JAITA

http://publisher.uthm.edu.my/ojs/index.php/jaita

e-ISSN : 2716-7097

Journal of Advanced Industrial Technology and Application

Hydrostatic Force on Submerged Gate: Computer Based Program Analysis

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DOI: https://doi.org/10.30880/jaita.2021.02.02.009
Received 10 November 2021; Accepted 30 November 2021; Available online 15 December 2021

Abstract: Resultant force caused by the pressure loading of a liquid acting on submerged surfaces are known as Hydraulic force. Calculating the hydrostatic force is necessary to design a building that can resist forces due to its fluid. There are 2 conditions of the submerged surface, those are fully submerged and partly submerged. In this study, three scenarios will be used for developing computer-based program for calculating hydrostatic force and will be compared to manual calculation. The numerical analysis will be conducted using GNU Octave, version 6.2.0. The scenarios are fully submerged plane with 90°, fully submerged plane with inclination angle and partially submerged plane with inclination angle. Overall, from scenario one to three, the percentage differences are 0%, with the mean percentage difference of the program is 0%. Hence, it satisfies all the elements that need to be checked based on the hydrostatic force calculation in Fluid Mechanics.

Keywords: Hydraulic, hydrostatic, submerged gate, computer-based program

1. Introduction

Hydraulic structures constructed for the purpose of retaining water are subjected to hydrostatic forces as long as water is at rest. Hydrostatic forces are the resultant force caused by the pressure loading of a liquid acting on submerged surfaces [1]. Calculation of the hydrostatic force and the location of the center of pressure are fundamental subjects in fluid mechanics [2]. The center of pressure is a point on the immersed surface at which the resultant hydrostatic pressure force acts [3]. There we are able determine the magnitude, direction and location of these forces. Hydrostatic force on submerged flat surface is given by equation F = ρghcA where ρ is the density of water, g is the gravitational constant, hc is the distance from the water surface to the centre of gravity (centroid) of the submerged flat surface and A is the area of the submerged flat surface [4]. The force, F acts through the center of pressure at hp whereby the center of pressure is lower than the center of gravity [5]. Hence there are two situations we can consider which is to determine the hydrostatic force due to water acting on a partially or fully submerged surface. The theory of hydrostatic pressure can be applied to various applications in our daily lives [6]. For example, elevated water tanks that are filled by water pumps. Water can be driven into lower-lying residences without the use of extra pumps due to the consequent hydrostatic pressure. The water level in the tower lowers slowly due to the vast water reservoir, which is normally several million litres. This maintains steady water pressure until the water level drops below a specific level, at which point the water is pushed again.

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1.1 Equation and Formula

Designing storage, tunnel, and gate inside the water varies each time, this happens because the force acting on the surface in the water develops due to the fluid [7]. Therefore, calculating the hydrostatic force is necessary to design a building that can resist forces due to its fluid as shown in Fig. 1 [8].

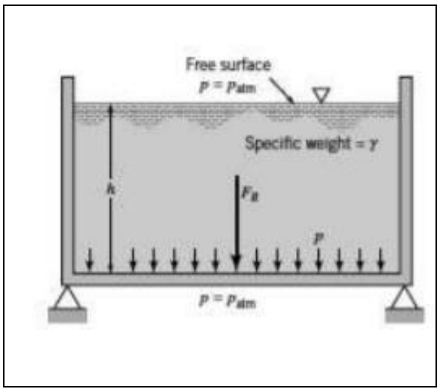


Fig. 1 - The hydrostatic force on horizontal plane

It is important to note that if air pressure operates on both sides of the bottom, the force on the bottom is merely due to the weight of the liquid in the tank. The resulting force acts through the bottom because the pressure is steady and equally distributed [9]. The area's centroid in the more general instance where a submerged planar surface is present, the determination of the resultant force acting on the surface is more complicated when the surface is sloped. The force acting on a planar surface is due to pressure, then the equation for the force acting on the area is [10].

$F = \rho g h c A$ (1)

ρ = Water density

g = Gravitational force

hc = Depth of water to the object A = Area of the object

It is also needed to calculate the force location acting in the middle of the pressure

$hp = \frac{IC \sin^2 \theta}{Ahc} + hc$ (2)

Ic = Moment inertia of the plane Θ = The inclined angle.

1.2 Graph and Figures

Since there are 2 conditions of the plane as shown in Fig. 2, those are fully submerged and partly submerged, therefore, it is needed to calculate each hc differently.

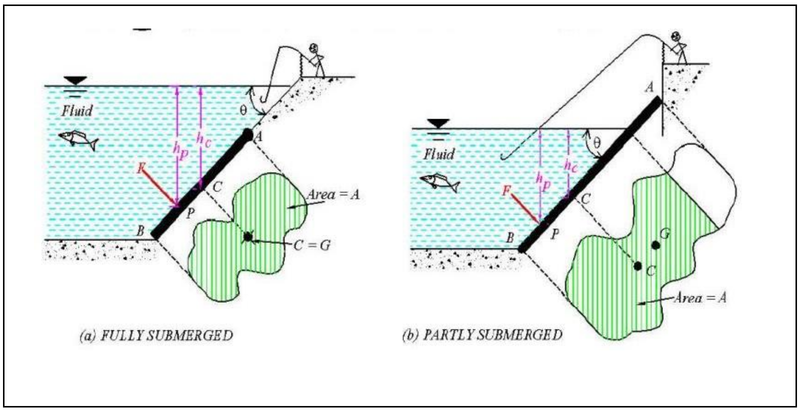


Fig. 2 - Inclined submerged plan surface

I. Fully Submerged

$$hc = d - \left(\frac{h}{2}\right) \quad (3)$$

d = Water depth
h = Height of the gate

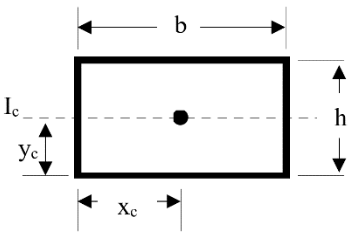
II. Partly Submerged

$$hc = \left(\frac{d}{2}\right) \quad (4)$$

d = Water depth

To calculate the hp it is also needed to find the moment inertia of the plane [1], since the plane itself is rectangular, therefore the calculation can be found here in Table 1.

Table 1 - F acts at the plane surface perpendicular to the wetted surface

Shape	Sketch	Area, A	Loc. Of Centroid	M. of Inertia, I_c or I
Rectangle		$A = bh$	$y_c = \frac{h}{2}$ $x_c = \frac{b}{2}$	$I_c = \frac{bh^3}{12}$

2. Case Study Scenarios

The analysis will implement three scenarios which are fully submerged plane with 90 fully submerged plane with inclination angle and partially submerged plane with inclination angle. The diagram of the scenarios is shown as Fig. 3 to Fig. 5.

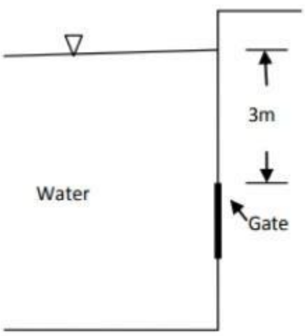


Fig. 3 - Fully submerged plane with 90° angle

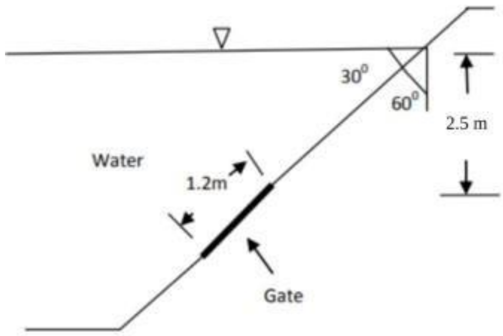


Fig. 4 - Fully submerged plane with inclination angle

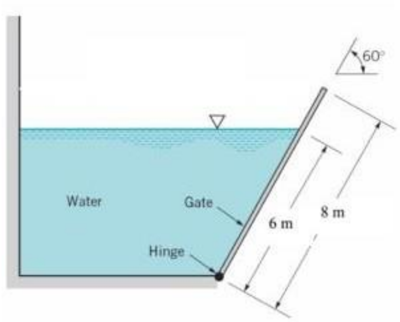


Fig. 5 - Partially submerged plane with inclination angle

3. Methodology

The numerical analysis will be conducted using GNU Octave, version 6.2.0. The flowchart for developing the analysis isshown as Fig. 6.

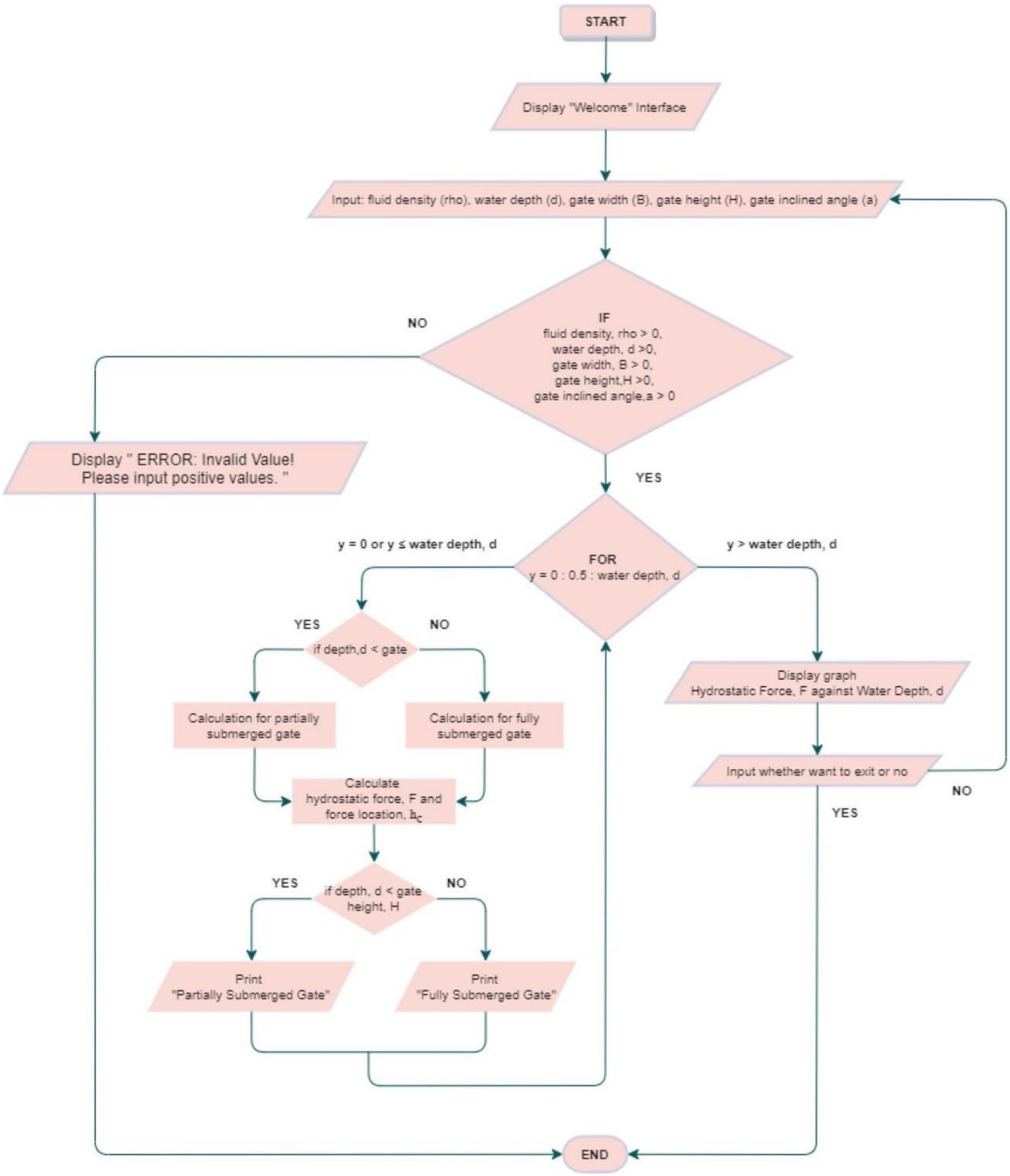


Fig. 6 - Flowchart in developing numerical analysis using octave software

3.1 Octave Code

The first part of the code is mainly focusing on input data from the user as shown in Fig.7 below. All the data will be later displayed in table form.

```
clc,clear

% Headline %
fprintf('\n\n\n\t\t\t---------------------------------------------------------------------------------')
fprintf('\n\t\t\t\tWELCOME TO HYDROSTATIC PRESSURE FOR SUBMERGED GATE CALCULATOR')
fprintf('\n\t\t\t-------------------------------------------------------------------------------')

% Input data from user %
fprintf('\n\n\n\tPlease input the data below in positive values only\n\n')

rho=input ('        Fluid Density (kg/m^3) = ');
d=input ('        Water Depth (m) = ');
B=input ('        Gate Width (m) = ');
h=input ('        Gate Height (m) = ');
ar=input ('        Inclined Angle of Gate (radian) = '); %angle from surface of water to gate in radian

function al=degree(ar)  %UDF
  al=ar*(180/pi); %changing rad to degree
end

a=degree(ar);
g=9.81;

%table
fprintf('\n\t_______________________________________________________________________________________________')
fprintf('\n\n\tWater Depth (m)\t\tHydrostatic Force (N)\t\tForce Location From Surface Water (m)\t\t\tCondition of Gate\n')
fprintf('\t_______________________________________________________________________________________________\n')
```

Fig. 7 - Octave code for input data

The second part of the coding were focusing on the data for each scenario which is the fully submerged and partially submerged plane as shown in Fig. 8.

```
% IF ELSE CONDITION
if rho>0 && d>0 && B>0 && h>0 && a>0
i=0;
  for y=0:0.5:d
    if d<h
    i=i+1;
    d=y;

          %Partially Submerged
           A=B.*d; %rectangle
           hc=(d.*sind(a))/2;
           Ic=(1/12).*(B.*d.^3);

    else
    i=i+1;
    d=y;

          %Fully Submerged
          A=B*h;
          hc=d+((h.*sind(a))/2);
          Ic=(1/12).*(B.*d.^3);

    end

  F(i)=rho*g*A.*hc;
  F(1)=0;

  hp(i)=hc+(Ic.*(sind(a)).^2/(hc.*A));
  hp(1)=0;
```

Fig. 8 - Octave code for scenario

The last part of the coding focusing on generate and displayed the result as shown in Fig. 9.

```
      %Print Results

      if d<h
      fprintf('\n\t%10.2f           %18.2f       %25.2f\t\t\t\t\t    PARTIALLY SUBMERGED GATE', [d,F(i),hp(i)])
      else
      fprintf('\n\t%10.2f           %18.2f       %25.2f\t\t\t\t\t      FULLY SUBMERGED GATE', [y,F(i),hp(i)])
      end

   end

else
  clear,clc
  fprintf('\n\t\tERROR: Invalid Value! Please input positive values.\n')
  fprintf('\n****************************************************************************')
  fprintf ('\n\t The programme will be terminated. Please re-enter the programme. ')
  fprintf('\n****************************************************************************')
return;

end
 dlmwrite('HydrostaticForce.txt',F','  ',3,5)


%Plotting Graph
        z =0:0.5:d;

        plot(z,F,'r-p')

        xlabel('Water Depth(m)')

        ylabel('Hydrostatic Force(N)')

        title('Hydrostatic Force(N) vs. Water Depth(m)')
```

Fig. 9 - Octave code for plotting the result

4. Result and Discussion

The main objective to code a program for hydrostatic force is to make the work of engineers easier, by calculating the force using the program they will have faster results and have the same accuration by calculating manually, as the program itself based on the formula. Other than stated above by determining the hydrostatic force, and force location, the engineers can save their time for designing the structure below the water and can proceed to determining the calculation based on the site, rather than time-consuming only theoretically.

$$\text{Percentage difference (\%)} = \frac{\text{Theoretical calculation} - \text{Program calculation}}{\text{Program calculation}} \; x \; 100 \qquad (5)$$

Based on the first scenario (Fully Submerged Plane with 90°) of the manual calculation and the program calculation, both got 101.63kN as the value of the hydrostatic force, thus, there is 0.0000 % percentage difference between theoretical and the program calculation. Based on the second scenario (Fully Submerged Plane with Inclination Angle) of the manual calculation is 53.33kN while from the program calculation is 53.32kN, as the value of the hydrostatic force, thus, there is 0.0002% percentage difference between theoretical and the program calculation. Based on the third scenario (Partially Submerged Plane with Inclination Angle) of the manual calculation is 612.14kN while from the program calculation is 611.69kN, as the value of the hydrostatic force, thus, there is 0.0007% percentage difference between theoretical and the program calculation. Overall, from scenario one to three, the percentage differences are 0.0000%, 0.0002%, and 0.0007% respectively, with the mean percentage difference of the program is 0.0003%. Table 2 shows the differences result of calculation using the manual calculation and by using the calculation from the program.

5. Conclusion

The difference between manual calculations with computer-based analysis using octave is 0% which is too small. Hence, it can be concluded that it satisfies the main objective and satisfies all the categories which is fully submerged plan with 90° angle, fully submerged plane with inclination angle and partially submerged plane with inclination angle that need to be checked based on the hydrostatic force calculation in Fluid Mechanics. Thus, this study will help any consultant, contractor and owner to construct a damp, a tunnel, and any structure that related to water pressures at different depths. Furthermore, it will help to reduce the costing due to shorter time period.

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