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Concrete Structure Crack Measuring Devices - A Case Study of Concrete Dam

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ABSTRACT - Cracking is a common phenomenon observed in many concrete structures. The cracks can develop due to consequence of plastic shrinkage or constructional movements, overloading concrete elements, creep, chemical reactions inclusive of alkali-aggregate reactions and corrosion etc. Crack width and depth are two important parameters used to determine the extent and severity of existing cracks. Crack monitoring and control procedures are essential to assess stability of the structure and quantify the development of the damage. This paper discusses different instruments/ methods available for evaluation of crack along with a case study of crack monitoring of 92 m high concrete gravity dam.

Index Terms: - Crack, Physical, Chemical, Alkali Aggregate Reaction, Plastic, Groutable, Triaxial etc.

1. INTRODUCTION

A crack is a linear fracture in concrete element which extends partly or completely through it. In a concrete element, tensile stresses are initially carried by the concrete and reinforcement. When the tensile stresses in the element exceeds the strength of concrete, the concrete cracks and tensile force is transferred entirely to reinforcement. Figure 1 shows a typical diagram of crack in concrete element.

In concrete dams, cracks are formed mainly due to shrinkage of concrete due to temperature variations. These cracks may develop internally in the body of the dam or externally on the surface of the dam. Surface cracks are more dangerous than interior cracks.

Figure 1: *Crack in Concrete Element*

2. CAUSES FOR CONCRETE CRACKS

Cracks can occur during the concrete construction, placement and curing and during the service life of the structure. Cracks can be sign of structural problems, or a result of concrete deterioration. Several issues can result in cracks in concrete, including excessive external loads, external restraint forces, internal restraint forces, differential movements and settlement etc. In a concrete element, the crack (shrinkage, thermal, and service loads) width and distribution is mainly controlled by steel reinforcement. In fiber-reinforced concrete, fibers help control cracking. Cracks that are also caused by internal or external chemical reactions, or a result of accidental loads i.e. blast, or impact load from accidents. These cracks are different in their nature and require further investigation to assess their impact on structural integrity and durability performance of the element.

2.1 CRACKING IN CONCRETE DAM

In concrete dams, cracks are formed mainly due to shrinkage of concrete due to temperature variations. These cracks may develop internally in the body of the dam or externally on the surface of the dam. Surface cracks are more dangerous than interior cracks. Figure 2 presents a typical example of crack in concrete dam.

Figure 2: *Crack in concrete dam*

3. EVALUATION OF CRACK

Visual inspection and monitoring is the first step towards understanding the nature of existing cracks, and the underlying causes. For example, inclined cracks over concrete beams near the supports can be a sign of shear stress, or cracks with a sign of rust can be a result of steel corrosion. Usually, crack widths are used to assess the severity of concrete cracks, whereas crack depth is used to evaluate overall structural integrity of the element.

3.1 CRACK WIDTH

Crack severity on the surface of concrete is normally measured using a crack width ruler. Depending on the opening of the cracks on the surface, cracks can be described (as tiny as hairline, or severe (few millimeters opening). Different methods to monitor crack width changes will be discussed further.

3.2 CRACK DEPTH

Evaluation of Crack depth measurement is important to make sure if surface cracking is well propagated into concrete or not. The depth of cracks in concrete can be measured by using Impact Echo method or Ultrasonic Pulse Velocity method. Crack depth is used to evaluate structural integrity, and verify durability performance. UPV utilizes ultrasonic wave propagation to measure the depth of cracks in concrete. UPV measures the transit time of the ultrasonic waves distance on concrete and be analyze as the speed of the wave. The effectiveness of repair methods such as epoxy injection relies on accurate prediction of crack depth.

4. DIFFERENT CRACK MEASURING DEVICES FOR MONITORING CRACK WIDTH CHANGES

There are varieties of crack measuring device available, which are used to measure crack width and change in crack width. Crack width can be measured through visual inspection within the specified range of the tool, while change in crack width can be monitored using a fixed gauge sensor to measure movement across surface cracks.

Some of the instruments used to monitor crack width variations are as follows:

- Crack Width Steel ruler
- Plastic tell-tale
- Glass tell tale
- Displacement transducer Crack Monitor
- Crack Width Microscope
- 2-D pins and caliper
- Vibrating Wire Crack Meter (Uniaxial)
- 3-D Crack Meter (Mechanical Type)
- Vibrating Wire Triaxial Crack Meter

4.1 CRACK WIDTH STEEL RULER

Steel ruler is simple instrument used to monitor crack width variation. The width of the crack can be measured to the nearest 0.5 mm provided that great care is practiced. Steel rule measurements are subjective because it is not possible to measure crack width from the same point each time the measurement is taken. Steel ruler measurements are used for assessing state of damage at the beginning of investigation. Figure 3 describes measurement of the crack through a steel ruler.

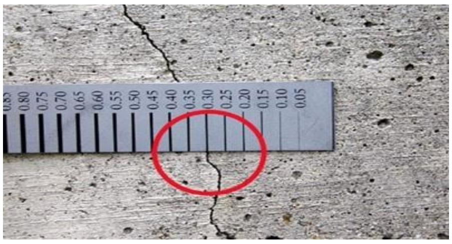

Fig.3: *Crack Width Steel Ruler*

4.2 PLASTIC TELL-TALE

It is the most famous system used to monitor crack width variation. Plastic tell-tale consist of two plates which overlap for part of their length. One plate is calibrated in millimeters and the overlapping plate is transparent and marked with a hairline cursor. The plate with scales marked in millimeter units of measurement is fixed on one side of the crack and the other plate marked with cursor is fixed on opposite side of the crack as it is shown in Figure 4. The instrument is screwed on the wall in such a way that the cursor of one plate and the middle of the scale of opposite plate will be aligned. So, as the crack experiences movement (including shear or normal movement), one plate moves relative to other and the variation can be measured to the closet of millimeters by recording the position of the cursor with respect to the scale (Range ±20 mm – Resolution 1 mm).

Figure 4*: Details and Installation of Plastic Tell-Tale*

4.3 GLASS TELL TALE

This technique used to measure crack width variation in the past, but it is not popular any more. It basically consists of strip of glass cemented on to the cracked structural element as shown in Figure 5. As it may be observed from the figure, glass tell-tale neither shows the direction of the movement nor the magnitude of the movement. That is why it is not used any longer.

Figure 5: *Glass Tell Tale*

4.4 DISPLACEMENT TRANSDUCER CRACK MONITOR

This instrument is used to continuously monitor the movement of cracks so as to provide warnings when abrupt movement or in the case where the location of the crack is not accessible like railway tunnel. Linear variable displacement transformer (LVDTs) and potentiometric displacement transducer are the two commonly devices used to continuously monitor crack width variations. Both instruments can be read either manually using hand held unit or automatically employing data logger. This method of monitoring crack width variation is expensive but the requirement for such monitoring would justify the utilization of these devices. Figure 6 shows a typical example of installation of LVDT crack monitor.

Figure 6: *Installation of Linear variable displacement transformer instrument*

4.5 CRACK WIDTH MICROSCOPE

The Crack Width Microscope is a small sized lightweight and conveniently portable microscope to precisely measure cracks in concrete and masonry construction materials. The objective lens is positioned on the surface over the crack and the knurled knob on the side is used to sharpen the focus. The battery-powered lamp adjusts to provide just the right amount of illumination, and the eyepiece rotates 360° to align the optical measuring grid with the crack. Figure 7 shows a typical crack width microscope.

With a magnification of 40 times this microscope can be used to accurately measure the width of cracks and also combines a calibrated focusing ring allow the depth of cracks to also be accurately measured. 40 times image magnification and measuring range of 1.6mm x 0.05 mm ensure highly accurate measurements for a wide variety of crack widths. The dual optical scale features coarse divisions of 0.2 mm with fine graduations of 0.02 mm.

Figure 7. *Crack Width Microscope*

4.6 2-D CRACK MONITOR

In this technique of monitoring crack width variation six hexagonal stainless steel pins are fixed three on each side of the crack as shown in Figure 8. Pin A and D are fixed across the crack line and rests of pins are fixed both side of pin A and D at 60◦ angle. The nomenclatures of pins are clockwise from pin A. After that, a Vernier caliper is used to measure the width of the crack as illustrated in Figure 9. This crack monitor is used for monitoring of crack movement in 2 directions viz. along the crack (X-axis) i.e. the shear movement of the crack and across the crack (Y-axis) i.e. the opening and closing of the crack/joint.

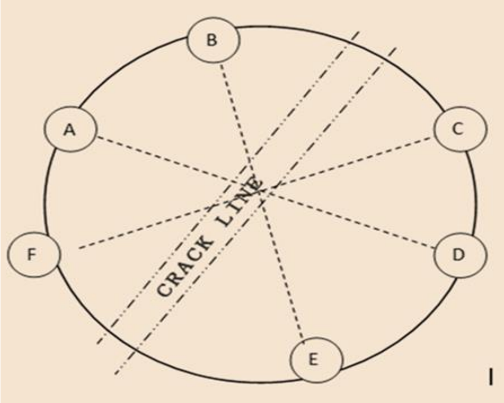

Figure 8: *Fixing pins on each side of the crack*

Figure 9: *Measuring crack width using caliper*

4.7 VIBRATING WIRE CRACK METER (UNIAXIAL)

The Vibrating Wire Crack Meter are used to measure movement in structures along surface cracks or construction joints. They consist of a sensor outer body tube and an inner free sliding rod which is connected at the internal end to a vibrating wire sensor by a spring as shown in figure 10.

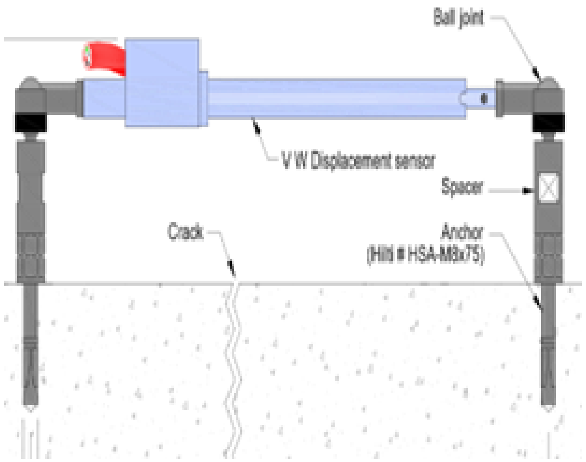

Figure 10: *Vibrating Wire Type Crack Meter (Uniaxial)*

If movement occurs within the structure causing the distance between the anchors on either side of the joint or crack to change, this change of distance will accurately be measured by the vibrating wire transducer. Joint Meters/Crack Meters can also be used to trigger an alarm if structural movement exceeds a pre-set maximum displacement.

4.8 3-D CRACK METER (MECHANICAL TYPE)

The 3-D crack monitor is capable of measuring crack deformations in three mutually perpendicular directions as shown in Fig. 11. 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.

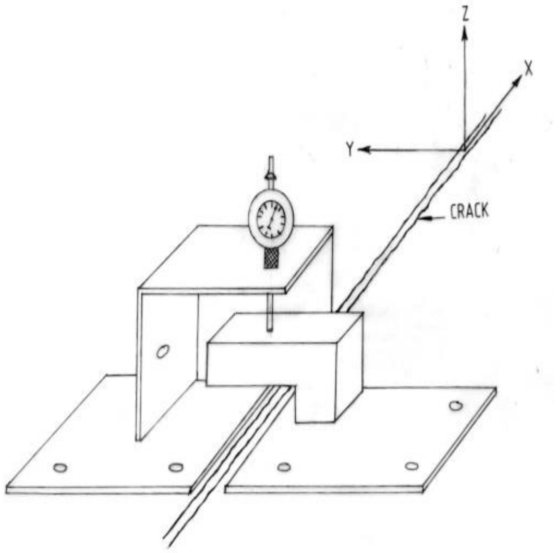

Figure 11: *3-D Crack Monitor*

4.9: VIBRATING WIRE TRIAXIAL CRACK METER

This is designed to monitor three way displacement at joints and cracks. The design allows the Vibrating Wire transducers to show independent movement in all directions, irrespective of each other. The crack meter comprises a 3D mounting system which consists of two arms and two groutable anchors. Three vibrating wire displacement transducers, which also monitor temperature, are installed within the mounting system and positioned for monitoring. Figure 12 shows diagram of a typical Vibrating Wire Triaxial Crack Meter.

Figure 12: *VW Triaxial Crack Meter*

5. CASE STUDY: RIHAND DAM PROJECT, U.P.

Rihand Dam is a 92 m high, 934 m long concrete gravity Dam was constructed during 1954-62 in the district Mirzapur (now Sonebhadra) of Uttar Pradesh. A powerhouse is located at the toe of the dam with an installed capacity of 300 MW. The dam consists of 61 blocks of width ranging from 12.80 to 18.3 m with un-grouted joints. Block 1 to 27 and block 47 to 60 constitutes to non-over flow portion. Block No. 28 to 33 constitutes intake and powerhouse, while the spillway is on blocks 34 to 46. The typical photograph of the dam is shown in Figure 13.

A reinforced concrete structure connects the toe of the dam with the Powerhouse, and has the floors at the same levels as in 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 columns. The penstock gallery is housed in this framed structure, which separates the powerhouse structure through a 25 mm joint.

Within a few years of commissioning of project in 1962, cracks began to appear in the various portions of the Dam and Appurtenant works. 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 downstream, etc. It becomes, therefore, very important to monitor the cracks in the dam and appurtenant structures.

Figure 13: *Rihand Dam*

The case study deals with 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 2-dimensionally with 2-D crack monitor and 3-dimensionally with 3-D crack monitor for evaluating the remedial measures required in the dam and powerhouse of Rihand Dam Project in Uttar Pradesh, India.

6.0 CRACK MOVEMENT MONITORING BY USE OF 2 D & 3D CRACK MONITORS

CSMRS, New Delhi took up instrumentation work for crack movement monitoring in 1986. Long term monitoring of crack movement is being done using through 2D crack movement monitoring at 27 locations and using 3D crack monitors at 12 locations.

6.1 2-D CRACK MOVEMENT MONITORING & DATA ANALYSIS

2D pins were installed at 27 locations and regular monitoring was done. Figure 14 show time dependent data analysis of crack movement monitoring by instrument (2D/10) installed between pillars no 5 and 6 in powerhouse in October 1998. Data indicates that significant gradual movement in both directions. Since its installation, there is gradual widening of crack and total gradual movement of 4.93 mm (across the crack) and 3.24 mm (along the crack) has been observed till March 2020. Over all monitoring data indicate cautious approach needs to be exercised during dam monitoring and maintenance services.

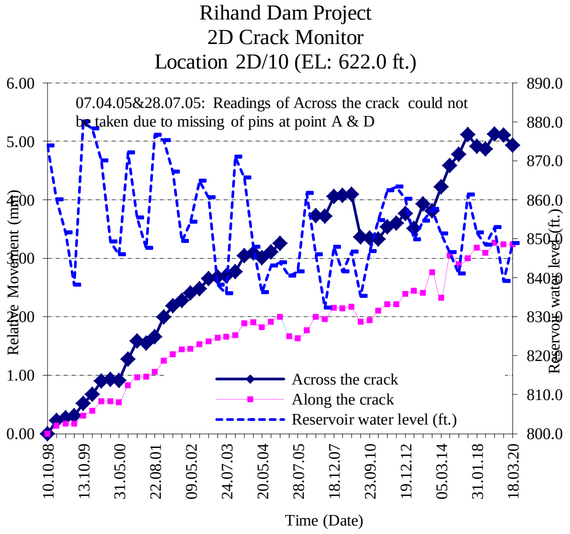

Figure 14[1]: *Plot of Relative Movement vs Time (Location 2D/10) i.e. 2-D Crack Movement Monitoring*

(Source: CSMRS (2020): Report on the Instrumentation Work for the Structural Behaviour Monitoring of Rihand Dam Project)

6.2: 3-D CRACK MOVEMENT MONITORING BY 3-D CRACK MONITOR & DATA ANALYSIS

Figure 15 shows data analysis of crack monitoring by instrument (3D/6) installed on column no 6 (D/S wall) in power house in October 1998. Significant gradual widening of crack in Y direction since its installation with total movement of 16.50 mm till March, 2020. However gradual widening of crack in X and Z directions since its installation with total movement of -3.53 mm and -2.93 mm till March, 2020. Over all monitoring data indicate cautious approach needs to be exercised during dam monitoring and maintenance services.

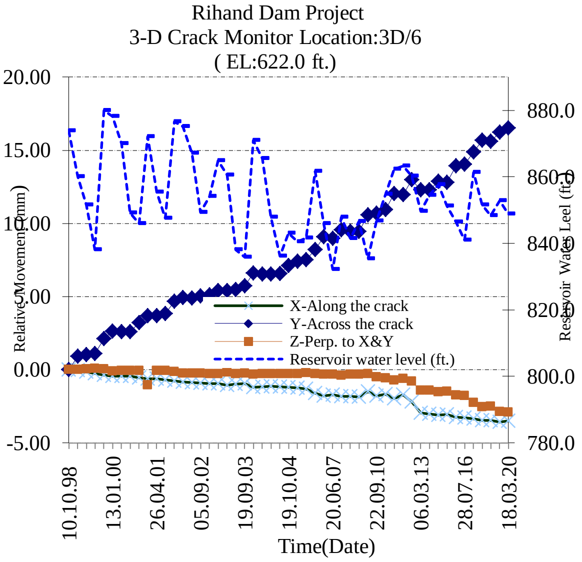

***Figure 15[1]:** Plot of Relative Movement vs Time (Location 3D/6) i.e.3-D Crack Movement Monitoring*

(Source: CSMRS (2020): Report on the Instrumentation Work for the Structural Behaviour Monitoring of Rihand Dam Project)

8. CONCLUSION

Cracks may appear in civil engineering structures, such as buildings, the body of a dam, its galleries, adjoining tunnels, and power plants during or after construction. Swelling or poor soils in the foundations, redistribution of stresses in the tunnels, creep of the materials, earthquakes or other vibrations are just a few reasons for cracks. The relative movements of the walls along and across the crack, and perpendicular to the plane of cracking surface or wall, beyond certain limits, may prove to be damaging. For considerations of safety and maintenance, the measurement of the magnitude and time rate of deformation of the cracks is essential. Instrumentation for deformation monitoring is of vital importance, especially in underground excavations in complex geological formations.

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