Engineering

Technical Guideline TG0639

General Technical Information for Geotechnical Design - Piles

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Only the current revision of this Guideline should be used which is available for download from the SA Water website.

Significant/Major Changes Incorporated in This Edition

This is the first issue of this Technical Guideline under the new numbering format. The original version of the document was last published in 2007 with the name of General Technical Information for Geotechnical Design Part I – Pile Driving (TG 10i). A full version history of this document is given in Document Controls. The major changes in this revision include the following items:

- Sections 3, 4 and 5 are added to cover the background and general requirements of piles
- Major revision of Section 6 (formerly Section 2 in TG 10i)
- Major revision of Section 7 (formerly Section 3 in TG 10i)

Document Controls

Revision History

Revision	Date	Author	Comments
0	1/1/2004	Ed Collingham	First Issue of TG 10i
1	10/1/2007		Nil
2	25/01/2020	Moji Kan	Major Revision, Reformatting to TG 0639

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1 Introduction

SA Water is responsible for operation and maintenance of an extensive amount of engineering infrastructure.

This guideline has been developed to assist in the design, maintenance, construction, and management of this infrastructure.

1.1 Purpose

The purpose of this guideline is to detail minimum requirements to ensure that assets covered by the scope of this guideline are constructed and maintained to consistent standards and attain the required asset life.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
CTQR	Cement Treated Quarry Rubble
SA Water	South Australian Water Corporation
SPT	Standard Penetration Test
TG	SA Water Technical Guideline
TS	SA Water Technical Standard

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
AS 1289.5.1.1	Methods of testing soils for engineering purposes - Soil compaction and density tests Determination of the dry density/moisture content relation of a soil using standard compactive effort
AS 1289.5.2.1	Methods of testing soils for engineering purposes - Soil compaction and density tests Determination of the dry density/moisture content relation of a soil using modified compactive effort
AS 1289.6.3.1	Methods of testing soils for engineering purposes - Soil strength and consolidation tests Determination of the penetration resistance of a soil - Standard penetration test (SPT)
AS 2159-2009	Piling - Design and installation

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
N/A	

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for TG 0639 defined on page 3 (via SA Water's Representative)

2 Scope

The scope of this document is to provide guidelines on design and construction of piles for SA Water infrastructure.

3 Pile Foundations

Piles are deep foundations which transmit the loads of superstructures through relatively weak or loose strata deep into the ground and to the stronger underlying soil or rock. Piles replace shallow foundations when the soil close to the surface does not have sufficient bearing capacity to withstand loads of the superstructure, or when the settlement of a shallow foundation is excessive. Piles may also be used to carry uplift loads, to carry loads below scour level in marine environments, to resist lateral loadings, or to reduce the settlement of shallow pad or raft foundations. Piles support the applied load by end bearing, adhesion or friction developed along their shaft, or both. They generally extend to a depth greater than 3 m below the surface. A pile can be installed into the ground by driving, screwing, jacking, vibrating, drilling or any other methods. A number of piles may be installed in a close proximity to each other, usually having a common cap, to form a pile group.

Pile foundations are more expensive than shallow foundations. However, they have extra capabilities and are commonly used in the situations shown in Figure 1.

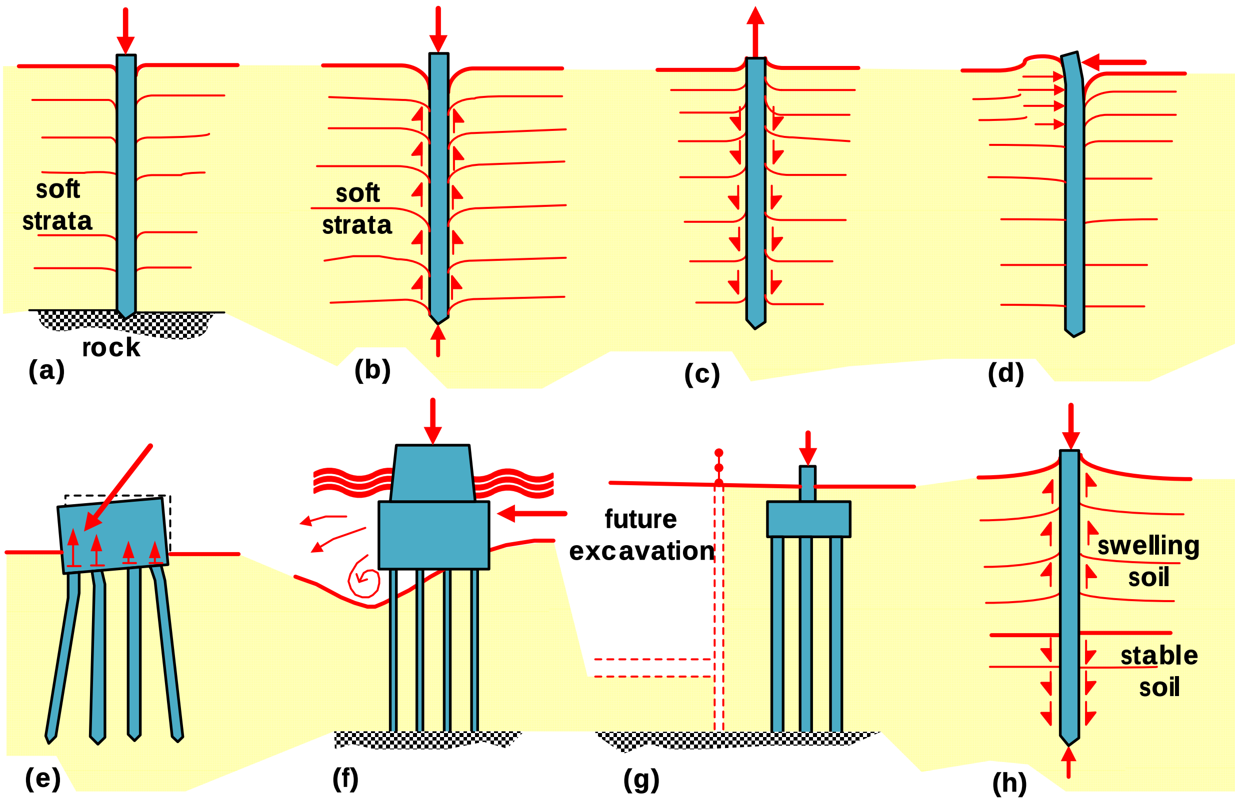

Figure 1: Situations were pile foundations are commonly used

These situations are further explained below:

a) Where a stiff layer of soil or rock exists below an upper softer layer. It may therefore be economical to transfer the structure loads to this lower layer using piles.

b) Where the upper layer is highly compressible and too weak to support the load transmitted by the super-structure. Gradual transfer of the load to the soil via pile-soil friction and adhesion is therefore required.

c) To resist uplift. This may be caused by wind loading, pump foundations or may be due to the use of piles as tension members, e.g., in soil nailing or anchors.

d) & (e) To resist horizontal loads. These loads may be induced by wind, earthquake loads or may be due to the type of structure itself, e.g. thrust forces of the pipes. Piles can transfer lateral loads much better than shallow foundations due to their depth.

f) Offshore or riverside structures where the upper layer is subject to erosion.

g) Adjacent to excavations where excessive ground movements are anticipated if shallow foundations are used.

h) Where expansive and/or collapsible soils prohibit the use of shallow foundations due to excessive movement.

Often a group of piles needs to be designed to carry a heavy load. In this case a pile cap is used to assist in transferring the load to all piles (cases e, f and g in Figure 1).

4 Classification of Piles

Piles can be broadly classified according to the pile material (timber, steel, concrete), the way they transmit their loads to the ground, the method of installation (driven, driven and cast-in-situ, bored or drilled shafts, screwed) and the effects of the installation procedure on the surrounding soil. The last one is a more useful means of classification for geotechnical design purposes and two main types can be identified: “displacement” piles and “non-displacement” piles. However, there is a range of other piles installed by various techniques that can be classified as partial displacement, post grouted, preloaded non-displacement piles, or sand piles for ground improvement. The sand piles are further discussed in Section 6.

4.1 Displacement piles

Installation of these piles causes relatively large horizontal displacements and movements of the ground through which the piles are being installed. These piles may be installed by hammering, pushing, jacking, vibrating, screwing or other methods to push them into the ground. Depending on the method of installation, these piles may be subdivided into the following categories:

- Driven cast-in-place piles are formed in-situ by driving a liner, either permanent or temporary, and filled with concrete. Temporary liners are extracted during concreting or grouting.
- Driven preformed piles are prefabricated piles driven to the ground and left in position. They may be formed from concrete, steel hollow section or H section, timber, etc. Installation of steel H piles and open-ended steel tube piles causes minimal lateral ground movements, and therefore these piles are often classified as partial displacement piles.
- Continuous flight auger piles are formed in the ground by drilling with a hollow flight auger. After drilling, the auger is withdrawn while the cavity below the auger tip being gradually filled with concrete injected from the auger tip under pressure.

- Screwed piles are pushed by screwing a threaded tube into the ground. Often screwed piles are made up of hollow section steel tube with helical plates attached to their tip.

4.2 Non-displacement piles

These piles are formed in-situ by removing soil to from a void in the ground which is then filled with concrete or grout. The soil may be removed using either rotary drilling or percussion, reverse circulation, grabbing, chiselling, and mechanical or hand excavation methods. These methods generally induce only small ground movements. During removal of the soil, the sides of the excavated void may be supported by permanent liners or temporary liners or drilling mud or continuous flight auger. In strong soil the excavated void may be stable and is left exposed during excavation. These types of piles are commonly referred to as bored cast-in-place or cast-in-situ piles.

4.3 Classification based on material

Driven piles may be made of steel, pre-cast concrete or timber. Steel piles are usually rolled sections, e.g., H beams, I beams, circular hollow sections and rectangular hollow sections.

Other types of steel piles include hollow segmented piles and sheet piles. Sheet piles are almost exclusively used to retain water due to its interlocking nature and strength. Timber piles are often useful in saturated environments due to their low cost and low corrosive potential in such environments.

Timber piles are generally not spliced due to the weak nature of these joints. They are, however, easily cut-off to length.

4.4 Classification based on load transfer mechanism

Resistance of piles to vertical loads is provided mainly by either a combination of pile shaft resistance and pile end bearing resistance, or only by end bearing resistance. Therefore, piles can also be classified based on the way they transmit the applied force to the ground:

a. End bearing piles transmit their forces to the ground through the reactions developed mainly at their base. The shaft of the piles has little contribution to their resistance and therefore the shaft resistance is often ignored in design.

b. Floating piles transmit their forces to the ground through the reactions developed along their shaft and on their base. In design of these piles both shaft resistance and end bearing resistance are considered. For long floating piles the base resistance has little contribution to the overall pile capacity and is often ignored.

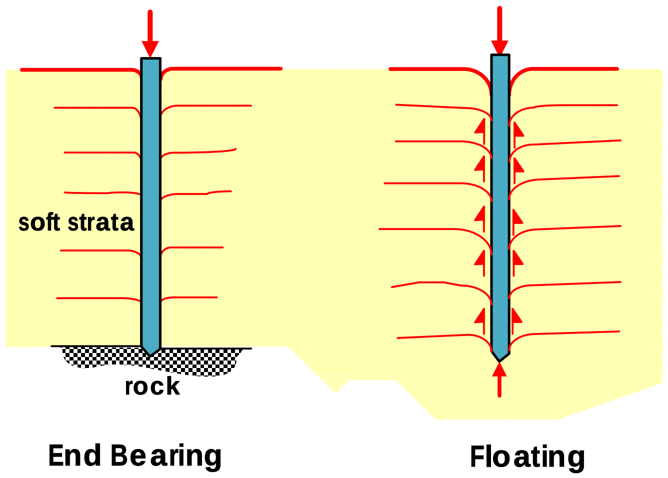

Figure 2: Pile load transfer mechanisms

5 Design Requirements

The design of a pile needs to consider the ultimate strength, serviceability, and durability of the pile. Different methods can be used to evaluate the ultimate strength of piles, among them are static analysis based on shearing resistance of the soil, static load testing, dynamic analysis using wave equation or other driving formulae based primarily on the penetration resistance, and dynamic load testing.

Piles should be designed with the following possibilities in mind:

- Scour by water or air action,
- Uplift by frost heave or expansive soils,
- Negative friction from shrinkage or consolidation,
- Alterations in the ground water table.

The current Australian Standard for pile design (AS 2159) needs to be adopted in design and construction of piles for SA Water projects. Note that AS 2159 in its latest revision (since 2009) is revised based on the "load and resistance factor design" (LRFD) approach, rather than traditional factor of safety approach.

Apart from AS 2159, other references that the designers are encouraged to use depending on the application are listed below:

- Broms, B.B. (1964). The lateral resistance of piles in cohesive soils, Journal of the Soil Mechanics and Foundations Division, ASCE, Vol 90, SM2, 27-63.
- Broms, B.B. (1964). The lateral resistance of piles in cohesionless soils, Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 90, SM3, 123-156.
- Poulos, H.G. and Davis, E.H. (1980). Pile Foundation Analysis and Design, John Wiley and Sons.

The above-mentioned references, e.g. Broms theory, may be used in design of the piles for lateral loads

6 Sand Piling

The sand piling technique is a method of improving soft ground by means of installing well-compacted sand piles in the ground. The method has both vibratory system with vibro-hammer and non-vibratory system with forced lifting/driving device. The vibro-hammer system has a negative effect in the form of vibration and noise on the surrounding environment, making it difficult to utilize the method in urban sites or at locations close to existing structures. To address this issue, a non-vibratory method has been developed, which does not require impact or vibration on the driving device to penetrate the ground.

This section provides the typical sand piling specifications for improvement of a foundation which were used for a proposed surge tank in the Cadell Irrigation District of South Australia.

These specifications were prepared on 16/10/1997 and are reproduced as part of these guidelines to document one of the successful past experiences in ground improvement in SA Water projects.

6.1 Background

A new surge tank was required as part of the rehabilitation of the Cadell Irrigation District. The tank was designed based on having an internal diameter of 7.5 metres, a footing diameter of approximately 8.8 metres, and a height of 25 metres.

A geotechnical investigation of the site for the proposed tank indicated that the footing area is underlain by a 6 m depth of relatively clean, loose to medium dense sand. Dense sands were encountered below six metres. The loose to medium dense sands in the top six metres were judged to be unsuitable as a foundation for the tank because of their potential for excessive settlement under the high loads from the tank.

It was proposed that the foundation be improved by using (mainly) the sand piling technique to compact insitu all of the natural sands above the dense sands at about six metres.

6.2 Scope of work

The scope of work in this project was:

1. The improvement of the tank foundation by compaction using the sand piling technique and any additional compaction techniques necessary.

2. The provision of test results to demonstrate that the required densities have been achieved.

3. The placement and compaction of a cement treated quarry rubble working surface over the area specified.

6.3 Geotechnical information

The geotechnical investigation of the preferred site for the tank consisted of two hollow auger trial holes. Continuous SPT samples were taken in both trial holes to 7 metres depth.

Brown, fine and medium sand with some patches of carbonate fines (lime) were encountered for the full depth of both trial holes. SPT N values averaged about 12 blows per 300 mm for the first 6 m of Trial Hole 1 and 14 blows per 300 mm for the first 6 m in Trial Hole 3. At 6 m in both trial holes N values rose abruptly to 30+ blows per 300 mm. No groundwater was observed, and all samples were logged as humid.

6.4 Performance requirements

The Contractor was required to achieve a compacted cylinder of ground with a diameter of not less than ten metres.

The compacted cylinder of ground extended down from EL 21.55 (150 mm below the underside of tank floor level) to the top of the naturally dense sands at a depth of approximately six metres. The Contractor was supposed to determine when the naturally dense sand was reached when driving the casing at each sand pile location.

The ground within this cylinder was asked to be compacted to a density of not less than 30 blows per 300 mm (N=30) as measured by the Standard Penetration Test (AS 1289.6.3.1), or a density of not less than 100% of the maximum dry density of the material as determined by the standard method (AS 1289.5.1.1).

It was recognised that, in order to achieve the specified densities within the specified cylinder of ground, it would be necessary for the Contractor to remove and recompact, in layers, the sand in the top metre or so within the specified diameter, and also possibly to install sand piles outside of the specified diameter.

6.5 Testing of compacted ground

The Contractor was responsible for arranging for insitu density testing to be carried out to demonstrate that the ground between the sand piles has been compacted to the required minimum density, and for presenting the results to the Superintendent's Representative.

The insitu density testing consisted of not less than four continuous SPT tests done from within hollow augers. The augers were advanced between each test. The tests were to begin 1 m below the surface and end at 6 m below the surface.

The test holes were located between the sand piles at positions selected by the Superintendent's Representative.

6.6 Testing of compacted surface

The Contractor were responsible for arranging for insitu density testing to be carried out to demonstrate that the top one metre of the compacted ground has been compacted to the required minimum density, and for presenting the results to the Superintendent's Representative.

The insitu density testing consisted of four sand replacement or nuclear densometer tests at each of the following depths below the surface: 100 to 250 mm, 450 to 600 mm, and 850 to 1000 mm.

6.7 Placement of quarry rubble working surface

When the compacted foundation was accepted by the Superintendent's Representative, the Contractor placed and compacted a 150 mm thick cement treated quarry rubble (CTQR) working surface over the 10 m diameter area.

The finished level of the top of the CTQR working surface was the proposed underside of tank floor level (EL 21.70) to within a tolerance of + 0 mm and - 20 mm. The CTQR consisted of 20 mm quarry rubble with 3% cement. The CTQR was compacted to a density of not less than 100% of its modified maximum dry density (AS 1289.5.2.1).

6.8 Testing of quarry rubble working surface

The Contractor was responsible for arranging for insitu density testing to be carried out to demonstrate that CTQR working surface was compacted to the required minimum density and for presenting the results to the Superintendent's Representative.

The insitu density testing of the CTQR consisted of five sand replacement or nuclear densometer tests from the surface of the CTQR to a depth of 150 mm.

7 Driving of Piles

The use of driven piles (steel/concrete) might appear suitable in design of foundation for SA Water infrastructures. In accordance with AS 2159, allowances need to be made for the stresses induced during installation for driven piles. Compressive and tensile driving stresses may be obtained from a wave-equation analysis or directly measured during pile driving, using dynamic pile testing equipment. The maximum stresses imposed by driving are not permitted to exceed the values given in Clause 7.3.3 of AS 2159.

The following requirements apply for foundation as per AS 2159:

a. The geotechnical strength of single piles needs to be assessed by using the measured set (net penetration of the pile per hammer blow) during installation.

b. The required set and the temporary compression of the pile per hammer blow needs to be determined from one of the following:

- Dynamic analysis (wave equation analysis or dynamic driving formula).
- Measurements taken during high-strain dynamic testing.
- Installation records of piles subjected to static load testing.

The following sections refer to specifications, hammers, sets, and the application of dynamic formulae, with specific reference to the "adjusted gates formula" for driving of steel piles in sand. These notes apply only to single, axially loaded, steel piles driven using an impact hammer.

These notes were originally prepared in 1992. They were intended to provide basic background information only, and it is strongly recommended that all piling jobs be referred to a geotechnical specialist for specification and design, mainly based on AS 2159.

7.1 Records

Complete and accurate records are essential. A typical specification clause might read as follows:

"The Contractor shall provide a driving record for each pile showing:

a. *The number and location of the pile.*

b. *The date and time at the beginning and end of each driving run, and of any pauses in the driving.*

c. *The make, model number and type of hammer used.*

d. *The manufacturers rated energy, stroke and blow rate for the hammer, the total mass of the hammer, and the mass of the piston.*

e. *The type of helmet used.*

f. *The type of material and thickness of the cushion blocks on the pile head (the main job of the cushion blocks is to shape the impact pulse for the most effective driving).*

g. *For each 250 mm increment of penetration, a log needs to be provided to record the depth of penetration of the pile toe, the elevation of the pile toe, and the number of hammer blows for the specified increment of penetration.*

h. *The speed of operation, stroke or drop of the hammer (as appropriate for the type of hammer being used) while the final set is being taken.*

i. *Any unusual phenomena observed during driving."*

7.2 Adequacy of hammer

The mass of the "ram" must be not less than 0.4 times the mass of the driven components. The "ram" referred to here is the dropweight itself for a drop hammer, or the piston or ram for a diesel or air hammer. The driven components include the hammer itself (less the mass of the ram), plus the helmet and the pile. If the hammer is too small most of the blow energy is dissipated within the hammer/helmet/cushion-block/pile system and not in advancing the pile into the ground.

Dynamic pile driving formulae will be invalidated if too light a hammer is used.

7.3 Correct operation of the hammer

The Contractor needs to make sure that the hammer is operating at its energy when taking the final set. This is usually indicated by the stroke of the piston for a diesel hammer and the blow rate for a double acting air hammer (refer to the manufacturer's specs). If it is lower than specified, the energy per blow may be well down and give a false impression that the required set has been reached.

7.4 The "Set"

The "driving set" is the depth driven per blow of the hammer when the pile is deemed to be able to carry the design load with an adequate factor of safety (i.e. at least 3).

The driving set may range from say 5 mm or less up to 100 mm or more per blow. In practise the set must be specified and measured over a depth range encompassing several blows to ensure that the pile toe has not hit just a thin hard layer or isolated boulder.

A typical specification clause for the "set" might read:

"The Contractor shall drive the piles (specify which) to a set of 25 mm per blow, measured as ten blows over the last 250 mm of driving. If there has been a pause during driving the pile shall be re-started by attempting to drive it 500 mm before considering that the blow counts recorded are an indication that the final set has been achieved."

It is obvious that the specification for the "set" and for the penetration increment over which it is measured must be adapted in each case to suit the hammer and the required pile capacity.

Other less obvious factors should also be considered such as whether the pile is sensitive to over-driving, will it be end-bearing on a dense stratum, or will it terminate within a deep sand profile. The penetration increment over which data is logged during normal driving may also need to be adjusted.

7.5 Dynamic pile driving formulae – general comments

There are several dynamic pile driving formulae around. All are empirical - even those that appear to consider a range of subtle parameters such as did the old Hiley Formula.

Some work well in some soils for some pile types, some are atrocious and give almost no correlation between set and load carrying capacity.

"Dynamic" means measured <u>during continuous driving</u> - NOT on restart after a period of no driving. The ground can tighten up during a break in driving (particularly in clays) and give a false impression that the required set has been reached.

7.6 The "Adjusted Gates Formula" for piles in sand

The "Adjusted Gates Formula" is one of the recommended "dynamic" formulas for calculating the load carrying capacity of a pile from the observed driving set, or for computing the required set for a given hammer and design axial pile load.

The formula applies only to piles in sand. Versions are available for steel, concrete and timber piles, more details are given in Olson et al. (1967).

7.7 Set for steel piles in sand

The following equation can be used to calculate the set:

$$s = 250 \div 10^{**} ((Q_c + 740) / 120(e_h.E_n)^{0.5})$$

where:

"s" is the set, in mm per blow

"Q_c" is the pile capacity, in kN (factor of safety x design load) (see Note 1)

"e " is the efficiency of the hammer (see Note 2)

"E " is the nominal energy of the hammer in inch.tons per blow (see Note 3)

Notes:

1. A factor of safety of at least 3 between design load and pile capacity Q is required to cover inaccuracies in the calculation procedure, uncertainties in loading, and to ensure relatively small settlements under load.
2. For values of e_h (a dimensionless ratio), see Table 1.
3. For conversion factors for E, see Table 2.

7.8 Capacity of steel piles in sand (Adjusted Gates Formula)

The following equation can be used to calculate the capacity of steel piles in sand:

$$Q_c = 120 \times \log(250/s) \times (e_h.E_n)^{0.5} - 740$$

where:

"Q_c" is the pile capacity, in kN (factor of safety x design load)

"s" is the set, in mm per blow

"$e_h.E_n$" is in inch.ton

Table 1: Values of e_h

Type of Hammer	e_h (m)	Comments
Winch operated DROP HAMMER	0.8	–
Trigger release DROP HAMMER	1.0	–
Single acting hammer	0.9	–
Double acting STEAM or AIR HAMMER	1.0	Use the manufacturers rated energy per blow at the actual speed of operation of the hammer. The speed of operation must be checked when taking the final set.
DIESEL HAMMERS	1.0	Use the manufacturers rated energy per blow corresponding to the stroke of the hammer at the final set.

Table 2: Conversion factors for E

Unit in which the rated energy of the hammer is quoted by the manufacturer	Multiply the rated energy by the factor below to convert to the inch and (US) ton units required by the formulae
Inch.(US)ton 1(US) ton = 2000 lb	1.0
inch.(Imp)ton 1 Imperial ton = 2240 lb	1.1
ft.lb	0.006
Joules (N.m)	0.0044
drop hammer (metric tonnes and metres)	43.0
drop hammer (Imperial tons and metres)	44.0

7.9 References

The following reference was used in preparation of Section 7:

- Olsen, R. & Flaate, K. (1967), Pile Driving Formulas for Friction Piles in Sand, ASCE Journal of the Soil Mech. and Foundations Div., Volume 93, SM6, Nov. 1967, 279-297.