International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 6, Issue 1, pp: (232-236), Month: April - September 2018, Available at: www.researchpublish.com

Design Optimization of Cellular Cofferdam using Genetic Algorithms

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Abstract: **This paper presents a procedure to optimize the design of circular cellular cofferdam structures using genetic algorithms. The design of the cellular cofferdam structures is usually done using a trial and error procedure whereby a designer usually considers a trial design based on previous experience of a designing a similar structure and checks for its feasibility for the given site conditions. This however is not the most cost effective design. In this paper a circular type cellular cofferdam is designed by minimizing the cost of materials required for the construction of the cofferdam. The stability of the design is ensured by keeping constraints on the design of the dam to protect against various modes of failure. The cost is minimized by using genetic algorithms, and the design corresponding to the minimized cost is the optimum design of the cofferdam.**

Keywords: **cellular cofferdam structures, circular type, genetic algorithms.**

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1. INTRODUCTION

Cofferdam is a temporary structure constructed into a waterway to contain or divert the movement of water and provide a reasonably dry construction area. It involves the interaction of structure, soil and water. The loads imposed on it include the hydrostatic forces of the water, as well as the dynamic forces due to currents and waves. The different types of cofferdams include the braced type, earth-type, timber crib type, double-walled sheet pile type and cellular type. Cellular cofferdams are the most suitable for moderate to large heights. This type of structure is widely used to provide a dry work area where dams are constructed in rivers and for water front construction.

A cellular cofferdam is made of two components, namely steel cells and cell fill. The steel cells are fabricated from the steel sheet piles. The cell fill should be free draining granular soil with high angle of friction, large density, large resistance to scour and leakage. Normally, mixed soil deposits of mixed soil and gravel possess all of these desirable properties and as such are the best materials for the cell fill.

The cellular structure is economical since stability is achieved using a soil cell fill for mass, which is relatively cheap. The sheet piling in steel cells may be pulled out and reused. Also it is not usually necessary to drive the piling to great depths, thus avoiding damage to the piles. To achieve a cell that is stable against bursting it is necessary that the sheet piling be driven so that continuity of interlocks is maintained.

Circular type cofferdams consist of individual large diameter circles connected together by arcs of smaller diameter. These arcs usually intersect the circles at a point 30°or 45° with the longitudinal axis of cofferdam. They are often perpendicular to the circle, but occasionally different angles may be used. The main advantage of the circular cellular cofferdam is that it will not collapse in the event of failure of adjoining cells. They also require less number of piles per lineal meter of cofferdam as compared to the diaphragm type of an equal design.

2. TYPES OF IMPOSED LOADS

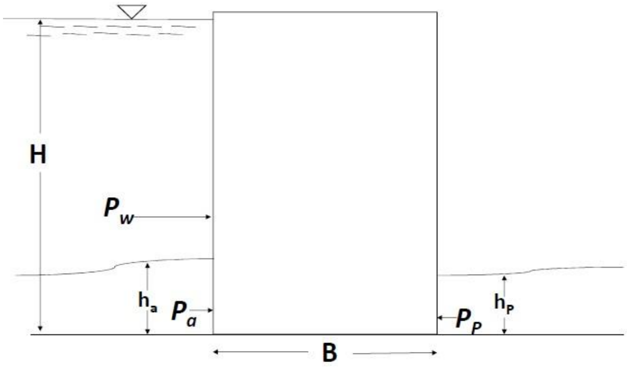

Figure 1: Loads on cofferdam

1. Hydrostatic Pressure

Force due to water: $$P_w = \frac{1}{2}\gamma_w H^2 \tag{1}$$

γ_w = weight per unit volume of water

H = height of the water body

This force will act at a height of $H/3$ from the base of cofferdam.

2. Force due to Soil Loads

Active Earth Pressure: $$P_a = \frac{1}{2}\gamma_0 K_a {h_a}^2 \tag{2}$$

Passive Earth Pressure: $$P_p = \frac{1}{2}\gamma_0 K_p {h_p}^2 \tag{3}$$

K_a, K_p = coefficient of active and passive pressure respectively

h_a, h_p = height of soil from rock level

γ_0 = weight per unit volume of submerged soil

The forces will act at a height of $h_a/3$, $h_p/3$ from the base of cofferdam respectively.

3. COST MODEL

The optimum design of the cofferdam may be characterized by the design in which the cost of materials required for construction is minimized. The materials used in large quantities in the construction of the cellular cofferdam are mainly cellular fill and sheet piles. We can minimize the cost of materials by adjusting the cofferdam dimensions appropriately. We shall fix the height of the cofferdam as equal to the maximum flood level of the water body.

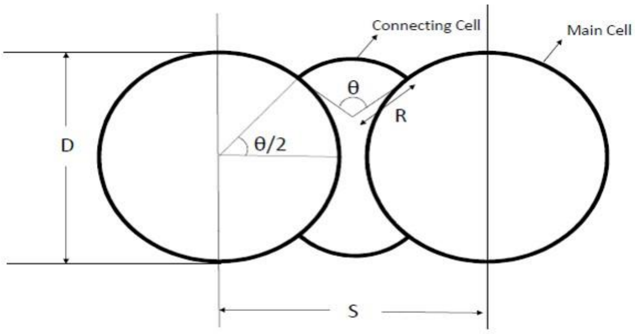

Figure 2: Plan view of cofferdam

Area of section: $A = \frac{\pi}{4} D^2 + \left(\frac{\theta}{180}\pi - \sin\theta \right)\left(R^2 - \frac{D^2}{4} \right) + 2RD\left(\sin\frac{\theta}{2} \right)^2$ (3)

Perimeter of section: $P = \pi D + \frac{\theta}{90}\pi R$ (4)

Section length: $S = 2R\sin\frac{\theta}{2} + D\cos\frac{\theta}{2}$ (5)

Average width: $B = \frac{A}{S}$ (6)

Volume of cell fill required (in m^3): $V_{cf} = \frac{L}{S} AH$ (7)

Weight of sheet piles required (in kg): $W_{st} = \rho \frac{L}{S} PH$ (8)

H = height of cofferdam

D = diameter of the cell

ρ = sheet pile area density

L = length of cofferdam

R = radius of connecting arc

The cost of the cofferdam will be directly proportional to the volume of cell fill as well as the weight of steel used. The two constants of proportionality may be considered equal to the cost of cell fill per m^3 (K_{cf}) and the cost of sheet piles per kilogram (K_{st}) respectively. Hence the cost function which will be used for design optimization is

$$f\left(D, R, \theta\right) = \left(K_{cf} \times V_{cf}\right) + \left(K_{st} \times W_{st}\right) \tag{9}$$

We will have to minimize $f(D,R,\theta)$ to calculate the cofferdam dimensions which will give us the optimum design of the cellular cofferdam.

4. DESIGN CONSTRAINTS

To ensure the stability of the designed cofferdam, we will need to set certain constraints on the design of the dams. The constraints shall ensure that the dam is safe against various modes of failure.

- Resistance to sliding

$$F_s = \frac{F_f + P_p}{P_w + P_a} \geq 1.25$$

F_f is the frictional resistance developed on the base of cell and is equal to $W \tan\varnothing$

($W = HB\gamma_1 + \frac{1}{4}B^2\left(\gamma - \gamma_1\right)$ is the weight of the fill inside the cell assuming a 2:1 slope of saturation line and Ø is internal angle of friction)

Constraint-1: $\left((HB\gamma_1 + \frac{1}{4}B^2\left(\gamma - \gamma_1\right))\tan\varnothing + P_p \right) - 1.25\left(P_w + P_a\right) \geq 0$ (10)

- Resistance to overturning-slipping of sheet piles

$$F_s = \frac{\left(P_w + P_a\right) B \tan\delta}{P_w \times \frac{H}{3} + P_a \times \frac{h_a}{3}} \geq 1.25$$

(where δ is friction angle between fill and sheet pile)

$$\text{Constraint-2:} \quad \left(P_w + P_a\right) B \tan\delta - 1.25\left(P_w \times \frac{H}{3} + P_a \times \frac{h_a}{3}\right) \geq 0 \qquad (11)$$

- Interlock stress at the joints

$$t_{max} = \frac{3}{8}(\gamma_w + K_a\gamma_0)\left(H - h_a\right)\left(2R\tan\frac{\theta}{2} + D\right) \leq t_{allowable}$$

$$\text{Constraint-3:} \quad t_{allowable} - \frac{3}{8}(\gamma_w + K_a\gamma_0)\left(H - h_a\right)\left(2R\tan\frac{\theta}{2} + D\right) \geq 0 \qquad (12)$$

5. GENETIC ALGORITHM

Genetic Algorithm (GA) is the optimization tool that will be used in optimizing the design of the cofferdam. GA is an iterative process that uses genetic operators such as reproduction, cross over and mutation. The steps involved in application of GA are

1. All variables in the optimization problem are represented in binary form.
2. We select binary numbers of appropriate lengths randomly. These selected numbers need to satisfy all the constraints. Length of the string is determined according to the desired solution accuracy.
3. Suitable parents are selected using any of the following methods such as tournament selection, roulette selection etc.
4. We then perform a cross over on two numbers selected from the parent pool.
5. Mutation is performed in the new off springs. The mutation process involves the interchange of the values 1 and 0 at a randomly chosen site.
6. If the selected variable violates the constraints at mutation, then the variable is discarded and a new number is generated. Steps 3 through 4 are repeated for the predefined number of generations. The best solution will be given at the end of all the iterations.

6. OPTIMIZATION USING GA

The function $f(D,R,\theta)$ is minimized subject to the constraint equations and the design variables of the cofferdam '*D*' and '*R*' are then obtained.

- Due to practical constraints θ cannot take any arbitrary value, hence we will check the results for θ equal to 30°, 45° and 60°.
- We use the optimization tool in Matlab i.e. optimtool for the optimization process. The cost function is set as the fitness function and the three constraint equations are considered as the nonlinear constraint function.
- The design variables '*D*' and '*R*' are set as the variables of GA.
- The lower bound of the design variables is set as [0 0] and the upper bound is not set as the dimensions should be positive numbers.

Table 1: GA Parameters

Parameter	**Value**
Population type	Double vector
Population creation function	Constraint dependent
Fitness scaling	Rank

Selection function	Roulette
Reproduction crossover fraction	0.8
Crossover function	Scattered
Mutation function	Constraint dependent
Migration direction	Forward
Other parameters	Default values

Numerical Example:

Table 2: Design Parameters

Parameters	**Value**
Height of cofferdam (H)	18.2 meters
Length of cofferdam (L)	100 meters
Cost of cell fill per m^3 (K_{cf})	₹400
Cost of sheet piles per kg ((K_{st})	₹10
Internal angle of friction of fill (ϕ)	35°
Friction angle between fill and sheet pile (δ)	30°
Sheet pile area density (ρ)	140 kg/m^2
Allowable interlock tension ($t_{allowable}$)	1400kN/m
Weight per unit volume of cell fill above saturation line (γ)	17kN/m^3
Weight per unit volume of cell fill below the saturation line (γ_1)	11kN/ m^3
Weight per unit volume of submerged soil (γ_0)	11kN/ m^3
Coefficient of active pressure (K_a)	0.27
Height of submerged soil on the outer side (h_a)	3 meters
Coefficient of passive pressure (K_p)	3.69
Height of submerged soil on the inner side (h_p)	0 meters

Using the above design parameters, we determine the three constraint equation and the cost function is minimized using GA. The following solutions are obtained for different value of θ.

Table 3: Optimization results

θ	***D***	***R***	**Cost of materials = $f(D,R,\theta)$**
30°	15.241 m	3.051 m	₹ 1.578 crores
45°	13.975 m	2.479 m	₹ 1.544 crores
60°	12.550 m	1.842 m	₹1.529 crores

We observe that we get the lowest cost for θ=60° and the corresponding values of D and R are 12.550 meters and 1.842 meters respectively.

7. CONCLUSION

We get the minimum cost of materials required for constructing the cofferdam with the value of design variables D=12.55 meters, R=1.842 meters and θ=60°. We observe that the cofferdam designed with the above design parameters is safe against modes of failure, such as sliding, overturning and excessive interlock stress. Hence we were able to provide the most cost effective design for the given design parameters and physical conditions. In a similar manner we can design many structures using this method using an appropriate cost model and the constraint equations corresponding to the failure modes of that particular structure.

REFERENCES

[1] Neghabat, F., and Stark, R.M. (1972). “A Cofferdam Design Optimization.” Mathematical Programming 3 North-Holland Publishing Company, 263-275.

[2] Nemati, K.N. (2007). “Cofferdams.” Temporary Structures CM-420. University of Washington.

[3] Murthy, V.N.S. (2007) “Cellular Cofferdam.” Advanced Foundation Engineering, CBS Publishers and Distributors, 593-607