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AN EXPERIMENTAL ANALYSIS ON PHYSICAL MODEL BASED ON KHOSLA'S THEORY OF INDEPENDENT VARIABLES

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Abstract — *In this experimental work, a physical model of weir with three cut offs/sheet piles is constructed by transparent acrylic sheets. At the cut offs, transparent vertical hollow tubes are arranged in such a way that the upward movement of waters in the tubes can be observed and measured. The model is filled up with sand i.e. non cohesive soil. Model also contains tank like arrangement in which water can be filled. The water seeps beneath the floor of the weir. As the water completes its path, the soil material gets saturated gradually and the upward movement of water in the tubes can be observed and measured. The levels of water in the tubes represents uplift pressure of seeping water on the floor at various key points. The model is thus validated as per khosla't theory of independent variable.*

To see the effect of pile inclination on uplift pressure, the sheet piles are inclined at various angles with respect to the floor of the weir. According to graphical analysis the uplift pressures increases or decreases when piles are inclined at different positions as compared to that while all the piles are in vertical positions.

Keywords-*Hydraulic Structures; Uplift Pressure; Khosla's method; Physical model; inclined sheet piles; Graphical Comparison*

I. INTRODUCTION

The hydraulic structures are supposed to be more expensive amongst the general civil engineering structures because of massive usage of concrete as main construction material. A weir which is one of the hydraulic structures has to face uplift pressure across the floor length because of seeping water beneath it depending on the upstream head. With a rise in the upstream water level, obviously the uplift pressure will be more. Many researchers have represented theories aiming to counteract these uplift pressures. Dr. A. N. Khosla[1] also has carried out number of experiments to obtain values of uplift pressures at key points and represented a theory known as method of independent variables. In his theory, he broke up the complex profile of the weir founded on permeable soil. He identified certain key points where the uplift pressure should be known.

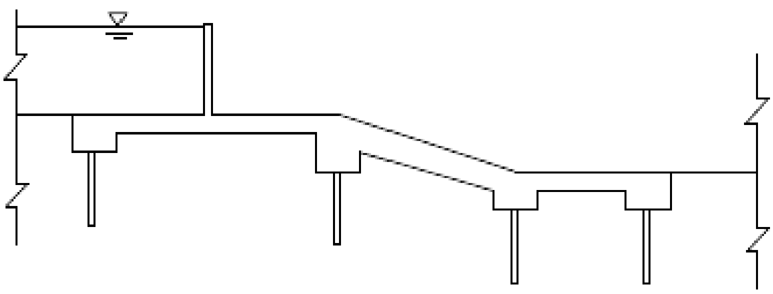


Figure-1. Weir Profile

The complex profile shown in the figure-1 is broken up into following simple profiles and pressures at key points are obtained.
1. Straight floor of neglible thickness with pile at u/s end
2. Straight floor of neglible thickness with pile at d/s end
3. Straight floor of neglible thickness with pile intermediate point
4. The pressure is obtained at the key points by considering the simple profile.

II. METHODOLOGY

Keeping in view the simple profile of weir as suggested by Dr. A. N. Khosla in his method of independent variable, a physical model was decided to be constructed. This process involved the following steps.
1. Arriving at a decision of shape and dimensions of the model
2. Preliminary model construction to test the expected results
3. Modifications in preliminary model based on the working of preliminary model
4. Construction and validation of final model and carrying out experiments on the same
5. Analysis of the experimental results and concluding remarks

2.1. Arriving at a decision of shape and dimensions of the model

To begin with is a crucial stage in any research work. The sketch of a weir founded on permeable soil as can be seen in curriculum of the subject, "Design of Hydraulic Structures" was taken into consideration.

The non linear alignment of floor, varying thickness, different depth of sheet piles, number of joints in floor etc. may not simultaneously work perfectly and failure of any one functionary may fail the model to operate as per the theory.

Hence, construction of a simple model with straight floor and three sheet piles of equal depth was found to be more convenient[2].

2.2. Preliminary model construction to test the expected results

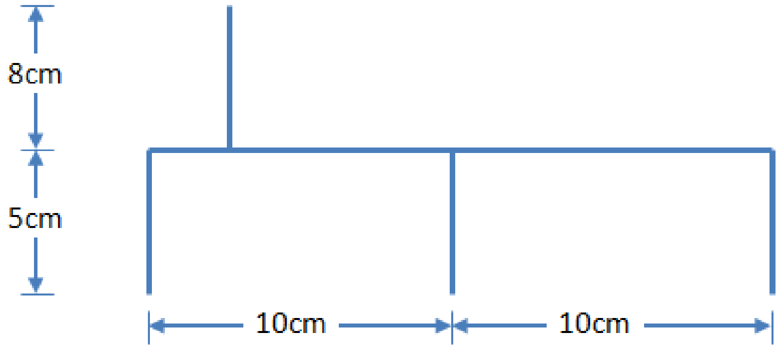


Figure-2. Preliminary model section

To direct the seeping water from upstream to downstream, the section needed to get enclosed by two planes along to longitudinal section (Figure-3).

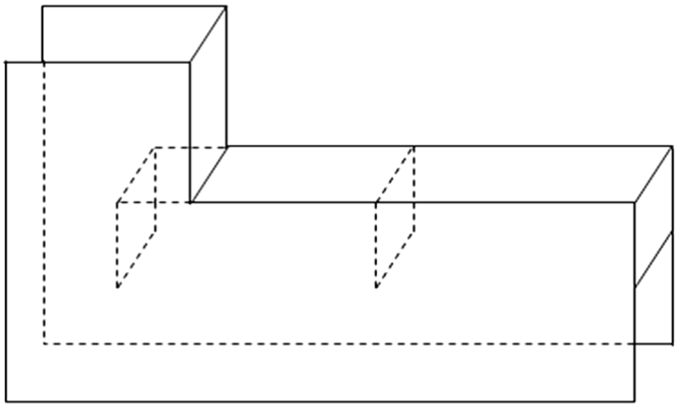


Figure-3. Preliminary model line sketch

To observe the pattern of seeping water beneath the weir, transparent acrylic sheets were used. This material became more convenient as water proof joints of surfaces with latest adhesives is more easy. To observe the upward movement of water (i.e. uplift pressure) at key points, flexible transparent plastic tubes were inserted into the drilled holes (Fig.-4).

Figure-3. Photographic view of Preliminary model

2.3. Modifications in preliminary model based on the working of preliminary model
Now, to maintain constant head at upstream side, the upstream side was also enclosed so as to form a tank like structure. Moreover, during testing the water should flow in horizontal direction which could not happen as the bottom surface of the model was kept open. Now, to maintain constant head at upstream side, the upstream side was also enclosed so as to form a tank like structure. Moreover, during testing the water should flow in horizontal direction which could not happen as the bottom surface of the model was kept open. This led one by one modification and the preliminary model became as shown in the Fig.-4..

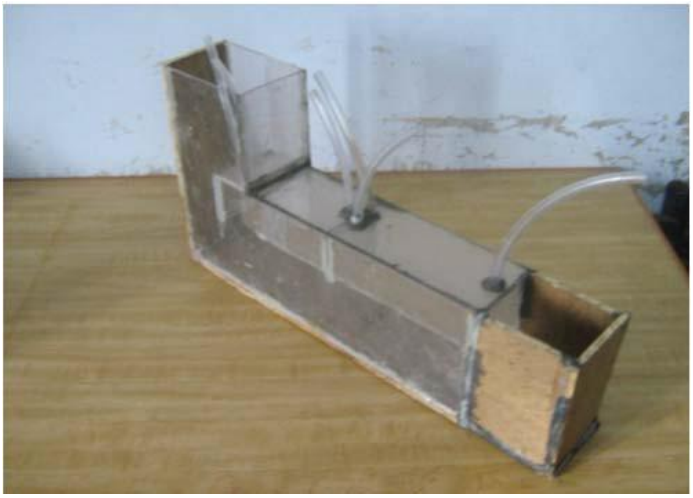


Figure-4. Photographic view of modified Preliminary model

This model was filled up with sand up to floor, the tank was filled with water and gave appropriate rise of water in the tubes (showing uplift pressure) inserted at the key points which can be seen in the Fig.-5.

Figure-5. Photographic view of modified Preliminary model in operation

2.4.Construction and validation of final model and carrying out experiments on the same
Now based on operation of this model the fair model was constructed which can be seen in the Fig.-6 and 7

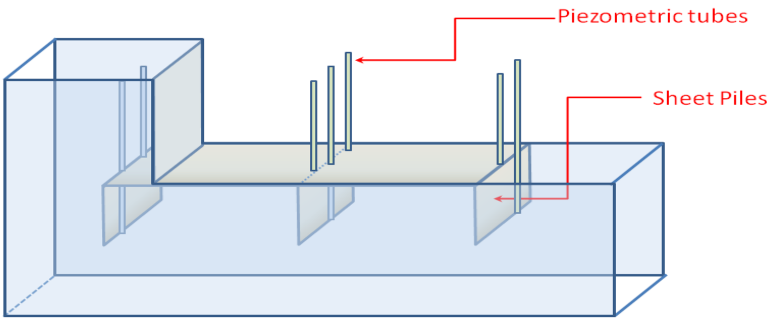


Figure-6. Schematic view of Fair model

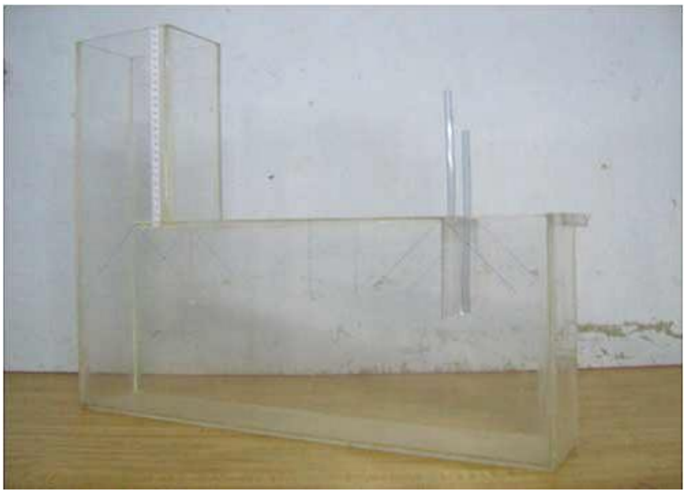


Figure-7. Photographic view of Fair model

Model validation:
Based on the dimensions of the model viz., floor length, depth of sheet piles, distance between the piles etc., the uplift pressures in terms of percentage of the upstream head were calculated using khosla's method of independent variables.

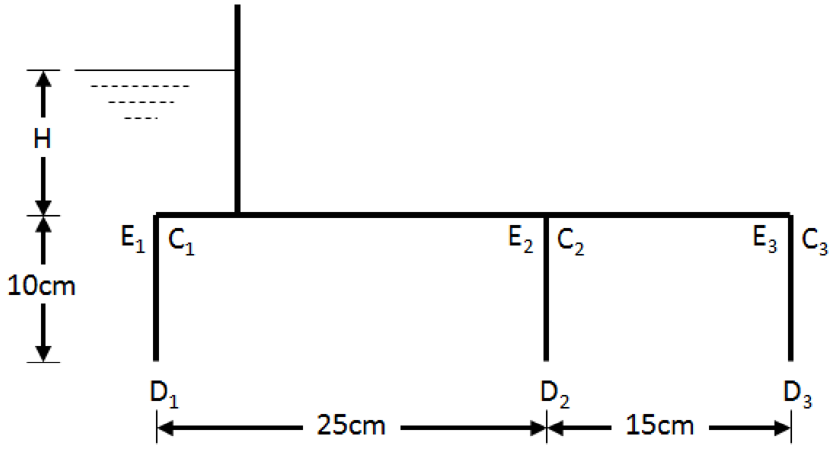


Figure-8. Dimensions of Fair model

Thus the final computed uplift pressure percentage after applying necessary corrections as suggested by khosla for the model dimensions are summarized in the following table:

Table-1. Calculated uplift pressures at key points in percentage of upstream head

ϕ_{D1}	ϕ_{C1}	ϕ_{E2}	ϕ_{D2}	ϕ_{C2}	ϕ_{E3}	ϕ_{D3}
70.86%	63.44%	51.50%	43.68%	36.00%	34.81%	29.14%

Experimental Set-up

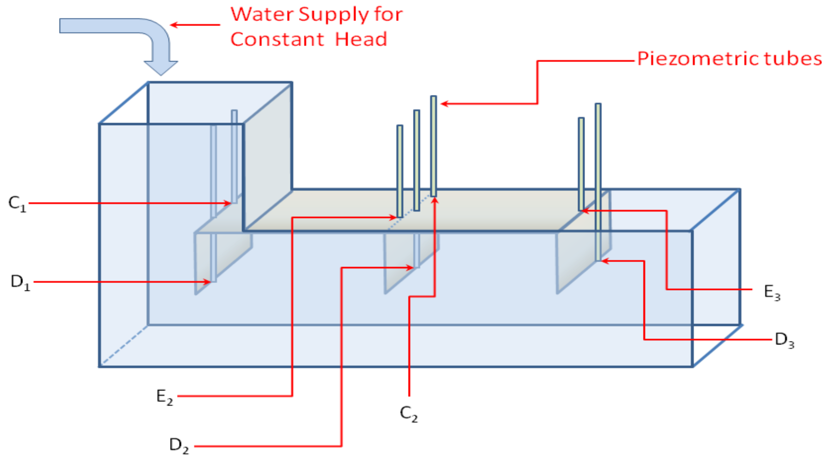


Figure-9. Schematic Experimental Set-up

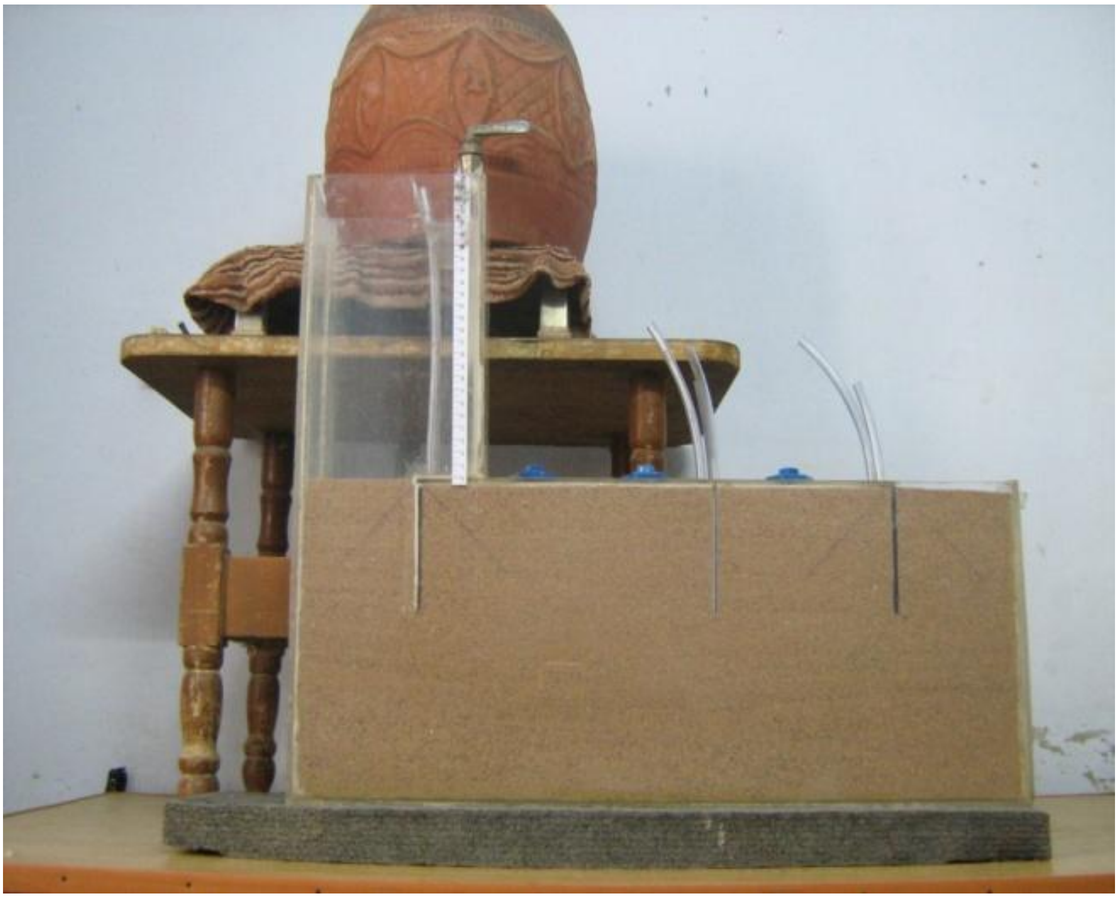


Figure-9. Photographic view of Experimental Set-up

Observations and comparison with theoretical values (Khosla):

The following table shows the theoretical values of uplift pressures at various key points in percentages as well as in cm head of water for the constructed weir model

Table-2. [Uplift pressures at key points computed by Khosla's Method of Independent Variable for the Model prepared]

	Uplift Pressures at Key Points						
Upstream Head	D_1	C_1	E_2	D_2	C_2	E3	D_3
100%	70.86%	63.44%	51.50%	43.68%	36%	34.81%	29.14%
15.00 cm	10.63	9.52	7.73	6.55	5.40	5.22	4.37

Model Validation for defined key points (Fig.-8)

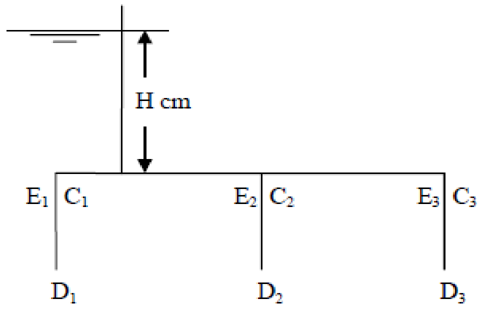
In the figure-8, the key points are defined where piezo-metric tubes were provided to obtain uplift pressure head with reference to constant head. The model experimental set up of the model is shown in figure-9.

A total five number of constant heads in the multiple of 3 from 3cm to 15 cm were selected to test model. Each of the observation was taken by three trials and then the same were averaged. The results obtained however are mentioned for head of 15 cm only.

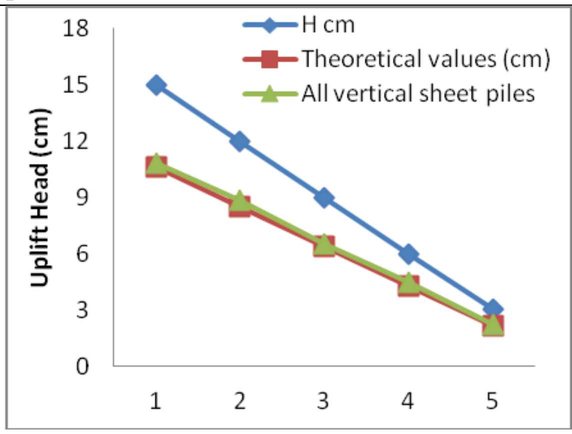
Table-3. Observed uplift pressures at key points (Average of 3 trials)

H cm	D_1	C_1	E_2	D_2	C_2	E3	D_3
15	10.83	9.07	8.60	6.93	5.13	5.03	3.77

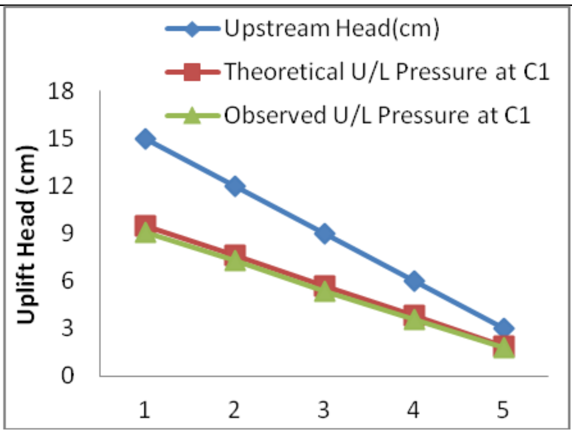
Table-4 Deviation of observed uplift pressures with theoretical values



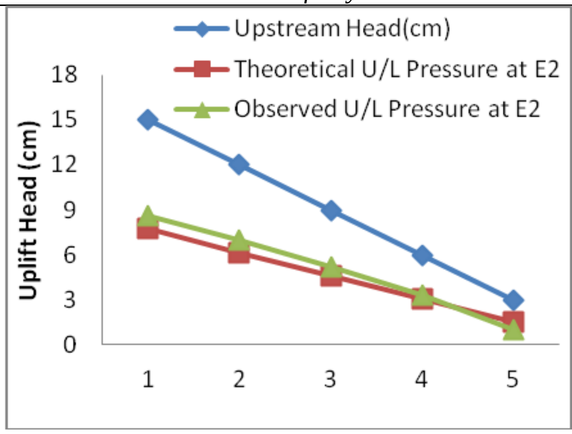
Defined Key Points



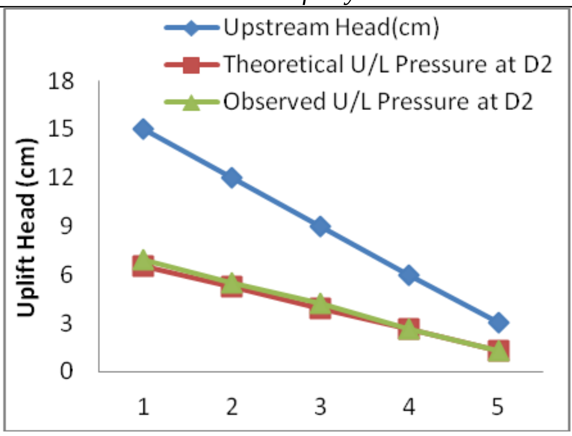
Validation of Key Point-D1



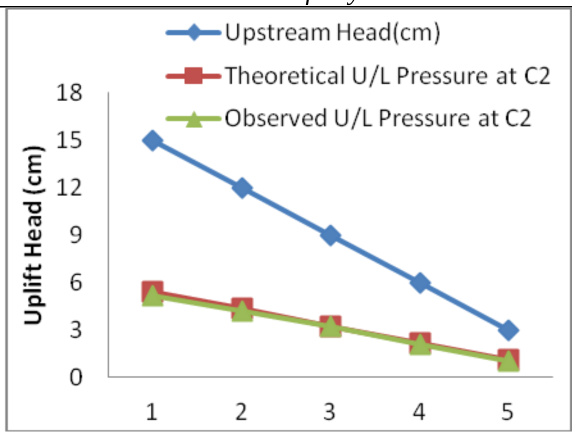
Validation of Key Point-C1



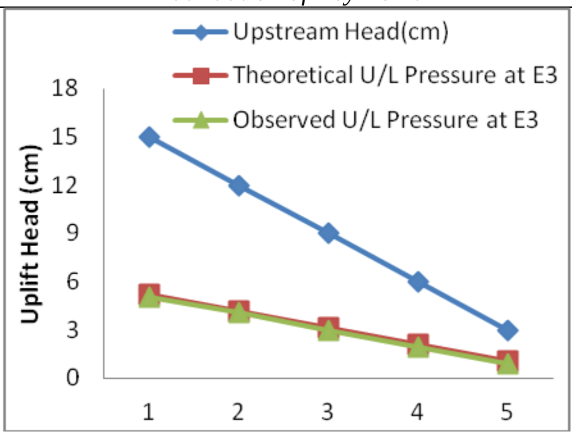
Validation of Key Point-E2



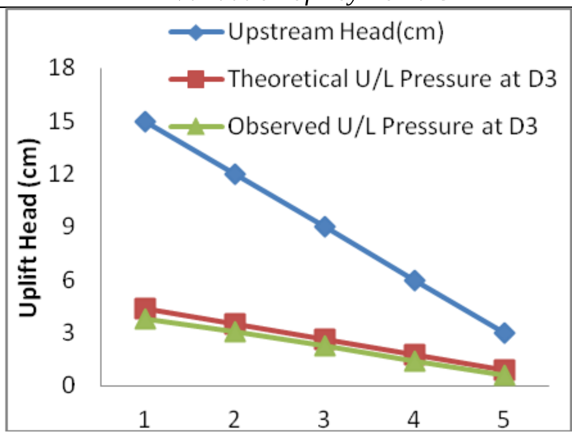
Validation of Key Point-D2



Validation of Key Point-C2



Validation of Key Point-E3



Validation of Key Point-D3

	H cm	D_1	C_1	E_2	D_2	C_2	E_3	D_3
Observed	15.00	10.83	9.07	8.60	6.93	5.13	5.03	3.77
Theoretical	15.00	10.63	9.52	7.73	6.55	5.40	5.22	4.37
Difference	0.00	0.20	-0.45	0.87	0.38	-0.27	-0.19	-0.60
% Difference	0	1.36	-3.00	5.83	2.54	-1.78	-1.25	-4.03

From table 3 and table 4, it can be inferred that the model results closely agree with the uplift pressure values at key points as computed by Khosla's method of independent variable; hence the model was validated for further experiments for different pile inclinations.

After validation, the model was tested for different pile inclinations as shown in the following figures. All the observations were taken three times and then averaged for different pile inclinations.

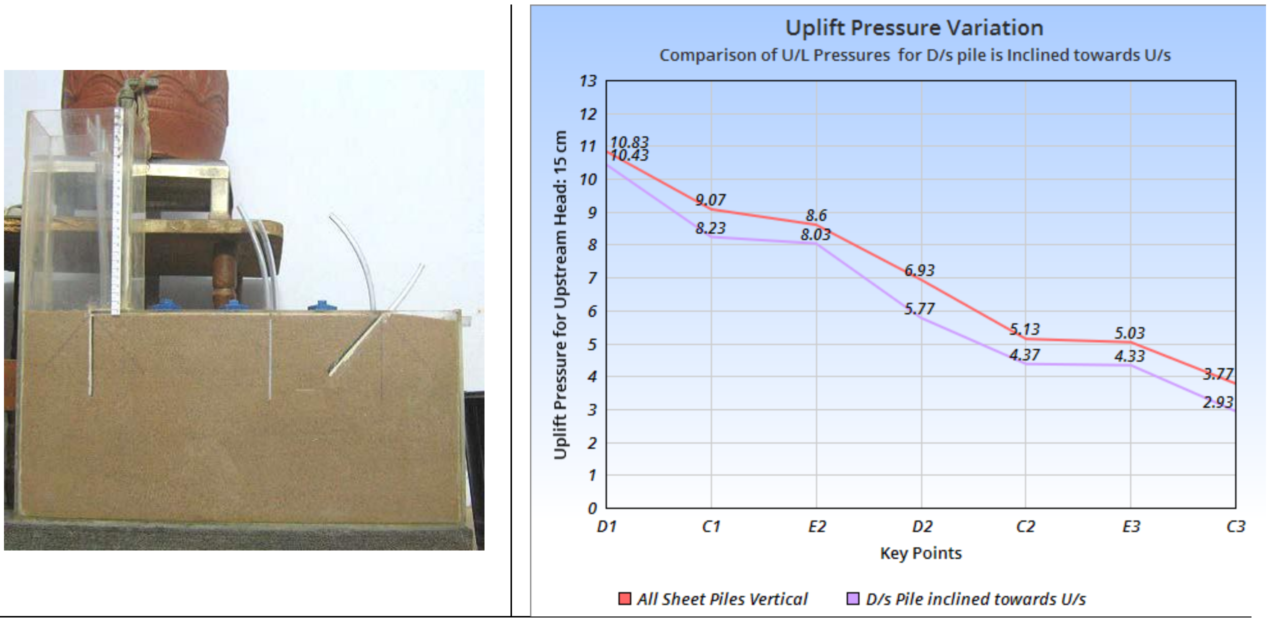


Figure-10. Variation of Uplift Pressure when downstream pile is inclined towards upstreaam

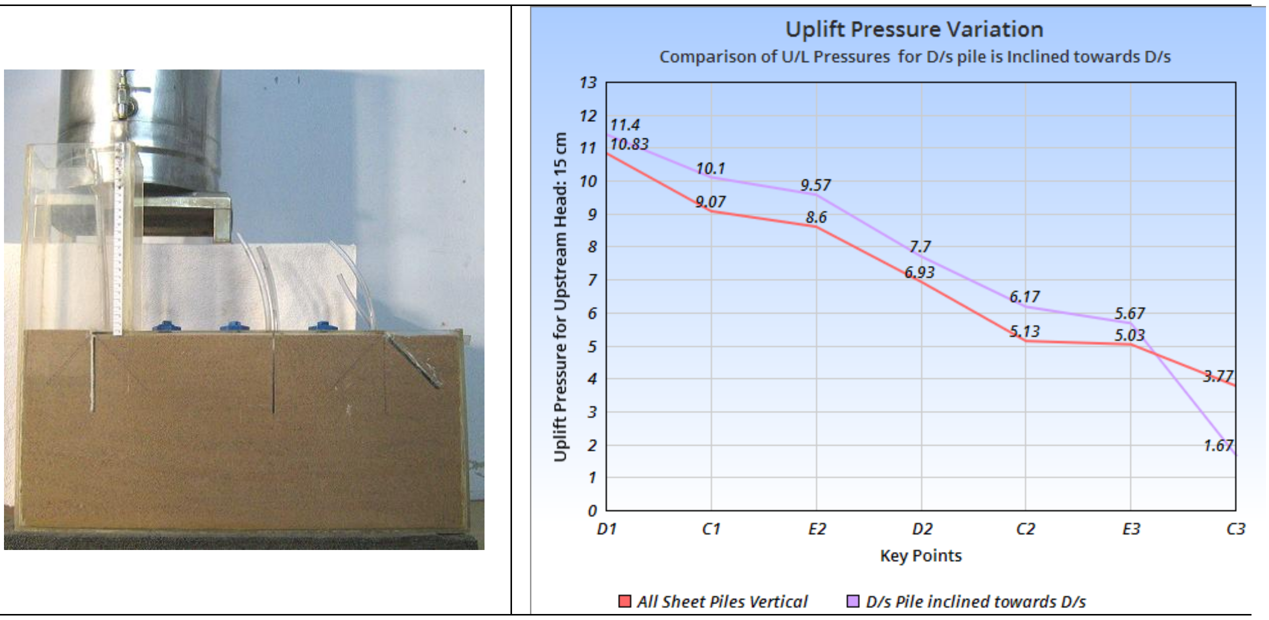
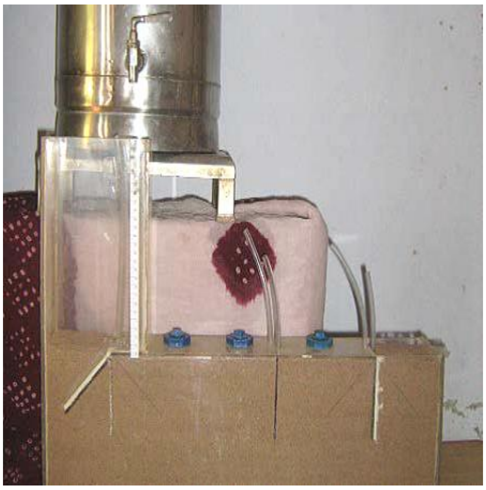


Figure-11. Variation of Uplift Pressure when downstream pile is inclined towards downstreaam

Figure-18. Variation of Uplift Pressure when downstream pile is inclined towards downstreaam



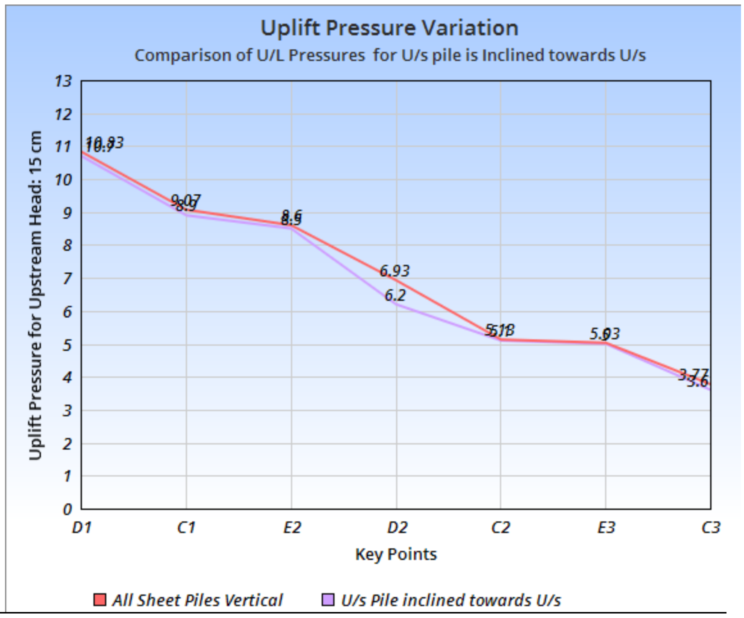
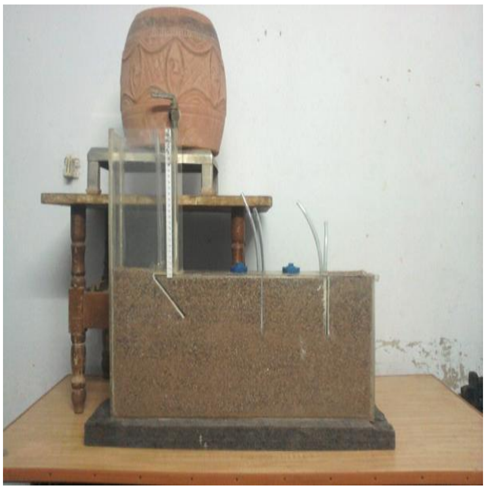


Figure-12. Variation of Uplift Pressure when upstream pile is inclined towards upstreaam



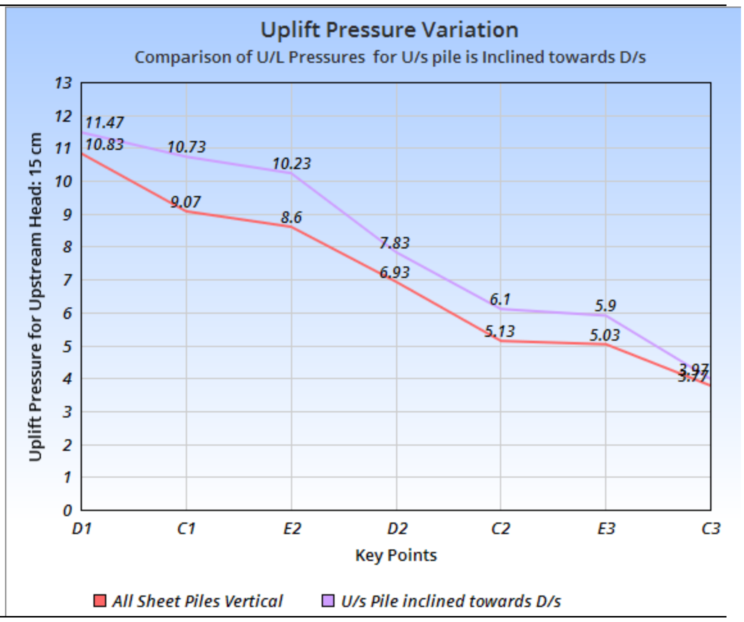


Figure-13. Variation of Uplift Pressure when upstream pile is inclined towards downstreaam

Observations and conclusions

- ✓ The observed uplift pressure for all piles vertical closely agree with values obtained by "Khosla's method of independent variable"
- ✓ Downstream pile (end pile) inclined towards Upstream (opposite to the direction of flow), gives minimum uplift pressure at almost all key points.
- ✓ In most of the previous studies, seepage was studied for one pile only. Our study also closely agrees with such study with an observation for placing a sheet pile at dam heel is not desirable at any angle.
- ✓ In general variation of uplift pressure shows reduction as we move from D1 to C3. The analysis reveals the fact that upstream pile is more effective than downstream pile in reducing seepage / uplift.
- ✓ In general it is observed that downstream pile inclined towards upstream gives maximum reduction in upstream pressure at all key points and upstream pile inclined towards downstream gives highest uplift pressure at all key points. This trend seems to be not followed for D3 key point. This may be because of location of D3 near boundary of the model.
- ✓ When Upstream pile (first pile) is inclined towards downstream (in the direction of flow), the observed uplift pressure at all key points is found maximum.

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