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Optimum Shape of Concrete Flood Walls Under Hydrodynamic Load

الشكل الامثل لجدران الفيضانات الكونكريتية تحت الحمل الهيدروديناميكي

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Abstract:

2D (Plain strain) wall – water – foundation interaction problem is modeled via ANSYS 11.0 to find the optimum shape of concrete flood walls considering the principle of fluid–soil–structure interaction analyses. Concrete gravity and cantilever flood walls types are subjected to hydrodynamic and impact loads have been considered in this research. Hydrodynamic load are a function of a wave velocity and structural geometry. Low velocity hydrodynamic forces are defined as situations where floodwater velocities do not exceed 3 m/sec, while high velocity hydrodynamic forces involve floodwater velocities in excess of 3 m/sec. Impact loads are imposed on the structure by debris carried by the moving water. The optimization process is simulated by ANSYS /APDL language programming depending on the available optimization commands. The components of the optimization process are the objective function (OBJ) is to minimize the cross–sectional area of the concrete flood walls, the state variables (SVs) are the factors of stability (sliding FS_s and overturning FS_o) and safety (maximum stress of foundation q_{max} , exit gradient FS_{eg} , and uncracked section e) of the flood wall, and the design variables (DVs) are the dimensions of the wall. The results showed that the optimum design method via ANSYS is a successful strategy prompts to optimum values of cross–sectional area with both safety and stability factors as compared with ordinary design. For gravity flood wall the reduction percentage of safe section area is 17.64%; while for cantilver flood wall, the reduction percentage of both safe section area and reinforcement are 0.8% and 27.76%; respectively. In other hand, it has been taking various heights of gravity and cantilver flood walls as 0.90m, 1.20m, and 1.50 m for gravity flood wall and 2.40m, 2.75m, and 3m for cantilever flood wall. The results showed that when the height of gravity flood wall is increased by 33.30% from (0.90 to 1.20m), the optimum cross-sectional area increases in a percent of (52.6%). While, in cantilever flood wall, the optimum cross–sectional area is increased by 46.89% when the value of the height are increased by (25%) from 2.40 to 3m. Moreover, from studying several common sections of gravity flood walls which have been designated in this research as sections (1 to 4), it is found that section 2 is the most safe compared with other sections.

Keywords: Concrete Flood Wall, Optimal Design, ANSYS Parametric Design Language (APDL), Soil-Structure-Interaction, Hydrodynamic Load.

المستخلص

تم استخدام برنامج انسز11.0 لعمل موديل تداخل الجدار– الماء– الاساس لإيجاد الشكل الافضل لجدران الفيضانات الكونكريتية وبالاعتماد على مبدأ تحليل تداخل المائع–التربة–المنشأ. تم في هذا البحث اختيار انواع جدران الفيضانات الكونكريتية الثقالية والناتئة تحت تأثير الاحمال الهيدروديناميكية والصدمات. تعتمد الاحمال الهيدروديناميكية على سرعة موجة الماء وشكل المنشأ. ان قوى الهيدروديناميكية الواطئة السرعة هي تلك الناتجة من الحالات التي تكون فيها سرع ماء الفيضانات لا تتجاوز3متر/ثانية، بينما القوى الهيدروديناميكية العالية السرعة هي تلك الناتجة من الحالات التي تتجاوز سرع ماء الفيضانات عن 3متر/ثانية. ان احمال الصدمات على المنشأ هي تلك التي تنتج عن الحطام المنقول بواسطة مياه الفيضانات. تم

في البحث نمذجة مسالة الامثلية باستخدام لغة الانسز وبالاعتماد على اوامر الامثلية المتوفرة فيه. تتمثل مكونات الامثلية بدالة الهدف والتي تهدف الى ايجاد اصغر مساحة مقطع لجدران الفيضانات الكونكريتية ، متغيرات الحالة والتي تمثل شروط ومقيدات التصميم وهي معاملات الاستقرارية (ضد الانزلاق والانقلاب) ومعاملات الامان (الاجهادات العظمى للأساس وتدرج خروج الماء والمقطع المتشقق) للجدران الفيضانات ، وبالمتغيرات التصميمية وهي لتي تمثل ابعاد الجدار. بينت النتائج بان التصميم الامثل بواسطة برنامج انسز هي طريقة فعالة في اعطاء مساحة المقطع الامثل للجدران مع تحقيق معاملات الامان و الاستقرارية بالمقارنة مع التصميم الاعتيادي. بالنسبة الى جدار الفيضانات الثقالية فان نسبة النقصان لمساحة المقطع الامين بمقدار 17.64% ، بينما لجدار الفيضانات الناتئ فان مقدار النقصان في كلا من مساحة المقطع الامين والتسليح بمقدار 0.8 % و 27.76 % على التوالي. من ناحية اخرى تم اخذ ارتفاعات مختلفة للجدران الفيضانات الثقالية والناتئة لتشمل 0.90 متر، 1.20متر و 1.50متر لجدار الفيضانات الثقالية و 2.40 متر، 2.75متر و3متر للجدار الفيضانات الناتئة. بينت النتائج بانه عندما يتم زيادة ارتفاع جدار الفيضانات الثقالي بنسبة 33.30% اي من ارتفاع (0.90–1.20 متر) فان مساحة المقطع الامثل للجدار تزداد بنسبة 52.6 %. بينما للجدار الفيضانات الناتئ فان مساحة المقطع الامثل للجدار تزداد بنسبة 46.89 %.عندما يتم زيادة الارتفاع بنسبة 25% اي من ارتفاع (2.40–3متر). واكثر من ذلك ومن خلال دراسة عدة مقاطع شائعة لجداران الفيضانات الثقالية والتي أشير لها في هذا البحث بالمقاطع (1– 4) ، تم التوصل بان المقطع 2 هو الاكثر امانا بالمقارنة مع بقية المقاطع.

I. INTRODUCTION

Flood walls are one of the main hydraulic structures which acting as buffers against flooding, also to protect the buildings from unequalled hydrostatic and hydrodynamic loading cases, and in some times, perhaps it repelled the debris and ice away from building. These structures are built by manmade materials being as concrete or masonry. The choice of the flood wall design depends fundamentally on the basis of the sort of expected flood wave at the construction site. The hydrodynamic and hydrostatic forces and impact loads can be produced from high water levels and velocities, and that must be representing in the floodwall design. To construct a flood wall must be concerned with three requirements which are overall stability of the wall identified with the external load, adequate strength as identified with the computed internal stresses, and ability to provide effective Attachments to meet the flood waters [1].

The most common types of flood walls are cantilever T-type and cantilever I-type walls. While, the less Commonly Used Types are buttress, counterfort, gravity, cellular, and cellular sheet pile [2]. Most flood walls are of the inverted T-type, the cross bar of the T serves as a base and the stem serves as the water barrier.

To manage the cost of the concrete flood walls under design constraints, the designer needs to change the dimensions of the wall a few times, making design process rather repetitive and dull. Since it is greatly hard to get a design fulfilling all the safety requirements, it is valuable to give the issue a role as an optimization problem. But, It is worth mentioning that the researches in the optimization design of flood wall are so little.

There are several manuals give specifications and limitation of flood walls. However, there are little research addressing this structure, so the idea of finding optimal shape under the influence of different loads has been considered as a subject of this research. Suraparb K. & Boonchai U. [3], Duncan J. M. & Brandon T. L. [4], Sudarshan A. & Chung R. [5], Jian Hu., et al. [6], Amnarj Y. [7], and Huang W. C., Yu H. W., & Weng M. C. [8].

In this research, the optimum design of concrete gravity and cantilver flood walls including fluid-soil-structure-interaction subjected to hydrodynamic and impact loads will be investigated.

In order to achieve the aim above, the research is organized as follows: Section II describes the numerical modelling of problem by finite element ANSYS programing which include simulate wall-water-foundation problem and all caverning equations related with fluid-soil-structure interactions. The formulation optimization problem is distributed in tow sections, namely Sections III and VI to describe the formulation of optimization problem by ANSYS and applied of different loads. The numerical applications and discussions are presented in Section V. Finally, Section IV presents conclusions.

II.NUMERICAL MODELLING OF PROBLEM BY FINITE ELEMENT SOFTWARE ANSYS

The wall–water–foundation interaction based on principle of fluid–structure and soil–structure interaction [9]. The procedure for the dynamic analysis of wall–water–foundation interaction based on the coupling equation of fluid–structure–soil interaction.

a- fluid-Structure interaction

The coupled fluid–structure interaction could be written as[10]:

$$\begin{bmatrix}[M_e] & [0]\\ [M^{fs}] & [M_e^p]\end{bmatrix}\begin{pmatrix}\{\ddot{U}_e\}\\ \{\ddot{P}_e\}\end{pmatrix}+\begin{bmatrix}[C_e] & [0]\\ [0] & [C_e^p]\end{bmatrix}\begin{pmatrix}\{\dot{U}_e\}\\ \{\dot{P}_e\}\end{pmatrix}+\begin{bmatrix}[K_e] & [K^{fs}]\\ [0] & [K_e^p]\end{bmatrix}\begin{pmatrix}\{U_e\}\\ \{P_e\}\end{pmatrix}=\begin{pmatrix}\{F_e\}\\ \{0\}\end{pmatrix} \dots\dots\dots(1)$$

Also, it could be denoted easily as [11]:

$$M_f\ddot{P}_e + C_f\dot{P}_e + K_fP_e + \rho_wQ^T(\ddot{u}_e + \ddot{u}_g) = 0 \;\dots\dots\dots\dots\dots\dots\; (2)$$

WhereM_f, C_f, and K_f are the fluid mass, damping and stiffness matrices, respectively, P_e , $\ddot{u}_e$ and $\ddot{u}_g$ are the nodal pressure, relative nodal acceleration and nodal ground acceleration vectors, respectively. The term ρ_wQ^T is also often referred to as coupling matrix.

In ANSYS (APDL language programming), a four-node FLUID 29 element shown in Fig. 1, is used to discretise the coupled fluid–structure interaction represented by Eq.(1).

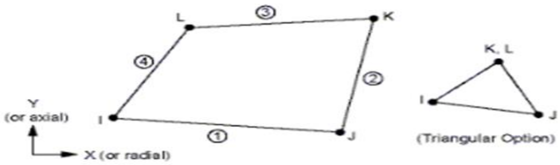

Fig. 1 FLUID29 Element Geometry [12]

b- Soil-Structure interaction

The discretized structural dynamic equation including the structure and soil subject to ground motion can be formulated utilizing the finite–element approach as [13]:

$$M\ddot{u}(t) + C\dot{u}(t) + Ku(t) = -M\ddot{u_g}(t) + Qp_e \dots\dots\dots\dots\dots\dots\dots\dots(3)$$

Where: , $\dot{u}$ and $\ddot{u}$ are represent the vector of system relative displacements, vector of velocity and vector acceleration with respect to base, respectively; M , C and K are represent the matrix of system mass, matrix of damping and matrix of stiffness, respectively; term $\ddot{u_g}$ represent the horizontal component of ground acceleration, and Qp_e represents the nodal force vector associated with the hydrodynamic pressure produced by the flood water.

A four–nodes PLANE 42 element (structural 2D solids) plain strain, shown in Fig. 2 which available in ANSYS is used for both wall body and the soil of foundation modeling.

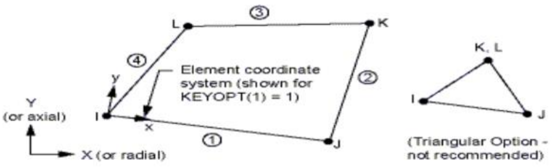

Fig. 2 PLANE42 Element Geometry [12]

c- The Coupled Fluid-Structure-soil Equation

The total finite–element discretized equations for wall-water-foundation interaction issue could be composed from both Eqs. (2 and 3) in an assembled form as:

$$\begin{bmatrix}[M_s] & [0]\\ [M_{fs}] & [M_f]\end{bmatrix}\begin{pmatrix}\ddot{U}_e\\ \ddot{P}_e\end{pmatrix}+\begin{bmatrix}[C_s] & [0]\\ [0] & [C_f]\end{bmatrix}\begin{pmatrix}\dot{U}_e\\ \dot{P}_e\end{pmatrix}+\begin{bmatrix}[K_s] & [K_{fs}]\\ [0] & [K_f]\end{bmatrix}\begin{pmatrix}U_e\\ P_e\end{pmatrix}=\begin{pmatrix}-M_s\ddot{U}_g\\ -M_{fs}\ddot{U}_g\end{pmatrix} \ldots\ldots\ldots\ldots\ldots(4)$$

Where $K_{fs} = -Q$ and $-M_{fs} = \rho_w Q^T$

Eq.(4) expresses a second order linear differential equation having unsymmetrical matrices and might be settled by method for direct integration techniques. In general, the dynamic equilibrium equation of systems modeled in finite elements can be expressed as [13]:

$$M_c\ddot{u}_c + C_c\dot{u}_c + K_c u_c = F(t) \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Where M_c, C_c, K_c and $F(t)$ are the structural mass, damping, stiffness matrices and dynamic load vector, respectively.

III. FORMULATION OF THE OPTIMIZATION PROBLEM BY ANSYS

In this section the optimization problem to be solved is explained. The design variables DVs, the parameters, the state variables SVs (constraints), the objective function OBJ and the optimum design process are presented.

a- Design variables

DVs represent independent quantities that are varied in order to achieve the optimum design. Upper and lower limits are determined to serve as "constraints" on the design variables. These limits define the range of variation for DVs [12]. Also these design variables could be indicated by:

$x = [x_1, x_2, x_3 \ldots\ldots, x_n]$……………………………….(6)

And the constraints be represented as follow:

$\underline{x_i} \leq x_i \leq \overline{x_i}$ (i=1,2,3,…,n) ………………………. (7)

Where:

n is the design variables number;

$\underline{X_i}$ is the constraint lower limit;

$\overline{X_i}$ is the constraint upper limit.

b- State variables (constraints)

The stability of the floodwall include different modes of failure as [14], overtopping, structural, overturning, sliding, and seepage failure.

The factors of safety that should be realized for stability and safety of optimization process could be given as [1]:

1. Against overturning, $FS_o = \frac{\sum M_R}{\sum M_O} \geq 1.5$ ……………………………(8)
   Where: M_R= resisting moments; M_O= overturning moments
2. Against sliding, $FS_s = \frac{\sum f_R}{\sum f_D} \geq 1.5$ …………………..……………..(9)
   Where: f_R= forces resisting sliding; f_D= sliding forces (cumulative lateral hydrostatic, normal impact, and hydrodynamic forces)
3. The tension crack should be avoided. The resultant force must passes through middle third of the dam width i.e. $e \leq \frac{B}{6}$
4. The maximum bearing capacity (q_{max}) should not exceed the allowable soil bearing capacity (q_{all}).
5. Exit gradient (seepage), $FS_{eg} = \frac{I_c}{I_e} = \frac{G-1/1+e}{H/B}$ ……..……………..(10)

Where G is the specific gravity of soil, and e is the void ratio.

6. The moment capacity of any reinforced concrete wall section (stem, toe, or heel) should be greater than the design moment of the structure.

c- Objective function

An objective function OBJ is a mathematical expression that should be maximized or minimized in certain conditions and chosen as the volume, cost, weight, etc.in structural engineering. The aim of this optimization problem is to minimize the cross-section of the wall so area of the wall is considered as OBJ.

$$Min. A = f(x_1, x_2, x_3, \dots\dots, x_n) \quad \dots\dots\dots\dots\dots\dots(11)$$

d- Optimization method

The ANSYS optimization procedure offers a few methods and tools that in different ways attempt to address the mathematical problems. In this research, the first order optimization method is applied to minimized the objective function.

In this method, it will be shown that the constrained problem will transform into an unconstrained one that is eventually minimized [12]. The OBJ is written as:

Minimize f = f(X)………………………(12)

Where : f(X) is the function of variables design.

IV. LOADS OF OPTIMIZATION PROBLEM

In the design of concrete gravity flood wall, it is essential to determine the loads required in the stability and stress analyses. There are two sorts of forces acting on the wall and its footing: lateral and vertical. These forces were are illustrated in Fig. 3.

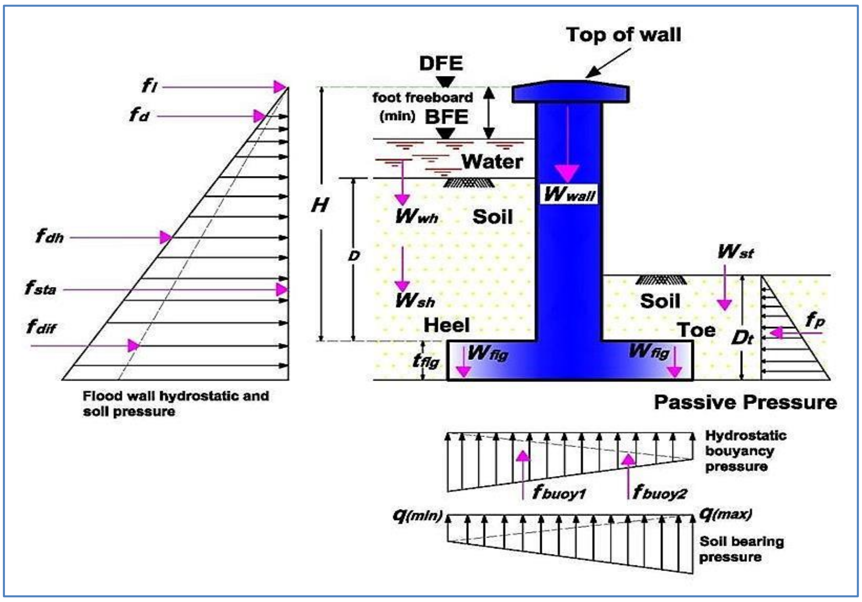

Fig. 3 Forces acting on flood wall [1]

1. **Lateral forces:** These forces which include hydrostatic, saturated soil, hydrodynamic, debris impact, and the saturated soil force on the toe side of the wall.

- The lateral force due to hydrostatic pressure from standing water above the surface of the ground is illustrated as:

$f_{sta} = \frac{1}{2}\gamma_w H^2$ ………………………………(13)

where:
f_{sta}= hydrostatic force from standing water (kN/m);
H = flood proofing design depth (m).

- The differential between the water and soil pressures, f_{dif} due to combined saturated soil and water forces is illustrated as:

$f_{dif} = \frac{1}{2}(S - \gamma_w)D^2$ ………………………(14)

where:
f_{dif} =differential soil/water force (kN/m); S = equivalent fluid weight of submerged soil and water (kN/m^3); and D = depth of saturated soil from adjacent grade to the top of the footer (m).

- Hydrodynamic forces due to velocity of flood water, in cases where velocities do not exceed 3 m/sec, the hydrodynamic effects of moving water can be converted to an equivalent hydrostatic force, which is given as:

$f_{dh} = \gamma_w d_h\, H$ ……………………….(15)

$d_h = \frac{C_d V^2}{2g}$ ……………………….(16)

where:
f_{dh} =equivalent hydrostatic force due to low velocity flood flows (kN/m); d_h = equivalent head due to low velocity flood flows (m); C_d =drag coefficient; V = velocity of floodwater (m/sec); and g = acceleration of gravity (m/sec^2).
For special structures and conditions, and for velocities greater than 3 m/sec, the basic equation for hydrodynamic pressure is written as:

$f_d = P_d A$ ……………….……..…..(17)

$P_d = C_d \rho \frac{V^2}{2}$ ………..……………….(18)

where:
f_d =total force against the structure (kN); P_d =hydrodynamic pressure (kN/m^2); A = submerged area of the upstream face of the structure (m^2); and ρ =mass density of fluid (slugs/m^3).

- Impact loads due to debris carried by the moving water is illustrated as:

$f_i = WVC_D C_B C_{str}$ ……………………….(19)

where:
f_i =impact force acting at the DFE (kN); W = weight of debris (kN); C_D= depth coefficient; C_B= blockage coefficient; and C_{str} = building structure coefficient.

- The saturated soil force over the toe is calculated as:

$f_p = \frac{1}{2}[k_p(\gamma_s - \gamma_w) + \gamma_w]D_t^2$ ……………(20)

where:
f_p = force of passive saturated soil over the toe (kN/m); D_t = the soil depth over the floodwall toe (m); and k_p =passive soil pressure coefficient.

2. Vertical forces:

The vertical forces are buoyancy and the different weights of the wall, footing, soil, and water acting upward and downward on the floodwall.

- The buoyancy force, f_{bouy}, acting at the base of the footing is processed as follows:

$f_{bouy} = f_{bouy1} + f_{bouy2}$ ……………………(21)

$f_{bouy} = \gamma_w(Vol)$ ……………………(22)

where:

f_{bouy} =vertical hydrostatic force resulting from the displacement of a given volume of floodwater(kN); f_{bouy1}=maximum buoyancy force at heel(kN); f_{bouy2}= minimum buoyancy force at toe (kN); $Vol =$ volume of floodwater displaced by submerged object (m^3).

- The gravity forces acting downward are:

1. The unit weight of floodwall (w_{wall}),is calculated as:

$w_{w\,all} = A_{wall}S_g$ ………………………(23)

where:

w_{wall} =weight of the wall (kN/m); A_{wall} =area of the wall(m^2/1m); and S_g =unit weight of wall material(kN/m^3).

2. The weight of the soil over the toe (w_{st}), is computed as follows:

$w_{st} = A_t D_t \gamma_s$ …..……………………(24)

where:

w_{st} =weight of the soil over the toe (kN/lm); A_t= width of the footing toe (m).

3. The weight of the soil over the heel (w_{sh}), is calculated as:

$w_{sh} = A_h D_h(\gamma_s - \gamma_w)$ ………………………..(25)

where:

w_{sh} =weight of the soil over the heel (kN/lm);
A_h =width of the footing heel (m); and D_h= depth of the soil above the heel (m).

4. The weight of the water above the heel (w_{wh}), is calculated as:

$w_{wh} = A_h H \gamma_w$ ……………………………(26)

where:

w_{wh} =weight of the water above the heel (kN/m).

V. NUMERICAL APPLICATION PROBLEMS

1. Gravity flood wall

To validate the efficiency of ANSYS programing in real world optimization design problem, the first-order optimization method by ANSYS is applied on a flood wall of Chiuliao First gravity-type which is located in Kaoshu village in Pingtung County [8], as shown in Fig.4. The configuration of this wall is shown in Fig.5 and all necessary parameters are presented in table 1.

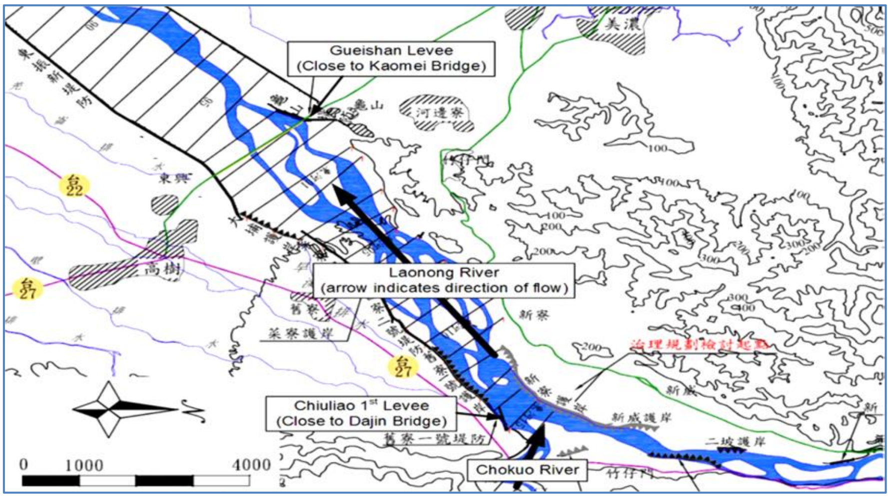

Fig.4 Locations of Chiuliao First gravity-type flood wall on Chokuo River[8].

Table 1 Design parameters and variables

N0.	Input Parameters	Symbol	Unit	Value
1	Height	H	m	3.5
2	Unit weight of backfill soil	γ_{sb}	kN/m^3	16.5
3	Unit weight of in-site gravel layer	γ_{sf}	kN/m^3	19.0
4	Unit weight of concrete	γ_c	kN/m^3	24
5	Unit weight of water	γ_w	kN/m^3	9.81
6	Internal friction of back fill soil	$\emptyset_1$	degree	30
7	Internal friction of gravel layer	$\emptyset_2$	degree	40
8	Cohesion of soil	C	kN/m^2	0
9	Safety factor of sliding	FS_s	-	1.5
10	Safety factor of overturning	FS_o	-	1.5
11	Allowable soil bearing capacity	$q_{all.}$	kN/m^2	250
12	Coefficient of friction	C_f	-	0.55

The optimum design of gravity flood wall is picked up by getting the optimum values of five design variables (DVs) which are: length of heel slab x_1, top width stem x_2, front buttress length x_3, length of toe slab x_4, thickness of base foundation x_5, where Fig. 5 shows the DVs of flood wall.

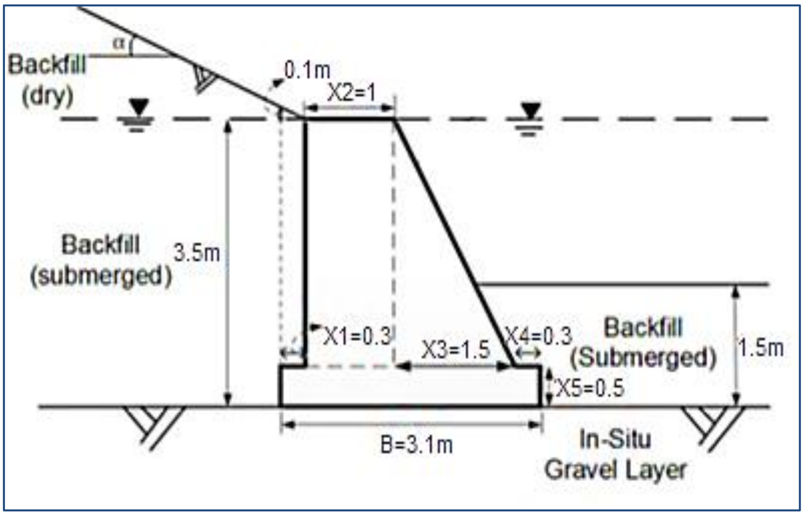

Fig. 5 Cross section of the flood wall of Chiuliao First gravity-type [8]

The optimum values of design variables for case along with the corresponding values of ordinary design [8] are reported in Table 2:

Table 2 Comparison results between ordinary design and optimal design methods by ANSYS

Design Variables	Variables Value	
	Ordinary Design [8]	Optimal Design
x_1 (m)	0.30	0.435
x_2 (m)	1.0	1.047
x_3 (m)	1.50	0.649
x_4 (m)	0.30	0.962
x_5 (m)	0.50	0.508
$f(x)$ (m^2)	6.80	5.678
FS_s	2.15> 1.5	2.35> 1.5
FS_o	1.45< 1.5	1.98 > 1.5
q_{max} (kN/m^2)	133.63 < $q_{all.}$=250/1.5	124.00< $q_{all.}$=250/1.5

The results given in Table 2 show that there are differences in design variables values between ordinary design and optimal design. The optimal section is more stable than ordinary section and the optimum area F(X) is lesser by 17.64% than of ordinary design.

In other hand, several cross-sections of gravity concrete flood walls have been selected in this research as shown in Fig. 6.the best section among them will be determined that achieve the requirements of safety and stability with minimum area.

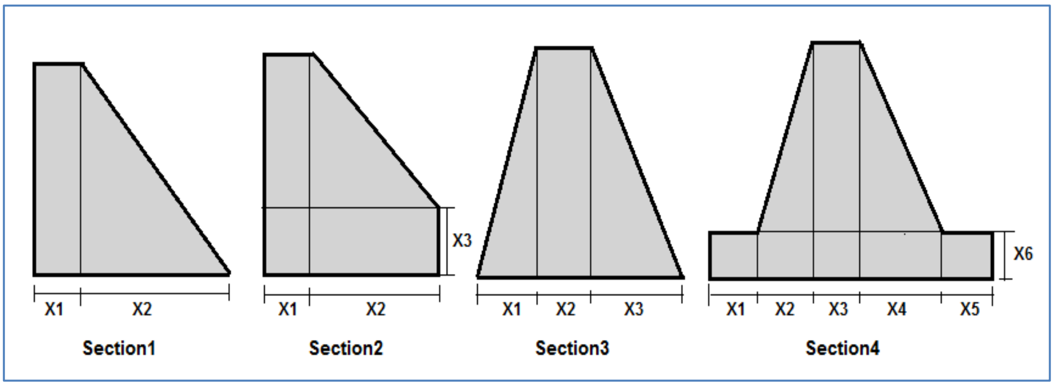

Fig. 6 Cross-sections of concrete gravity flood walls.

According to input parameters [1] which are height of the wall (H=1.8m), unit weight of soil (γ_s=16kN/m^3), unit weight of water (γ_w =9.81kN/m^3), Internal friction of back fill soil (φ_1=30^0), Cohesion less soil (C=0 kN/m^2), Unit weight of concrete (γ_c =23.5 kN/m^3), coefficient of friction (C_f =0.55), passive soil pressure coefficient (Kp =3.69), allowable soil bearing capacity (q_{all}=95.76 kN/m^2), safety factors for sliding and overturning (FS_s and FS_o $= 1.5$), expected flood velocity (V=3m/sec), and soil depth of toe and heel (D_t and D_h=0.9m), the final results of the initial and optimal design for all cross-sections (sections 1 to 4) are given in Table 3.

Table 3 Initial and optimal design results for all cross-sections of gravity flood wall

Design Variables	Section1		Section 2		Section 3		Section 4	
	Initial section*	Optimal section	Initial section	Optimal section	Initial section	Optimal section	Initial section	Optimal section
x_1 (m)	1.22	0.561	1.22	0.304	1.22	0.988	0.65	0.305
x_2 (m)	1.22	2.432	1.22	2.386	0.9	0.305	0.36	0.478
x_3 (m)	-	-	0.6	0.305	1.82	2.176	0.35	0.305
x_4 (m)	-	-	-	-	-	-	0.70	0.869
x_5 (m)	-	-	-	-	-	-	1.52	1.106
x_6 (m)	-	-	-	-	-	-	0.46	0.457
F(x) (m^2)	3.34	3.249	3.71	3.102	4.45	3.451	5.75	4.220
FS_s	1.53	1.641	1.58	1.57	1.73	1.69	2.03	1.87
FS_o	1.28<1.5	1.722	1.41	1.66	1.87	1.78	2.61	2.10
q_{max} (kN/m^2)	66.78	37.92	77.16	43.30	43.10	40.89	76.39	69.44
q_{min} (kN/m^2)	-19.50<0	3.72	-18.59<0	2.20	1.31	0.049	11.37	3.50
e (m)	0.74>B/6 =0.4	0.41 <0.48	0.66>0.41	0.40 <0.43	0.62 <0.65	0.57< 0.58	0.44< 0.59	0.46 <0.47
FS_{eg}	1.54	1.88	1.54	1.69	2.50	2.19	2.26	1.93

* Initial sections have proposed by researchers

From this table, it is founded that the reductions in area from initial design are (2.86%, 16.5%, 22.6%, and 25.6%); respectively. Also, it is found that the section2 has less optimum section among other sections with achievement all requirements of safety and stability. For including a parametric study in this research, several heights of optimum section (i.e., section2) have been chosen as 0.9, 1.2, and 1.5m [1]. The results of optimization process are given and shown in Table 4 and Fig. 7; respectively.

Table 4 Results of several heights for section 2

Design Variables	H=0.9m	H=1.2m	H=1.5m
x_1 (m)	0.305	0.305	0.306
x_2 (m)	1.347	1.703	1.788
x_3 (m)	0.438	0.477	0.745
F(x) (m^2)	1.176	1.794	2.496
FS_s	1.559	1.508	1.500
FS_o	1.717	2.613	2.496
q_{max} (kN/m^2)	30.87	23.40	30.44
q_{min} (kN/m^2)	0.04	16.59	22.64
e (m)	0.274	0.057	0.015
FS_{eg}	2.084	1.900	1.586

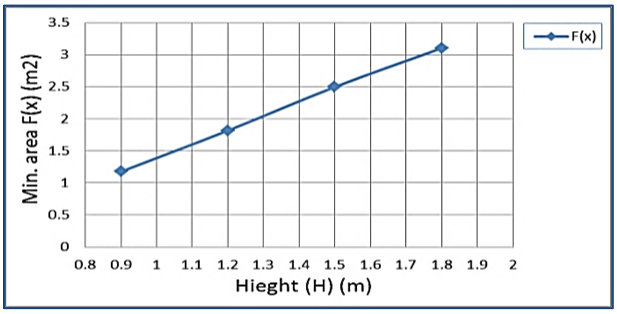

Fig. 7 Relation between height of wall and min. area for section 2

From Table 4 and Fig.8, the results showed that when the height of gravity flood wall is increased by 33.30% from (0.90 to 1.20m), the optimum cross-sectional area increases in a percent of (52.6%). Which means that the height is an effective parameter for getting the optimum section (min. area).

2. Cantilever flood Wall

A first order optimization method by ANSYS programing is applied on an section taken from [1], as shown in Fig. 8. The optimum design of cantilver flood wall is picked up by getting the optimum values of seven variables which are: heel slab length x_1, top width of stem x_2, length of toe slab x_3, base foundation thickness x_4, steel reinforcement required to resist moment at stem slab A_{s1}, steel reinforcement at heel slab A_{s2} and steel reinforcement at toe A_{s3}.All necessary parameters of this section will be occupied in the optimization process could be given in Table 5.

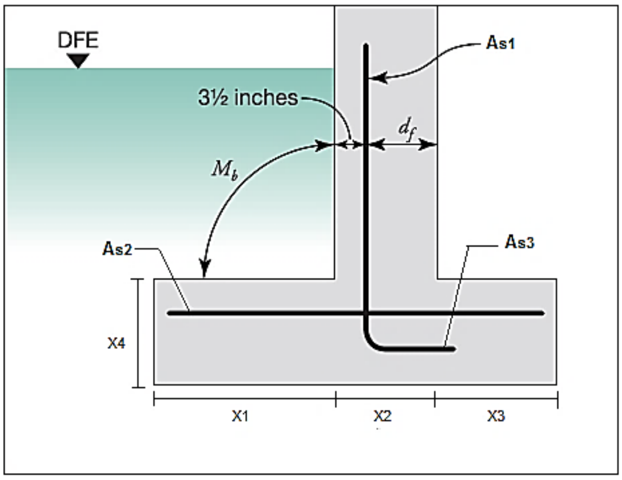

Fig. 8 Cantilver flood wall geometry dimensions and design variables [1]

Table 5: The values of design parameters of example [1]

N0.	Input Parameters	Symbol	Unit	Value
1	Height	H	m	2.10
3	Unit weight of soil	γ_s	kN/m^3	16.0
4	Unit weight of water	γ_w	kN/m^3	9.81
5	Internal friction angle of back fill soil	$\emptyset_1$	degree	30
6	Cohesion of soil	C	kN/m^2	0
7	Unit weight of concrete	γ_c	kN/m^3	23.5
8	concrete compressive strength	f'_c	Mpa	20.0
9	reinforcement yield strength	f_y	Mpa	413.6
10	Safety factor of sliding	FS_s	-	1.5
11	Safety factor of overturning	FS_o	-	1.5
12	Allowable soil bearing capacity	$q_{all.}$	kN/m^2	95.76
13	equivalent fluid pressure of soil	S	kN/m^3	12.25
14	coefficient of friction	C_f	-	0.47
15	passive soil pressure coefficient	k_p	-	3.69
16	Expected flood velocity	V	m/sec	1.52
17	Area of potential normal impact loading	C_B	-	0.2
18	moderate upstream blocking	C_{Str}	-	0.8
19	Toe soil depth	D_t	m	1.22
20	Heel soil depth	D_h	m	1.52

Continue…

The results of this case are tabulated in Table 6:

Table 6: Comparison results between ordinary design method of case [1] and optimal design method by ANSYS

Design Variables	Variables Value	
	Ordinary Design	Optimal Design
x_1 (m)	1.219	1.025
x_2 (m)	0.305	0.305
x_3 (m)	0.609	0.768
x_4 (m)	0.305	0.305
A_{s1} (m^2/lm)	$3.597*10^{-4}$	$3.012*10^{-4}$
A_{s2} (m^2/lm)	$6.771*10^{-4}$	$4.843*10^{-4}$
A_{s3} (m^2/lm)	$1.904*10^{-4}$	$1.021*10^{-4}$
$\boldsymbol{f}(\boldsymbol{x})$ (m^2)	1.207	1.197
$\boldsymbol{FS_s}$	1.788	1.746
$\boldsymbol{FS_o}$	1.506	1.5060
q_{max} (kN/m^2)	$32.23 < q_{all.}=95.76$	$28.96 < q_{all.}=95.76$
q_{min} (kN/m^2)	$4.51 > 0$	$5.97 > 0$
e (m)	$0.28 < B/6=0.35$	$0.23 < B/6=0.35$

In this case, the optimization was performed for minimum cross-sectional area of cantilver flood wall. The results indicated that the optimal design method by ANSYS is a viable technique prompts to optimum estimations of cross-sectional area and safety factors compared with ordinary design. Also, the results showed that the area of optimum section is less by 0.86% than ordinary section; while, the reinforcements area is less by 27.76%. Additionally, several heights which are 2.40, 2.75, and 3.0m have been selected as parametric study for this case. The results are given in Table 7 and shown in Fig. 9; respectively.

Table 7 Results of several heights for cantilver flood wall [1]

Design Variables	H=2.40m	H=2.75m	H=3.0m
x_1 (m)	1.032	1.345	1.297
x_2 (m)	0305	0.367	0.554
x_3 (m)	2.409	2.138	1.795
x_4(ft)	0.305	0.305	0.305
A_{s1} (m^2/lm)	$4.819*10^{-4}$	$7.201*10^{-4}$	$1.023*10^{-3}$
A_{s2} (m^2/lm)	$5.413*10^{-4}$	$1.004*10^{-3}$	$1.015*\ 10^{-3}$
A_{s3} (m^2/lm)	$1.771*10^{-4}$	$2.038*10^{-4}$	$2.404*\ 10^{-4}$
F(x) (m^2)	1.792	2.068	2.633
FS_s	1.560	1.839	1.580
FS_o	1.514	1.544	1.507
q_{max} (kN/m^2)	15.51	20.18	28.92
q_{min} (kN/m^2)	10.95	13.24	9.88
e (m)	0.107	0.133	0.298
FS_{eg}	1.77	1.62	1.38

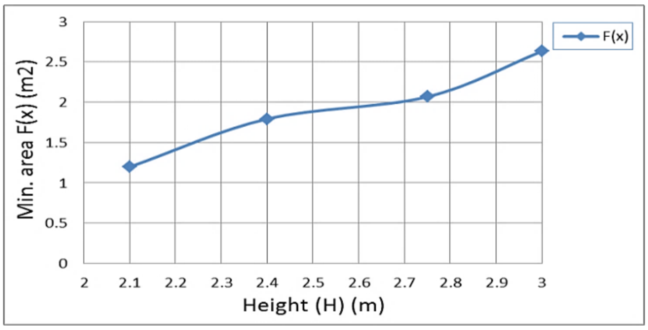

Fig. 9 Relation between height of wall and min. area for cantilver flood wall

The results from Table 7 and Fig. 9 showed that the optimum cross–sectional area of cantilver flood wall is increased by 46.89% when the value of the height increases by (25%) from 2.40 to 3m. Which means that the height is an effective parameter for getting the optimum section of cantilver flood wall also.

VI. CONCLUTION

1. The ANSYS / APDL is efficient tool to simulate wall-water-foundation interaction problem and optimization process.
2. Through the collection of optimization module (/OPT) and APDL, the optimal recycle analysis is fast and the results are reliable and reasonable.
3. The optimum design method by ANSYS is a viable technique prompts to optimum values of cross–sectional area with both safety and stability factors as compared with ordinary design.
4. from several common sections of gravity flood walls which have been designated as sections (1 to 4), it is founded that the section2 is the most safe and economic section compare with other sections.
5. The cross–sectional area of gravity flood wall more effect by increasing height than cantilver flood wall.

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