**International Journal of Advances in Applied Sciences (IJAAS)**
Vol. 3, No. 2, June 2014, pp. 95~103
ISSN: 2252-8814 

# A View Plan Sheet Pile: Design Chart for Cantilever Retaining Wall Construction for Active and Passive Earth Pressure in Baghdad Soil

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**Article Info**

***Article history:***

Received March 11, 2014
Revised May 15, 2014
Accepted May 24, 2014

***Keyword:***

Active earth pressure
Baghdad soil
Cantilever retaining wall construction
Passive earth pressure
Sheet pile

**ABSTRACT**

As society begins to demand greater and more efficient use of underground space, deep excavations are being carried out to meet the surging need for infrastructure in big cities. During excavation, an in situ wall system is often constructed to provide stability and to minimize movements of the adjacent ground. The choice of an appropriate retaining system depends on certain factors such as subsoil characteristics, groundwater condition, and building protection considerations. For some circumstances, steel sheet piling typically provides the most usual solution for the conditions encountered in the field. In order to ensure successful excavation work, the behaviors of the wall must be considered during the design phase. In this paper, the design of cantilever sheet pile walls involves the evaluation of loads imposed by soil, water, and surcharging was conducted using specialized computer program. The effect of variation in height, loading, and soil properties on the design was investigated.This paper is intended to enable the pile selection and penetration to be quickly determined for the certain construction cases of cantilever sheet pile in Baghdad soil. Finally, some simple guidelines to installation method and to prevent failures related to geotechnical works of sheet pile are presented.



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## 1. INTRODUCTION

Due to the rapid growth of Baghdad city, the population has increased by many folds. Thus, a greater and more efficient use of underground space, deep excavations are being carried out to meet the surging need for infrastructure in this city. Excavations of soil are one of the most important elements in laying the subsurface structures. These excavations usually require excavation support systems that have fundamental influence on the safety, profitability, speed and quality of construction projects [1]. The choice of an appropriate retaining system depends on certain factors such as subsoil characteristics, groundwater condition, and building protection considerations. For some circumstances, steel sheet piling typically provides the most usual solution for the conditions encountered in the field. In order to ensure successful excavation work, the behaviors of the wall must be considered during the design phase [2].

This study aims at understanding the design of cantilever sheet pile walls constructed in multilayered ground conditions of Baghdad soil. To meet this goal, an evaluation of loads imposed by soil, groundwater, and surcharging was conducted using specialized computer program. The effect of variation in height, loading, and soil properties on the design was investigated. Comparisons of lateral earth pressure and maximum bending moment by various existing methods are presented. Finally, some simple guidelines to installation method and to prevent failures related to geotechnical works of sheet pile are presented.

## 2. GENERAL DESCRIPTION

A sheet pile wall is a row of interlocking, vertical pile segments installed to form an essentially straight wall with a plan dimension sufficiently large enough for its behavior to allow for the analysis of a 0.3048 m wide vertical segment of the wall cross section. Since the early twentieth century, sheet piling has been in common use, particularly for waterfront structures and temporary works [3]. Sheet piling used to retain fill around open landside excavations via rectangular trenches or circular cofferdams. Sheet pile can also be used as earth-retaining structures along shorelines to allow for higher exposed grades to occur adjacent to lower river bottoms, dredge, or mud lines. There are two primary types of sheet pile walls. A cantilevered sheet pile is a wall that derives its support entirely through the interaction with the surrounding soil [4], mentioned that when the wall is under (3 m) in height it is often cantilever. An anchored sheet pile is a wall that derives its support through a combination of interaction between the surrounding soil and one or more mechanical anchors, or internal braces, in the case of open excavations which restrict the lateral deflection of the wall. Stability of sheet-piling wall depends on pressures excreted on its faces. They include the overturning, that results from active earth pressure; unbalanced water, acting upon the inner face of the wall and the passive pressure, acting on the wall's front embedment depth below the dredge line, so that the depth of penetration is the key of any sheet-piling wall's stability, [5] . Support from the surrounding soil for both types of walls refers primarily to the passive soil pressure exerted on the embedded portion of the wall below the dredge line or bottom of excavation, [6]-[9].

Sheet piles are commonly used for support excavation to depth up to two stories of basement [10]. They are suitable for only moderate height up to (5m) [11], or about (6 m) or less [8]. The use of cantilevered sheet pile is suitable for depth of driving greater than (3 m), [9]. This depth, some time, is limited to retained heights of between (3.048m) and (4.572m) [12]-[14].

In general, steel is the most common material used for sheet piling because of its inherent strength, relative light weight, and potential for long service life. Steel sheet piling can be supplied in lengths up to 31 m (HZ piles are available up to 33m long). Light-gauge steel piling is used only for small temporary and other minor installations. Hot-rolled steel is predominately used in Z-type sections for retaining and floodwall design applications where flexural bending governs the design. In general, uncoated and exposed sheet piles corrode at a rate of 0.0508 mm to 0.254 mm per year. Sheet pile driven in natural undisturbed soil will experience negligible corrosion because of the lack of oxygen below grade [15].

## 3. SHEET PILING INSTALLATION

Steel sheet piling is typically installed by driving, jetting, or trenching. Installation by driving is most commonly conducted with Impact driving, Vibro driving, Pressing, or Mixed driving methods. Impact driving is the best method for driving piles into difficult ground or final driving of piles to level in panel form. Vibro driving is usually the fastest and most economical method of pile installation but usually needs loose or cohesionless soil conditions for best results. Pressing is very effective in clay soils but less so in dense cohesionless ground unless pre-augering or jetting techniques are used.

There are two principal pile driving methods available to installers, pitch and drive and panel driving. Pitch and drive method requires equipment to control the verticality of the pile during installation so that piles can be pitched and driven one by one (Figure 1(a)). This method is the simplest way of driving piles but is only really suited to loose soils and short piles. For dense sands and stiff cohesive soils or in the case of possible obstructions, pitch and drive is not recommended.

Panel driving is the best method for driving sheet piles in difficult ground or for penetrating rock - which is unlikely to be possible with the pitch and drive method. In this method, piles may be threaded together above the ground in a support frame to form a panel prior to driving. The piles are then driven in stages and in sequence into the ground. Sequential driving enables verticality to be maintained, (see Figure 1 (b)) [15].

The installation method of sheet pile was correlated with standard penetration value of subsoil [16]. They stated that piles can comfortably advance to hard ground with (SPT $N \leq 30$) by means of hydraulic vibro hammer. When encountered very hard to stiff ground (SPT $N>50$), which is undealable with conventional driving, either pre-boring or used of other retaining systems like bored pile wall, are generally specified. Nevertheless, an effective and economic method was suggested to be used in the construction sheet pile wall retaining system that is Jet-Vibro pile installation method [16]. This method can be used to penetrate the hard ground (SPT 'N'>50) to the designed depth. Jetting is typically performed on both sides of the piling simultaneously and is discontinued during the last 1.524 m to 3.048 m of penetration. Jetting involves the control, treatment, and disposal of runoff water and spoils.

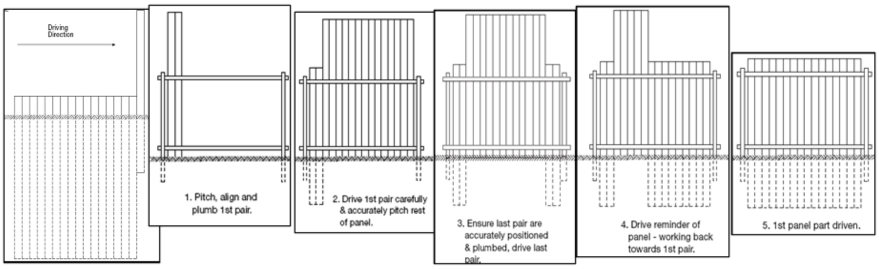



Figure 1. Pile driving methods (A) pitch and drive, (B) panel driving

Jetting in clay proved to be a highly effective aid to pile installation, considerably shortening installation time with a limited risk of refusal, but caused significant disturbance to the soil immediately adjacent to the pile, leading to a loss of friction of order of 10% to 40% [17].

Trenching of sheet piling is typically required when the penetration of the pile is relatively shallow and/or there are mitigating circumstances that preclude driving [7].

Nevertheless, driving of sheet piles into dense soils may necessitate the provision of section larger than that needed to satisfy the structural requirements. Drivability should be considered at an early stage in the design process as the need to provide a minimum section for driving may lead to a more efficient support system and may also offset any additional thickness needed to achieve the desired life expectancy for the structure [15].

## 4. SIMPLE GUIDELINES TO PREVENT FAILURES OF RETAINING STRUCTURES

It is a legal necessity when a new construction is launched in a developed area to provide protection to the excavation itself and to adjacent structures and facilities like buildings, roads, utility lines, etc. Despite the great importance of excavation support systems, most designers and contractors know very little about their design and construction, and they rely heavily on experience [1].

It is difficult to predict the behavior of retaining structures in details before the actual execution of the work. Therefore, the involvement of the design engineer should be not stop after designing the retaining structures. Therefore, the design engineer should closely supervised the construction works at the site and review the performance of the retaining structure and compare to the design requirements to take necessary action.

The major consideration to be taken during construction can be divided into three sections [18]. They are dilapidation surveying of adjacent structures, instrumentation and monitoring program, and supervision and construction control. During each stage of bulk excavation in the front of wall, the supervisor engineer should make sure that the contractor follows the predetermined design level. Over excavation increases additional stresses resulting in the increasing wall movements. Excessive over excavation might even cause catastrophic failure of the wall.

Many case histories indicate that excavation failures are usually caused by inadequacy of geotechnical design considerations, and lack of construction control and site supervision by consultant such as over-excavation (e.g. excavate deeper than designed depth) and uncontrolled surcharging at retained soil (e.g. stacking of excavated materials or other materials behind the wall at the retained side). These failures are usually man-made and caused by failing to comply with one or a combination of factors which include planning, analysis, design, construction control and supervision. Observational method should be used to compare design prediction with field performance to ensure safety [19].

From the 55 cases of failures investigated, 50% of them are due to inadequacy in design. In order to prevent similar failures, it is important for design consultant, consultant's site representatives and contractor to have some fundamental geotechnical knowledge so that any inconsistencies at site can be spotted and precautionary actions taken before failure occurs. Proper full-time site supervision by the consultant's representatives with adequate experiences, knowledge is a must. It is also the obligation of the consultant to properly brief the supervising team on the design and construction requirements [19].

Another important factor to consider when selecting and designing retaining wall system for excavation adjacent to properties sensitive to ground settlement is the lowering of groundwater at the retained soil due to excavation. Recharge wells should be considered and used if settlement of adjacent ground due to lowering of groundwater level likely to cause distortion and damage to adjacent properties [19].

## 4. EARTH PRESSURE CALCULATIONS

Several earth pressures theories are available for estimating the minimum (active) and maximum (passive) lateral earth pressures that can develop in a soil mass surrounding a wall [20]. A detailed discussion of various theories is presented in literatures [3]-[4], [8], [21]. A brief description about earth pressure theories is shown herein.

Classical methods of retaining wall analysis can be traced back to the work in (1776) and (1857) [22], [23]. In (1776) upper bound calculations was calculated assuming a planar wedge failure mechanism from which he derived the limiting (active) force on a retaining wall, as a function of depth below the retained soil surface. This form of calculation does not indicate a unique stress distribution. In (1857) lower bound calculations was carried out based on the assumption that the stress field behind the wall was in a uniform state of plastic equilibrium; from this he derived limiting earth pressures which, due to his assumptions, increased linearly with depth in uniform materials. For the simple case of a frictionless wall in uniform soil, the two solutions coincide provided it is assumed that the active force calculated using Coulomb's approach results from a lateral earth pressure that increases linearly with depth.

Later workers have used more complex calculations to determine earth pressure coefficients, based on either upper bound (following Coulomb) or lower bound (following Rankine) approaches, to refine the results and to extend them to include wall friction, sloping ground surfaces, and non-vertical walls.

A general solution for active and passive earth pressure coefficients of cohesionless soil wedge failing along a straight slip plane was provided in (1906) [24]. In the Dutch code this theory is extended for cohesive soil. A chart for estimating the value of the passive coefficient with curved failure surface in granular soil was developed in (1948) [25]. In design of this chart, a portion of the failure surface was assumed to be an arc of a logarithmic spiral. In some arth pressure theories, the failure mechanism in the soil depends on the shape of deformed wall. This mean that for the same problem other earth pressure coefficients are found when the passive earth wedge fails than in the case of e.g., anchor failure. Consequently, arching in the soil is implicitly taken into account. This theory was developed for rigid walls with a frictionless hinge and is still used for plastic design [26].A lower bound method was used in (1960) [27]. A finite deference solution using a highly mathematical method was adopted. In (1972) a closed form earth pressure solution using plasticity theory that can be used for both active and passive earth pressures computations WAS developed [28]. The problem of passive pressure for vertical wall with a horizontal granular soil backfill was analyzed in (1973) [29]. This analysis was done by considering the stability of soil wedge using the method of slices. Tabulated active and passive earth pressure coefficients for weightless soil without surcharge based on the values of effective cohesion, internal friction and wall friction was provided in (1990) [30]. The passive earth pressure coefficient were determined in (2000) by using the triangular slices within the framework of the limit equilibrium method for vertical retaining wall with a granular soil backfill [31].

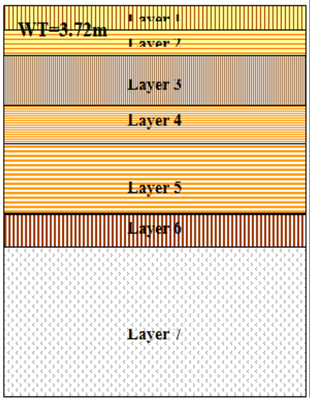
The degree of refinement is now such that the practical difference between the bounds is small, at least in cases where it can be assumed that earth pressures increase linearly with depth. However, there has been a considerable debate about how the earth pressures giving rise to these forces may be distributed, linearly or otherwise, both at collapse and under working conditions, [3]. However, the effect of lateral earth pressure calculated using some of presented theories on design of cantilever sheet pile walls was conducted using specialized computer program.

## 5. SUBSURFACE CONDITIONS IN BAGHDAD CITY

Subsurface conditions encountered at Baghdad city generally consisted of fill, the upper subsoil natural strata, and the lower natural soil strata. The fill or made ground layer encountered in numerous district of Baghdad city and consist of brown silty clay or clayey silt some time with trace of sand, brick, gravel and organic matters. The thickness of this layer ranged from (0.5 to 18) m. The deeper fill layer (>5m) encountered in timeworn district of Baghdad such as Saik Omer, AL-Tashria, Al-Adamiya, Al-Karama, Al-Khadhimiya, Al-Kindi, and Al-Sadon districts. While the shallow fill layer (<5m) distributedin Al-Waziriya, Al-Motanabbi, Al-Rashid Street, Al-Reid, Al-Wahdah, Al-Andalos, Al-Thawra, Al-Elam, Al-Nedal, Al-Kindi, and Al-Mustanseriya districts. The upper natural subsoil strata are medium stiff to hard brown silty clay to clayey siltsome time with sand and trace of gravel. The N value from SPT test for this layer ranged from 7 to 40 blows. The lower natural soil strata which found below the upper layer and consist of medium dense to very dense gray to brown sand some time with gravel, clay, or clayey silt. The N value for this layer ranged from 15 to 122 blows [32].

The assessment of soil stratification and assignment of appropriate engineering parameters is a fundamental part of the design process for an embedded retaining wall such as sheet pile. The soil not only creates the forces attempting to destabilize the wall but also provides the means by which stability is achieved so an understanding of the importance of soil in the design of sheet pile walls is paramount, [14].

This study aims at understanding the design of cantilever sheet pile walls constructed in multilayered ground conditions of Baghdad soil with shallow depth of fill. Typical profile of Al-Waziriya district (Figure 2) was adopted. The subsoil underlying the site under consideration divided into seven sub layers with 29m depth. The main soil properties of the layers are also shown in Figure 2.




| Layer | Mc % | LL % | PI % | Qu kPa | SPT | Soil Description |
|---|---|---|---|---|---|---|
| 1 | 23 | 51 | 26 | 45 | - | Fill/Soft Brown Silty CLAY with sand |
| 2 | 25 | 56 | 31 | 200 | - | Firm Brown Silty CLAY with sand |
| 3 | 24 | 52 | 25 | 250 | - | Stiff to Very Stiff Brown Silty CLAY with Organic Matter and Gyp. |
| 4 | 22 | 36 | 17 | 175 | 10 | Stiff Brown Silty CLAY with Org. Matter and Gyp. |
| 5 | 25 | 41 | 19 | 330 | - | Very Stiff Brown Sandy CLAY with silt ,Organic , Matter and Gyp. |
| 6 | 31 | 68 | 35 | 270 | - | Very Stiff Brown CLAY with Organic Matter and Gyp. |
| 7 | 25 | - | - | - | 30 | Medium Dense to Dense SAND becoming Gravelly SAND at the Bottom |

Figure 2. Typical profile and main soil properties of Al-Waziriya District- Baghdad (Modified after [32])

## 6. THIS STUDY

In this study the horizontal components of earth pressure acting on the active and passive sides of the cantilever sheet pile walls constructed in multilayered ground conditions of Baghdad soil were obtained by two classical earth pressure theories in common use (i.e. Rankine and Coulomb) and compared the results with lateral earth pressure obtained from the theory of Kerisel and Absi [30]. In addition to earth pressure, other common superimposed lateral pressures result from surcharge, and groundwater were studied. The sheet pile wall was designed using computer program "ReWaRD 2.5" developed by Geocentrix and commissioned by British steel Ltd. This program is an advanced program for designing embedded retaining walls under a variety of ground and loading conditions. By the aid of "ReWaRD 2.5", the lateral earth pressure, bending moment, and shear force along the full depth of the sheet pile were calculated for the above defined conditions. ReWaRD determines the required embedded length of cantilever sheet pile under fixed earth condition.

## 7. GEOMETRY AND PARAMETRIC STUDY

In this study the horizontal components of earth pressure were obtained by the mentioned earth pressure theories. Based on the literatures, the maximum retained height adopted in this paper at which cantilever wall considers to be effective is not exceeds 5m. It is assumed that there is no seepage occurring below the tip of the wall. Also, it will be assumed that the preexisting water table was high, so that, the phreatic surface in the long term will be taken at the level of the ground surface each side of wall. A surcharge of at 10, 20, and 30 kPa is placed on the retained soil. Finally the load and partial strength factors recommended in BS 8002 have been used in the obtaining numerical results. The geometry of the cantilever sheet pile wall and the deferent variables are defined in Figure 3.

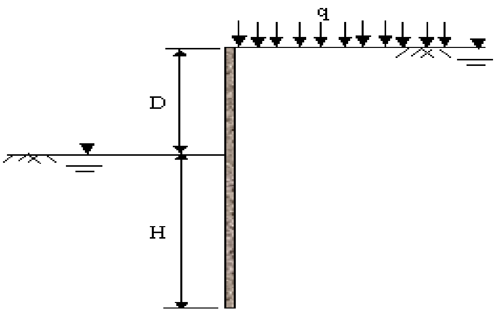



Figure 3. Definition diagram

## 8. RESULTS AND DISCUSSION

The choice of the parametric study in this paper was based with primary aim of studying the effect of loads imposed by soil, water, and surcharging on the calculated embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment.

Figure 4 to 8 show the results of parametric study. The results are shown in form of excavation depth versus embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment curves.

As can be anticipated, as excavation depth increases, the embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment increase. For the results obtained from Coulomb, and Kerisel and Absi theories, the incensement appears a linear trend. While the results of Rankine theory, show linear behavior up to excavation depth 3m, then trend changes in non linear behavior.

Furthermore, for each earth pressure theory, as the surcharge increases, the embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment increase. The effect of Surcharge, however, is more pronounced for the excavation depth more than 3m.

Comparison between the results of earth pressure theories reveals that in virtually all cases Rankine earth pressure theory results in substantially larger estimated embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment. For all cases studied Rankine earth pressure theory results in 1.48, 1.52, 1.51, 1.77, and 2.06 times the embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment, respectively as compared to other used methods.

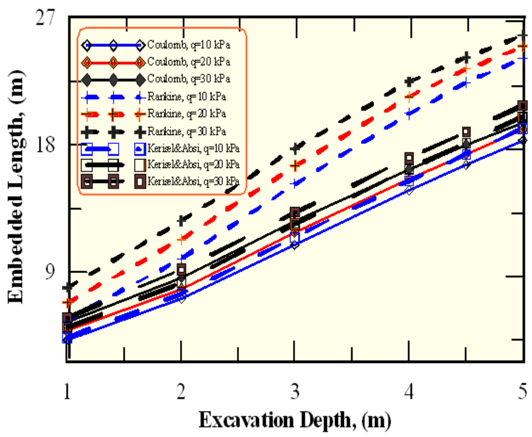



Figure 4. Excavation depth vs. embedded length

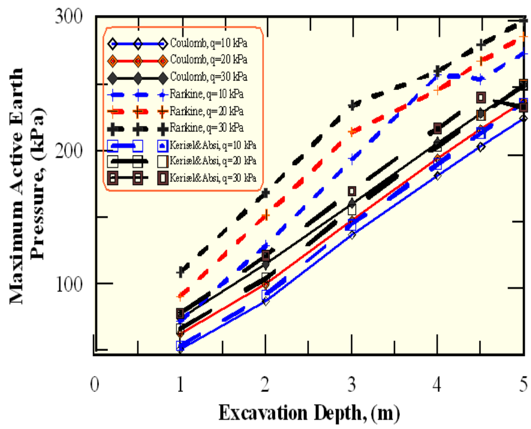



Figure 5. Excavation depth vs. maximum active earth pressure

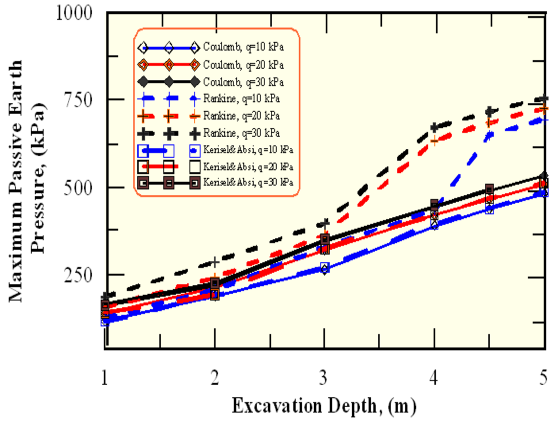



Figure 6. Excavation depth vs. maximum passive earth pressure

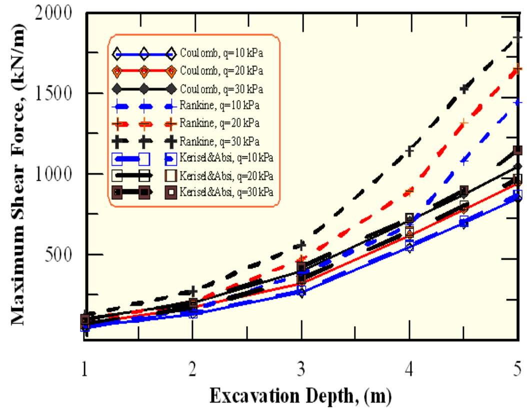



Figure 7. Excavation depth vs. maximum shear force

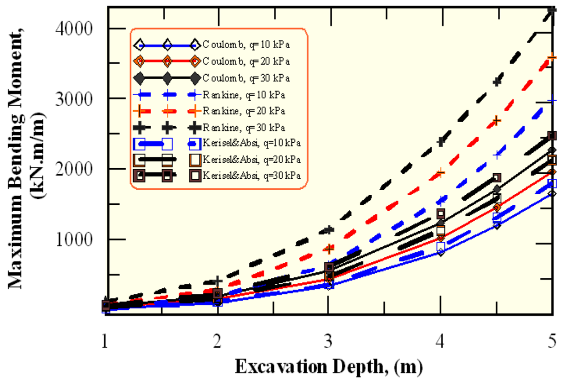



Figure 8. Excavation depth vs. maximum bending moment

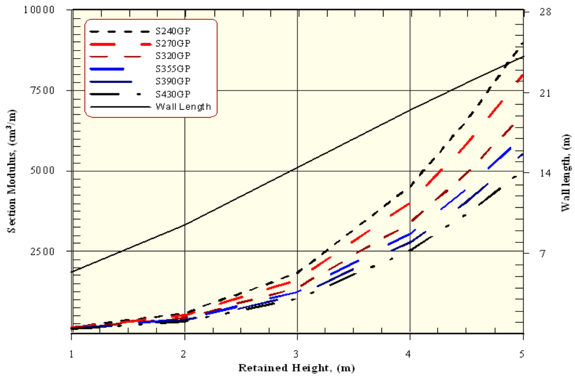



Figure 9. New design chart

## 9. NEW DESIGN CHART

To enable pile selection and penetration to be quickly determined for the certain construction cases of cantilever sheet pile in Baghdad soil, design chart was developed, (Figure 9). This chart indicates the structural requirements for a cantilever steel sheet pile operating in the conditions specified. While it is not intended that this chart should be used as a substitute for actual design for a set of circumstances it may be useful when assessing the likely requirements for a project at project appraisal stage.

The soil parameters used in this chart (Figure 2) are assumed to be the representative values for the multilayer soil which are then factored before carrying out the design calculations. This will ensure that the wall displacements in service will be limited to 0.5 % of the wall height [11].

The user should select the conditions which represent the case in question and then read off the minimum section modulus by steel grade, and minimum pile length from the chart. The values, thus obtained should be regarded as ultimate loads. Note that the depth (D) from Figure 11.16 corresponds to a factor of safety of 1.2.

This chart is based on the assumptions and requirements of BS 8002 at which safety and serviceability are delivered by the selection of the value of design soil strength, from which earth pressure have been deduced based on the theory of Kerisel and Absi. At the same time, water table are to be set as high as would be reasonable, a surcharge of at least 10kPa is placed on the retained soil. The wall must simply be shown to have equilibrium free body diagram.

The results shown in Figure 9 indicate that the critical depth of excavation using 12m deep sheet pile in the above site is 2.75m. The results confirm that the 12m penetration depth of the sheet pile is not adequate to support an excavation depth exceeding 3m.

Finally, an examination to Figure 9 reveals that in most cases hot-rolled steel sheet piling provided the most economical, structurally feasible solution to the design constraints of the this paper. On the other hand, for the design purposes, no commercially available section modulus could be found for retained height greater than (4m) Thus, for practice, the use of cantilevered sheet pile in Baghdad soil is suitable for a maximum retained height of (4m) or less.

## 10. CONCLUSION

The design of cantilever sheet pile walls involves the evaluation of loads imposed by soil, water, and surcharging was conducted using specialized computer program. An evaluation of loads imposed by soil, groundwater, and surcharging was conducted using specialized computer program. Comparisons of lateral earth pressure and maximum bending moment by various existing methods are presented. Finally, some simple guidelines to installation method and to prevent failures related to geotechnical works of sheet pile are presented.

1) Rankine earth pressure theory results in substantially larger estimated embedded length, maximum active earth pressure, maximum passive earth pressure, maximum shear force, and maximum bending moment.
2) Design chart was developed to enable pile selection and penetration to be quickly determined for the certain construction cases of cantilever sheet pile in Baghdad soil.
3) The 12m penetration depth of the sheet pile is not adequate to support an excavation depth exceeding 3m.
4) Hot-rolled steel sheet piling provided the most economical, structurally feasible solution to the design constraints of the present paper.
5) For practice, the use of cantilevered sheet pile in Baghdad soil is suitable for a maximum retained height of (4m) or less. For large excavation depths and to restrict the deformations of the wall, it is necessary to anchor the wall.
6) For subsurface conditions encountered at Baghdad city, generally, Vibro-driving and Impact driving are the most suitable methods for installation of piles. However, it is also necessary to consider installation of the piles when determining the section to be adopted as hard driving conditions may require a heavier section to prevent buckling during installation.

Finally, some simple guidelines to prevent failures related to geotechnical works of sheet pile are presented herein.

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