Assessing Inclined Cutoff Impact On Creep Line Underneath Hydraulic Structures

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ABSTRACT

Stability of the irrigation structures must be ensured against uplift pressure, undermining and piping. Providing the aprons with cutoffs at critical sections is one of the most familiar solutions that are used by engineers to ensure safety of aprons of hydraulic structures against such phenomena. The cutoffs lengthen the seepage path (creep line) which is the contact length between the apron and the soil underneath and hence render the hydraulic gradient less steep.Seepage under the aprons of heading-up structures causes many problems like piping and excessive uplift pressure that can threaten the stability of the structures. Seepage can't be totally prevented but many seepage control methods are suggested to safeguard structures against the threats of seepage. Increasing the length of the apron, using cutoffs or using a drainage blanket downstream the structure's apron are among those methods. Using cutoffs under the aprons of heading-up structures is a well-known method that is used to increase the percolation length, decrease the hydraulic gradient and increase the structure's safety against piping and excessive uplift pressure. Cutoffs can be used to decrease the horizontal length of the structure's aprons whenever needed due to either construction or economic reasons. According to Bligh's theory, the percolation length is calculated as the total sum of both the horizontal and the vertical lengths considering that both lengths have the same effect on the percolation. Lane's theory gives the seepage through a vertical length a weight equals 3 times the horizontal length.

In terms of the importance of constructing mega hydraulic structures in Egypt, this research was initiated with the impartial of assessing the inclined cutoff (CO) impact on creep line beneath them. Primarily, literature was

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assembled from research sources; scrutinized and categorized. A numerical model, based on finite element, GMS- SEEP2D was tooled to mimic cutoff orientation scenarios. An electric analogue model was implemented to verify the numerical results. Experimental and numerical results were analyzed. The research flagged out that the suitable CO inclination angle should be estimated, as a backbone for sustainable development of hydraulic structures.

Index Terms: Cutoff, Apron, Energy Dissipation, Sheet pile and creep length

1. INTRODUCTION

Egypt has the oldest irrigation system, which indicates that many waterways exist with many hydraulic structures. Due to their long lifetime, they are confronted by seepage under their aprons.

Accordingly, many researchers investigated the CO behavior below hydraulic structures. Among them are El Molla (2012), (2014) and (2018). However, assessing its impact is not yet. Accordingly, this research was initiated with the objective of assessing the inclined CO impact on creep line beneath them to rely on them as sustainable structures.

2. RESEARCH OBJECTIVES

Hydraulic structures are very old structures in Egypt. Accordingly, many of them are rehabilitated to regain their performance. Most of the rehabilitation motivations are to add a CO to their aprons to increase their safety. However, many challenging 3-folded question arose that challenged the researcher to initiate this study. This question was; what is the best position for a CO; what is its creep length impact on uplift and what is its suitable inclination?

In terms of the importance of answering the questions, this research was initiated with the main objective of assessing inclined CO impact on creep line beneath hydraulic structures. On the other hand, the subsequent objectives were to investigate the theoretical background of implementing a CO; simulate the different parameters affecting the uplift, numerically; mimic the different parameters influencing the uplift, experimentally, to validate the numerical model.

3. NUMERICAL INVESTIGATION

Many models that estimate creep line under hydraulic structures are available. For example:

- ***FLAC*** is software for solving stress so as strain. It solves nonlinear problems related to Geotechnical Engineering and dynamics research.

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- ***MODFLOW:*** It is a modular finite-difference flow model. It solves flow equations. The program simulates groundwater flow.
- ***UNIX*** is a modular design software.
- ***SEEP2D*** is a 2-D seepage program by US Corps of Engineers. It analyzes water seepage under sheet piles. It is known in the Engineering domain.

3.A IMPLEMENTED MODEL

The above models were scrutinized, from which SEEP2D was selected, as it is worldwide accepted and it proved its efficiency in simulating creep with reasonable accuracy. It has a friendly interface.

3.B THEORETICAL BACKGROUND OF SEEP2D

This section elaborates the basic equations so as the internal computation in SEEP2D.

- SEEP2D is theoretically based on the finite element technique.
- The governing equation in SEEP2D is Laplace equation.
- The internal calculation of SEEP2D goes through an explicit sequence to perform specific tasks, where each of these tasks is designated in SEEP2D primer (1998).

3.C. OPERATING SEEP2D

In order to operate SEEP2D, the mesh, describing the structure to be mimicked, is to be designated; the boundary conditions should be specified and the material properties should be selected, as follows:

- ✓ ***MESH CONSTRUCTION:*** A finite element mesh, representing the required area to be modeled, should be constructed using Groundwater Modelling System**.**
- ✓ ***BOUNDARY CONDITIONS:*** Boundary conditions should be applied to the constructed mesh. They are to be entered at nodes as constant heads; to be entered at exit as exit elevation.
- ✓ ***MATERIAL PROPERTIES:*** Among material properties is hydraulic conductivity. It must be entered to the mesh to represent soil type for the 2 principal directions**, *EL MOLLA (2014).***

3.D. NUMERICAL MODELLING PROGRAM

- Once the above is accomplished, SEEP2D calculates the head, discharge, velocity and pore pressure at all nodes in the mesh. Accordingly, a numerical modelling program was designed that considered the following:
- SEEP2D it tooled to simulate the apron with 1 and 2 cutoffs for a homogeneous soil layer underneath it.
- For single homogeneous layer, the model scrutinized the impact of CO inclination on its efficiency in decreasing the seeping gradient. The apron was supplied with 1 CO and 2 CO.
- The model mimicked a hydraulic structure on pervious soil with a certain thickness T = 60 m, where the US and DS head difference is H = 6 m. The US and DS depths are d1 and d2, respectively. US to DS distance is S = 40 m.

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3.E. The different scenarios considered the following:

- ✓ 1 CO in the US
- ✓ 1 CO at the DS
- ✓ 2 CO at the US and DS, respectively.
- ✓ 3 US depths (i.e. d1 = 12 m, 16 m and 20 m)
- ✓ 3 DS depths (i.e. d2 = 4.8 m, 6.4 m and 8 m)
- ✓ 5 US inclination (i.e. 0o, 15o, 30oand 45o)
- ✓ 5 DS inclination (i.e. 0o, 15o, 30oand 45o)

Figures (1) to (6) are provided to indicate 1 CO interface, 2 CO interface, mesh size of 0.5 m and 4 m for 1 CO, mesh size of 0.5 m and 4 m for 2 CO, obtained flow net for 1 CO and obtained flow net for 2 CO.

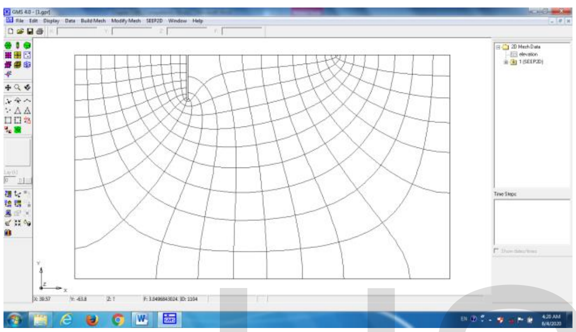

Figure (1)

1 CO interface

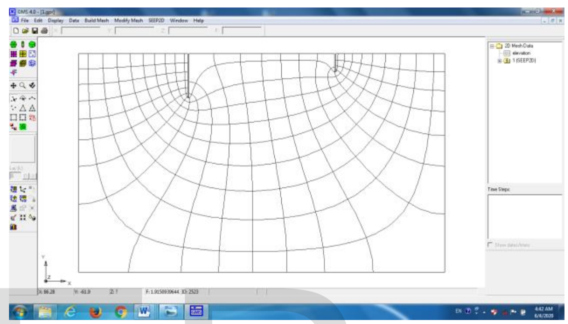

Figure (2)

2 CO interface

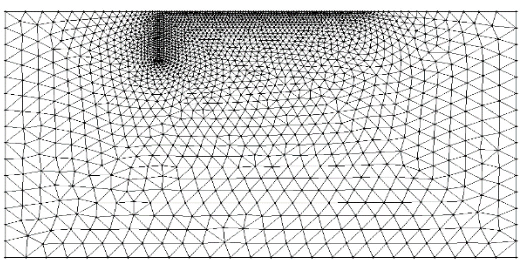

Figure (3)

0.5 m mesh size and 4 m for 1 CO

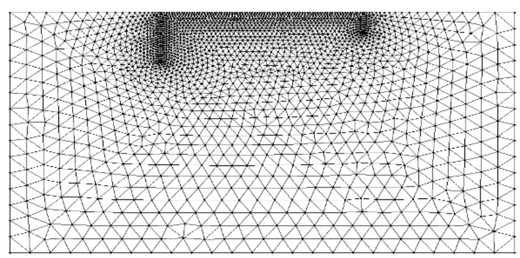

Figure (4)

SEEP2D mesh size of 0.5 m and 4 m for 2 CO

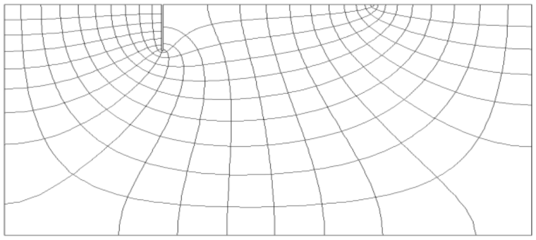

Figure (5)

Obtained flow net for 1 CO

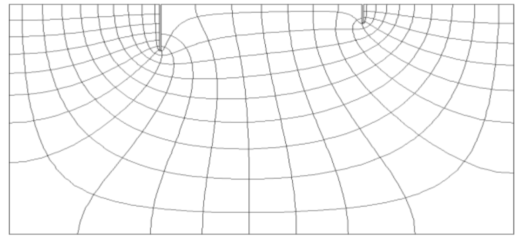

Figure (6)

Obtained flow net for 2 CO

4. EXPERIMENTAL INVESTIGATION

This section introduces the achieved experimental investigation, where the model and experimental procedure are described.

4.A. EXPERIMENTAL MODEL

The experimental model; figures (7) and (8), is described, as follows:

- It is a shallow 1000x600x50 mm glass tank equipped by 2 copper strips as electrodes (i.e. cathode and anode).
- It is equipped by rheostat (variable resistor) and plastic strips representing the CO.
- The experimental model is equipped by DC POWER SUPPLY that feeds the system with the requested potential. It feeds the system with 1 to 15 volts.
- The experimental model is equipped by a digital ammeter that measures the potentials at different points.
- The experimental model was filled by water to a 5 mm depth.
- The experimental model is equipped by 2 electric probes connected to a digital ammeter to measure the equipotential lines equivalent to voltage drop due to electrodes flow field.
- The digital ammeter and minimizes the experimental run time.
- This eliminates the polarization process between the electrodes and the electrolyte during testing.

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Figure (7) Electrical analogue device

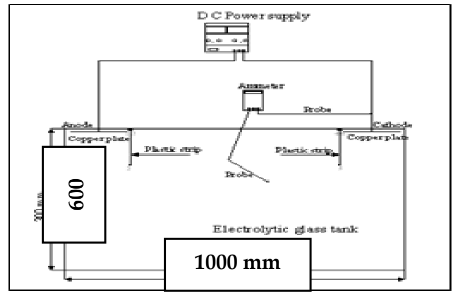

Figure (8) Experimental model

4.B. EXPERIMENTAL PROGRAM

An experimental program, similar to the numerical program, was planned to examine the different parameters contributing in the phenomenon in hand and the experiments proceeded, as follows:

1. Water was filled in the tank with a depth of 5 mm.
2. 2 copper plates were placed at the US and DS, respectively.
3. The copper plates were connected to electric circuit.
4. A potential head of 6 v was used to produce a potential difference to mimic the head.
5. A probe was mounted on the tank to measure the potential at points 1, 2 and 3 for the case of 1 CO; figure (9).
6. A probe was mounted on the tank to measure the potential at points 1, 2, 3, 4, 5 and 6 for the case of 2 CO; figure (10).
7. The total potential drop was measured, at the end of each test to make sure that it was constant during the test.

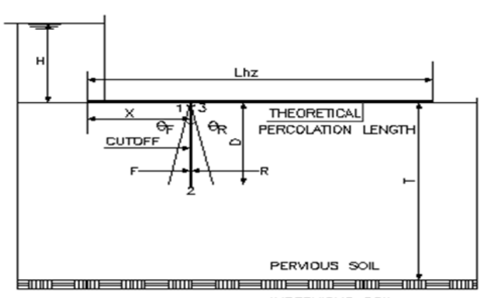

Figure (9)

Measuring points for the case of 1 CO

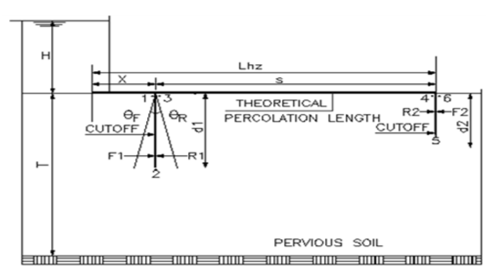

Figure (10)
Measuring points for the case of
2 CO

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5. RESULTS ANALYSIS AND DISCUSSIONS

Experimental versus SEEP2D results were analyzed and presented on tables and graphs. They are discussed, as follows:

The experimental results were compared to the numerical results and table (1) for 1 CO, table (2) for 2 CO, figure (11) for 1 CO and figure (12) so as (13) for 2 CO were provided, from which clear was the following:

- Both results were in good agreement.
- Electric analogue underestimated (F/R) by 4 to 8%.

<u>For 1 CO,</u> The following was apparent:

- The depth to thickness of the pervious layer (D/T) was 0.33.
- The relative position of CO to the total horizontal length of the apron (X/Lhz) is 0.

<u>For 2 CO,</u> The following was obvious:

- The ratio of US CO depth d1 to DS CO depth (d1/d2) is 2.5.
- The ratio of horizontal length of the apron to soil layer thickness (L_{hz} /T) is 2/3.

Table (1): Electric analogue versus SEEP2D for 1 CO

RUN NO.	H(VOLT)	D/T	Θ		F/R	
					SEEP2D 2D	Exp.
3	6	0.33	Θ	0	2.18	2.06
6	6	0.33	ΘF	15	1.74	1.61
9	6	0.33	ΘF	30	1.40	1.30
12	6	0.33	ΘF	45	1.09	1.01
15	6	0.33	ΘR	-15	2.74	2.62
18	6	0.33	ΘR	-30	3.59	3.42
21	6	0.33	ΘR	-45	5.02	4.77

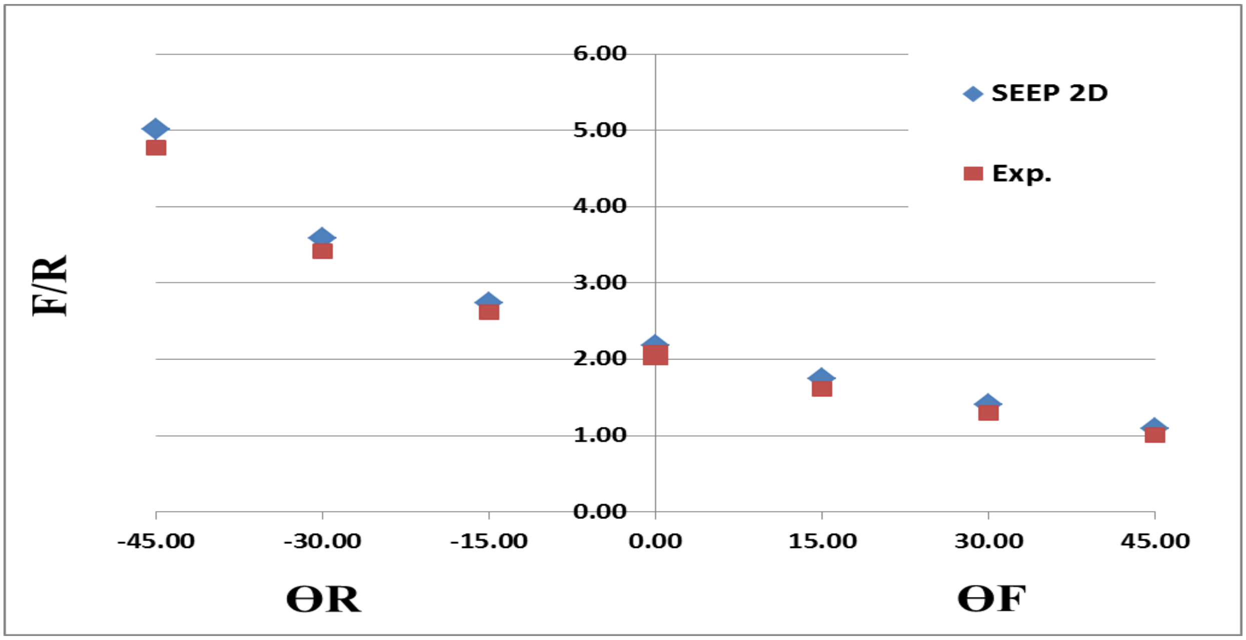

Figure (11): Electric analogue versus SEEP2D results for (F/R) at 1 CO

Table (2): Electric analogue versus SEEP2D results for 2 CO

RUN NO.	H(VOLT)	LHZ/T	d1/d2	Ө		F1/R1		F2/R2	
						SEEP2D 2D	Exp.	SEEP2D 2D	Exp.
1	6	2/3	2.5	Ө	0	2.27	2.16	2.39	2.25
10	6	2/3	2.5	ӨF	15	1.75	1.67	2.40	2.26
19	6	2/3	2.5	ӨF	30	1.35	1.29	2.41	2.26
28	6	2/3	2.5	ӨF	45	1.02	0.97	2.39	2.24
37	6	2/3	2.5	ӨR	-15	2.99	2.82	2.38	2.24
46	6	2/3	2.5	ӨR	-30	4.02	3.75	2.41	2.27
55	6	2/3	2.5	ӨR	-45	5.79	5.31	2.38	2.28

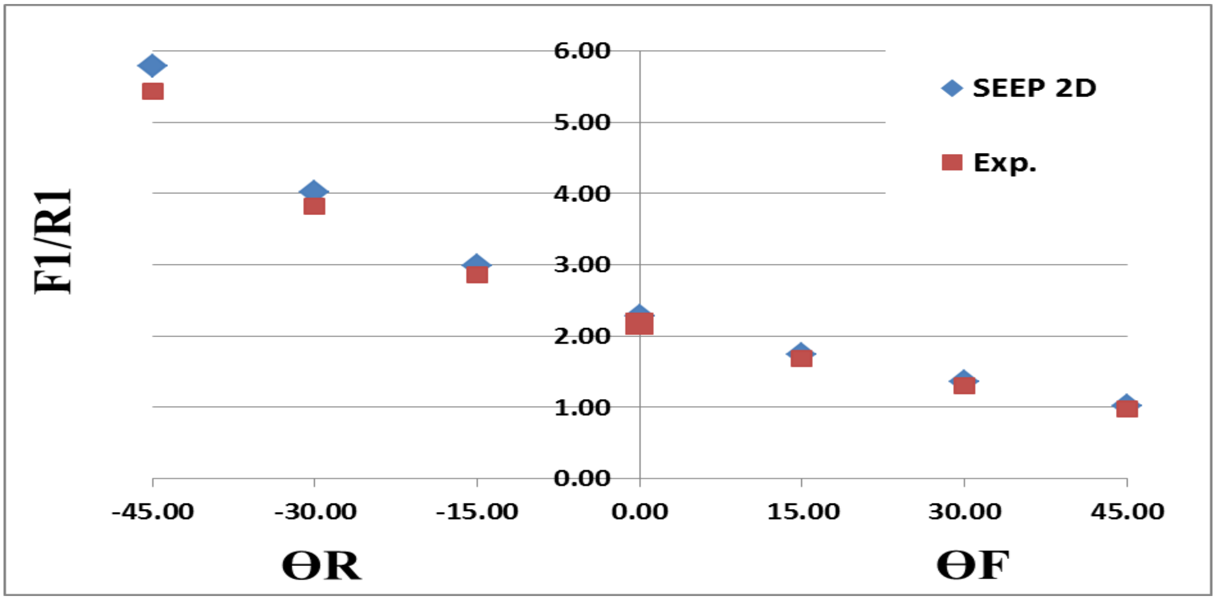

Figure (12): Electric analogue versus SEEP2D results (F1/R1) for 2 CO

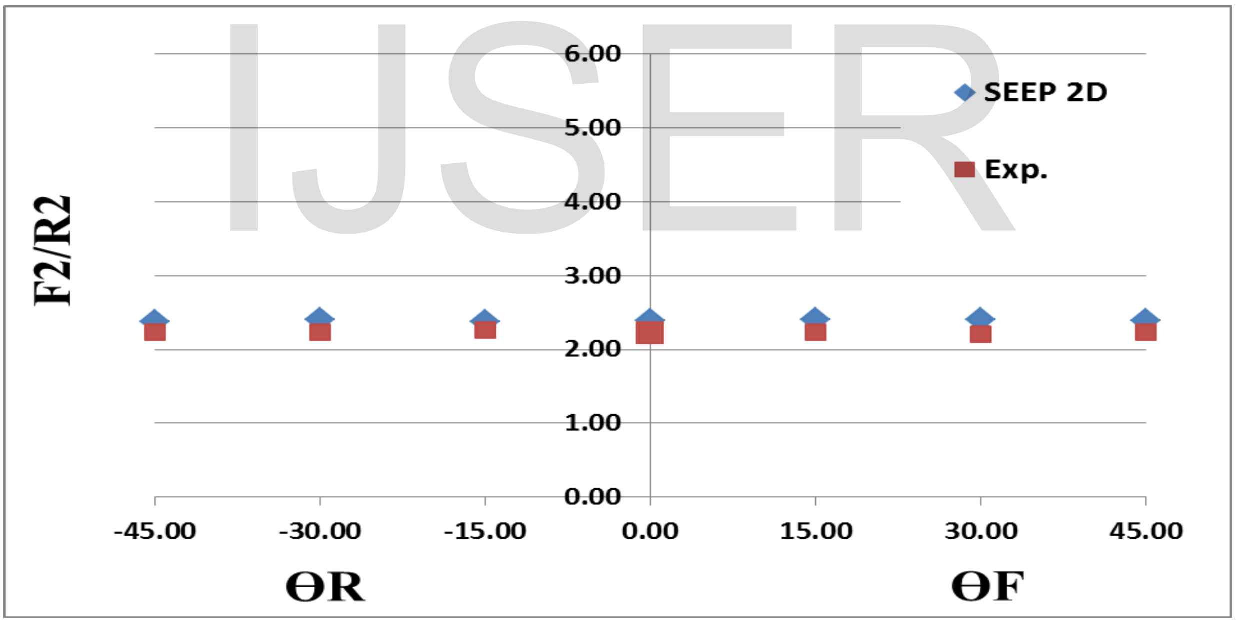

Figure (13): Electric analogue versus SEEP2D results (F2/R2) for 2 CO

6. CONCLUSIONS AND RECOMMENDATIONS

The following are the deduced conclusions:

- There is a good agreement as the results are found to be very close at most measured points; also electric analogue gives (F/R) less than SEEP2D with ratio from 4% to 8%.
- The research flagged out that the suitable CO inclination angle.
- The research confirmed that increasing CO efficiency reduces apron cost.

The following are the suggested recommendations:

- A wider range of influencing parameters should be investigated numerically
- A wider range of influencing parameters should be investigated experimentally.

8. LIST OF REFERENCES

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APPENDIX NOTATION

The following symbols are used in this paper:

C_B = Bligh's coefficient.

C_L = Lane’s coefficient.

d = Average diameter of particles.

D = Depth of cutoff.

d_d = Downstream depth of water.

F = Potential difference along front face.

R = Potential difference along rear face.

g = Gravitational acceleration.

h = Pizometric head.

H = Total net potential difference.

K = Coefficient of permeability of soil.

L_{hz} = Total horizontal length of apron.

L_V = Total vertical length of apron.

L_W = Percolation length according to Bligh.

R = Potential difference along rear face.

T = Thickness of pervious stratum.

v = Seepage velocity.

X = The horizontal distance of cutoff meaured from upstream the apron in a downstream direction.

γf = Specific weight of floor material.

γ_W = Specific weight of water.