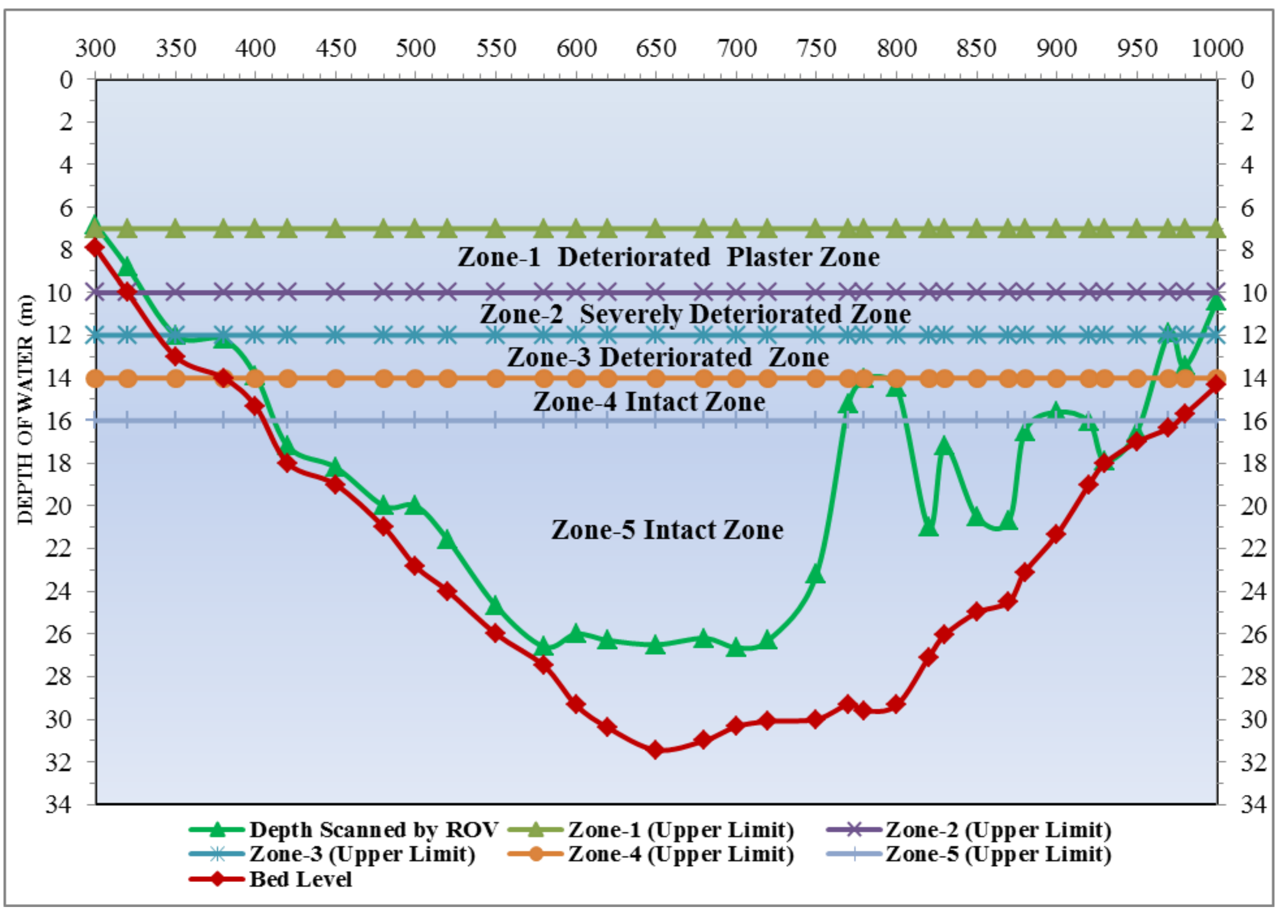

Figure-5: Classification of upstream face of the dam zone wise.

Table-1: Summarized interpreted results.

Depth (m) from W.L	Classification of zones	Interpretation from the images
0-3	Zone 1	The plaster seems to be deteriorated. The plaster has been peeled off in some places. Horizontal and/inclined joint with separation exist. Plaster getting crushed at the impact of bumpers and making marks on plaster. Deteriorated plaster zone.
3-5	Zone 2	The mortar is missing in many areas of masonry. Whatever little masonry is remaining is deteriorated. Cavities in greater extent varying in depth are also visible. It seems the plaster has been done but the same is deteriorated. Not getting reflection of light from some cavities. Algae growth seen. Mortar is not flush with rubble. Severely deteriorated zone.
5-7	Zone 3	The mortar is missing in some areas of masonry. Cracked mortar was visible. The mortar is not in flush with rubble. Cavities in lesser extent with smaller in opening size present. Algae growth seen. Deteriorated zone.
7-9	Zone 4	In the masonry minor cracks were visible in mortar joints. Minor/Moderately disturbed masonry seen. The mortar is in flush with rubble in all places. Generally intact rubble masonry. Intact zone.
Below 9 up to depth scanned	Zone 5	Intact rubble masonry with well healed joints. The mortar is in flush with rubble. No cavities. No missing of mortar. Many black marks were detected but could not be identified. But not problematic. Isolated cracks cavities also present. Even then the masonry is intact.

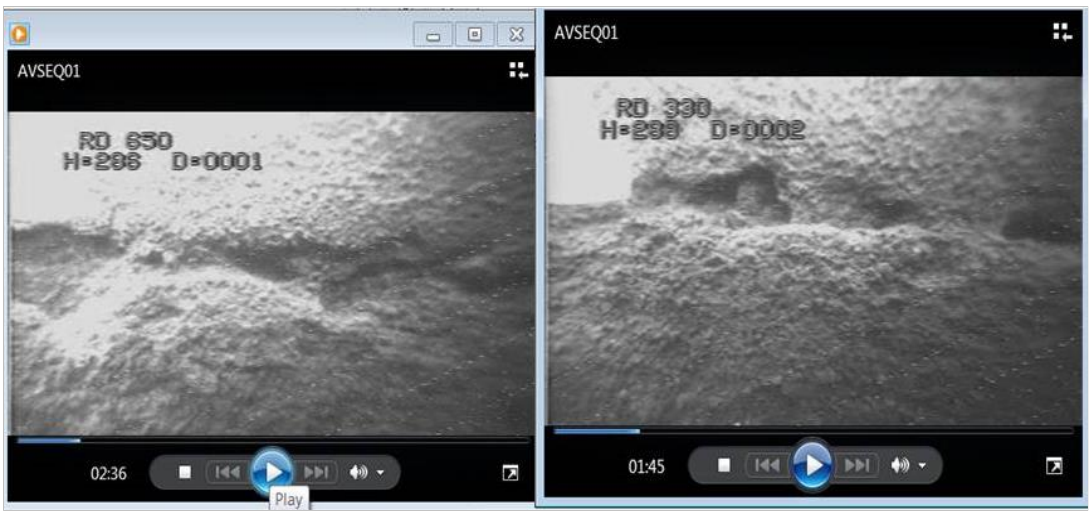

Figure-6: Deteriorated plaster zone at 1and 2 m depth (zone-1).

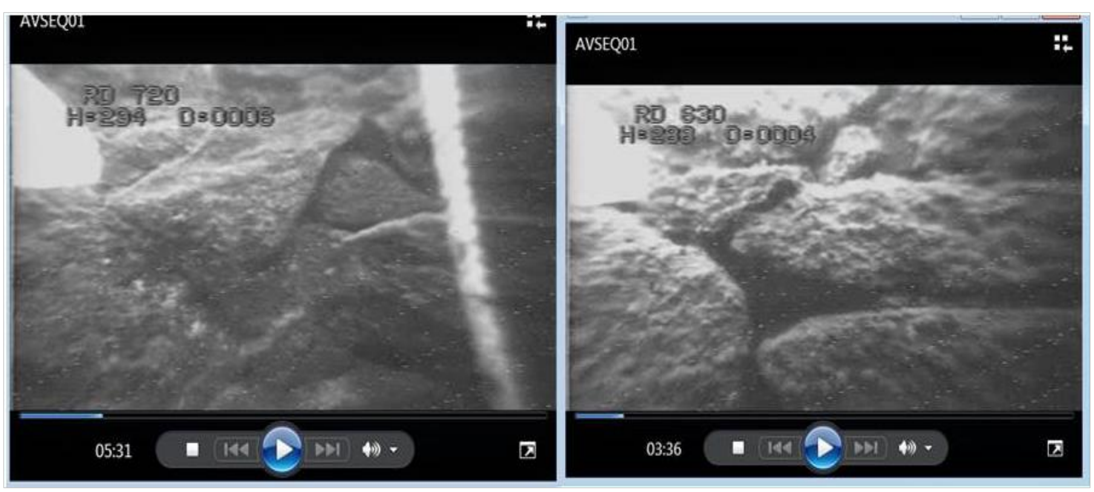

Figure-7: Severely deteriorated zone at 3 and 4 m depth (zone- 2).

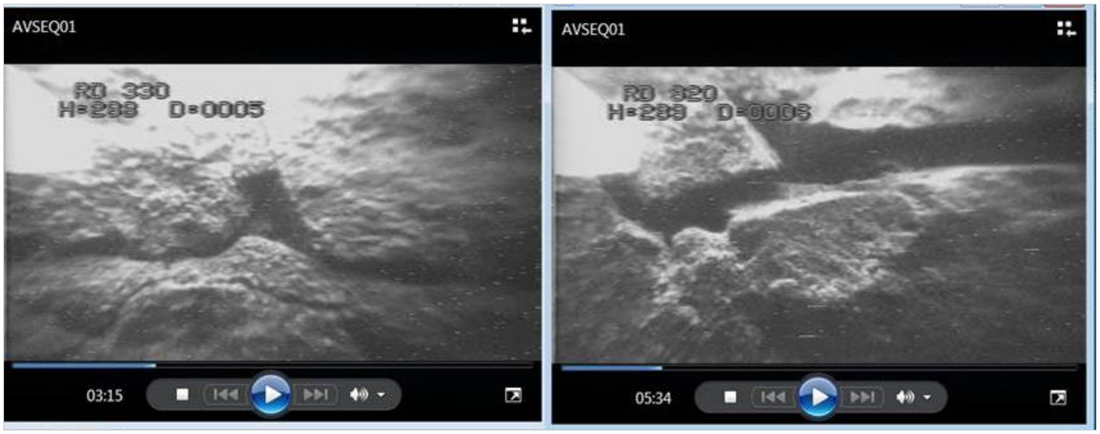

Figure-8: Deteriorated zone at 5 and 6 m depth (zone- 3).

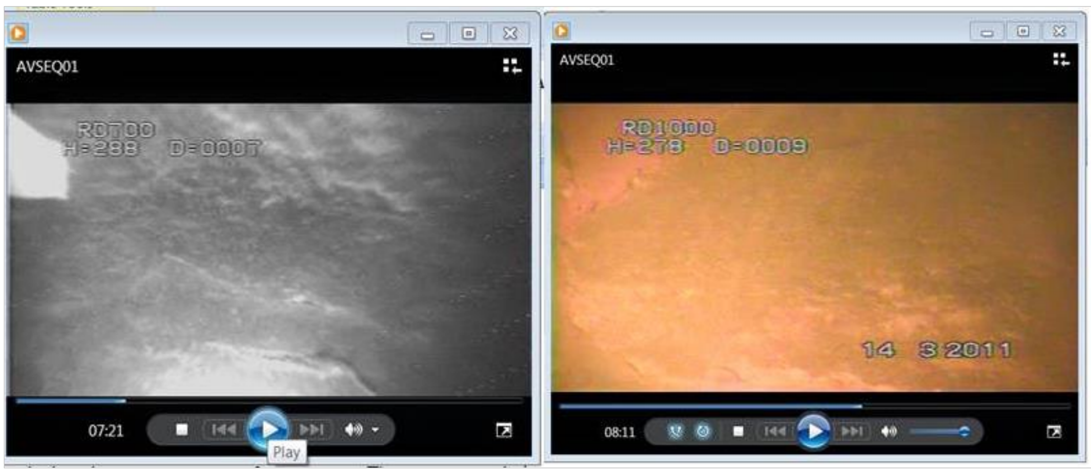

Figure-9: Intact zone at 7 and 9 m depth (zone- 4).

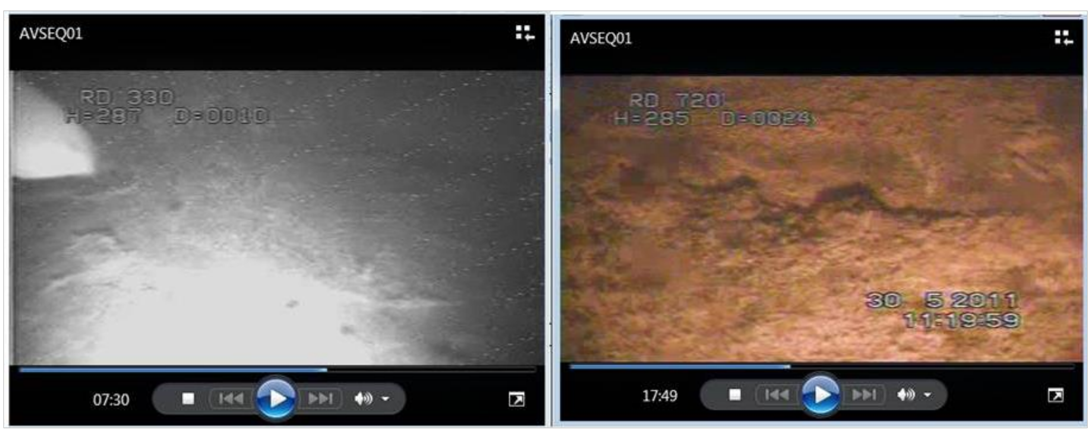

Figure-10: Intact zone at 10 and 24 m depth (zone- 5).

Conclusion

Based on the relative scale of deterioration of upstream face of the dam surface was divided into five zones from the depth of water up to the scanned area by ROV. The first, second and third zones was identified as deteriorated plaster zone, partially deteriorated zone and deteriorated zone respectively. The fourth zone and fifth zone below 9m up to the maximum depth of scanned area by ROV was classified as intact zones. Generally it was observed that the plaster is deteriorated or peeled off 0-3 m depth from the water level at all scanned RDs. The extent of deterioration or peeling off is more between 1-2m depth from the water level. The depth between 2-5m the mortar of the masonry is deteriorated or missing. The mortar is also missing is seen some other areas of masonry at 2m, 5m and 6m depth from the water level. Beyond the depth of 6m the masonry is good and intact and no any cavities are seen up to the depth scanned by ROV. It seems that due to weathering effect and combined with wave action the plaster and mortar in the masonry has deteriorated/dislodged.

After visual examination of all the captured imaged the possibility of missing mortar beyond the surface cannot be ruled out. The video images captured from all the RD's are similar at the same depth. In the zone 2 and zone the masonry are suffered damage throughout the dam. The extent of damage is more at the top and lesser towards bottom in the entire dam. The periodically inspection can save huge amount of retrofitting costs by timely small repairs.

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