Research Corridor Journal of Engineering Science
ISSN Online: 3078-3054, ISSN Print: 3078-3046
Volume No: 02 Issue No: 02 (2025)

International Conference on Innovating for a Sustainable Future: Global Challenges and Solutions
April 24-25, 2025

HYDRAULIC AND STRUCTURAL ASSESSMENT OF THE RAVI SYPHON STRUCTURE FOR UP GRADATION

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ABSTRACT

The canal system in District Lahore and Kasur Irrigation Divisions have been suffering from shortage of water for a long time, due to reduction in capacity of Ravi Syphon (4200 Cs) as compared to design capacity (4853 Cs) at BRBD Link Canal which is outlived being a 70 years old structure. Irrigation Department carried out an underwater inspection of the Ravi Syphon with the help of divers in 2007.About 33% of the overall length could only be examined due to limitations and constraints. The inspection of Ravi Syphon structure is carried out recently though out the length of barrels (100%) by Irrigation Department and consultant whereas I supervise the inspection of barrels as Sub Divisional Officer, Ravi Syphon. Underwater and dry inspection of barrels were done through divers and recorded the images and videos for assessment of heath of structure. The results of underwater inspection revealed that the concrete face has been eroded at the syphon inlet leaving coarse aggregate exposed and in some places reinforcement steel bars are exposed. Many of the barrel joints were found to be leaked. Traverse joints in all five barrels were found to be in poor condition. Cracks in the concrete of the five barrels were observed. Two large holes were found in one of the barrels. Water stops are exposed at many places. In this research repairing of existing barrels is recommended by using sprayed concrete (shotcreting or guniting) for the top and sides of the barrel with reinforced concrete at the base. The proposed thickness of sprayed concrete is 2 inches (50 mm) and that of reinforced concrete is 4 inches (100 mm). Repairing of the damaged upstream bed protection is essential and proposed that scour holes should be rock filled.

Keywords: Hydraulic, Structures, Ravi Syphon

1. INTRODUCTION

The Ravi Syphon conveys the flow of the BRBD Link Canal under Ravi River. The BRBD Link Canal crosses Ravi River through a syphon between Rd: 282+760 to Rd: 284+623. The structure was built in 1952 comprising five 10'-3" square reinforced concrete barrels 1759 ft (536 m) long with total design discharge of 4,853 Cs (138 m^3/sec). The discharge capacity is reported to have reduced because of increasing hydraulic roughness and downstream water levels in the canal being higher than design and also due to the damages of syphon structure and leakages from different barrels being a 70 years old structure. The Ravi Syphon passing the discharge only 4000-4200 Cs against the design discharge 4853 Cs. The conveyance capacity of the syphon is a constraint to agricultural development of district Lahore and Kasur in command areas of Central Bari Doab Canal (CBDC) and the Upper Depalpur. Punjab Irrigation Department has initiated a study "Remodeling of BRBD Link Canal to meet Water Shortage for District Lahore and Kasur Irrigation Division", which includes rehabilitation of Ravi Syphon and allied structures. Irrigation Department recently inspected Ravi Syphon to identify structural conditions of the Syphon before finalizing various components of rehabilitation. The inspection was done jointly by Irrigation Department

where as I have worked as Sub Divisional Officer, Ravi Syphon (Representative of Irrigation Department) and experts of Consultants. No repair or rehabilitation have so far been reported on the Syphon since its inauguration. The general layout plan of Ravi Syphon with respect to salient ground features is shown in the **Figure *1*.**

2. RESEARCH SIGNIFICANCE AND OBJECTIVES

The primary objectives of this research is to evaluate the current hydraulic capacity of the Ravi Syphon by conducting flow measurements, assessing water conveyance efficiency and identifying hydraulic limitations. The other purpose is to assess the structural health of the Ravi Syphon by identifying damages due to corrosion, erosion, sedimentation, or due to other degradation mechanisms and evaluate the leakages and their impact on existing operational performance of the syphon. Further, this research will help to develop recommendations for the up-gradation and rehabilitation of the Ravi Syphon, based on the findings of the hydraulic capacity and structural evaluation.

3. METHODOLOGY

Ravi Syphon structure includes the five number concrete reinforced square barrels of size 10.25 ft each having length 1759 ft which was constructed in 1952.The design capacity of Syphon has been reduced to 4200 Cs against the design discharge 4853 Cs. This research will help to evaluate structural health and mechanism to upgrade existing structure.

3.1.Inspection of Ravi Syphon (Underwater Condition)

Services of expert divers were hired for the condition survey of Ravi Syphon structure and inspection of each barrel throughout the length. High-resolution images and videos were recorded with respect to chainage and location. Initially, it was planned for underwater inspection of the barrels. Team of expert divers entered into the barrels to observe and record the condition of the visible portions of the structure. Live on-screen viewing on a monitor stationed outside enabled to expose hydraulic and structural condition to observe the inside condition and visible structural features of various components of the Syphon. The observations were noted and the videos through camera which assisted the inspection were also recorded. The scuba divers were sent inside the barrels for underwater inspection without any appreciable success due to poor visibility; the water was excessively turbid due to suspended clay particles which could not be settled owing to movement of the divers and aquatic life in the barrels. In view of the poor visibility, it was decided to undertake the inspection by draining the water from syphon barrels, as much as possible.

3.2.Inspection of Ravi Syphon (Dry Condition)

In order to dewater the barrels, pumps were installed to remove the water. However, after continuous pumping for about five days, the barrels could not be completely dewatered, the pumping afforded dewatering of only incline portion of the barrels. A huge opening of size 1.5 ft x 1.5 ft was found at the transition of sloping at upstream side of the barrel which allowed constant flow of 1-1.5 Cs from the River Ravi. Owing to this, pumping was increased yet the water level in Barrel No. 1 remained at around 8 ft and in Barrel No. 2 at about 6-7 ft in the mid straight portions. However, in the remaining barrels the water level generally varied from 2-5 ft. The divers were able to physically enter the barrels along with their equipment including underwater cameras and steel pointer/ sounding rod to measure the depth of holes and pitting along the concrete surface. While moving inside the barrel, the divers facilitated the team of experts to visually observe the structure by pointing the camera and graduated steel rod at the walls and slabs. The location of any point inside the barrel was

identified by means of the calibrated umbilical cord attached to diving gear. The length of the umbilical cord was about 200 m which limited the extent of visual inspection from either side of syphon. Accordingly, the visual inspection was carried out from upstream and downstream ends for only up to this length while the remaining middle portion of each barrel was inspected by the divers independently. For the middle portions, live viewing from outside was not possible and the divers have recorded the shot images and short clips using cameras for evaluating the structure health. Upon completion, the diver's team provided detailed videos, images and a report for underwater inspection of the syphon.

4. INSPECTION RESULTS

The general condition and structural aspects including quality of concrete, status of joint filling, extent of leakage/ seepage and overall structural integrity of side walls, chamfer and top and bottom slab in all the barrels were observed on-screen. The exposed portions/ components of the structure were inspected during the procedure with a view to observe any visible signs of structural damage/ distress, cracks, deformation, settlement, dampness and other signs of deterioration. Critical findings of the visual inspection are given below.

4.1.Barrel No. 1:

i. It is the exterior barrel towards the u/s side of the river having its outer wall exposed to scouring/ erosion caused by the river flow. In order to protect the syphon, the u/s river bed was protected with stone pitching and concrete blocks. Apparently, the u/s bed protection has been damaged over the years, as evident from the settlement/ structural distortion at the joints in the barrel.

ii. A huge opening of size 1.5 ft x 1.5 ft has been developed in the joint at the transition of sloping and straight portions of the barrel. Heavy flow of water through this opening prevented complete dewatering of barrel even after continuous operation of pumps.

iii. The surface concrete of side walls, chamfers and slabs has been eroded leaving coarse aggregate exposed.

iv. Surface pitting, holes and patches have developed at various locations causing loss of concrete strength and reinforcement cover.

v. At some places, steel reinforcing steel bars are exposed and are subjected to rusting and corrosion.

vi. Most of the joints are in deteriorated condition and the joint filling of water proofing material has been removed. Concrete has lost its strength at such locations and steel reinforcement is exposed.

vii. Relative settlement has been observed in the adjacent slabs (top as well as bottom) across some of the joints in the straight portion of the barrel. Maximum measured depth of settlement is 2 inches.

viii. Structural distortion/ dislocation in the side walls at joints has been witnessed. As observed, the orientation of such structural movements is in the direction of river flow which points out that the scouring in the u/s bed protection has caused instability in the structure.

ix. Noticeable cracks in the concrete have been observed which are also causing seepage/ leakage at some locations.

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4.2.Barrel No. 2:

i. The surface concrete of side walls, chamfers and slabs has been eroded leaving coarse aggregate exposed.
ii. Surface pitting, holes and patches have developed at various locations causing loss of concrete strength and reinforcement cover.
iii. At some places, steel reinforcing steel bars are exposed and are subjected to rusting and corrosion.
iv. Most of the joints are in deteriorated condition and the joint filling of water proofing material has been removed. Concrete has lost its strength at such locations and steel reinforcement is exposed.
v. Relative settlement has been observed in the adjacent slabs (top as well as bottom) across some of the joints in the straight portion of the barrel.
vi. Structural distortion/ dislocation in the side walls at joints has been witnessed. It appears that distortion in Barrel No. 1 has been further translated into Barrel No. 2.
vii. Noticeable cracks in the concrete have been observed which are also causing seepage/ leakage at some locations.

4.3. Barrel No. 3:

i. The surface concrete of side walls, chamfers and slabs has been eroded leaving coarse aggregate exposed.
ii. Surface pitting, holes and patches have developed at various locations causing loss of concrete strength and reinforcement cover. Bulging of a significant patch of surface concrete has been observed which indicates excessive deterioration of the concrete.
iii. At some places, steel reinforcing steel bars are exposed and are subjected to rusting and corrosion.
iv. Most of the joints are in deteriorated condition and the joint filling of water proofing material has been removed. Concrete has lost its strength at such locations and steel reinforcement is exposed.
v. Relative settlement has been observed in the adjacent slabs (top as well as bottom) across some of the joints in the straight portion of the barrel.
vi. Structural distortion/ dislocation in the side walls at joints has been witnessed.
vii. Noticeable cracks in the concrete have been observed which are also causing seepage/ leakage at some locations.

4.4. Barrel No. 4:

i. The surface concrete of side walls, chamfers and slabs has been eroded leaving coarse aggregate exposed.
ii. Surface pitting, holes and patches have developed at various locations causing loss of concrete strength and reinforcement cover.
iii. Some significant openings/ holes at joint locations have been noticed which may be attributed to removal of joint filling due to excessive abrasion. One such opening has been observed in the mid portion by the diver through which water is freely flowing between Barrel No. 4 & 5.
iv. Bulging/ spalling of a significant patch of surface concrete has been observed which indicates excessive deterioration of the concrete.
v. At some places, steel reinforcing steel bars are exposed and are subjected to rusting and corrosion. Appreciable corrosion marks are also evident.

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vi. Most of the joints are in deteriorated condition and the joint filling of water proofing material has been removed. Concrete has lost its strength at such locations and steel reinforcement is exposed.
vii. Excessive seepage, continuous dripping and leakage of water has been seen in the top slab and side walls around the joints.
viii. Relative settlement has been observed in the adjacent slabs (top as well as bottom) across some of the joints in the straight portion of the barrel.
ix. Structural distortion/ dislocation in the side walls at joints has been witnessed.
x. Noticeable cracks in the concrete have been observed which are also causing seepage/ leakage at some locations.

4.5. Barrel No. 5:

i. The surface concrete of side walls, chamfers and slabs has been eroded leaving coarse aggregate exposed.
ii. Surface pitting, holes and patches have developed at various locations causing loss of concrete strength and reinforcement cover.
iii. Bulging/ spalling of a significant patch of surface concrete has been observed which indicates excessive deterioration of the concrete.
iv. Some significant openings/ holes at joint locations have been noticed which may be attributed to removal of joint filling due to excessive abrasion. One such opening has been observed in the mid portion by the diver through which water is freely flowing between Barrel No. 4 & 5.
v. At some places, steel reinforcing steel bars are exposed and are subjected to rusting and corrosion.
vi. Most of the joints are in deteriorated condition and the joint filling of water proofing material has been removed. Concrete has lost its strength at such locations and steel reinforcement is exposed.
vii. Appreciable seepage, continuous dripping/ leakage of water has been seen in the top slab and side walls around the joints. **Inspection results are shown in figure 2-12**.

5. CONCLUSION

The syphon structure is in service for about 70 years, and the effects of structural distress are evident in the barrels. The concrete in side walls, chamfer and top slab has significantly deteriorated over the period of time due to continue erosion and excessive seepage. The concrete surface has undergone severe abrasion, pitting and development of holes along with loss of concrete cover at various locations. At some locations, the steel has been exposed which has led to corrosion and loss of strength. Cracks have developed at several locations in walls where appreciable leakage has been observed. The joints are in worst condition where in most cases, filling has been removed. Steel exposed and concrete has lost its structural integrity at multiple locations. Seepage, dripping and leakage was observed at different locations in the joints in exterior and interior walls as well as top slab of the syphon structure. A huge damage/hole opening (1.5ft x 1.5ft) has been developed in the joint at river side exterior wall of Barrel No. 1 resulting continuous flow of about 1-2 Cs indicates that the upstream approach floor and protection arrangement is no more intact. The discharge of water from this opening under syphonic action when running under full capacity, may have been causing a reduction in the syphon capacity. Similar opening was found in the joint of interior

wall between Barrels No. 4 & 5. There might be other locations allowing free flow between the barrels as the water level could not be completely lowered even after continuous pumping. An important finding with regards to structural stability of the syphon is settlement and distortion at the location of joints. Settlement in slabs (top and bottom) and lateral distortion in side walls (along the direction of river flow) has occurred at various joints most evidently in Barrel No. 1. The same has also been observed in other barrels to some lesser extent. The concrete at such locations is particularly more vulnerable to continuous damage due to cavitation phenomenon. We suspect that the damages including settlement and lateral distortion in side walls of the Barrel No. 1 were occurred during the 1955 flood and repairs were made. The physical obstructions to water flowing at appreciable velocity causes vapour bubbles which upon their collapse, exert forces on the adjoining areas damaging the joint filling, concrete and exposed steel reinforcement. The prolonged effect of cavitation is quite significant which may have caused severe damage to the structure. The exterior structure and external protection arrangements i.e., u/s and d/s approach floor and protection arrangements i.e., stone aprons could not be inspected. However, inside of the barrels were physically inspected by the divers to view and record the exposed areas above the water lever (side walls, chamfer and top slab). In such a situation, it is very difficult to accurately predict the structural behavior and to establish the structural adequacy for continued use only on the basis of the visual inspections. Hence, in this research repairing of existing barrels is recommended by using sprayed concrete (shotcreting or guniting) for the top and sides of the barrel with reinforced concrete at the base. The proposed thickness of sprayed concrete is 2 inches (50 mm) and that of reinforced concrete is 4 inches (100 mm). Repairing of the damaged upstream bed protection is essential and proposed that scour holes should be rock filled. This treatment of syphon structure will enhance the capacity and will also increase the life of structure for almost 30 years.

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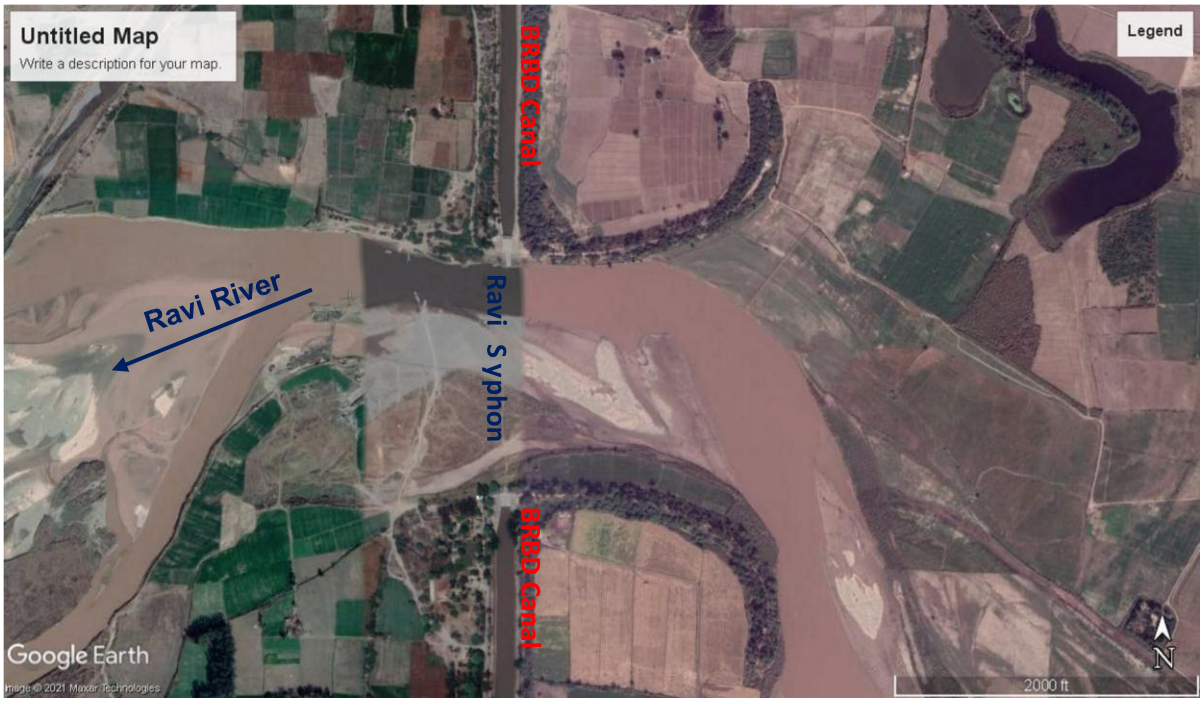

Figure 1: Location of Ravi Syphon

Figure 2: Inspection of Barrels

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Figure 3: River flow through damaged and concrete at joint with leakage

Figure 4: Removal of joint filling wall in Barrel No. 1

Figure 5: Damaged wall in Barrel No. 1 in Dry Condition (steel exposed)

Figure 6: Leaking Joint with removed filling

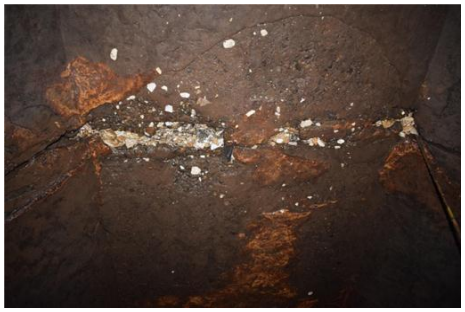

Figure 7: Rusting of Steel at Joint Location

Figure 8: Opening of Joint with appreciable leakage between the Barrels 4 and 5

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Figure 9: Deteriorated joint

Figure 10: Deteriorated joint with seepage marks

Figure 11: Chipping of Concrete and Corroded Steel

Figure 12: Leakage of Roof at Joint

Inspection Results of Ravi Syphon Structure (Five Barrels)

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