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Underwater Inspection of Upstream Face of Dam Surface, Using Remote Operated Vehicle

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ABSTRACT: Dams are significant infrastructure for multipurpose uses and constructed with large investments of money and time. In dealing with the safety concern many investigations are involved during the design and construction of the dam. Safety of the dams and its appurtenant structures are a very important aspect for trouble free operation of the dam. A continuous and effective monitoring is essential for safeguarding the national investment and human lives. The conventional techniques of inspection of dam are generally having many drawbacks, expensive and challenging task from the safety and efficiency point of view. On the other hand, advanced development of remote operated vehicle in the underwater robotic technology increasingly adopted as efficient and effective tools for underwater inspection, evaluation and investigation. The purpose of this work is to evaluate the performance of remote operated vehicle to inspect the focusing efforts on underwater structure of dam river outlet trash racks, penstock trash racks and dam block joints and state of concrete of Bhakra Dam, Punjab, India. The inspected results are achieved through the visualization of a video image recorded in video-cassettes and compact disk. The inspected results are achieved through the visualization of a video image recorded in video-cassettes and compact disk.

KEYWORDS: Inspection, Remote operated vehicle, Dam, Underwater structure, Upstream face

I. INTRODUCTION

Dam inspection is essential for the long-term stability, safety, evaluation of structural and operational aspects of the dam and suggests remedial measure for its repair and rehabilitation [1, 2, 3]. An effective inspection helps to protect the future calamity and reduces the risk of financial and legal liabilities due to the failure of dam and its appurtenant structures. Most of the dams existing in India were constructed long back and many of them are having deficiencies, shortcomings in operation, desires monitoring facilities on account of ageing and some of them do not meet the present design standards [4, 5]. Therefore, it becomes very important to ensure that the existing dams continue to operate as designed and producing benefits to the society in the form of water supply, irrigation, flood control and hydropower. The continuous periodical inspection of dam and its associated structures is considered essentially by dam safety committees and issue dam safety standards guidelines under Dam Rehabilitation and Improvement Project (DRIP) [6,7]. These guidelines provide the dam safety standards, which follow the international standards, global protocols by advanced leading countries and specifically carved to meet the Indian needs [5]. Civil engineering structures of hydroelectric project such as dam, water intake, trash rack of penstocks, etc. are usually submerged, and there are few effective methods for their inspection [8]. Monitoring of dam can be carried out in many ways such as visual inspections, instrumentation, non-destructive testing (NDT) and underwater inspection using divers and remote operated vehicle (ROV).

The demand for underwater inspection of dam structure monitoring, hydropower plants, mining, oil and gas etc. is increasing rapidly [9]. With ageing and increasing demand it is more likely that these structures will undergo stress in the coming times. The increase in exploration, prospecting, monitoring and security in lakes, rivers and seafloor both in commercial and scientific applications has led large companies and research centres to invest in the development of underwater vehicles [10, 11]. The ROV provides direct visual information for safety analysis and augments studies for the conditional assessment of dams. In the dam inspection, remote operated vehicle has to grab images of underwater area of upstream face of dam surface with maintaining a certain distance from the dam underwater structures.

The remote operated underwater vehicle has gain an increased interest in the last decades due to the multiple tasks completed in the various fields of dams inspection, oil and gas industry and environmental investigations [12].

The potential applications of remote operated vehicles deals with underwater inspection facilities such as bridges, tunnels, hydraulic structures of hydropower plants, dams, boat hulls and aquatic environments [13,14,15,16,17,18].

The Bhakra Nagal dam is the largest dam in the India and second largest dam in the Asia. Bhakra dam project built across river Satlej near village Bhakra is one of the most important projects in the country. It was commissioned in the year of 1963. It is a concrete gravity dam. The maximum height of the dam above deepest foundation level is 225.55 meter and its maximum height above riverbed is 167.64 meter. Its length at the top is 518.16 meter and width at top is 9.14 meter. The dam consists of 34 blocks. The maximum reservoir level is at an elevation of 515.11 meter (1690 feet) and the normal reservoir water level is at an elevation of 513.58 meter (1685 feet). Its reservoir known as the gobind sagar, it is the second largest reservoir in the India.

In this paper, remote operated vehicle was used for the inspection of upstream face of Bhakra dam in order to assess the state of the concrete, river outlet trash racks, penstock trash racks and dam block joints Fig. 1. These inspections were commonly achieved through the visualization of a video recorded in video-cassettes (VHS) and compact disk (CD) format.



Fig. 1. Upstream face of Bhakra dam marked with penstocks and river

II. REMOTE OPERATED VEHICLE (ROV) FOR UNDERGROUND INSPECTION

A Remotely Operated Vehicle (ROV) is mobile underwater vehicle that can be equipped with multiple electronic survey systems to aide in an inspection. The ROV outfitted with HD video systems and sonar imaging equipment to navigate and collect valuable information [19]. These vehicles are ideal for scour inspections, confined spaces, deep water inspections, or deployment in any condition unsafe for diver entry [12]. The use of an ROV system can dramatically reduce inspection costs while eliminating the risks associated with the use of divers to complete the task [20].

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 300 m. 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 [20]. 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 [21]. 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 below [22].

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

Weight in air with ballast weights for freshwater

-W/O CECH300 clear water cylinder:	77 Kg.
-With CECH300 clear water cylinder:	82 kg.

Vehicle operating conditions

Operating temperature	0 ⁰ C to + 50 ⁰ C
Storage temperature	-10 ⁰ C to + 60 ⁰ C

Equipments

The picture of ROV with number markings as mentioned below is shown in Fig. 2.

# 0: frame assembly:	Frame pressed polypropylene
Fittings:	316 L stainless steel
Buoyancy:	PVC foam 0,25Kg/dm3.
#1: Horizontal thrust:	2 x 435 W thrusters, thrust 200 N
#2: Vertical thrust:	1 X 435 W thruster, thrust 100 N
#3: Lateral thrust:	1 x 435 W thruster, 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 360° 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

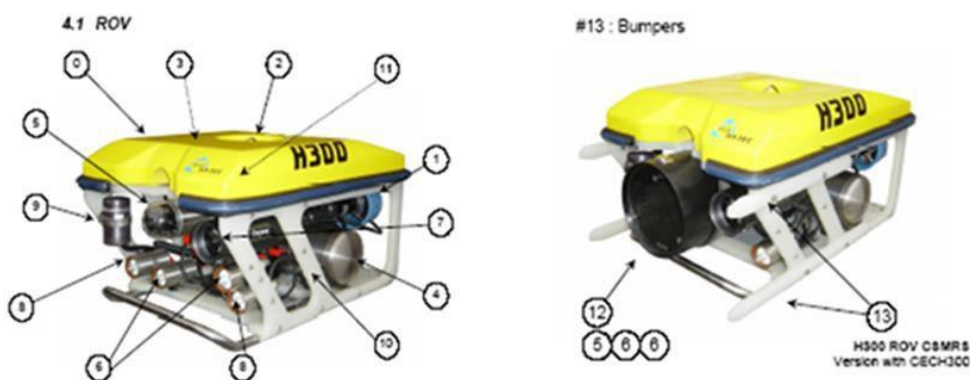


Fig. 2. ROV shown its parts with number markings and with CECH300 clear water cylinder.

III. METHODOLOGY

The deployment of ROV for underwater investigation generally involves arrangement of a working platform on the reservoir and power supply for the operation of the ROV. A general sketch of deployment of ROV is shown in Fig. 3.

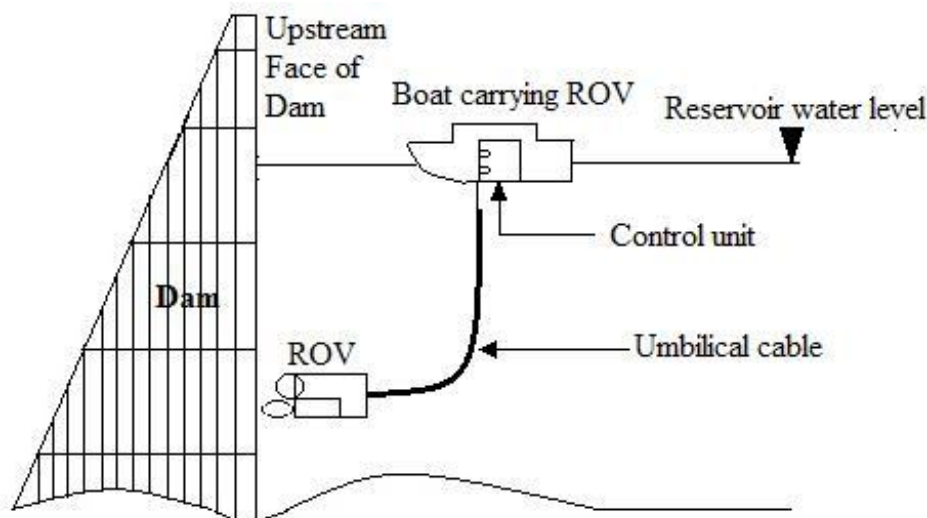


Fig. 3. A typical sketch showing ROV inspection of upstream face of Dam.

The area to be inspected was marked on the block wise with reference to the reduced distance (RD) and depth using ropes. Complete inspection of the instrumentation system for mechanical and electrical checks is carried out on the various components of the ROV system before launching the vehicle into the reservoir. The vehicle is taken to the desired location with the help of control system of ROV. Navigational aid provided by the control system in the form of automatic depth indication and bearing of the vehicle keeps track of the vehicle position. The ROV is lowered along the vertical direction seeing the rope to avoid deviation and the same is brought up. The video film of the scanning work is recorded during both the upward and downward movement of ROV under water. The distress point, if any is clearly noted along with depth. At the end of the survey, recorded video tapes were run to see the recorded featured of underwater structures.

The ROV was deployed at specific points for assessing the condition of dam block joints. For inspection of dam block joints, a rope with a weight attached to its bottom was lowered along with the dam block joint for reference of scanning area/path. While scanning of trash racks of river outlets, adjacent generating units were shut down to avoid sucking action, safety of ROV and to maintain still water conditions for clear image recording [13]. Similarly, during scanning of trash racks of penstocks, shut down of adjacent generation units on left and right side was shut down. Lot



of time was wasted due to co-ordination activities for shutting down of adjacent generating units. Hence, trash racks of all the penstocks could not be scanned.

IV. RESULTS AND DISCUSSIONS

Generally, the concrete surfaces of the dams are intact at all the depths. Signs of any major deterioration/ defect could not be seen at any locations. Dam block joints, trash racks for river outlets and trash racks of penstocks were inspected using ROV. Underwater inspection was done up to a maximum depth of 81 m from the reservoir level at river outlets (R/o) 5, 6, 13 and 14. During the inspection of river outlet trash racks, a fishing string along with wooden stick and silt got trapped inside one of the thrusters of the ROV as shown in Fig. 4. Similarly, a fishing string was seen mingled with the trash rack bars of penstock 5 at a depth of 44 m in recorded video image Fig. 5.

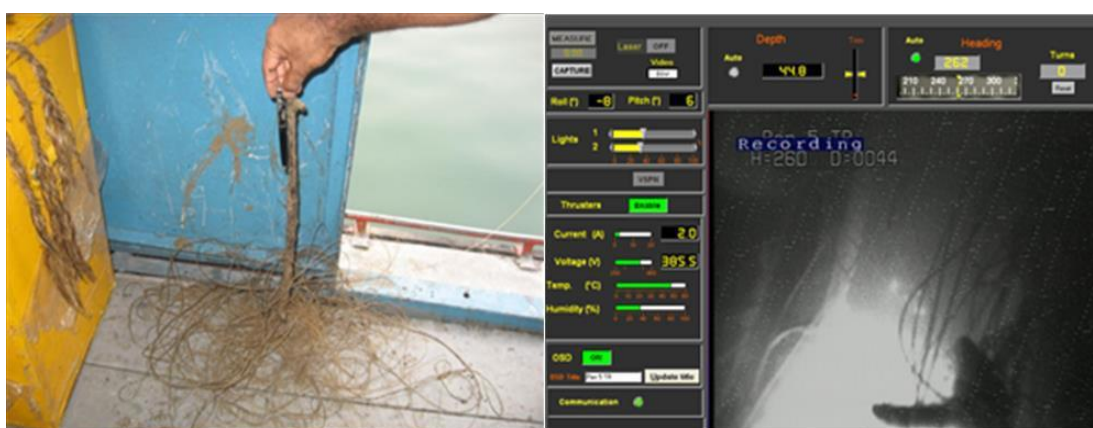


Fig. 4. Fishing string along with wooden stick Fig. 5. Fishing string intermingled with trash rack bars of Penstock 5.

Thick layer of silt deposited was seen on the trash rack bars of the river outlets particularly those at lower elevation. It means the lower river outlets have not been operated since long time. Deposited silt gets detached from the bars, as the ROV strikes these bars. Scanning of trash racks of river outlets was possible up to a depth of 81 m due to poor visibility conditions as well as deposition of silt. Thick layers of silt deposition on the steel bars can be seen in Fig. 6. Suspended silt particles may also be seen, these suspended silt particles lead to visibility problems during underwater scanning work. Fig. 7 shows the condition of bars after partial removal of silt. The condition of penstock steel bars may be seen in Fig. 8. Lesser amount of silt was noticed in penstock trash racks bars as compared to river outlets.



Trash rack of river outlet at 79 m depth Trash rack of river outlets at 53 m depth



Trash rack of river outlet at 73 m depth Trash rack of river outlets at 60 m depth

Fig. 6: Silt deposition in trash racks of river outlets.



Fig. 7. Steel bars of river outlet trash racks after partial removal of silt.



Fig. 8. Steel bars of penstock trash racks.



The list of inspected zones/structures and inferences drawn is presented in Table 1.

Table 1
Details of Underwater Inspection of Structures of Bhakra Dam

Sl./CD No.	Location	Depth of Scanning (m)	Reservoir Level (ft.)	Inferences/ Results
1.	Block Joint 21-22	34.7	1580	No defects were observed
2.	Trash Racks of River Outlets 5, 6, 13 and 14	81	1580	While navigation downwards, silt deposited on steel bars was seen as flying objects.
3.	Block Joint 19-20 35		1580	No defects were observed. ROV had to be deployed twice due to visibility problems between 19 m and 35 m.
4.	Trash Racks of River Outlets 3, 4, 11 and 12	16	1580	No defects were observed.
5.	Block Joint 18-19 21	1581.16		No defects were observed. Up to 18 m good quality of image was observed.
6.	Trash Racks of River Outlets 1, 2, 9 and 10	67	1581.16	Navigation was difficult as bars were clogged with silt. Presence of silt Deteriorates the image quality. Trash racks were in good condition.
7.	Trash Racks of River Outlets 1, 2, 9 and 10	76	1581.16	Second time deployed the ROV at Trash Racks of River Outlets 1, 2, 9 and 10. Started scanning from 16 m to 76 m depth. No defects were observed in R/o Trash racks. Clear visible image was recorded.
8.	Trash Racks of River Outlets 7, 8, 15 and 16	42	1581.16	Trash racks visible from a depth of 36 m. No defects were observed in R/o Trash racks.
9.	Trash Racks of River Outlets 7, 8, 15 and 16	79	1581.16	Trash racks were clearly seen at depth of 52 m to 79 m. No defects were observed in R/o Trash racks.
10.	Trash Rack for Pen-Stock No.5	55	1581.5	Second time ROV deployed at the same position and trash racks seen from a depth of 37 m to downwards. At a depth of 42-47 m fishing net was struck inside the ROV. A bunch of fishing net can be seen in the video Fig. 5.
11.	Trash Rack for Pen-Stock No.10	50	1581.38	Second time ROV deployed at the same position and trash racks seen at 37 m depth to downward. No defect were observed in R/o Trash racks. Fishing net was also seen. Turbidity in water affected the picture quality.
12.	Block Joint 22-23 25		1581.38	No defects were observed. Poor visible image recorded below 18 m.
13.	Trash Rack for Pen-Stock No.6	59	1583.72	No defects were observed. Clear image of trash racks may be seen in the video.



V. CONCLUSION

Underwater scanning of block joints revealed that these are free from any defect. Grooves of all the joints were clearly visible up to the scanned depth. However, fishing nets inter mingled with trash racks were observed and one of which got struck in the thruster of ROV. Thick layers of silt were seen deposited on the trash rack steel bars of river outlets. Lesser silt deposition on trash rack bars of penstocks were seen as compared to the river outlet trash racks. Silt deposition seems to be loose as the same removed due to disturbances caused by movement of ROV. Larger amount of silt deposition in river outlet trash racks may be attributed to the fact that the river outlet gates are not operated regularly. Barring silt deposition, the condition of bars seems to be good.

Trash racks of different penstocks and river outlets were observed to be free from any physical damage. No clogging was observed between the adjoining bars of trash racks. General condition of the dam block joints seems to be good. The river outlets trash racks contain silt deposition particularly those at the lower elevation, it need to operate, clean the river outlets regularly for removal of deposited silt and inspection of the upstream face of the dam at regular intervals.

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