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Research Article

SHAPE OPTIMAL DESIGN OF AN EARTH DAM, USING ARTIFICIAL BEE COLONY ALGORITHM

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ABSTRACT
Earth dams are one of the most important types of dams. In earth-type dams, the main component providing the dam with stability and resistance against driving forces like hydrostatic kinds, is the dam weight. Considering great volume of earth materials, dam section shape optimum designing will result in reduction of consumed materials and costs. In this paper, according to importance of earth-dams stability, determining an optimum section - shape for these types of dams is the point of concentration. So Artificial Bee Colony (ABC) algorithm has been used for achieving our desired goal. Artificial Bee Colony method tries to model natural behavior of bee swarm looking for the food resource with the maximum amount of nectar. Results earned form bee colony algorithm indicate that upstream face slope and optimum quantity of dam down base length gained from optimization, in addition to providing stability conditions against sliding and overturning and satisfying stability situation related to dam slope, minimize dam total weight

Keywords: *Earth Dam, Optimization, Artificial Bee Colony Method (ABC), Stability and Weight of the Dam*

INTRODUCTION
Earth dams are of those types called "reservoir dams". Such dams make a storage place for water in their upstream and therefore, an increase in free water level. Gravity embankment dams often have high height and relay on their weight for their stability.
It should be noted that, while constructing dam or its side structures like spillway and stilling basin, if designer consider higher capability criteria for dam failure than what relay needed, costs will be flying above the normal. On the other hand, ignoring necessary failure boundaries by designing parameters quantities lower than needed, will result in disasters like dam- break. So, obtaining an optimum section for weight – embankment dams, reduces the consumption of materials and therefore, the costs. Besides, it satisfies the stability criteria for dam structure.
Concrete arch dams own the most researches performed on optimizing section-shape. Bofang (1992) has conducted researches on the optimization of arch dams section shapes. In order to create the geometry of dams as horizontal sections, he proposed circle patterns with one or multiple centers, and parabolic and elliptical patterns. Fanelli *et al.,* (1996) conducted researches on optimizing the shape of arc dams using artificial neural networks method. Li *et al.,* (2009) tried their chance on optimum designing of arch dams using modified complex methods. Earthquake effect on optimum shape of arch dams considering interactions between water and dam structure, was investigated by Seyedpoor (2009). They achieved optimum shape of dam section using a set of optimization methods (e.g. pso method). Zho (1990), Zho *et al.,* (1992), Zho (2000), Gholizadeh and Seyedpoor (2011), Seyedpoor *et al.,* (2010) are the other researches who have worked on this issue. Simoez and Lapa (1994) and Simoez (1995), performed determination of weight -concrete arch dam optimum section shape. It should be noted that they considered static and dynamic forces simultaneously. Fairbairn *et al.,* (2003) represented optimizing procedure of constructing huge concrete structures like dams in which due to cement hydration in fresh concrete, thermal and contraction strains occur, using genetic algorithm. Shouyi *et al.,* (2005) optimized ash dam, using gridding method.
Noorzad and Rezaeian (2011) conducted a research on optimizing earth dam section shape optimization, using Ant Colony Optimization (ACO) algorithm. Noorzad and Rezaeian (2011) used 4 different ACO

algorithms to optimize earth dams' section shapes. It was showed that for earth dams and dikes with the height less than 40 meters constructed with coarse-grained materials on extremely strong rock foundation, compared to the cases without platforms, we can have an 10% reduction of earthworks amount in the case of using platforms in sufficient numbers and with suitable width and arrangement.

In the current paper, it is tried to obtain earth dams optimum section shape on rock foundations, using ABC algorithm.

It should be noted that in this study, the target function is the volume of the dam body which in this optimization procedure we want to minimize that volume. Constraints in this optimization are stability criteria's against sliding and overturning and also stability related to slope sliding. Besides designing variables which are experience optimization, are dam upstream face slope (the face connected to the reservoir) and dam basis length

MATERIALS AND METHODS

In this study the main section used is just the main section in figure 1, and dam weight and upstream hydrostatic forces are only used as main forces. Besides, foundation was considered rock. On the other hand, in order to calculate and determine forces affecting a weight- dam, width of dam was considered unit. Hence, noted forces are respectively as:

$$F = W = \gamma_c \mathrm{V} = \gamma_c \left[\frac{\mathrm{b} + \mathrm{b_c}}{2} (h_1 + F_b) \right] \tag{1}$$

$$F_{h1} = \frac{1}{2} \gamma h_1^2 \tag{2}$$

$$F_{v1} = \frac{1}{2} \gamma h_1^2 m \tag{3}$$

In which W, γ_c, V are the weight of dam, special weight of earth materials and volume of dam, respectively. Also, h_1, γ are reservoir normal water level and water special weight (9806 N/m^3), respectively. m is side slope of upstream face, b is the earth-dam down base length, b_c width of dam top value, and F_b free board.

Typically, width of earth dams top varies between 6 to 12 meters and increases with dam height growth. The formulas represented below, have been used to calculate dam top width.

$$\begin{cases} if \ \ 5 \le H < 10 \rightarrow b_c = 1.11\sqrt{H} + 3 \\ if \ \ 10 \le H < 30 \rightarrow b_c = 0.55\sqrt{H} + 0.2H \\ if \ \ H \ge 30 \rightarrow b_c = 3.64\sqrt[3]{H} - 1.83 \end{cases} \tag{4}$$

Besides free board values in short dams are considered at least 1.5 meters. However this quantity is mainly 4 % of the dam reservoir water depth.

In relation to weight earth dams, 3 points of view should be considered: stability against sliding, stability against overturning, and finally the stability of slopes.

Algorithm for optimizing earth dams' section shapes, is as below:

1- According to safety factor (SF), Stability against sliding is being used. This method can be applied for both short dams (with a height less than 15 meters) and high dams (with a height bigger than 15 meters). It should be noted that for short and high dams, considering financial and human being losses due to dam failure, this factor takes the minimum values of 1.5 and 1, respectively. So we set right side of the equation related to safety factor for sliding $SF = \frac{f' \sum F_v}{\sum F_h}$ equal to the value of this factor (according to dam height). In this equation, value of f' is considered as 0.7 for movement of materials on rock.

Therefore, there would be an equation with 2 indeterminate parameters of m and b. So here, another equation should be carried to calculations. The other equation is the equation of normal stress in the hell dam $\sigma_u = \frac{\sum F_v}{b} - 6\frac{\sum M_0}{b^2}$ whose value should be least 0. Zero value of this equation indicates that there would be no overturning for earth dam.

In the other words, having water depth h1, we could calculate m and b in a manner that in addition to satisfying desired conditions, target function of dam weight would have the minimum value.

2- In the next step, stability of earth dam against overturning is tested according to the $SF_{(over)} = \frac{\sum M_{E1}}{\sum M_{E2}}$, that $SF_{(over)}$ must result in a value greater than 1.5.

3- Stability of slope that belongs to sliding of declivitous domains in critical situations, is tested by the equation below and must have a value greater than 1.5.

$$S.F.S = 0.031h - 0.015\alpha + 0.079\gamma + 0.015C + 0.025\phi > 1.5 \quad (5)$$

It should be noted that in this paper, in order to optimize shape of dam section, ABC algorithm has been used. And target function (dam weight) should be minimized in a way that stability criteria against sliding, overturning, and over turning of slopes could be satisfied.

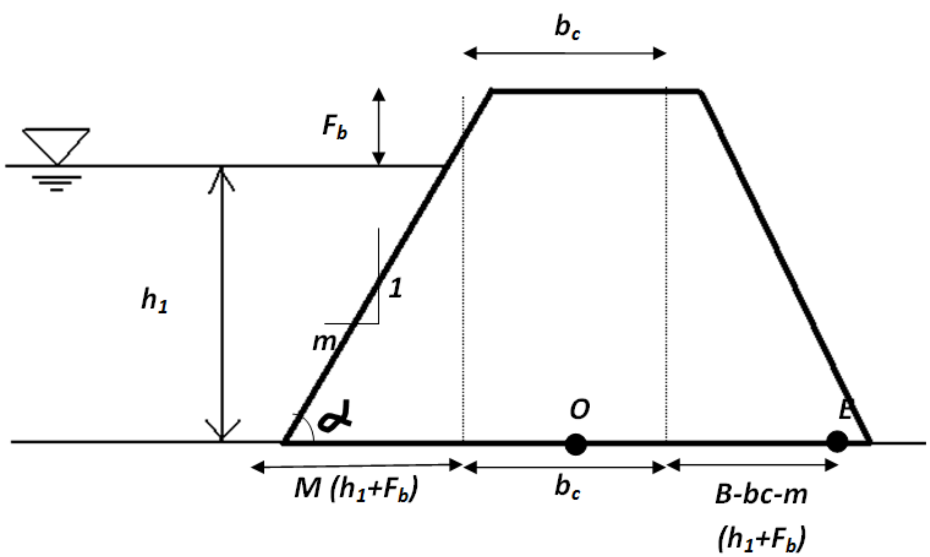

Figure 1: Shape of dam section in this study

Artificial Bee Colony Algorithm

ABC algorithm is a collective algorithm, based on foraging behavior of bee colony. This model has been established upon 2 main components: bees and food resources. 3 groups of bees are employed bees, onlooker bees and scout bees (Karaboga and Basturk 2007).

Main procedure of this algorithm is as:

1- Sending employed bees to find and evaluate amount and quality of the nectar of each food source

2- Onlooker bees watch employed bees dances, and evaluate the quality of food nectar source.

3- Determining scout bees and recruiting them to explore and discover new random seeds:

Primary position of food sources are initialized randomly and the each one's quality is calculated by employed bees. Then these bees share the information related to the quality of each source nectar with onlookers, by performing special dances.

Then each employed bee returns to his food source and memorizes the location of food source and after that starts searching around the source and its neighborhood for other new food sources. In last stage, onlooker bee chooses the food source using the information received from employed bees. Probability of choosing every food source has direct relation to its quality. Hence, the employed bee with the best information would have more chance to attract the onlooker bee. It means that the employed bee been successful in attracting onlooker, gives his food sources to onlooker bee and the employed bee himself starts searching the neighborhood of that source. Besides, a new food source is chosen by the scout bee in order to make the abandoned resources replaced.

RESULTS AND DISCUSSION

In this study, a type of clay with special mass of 2100 kg/m^3, friction angle of 19.5 ^{o} and adhesion of 30.8 kN/m^2 was chosen as the material of dam body.

Referring to figure 2, volume and weight of dam increase with h1 (water depth in reservoir) increases. This is a logical result. Moreover, it can be seen that for the greater values of h1, graph slope tends to be steeper. So, it could be expected that for higher dams, the percentage of optimized weight increase would be more compared to shorter dams.

Figure 3 represents variations of slope stability safety factor. As seen, for all heights this factor would be greater than 2 which is a sufficient value to make sure of slope stability. Moreover, as h_1 increases, the mentioned factor increases linearly too.

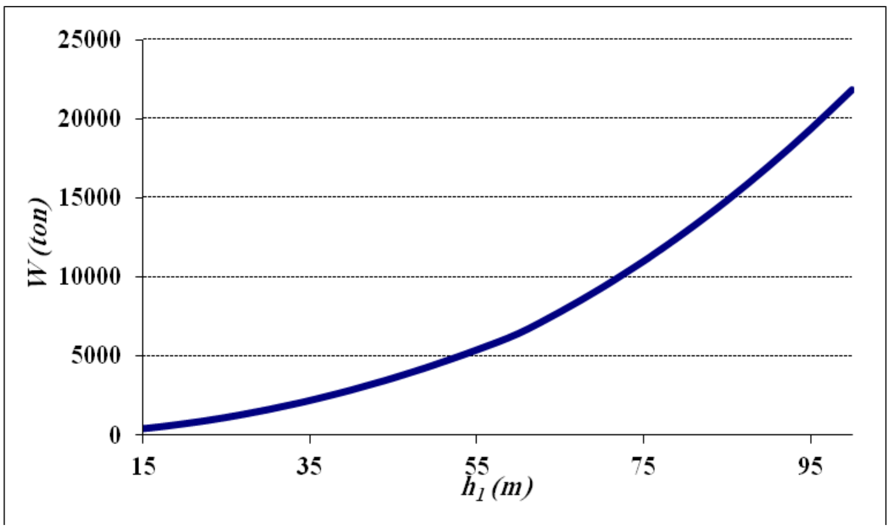

Figure 2: Illustrating the comparison between dam weight values in optimized section shape for high dams

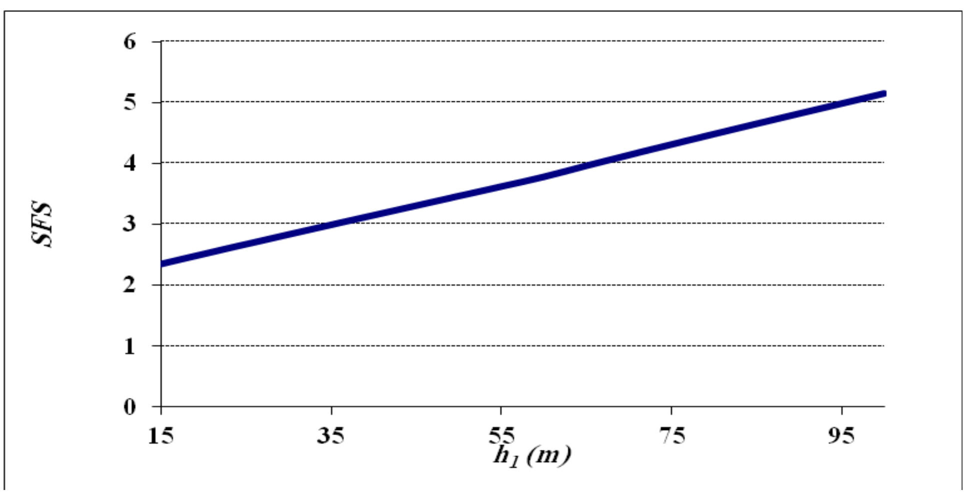

Figure 3: Shows the evaluating safety factor value of slope stability in optimized section shape for high dams

As figure 4 indicates, dam upstream face slope values in optimized mode increases with normal depth growth which in normal depth values bigger than 58 meters, increase in m value is noticeable.
Effects of optimization and reservoir water depth (h1) on safe sliding factor have been illustrated in figure 5. As seen, f value for all short dams height ranges, is greater than 0.45. Optimized results show that in h_1's values less than or equal to 58 meters, the f value related to the optimum section shape would be equal to 0.47. But for h1's values bigger than 58 meters, having increase in this parameter would result in f coefficient value reduction.

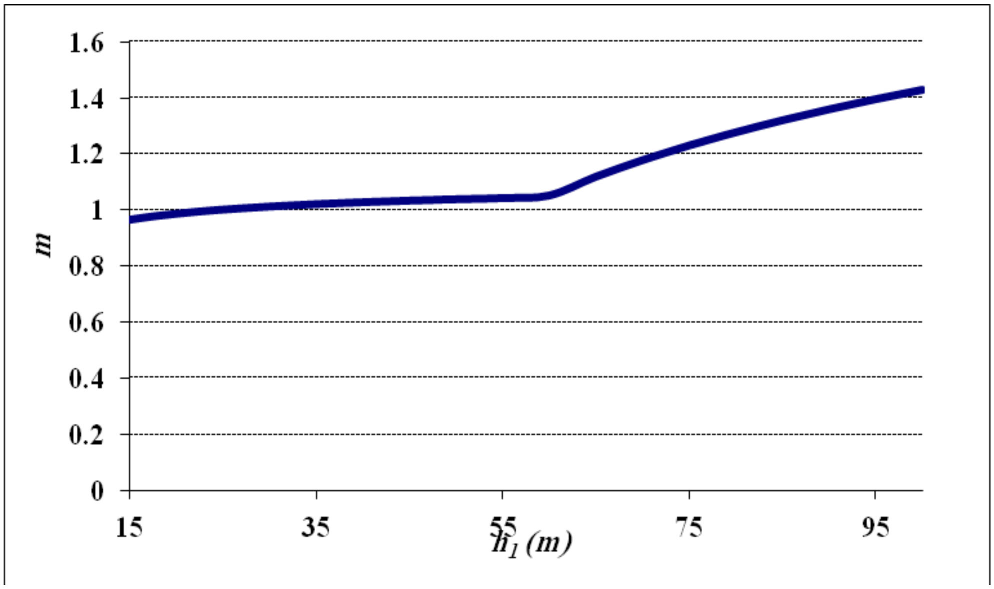

Figure 4: Comparison of optimum upstream face slope for high dams

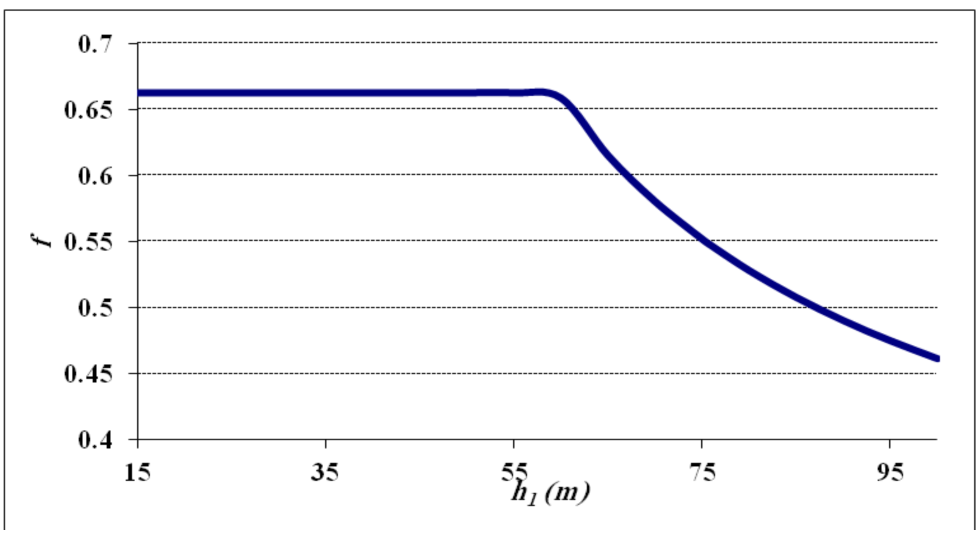

Figure 5: Comparison of safe sliding factor in optimized section shapes of high dams

As shown in figure 6, the safety factor against overturning is almost equal to 1.58 for all h1's values less than or equal to 58 meters. However, for values greater than 58 meters, quantity of this factor increases with normal depth growth. So, it can be concluded that all the safety factor values against overturning are greater than 1.5. In the other words, the optimized section is stable against overturning.
It should be noticed as seen in figure 7, safety factor value against sliding takes unit value till h1 increases to 58 meters and after that, it increases too.

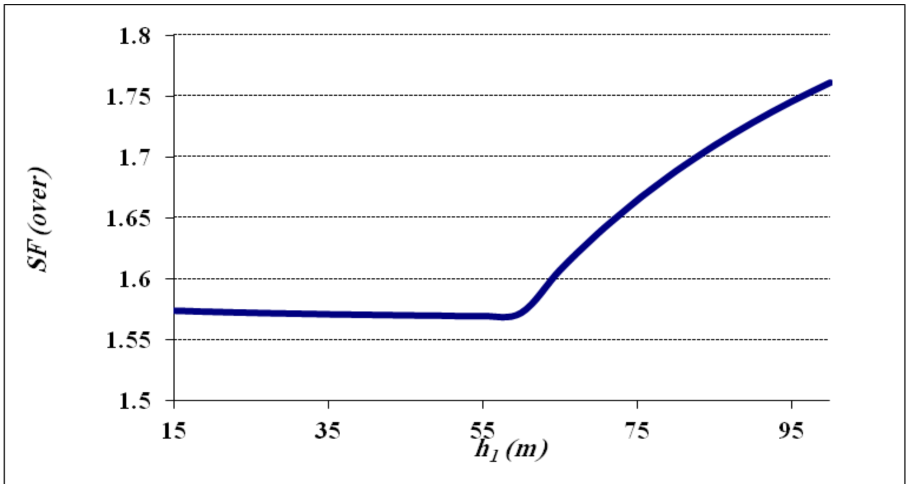

Figure 6: Illustrating comparison of safety factor against overturning in optimized section shapes for high dams

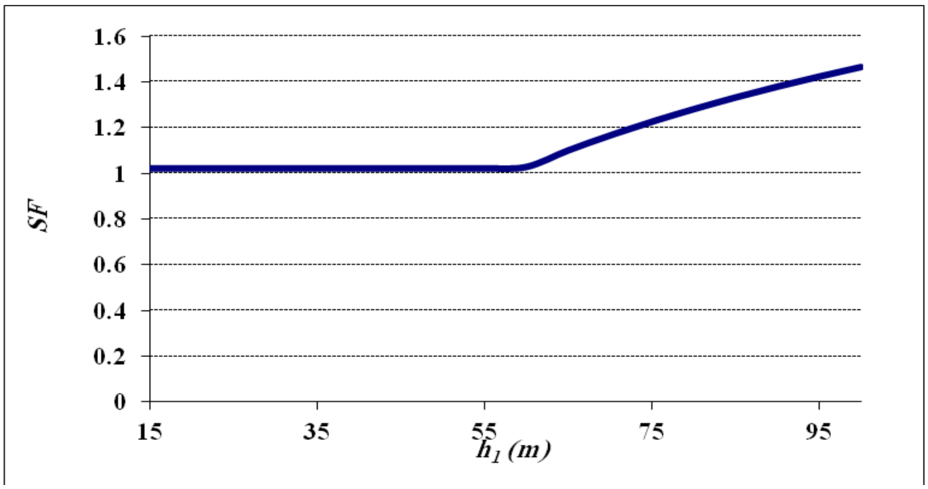

Figure 7: Shows the comparison of safety factor against sliding in optimized section shapes for high dams

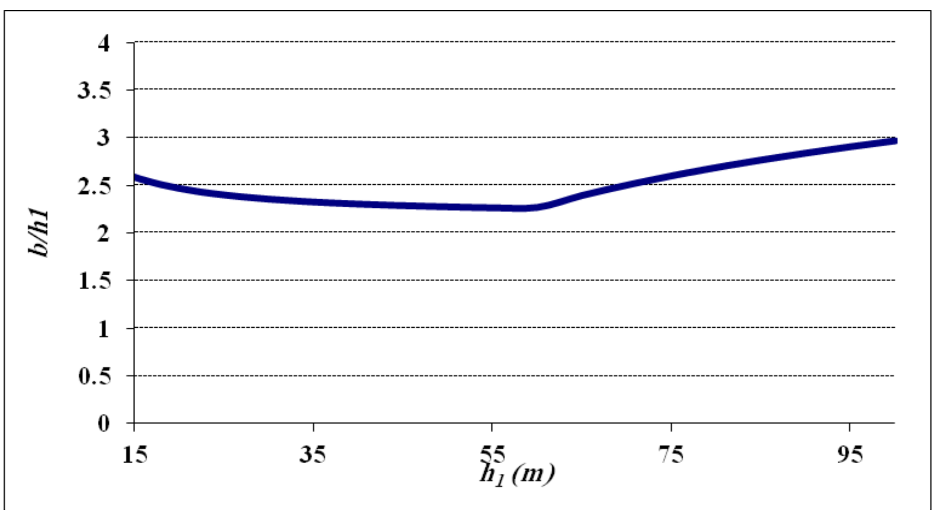

Figure 8: Represents comparison of b/h1 ratio in optimized section shapes for high dams

You could see in figure 8 that, the optimum quantity of the ratio b/h1 reduces when h1 increase from 15 meters to 58 meters. This reduction of b/h1 ratio, is seen more in normal depths smaller values compared to h1 depth bigger values. For the normal depths bigger than 58 meter, the ratio mentioned above increases with increase in reservoir normal depth.

Conclusions

1. As h1 value increases, dam weight and volume grow too. In h1's higher values, graph slope is steeper, so it could be expected that in higher dams, the percentage of optimized weight value growth will be more in comparison to shorter dams.
2. In all heights, safety factor value of slope stability exceeds 2, which is a sufficient value to make sure about slope stability.
3. Upstream face slope value in optimized- mode, increases with reservoir normal depth growth, which for the normal depth values bigger than 58 meters, m value increase noticeably.
4. f value is greater than 0.45. Optimized results show that for h1's values less than or equal to 58 meters, corresponding f value related to optimum section, takes a value equal to 0.47. But for h1's values bigger than 85 meters, increasing this parameter will lead to f factor reduce.
5. Amount of safety factor against overturning for the h1 heights less than or equal to 58 meters in optimized section, is almost equal to 1.58. But for h1 values bigger than 58 meters, it increase with reservoir normal depth growth. So it could be said that all the safety factors against overturning are bigger than 1.5. In the other words, the optimized section is stable against overturning.
6. Safety factor quantity against sliding stays takes unit value till h1 increases to 58 meters, after that factor increases too.
7. Optimum value of b/h1 ratio decreases when h1 increases from 15 to 58 meters and this reduction is seen more in reservoir normal depth smaller values, in comparison to reservoir normal depth bigger values. Moreover for reservoir normal depth values bigger than 58 meters, the mentioned ratio increases parallel to reservoir normal depth growth.

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