DIAGNOSTIC ANALYSIS OF DISTRESSED HYDRAULIC STRUCTURES: CASE STUDIES OF GUJARAT, INDIA

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ABSTRACT

Dams and canals are complex structures which sometimes do not timely manifest the sign of distress and hence the damage to them becomes irreparable or very difficult to repair. Many times that the diagnosis of the fault becomes an issue as the symptoms are strange and hence the repairs can not be done timely. Sometime some aspects which required attention at the time of construction are ignored and therefore they do not perform as per expectations or suddenly manifest signs of distress. Repairs of every dam or canal become a unique case study because of the said reasons. The paper discusses two complex case studies - one of canal and one of dam that exhibited some strange signs which were properly understood and the restoration was done.

Keywords: *canals, dams, distress, diagnosis, repairs*

CASE STUDY – 1 NARMADA MAIN CANAL

Historical Background

Sardar Sarovar Project consists of a dam and reservoir on the Narmada River having its command area of 1.8 million hectare. Its canal network is 76000 Kilometer long. The command area is shown in Figure 1. The main canal of the Sardar Sarovar Project is 458 Kilometer long in the Gujarat reach only. Because of huge length, the design of the embankment has been made as per height of embankment, available soil for the construction and discharge.

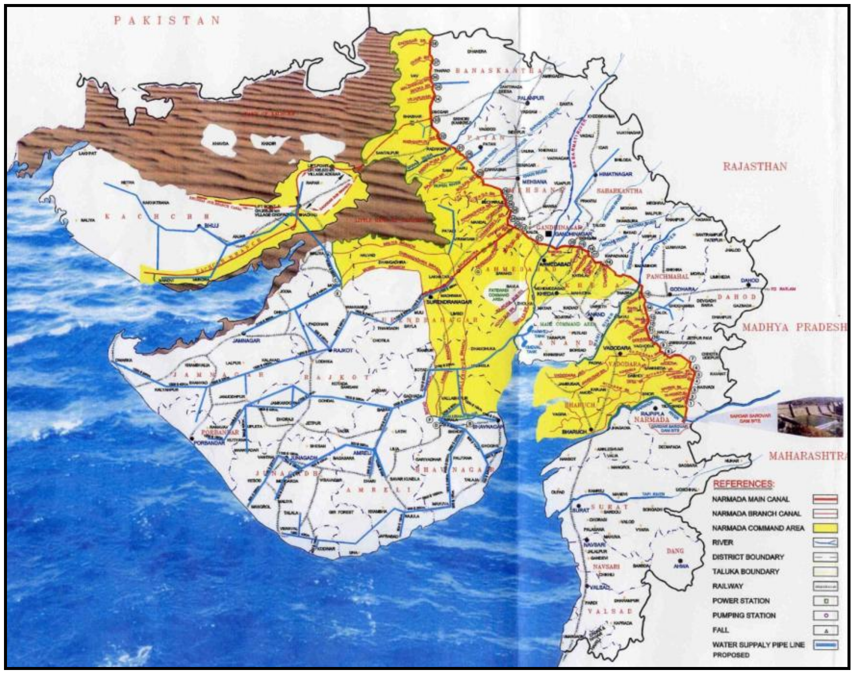

Figure - 1 Command area of Sardar Sarovar Project

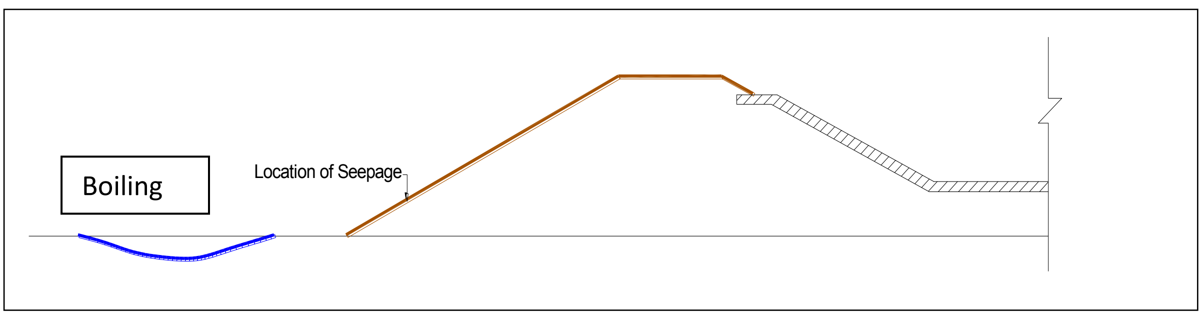

Figure – 2 Conceptual View of Canal Section in Problematic Reach

After construction of the main canal, because of overdependence for the drinking water, it has never been given closure and hence the saturation of embankment has been an issue especially where the embankment is very high. At some locations high groundwater table beneath the canal and at some locations subsurface flow have also manifested some issues. One such location is the upstream side of the Watrak Canal Syphon near Ch.195.00 km which is in heavy banking. The average height of bank is 12.50 m. Water depth in the canal section is 7 meter. Some boiling was observed on left bank at 30 m away from the outer toe of the canal bank during 2001 to 2005. Some seepage was also observed on the outer side of the canal embankment above its toe. This problem was in a length of more than 50 meter.

Investigations, Findings and Solution in Steps

As this problem was very complex and diagnosis was not simple, stepwise analysis of the problem was selected as an approach. The phenomenon was like what is generally experienced in a dam though the canal did not completely resemble a dam. An additional constraint was that the canal flow was not possible to be stopped.

The problem of boiling at some distance from the toe of the canal embankment suggested subsurface flow due to favorable hydraulic gradient. Subsurface flow could not be attributed to the canal flow as the canal was lined and the bed banking was more than 3.5 meter. Some punctures were required to be made in the soil at some distance away from the outer toes of the canal embankments which helped in finding that there was a shallow live aquifer which was not noticed during the construction of the canal. This aquifer might have dried up during the construction period as there were two preceding years lean from rainfall point of view and hence at that time no one could notice anything during the construction. The aquifer was cut due to construction of the canal siphon in the downstream which spread and saturated the surrounding soil above in some years which finally took the form of boiling as the waterway was obstructed. This important finding gave the clue as to why the canal that did not completely resemble a dam manifested a problem that is generally found with dams.

Seepage from the canal embankment above its toe suggested either the phreatic line developed within the canal embankment cutting it across or capillary action developed near the toe from within the ground itself or both together. The said diagnosis was made by considering the loam type of soil from which the canal embankment was constructed. Loam is generally erodible type of soil and phreatic line or capillary action could be easily developed in to due to high permeability when the compaction is not sufficient. Deep rain-cuts on the outer side of the canal embankments were also observed which also suggested erodible soil.

It was planned to provide exit to the subsurface flow by providing a lateral drain somewhat away and establish a steady state of the soil beneath the canal embankment so that crumbling of the foundation resulting in to failure of the embankment could be avoided. This would also stop the capillary action of water in to the canal embankment near the toe if any. The lateral drain which was a collecting drain was extended to a far situated pond for the disposal. This was aimed at releasing the water accumulated in large quantity within the soil beneath the canal embankment. Figure – 3 represents the said arrangement.

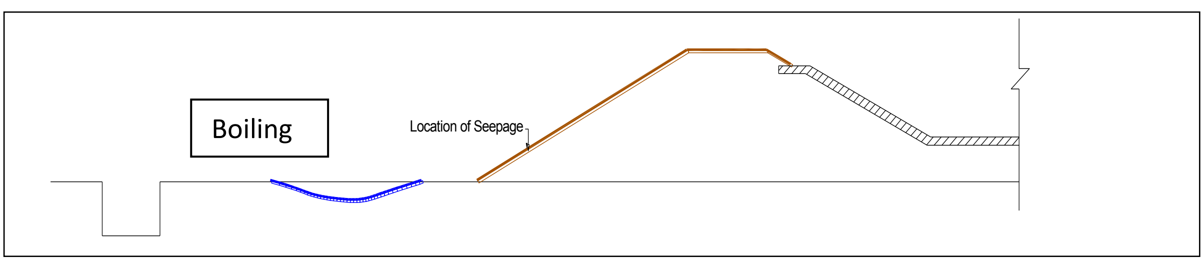

Figure – 3 Initial Stage of Solution

The canal embankment was kept under observation for some days with the aforesaid mechanism working continuously. It was observed that the boiling phenomenon had almost disappeared. It was also observed that seepage from above the toe of the embankment was reduced but was not completely stopped which suggested that the phreatic line had established within the embankment which had an exit above the toe. This state could not be taken lightly.

In order to ensure the phreatic line to be within the width of the embankment, increasing the width of the canal embankment was necessary. Moreover, this could also control the exit gradient within the foundation. It was planned then to provide an additional berm of 5 meter width and 5 meter height to ensure the stability of the embankment in addition to the said two benefits. The additional berm thus constructed resulted in to total disappearance of the boiling phenomenon and the seepage from within the embankment. But the chances of adverse effect of saturated soil already within the embankment and further saturation due to continuous flow in the canal could not be ruled out. In this situation, the solution provided must of a long term nature was the general feeling.

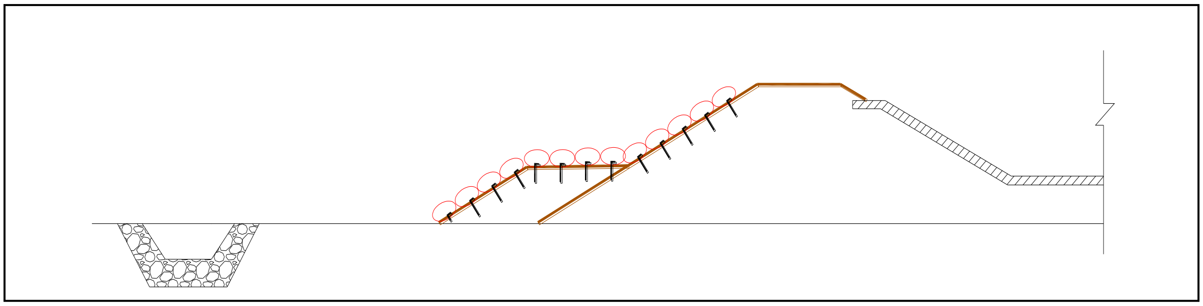

Figure – 4 Conceptual View of Solution

Counter weight through the additional berm was planned to be further improved by providing some additional burden in the form of sand bags which could also function as protection against the rain and the rain-cuts could be avoided. Finally jute textile bags were selected for this purpose which were specially designed in the form of long rolls. They were filled up with cement soil in 1:9 ratio and were nailed on the outer slope of the canal embankment. This was aimed at avoiding rolling down of the jute rolls. The objective was to prove an anti-erosion surface on the outer slope of the embankment and to add extra burden to provide more stability. In course of time the jute might be disintegrated but would have vegetation on it which would provide good drainage facility in addition to protection against rain-cuts. The lateral drain was then provided with a trapezoidal section with inner side having dry pitching which could easily collect the water without any destabilization. Figure – 4 represents the conceptual view of the solution.

The said solution was provided between Ch.195.225 KM and Ch. 195.375 KM was carried out during June-2005 to August-2005. The extra length of the solution on both – upstream and downstream of the problematic reach was keeping in view the chances of spreading of subsurface flow. The solution has been found working well and till date there is no problem in the said length of the canal.

CASE STUDY – 2 GORATHIYA DAM

Introduction

One minor irrigation dam – Gorathiya has been situated in Sabarkantha district i.e. in North Gujarat in India. Its construction was completed only before 10 years. It has been constructed across river Meshwo. Its Gross Storage Capacity has been 146 Million Cubic Feet. Its catchment area is 371 square Kilometers and the designed flood at the dam site with 1 in 50 year frequency is 3774 cubic meter per second. The storage is small but the spillover capacity is large. Length of the spillway section is 101.80 meter. The concrete gravity dam has been provided 9 vertical gates. Hydraulic jump type stilling basin has been provided in the downstream for energy dissipation. Upstream and downstream keys were 3.5 meter deep.

The Gorathiya dam manifested some signs of distress in only 2 years from its completion. The downstream glacis slope has been 1:3 whose toe got disintegrated and the reinforcements were pulled out as a sign of distress as shown in Photo-1. The next year the downstream apron got damaged but not in the entire length of the dam, only in the right half of the length i.e. river's half width as shown in Photo-2.

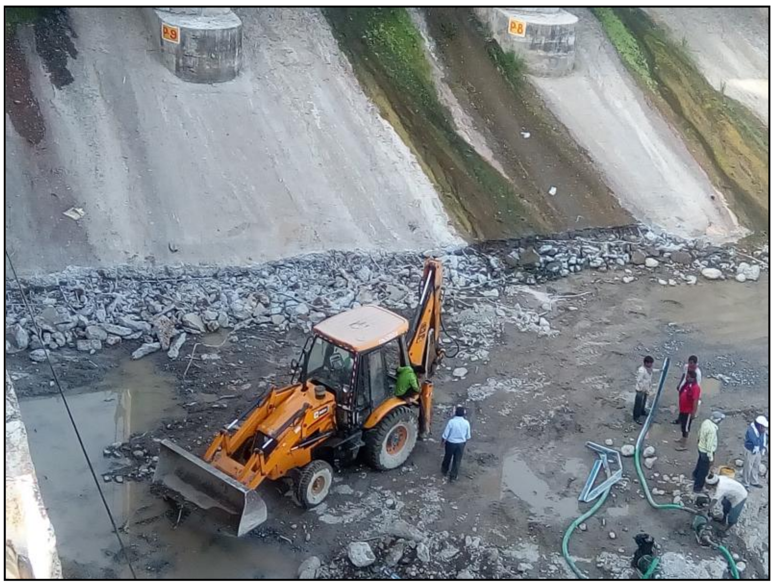

Photo – 1 Pullout of Reinforcement at Toe

Photo – 2 Tope View of Pulled Out Reinforcement at Toe and Damaged Apron

The loose concrete was removed and fresh concreting was done twice but the same problem recurred.

Diagnostic Analysis

Disintegration of concrete at toe of the downstream slope of the dam and pulling out of reinforcement in the entire length at the same location clearly suggested that it was not a construction flaw but it was due to cavity formation during release of water. This was because the glacis with 1:3 slope was insufficient to avoid cavity formation. There should have been a much flatter slope or an ogee. This part of the diagnosis was comparatively easy as it required only inspection and some knowledge of design.

The reason for repeated damage in the half of the length of the apron was difficult to understand. If it were a design flaw, the damage would have been in the entire length of the dam. If it were a poor quality concrete in the apron, repeated failure could not be there as the repairs were done meticulously. The history of site investigation was thoroughly studied to commence with. There was some record that there was originally a basalt mine in the gorge of the river as the river was having good quality basalt in its bed. For preparation of the site, the design included lean concrete filling with large coarse aggregate i.e. plum concrete in the pit. The investigation began with identification of width and depth of the mine. Some other records with geological mapping suggested that the mine was only in the right half width of the river and the depth was about 9 meter. It was not a big mine but only some removal of basalt from this location which was advised to be filled up with plum concrete. The apron was removed and the plum concrete beneath was investigated. It was learnt that the large coarse aggregates were there in place with mechanical locking and no compaction could be done but the cement and sand were in loose form and hence there was substantial amount of water beneath the apron in the voids of the aggregates. The dam was full up to crest level i.e. approximately 6 meter from the bed of the river. This gave a clue that the filling of the pit was aimed at plugging it but either the concrete was not allowed to set properly or the casting was not done properly and hence the concrete was not in a solid form and hence the voids between the large coarse aggregates were filled up with water which was not the groundwater; it was the water from the reservoir in the upstream of the dam. The water started flowing out after some hours which corroborated the said finding. This condition was extremely dangerous as at any time the subsurface flow could result in to undermining the foundation and collapse of the concrete dam itself.

The reason for damage to the apron in the right half length of the dam was then understood. When the gates were opened and water was released, the impact of the water fall was supposed to be taken up by the apron which required a solid foundation beneath which actually was not there and hence the concrete apron used to settle which caused sagging resulting in to damage at the bottom and top – bottom damage was not visible but the top was. Every time the gates were operated and the apron was found badly damaged due to this situation.

The diagnostic analysis required experience and insight in to the behavior of the dam, spillway, flow of water and its kinetics and of structural behavior of reinforced concrete.

Restoration

The objective of filling the pit with plum concrete was to plug the waterway beneath the apron so as to check the hydraulic path beneath the foundation. Keeping in view the same, plum concrete up to 1.5 meter of depth from the bottom of the apron was removed to see the condition of the plum concrete which was tremendously risky but was somehow done by taking necessary risk. Albeit, a precaution was taken in the form of a temporary plugging of subsurface waterway beneath the toe of the downstream slope. Cement and sand were mixed in 1:4 proportion with high water cement ratio and it was poured up on the loose material so as to allow it to creep inside the dump of aggregates in the pit and plug it. It was allowed to properly set. Then the initial layer of 1.5 meter which was removed was recast with high cement level and polymers so as to ensure a high strength concrete as the foundation. It was a concrete with normal coarse aggregate so as to ensure proper strength and compaction.

Photo – 3 Construction of Cut-off under Abutment

The apron was to be recast but it was decided to go for a 5 meter downstream cut-off to ensure checking the hydraulic path from the foundation. Additional cut-off was provided with the new apron. The right side abutment was also found vulnerable and hence the shuttering was made at its foundation after opening it and additional cut-off was also constructed there as shown in Photo-3. A peripheral cut-off was thus provided as shown in Photo-4. Entire construction activity required constant dewatering. Rapid hardening agents were added to concrete to ensure early setting of the concrete to reduce the construction time as the risk was very high.

Photo – 4 Construction of Peripheral Cut-off

Removed portion of concrete apron in half of the length of the dam was provided with horizontal and vertical drainage embedded in to the concrete and the new construction of apron was done with properly compacted polymer concrete with reinforcement mesh at the top. These reinforcements were welded with the reinforcements which were pulled out at the toe of the downstream slope of the dam. The concrete was cast for the apron such that at the toe of the dam was made a curved fillet to avoid pullout during the cavity formation. Strong foundation and strong apron with peripheral key checked the hydraulic path beneath the foundation and also assured impact resistance against the fall of water.

Photo – 5 Post-Repair Performance of Dam

It is learnt that generally the concrete apron provided to dissipate energy in the downstream of the dam is subjected to pitting or erosion in many cases. This is because the impact of water is very high and the design engineers provide strong concrete to resist the impact but the property actually required is surface hardness rather than strength. Hardness is tried to be attained by increasing strength in most of the designs but it is found that over some value of strength, much increase in strength is required to have little increase in hardness and hence it is not a cost-effective proposition. Here was used special construction chemical to provide surface hardness on the top of the apron just as it is done with the floor of the factory which requires high impact resistance.

Finally to provide a proper hydraulic condition to the water flowing down, the river channel in the downstream of the dam was retrenched. The entire repairs got completed in a time of four months.

The solution worked out was tested soon i.e. monsoon 2016 and there was full discharge released from the gates twice as shown in Photo-5 and it was found that the performance was as per expectations.

CONCLUSION

Problems in civil engineering are very complex and understanding the real cause of the problem is the most important aspect. A small aspect ignored at the construction stage may lead to difficult problems. The diagnostic part in designing the solution of such problems is the most important as that is the key to address the real issue and it needs experience and insight as mostly the findings can be reached by way of using judgmental and intuitive decisions. Therefore, sometime the diagnosis is required to be done stage-wise along with step by step implementation of solution. The solution of such problems may involve several activities to be executed with proper sequence and proper materials.