Effect of Flange to Web Ratio of H-Pile On Compression Bearing Capacity

Mahmood R. Mahmood¹ Nahla M. N. Salim² Mohammed F. Abdulsamad³

(1) Assistant Professor, Civil Engineering Department, University of Technology, Baghdad, Iraq. E-Mail mahmoudal_qaissy@yahoo.com Phone No.009647901315445
(2) Assistant Professor, Civil Engineering Department, University of Technology, Baghdad, Iraq. E-Mail nahla_salim2007@yahoo.com
(3) MSc. student, Civil Engineering Department, University of Technology, Baghdad, Iraq. E-Mail mohamed913fh@gmail.com

Abstract:

Steel H-piles are applicable to many different geological deposits. They are the preferred foundation choice in terms of cost. It can withstand high driving stresses and have good resistance to buckling. Since a few researches are available about H-piles, therefore this research introduces an experimental study to evaluate compression bearing capacity of driven H-piles within a cohesionless soil.

The normal dimensions ratio of flange (f) to web (w) of H-pile is unity (1.0), at this study different flange to web ratios below unity and more than unity were chosen to investigate the effect of flange to web ratio on compression bearing capacity.

Sixteen model tests of H-pile are tested with different flange to web ratios (f/w) (0.6, 0.85, 1.0, 1.2, 1.4, 1.75, 2.0, 2.5) of the same pile length of (50 cm) and the same surface and cross sectional area, embedded within two different relative densities of sand (40 and 70)% to investigate the effect of relative density with the different flange to web ratios.

The results shows that the ultimate bearing capacity of H-pile increases more than that H-pile of unity flange to web ratio with increasing flange to web ratio (f/w) more than 1.4, and decreases for flange to web ratios below unity.

The results shows that also, the reduction and improvement ratio of ultimate bearing capacity of H-pile in a sand of relative density of 70% more than that of 40% ,which shows that the increasing in relative density has an effect on the ultimate bearing capacity with different flange to web ratios.

Keywords: H-pile, Sandy soil, Flange to web ratio, bearing capacity, relative density formation of plug
1. Introduction

Steel H-piles are high-capacity, low-displacement piles can be driven to refusal onto hard stratum. The name H-pile refers to the shape of the pile cross-section. In the Handbook of Steel Construction (2004), H-piles are referred to as HP shapes.

H-Piles are can be driven in a wide range of soil from very soft clay to very dense sand. It is used as deep foundations to support structures of low cost construction, such as buildings and bridges. They are also used for heavy highway, public works, offshore and industrial applications. Due to their strength, they can be utilized for driving in soil conditions that other piling would have difficulty penetrating. The durability of these steel piles works well for applications in areas that are existing to earthquakes or other natural disasters.

H-Pile consists of two flanges and a web of varying widths, depths, and thicknesses as shown in fig (1). It is available in 8, 10, 12, and 14 inch sections, in lengths up to 100 feet.

![H-pile components](image1)

![Actual driving H-pile](image2)

Figure (1): (a) H-pile components   (b) Actual driving H-pile

Based on Tomlinson and Woodward (2008), Chellis (1961), Peck et al. (1974), the benefits of driven steel H-piles are attractive to both contractors and designers due to their low costs, simple design, easy installation, and high bearing capacity. H-piles are versatile, easy to handle, and have good driving characteristics. They are more practical than driven concrete piles in terms of drive ability when the presence of boulders is frequent.
Opinions on the formation of a soil plug vary, according to (Hussein et al. 2003), a soil plug may form between the flanges and the web of an H-pile during driving, changing the driving characteristics to that of a displacement pile. According to Tomlinson and Woodward (2008), an H-pile driven into silty and sandy soils does not form a soil plug. The Federal Highway Administration (FWHA 2006), states that it can usually be assumed that a soil plug is formed during driving of an H-pile in both fine-grained and coarse-grained soils.

Chellis (1961) states that it is important to identify the presence of a soil plug for calculation of shaft friction resistance, since shaft friction develops around the outside (box) perimeter of the pile when a soil plug forms, where the soil becomes confined between the flanges and web, as shown in Figure (2).

Figure (2): Formation of plug in pipe and H-pile

David White (2002) shows analysis of shaft bearing capacity of H-piles based on arching theory. This analysis gives the capacity of each an H-pile wall is greater than the force required to install the pile. This application is checked by field load testing and, demonstrate the efficiency of this type of foundation system.

Yang, J. et.al (2006) describes a comprehensive field study to investigate the differences and similarities between the behavior of jacked H-piles and driven H-piles. The load test results shows that, the shaft resistance of jacked piles is generally more than that of driven piles, but the base resistance of jacked piles is lower than that of driven piles.
Ryan Belbas (2013), shows that the limit states design (LSD) criteria is unreliable, as the bases pile capacity on the structural strength of steel as opposed to the strength and condition of the surrounding soil strata. Also, the serviceability limit state (SLS) criterion ignores the settlement. His research conducted in the development of comprehensive LSD criteria for driven steel H-piles in Winnipeg city.

In this study it is going to investigate the effect of flange to web ratio (f/w) of H-pile on the bearing capacity and formation of plug, in order to improve the bearing capacity and get the optimum flange to web ratio for H-pile.

2. Ultimate Bearing Capacity of H-Pile

Ultimate bearing capacity is a function of strength and integrity of the pile, the soil resistance, the pile-soil interaction characteristics, and the applied load (Goble and Hussein 1995). Ultimate capacity is governed by bearing resistance of the strata and / or the weaker of the pile material. The estimation of $Q_{ult}$ is based on the manner in which the load is transferred to the soil and underlying strata (Fellenius 2011). A pile resists an applied axial-compressive load in end bearing, shaft friction, or a combination of the two, as illustrated in Figure (2). Shaft friction capacity develops along the pile shaft through friction (or adhesion) at the pile-soil interface and end bearing capacity develops at the pile toe from the bearing strength of the underlying stratum (Fellenius 2012), and the effect of soil plug should be considered according to figure (2c). The maximum amount of shaft friction capacity that a pile can develop is referred to as the $Q_{s-ult}$, the maximum amount of end bearing capacity that a pile can develop is referred to as the $Q_{b-ult}$, and the summation of $Q_{s-ult}$ and $Q_{b-ult}$ equates to $Q_{ult}$ and is expressed as:

$$Q_{ult} = Q_{s-ult} + Q_{b-ult}$$

The most accurate and desirable way to determine the $Q_{ult}$ of a pile is by static load testing (Craig 2004).

3. Methodology

3.1 The Soil Used

The soil used in testing model is a fine to medium poor graded gray sand brought from Abo-Nooass reign in Baghdad city. The sand was air dried and sieved according to (ASTM D 422-02 standard test method for particle-size analysis of soils).
3.2 Physical, Chemical and Mineralogical Properties

Standard tests were conducted to classify the soil and determine physical and engineering properties of the sand used; the results are summarized in Tables (1). The grain size distribution was carried out according to (ASTM D 422-98) and the results are shown in Figure (3).

Figure (3): Distribution of grain size for the sand used in the present study.

Table (1): Physical properties of the sand used

| Physical properties                                      | values | Specification |
|----------------------------------------------------------|--------|---------------|
| Specific gravity (Gs)                                    | 2.65   | ASTM D 854    |
| Coefficient of uniformity (Cu)                           | 1.88   | ASTM D 422    |
| Coefficient of curvature (Cc)                            | 1.2    | ASTM D 422    |
| Maximum dry unit weight (\(\gamma_{dry}\))\(_{max}\) (kN/m\(^3\)) | 16.96  | ASTM D 698    |
| Minimum dry unit weight (\(\gamma_{dry}\))\(_{min}\) (kN/m\(^3\)) | 13.36  | ASTM D 698    |
| D\(_{10}\)                                               | 0.11   | -             |
| D\(_{30}\)                                               | 0.16   | -             |
| D\(_{60}\)                                               | 0.20   | -             |
| Angle of Internal Friction \(\phi^\circ\) At Dr. 40%      | 35     | ASTM D 3080   |
| Angle of Internal Friction \(\phi^\circ\) At Dr. 70%      | 41     | ASTM D 3080   |
| "Soil symbols according to USCS"                          | SP     | ASTM D 422    |
Figure (4) shows maximum dry density and optimum moisture content for the soil used which conducted according to (ASTM D 1557) specification.

![Figure (4): Maximum dry density and optimum moisture content for the soil used](image)

3.3 The Equipments used

- Steel soil container (600x600x700) mm.
- Frame of applied load and hydraulic compression jack.
- "Load cell".
- "Digital weighting indicator".
- H-pile models

1- **Soil container**

   Soil container was used of inner dimensions (600x600) mm and 700 mm in depth, the container is made of (3mm) thick steel plate, as shown in Plate (1).

2- **Frame of applied load and hydraulic compression jack**

   The loading frame was designed to support the hydraulic jack of 10-ton capacity and the load applied on the soil samples by running the piston downward. A manual system is suspended on the frame to control the flow of the hydraulic jack as illustrated in Plate (2).
3- "Load cell"

A compression load cell of S shape (model: SM 600E) was used to measure the applied load. It is made of stainless steel of maximum capacity (5 tons).

4- "Digital weighting indicator"

A digital weighting indicator connected to the load cell to record the amount of applied load (model SI 4010). Input sensitivity (0.2 N/Digit), load cell excitation DC (10V ± 5 V) and maximum signal input voltage (32 mV).

5- H-Pile Models

To manufacture H-pile model, two identical plates of 3mm thickness represent the flange that welding as perpendicular with another plate represent the web of the same thickness to form H-pile.

Since the common H-pile dimension of flange to web is a unity, the H-pile model dimensions are chosen as (4cm of flange and web width and 50cm length). To perform other H-pile models different flange to web ratios were chosen to perform H-pile models of the same length with a condition of same surface and cross sectional area to conduct the tests. Two H-pile models of (f/w) ratios less than unity of (0.6 and 0.85), and six H-pile models of (f/w) ratios more than unity of (1.2, 1.4, 1.75, 2.0, and 2.5) were used to investigate the effect of different dimensions of flange and web on uplift and bearing capacities of H-pile. Plate (3) shows the different models of H-piles.
Plate (3): Types of H-pile models

H-pile models were inserted by jacking and suited in a position at the center of soil bed. Two steel wings of 2mm thickness were welded to the edge of the pile for supporting two dial-gages which are fixed to the sides of the soil-container by magnetic holders as illustrated in Plates (4) which shows also the compression and uplift load process.

Plate (4): soil-container with two-magnetic holders shows the compression and uplift load process
3.4 Test model preparation

The amount of sandy soil used in the container was determined according to the relative density of (40% and 70%). The steel container of (700mm) depth is marked into six layers; each layer of 100mm in height, the soil was placed and compacted to fit the marked volume for each layer and to reach a full depth of (600mm). Small hammer was designed to compact the soil and to reach the required density; Plate (5).

![Plate (5): The hammer used for soil compaction](image)

3.5 Testing Program

16 model tests were conducted and can be summarized as follows:

- 8 models were tested under compression load at relative density of 40%.
- 8 models were tested under compression load at relative density of 70%.

4. Failure criteria for compression load of H-Pile

The ultimate failure load for a pile is defined as the load when the pile settlements occur rapidly under sustained load.

Other failure definitions consider arbitrary settlement limits such as the pile is considered to have failed when the pile head has moved 10 percent of the pile end diameter or the gross settlement of 1.5 in. (38 mm) and net settlement of 0.75 in. (19 mm) occurs under two times the design load.

Terzaghi (1943) proposed failure load as the load corresponding to displacement of 10% of the footing width (or pile diameter). This proposal was adopted to specify ultimate bearing capacity.
5. Results and Discussion

5.1 Effect of Flange to Web (f/w) Ratio

Typical load-settlement curves of loaded H-pile models for (f/w) ratio of (0.6, 0.84, 1, 1.2, 1.4, 1.75, 2, and 2.5) of dry relative densities of 40% are illustrated in figures (5) and (6) for (f/w) ratio more than unity and less than unity respectively. Analysis of the results revealed that the increase of (f/w) ratio lead to increase in bearing capacity.

Figure (5): load-settlement behavior of H-pile under compression load on dry soil at relative density of 40% for (f/w) ratio more than unity (1).

Figure (6): load-movement behavior of H-pile under compression load on dry soil at relative density of 40% for (f/w) ratio less than unity (1).
The results of ultimate bearing capacity for compression load test for relative density of 40 % are illustrated in table (2).

The results of ultimate bearing capacity shown in table (2) shows a reduction ratio of ultimate bearing capacity for (f/w) ratio of (0.6, 0.84, 1.2, and 1.4) than unity by (20.6, 10.3, 13.1, and 1.37) % respectively, and there are an improvement ratio of ultimate bearing capacity for (f/w) ratio of (1.75, 2.0, and 2.5) than unity by (10.3, 17.2, and 37.9) % respectively.

Table (2): Ultimate bearing capacities of H-pile models under compression for different (f/w) ratios at (RD= 40 %)

| Flange to width ratio (f/w) | Settlement at 10% of the flange width (mm) | Ultimate bearing capacity x10 (N) |
|----------------------------|---------------------------------------------|-----------------------------------|
| 0.60                       | 4.1                                         | 115                               |
| 0.84                       | 4.7                                         | 130                               |
| **1.00**                   | **5.0**                                     | **145**                           |
| 1.20                       | 5.3                                         | 126                               |
| 1.40                       | 5.6                                         | 143                               |
| 1.75                       | 5.8                                         | 160                               |
| 2.00                       | 6.0                                         | 170                               |
| 2.50                       | 6.2                                         | 200                               |

Figures (7) and (8) show typical load-settlement curves of loaded H-pile models for (f/w) ratios of (0.6, 0.84, 1, 1.2, 1.4, 1.75, 2, and 2.5) for dry relative density of 70%. Analysis of the results revealed that also there is an increase of bearing capacity more than that of H-pile of unity for (f/w) ratio more than 1.4, and a reduction of bearing capacity less than that of H-pile of unity for (f/w) less than 1.4. This is also, attributed to inability of forming a plug within the smallest flange with respect to web (f/w) less than unity, and not fully mobilized of friction occurs along the web shaft in both sides. When increasing flange to web ratio more than unity confining pressure will introduce due driving and shear strength of the confining soil will be improved which lead to increase soil resistance and bearing capacity.
Figure (7): load-movement behavior of H-pile under compression load on dry soil at relative density 70% for (f/w) ratio more than unity (1).

Figure (8): load-movement behavior of H-pile under compression load on dry soil at relative density 70% for (f/w) ratio less than unity (1).

The results of ultimate bearing capacity for compression load test for relative density of 70% are illustrated in Table (3).
Table (3): Ultimate bearing capacities of H-pile models under compression for different (f/w) ratios at (RD= 70 %)

| Flange to width ratio (f/w) | Settlement of 10% of the flange width (mm) | Ultimate bearing capacity x10 (N) |
|-----------------------------|--------------------------------------------|----------------------------------|
| 0.60                        | 4.1                                        | 155                              |
| 0.84                        | 4.7                                        | 190                              |
| **1.00**                    | **5.0**                                    | **231**                          |
| 1.20                        | 5.3                                        | 220                              |
| 1.40                        | 5.6                                        | 225                              |
| 1.75                        | 5.8                                        | 290                              |
| 2.00                        | 6.0                                        | 313                              |
| 2.50                        | 6.2                                        | 340                              |

The results of ultimate bearing capacity in table (3) shows that a reduction ratio of ultimate bearing capacity for (f/w) ratio of (0.6, 0.84, 1.2, and 1.4) than unity by (33.0, 17.7, 5.0 and 2.6) % respectively, and there are an improvement ratio of ultimate bearing capacity for (f/w) ratio of (1.75, 2.0, and 2.5) than unity by (26.0, 35.5 and 47.1) % respectively.

5.2 Effect of relative density

Two different relative densities of sand were used to conduct the tests. The result of ultimate bearing capacity of H-pile for different (f/w) ratios shows the same increment and reduction with different (f/w) ratios but with different increment and reduction ratios as shown in tables (2) and (3). Figure (9) shows the effect of flange to width ratio with ultimate bearing capacity for the two relative densities of sand 40 and 70%.
6. Conclusions

1. The results show that there is great effect of flange to width ratio on the bearing capacity values with the same surface and cross sectional area.

2. Increasing of flange to web ratio more than 1.4 led to increase the bearing capacity of H-pile than that of (f/w) ratio of unity, and decreases less than unity for H-pile of (f/w) ratio less than 1.4.

3. For H-Pile in sand of relative density 40% a reduction ratio of ultimate bearing capacity for (f/w) ratio of (0.6, 0.84, 1.2, and 1.4) than unity by (20.6, 10.3, 13.1, and 1.37) % respectively, and there are an improvement ratio of ultimate bearing capacity for (f/w) ratio of (1.75, 2.0, and 2.5) than unity by (10.3, 17.2, and 37.9) % respectively.

4. For H-Pile in sand of relative density 70% a a reduction ratio of ultimate bearing capacity for (f/w) ratio of (0.6, 0.84, 1.2, and 1.4) than unity by (33.0, 17.7, 5.0 and 2.6) % respectively, and there are an improvement ratio of ultimate bearing capacity for (f/w) ratio of (1.75, 2.0, and 2.5) than unity by (26.0, 35.5 and 47.1) % respectively.

5. The reduction and improvement ratio of ultimate bearing capacity of H-pile in a sand of relative density of 70% more than that of 40% which shows that the increasing in relative density has an effect on the ultimate bearing capacity with different flange to web ratios.
References

- **ASTMD 422 (2010)**, 'Standard test method for particle-size analysis of soils', Annual Book of ASTM Standards, Vol.04.08, Philadelphia, PA, ASTM, USA. Copyright, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

- **ASTMD854 (2010)**, 'Standard test methods for specific gravity of soil solids by water pycnometer1', Annual Book of ASTM Standards, Vol.04.08, Philadelphia, PA, ASTM, USA. Copyright, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

- **ASTM D698 (2012)**, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (600KNm/ m3)". Reprinted from the Annual Book of ASTM Standards. Copyright ASTM, Vol.4, No.8.

- **Chellis, R. D. 1961**. Pile foundations (2nd ed.). McGraw-Hill Book Co., New York, NY, USA.

- **Craig, R. F. 2004**. Craig’s soil mechanics (7th ed.). Spon Press, New York, NY, USA.

- **DAVID WHITE (2002)" The use of Pressed –in H-pile for Large Foundation Structures" Proceedings of the 7th BGA Young Geotechnical Engineers’ Symposium, 2002, Dundee, UK.

- **FHWA. 2006**. Design and construction of driven pile foundations reference manual-volume 1. FHWA-NHI-05-042. Hannigan, P.J., Goble G.G., Likins, G.E. and Rausche, F

- **Fellenius, B. H. 2011**. Basics of foundation design. Retrieved from www.Fellenius.net

- **Geology and Geotechnical Engineering: Utah State University, UT, USA.**

- **Hussein, M.H., Bixler, M., Rausche, F. 2003**. Pile driving resistance and load bearing capacity. 12th Pan-American Conference on Soil Mechanics and Geotechnical Engineering: Cambridge, MA, USA, 1817 - 1823.
- Mirasa, A. K., Sapari, N. A., Yusuf, M. Z., and Nazir, R., 2001, “Design Guide for Pile Using Locally Produced Steel H-Section.”, university of technology, Malaysia, 31310Skudia, Johor DarulTa’zim, Malaysia.
- Tomlinson, M., & Woodward, J. 2008. Pile design and construction practice (5th ed.). Taylor & Francis, New York, NY, USA.
- Peck, R. B., Hanson, W. E. and Thornburn, T. H. 1974. Foundation engineering. John Wiley & Sons Inc., New York, NY, USA.
- Yang, J., Tham, L. G., Lee, P. K. K., Chan, S. T. & Yu, F. (2006). "Behaviour of jacked and driven piles in sandy soil" Geotechnique 56, No. 4, 245–259.
- yan Belbas (2013) "The Capacity of Driven Steel H-Piles in Lacustrine Clay, Till and Karst Bedrock: A Winnipeg Case Study" A Thesis submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of MASTER OF SCIENCE Department of Civil Engineering University of Manitoba Winnipeg.