property	timber	steel	concrete (in situ)	concrete (prestressed and/or precast)
self weight	small (4 to 10 kN/m^3, depending on the species)	large (78,5 kN/m^3), but with a relatively low self weight, large spans are possible (optimized cross sections); steel use per m^2 roof area: 0,3 to 1 kN	large (24 kN/m^3) this has concequences for the foundation and maximum span; not economical with low variable load	large (24 kN/m^3), this has concequences for the foundation
dimensions	fairly large, but favourable with respect to buckling and deformation limits	favourable; due to the different steel grades and sections, within certain limits possiblities are numerous	large	acceptable due to the high concrete class and prestress
resitance against corrosion	if the structure is well designed (ventilation and suitable wood species), timber has good resistance against moist enviroments and chemicals	not very good in moist or agressive enviroments, maintenance is required	acceptable resistance against enviromental influences (weather), but less resistant against acids. Crack widths need to be limited	No cracks due to the absence of tensile stresses. No direct corrosion danger; Low resistance against acidic enviroments
fire resistance	small dimensions have low fire resistance; Larger sections have good fire resistance	the structure has low fire resistance, but does not burn itself	good resistance, if the cover is sufficient	less resistance than in situ concrete due to deterioration of the prestressing steel. Does not collapse easily, but is not reliable after a fire
water tightness	dependent on the application	not applicable	good	good
thermal properties	not susceptible to thermal influences	sensitive for temperature changes; bad without insulation	low thermal insulation, beware for thermal bridges	low thermal insulation, beware for thermal bridges
acoustic properties	acceptable to good	sound reflection is high with corrugated sheet metal in roofs and walls	air sound insulation is good, contact sound insulation is bad	air sounnd insulation is good, contact sound insulation is bad
adaptability in relation to doors, windows etc.	good	good	good, if the appropriate measures are taken in advance	standard product; tolerances must in incorporated in the design

properties	timber	steel	concrete (in situ)	concrete (prestressed and/or precast)
adaptability to ducts	easy fastening and adaption	trusses are especially suitable for carrying trough of ducts; connection can be done fairly easy	information is needed up front and must be processed very accurately. After casting, extra measures are difficult to incorporate	Limited possibilities up front. After casting, adaption is very difficult.
suitability for later adjustments	good	good	difficult	low
labour intensity	see steel	a lot of preparation in the factory, resulting in fast and simple assembly on site	the formwork and falsework are very labour intensive. If possible, use standard formwork. Avoid small amounts of concrete at great heights	factory product with fast assembly on site. Extra stressing on site requires specialized tools and crew
necessity of serial production	not necessary	not necessary	preferred, but less necessary than with prefab concrete	necessary, because of the high costs of moulds
residual value after demolition	low positive residual value, but demolition is easy	positive residual value	negative residual value, demolition is expensive	negative residual value
erection speed	fairy quick	short construction time	low construction speed due to the time needed for hardening, reuse of formwork and influences of the weather	fast montage, but delivery and hardening times must be accounted for
needed construction site	limited	small	a lot of space needed for preparation of formwork and reinforcement	small
hygiene	when the correct sections are used, almost no dust collection	on certain profiles dust is easily collected	very suitable for dust sensitive structures	good, partially dependend on cross section

fm

|quick reference|foundations|methods|

introduction

This chapter provides the basis for foundation design. With the aid of the different methods and given tables, a preliminairy design of the foundation can be made. This design guide is, as are the other chapters, a way of supporting the students design rather than presenting all solutions.

fm|i information

source	keywords
www.vroom.nl/in/	detailed information on: Prefab piles, Wood piles, Steel pipe piles, Vibro-piles, Vibro-combi-piles, Concrete screw piles, DPA piles, and Tubular screw piles.
www.walinco.co.uk	special foundation methods with clear explanation, photos and videos

fm|a design guide

The designguide contains several important issues for foundation design. Before starting the design, first information needs to be obtained. Of course the local soil conditions are necessary, but also the general layout of the structure needs to be known. With this information a sensible choice can be made of the different foundation methods. Finally a design calculation and strength check need to be made. This calculation is not always in the scope of the courses using this document. Mostly only the general design and foundation method are important.

reconnaissance

- building layout
- soil conditions
- foundation loads

foundation method

- relation between foundation and structure
- foundation method
- connection between main structure and foundation
- foundation depth

check

- Calculation of connection between structure and foundation
- Calculation of slab- or pile foundation or sheet piling.

foundation methods I, slab foundations

>>

considerations

settlements

Settlements of a slab foundation are only comparable to settlements of a pile foundation (around 5 mm) if below the foundation depth only sand layers occur. If this is the case, a bearing capacity of 50 kN/m² may be assumed. A calculation is unnecessary. Greater bearing capacities are possible but must always be verified with a calculation. However, especially in the Netherlands, often layers of clay and peat are present. These soil types are 50 to 100 times more compressible than sand layers, and will therefore cause greater settlements.

soil improvement

In Dutch soil highly compressible layers often occur just below ground level. Removing this layer and replacing them with sand may enable a slab foundation to be used. It has been shown in practice that using a soil improvement reaching below the ground water table tends to be more expensive than a pile foundation. This can already be the case with soil improvements to a depth of 1 m.

>>

slab foundation

application	appearance	depth norm/max.[m]	diameter ø or □ [mm]	indication of bearing capacity
light structures, depending on soil condition, e.g. low rise housing on sandy soil.	strip- or slab foundation masonry foundation	n.a.	n.a.	depending on soil conditions: 50-2500 kN/m²

explanation

A slab foundation must always reach to a frost-free depth. In practice this means a depth of at least 0,8 m below ground level.

introduction

There are several criteria which need to be kept in mind when choosing a pile type:

- the degree to which the surroundings are influenced by vibrations and noise
- the degree to which the installation of the pile leads to soil deformations
- the value of the foundation load and the type of loading (compression, tension, bending, static or dynamic)
- demands on force-displacement behaviour
- durability
- difficulties during execution
- costs

Each critirion has to be judged for each case separately. Execution aspects and difficulties are especially important. For example: a very weak soil can lack the strength to support the freshly casted concrete of a cast-in-place concrete pile (e.g. a vibro-pile). Another example: a wood pile cannot be driven 5 m into a sand layer without breaking.
In the scheme on page fm4 the different pile types are sorted according to their application areas.

In general, driven piles lead to vibrations and noise in the direct surroundings. Therefore the first selection is usually based on the question whether pile driving is acceptable. This is important because driven foundations have important benefits over non-driven alternatives. For example:

- driven systems can be calendered, which makes it possible to verify the assumed soil conditions during driving.
- When driving a pile, it pushes aside the soil, thereby increasing strength and stiffness of the soil. The force-displacement behaviour is relatively stiff.
- The pile shaft is relatively insensitive to the presence or absence of lateral soil pressure and groundwater flow.

>>

considerations

vibrations

Pile driving can cause nuisance due to vibrations and even lead to damage to adjacent buildings. This damage is caused by the reduced strength of the soil beneath the adjacent building, induced by the deformation of this soil caused by the vibrations. Pile driving at a distance of 2 m does usually not give problems, but can cause nuisance (e.g. cracks in plasterwork). If there is a possibility of vibrations, deformation of the soil due to vibrations or compaction due to vibrations, vibration-free pile systems can be used. These contain several screwed systems and drilled piles. By means of an isolation sheet, a sound reduction of 5 dB(A) is possible.

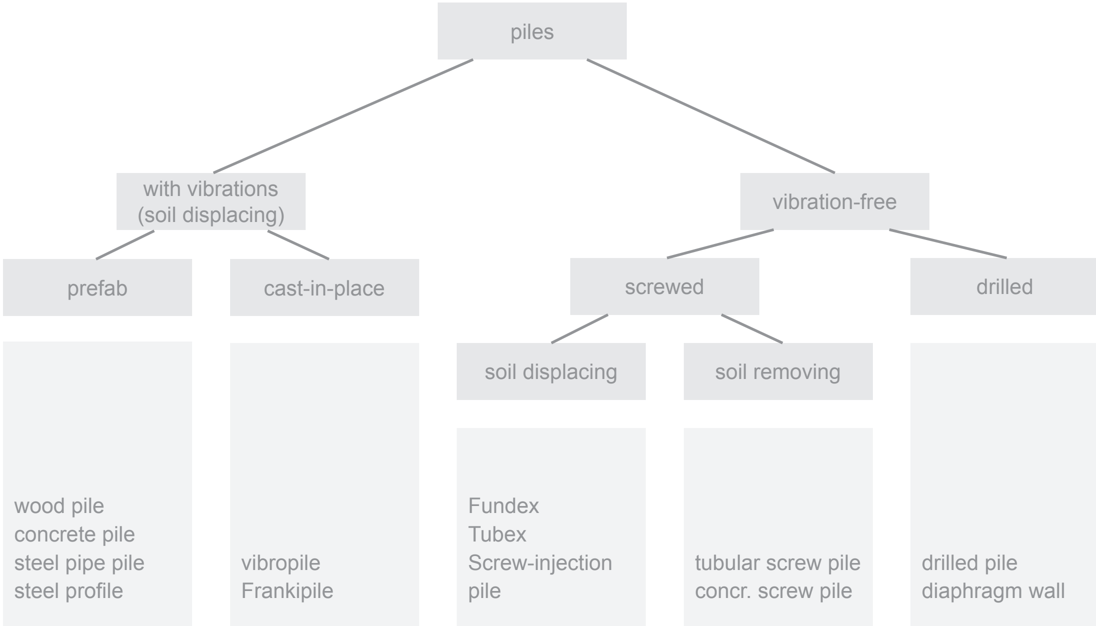
influence on surroundings

While driving displacement piles, a temporary situation of perched water can occur which can lower the bearing capacity of adjacent foundations. Outside a circle with a radius of 8D (D= pile diameter) this effect is small. All screwed piles lead to a locally lower groundwater pressure. This relaxation can affect an area with a radius of about 4D to 6D. To keep the bearing capacity of existing piles intact, the cilinder of influence around the existing piles (about 2D) must remain undisturbed.

pile length & transport

All driven piles have a maximum length, dictated by the driving equipment. A typical maximum length is about 40 m, of which 5 m is reserved for the driving ram. The maximum therefore is about 35 m. For prefab piles, another limitation is the slenderness of the piles. This affects transport and drivability of the piles. A a rule of thumb: the slenderness of a pile (length/diameter) may not exceed 80. In urban areas, where access roads may be narrow, an additional limit to pile length may exist. This can reduce the maximum pile length to about 25 m.

>> foundation tree



>> prefab concrete piles |with vibrations|soil displacing|prefab|

explanation

In practice for prefab piles shaft stress of no higher than 12 N/mm² is chosen. This means that the maximum bearing capacity of a pile with a width of 450 mm at most is 2500 kN. Note that the soil conditions always determine the bearing capacity.

For standard foundations concrete of strength class C45/55 is used for piles □ 180 to □ 320. Prestress of 4 N/mm² commonly used. For heavy driving, for example in a 15 m sand layer, higher strength concrete can be used. Also the prestress is increased.

Vibrations due to pile driving can lead to minor or major damage to adjacent buildings.

length	2 - 32 m [1)]
diameter	150-500 mm (□)
$F_{s;d}$	400 - 3000 kN

[1]) can be elongated

features

- only smooth square shaft
- design value of shaft bearing stress in practice no more than 12 N/mm²
- concrete strength class: C25/30 to C50/60 with a prestress of 0 to 7 N/mm²
- after driving the piles are broken at the head to enable the reinforcement of the pile to be connected to the structure.
- piles are driven one by one
- maximum angle approx. 1:3
- age during driving >1 month
- delivery time 2 months
- common failures: broken pile or pile head

application area

- high strength for both compression and tension
- a lot of nuisance due to vibrations and noise
- capable of handling large bending moments
- stiff force-deformation behaviour
- drivable to great depths (15 m) in compact sand (cone resistance 25 MPa)

>> wood piles |with vibrations|soil displacing|prefab|

explanation

Wood piles are still very useful, provided that the pile heads are driven at least 0,5 m beneath the lowest possible groudwater table. Concrete lengthening pieces can be used to bridge the groundwater zone. Despite the possibilities, wood piles are not used frequently. The characteristic wood stress is mostly assumed to be 7 N/mm². In practice the bearing capacity of wood piles is limited to 130 kN. Wood piles gain their strenght trough both tip resistance and friction.

length	5 - 15 m 7 - 20 m [1]
tip diameter	90 - 160 mm (ø)
$F_{s;d}$	150 kN

[1]) with concrete lenghtening piece

features

- for foundations only round piles are used
- whole pile must be driven at least 0,5 m beneath ground water table
- ground water zone is bridged with concrete lenghtening pieces
- taper of approximately 7,5 mm/m can be driven with a pile driver of 600 to 1200 kg.

application area

- a lot of vibrations
- stiff load-displacement behaviour
- no tensile capacity
- low bearing capacity
- very flexible
- pile lenght easy adjustable
- cheap
- only light equipment necessary

>> steel tube piles |with vibrations|soil displacing|prefab|

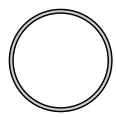
explanation

Suitable for application in areas with limited working height or space. Is able to resist large bending moments, also in soil retaining structures. Can be used in combination with sheet piles.

length	variable
diameter	114 - 813 (ø)
$F_{s;d}$	up to 5000 kN

features

- a steel tube, either with or without footing plate is driven into the soil
- tubular segments can be welded to eachother on site, making this technique suitable in confined spaces
- the tube is provided with reinforcement and filled with concrete. (this also gives corrosion protection)
- besides the mentioned commercial sizes, special ordered (larger) dimensions are possible



CHS

application area

- very large bearing capacity
- able to take up large bending moments
- can sustain heavy driving
- suitable as tensile pile
- suitable in confined spaces

>> steel profiles (I, H en Z-profiles)

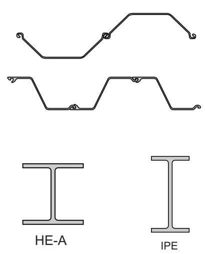
explanation

Designed as walls to resist horizontal forces in for example building pits and soil retaining structures. Can also be used to resist vertical forces.

length	variable
diameter	variable
$F_{s;d}$	variable

features

- mostly in the shape of I-, H- or Z-profiles.
- same features as steel tube piles, although open profiles cannot be filled with reinforced concrete, and they are less able to retain their shape



application area

- can be coupled and used as water or soil retaining structure
- limited drivability
- suitable to take up tensile forces

>> Vibropile |with vibrations|cast-in-place|

explanation

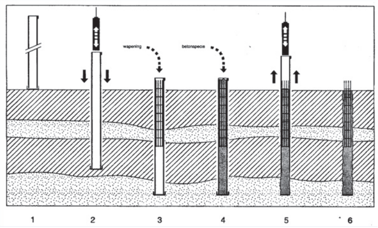
A steel tube with loose footing plate is driven in the soil. The tube is provided with reinforcement and filled with concrete. Before the concrete hardens the tube is removed either by driving or vibrating. The footing plate remains in the soil.

For cast-in-place piles the stresses during driving are absent (as the actual pile is not driven). The concrete strength used is far less than the ones used for prefab piles. In practice shaft stresses of about 12 N/mm² are used. This type also occurs as combi- pile, where a prefab pile is placed in the casing during casting.

length	up to 35 m
diameter	273 - 610 mm
$F_{s;d}$	3000 kN

features

- fresh concrete must be sufficiently supported with small deformations
- prestress possible
- not possible on open water
- angle possible
- common failures:
  - necking of the shaft due to lack of support or driving to close to another fresh pile.
  - rock pockets
  - bleeding



application area

- high bearing capacity
- a lot or nuisance due to vibrations and noise
- can take up large bending moments
- stiff load-displacement behaviour
- drivable up to 10 m in compact sand (cone resistance 20 MPa)
- pile length easily adjustable

1 place tube on footing plate
2 drive tube
3 place reinforcement
4 cast concrete
5 remove tube
6 finish pile head

>> Frankipile |with vibrations|cast-in-place|

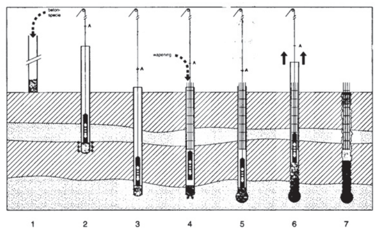
explanation

A steel tube is driven in the soil by hitting a cement clog inside the tube. When the desired depth is reached the clog is driven out by holding the pile in place. The shaft can be made out of concrete.

length	up to 25 m
diameter	324 - 610 mm
$F_{s;d}$	4000 kN

features

- reinforced shaft possible
- maximum diameter footing 2D (actual used dimensions are unknown)
- common failures: same as Vibro- piles



application area

- high bearing capacity
- less vibrations that vibropile
- variable pile length
- stiff load-displacement behaviour
- suitable to take up tension forces
- drivable as Vibro-pile

1 fill tube with gravel and cement
2 drive pile (internally)
3 fixate tube and drive clog out
4 place footing and reinforcement
5 same as 5
6 fill tube with concrete and remove tube; alternative: phased filling with dry concrete, compact and partially remove tube

>> Fundexpile (steel tube pile) |vibration-free|cast in place|

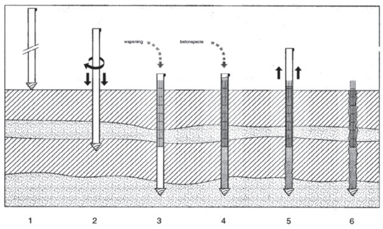
explanation

Fundex and Tubex piles are mostly applied when vibrations and soil relaxation (which causes bearing capacity reduction for nearby piles) is unwanted. Fundexpiles are made by screwing a steel tube with a loose tip into the soil. When the desired depth is reached the tube is provided with reinforcement and filled with concrete. Before the concrete hardens the tube is removed, also by screwing to avoid vibrations. The tip of the pile remains in the soil. A Fundexpile can be used up to 3 or 4 times in a sand layer.

length	up to 35 m
diam. tube	380/450/520 mm
diam. tip	450/550/650 mm
$F_{s;d}$	1500 kN

features

- a steel tube with a loose tip is screwed into the soil by applying an axial compression force and a torsional moment (max. approx. 400 kNm)
- when the desired depth is reached the tube is provided with reinforcement and filled with concrete. The tube is removed vibration-free
- placing under an angle is possible



application area

- relatively high bearing force
- almost vibration-free
- little soil relaxation
- pile tip level easily adjustable

1 attach cast-iron tip
2 screw in pile
3 place reinforcement
4 fill auxiliary tube with concrete
5 remove auxiliary tube
6 pile is finished, tip remains in soil

© Ten Hagen Stam

>> Tubexpile (steel tube pile) |vibration-free|cast-in-place|

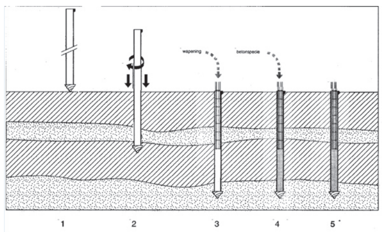
explanation

A steel tube with pile tip is screwed into the soil. When the desired depth is reached the tube is provided with reinforcement and filled with concrete. Both the pile and tip remain in the soil. If necessary, during screwing grout can be injected.

length	up to 35 m
diam tube	380/450/520 mm
diam tip	450/550/650 mm
$F_{s;d}$	1500 kN

features

- A steel tube with screwtip welded to it is placed (placed identical as Fundexpiles)
- When the desired depth is reached, the tube is filled with concrete and if necessary provided with reinforcement
- during screwing, grout can be injected
- placement under an angle is possible (max 1:1)
- by welding short segments together on site, this pile is suitable for placement in confined spaces (min. working height approx. 2,5 m)
- by injecting grout, the pile can be placed deep in the sand layer (approx. 7 m)



application area

- little vibrations allowed
- large bearing force needed (inject during installation)
- very little soil relaxation

1 steel tube pile with attached screw tip is placed on groud level
2 screwing of the pile into the soil. If necessary, grout can be injected
3 place reinforcement
4 fill tube with concrete
5 both tube and tip remain in soil

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>>	augerpile	|vibration-free|soil removing|cast-in-place|

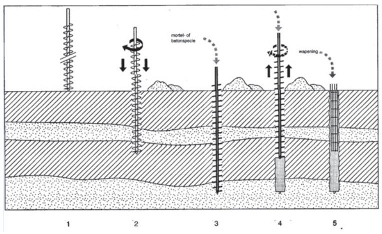
explanation

Auger piles are mainly applied in light structures where the foundation depth is not too great and no vibrations are allowed. Auger piles are made by screwing a hollow axle with an auger into the soil. If the desired depth is reached, the auger is screwed back and mortar is injected trough the hollow axle. After removal of the auger, a reinforcement cage is placed. Auger piles are not suitable for tension loads.

length	up to 20 m
diameter	300 - 900 mm (ø)
$F_{s;d}$	1000 kN

features

application area



1 auger is placed on ground level with loose footing plate
2 screw in auger
3 fill hollow axle with mortar
4 screw out auger while injecting mortar
5 after removal of the auger, place reinforcement

>>	diaphragm walls	|vibration-free|soil removing|cast in place|

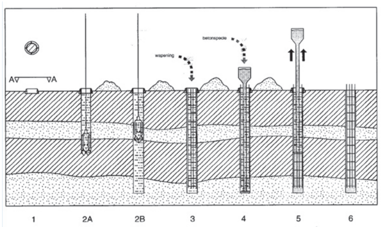
explanation

For drilled piles, as a rule of thumb, the shaft stresses (at the connection between foundation and structure) are assumed to be not greater than 5 N/mm^2. This is done to avoid large settlements. However, due to the large cross sections of the diaphragms very high loads are possible. Also tension loads can very well be taken by diaphragm walls.

length	more than 60 m
diameter	up to 2400 mm (ø)
$F_{s;d}$	2-20 MN

features

application area

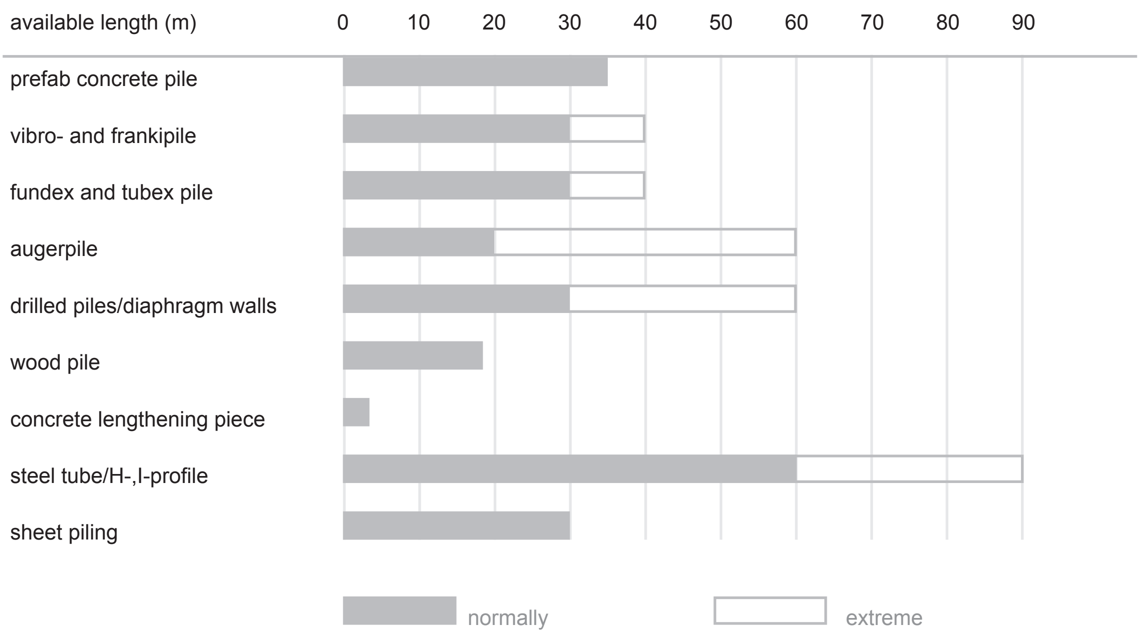


1 place guiding structure
2 excavate diaphragm, while filling the cavity with supporting fluid
3 place reinforcement
4 inject concrete from the bottom up
5 same as 4
6 diaphragm wall ready

tables

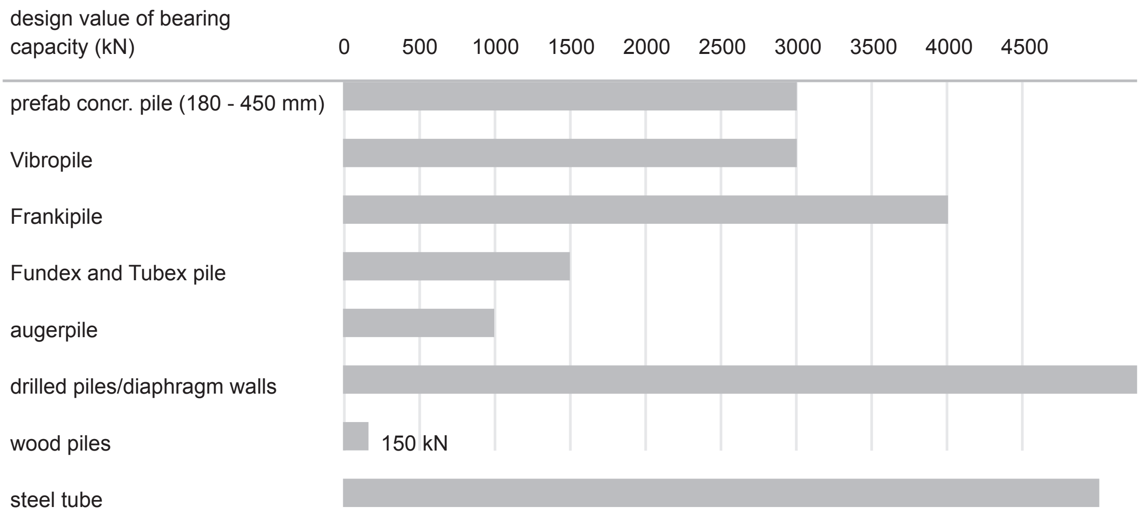
table

available lengths



table

indication design value of maximum bearing capacity*



*) indication of the design value of the maximum bearing capacity based on the pile cross section. Note that local soil conditions *always* need to be taken into account to accurately calculate the maximum bearing capacity.

sources

title	author	publisher	date
Lecture Notes: CT5330: Foundation and Construction	prof. ir A.F. van Tol		
NEN 6743; “Calculation method for pile foundations”			dec. 1991 (1993)
NEN 6744; “Calculation method for slab foundations”			dec. 1991
Collegedictaat CT2330; “Basic foundation technology”	prof. ir A.F. van Tol		
Moderne funderingstechnieken (Modern foundation technology)	prof. ir A.F. van Tol		
Hogere bouwkunde (Advanced architecture)	Jellema		1998
Foundations		Ten Hagen Stam Publishers	

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