A Study on Seepage Problems of Chamravattam Regulator cum Bridge

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ABSTRACT
Chamravattam regulator cum bridge is the largest road bridge in Kerala, which was constructed in the form of a barrage to store the water in Bharathapuzha River. Within a short span of time after construction, a large amount of seepage was observed beneath the structure. This project aims to study about the seepage problem of Chamravattam regulator cum bridge. The study was conducted with the help of 2D Finite element model, Geo-slope. Using the model the quantity of seepage, exit gradient and uplift pressure distribution in different cross sections were found. The check for resistance to the uplift and piping phenomenon was done in the cross-section where the seepage flow was found maximum. The obtained results were compared with the existing site conditions. The possible reasons for seepage problems were found.

Key words: Seepage, Exit gradient, Uplift pressure, Piping phenomenon, Geo-Slope

I INTRODUCTION

Barrages or regulator cum bridges are low level dams which are intended to store water in its upstream to feed water for the purposes like irrigation, domestic and industrial uses. Comparing to big dams, these structures will have a small head of water in its upstream. Gates will be provided to control the water storage and head of upstream water. These structures also contributes to ground water recharge.

Most of these structures are constructed over pervious soil media, which causes seepage of water below the structure. This seepage in a very high quantity will affect the stability of the structure. So hydraulic stability is an important factor that affects the performance of a hydraulic structure. Seepage problem mainly depends on foundation soil characteristics and head at upstream and downstream. Seepage flow though the foundation soil is driven by the differential pressure created from water level difference between upstream and downstream. The seepage flow, as it increases will wash away the soil beneath the structure, leading to piping phenomenon, which ultimately leads to the failure of structure. The uplift pressure acting on the foundation of structure can also cause the failure of structures.

Chamravattam regulator cum bridge is a barrage constructed across Bharathapuzha River in 2013. Within one year after the construction of structure, heavy amount of seepage was observed beneath the structure. This paper aims to study about the seepage problems of Chamravattam Regulator cum Bridge.

II BASIC DATA AND DESCRIPTION OF STRUCTURE

Chamravattam regulator cum bridge is the largest road bridge in Kerala state. It is situated 6 km away from Ponnani, where Bharathapuzha joins Arabian Sea. It is having a length of 978 m and has got 70 shutters to regulate the flow of water. The project was supposed to serve water to fourteen panchayats and two municipalities. The main aim of the structure was to distribute excess water in the river to those areas where drinking water shortage is a problem during summer season.

At present condition, the downstream aprons of the bridge are almost completely collapsed, which is mostly observed in between the chainage 340 m and 390 m from eastern bank of the river. Also till 200 m chainage, the aprons were constructed in an unscientific manner with a length of 6 to 7 meters long. The loose rubble packing were found to be destroyed in almost whole length and the rubble stones used were found to be lighter than the required weight.

The basic characteristics of the bridge, which are used as input data for the analysis of the seepage problem are as follows.

(a) The total width of the structure is 33.35 m.
(b) There are two rows of sheet piles are provided along the length of the structure.
(c) Upstream sheet pile is 2.9 m deep.
(d) Downstream sheet pile is 5.75 m deep.
(e) The borehole data of 31 different points along the length of the structure.
(f) The crest elevation is 1.5 m.
(g) The maximum water level at the upstream is 4.5 m

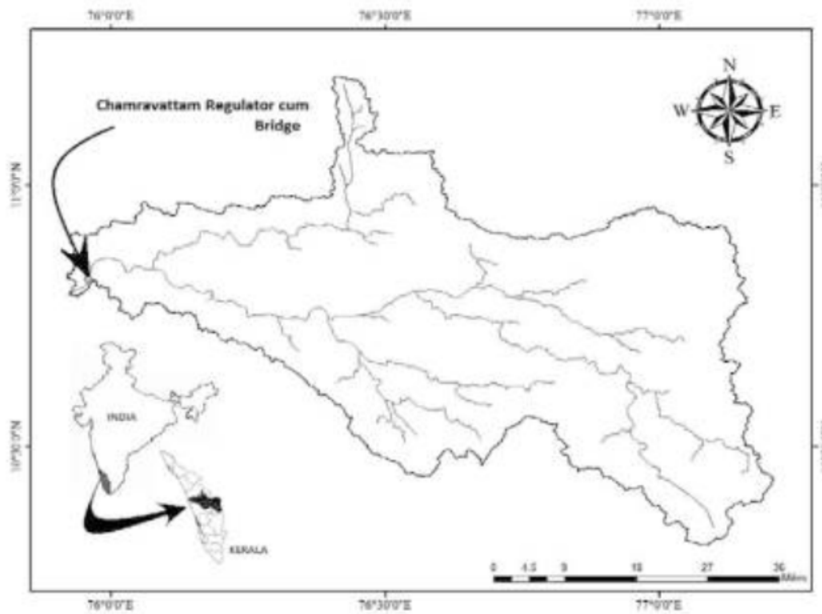

Fig. 2-1: Location of Chamravattam Regulator cum Bridge in Bharathapuzha

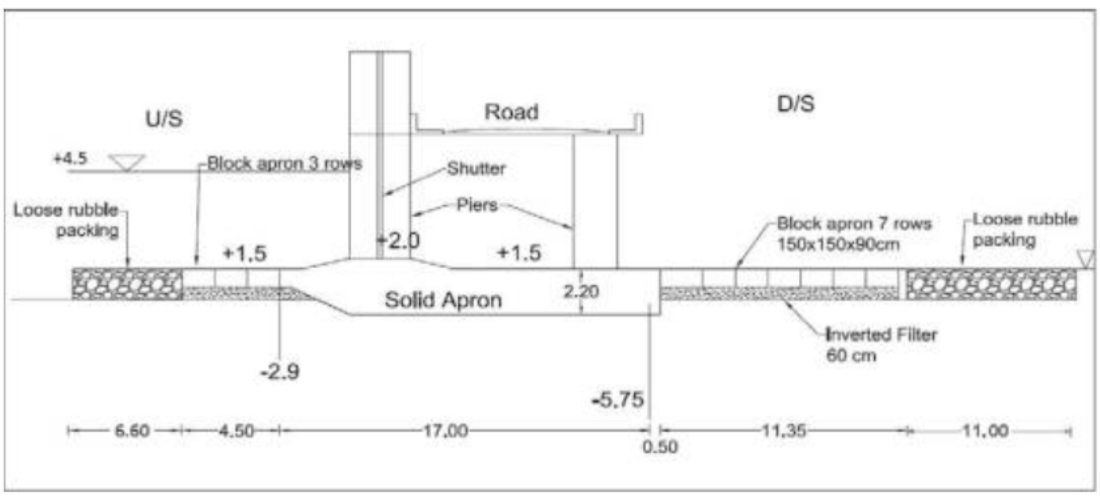

Fig. 2-2: Cross-section of Chamravattam Regulator cum Bridge

III METHODOLOGY OF THE PROBLEM

The analysis of the seepage analysis is the primary step to study about the hydraulic failures that occurred in the hydraulic structure and to find an optimum precaution for that. GEO SLOPE SEEP/W is one of the advanced and accurate method to study about the seepage phenomenon. A numerical model is a mathematical simulation of a real physical process. SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. This model is based on Darcy's law which relates quantity of seep-age and head which causes the flow. Finite element numerical methods are based on the concept of subdividing a continuum into small pieces, describing the behavior or actions of the individual pieces and then reconnecting all the pieces to represent the behavior of the continuum as a whole. This process of subdividing the continuum into smaller pieces is known as meshing. The pieces are known as finite elements. The basic equation will solve in this element level. The basic equation of SEEP/W model is

$$[K]\{H\} = \{Q\} \qquad (1)$$

Where:

[K] = Hydraulic conductivity of soil
{Q} = a vector of the flow quantities at the node.
{H} = a vector of the total hydraulic heads at the nodes,

The steps of seepage analysis using this software are:

(a) Defining the problem: In this step, we input the cross section of structure, soil layer properties and boundary conditions (Upstream head and downstream head). Then the model will get discretize into finite element mesh of quadrilateral elements.

(b) Solving the problem: The model works based on the principle of Darcy's law. Through this process, the model will find total head, gradient of seepage flow and quantity of seepage flow at each point in the flow domain.

(c) Analyzing the results: This model is not capable of taking us instantaneous conclusions, instead we need to analyze the outputs from the software to reach in a conclusion. The uplift pressure at the bottom of the foundation helps to study about the stability of structure to withstand against uplift pressure. The gradient of flow at the downstream represents the safety against piping phenomenon. The flow quantity at the outlet can be used to find the intensity of seepage at that particular point.

IV ANALYSIS OF THE PROBLEM

While studying about the seepage problems of Chamravattam Regulator cum bridge, my first aim was to find the cross section which is most vulnerable to seepage phenomenon. The seepage analysis was carried out for 31 different cross sections along the length of structure. The flows at outlet point were calculated for each cross section. The highest amount of seepage flow obtained was 5:47E 05m^3/sec/m at 370 m from one bank. The highest value of exit gradient was obtained also at the same point (0.2797). These results clearly define this point as the most vulnerable one along the length of structure. Now the hydraulic stability of the whole structure can be obtained from analyzing the results from this particular cross section. The two major parameters that affects the hydraulic stability are uplift pressure acting at the bottom of foundation and gradient of flow at the point where seepage flow exit at the downstream.

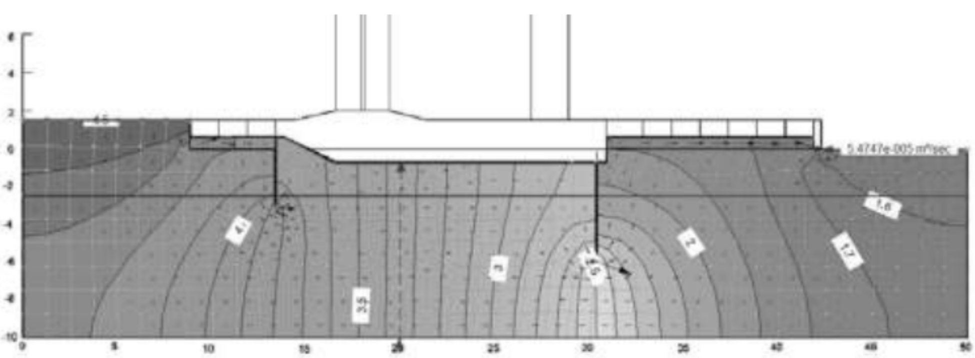

Fig. 4-3: Finite Element mesh for different soil layers below the foundation of structure

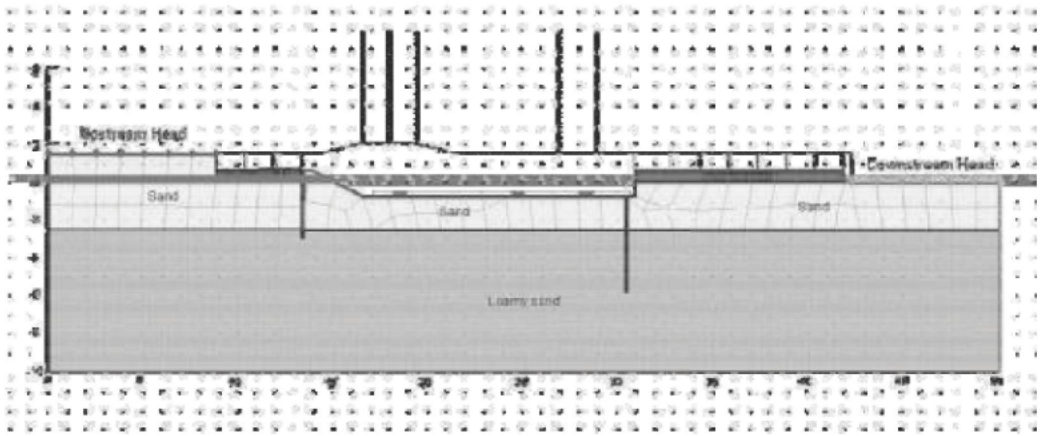

Fig. 4-4: Seepage of water underneath Chamravattam RCB at 370m chainage

For a hydraulic structure to have stability against uplift, the uplift pressure acting below the floor should be balanced by the weight of the floor.

$$\text{Thickness required at a point} = \frac{h}{(G\ \ 1)} \qquad (2)$$

Where:

h = Head of water with respect to top of the floor G = Specific gravity of floor material

According to IS: 11130-1984 additional 10% floor thickness should be provided to counter act the uplift force to meet worst possible combinations of loads like seismic loads.

$$\text{So; thickness required to be provided; } T = \frac{1{:}1h}{(G\ \ 1)} \qquad (3)$$

Thickness required to be provided at different points were calculated by using the above formula and compared with the existing site situation to check the hydraulic stability of the structure.

The next parameter that affect the hydraulic stability of a structure is exit gradient. According to IS 6966 (Part1) 1989, the exit gradient which a soil at the end of a structure exactly balances the weight of soil is mathematically expressed as

$$\text{Critical exit gradient; } CEG = (S\ \ 1)(1\ \ n) \qquad (4)$$

Where:

S = Specific gravity of soil n = Porosity of soil

$$\text{Sa f e exit gradient; } GES = \frac{(S\ \ 1)(1\ \ n)}{FOS} \qquad (5)$$

V RESULT ANALYSIS

The result from the seepage analysis conducted on 31 different cross section were as follows:

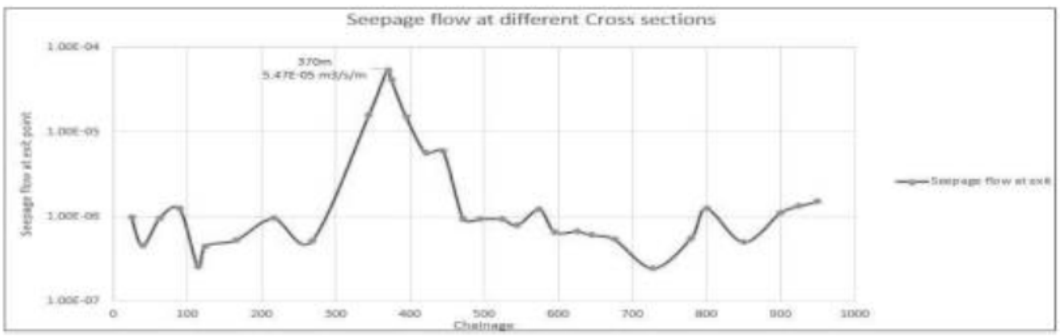

Fig. 5-5: Seepage flow for different cross sections

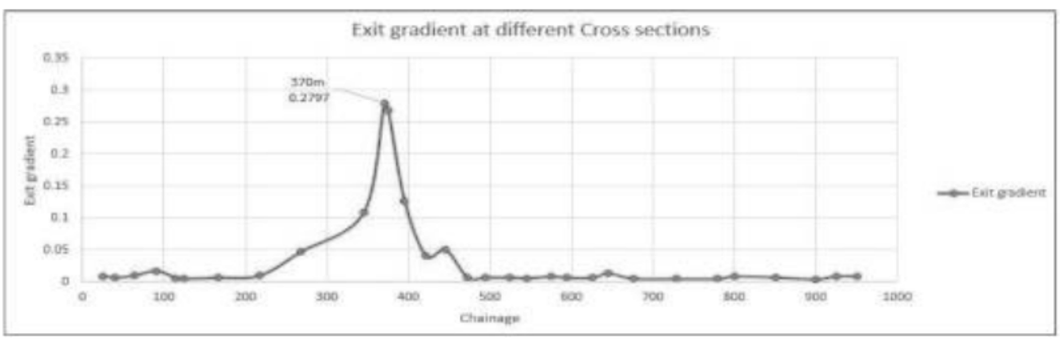

Fig. 5-6: Exit gradient of flow at different cross sections

As mentioned earlier, the maximum flow and maximum exit gradient were obtained in 370m chainage, which clearly represent it as the most vulnerable section along the length of river. So if this section is found to be safe, the whole structure can be considered safe and vice versa. In this section, up to -2.5m it is medium sand and below that is loamy sand.

The thickness required to counter balance the uplift pressure were checked at different points of the above cross section and the results were as fol

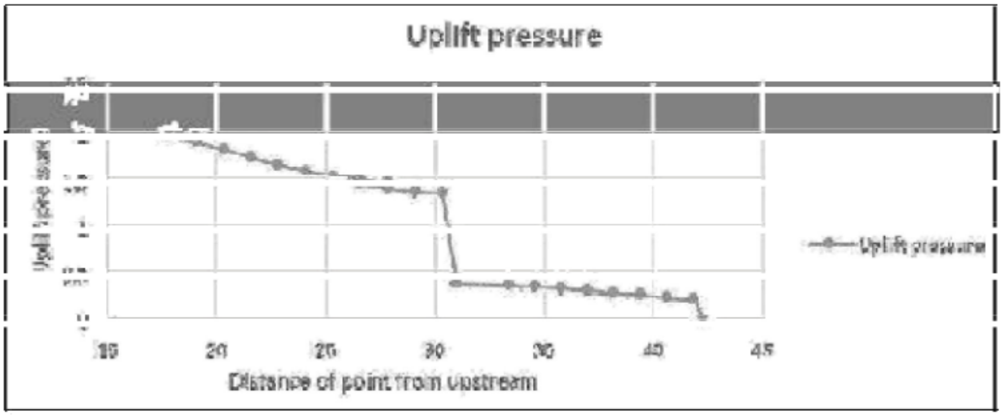

Fig.5-7: Value of uplift pressure at different points along the cross section

Table 5-1:
Checking thickness requirement to withstand uplift force

Chainage	Uplift pressure	Req.thickness	Provided	Saftey,
17.84	2.00658	1.57660	2.7	Safe
19.09	1.92544	1.51284	2.7	Safe
20.35	1.84456	1.44930	2.5	Safe
21.61	1.76465	1.38651	2.2	Safe
24.12	1.61170	1.26634	2.2	Safe
26.63	1.47992	1.16279	2.2	Safe
27.88	1.43009	1.12364	2.2	Safe
30.40	1.38542	1.08854	2.2	Safe
30.48	0.46874	0.36830	2.2	Safe
30.99	0.40831	0.32082	0.9	Safe
34.62	0.38019	0.29872	0.9	Safe
37.05	0.34030	0.26738	0.9	Safe
39.47	0.29092	0.22858	0.9	Safe
41.90	0.24566	0.19302	0.9	Safe
41.93	0.23769	0.18676	0.9	Safe
42.37	0	0	0.9	Safe

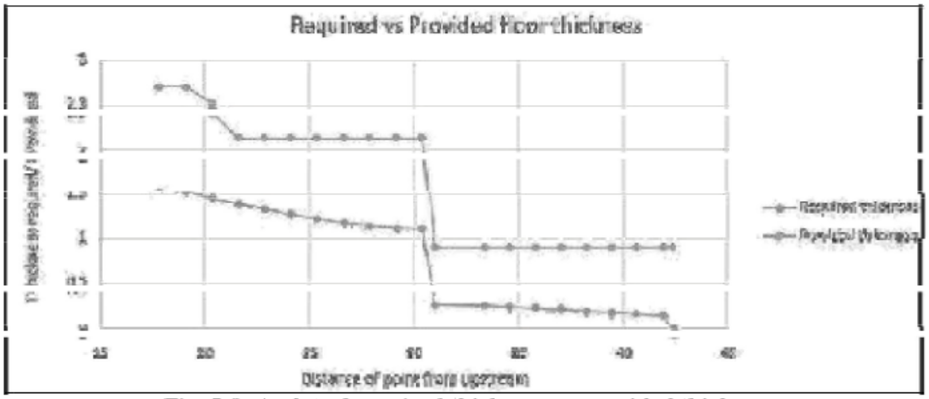

Fig. 5-8: A plot of required thickness vs provided thickness

From the result of the analysis, the floor of the regulator cum bridge was found safe against uplift at every point. Check for exit gradient is another criteria in finding the stability of the structure.

Critical exit gradient; CEG = (S -1)(1-n)

= (2.6 – 1) (1 - 0.4)
= 9.6

After substituting factor of safety,

$$\text{Safe exit gradient, GES} = \frac{(S\text{-}1)(1\text{-}n)}{FOS}$$

= 0.96/ 6
= 0.16

The value of exit gradient obtained from the model was 0.2797, which is much more than the safe limit of exit gradient, but at the same time it is much lower than critical exit gradient.

VI CONCLUSIONS

From the analysis of results from GEO SLOPE - SEEP/W package, which calculates seepage quantity, exit gradient and uplift pressure underneath the foundation the conclusions derived are

(a) The Finite Element Model was able to demonstrate the seepage flow below the foundation of Chamravattam Regulator cum Bridge successfully.

(b) The points obtained from model as most vulnerable to seepage seems matching with the site conditions.

(c) The uplift pressure acting below the floor of the structure does not affect the stability of the structure.

(d) The exit gradient of structure even though does not satisfy the safety limits, is much lower when compared to the critical exit gradient.

(e) In field the effect of seepage observed was much higher than what is obtained from model results.

(f) These results conclude with the possibility of some defect in construction of bridge.

(g) Also due to excessive digging of sand from downstream of river, the bed level might have gone down. For proposal of a solution to the existing problem, a survey needs to be conducted to study about the existing condition of field.

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