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# Use of Artificial Neural Networks and CPT Data to Assess a Pile Base Influence Zone

**presented by**


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# INTRODUCTION

Assessing pile load carrying capacity in any soil is a challenge due to the complex mechanisms involved and the effects of soil variability and pile installation process.

As such there is no 100% reliable and accurate method of predicting pile capacity, whether utilising soil lab tests, in-situ tests or full scale pile loading tests.

So it is easy to appreciate why some pile analysis methods can under-estimate or over-estimate pile capacity by as much as 300% or more.

This research focuses on using artificial intelligence (AI) approach to develop a computer based tool for assessing pile capacity with a realistic set of input parameters that can be abstracted a conventional ground investigation report .

The AI tool involves designing an artificial neural network (ANN) which is then "trained" with data from pile load test and cone penetration test (CPT) data.

Also, using the ANN tool, parametric studies are carried out to modify some existing pile analysis methods hence increase their accuracy.

## DEVELOPMENT OF THE NEURAL NETWORK METHOD

Artificial neural networks are used in many fields e.g. Finance and Statistics for problem identification, decision-making and prediction.

The success of a neural network relies on:

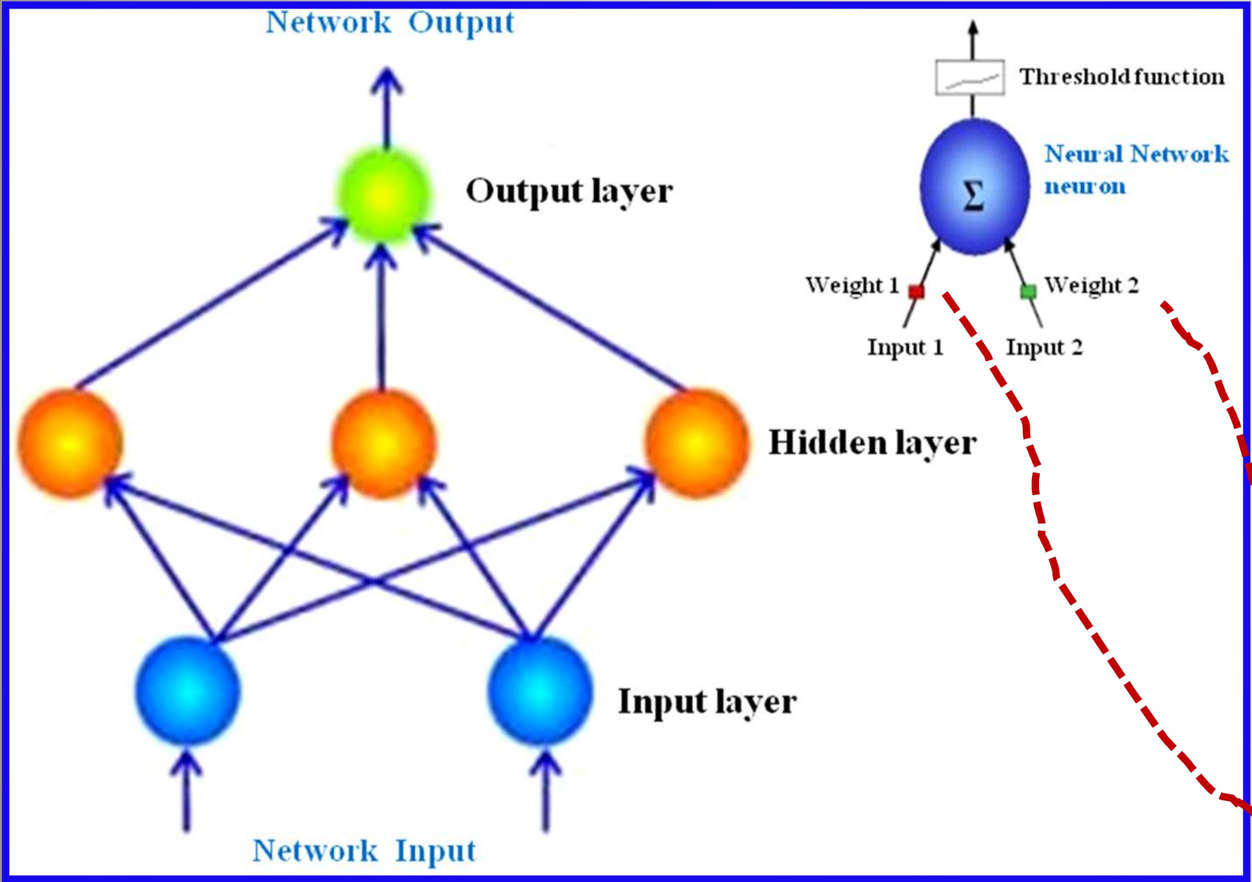
- Identification of the most representative models
- Quality and quantity of the training data sets from which the network can learn models.
- Ability of the network to correctly categorize new models hence make forecasts and predictions.

**Here a ANN algorithm is TRAINED by giving it a large number of correct predictions (of pile capacity) from which it can learn underlying relationships between input variables (pile-soil parameters) and outputs (pile capacities).**

**The basic building block of the neural network is the simulated neuron that generates, classifies, and/or predicts outputs by processing the input data.**

**Figure 1 shows the general architecture of a neural network.**

## Fig. 1: General architecture of a neural network




**Neurons related by weights, which are represented by values that move inside the linked neurons.**

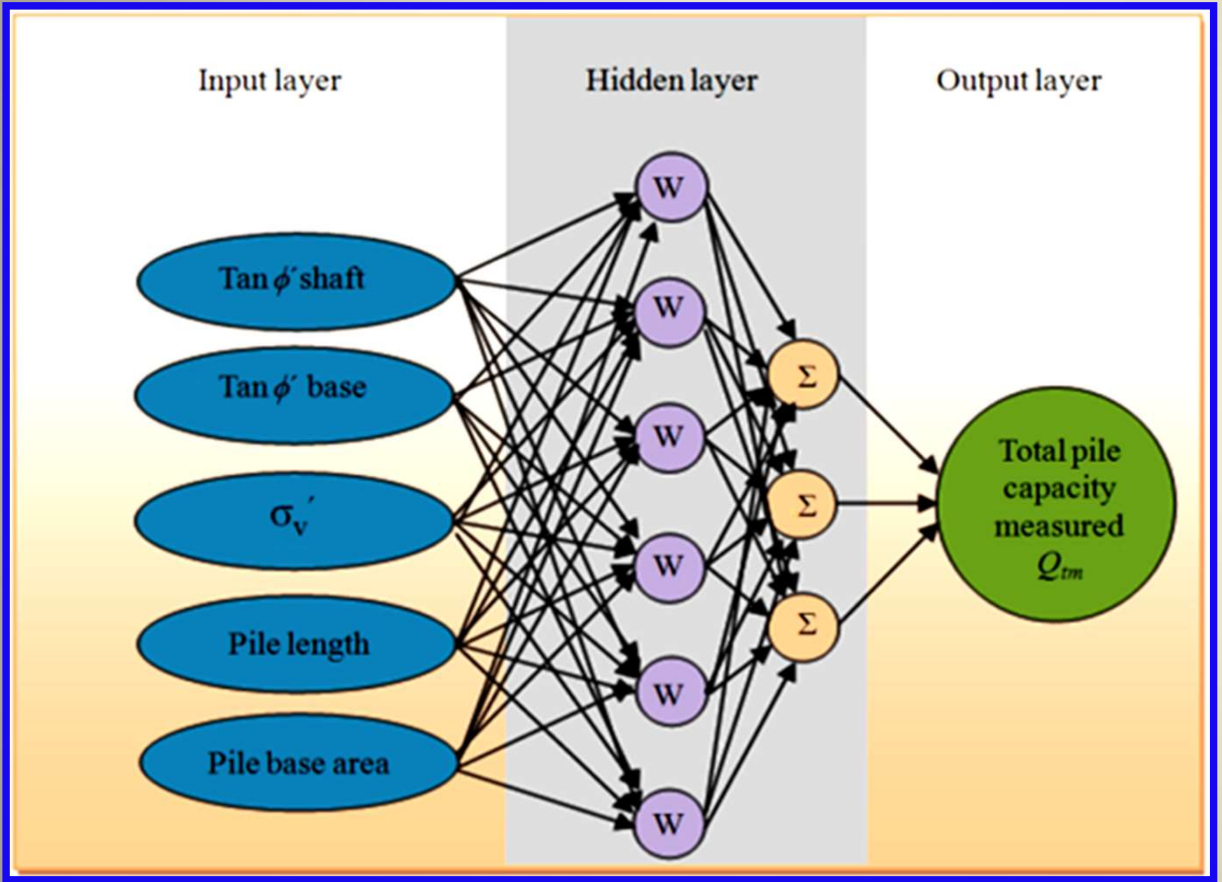
**In this work, using MATLAB software, a Back-Propagation Neural Network (BPNN) is formulated with five inputs comprising:**

**(i) effective overburden stress $\sigma'_v$ at pile base depth,**
**(ii) pile length L,**
**(iii) pile cross sectional area A,**
**(iv) tangent of the mean angle of soil shear resistance along pile shaft, $\tan \phi_{shaft}$**
**(v) tangent of the mean angle of soil shearing resistance at pile base, $\tan \phi_{base}$**

**The target parameter (output) in the network is the true pile head capacity $Q_{tm}$ measured in a pile load test.**

**Figure 2 shows the design of the network:**

**Figure 2: Proposed neural network structure**




**Next, pile test data involving the above parameters are divided into two groups, namely training data and validation data.**

**The training data included 59 full-scale pile tests [Aziz (2010)], enabling the neurons to learn the association between input and target data.**

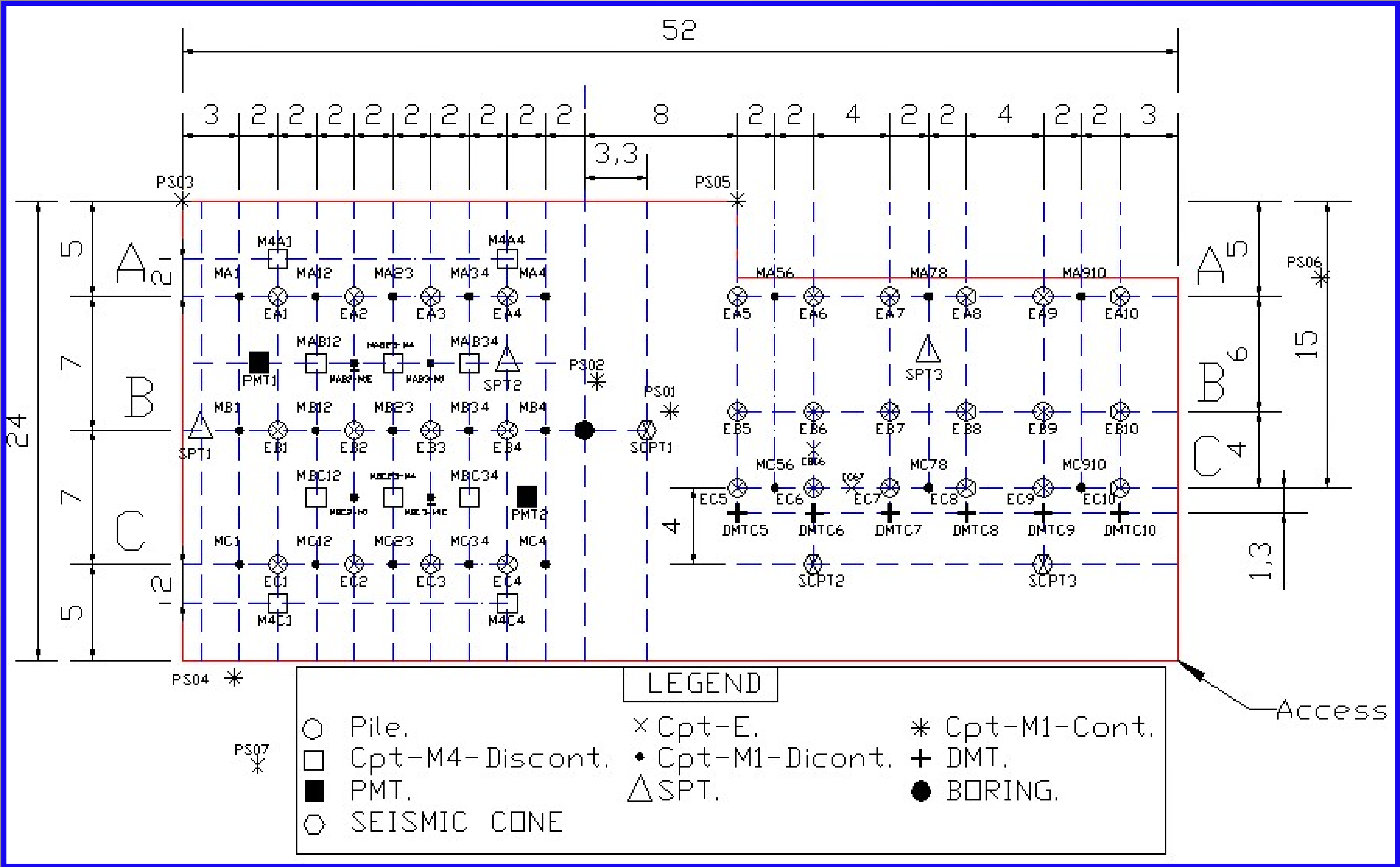
**New data from similar input parameters are then simulated in the new network to obtain output values (predicted pile capacity, $Q_{tp}$).**

# APPLICATION OF THE PROPOSED NEURAL NETWORK TO A CASE STUDY OF PILE TESTING IN BELGUIM

**The case study analysed here relates to a major research project carried out by the Belgian Building Research Institute (BBRI) and reported in an article by Huybrechts (2001).**

**The project involved ground investigation and load testing of 32 full-scale piles in sand at a site situated 30 km south of Brussels, see Fig. 3.**

## Fig. 3: Case study site (BBRI pile tests, Belgium) [Huybrechts (2001)]



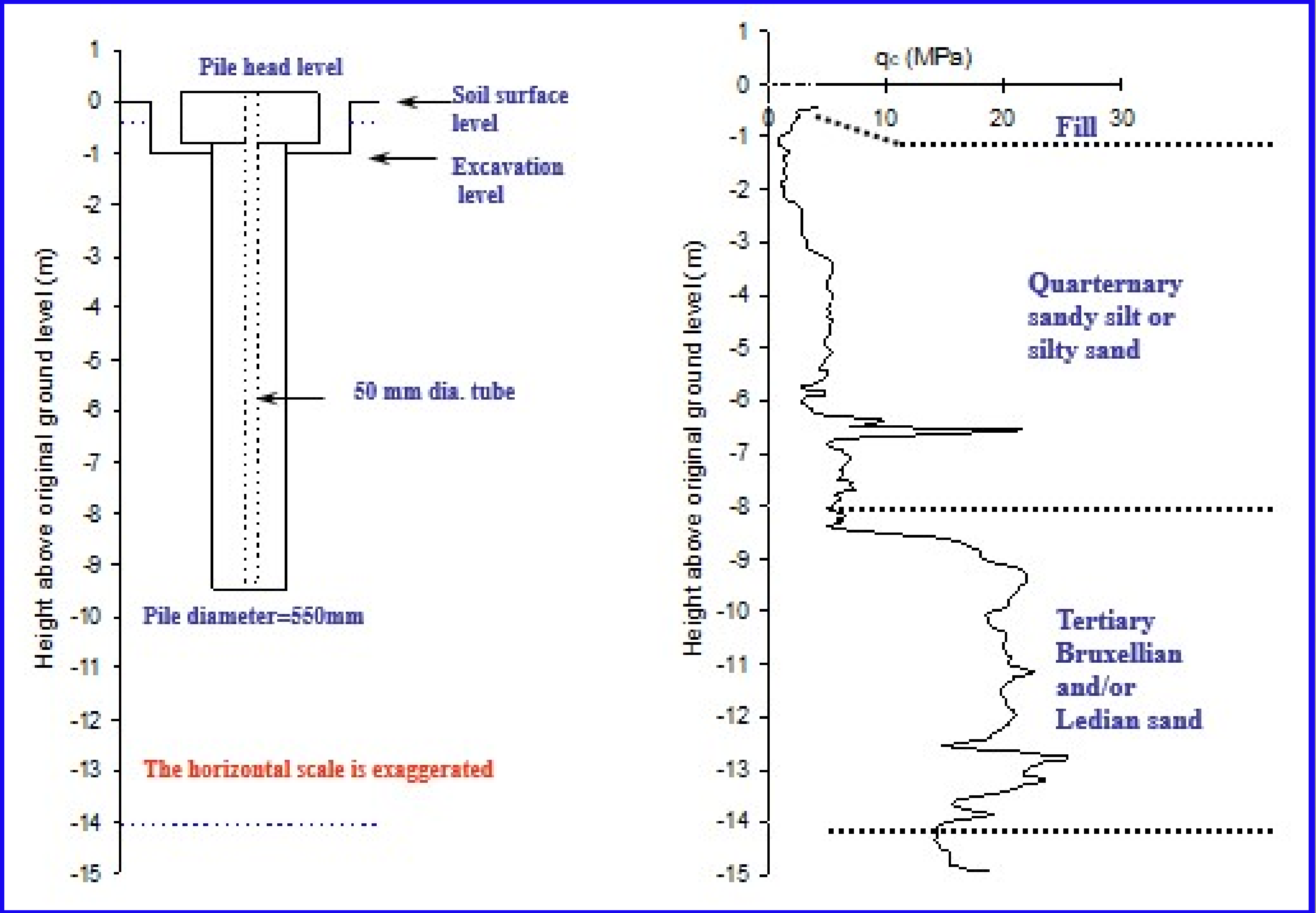

**Prior to installing the piles, CPTs (at each predetermined pile location) and other tests (see Fig. 3) were carried out as part of the ground investigation programme.**

**Additionally , boreholes provided soil lab test results. The following 11 piles, of different proprietary types were statically tested to near failure (Table 1):**

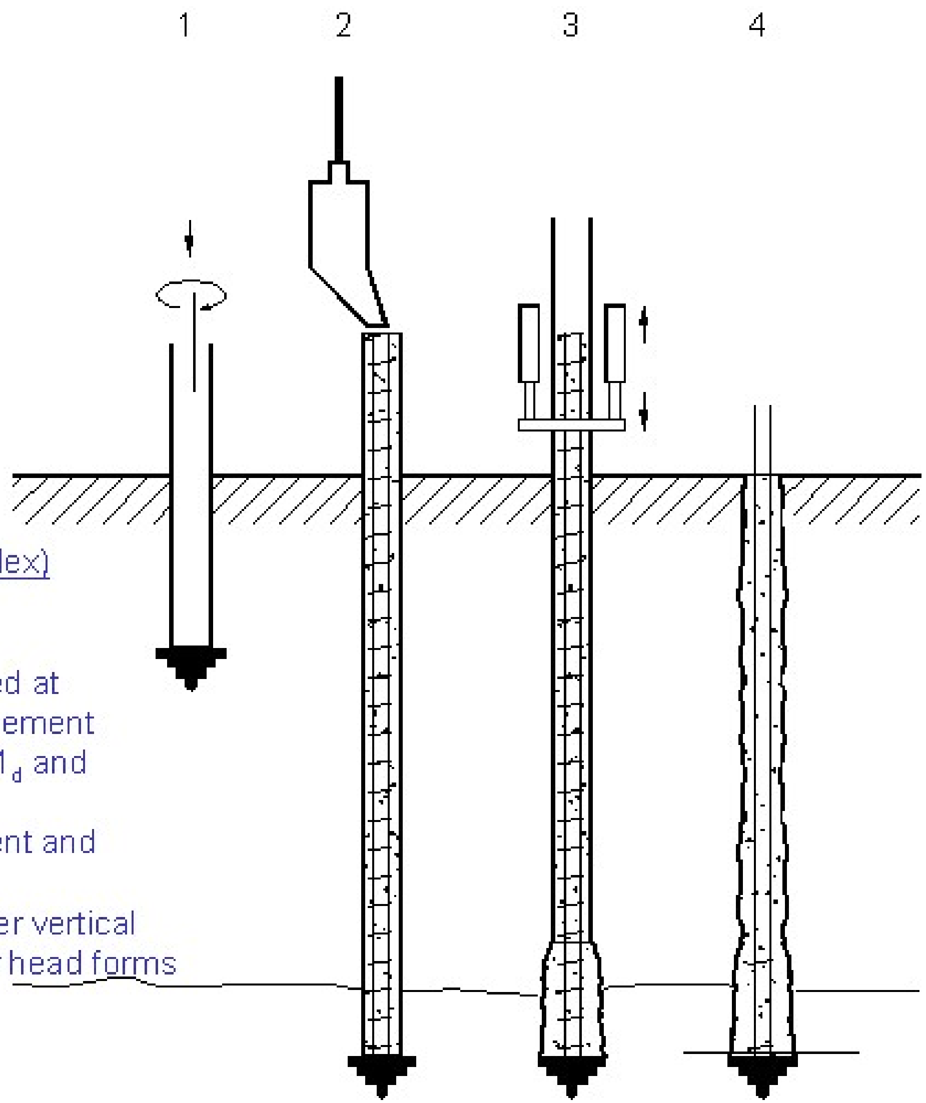
**Table 1 – BBRI static pile loading test (Huybrechts (2001)**

| Pile No. | Date installed | Pile type & nominal diameters $\phi_{shaft}/\phi_{base}$ | Shaft dia. $\phi_{shaft}$ (m) | Base dia. $\phi_{base}$ (m) | Pile base depth (m)*** |
|---|---|---|---|---|---|
| A1bis | 11/06/2001 | Fundex 38/45 | 0.390* | 0.450 | 9.59 |
| A2 | 12/06/2001 | Olivier 36/51 | 0.550* | 0.550* | 9.45/9.20** |
| A3 | 19/06/2001 | Omega 41/41 | 0.410 | 0.410 | 9.45 |
| A4 | 26/06/2001 | De Waal 41/41 | 0.410 | 0.410 | 9.53 |
| B1 | 20/06/2001 | Prefab 35x35 | 0.446 | 0.395 | 9.51 |
| B2 | 20/06/2001 | Prefab 35x35 | 0.446 | 0.395 | 9.57 |
| B3 | 29/06/2001 | Atlas 36/51 | 0.510 | 0.510 | 9.58/9.43** |
| B4 | 29/06/2001 | Atlas 36/51 | 0.510 | 0.510 | 9.58/9.43** |
| C2 | 12/06/2001 | Olivier 36/51 | 0.550* | 0.550* | 9.38/9.13** |
| C3 | 19/06/2001 | Omega 41/41 | 0.410 | 0.410 | 9.45 |
| C4 | 26/06/2001 | De Waal 41/41 | 0.410 | 0.410 | 9.52 |

## Fig. 4: Pile eleveation & Soil profile [Huybrechts (2001)]



## Fig. 5: FUNDEX pile [Huybrechts (2001)]




FUNDEX pile (Firm: Fundex)

**Installation procedure**

1. Screwing in tube, closed at the bottom with displacement auger tip, with torque $M_d$ and vertical crowd P.
2. Bringing in reinforcement and concreting.
3. Pulling out of tube under vertical oscillations. Lost auger head forms enlarged base.
4. Finished pile.

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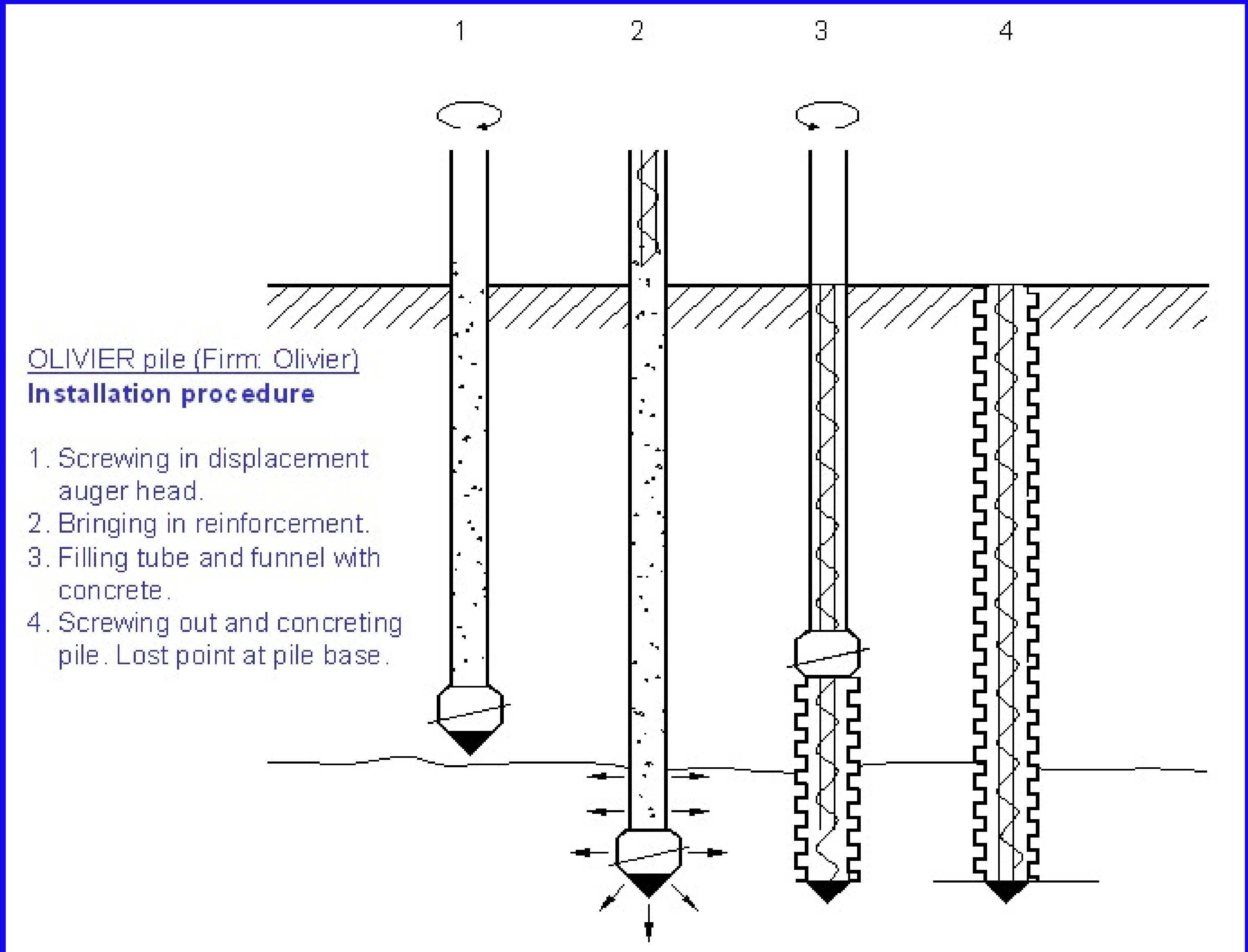
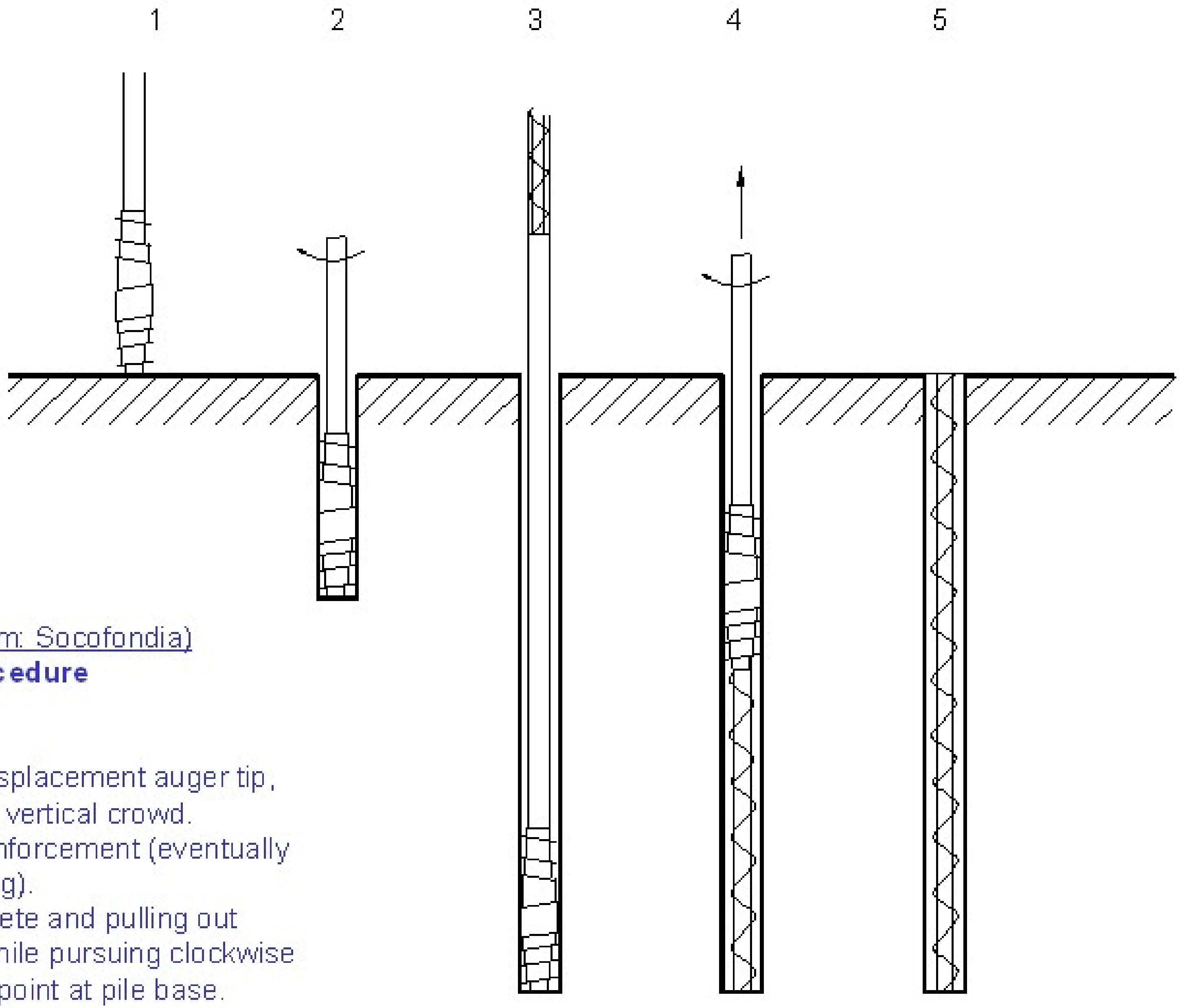
## Fig. 6: OLIVIER pile [Huybrechts (2001)]



## Fig. 7: OMEGA pile [Huybrechts (2001)]

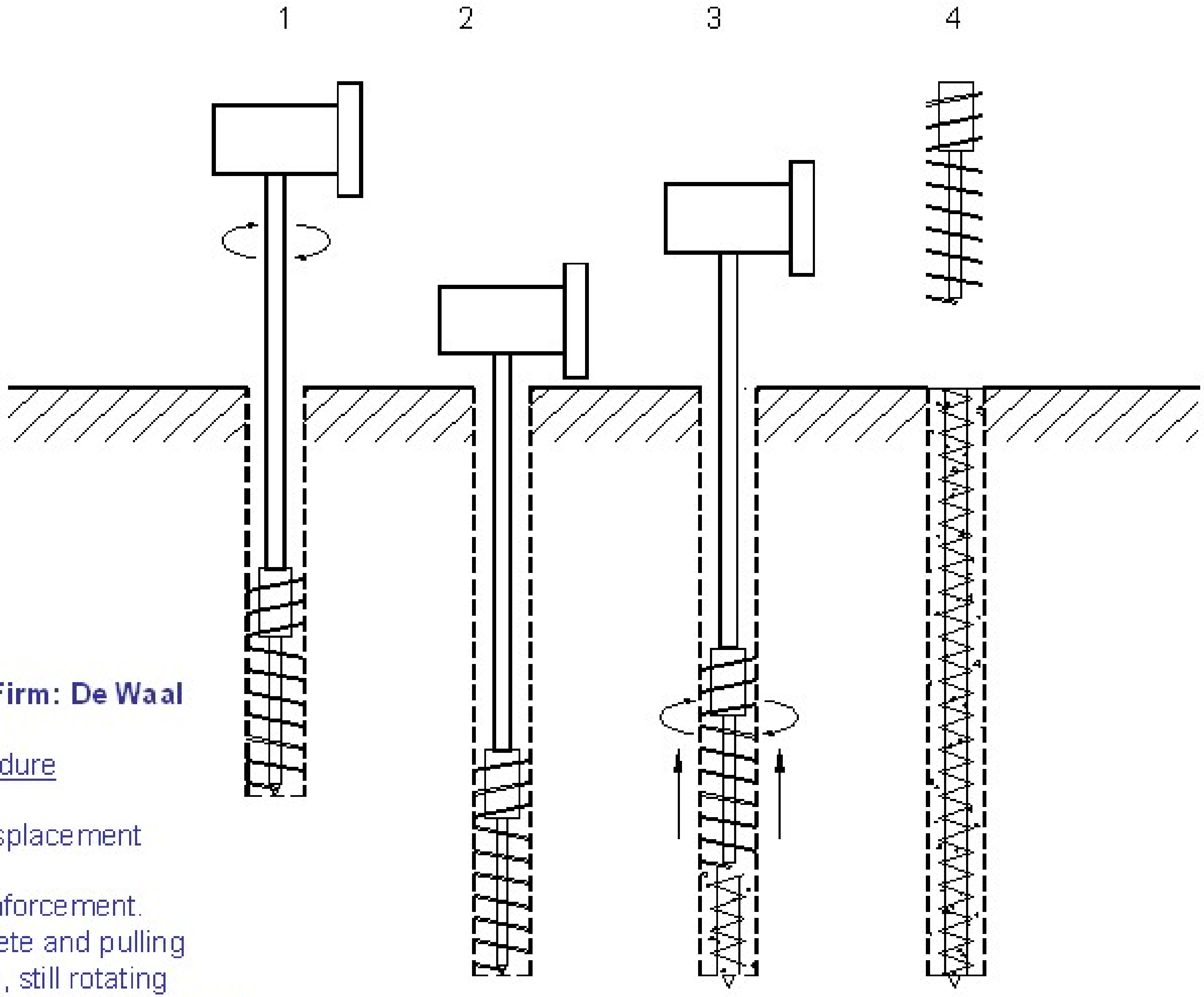



OMEGA pile (Firm: Socofondia)

**Installation procedure**

1. Setting up rig.
2. Screwing in displacement auger tip, optionally with vertical crowd.
3. Bringing in reinforcement (eventually after concreting).
4. Injecting concrete and pulling out auger head, while pursuing clockwise rotation. Lost point at pile base.
5. Finished pile.

## Fig. 8: DE WAAL pile [Huybrechts (2001)]

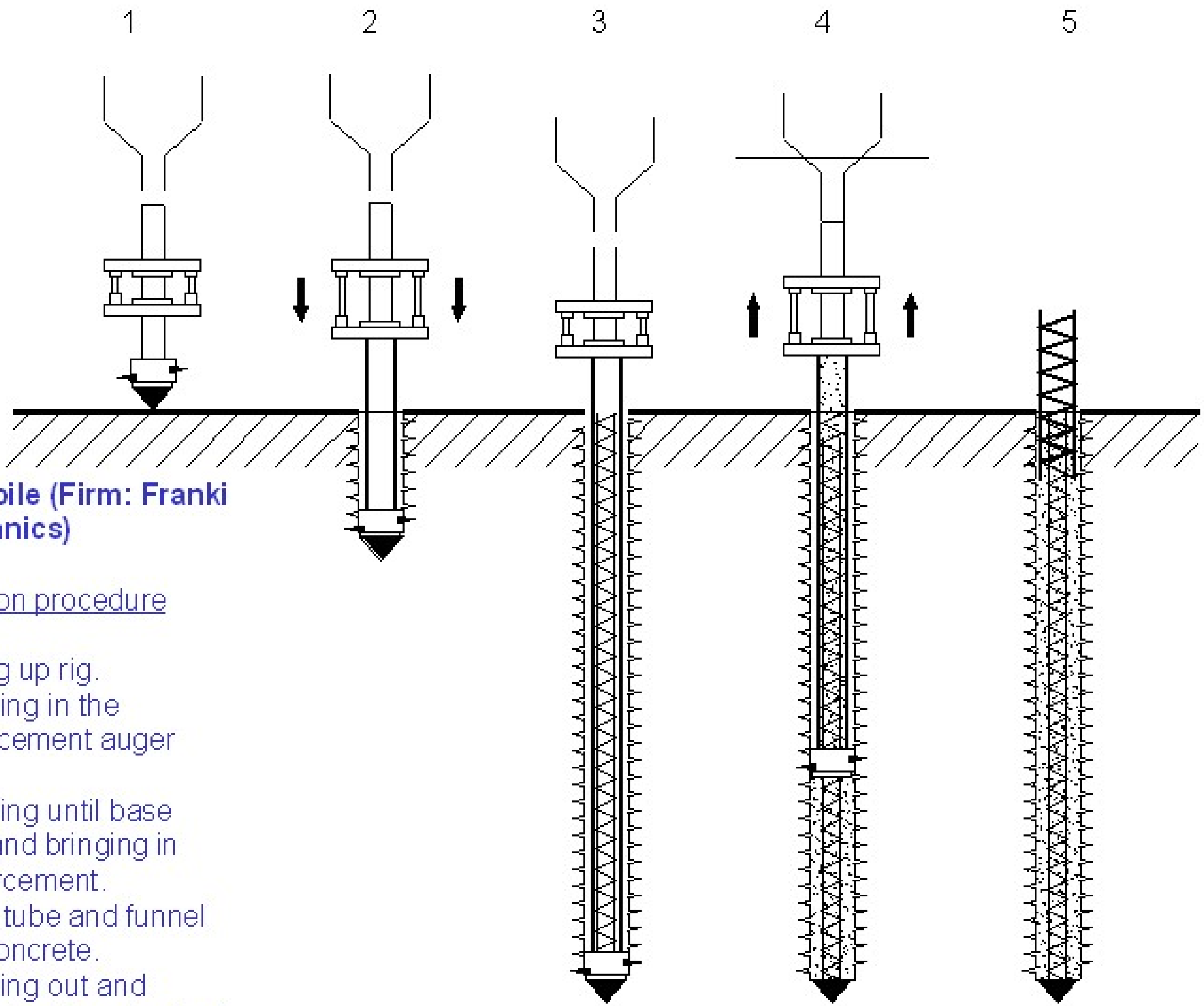



**DE WAAL pile (Firm: De Waal Palen)**

Installation procedure

1. Screwing in displacement auger head.
2. Bringing in reinforcement.
3. Injecting concrete and pulling out auger head, still rotating clockwise. Lost point at pile base.
4. Finished pile.

## Fig. 9: ATLAS pile [Huybrechts (2001)]




**ATLAS pile (Firm: Franki Geotechnics)**

Installation procedure

1. Setting up rig.
2. Screwing in the displacement auger head.
3. Screwing until base level and bringing in reinforcement.
4. Filling tube and funnel with concrete.
5. Screwing out and concreting the pile. Lost point at pile base.

**The author's neural network (BPNN) and 13 other methods were applied to the 11 static test piles (see Table 1) to predict load capacities and draw comparisons.**

**The 13 methods (Table 2) were programmed by Omer et al. (2006).**

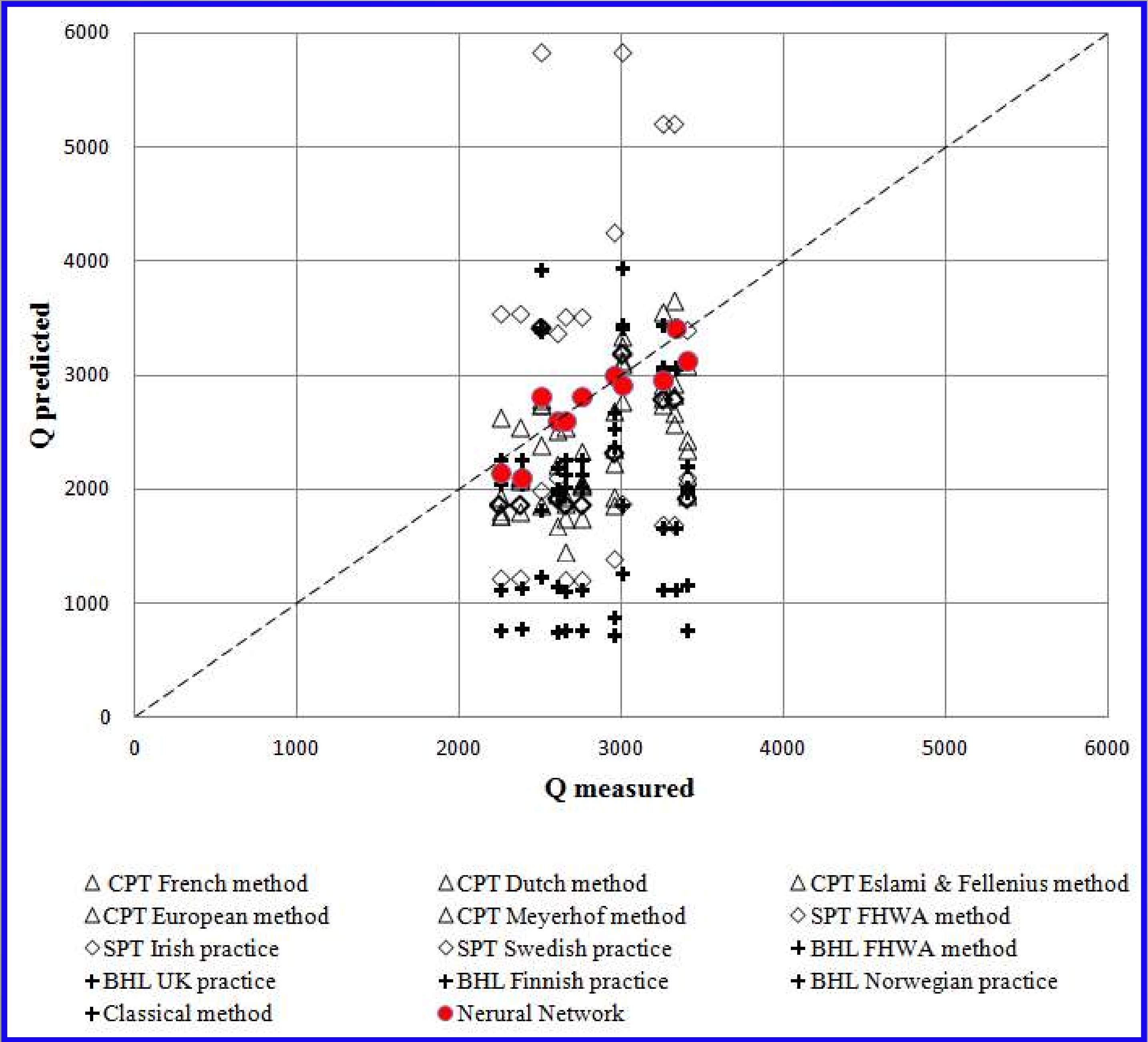
**Table 2. Pile calculation methods applied.**

| Methods based on Cone Penetration Test (CPT) data | Methods based on SPT (Standard Penetration Test) data | Methods based on borehole log data (BHL) | Based on Soil Mechanics theory |
|---|---|---|---|
| 1. French (Bustamante & Gianeselli, 1982)<br>2. Dutch Standards (1993)<br>3. European (De Ruiter & Beringen, 1979)<br>4. Meyerhof (1976, 1983)<br>5. Eslami & Fellenius (1997) | 6. Irish*<br>7. Swedish*<br>8. FHWA (1998) | 9. United Kingdom*<br>10. Finnish*<br>11. Norwegian*<br>12. FHWA (1998) | 13. Classical formula (Tomlinson & Woodward, 2008) |

*** Articles contained in De Cock and Legrand (1997)**

**Fig. 10 compares the predictive accuracy of the author's BPNN method with the 13 methods, for all 11 piles analysed.**

**Fig. 10 Predictive accuracy – author's neural network method compared with the 13 methods (data points from 11 piles analysed prior to load testing).**



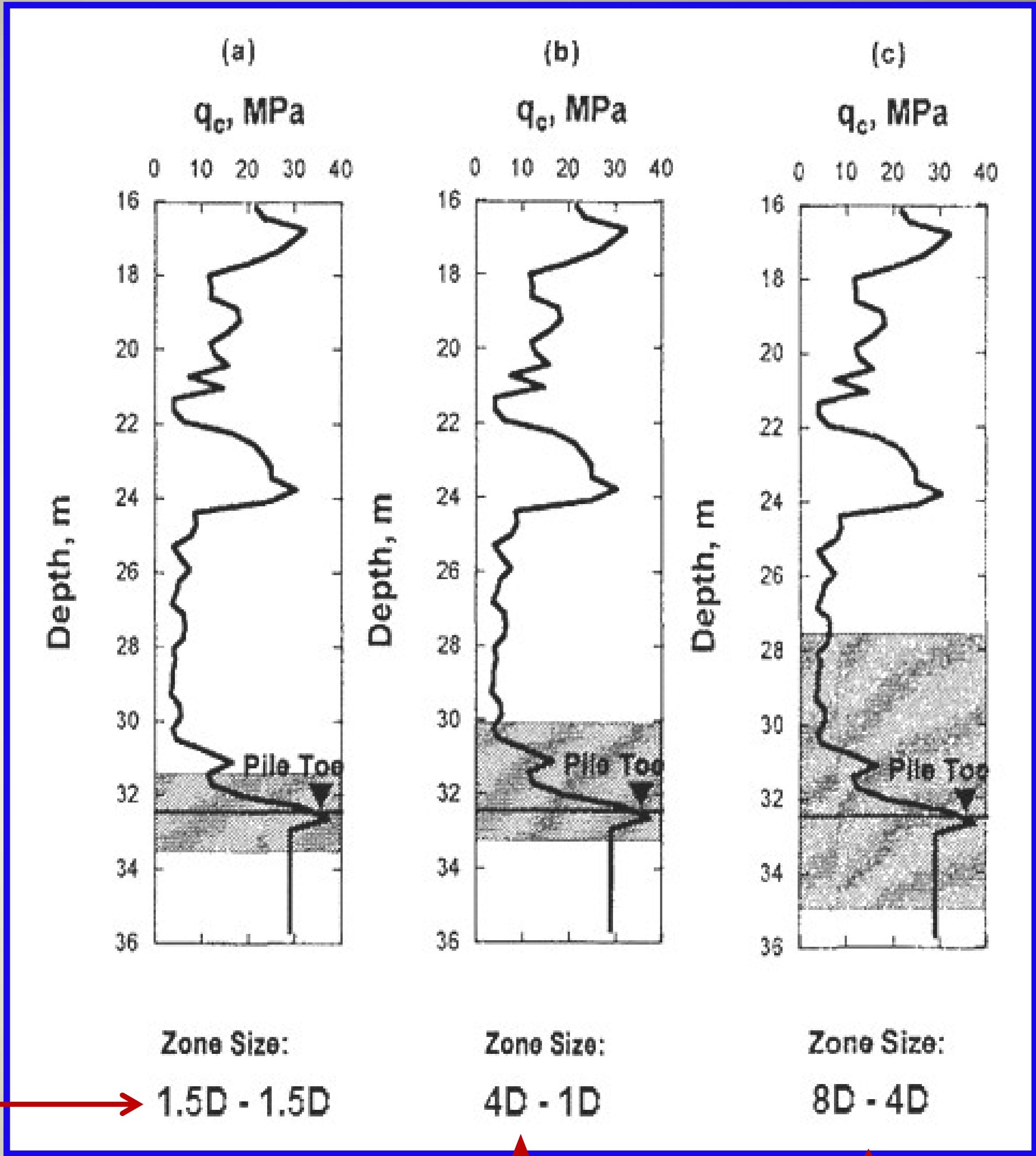
From Fig. 10 it is clear that, for these piles, the author's neural network method is far more accurate than the other 13 methods as its data points are consistently closest to the equality line (y=x).

## USING THE NEURAL NETWORK METHOD TO IMPROVE THE ACCURACY OF SOME OF THE EXISTING CPT BASED METHODS

A major reason for the inaccuracy of most of the existing CPT based calculation methods is the uncertainty in the depth range (influence zone) over which cone resistance values should be averaged to compute pile base resistance capacity.

Fig. 10 illustrates the different influence zones adopted by the various methods examined in this work.

**Fig. 11 Different influence zones used in different methods**




**Note:**
**D=pile diameter**

**French**

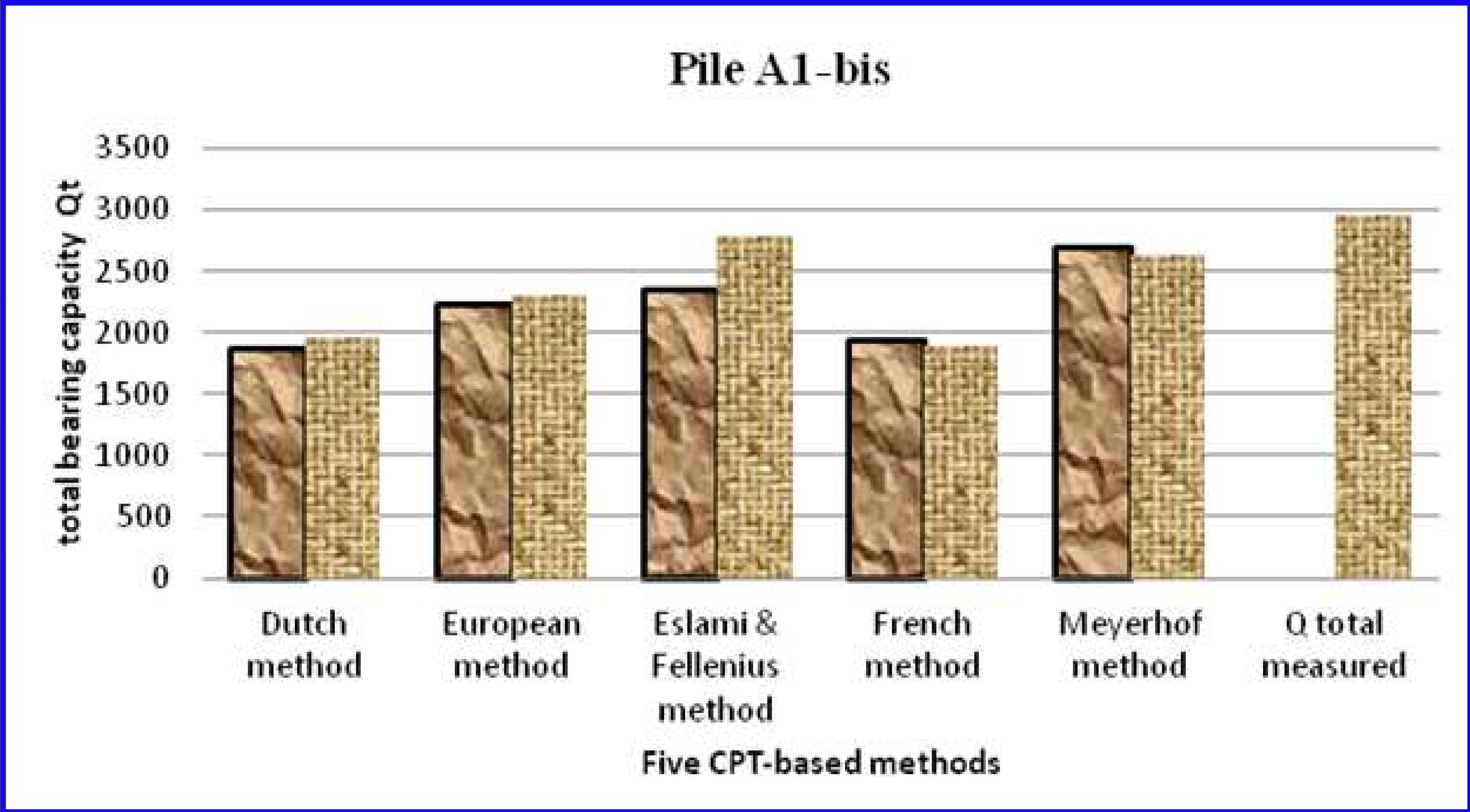
**Meyerhof**

**Dutch/European/Eslami-Fellenius**

**Taking each of the 5 methods (Fig. 10) one at a time, a typical test pile (Pile $A1_{bis}$) was analysed with the author's BPNN algorithm by inputting many trial influence zones and checking the predicted pile capacity against the measured value.**

**The large number of trials demonstrated that when the Eslami-Fellenius is modified by taking the influence zone as 6D-3D (i.e 6 pile diameters above pile based to 3 pile diameters below pile base), the predictive accuracy is markedly increased. The comparisons are shown in Fig. 12.**

**Fig. 12 Effect of modifying the influence zone to 6D-3D**



# CONCLUSIONS

**The proposed neural network BPNN is shown to produce more accurate predictions of pile head capacity than all the other 13 published methods examined.**

**The present work demonstrates that the assumed extent of the influence zone of soil around a pile base has a significant effect on the calculated pile capacity, when using CPT-based empirical methods.**

**The accuracy of the Eslami-Fellenius method, which is highly regarded due ability to account for pore pressure (using piezo-cone/$CPT_u$ data) further improved if the influence zone is modified from 8D-4D to 6D-3D. However, there is need to validate this definitively by analysing a large variety of test piles using this modification.**

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# THANK YOU

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