Application of Remote Operated Vehicle as a Post Construction Instrumentation for an Existing Dam- A Case Study

Alex Varughese

Central Soil and Materials Research Station, New Delhi- 110016

Abstract- **Civil engineering structures of hydroelectric project such as dam, water intake, trashrack of penstocks, etc. are usually submerged; and there are few effective methods for their inspection. Monitoring of the health of dams is paramount as the failure of such structures will have disastrous consequences by way of loss of life, property and on account of heavy expenditure towards its repair and rehabilitation. Regular safety appraisal of dam and its appurtenant structures is considered essentially by dam safety committees. 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). This paper presents case study of underwater scanning of a dam using the Remote Operated Vehicle.**

I INTRODUCTION

Dams and its appurtenant structures for a river valley project are very important and involve huge investment of money and time. In dealing with the safety problems during design, construction, operation, maintenance and surveillance of dams, it is essential to carefully collect, process and study all available information. For the dams to provide long and trouble free service, a continuous and effective monitoring is required to foresee the changes in the characteristics of the materials due to aging, thermal and hydrostatic cycling, extraordinary events such as earthquakes, floods etc.

II MONITORING OF DAMS

Mostly the deterioration in concrete and masonry dams is attributed to several factors like improper foundation, poor quality of concrete, alkali-aggregate reactivity, poor maintenance etc. Therefore, regular visual inspection and adequate monitoring is required. Finally a rapid analysis of recorded data from monitoring will give the best opportunity to the engineer for the assessment of the dam condition and for taking timely action for mitigating the same. The various factors to be monitored in dams and other hydraulic structures are Structural displacement, Deformation, Settlement, Seepages, Piezometric levels in dam foundation, Uplift pressures etc. The instrumentation in the body of the dam is designed and executed in all major projects. The visual instruction of the exposed portion of the dam can be done by naked eye. But monitoring of any kind of cracks, seepage and other defects in the submerged portion has to be carried out either with the help of divers or by ROV. For underwater scanning of upstream face of the dam, ROV is used to make the video film. It helps to locate the orgin/sources and causes of distresses like seepage, cracks and corrosion of metallic structures.

III REMOTE OPERATED VEHICLE FOR UNDER WATER MONITORING

ROV for sub-sea research has been under study and development in the United States and Western Europe since the mid 1960s in both military and academic objectives. In recent time some of the operations by divers and manned submersibles have been gradually replaced by ROV as a more effective and safer method.

The employed ROV was a sub-sea inspection and observation system, capable of operating down to a depth of 300 m. Remote Operated Vehicle comprises a Submersible Vehicle, a Surface Control Unit (SCU), an Umbilical Cable connecting the control console to the submersible vehicle, a multimedia recording system, a VCR and other accessories. It has two video cameras one DTR 100Z coloured camera and other black and white . These are mounted on vehicle to capture the underwater video and can also be used for underwater scanning of the submerged structure (Fig 3.1). The SONAR system fitted in the ROV is used for navigation aid for obstacle avoidance and to capture acoustic image of the structure. The area of interest was filmed using the video cameras mounted on the underwater vehicle and recording the video on the videotape and compact discs.

Navigational aid in the form of a SONAR system and depth and heading information's of the ROV is displayed on operator's screen in SCU. The video signal of underwater object is brought to control console for online viewing and can be recorded in recording system. The black & 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.

Fig.3.1: ROV System (Vehicle) parts shown with number markings without & with CECH300 clear water cylinder.

Technical Specifications of ROV[4]
Performance:
Motion: 3 axes (horizontal, vertical, lateral) and rotating around vertical axis
Speed: 3 knots forward speed (5.56 Km/hr)
Maximum working depth: 300 m

Fig.3.1 shows the ROV with number markings as mentioned below:

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
#6 Lights : 2 halogen lights, 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. Vehicle health monitoring
#11. Compass. Navigational aid.

Heavy-duty industrial motors for horizontal, lateral and vertical movements and controls to power the submersible vehicle through its propellers. This B&Wcamera is having an auto-iris, auto focus function. The B&W camera can record approximately 37cm x 27cm wide images when ROV's bumpers are touching the image. In addition to this high resolution colour camera installed in ROV is capable of pan and tilt. The image of Colour camera depends upon the zoom and focus of the lens and area of vision is only 8 cm x 6 cm when the axis of the camera is horizontal and the bumpers are touching the image. The size of the display on Surface Control Unit is 24cm x 19cm . The data is collected and saved in CD and Video casette.

IV UNDERWATER SCANNING OF a COMPOSITE DAM.

A dam over 1000 ft long and over 100ft high lime surkhi and masonry composite dam(Fig.4.1) constructed long ago, was strengthened by cable anchoring at the upstream face in 1981 , RCC capping on the toping 1981 and backfill of concrete on the downstream to widen the base by 1995 .

V FIELD METHODOLOGY

The field deployment of ROV involves arrangement of a working platform on the reservoir and power supply for the operation of the instrument (Fig 5.1). The area to be scanned was marked on the block with reference to the RD and depth using ropes.[2]. The vehicle is taken to the desired location with the help of control system. 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. The distress point, if any is clearly noted along with depth. At the end of the survey, recorded tapes were run to see the recorded featured. The images were further analysed in conjunction with the daily variation of reservoir level data.

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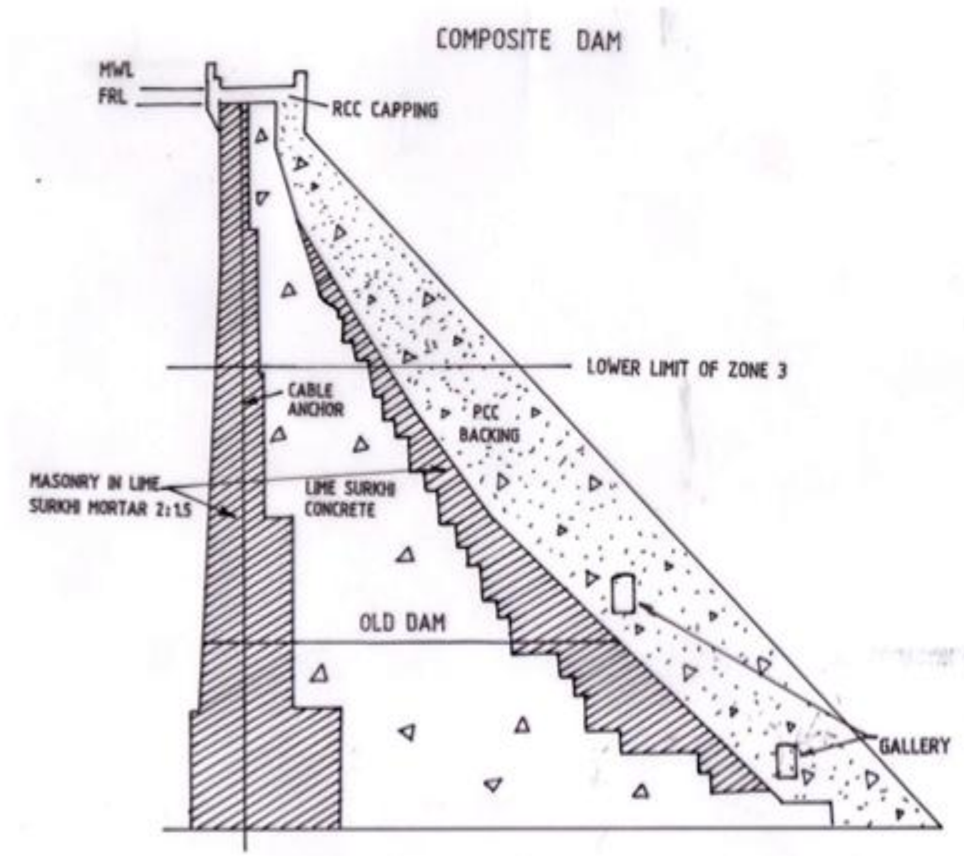

Fig 4.1 Cross Section of the Dam after Strengthening

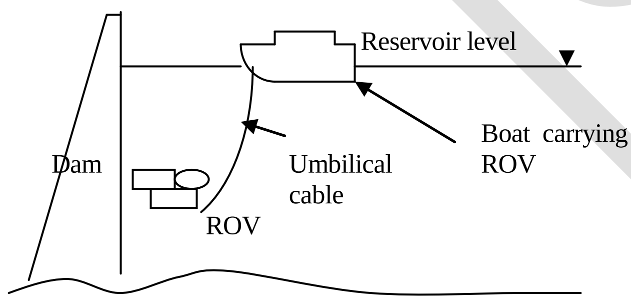

Fig. 5.1: A Typical Sketch Showing ROV Scanning upstream face of a Dam.

VI RESULTS AND DISCUSSIONS

The analysis of the images helped divide the upstream surface into six zones based on the relative scale of deterioration. (Fig. 5.2)[1] The first (FRL-32.3ft to FRL-42.1ft) second (FRL-42.1ft to FRL-21.7ft) and third (FRL-21.7ft to FRL-55.3ft) zone were classified as deteriorated plaster zone , severely deteriorated zone and deteriorated zone. The rest of the zones were termed as intact zone . The present FRL was MWL before strengthening and MWL is 3 feet more than FRL after strengthening.

Zone 1-It is seen from the plot of reservoir level data made available that the water level fluctuated in this zone (Fig.5.3) at least 80 times. With this data it was not possible to draw any conclusion whether alternate wetting and drying has had effect on plaster/surface treatment or not. Further no comment can be made on the alternate wetting and drying cycles on the rubble masonry behind. But this zone has been categorized as a deteriorated plaster zone observing the present status of the u/s face.

Zone 2-Since this zone 2 (Fig.5.4) has been categorized as 'severely deteriorated zone' as far as mortar in rubble masonry is concerned . An attempt was made to study the number of alternate wetting and drying cycles within this zone . From reservoir level data falling in zone 2 i.e starting from (FRL-42.1ft to FRL-21.7ft). The possible number of alternate wetting and drying cycles has been worked out in table 5.1. The table has been drawn based on pre 1981 and post 1981 basis. It is understood that strengthening measures were undertaken in 1981. The deterioration of the masonry taken place in Zone 2 is many times more than deterioration that may take place by weathering action. From these graphs we can see clearly the Zone 2 has not been subjected to enough wetting and drying for weathering action before 1981 (before adopting strengthening measures). The zone 2 was further divided into 7 zones(2.1 to 2.7) of approximate 1 ft width .After 1981 a maximum of 30 cycles to 13 cycles of wetting and drying action has taken place in Zone 2.1- Zone 2.3 which may also not be sufficient for weathering action. Between Zone 2.4 – Zone 2.7, from the reservoir level variation it was observed no weathering action has taken place. Keeping in view the actual observations already made about zone 2 in table 7.1 and the number of alternate wetting and drying cycles encountered it is possible to arrive at a conclusion that it may not have actually contributed to deterioration of mortar in rubble masonry.

Zone 3- Since the lowest reservoir level recorded in the history of the dam is in Zone 2, Zone 3 (Fig.5.5) has not experienced any weathering action at all. Here also the deterioration of masonry is not due to weathering. In view of the above it was concluded that alternate wetting and drying has not contributed to deterioration of mortar. The fact that deterioration of mortar is visible in zone 2 and zone 3 (to lesser extent) and not significantly elsewhere, calls for identifying factors which might have contributed to deterioration.

Zone 4,5 &6 -The Zone 4&5(Fig. 5.6 & 5.7) are generally intact rubble masonry from one end to other. And zone 6 was inaccessible to ROV due to debris.

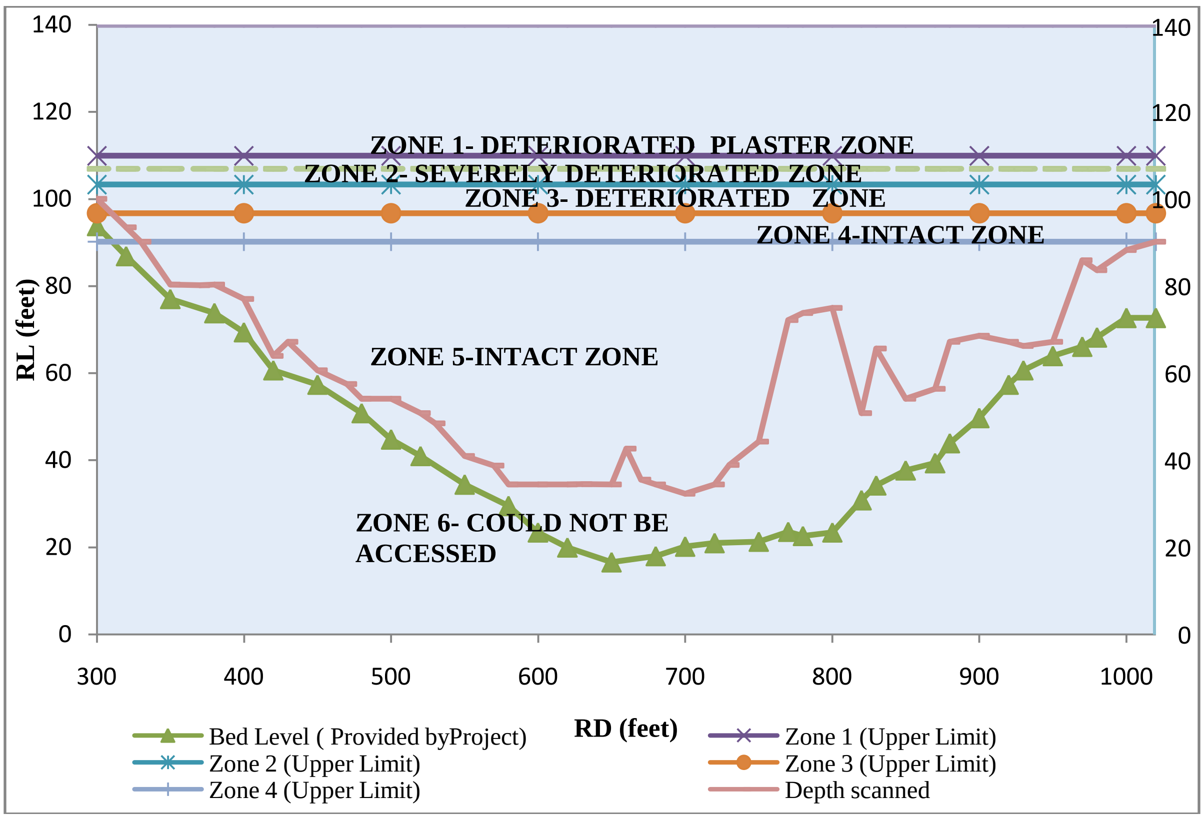

Fig 5.2 Summary of the Results (upstream face of the dam)

Table 5.1 Details of the wetting and drying cycles in Zone 2

Zone	Reservoir Level (feet)	No: of wetting and drying cycles (approximately)		
		Before 1981	After 1981	Total
2.1	FRL-43.0 to FRL-42.1	11	30	41
2.2	FRL-44.0 to FRL-43.0	9	27	36
2.3	FRL-45.0 to FRL-44.0	6	13	19
2.4	FRL-46.0 to FRL-45.0	0	8	8
2.5	FRL-47.0 to FRL-46.0	0	3	3
2.6	FRL-48.0 to FRL-47.0	0	2	2
2.7	FRL-48.7 to FRL-48.0	0	0	0

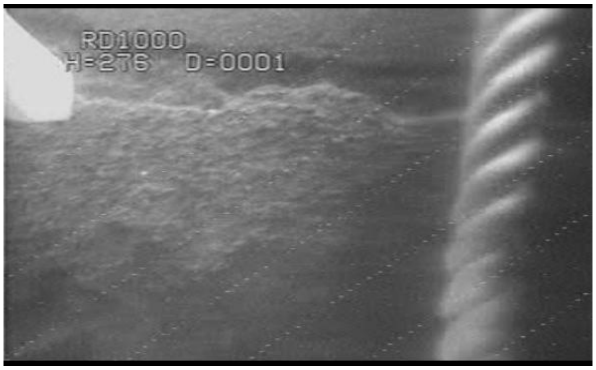

Fig 5.3 Zone 1

Fig 5.4 Zone 2

Fig 5.5 Zone 3

Fig 5.6 Zone 4

Fig 5.7 Zone 5

Analysis of Reservoir Level Data

The reservoir level data is not available for a period of 30 years out of total life of the dam till 2011. The variation of Reservoir Level during the period for 10ft below FRL is as given at table 2.

During the period of the available data it can be seen the water level has crossed FRL 746 times, FRL -2ft to - FRL -1.1ft 781 times and FRL -3ft to - FRL -2.1ft 598 times. And the water level has not gone below 104.20 ft in the history of the dam. The height of the dam has increased by three feet after strengthening, it clearly tells that the water was overflowing the dam during the period or was upto the brim and that too after 1955 the water level has not gone above and the maximum Reservoir Level reached one feet less than FRL in 1965.

Table2 Variation of Reservoir Level upto 10ft below FRL upto 2011

Variation of R.L (feet)	No of times (days)
Above FRL	746
FRL -1 to - FRL -0.1	781
FRL -2 to - FRL -1.1	598
FRL -3 to - FRL -2.1	505
FRL -4 to - FRL -3.1	517
FRL -5 to - FRL -4.1	440
FRL -6 to - FRL -5.1	434
FRL -7 to - FRL -6.1	541
FRL -8 to - FRL -7.1	458
FRL -9 to - FRL -8.1	464
FRL -10 to - FRL -9.1	504

Afterwards the maximum water level was coming down in the next years. As the deterioration of the mortar was seen in zone 2 and 3 and the same is not due to alternate wetting and drying it can be very well be concluded that tensile stresses has developed on upstream portions due to continuous bending of the dam as water level has crossed the FRL and also the dam has not been strengthened during the period. The base width of the dam at the lower limit of zone 3(Fig.4.1) was much less than the base width actually required at that location of the dam before strengthening. The possible reason for the deterioration of the mortar may be due to this bending. Deterioration of the mortar might have taken place above zone 2 also but it was not visible as those portion has subjected to pointing with cement mortar of 1:3 & plastering with cement mortar 1: 3-3/4" thick, was done whenever the old guniting had blistered. The work was done departmentally upto 1954-1965

VII CONCLUSION

Based on the relative scale of deterioration of upstream surface, it has been divided into 6 zones. The alternate wetting and drying cycles has not contributed towards the deterioration of mortar in the rubble masonry in Zone 2 & Zone 3. The possibility of missing mortar beyond the surface cannot be ruled out. The zones 2 &3 have been recommended for renovation.

The conclusions drawn above especially w.r.t zone 2 and zone 3 needs to be examined taking into consideration all other factors including Reservoir Level data. The findings may also be examined with the other proposed studies on the dam.

Under water monitoring of dams forms a vital part of dam safety appraisal. Scanning of the underwater structures of dam can be carried upto bed level, which is otherwise a very difficult task for the divers. Based on the video recording, the necessary and timely remedial action can be initiated. This can be used to scan the repaired portions of the dam to confirm the efficacy of the treatment [3].

Thus ROV was effectively used as a post construction instrumentation for an existing dam.

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