Cross Section Optimization of Gravity Type Block work Quay Walls Using Sequential Quadratic Programming Method

M. Shafieefar, A.R. Mirjalili

Abstract— Quay walls are waterfront structures for connecting land and sea, berthing and mooring of ships and facilitating loading and unloading cargo. Gravity structures are usually an excellent alternative for waterfront structures where the seabed soil condition is appropriate. Optimum design of block work gravity type quay walls with pre-cast concrete blocks is the object of this paper. The advantages of these quay walls are simple construction technology, preferred costs and good durability. In this research, a procedure for optimization of cross section of a block work gravity type quay wall is introduced and a numerical program for this procedure is developed. The main modes of failure of this gravity structure are: sliding, overturning, deep slip and foundation failure, therefore in the stability calculations settlement, circular slip, bearing capacity of the foundation, Sliding and Overturning at all horizontal surfaces between blocks should be examined. To study the behavior of a block work quay wall and to check the stability against probable different failure modes, a computer program has been developed. This program can easily consider the effects of different parameters such as section geometry of quay wall, material property and loading conditions in design. After reviewing design and construction considerations for such quay walls, available methods for optimum design of such structures are discussed and objective function, constraints and design variables are considered. The main constraints of the optimization problem in the present study are safety factors in various modes of failures. As the relation of safety factor with design variables is unknown, therefore, first a proper method should be used for approximating the objective function and constraints according to design variables. Then, an efficient method should be selected for formulating mathematical optimization of the objective function under existing constraints. For this purpose, the optimization of the cross section is accomplished using Sequential Quadratic Programming (SQP) method in the present work. Results indicate that the cross section of a block work quay wall has an important role in stability of the structure and one can reduce costs of such structures by optimizing the cross section. Finally, some recommendations for optimum design of this type of quay wall are presented.

Keywords— Cross Section, Optimization, Block Work, SQP Method, Quay Wall, Safety Factor

I. INTRODUCTION

The structural system of different quay wall alternatives can be categorized into: suspend deck, gravity and sheet pile types. Gravity structures are usually an optimum design as waterfront structures where the seabed soil condition is appropriate. If the thickness of the inefficient surface layer is low, this layer can be removed and replaced by efficient materials to improve the geotechnical condition of the seabed [1]. Some gravity walls are built behind a cofferdam in the dry but most walls are constructed in water by a method used only in maritime works, where large pre-cast units are lifted or floated into position and installed on a prepared bed under water. It is usual to use rubble or a free-draining granular fill immediately behind a quay wall so that the effects of tidal lag are minimized and earth pressure is reduced.

Gravity quay walls can be classified into different types such as caissons, L-shaped blocks, rectangular concrete blocks, cellular concrete blocks and cast in-place concrete. Optimum design of block work gravity type quay walls with pre-cast concrete blocks is the object of the present investigation. The advantages of these quay walls are: simple construction technology, preferred costs and good durability.

The external and environmental loads acting on these structures are Surcharge, Deadweight of the wall, Earth pressure, Residual water pressure, Buoyancy, Seismic forces, Dynamic water pressure during an earthquake and Tractive forces of vessels. The main modes of failure of this gravity structure are: sliding, overturning, deep slip and foundation failure, therefore in the stability calculations the following items should be examined in general: Settlement, Circular slip, Bearing capacity of the foundation, Sliding and Overturning at all horizontal surfaces between blocks.

To study the behavior of a quay wall and to check the stability against probable different failure modes, first a computer program has been developed. This program can easily consider the effects of different parameters such as section geometry of quay wall, material property and loading conditions in design.

In common designs, designers often select an accepted sketch with their experiences and cannot review different sketches and present the best one. Sometimes the final drawing may be uneconomical and also the transport and placing of blocks may be very difficult and sometimes impossible. Therefore, adopting an optimization procedure for design of these structures is needed.

This paper presents some methods for optimization of "Block work Gravity Quay walls". In this research the blocks are assumed to be rectangular and unreinforced.

Arrangement of blocks usually is bonded for seabed with good geotechnical condition. For weaker seabed, that settlement is probable; column block work with vertically discrete blocks is desirable, because this arrangement permit to every row of vertical blocks to be settled separately.

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Optimization of marine structures has been subject of many researches in the literature. For example, an optimum design of rubble mound breakwater cross section has been addressed in [2] and [3], and optimization of composite breakwaters has been discussed in [4], [5] and [6] focusing on minimizing the cost function imposed to structural failure constraints. Elchahal et al. in [7] and [8] have worked on topology and shape optimization of floating breakwaters.

Although a number of researches has been carried out for optimization of waterfront structures such as caisson-type quay walls [4], [5] and suspended quay walls, however, research on optimization of block-type quay walls is rare.

The motivation for this research came from design and constructions of a quay wall with 2100-meter length in Pars Petrochemical Port in the Persian Gulf. Precast blocks were used for construction of this quay wall and only in the upper part in-situ concrete was applied to distribute loads on deck into the lower block uniformly. A typical cross section of a block work quay wall is given in Fig. (1).

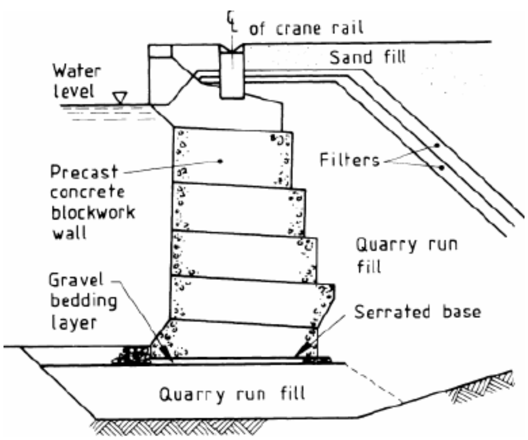

Fig. 1 Cross section of a block work quay wall [1]

II. CONVENTIONAL DESIGN METHOD FOR GRAVITY QUAY WALLS

Gravity quay walls are designed for three main criteria; sliding, overturning and allowable bearing stress under the base of quay wall. A cross section of these structures should be controlled under three loading states: 1-service state; 2-earthquake state; 3- construction state, [9].

Conventional design method of quay walls is based on providing capacity to resist a design seismic force, but it does not provide information on the performance of a structure when the limit of the force-balance is exceeded. In this regard, gravity quay wall failures have caused much progress in the development of deformation-based design methods for waterfront structures. Accordingly, much significant experimental and theoretical research work has been carried out, e.g., [10], [11], [12],

A new design methodology, named performance-based design, has born from lessons learned caused by earthquakes in 1990's to overcome the limitations of conventional seismic design, [13]. In this framework, lateral spreading of the saturated backfill and foundation soils along with the effect of quay wall as the supporting structure (saturated soil-structure interaction) are taken into account as a more logical design.

Initial design of this structure is determined by limited state method and the stability of structure is examined in the first earthquake level for sliding, overturning and eccentric of loads at all horizontal surfaces between blocks and foundation surface. Also deep slip and bearing capacity of seabed should be controlled. At the end of this process, an acceptable and safety sketch will be determined. The next step, this sketch will be controlled in the second seismic level for occupancy criteria (settlement, rotation and horizontal displacement) [9] and [13].

In design process, various variants can be considered, but because of complex and expensive calculations, usually only some probable sketches are controlled and evaluated and an accepted sketch is chosen. However, this final sketch maybe is not an optimum and appropriate design. Thus it is necessary and important to define criteria to evaluate probable sketches and find ways that can be reached to the best design easily.

2.1 Loads acting on block work quay wall

The external forces and loads acting on a quay wall include the following:

(1) Surcharge
(2) Deadweight of the wall
(3) Earth pressure and residual water pressure
(4) Buoyancy
(5) Seismic forces
(6) Dynamic water pressure during earthquake
(7) Tractive forces of vessels

In the next section, some technical notes for considering above loads will be mentioned.

2.1.1 Dead load

The body of a quay wall can be taken as the portion between the face line of quay wall and the vertical plane passing through the rear toe of the quay wall. Normally a backfill is provided at the rear of the quay wall. Some part of this backfill acts as self-weight of the quay wall, and the portion of the backfill can be considered as a part of the quay wall body. However, it is difficult to apply this concept to all cases, because the extent of backfill considered as a part of the quay wall body varies depending on the shape of the quay wall body and the mode of failure. However, it is common practice to define the extent of backfill considered as a part of the quay wall body as shown by hatching in Fig. (2) and (3) to simplify the design calculation.

The quay wall stability must be examined for each horizontal layer, the virtual quay wall body should be considered as follows (usually, shear keys are formed between blocks for better interlocking, but in this examination, their effect may be ignored.):

(a) Examination of sliding

As shown in Fig. 2, the portion in front of the vertical plane passing through the rear toe at the examining level should be regarded as the quay wall body.

(b) Examination of overturning

For the examination of overturning, when there are two blocks at the examining level, the portion in front of the vertical plane passing through the rear toe of the upper block on the seaside block can be regarded as a part of the body. For example, as in case of Fig. (3), it is assumed that the weight of block and the weight of backfill above the block do not contribute to the resisting force against overturning.

(c) Examination of bearing capacity

If the same virtual quay wall body as that used against examination of overturning is employed for calculation of the safety factor for bearing capacity, it becomes quite small. However, when the weight of the wall body is locally concentrated on the ground, settlement occurs in that portion. Therefore, the load is actually expected to be distributed over a wide area without being overly concentrated. Results of examination on the stability of existing structures show that the portion in front of the vertical plane passing through the rear toe of the quay wall can be considered as a virtual wall body. However, it is preferable to use one solid block of the bottom to ensure enough bearing capacity.

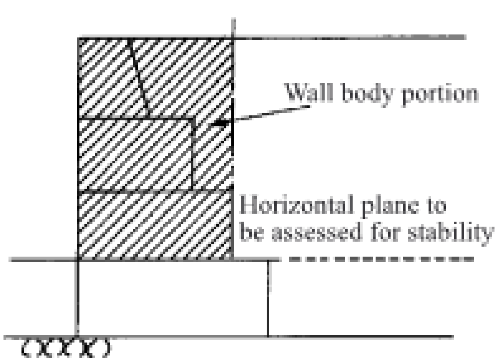

Fig. 2 Determination of quay wall Body Portion for Stability of Sliding at Horizontal Joints

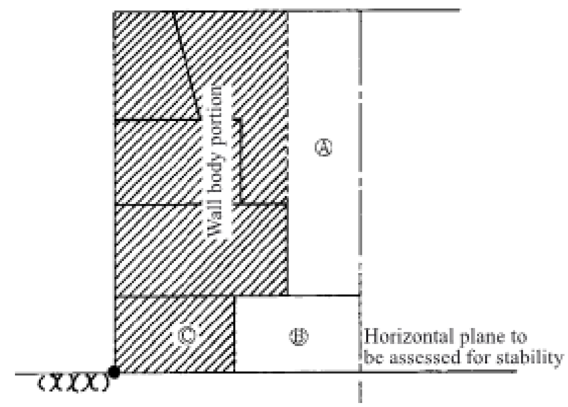

Fig. 3 Determination of quay wall Body Portion for Stability of overturning

The buoyancy is calculated on the assumption that the part of the quay wall body below the residual water level is submerged in the water.

2.1.2 Seismic load

For structures such as gravity type quay walls that are comparatively rigid and their amplitudes of vibration is small compared with the ground motion during an earthquake, the seismic resistance can be examined using the seismic coefficient method.

The quay walls shall be capable of retaining their required structural stability without losing their function when subjected to the “Level 1” earthquake motion (earthquake motion with a high probability of occurrence during the lifetime of facilities) and they will sustain only slight damage during the “Level 2” earthquake motion (earthquake motion that has a very low probability of occurrence during the lifetime of structure, but which is very large when it occurs) and whose functions can be quickly restored after a Level 2 earthquake and are able to retain their expected function throughout the rest of its lifetime.

For the seismic design of port and harbor facilities, earthquake motion with a 75-year return period should be used as the “Level 1” earthquake motion. Earthquake motion from an inter-plate earthquake or a plate earthquake near the coast should be used as “Level 2” earthquake motion, of which the return period will be several hundred years or more.

It shall be standard to use the seismic coefficient method for determining the seismic load for structures having a comparatively short natural period and large damping factor. In this case, the seismic load can be determined using the seismic coefficient method. This coefficient is determined from multiple regional seismic coefficient, subsoil condition factor and importance factor. The seismic forces calculated for every block from multiple seismic coefficient and dead weight.

2.1.3 Soil lateral pressure

The actual phenomenon of the earth pressure during an earthquake is caused by dynamic interaction between backfill soil, structure and water. Many analyses of past damage due to earth pressures during earthquakes have enabled to formulate the practical calculation method of earth pressure during an earthquake for designs. The hydrostatic pressure and dynamic water pressure acting on a structure should be evaluated separately.

Earth pressure during an earthquake is based on the theories proposed by Mononobe (1917) and Okabe (1924). Angle of friction between backfilling material and back face wall normally has a value of 15 ~ 20 degrees. It may be estimated as one-half of the angle of internal friction of backfilling material.

2.1.4 Residual water pressure

The residual water level should be set at the elevation with the height equivalent to one third of the tidal range above the mean monthly-lowest water level (LWL). The residual water level difference can be reduced by increasing the permeability of backfill material, but this approach may cause leakage of the backfilling material. The standard residual water difference (1/3 of the tidal range) is that for cases where a certain level of permeability can be established after a long period. In those cases where permeability is low from the beginning or reduction in permeability is expected in the long term, it is desirable to assume a large residual water level difference in consideration of those conditions. When the wave trough acts on the front face of the wall body, it is considered that a residual water level difference increases. However, in ordinary quay wall design, the increase in the residual water level difference due to the waves does not need to be considered.

2.1.5 Hydrodynamic load during earthquake

The dynamic water pressure during an earthquake can be calculated using the Westergaard equation as follow:

$$P_{dw} = \frac{7}{8}\int_0^H K_h \gamma_w \sqrt{H_w .y .dy} \quad (1)$$

Where H_w is the draught of the quay wall, y is distance between water level and deck level of the quay wall, K_h is the horizontal seismic coefficient, and γ_w is specific gravity of seawater.

2.1.6 Berthing and mooring forces

In many cases, the fender reaction force (vessel berthing force) is not taken into consideration in quay wall design, because the deadweight of the coping and the earth pressure of the material behind the quay wall work as the resistance forces. In the design of coping, however, the fender reaction force is taken into consideration.

When a ship stands beside the quay wall, ship mooring force will act on bollard and transfer into the cop beam of the quay wall. This force can affect quay wall stability and should be taken into account in design.

2.2 Section stability control

In the stability calculations of a gravity type quay wall, the following items should be examined in general:

1. Sliding
2. Overturning
3. Bearing capacity of the foundation
4. Circular slip
5. Settlement

For examination against sliding, vertical and horizontal forces should include the followings:

The resultant vertical force should be the weight of the virtual quay wall body with subtraction of buoyancy and without a surcharge on the virtual wall body. The vertical component of earth pressure acting on the virtual plane should also be added.

The resultant horizontal force should include: (a) Horizontal component of the earth pressure acting on the rear plane of the virtual wall body with a surcharge applied; (b) Residual water pressure; (c) In the stability calculations during an earthquake, the seismic force acting on the mass of the wall body with no buoyancy subtracted; (d) the horizontal force transmitted through cargo handling equipment on the wall.

Examination concerning the bearing capacity of the foundation shall be made appropriately in accordance with Bearing Capacity of shallow foundation for Eccentric and Inclined Loads. In this case, the force acting on the bottom of the quay wall is the resultant force of vertical and horizontal loads. In general, the assessment of reaction force onto the bottom of quay wall is made for cases where no surcharge is applied on the quay wall. When a surcharge is applied on the quay wall, the distance of eccentricity decreases, but the bottom reaction may increase as the vertical component of the load increases. Thus there may be cases where assessment needs to be made for cases in which a surcharge is applied. The thickness of a foundation mound is determined by examining the bearing capacity of the foundation, the flatness of the mound surface for installing the wall body, and the degree of alleviation of partial stress concentration in the ground.

In this research, for design of block work quay wall, we studied different codes including [1], [9], [13] and [14]. The safety factors against different failure modes are selected according to values given table 1.

To study the behavior of a quay wall and to check the stability against probable different failure modes, a computer program has been developed. This program can easily consider the effects of different parameters such as section geometry of quay wall, material property and loading condition in design.

Table 1. Safety factors for stability control of quay wall

Failure mode	Normal (service) condition	Seismic condition
Sliding for single block	1.2	1.0
Overturning for a single block	1.2	1.1
Bearing capacity of the foundation	1.2	1.0
Circular slip	1.3	1.0

3. Design Optimization of Quay Wall

In conventional design procedure, designers often work on a limited number of variants with their experiences but do not and cannot take into consideration all conditions to present the best one. Sometimes the final drawing may be uneconomical and also the transport and placing of blocks may be very difficult and sometimes impossible. Therefore, adopting an optimization procedure for design of these structures is needed. Some strategies for optimization of quay wall design can be considered. For example, when a backfill of good quality is used in a gravity type quay wall, the quay wall can be designed by considering the effect of the backfill. The effect of earth pressure reduction by backfill can be calculated using an analytical method that takes into consideration the composition and strength of the soil layers behind the quay wall. In ordinary gravity type quay walls, rubble or cobble stones are used as backfilling material. In this case, the effect of earth pressure reduction can be evaluated using the following simplified method.

The negative slope behind the blocks can help to reduce earth pressure acting on quay wall. The negative slope for blocks is shown in Fig. (3). To optimize the quay wall, using such negative slope is a good solution, especially for seismic regions [11].

Fig.3 Precast sloping blocks for construction of block work quay wall, Pars Petrochemical Port in Assaluyeh (Iran)

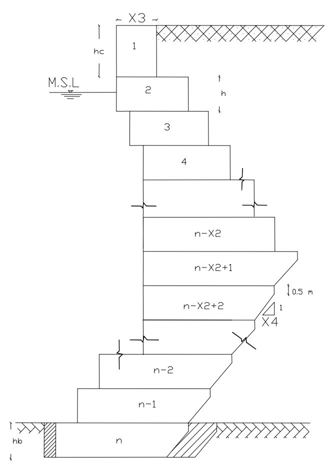

Fig. 4 cross section and design variables considered for optimization of block work quay wall

In this research, a procedure for optimization of cross section of a block work gravity type quay wall has been introduced and a numerical program for this procedure has been developed. After reviewing design and construction considerations for such quay walls, we determined available methods for optimum design of these structures. Design variables are given in Fig. (4). The objective function is area of cross section of this structure. The main constraints of the optimization problem in the present study is the safety factor in various modes of failures. As relation of safety factor with design variables is unknown, therefore, a proper method should be used for approximating the objective function and constraints according to design variables first. Then, an efficient method should be selected for formulating mathematical optimization of the objective function under existing constraints. For this purpose, the optimization of the cross section is accomplished using a Sequential Quadratic Programming (SQP) method in the present work. SQP methods solve a sequence of optimization sub-problems, each of which optimizes a quadratic model of the objective subject to a linearization of the constraints.

The four design variables include:

X_1: lower length of section;

X_2: number of sloping blocks;

X_3: length of upper block;

X_4: slope of sloping block.

The objective function, area of cross section of quay wall, is equaled with:

$$V(x)=(2X_1-X_2.X_4).X_2/2 + (X_3-X_1-X_2.X_4)(H-X_2) - b.X_4.(n-2-b).h^2 \quad (2)$$

Where H: total height of quay wall; h: height of every of blocks; n: number of blocks in cross section; b: number of same blocks in down part of section.

As it was mentioned, constraints of this optimization problem are the safety factor in various modes of failure: sliding and overturning of every block in normal and seismic condition. Also, EAU propose that the eccentric of loads in every horizontal surface between blocks should be less 1/6 of length of block [14]. It is known that sliding forces in seismic condition are critical and we can neglect sliding control in normal condition. Other modes of failure including bearing capacity of foundation, circular slip and settlement can be satisfied with modifying lower block, for example, increasing length and thickness of lower block.

The relation between constraints and design variables is complex and should be approximated with an appropriate function. In this research, we used an approximation function according to equation (2).

$$g(x) = g(x^o) + \nabla g^T(x).\nabla x + 0.5 \nabla x^T.H_g.\nabla x$$

$$\nabla g^T(x) = \langle \partial g/\delta x_1 \quad \partial g/\delta x2 \quad \partial g/\delta x_3 \rangle \quad (3)$$

$$\partial g/\delta x_1 = \frac{g(x_1^o + \delta x_1) - g(x_1^o - \delta x_1)}{2\delta x_1}$$

$$H_g = \begin{bmatrix} \frac{\partial^2 g}{\partial^2 x_1} & 0 & 0 \\ 0 & \frac{\partial^2 g}{\partial^2 x_2} & 0 \\ 0 & 0 & \frac{\partial^2 g}{\partial^2 x_3} \end{bmatrix}$$

$$\frac{\partial^2 g}{\partial^2 x_1} = \left(\frac{g(x_1^o + \delta x_1) - g(x_1^o)}{\delta x_1} - \frac{g(x_1^o) - g(x_1^o - \delta x_1)}{\delta x_1}\right)/(2\delta x_1)$$

We developed our program to approximate constraints by equation (2) from start point and two additional points. For example, one of constraints (eccentrics of loads of seventh block on normal condition) is formulated as:

$$G(x)=(0.96604-0.09383X_1-9.9)*(9.9 / X_1)*(2-9.9/X_1+0.55*(9.9 / X_1)^2*(X_1-9.9)^2*0.00839-0.00738*(X_3-5.4)*(5.4/X_3)*(2-5.4 / X_3)+0.5*(5.4/X_3)^2*(X_3 -5.4)^2*(-0.00133)-0.005748*(X_4 +0.45)*(-0.45/X_4)*(2+0.45/X_4) + 0.5*(-0.45 / X_4)^2*(X_4 +0.45)^2*(-0.13264))-1.2 \quad (3)$$

Now, we have an optimization problem that has a format similar to equation (4).

$$\text{Minimize:} \quad f(X)$$
$$\text{Subject to:} \quad g_j(X) \le 0, \quad (j = 1,2,...,m) \quad (4)$$

The design problem in this research has a third order nonlinear objective function with 4th order nonlinear constrain. To solve the problem and to reach to the optimal point, one should start from a point in such a way that all constraints are satisfied and the objective function is minimized. Eq. (5) is a QP sub-problem that can be used to find the direction and amount of movement in each step. This QP sub-problem has a 2nd order objective function and linear constraints.

$$Q(S) = f(X^{(k)}) + \nabla f^T(X^{(k)}).S + \frac{1}{2} S^T.B(X^{(k)}, \lambda^{(k)}).S \quad (5)$$
$$g_j(X^{(k)}) + \nabla g_j^T(X^{(k)}).S \le 0, \quad (j = 1,2,...,m)$$

In this formulation, x^k indicates design vector in k^{th} circle of optimization and has a define value and S is direction of movement and is unknown, ∇f is a 2nd order Lagrangian approximation and λ is Lagrange coefficient.

After finding vector S which defines seeking direction, the next point in design space is found using following equation:

$$X^{(k+1)} = X^{(k)} + \alpha.S \quad (6)$$

Replacing $X^{(k+1)}$ to objective function and constraints, relations based on α are gained. Then α should be defined in such a way that all constraints are satisfied and also the objective function decreases. A penalty function such as that proposed in [15] should be defined. This function is known as reduction function and can be minimized due to α. Thus α is found.

$$\phi_H = f(x^{(k)}) + \sum_{i=1}^{p} r_i^k \, |hi| + \sum_{i=1}^{m} \mu_i^{(k)} \max\{0, g_i\}$$

(7)

After finding a new point, above steps are repeated until the problem reaches to an optimum point.

we need a mathematical method to solve this problem with its obtained objective function and constrain to determine optimum design variables. This problem has nonlinear relation between design variables and objective function and constraints. Therefore we have a NLP (Nonlinear problem). The method used for solving this problem is Sequential Quadratic Programming (SQP) method. SQP is a suitable method that approximates objective function and constraints with sequence quadratic and linear functions. SQP methods have been used for optimization in many researches, e.g., in [16], [17], [18] and [19].

There are some software packages that have SQP method are available for optimization. We used DOT program for solving our problem.

DOT is a general-purpose gradient-based optimization software library that can be used to solve a wide variety of optimization problems [20]. DOT provides the optimization technology, while the rest of the program has to provide the required function evaluations needed to perform the optimization. Function evaluations can be linear or nonlinear functions of the design variables. They may be very simple analytical functions or may be highly complicated implicit functions.

DOT can handle constrained, unconstrained, linear and non-linear optimization problems and can automatically calculate finite difference gradients needed during the optimization. DOT can also deal with user supplied gradients. The DOT program helps to optimize objective function with 3 methods: SLP, SQP, and MFFD). SQP is a suitable method that approximates objective function and constraints with sequence quadratic and linear functions.

Briefly, for optimum design of this structure, we do below steps, respectively:

Step 1: Prepare a computer program with visual basic for stability checking of every sketch; this program can easily consider the effects of different parameters (such as cross section geometry of quay wall, material property and loading condition). With this program, control of sketches is easy and fast.

Step 2: Choose a suitable cross section and define design variables and objective function.

Step 3: Calculate constraints related to each variable.

Step 4: Develop this program and combine it with another program (DOT program) to find the optimum variable.

Step 5: complete the design by controlling other failure modes. In this step, we used STABLE software to control slipping circular. We could satisfy settlement, bearing capacity of foundation and circular slip by modifying lower block, see Fig. 5.

The required inputs for DOT software are:

a) Initial design point,
b) Objective function,
c) Formulated constraints,
d) Interval of movement.

The applied optimization algorithm in the present research is shown in Fig. (6).

4. CASE STUDY

Optimization of quay wall for Pars Petrochemical Port in Assaluyeh in the Northern coast of Persian Gulf is reviewed in this paper to present the efficiency of the presented procedure. First, a conceptual design is obtained for the site condition by trying different probable variants. This preliminary design is shown in Fig. (7) which fulfills all design criteria and is stable in different failure modes.

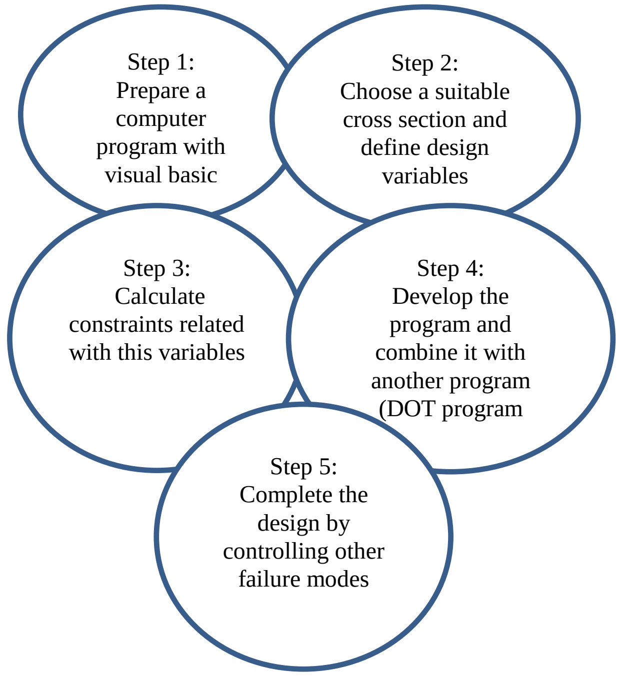

Fig. 5 Steps of optimum design procedure

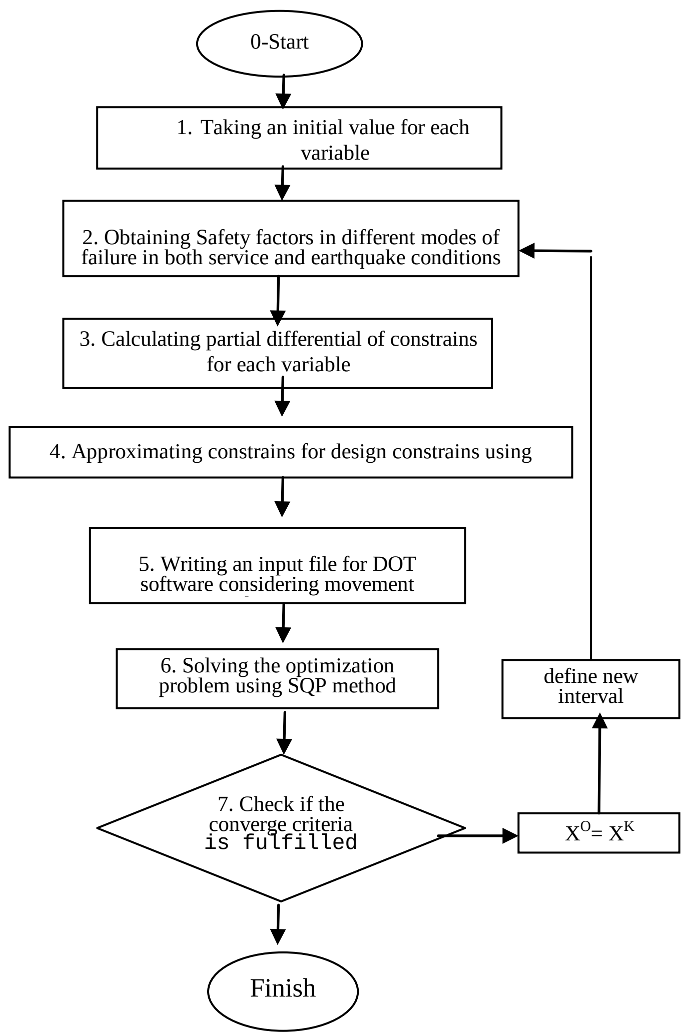

Fig. 6 The optimization algorithm

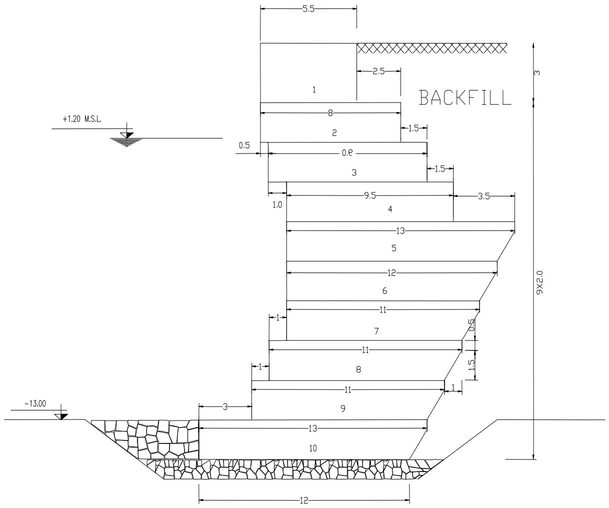

Fig. 7 An initial sketch for case study condition

Using the developed program and the procedure for cross section optimization, one can obtain the optimum design as illustrated in Fig. (8). Comparing this with the preliminary design of Fig. (7), we see that the cross section area decreases from 203 m^2 to 161.2 m^2. This means that we can reduce the cross section about 20.6% using the optimization procedure and can save construction cost expense considerably.

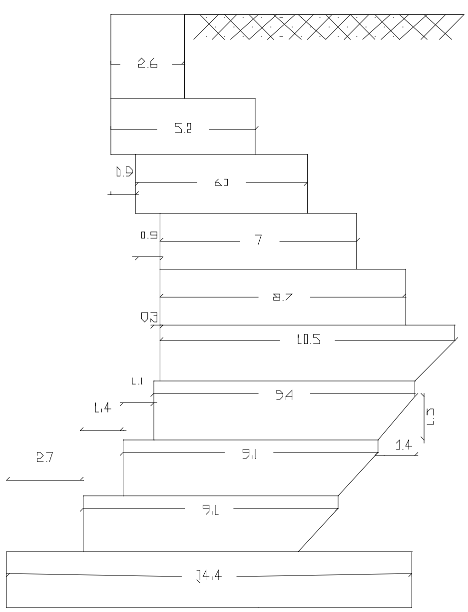

Fig. 8 The optimum cross section for case study condition

Results of a parametric study show that if the blocks are placed vertically – without negative slope – the cross section area increases to 253.4 m^2 as shown in Fig. (9) and concrete volume increases 49.7% and also the weight of the heaviest block increases 34.7%. Therefore, it is preferred to have negative slope behind blocks to decrease soil pressure. Results of various analyses indicate that the best negative slope is equal to the internal friction angle of back filling materials. This is an important outcome to be considered by designers of block work gravity quay walls.

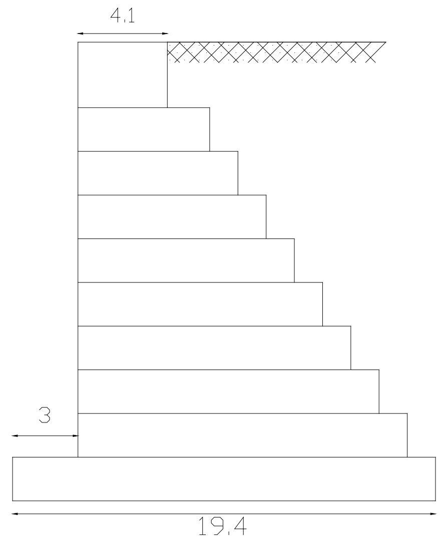

Fig. 9 Optimum sketch without sloping blocks for case study condition

In addition, results of analyses show that the effect of shear keys is considerable. OCDI notes about effect of shear keys reads: “Usually, keys are formed between blocks for better interlocking, but in this examination, their effect may be ignored”. In this research, we observed if shear keys were neglected, the area section would be increased 18.2 %. Therefore, shear keys have an important role in design of this kind of quay walls and should be taken into consideration.

Compare optimum design for two seismic coefficients indicate that when seismic coefficient decreases from 0.21g to 0.15g, the objective function (section area) decreases 26%. Therefore, selection of this parameter is very important and designer should pay attention to geotechnical condition very much.

Backfill with good quality can decrease soil pressures acting on quay wall and finally it can improve the stability of quay wall. For case study condition, if internal friction angle of backfill material decreases from 40 degrees to 35 degrees, the objective function will be increased 25.1%. Therefore, quality of backfill has a key role on optimization of cross section.

5. Conclusions

A procedure is presented for optimization of the cross section of block work quay walls and based on that a code is developed. The optimization of the cross section is accomplished using SQP method. This program helps to control every block work quay wall cross section very fast. Applying the proposed procedure to a real case study provides successful and acceptable results.

Furthermore results of parametric studies carried out by this program indicate that shear key, internal friction angle of back filling material and negative slope behind the blocks have considerable effect on cross section optimization.

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