Instrumentation for Study of Distress in Powerhouse and Concrete Dam – A Case Study

Rajbal Singh*
S.K. Verma**
A.K. Dhawan**

**Tala Hydroelectric Project Authority*
Tsimalakha, Bhutan
Tel.: +975-5-272002; Fax: +975-5-272005

***Central Soil and Materials Research Station*
Olof Palme Marg, New Delhi-110016, India
Tel.: 011-6562114; Fax: 011-6853108
E-Mail: csmrs@hub.nic.in

ABSTRACT

The distressing in a concrete dam due to the alkali-aggregate reaction has become a common phenomenon at Rihand dam which was constructed forty years ago. The expansion of concrete due to the alkali-aggregate reaction is leading to cracking of concrete and consequently difficulty in operation of spillway gates, snapping of reinforcement bars of the concrete column, smooth running of turbine in the surface powerhouse at the down stream, etc. It becomes, therefore, very important to monitor the cracks in the dam and appurtenant structures. This paper deals with the case study of distress at Rihand Project and implementation of instrumentation programme to monitor the distress due to opening and closing of the joints/cracks. The cracks in the concrete and the existing construction joints in the dam body and the powerhouse are being monitored with the help of demac gauges/vernier gauges and 3-dimensional crack monitors for evaluating the remedial measures required in the dam and powerhouse of Rihand Dam Project in Uttar Pradesh, India.

Key Words: Instrumentation, Distress, Powerhouse, Dam, Crack Monitor.

1. INTRODUCTION

Rihand Dam is a concrete gravity dam of 934.45 m length and 91.96 m height. It taps river Rihand, which is a tributary of river Sone and the project is situated in District Sonebhadra of Uttar Pradesh (U.P.) State in India. For dam, the concrete was laid in lifts of 1.5 m, consisting of 3 layers of 0.5 m each. The dam comprises of 61 independent blocks of widths ranging from 12.8 m to

18.3m with ungrouted joints. Block numbers 28 to 33 constitute intake and Powerhouse, while the spillway is on blocks from 34 to 47 and the rest are non-overflow blocks. The powerhouse is located at the toe of the dam, and was commissioned in 1962 with 5 units of 50 MW each, with a provision for the sixth machine which was added in 1966 (total installed capacity of 300 MW). Several galleries have been provided in the body of the dam at various levels. Foundation gallery, which runs all along the length of the dam, is provided with drainage pipes openings, form drains and grout pipes. The view of the Rihand dam along with surface powerhouse is shown in Fig. 1.

Fig. 1 - Down stream view of Rihand dam along with surface powerhouse

A reinforced concrete structure connects the toe of the dam with the powerhouse and has the floors at the same levels as in the powerhouse. The transformers are placed on the top most floor of this framed structure. The load of the transformers is being transferred directly to the dam toe through separate columns. The penstock gallery is housed in this framed structure, which separates the powerhouse structure through a 25 mm thermocole filled joint.

The quantity of concrete used in the gravity dam and appurtenant works was of the order of 1.68 x 10^6 cubic meters; and the following details about the constituents of concrete need attention.

Cement: The cement used in the construction was Ordinary Portland Cement (O.P.C.), obtained from Churk Cement Works, U.P. generally conformed to the relevant specifications of the Bureau of Indian Standard (B.I.S.), at that point of time, with regard to strength, setting time, fineness, etc.

Sand: The sand used was a blend of crushed stone with natural sand having a fineness modulus of 2.3 to 2.9.

Coarse Aggregates: Coarse aggregates were obtained from Makra quarry, which consisted mostly of granite gneiss rock. The rock had good resistance to abrasion, and its compressive strength was in the range of 108 to 157 MPa.

Air Entraining Agent and Fly Ash: Indigenous air entraining agent developed at the Rihand Laboratory was used. Bokaro fly ash was used as a pozzolana to replace 5 percent by weight of cement in concrete.

Water: The mixing water was obtained from the river, which during dry season was quite clear and free from harmful impurities.

This paper deals with the case study of distress at Rihand concrete dam and surface power house and implementation of instrumentation programme to monitor the distress due to opening and closing of the joints/cracks. The cracks in the concrete and the construction joints are being monitored with the help of demec gauges/vernier gauges and 3-dimensional crack monitors for evaluating the remedial measures required in the dam and powerhouse of Rihand Dam Project in U.P.

2. FOUNDATION GEOLOGY

According to Geological Survey of India, the agency associated with the investigations of the dam site, the rocks at Rihand site are essentially granite, massive to thinly foliated granite gneiss and injection gneiss. Minor bands of phyllite, schist, amphibolites and quartzite are also present within the bedrock at the dam site. The dam is founded on gneissose granite, while the powerhouse is founded on injection gneiss with bands of dioritic rock, amphibolites and mica schist. The contact zones of the granite and injection gneiss are sheared at places. In addition to this shear zone, there are seven other prominent cross shear zones extending from the axis to the toe of the dam. Portions of amphibolites and mica schist in parts of powerhouse foundation are sheared and weathered. The weaker materials encountered in the foundation of the dam and powerhouse was treated.

3. THE DISTRESS

Cracks had been, in fact, noticed in different concrete structures, since the time when dam and powerhouse were commissioned in 1962. However, at that time, the cracking did not warrant any serious notice. Within a decade of commissioning of the project, the distress of the structure became alarming. Since 1972, generating units frequently tripped due to high spill current. The distress mentioned above became excessive, requiring immediate remedial actions for generating electricity. It was also observed that in some of the machines, that clearance between moving and stationary parts had gone beyond permissible limits.

The following distress in the dam and related structures are significant and indicate the scenario of general distress:

Distress in the Dam

- Excessive deformation and bulging of spillway piers.
- Difficulty in operation of crest and penstock gates due to shifting of guide rails.
- Cracks on the upstream face of the dam, intake structure and various galleries.

Distress in the Powerhouse

- Tilting of generating shaft.
- Snapping of reinforcement and deformation in penstock gallery frame columns.
- Tilting and deformation of draft tube structure.
- Difficulty in operation of overhead gantry crane and draft tube crane.

4. PERFORMANCE MONITORING

4.1 Initial Phase

The distress being minor during initial stages did not attract any special attention. However, the instruments that were installed at the time of construction of the dam and appurtenant works were there. These instruments included thermometers, strain meters, stress meters, joint meters, deflection meters and instruments for the measurement of uplift pressure. Deflection of the dam axis was being measured with the help of plumb bob with mirror-scale arrangement. However, all these instruments installed at the time of construction of the dam had become in operational by seventies. The observations, available for the initial period after construction, were analysed, and the data did not reveal any unusual trend indicating structural distress or instability.

4.2 Second Phase

Even during seventies, when it was no longer possible to run the hydroelectric project without attending to the wide ranging distress mentioned above, problem-specific response approach was adopted i.e. in the event of a problem in a particular operation, the measures necessary to make that functional were taken. The problem had become quite acute by now, and was brought to the notice of senior officers of Irrigation Department of U.P., who inspected the dam in 1973, and the remedial measures suggested by them were carried out by the field engineers.

This was the time when need was felt to conduct a detailed study of Rihand Hydroelectric Project; sub-groups on structural aspect and instrumentation were constituted in August 1984. The following studies were taken up in accordance with the recommendations of the Expert Committee:

- Study of expansion of cement concrete.
- Mathematical model studies of framed structure, hoists and penstock gallery.
- Geodetic survey of dam by Survey of India, Dehradun.
- Finite element analysis of the dam section by Central Water Commission, New Delhi.
- Geological studies of the dam by Geological Survey of India, Lucknow.
- Monitoring of dam and appurtenant works by Central Soil and Materials Research Station, New Delhi and Central Water and Power Research Station, Pune.

The most important finding of the above studies was expansion of concrete. Expansion of concrete is due to alkali-aggregate reaction. Various investigations including electron microscopy revealed that alkali aggregate reaction in concrete is the most probable cause of distress. There is definite gel formation around the concrete cores from the dam. The committee also concluded that expansion potential still existed.

During the first inspection of Rihand dam and powerhouse in 1985 by the monitoring sub-committee, the cracks were observed all over the body of the dam, its galleries and in the powerhouse. The distressed components of the structure included the powerhouse, intake gate hoist operating gallery, reinforced concrete framework between dam and powerhouse, penstock gallery, upstream face, generator supports walls, elevator shaft walls, bridge structure, tail race structure, roadway adjacent to downstream cantilever and spillway. Snapping of reinforcement bars of the concrete columns in penstock gallery was observed. Sudhindra and Sharma (1989) described some details of the distress.

Having identified the alkali-aggregate reaction as the root cause of the ills afflicting Rihand Dam Project, the following major remedial measures were suggested by Rihand Dam Experts Committee:

- Emergency passenger lift located in shaft of the block 34 at RL 830 ft should be closed by concrete and the cracks be grouted, which was done in 1985.
- To release any uplift pressure coming on the foundation rock, 4-inch diameter uplift pressure pipes provided in the foundation gallery was cleaned by compressor.
- The penstock gallery columns showing distress were rehabilitated by epoxy grouting and steel jacketing during 1985-87.

- The interaction of the dam and penstock gallery frame with the mass concrete of Powerhouse was done away with by making the expansion joint between the Penstock Gallery frame and powerhouse functional through the removal of thermocole.
- To minimize the ingress of water, the upstream face was treated by injecting epoxy resin and subsequently painting the upstream face.

4.3 Present Phase

The cracks and joint in the dam body and the powerhouse are shown in Figs. 5 to 7 along with the installed 3-dimensional crack monitors for measuring the movements in the cracks. The deterioration of the concrete is seen in Fig. 5.

The Expert Committee appreciated the crucial importance of instrumentation and a subgroup on structural aspect and instrumentation was constituted. The Central Soil and Materials Research Station (CSMRS), New Delhi played an active role in suggesting and providing in part the instrumentation required for the surveillance of the performance of the dam and appurtenant works.

4.4 Suggested Instrumentation Plan

Since alkali-aggregate reaction was identified as the root cause of distress at such a large scale, the experts of monitoring sub-committee suggested the following instrumentation plan:

Monitoring Distress in Dam and Spillway Structure

- The rate of opening of cracks and other movements were proposed to be monitored in Intake Gate Hoist Operating Gallery and Foundation Gallery.
- To measure absolute and relative deformation of dam as a whole, it was suggested that a new plumb line with a proper travelling microscope, with an accuracy of ±0.05 mm be arranged. Also suggestion was that permanently fixed targets be installed on the downstream face of the dam and on top of the powerhouse.
- Evaluation of deformation modulus of rock and concrete and determination of In-situ stress were suggested.
- The total quantity of seepage water being collected in the sump was suggested to be monitored.
- Mechanical joint meters, with 3 sets of pins in orthogonal directions were proposed to determined the three directional movements of the parapet on top of the spillway block No. 35 which was dislocated with respect to the adjoining mass concrete of block No. 34. Monitoring of movement across each bay of spillway was also recommended.

Measurements in Powerhouse Structure

- It was suggested to measure deformations in two directions at three levels in each of the column of the powerhouse.

- Convergence measurements were also suggested to supplement deformation data.
- Installation of the permanent target for geodetic measurement on the column over the powerhouse roof was suggested to link the plane geodetic network.
- Tilt meters were proposed to determine the tilt of the powerhouse. Monitoring of movement of cracks, as in case of dam, was also suggested.

Sharma et al. (1991) described details of instrumentation plan and monitoring at Rihand dam up to that period. The Results of the above studies are discussed in the following paragraphs:

Discharge in Foundation Gallery: The discharge in the foundation gallery was reduced greatly-almost to fifty percent as a result of treatment. The maximum water level of around 880 ft (293.33 m), the discharge of around 2200 Gallons per minute (GPM) in 1987-88 came down to around 1200 GPM in 1991-92 and 1997-98.

Tilt of the Dam: The reduction in seepage water, however, had no effect on the tilting of the centerline of the dam, where maximum tilt continued to increase, albeit marginally. Also, the minimum deflection shows an increasing trend and in conjunction with the variation of water level with time.

Geodetic Survey of Dam: The Survey of India’s observations regarding horizontal and vertical control indicate that bottom position of Rihand dam was stable, but the middle and top points indicate appreciable movement. Further geodetic survey is very essential for the safety of the dam.

Movement Across Cracks: In all, monitoring of around 70 cracks spread all over dam body and powerhouse was done, and the details are available in the report of CSMRS (1991). Monitoring of cracks has revealed that both, horizontal and vertical cracks are active. The general behavior of cracks is of two types. At some locations, the cracks are steadily widening with time. The other type of behavior is cyclic in nature, which suggests its linkage with the variation in water level of the reservoir. However, a time lag of about four months is observed between the movement of crack and water level of the reservoir as shown in Fig. 2 (Sharma et al., 1991 and Abdullah et al., 1998).

5. INSTRUMENTATION BY CSMRS

5.1 Three-Dimensional Crack Monitor

The 3-D crack monitor developed by CSMRS New Delhi is shown in Fig. 3. The crack monitor is capable of measuring crack deformations in three mutually perpendicular directions as shown in Fig. 4. X-axis measures the deformation along the crack i.e. the shear movement of the crack. Y-axis measures the deformation across the crack or perpendicular to the crack. The opening and closing of the crack/joint can be measured by Y-axis accurately. Z-axis measures the relative deformation of the two walls of the crack/joint perpendicular to X and Y-axes. Thus, the deformations in all the three directions can be measured with the help of the 3-D crack monitor. The crack monitor can also be placed/fixed in any direction of the crack and the deformations can be measured accordingly. The crack monitor is lightweight, portable, compact and is very easy to install. The dimensions of the instrument for measuring the deformation can be changed suiting to the requirements at particular site.

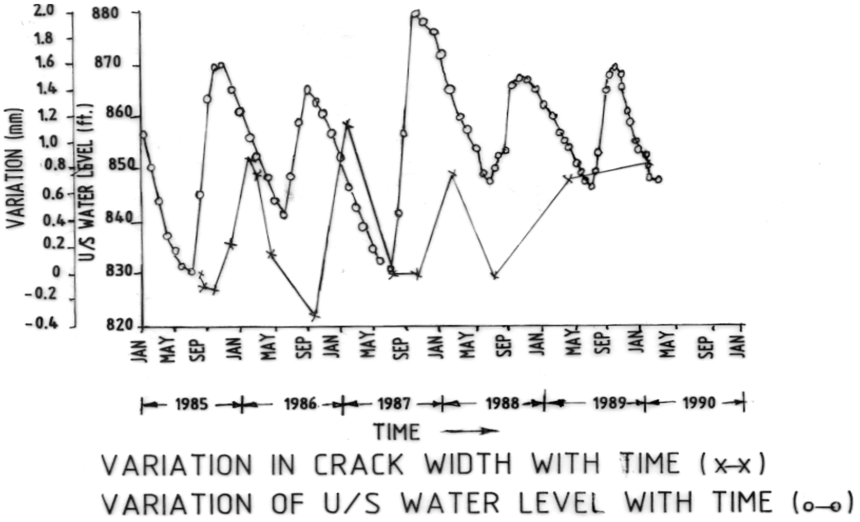

Fig. 2 -Variations in crack width and up stream reservoir water level with time (Sharma et al., 1991)

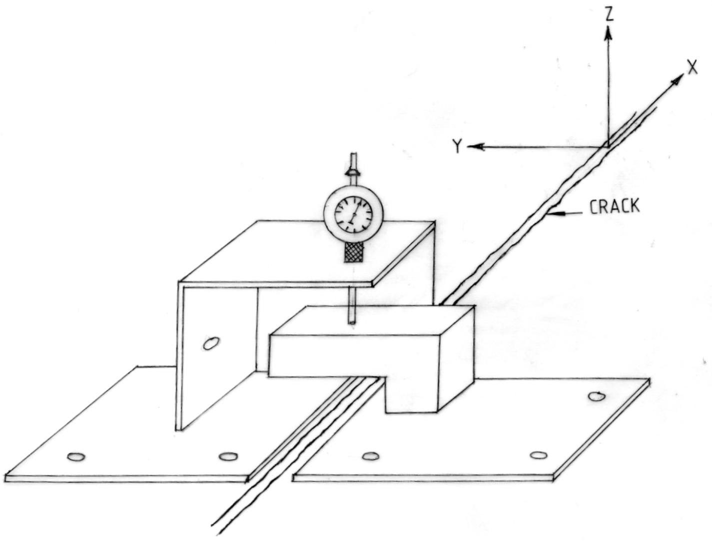

Fig. 3 - Layout presentation of 3-Dimentional crack monitor on the crack/joint

5.2 Monitoring of Cracks

The cracks at many locations in the dam body and the powerhouse complex are being monitored with the help of demec gages/ vernier gauges and 3D Crack Monitor. Three-dimensional monitoring of the cracks at 10 locations is discussed in detail in this paper. The 3D crack monitor is shown in Fig. 3. The 3D crack monitors installed at one location is shown in Fig. 4 on cracks and existing joints. The dates of installation, location of the crack monitors etc. are shown in Table 1.

Table 1 - Locations of 3D Crack Monitors at Rihand Dam

Location	Date of Installation	Location Reference Point	Elevation m (Feet)
3D/1	24-05-1998	Near Turbine Intake-1 of Powerhouse (PH)	207.33 (622)
3D/2	24-05-1998	Near Lift (PH)	216.67 (650)
3D/3	24-05-1998	Erection Bay Turbine Unit No. 1 (PH)	227.67 (683)
3D/4	24-05-1998	Spillway Joint Between Block 35 and 36 (D/S of Dam Top)	298.33 (895)
3D/5	24-05-1998	Spillway Joint Between Block 39 and 40 (U/S of Dam Top)	298.33 (895)
3D/6	10-10-1998	Column No. 6 (D/S Wall of PH)	207.33 (622)
3D/7	10-10-1998	Opposite to Column No. 8 and 9 (U/S Wall of PH)	207.33 (622)
3D/8	10-10-1998	Column No. 22 (D/S Wall of PH)	207.33 (622)
3D/9	27-03-1999	Joint of Turbine Unit No. 1 and Erection Bay (PH)	227.67 (683)
3D/10	27-03-1999	Block No. 34 of Dam Top (D/S of Dam Top)	298.33 (895)

Fig. 4: Crack and Crack Monitor Near Lift of Powerhouse

5.3 Results of Crack Monitoring

The minimum and maximum deformations recorded with the help of the 3D crack monitor during the complete period of monitoring are shown in Table 2. The variations of deformations with time based on the consecutive readings of the crack monitoring for all the 10 locations have been shown in Figs. 5 to 7 in the X, Y and Z directions, respectively.

There have been significant movement across the cracks/joints i.e. opening and closing of the cracks have taken place during the recording period. There have been some shear and relative movements between both the walls of the cracks. The maximum shear movement in x-direction (Fig. 5) has been 1.00 mm in about 3 years time, which is not very significant. The maximum relative movement between both the walls of the cracks in z-direction (Fig. 7) has been 1.45 mm in about 3 years time, which is also not very significant

There have been significant movements at some locations across the crack in Y-axis as shown in Fig 6. The maximum movements in Y direction have been noticed as 4.56 mm at 3D/3 location, 3.69 mm at 3D/6 location and 4.78 mm at 3D/8 location (Table 2). In most of the cases the cracks have been opened up with time. The opening and closing of the cracks are also taking place at some locations as shown in Fig. 6.

Table 2 - Deformations at Different Locations from 3D Crack Monitors

Loc-ation	Ele-vation (m)	Minimum and Maximum Deformations Between April 1998 and March 2001 (mm)					
		X-Axis		Y-Axis		Z-Axis	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
3D/1	207.33	0.22	0.83	0.09	1.09	0.40	0.95
3D/2	216.67	0.13	0.53	0.29	0.67	-0.55	0.24
3D/3	227.67	-0.20	0.45	0.85	4.56	-2.67	0.78
3D/4	298.33	0.15	0.50	0.08	1.00	-0.32	0.08
3D/5	298.33	0.26	1.00	-0.16	0.31	-0.44	0.14
3D/6	207.33	-0.63	-0.04	0.91	3.69	-0.12	0.07
3D/7	207.33	0.02	0.10	-0.19	0.05	-0.10	0.02
3D/8	207.33	-1.63	-0.55	1.11	4.78	-1.58	-0.33
3D/9	227.67	-0.63	0.10	-0.91	0.71	-0.65	1.45
3D/1	298.33	-0.45	-0.03	-0.06	0.05	-0.31	-0.06

Note: Plus deformation means opening of crack and minus deformation means closing of crack

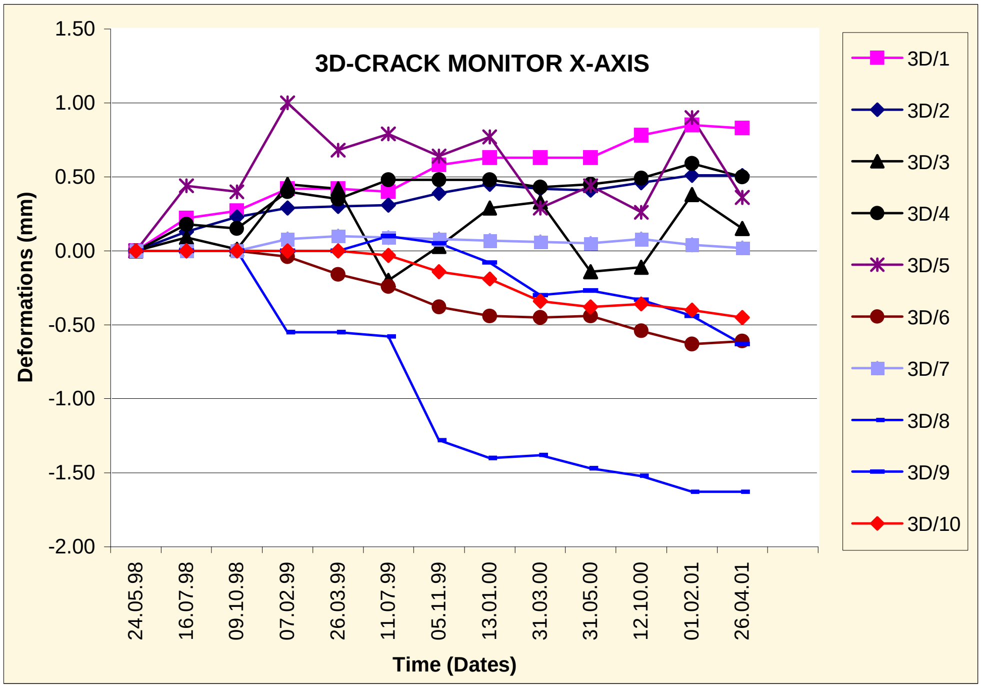

Fig. 5 - Variations of deformations with time at X-axis of the crack/joint

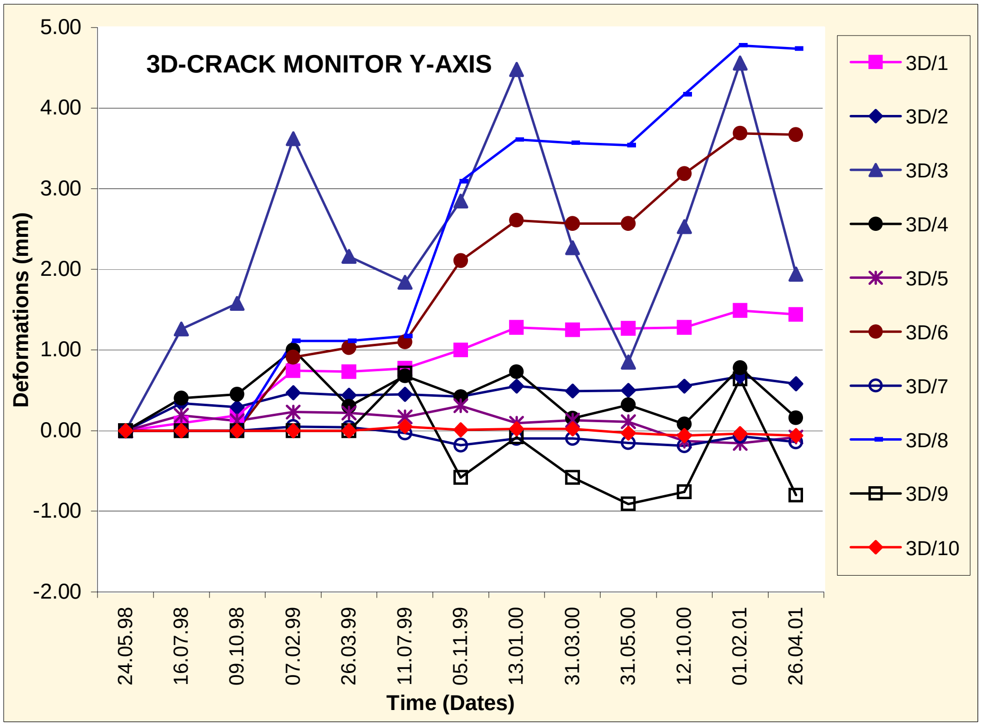

Fig. 6 - Variations of deformations with time at Y-axis of the crack/joint

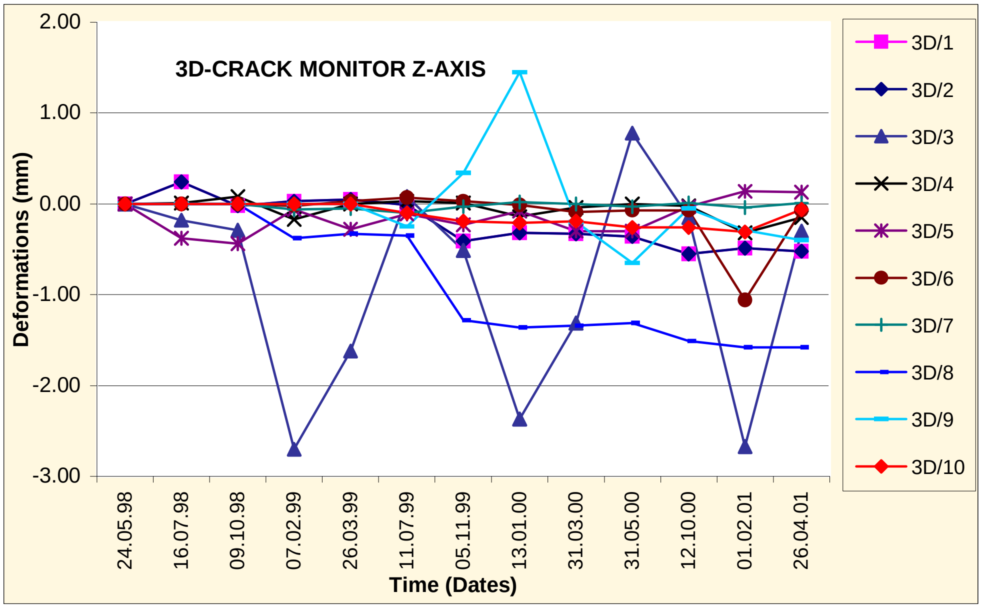

Fig. 7 - Variations of deformations with time at Z-axis of the crack/joint

The movement across the crack have further been analysed as shown in Figs. 8 and 9 at elevations equal and below 216.67 m and at elevations equal and above 227.67 m, respectively.

The crack monitor, 3D/10 (Fig. 9) installed at an elevation of 298.33 m is dummy (not installed on any crack or joint but installed on surface of the concrete at top of the dam) and it shows insignificant deformation variations of -0.06 mm to 0.05 mm (Table 2).

The deformations at elevation 207.33 m as shown in Fig. 8 are significant and are in increasing order with time. The maximum movements in Y direction have been noticed as 4.78 mm at 3D/8 location i.e. at an elevation of 207.22 m as also shown in Table 2. Crack monitors at locations 3D/1, 3D/2, 3D/6 and 3D/7 also showed similar behavior. All the crack monitors (as shown in Fig. 8) are installed at elevations 207.33 m except 3D/2 at an elevation of 216.67 m. It shows the effect of continued distress in the dam body as well as in the powerhouse.

The deformations at elevations equal and above 227.67 m as shown in Fig. 9 are very significant and are increasing and decreasing with time i.e. opening and closing of the joint/cracks are taking place. This variation at higher elevation can also be related with reservoir water level as also shown in Fig. 2 by Sharma et al. (1991).

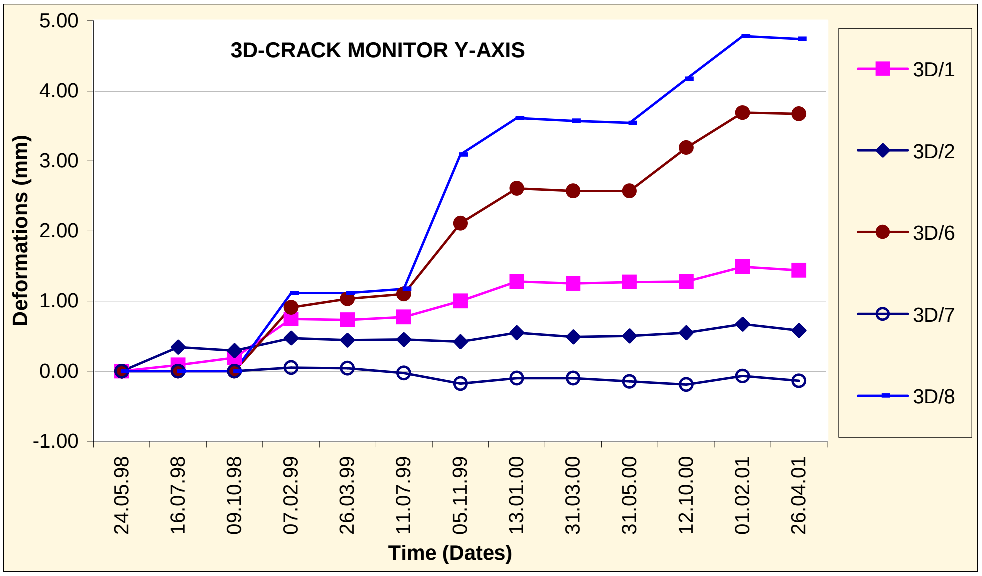

Fig. 8 - Variations of deformations with time at Y-axis of the crack/joint at Elevations below 216.67 m

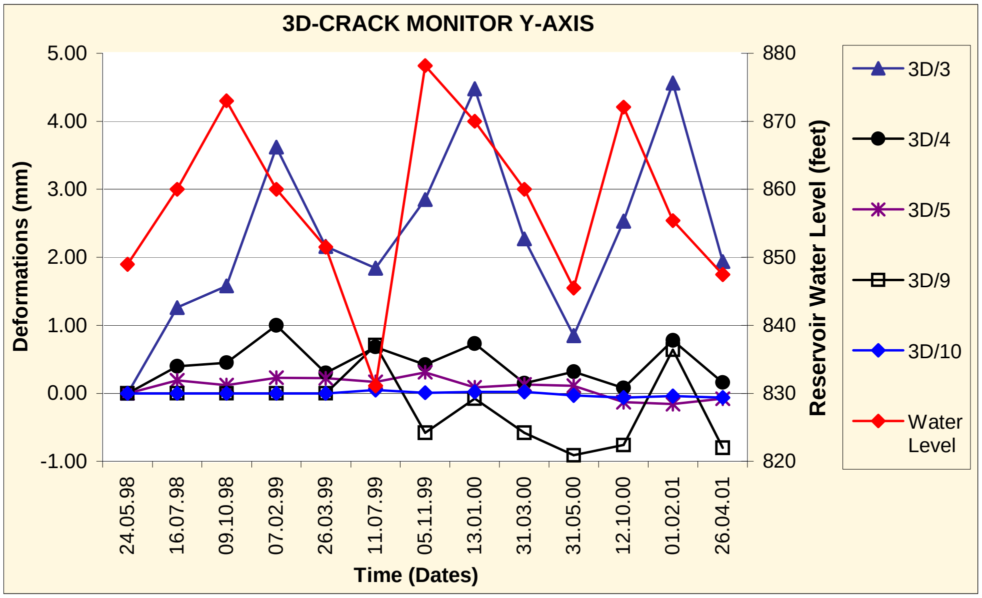

Fig. 9 - Variations of deformations with time at Y-axis of the crack/joint at Elevations above 227.67 m

It is evident from Figs. 8 and 9 that the deformations at lower level are increasing with time due to the distress in the dam and powerhouse and the cracks and joints are closing and opening at higher elevation due to distress and water level in the reservoir. The crack monitors installed at locations 3D/3, 3D/6 and 3D/8 must be monitored carefully due to significant variations in the deformations with time in all the three directions.

6. CONCLUSIONS

On the basis of this case study and instrumentation programme of monitoring of cracks/joint by using 3-D crack monitor at Rihand dam, the following conclusions may be drawn:

- The dam and the powerhouse are under distress as confirmed by the deformations in the cracks/joints.
- There have been some significant movements, which calls for remedial measures to keep the powerhouse in running condition.
- The deformations at lower elevations are observed as increasing with time due to the distress in the dam and the powerhouse. However, cracks/joints at higher elevations are observed to be closing and opening due to distress in the dam and also due to water level fluctuations in the reservoir.
- There is a definite need for continued monitoring for ensuring safety and enhancing confidence in the structure. The importance and advantages of monitoring clearly shows the continuance of the present instrumentation programme. Indigenously developed 3-dimensional crack monitors must be monitored regularly to ascertain the 3-dimensional movements of the cracks developed due to distress and movements in the construction joints.

References

Abdullah, Hasan, Verma S.K. and Dhawan A.K. (1998). Rihand H.E. Project – A Case Study, National Seminar: Geotechnical Problems – Case Studies, IGS Indore Chapter, 10th October, Indore.

CSMRS (1991), Sixth Interim Report of Instrumentation work at Rihand Dam Project, Central Soil and Materials Research Station, Olof Palme Marg, New Delhi, India.

CSMRS (2001), Interim Report On the Instrumentation for Crack Deformations in Rihand Dam (UP) – Structural Behaviour Monitoring, Central Soil and Materials Research Station, Olof Palme Marg, New Delhi, July 2001, India.

Sharma, V.M., Singh, R.B., and Abdullah, Hasan (1991). Instrumentation for Detection of Ageing at Rihand Dam in India, 17th International Congress on Large Dams, Vienna, Q 65, R 45, pp 825-833.

Sudhindra, C. and Sharma, V.M. (1989). Instrumentation- A Potential Tool for Performance Surveillance of Rihand Dam, International Workshop on Research Needs in Dam Safety, New Delhi, pp 255-259.