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PILE FOUNDATION – SPECIFICATIONS FOR DESIGN

(This English version is for reference only)

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Pile foundation – Specifications for design

1. General principles

1.1. Scope

This standard is applicable to constructions in civil building, industry, transportation, irrigation and other related constructions.

Constructions with special requirements which are not referred in this standard will be specially designed or consulted under agreement of the host.

1.2. Normative references:

- TCVN 4195 ÷4202 :1995 Estate – Testing method;
- TCVN 2737:1995 – Load and effect – Designing standards;
- TCVN 5574:1991 – Concrete structure – Designing standards;
- TCVN 3393 ÷3394 :1985 – Anti-corrosion in building concrete and steel concrete structures;
- TCXD 206:1998 - Bored cast-in-place pile – Requirements for construction quality;
- TCVN 160:1987: Geo-technical investigation for pile design and construction;
- TCXD 174:1989 – Estate – Permanent penetration tests;
- TCXD 88: 1982 –Pile – Site tests;
- ASTM D4945: 1989 – Standard Test method for High-strain dynamic Testing of Piles;
- BS 8004:1986 – Foundations;
- SNiP 2.02.03.85 – Pile foundations;
- SNiP 2.02.01.83 – Floor and Constructions;

1.3. Main conventional symbols

A_p – Pile section area

A_s – Total side area accountable in computing

B – Conventional base dimension

c - Soil binding force.

d – Pile section dimension

d_p- Pile diameter

E_s – Foundation soil strain module

E_p – Pile material strain module

FS – Pile general safe factor

FS_s– Safe factor for pile side friction

FS_p – Safe factor for resistance force at pile point

G_1 – Cutting module of soil around pile

G_2 – Cutting module of soil under pile point

L – Pile length

l_l – Soil consistence index

M_x, M_y – Moment value on pile from X and Y axis

N – Compressing load on pile

N_k – Withdrawal load on pile

N_h – Transversal load on pile

N_c, N_q, N_y – Load bearing parameters based on value of internal friction angle.

N_{SPT} – SPT index from standard penetration test (SPT)

Q_a – Pile allowable compressing load

Q_{ak} – Pile allowable withdrawal load

Q_{ah} – Pile allowable transversal force

Q_u – Pile maximum compressing load

Q_{uk} – Pile maximum withdrawal load

Q_{uh} –Pile maximum transversal force

Q_s – Maximum load of isolated pile caused by side friction

Q_p – Maximum load of isolated pile caused by resistance force

S – Assumed settlement of pile foundation

S_{gh} – Limited settlement

W – Pile weight

c_a – Binding force among pile and surrounded soil

c_u – Undrained shearing resistance of foundation soil

f_i – Side friction at i soil layer

f_c – Concrete compressing tension

f_{pc} – Pre-stress value of concrete section including loss

f_y – Steel's limit of plasticity

l_i – Thickness of i soil layer in pile assumed length

q_p – Maximum bearing load of soil at pile cap

q_c – Resistance at pile point in permanent penetration test

U – Cross section perimeter of pile

γ - Soil natural volumetric mass

ν - Soil Poisson's ratio

φ - Soil internal friction angle

φ_a - Friction angle between pile and soil

1.4. Terms and definitions

– Pile: A structure with length greater than cross section, which is driven into soil or stone base to transmit construction load to deeper soil/stone layer so that the upper construction can be able to bear with load as required.

- Fill-in pile: A type of pile which is driven into soil base by pushing surrounding soil, which includes pre-cast piles injected into soil's designing depth by driving (called driving pile), compressing (called compressing pile) and vibrating, or cast-in-place piles of which bores are made by driving method.
- Replacement pile: A type of pile which is driven by boring and filling in with other material (i.e: cast-in-place piles) or pre-cast pile.
- Testing pile: Type of pile used for testing load or pile quality.
- Pile group: A number of piles bunched together and sharing the same pile-work.
- Pile tape: A number of piles arranged in 1 to 3 rows below strip foundation.
- Pile raft: A number of piles with the same pile-work with dimension greater than 10x10m
- Pile work: Structure to bind piles in pile group with upper construction.
- Over-ground pile-work: Pile system in which pile work is above ground.
- Bearing pile: Pile which bears load mainly by resistance at pile cap.
- Friction pile: Pile which bears load mainly by soil friction at pile side.
- Negative friction force: Force arising under effect of soil on pile body which has the same direction with construction load on pile when displacement of surrounding soil is greater than pile displacement.
- Standard penetration test (SPT): The test carried out in boring hole by driving a testing pile into soil bed with free drop energy of a 63,5 kg hammer from a height of 76 cm.
- N_{SPT}: The result from standard penetration test (SPT), reflected by numbers of hammer blows required to drive a pile 30cm into soil bed.
- Maximum bearing load: The maximum bearing load of pile before destruction, which is defined by calculation or tests.
- Safe bearing load: Allowable bearing load of pile, which is defined by dividing maximum load to conventional safe factor.
- Designed load (applied load): Assumed value on pile.

2. Requirements for investigation

2.1. Construction site investigation

2.1.1. General issues

Investigation for construction site and geotechnical conditions for pile foundation design should be supposed by consultant or designer under agreement of investor and then given to investigation experts. Types of pile, dimensions and construction solutions should be clearly specified to be the basic for investigation requirements.

Based on investor's requirements, geotechnical investigation will be planned to carry out.

2.1.2. Investigation phases

Investigation should be carried out as specified in Standard TCXD 160:1987: "Geotechnical investigation for pile design and construction". In general, the investigation may consist of 2 phases depending on investor's requirement, including:

- Preliminary investigation: This phase is carried out in construction site planning in order to provide source information for drafting and establishing expected pile and construction solutions.

- Technical investigation: This phase is carried out when construction solutions are fixed, in order to bring calculate indices into detail design of pile foundation construction solutions.

2.1.3. Investigation volume

- In term of preliminary investigation: Investigation points should be sufficient depending on complexity of foundation soil and extension of construction site so that basic information on foundation soil's depth can be defined. In which, at least one point should be bored to the depth able to bear load.
- In term of technical investigation: Investigation points should be sufficient depending on complexity of foundation soil and extension of construction site but not less than 3 points for the whole expected site or work. For pier and bridge abutment, each position should have at least one investigation point.

2.1.4. Depth investigation

- In term of preliminary investigation: Depending on each construction project, the depth of investigation point is marked when N_{SPT} > 50-100 and succeeds in 5 continuous tests. The distance between 2 succeeding tests should not be more than 1.5m. In circumstance that SPT test is not applied, other methods can be used provided that the soil depth is safe for piling.
- In term of technical investigation: The depth of investigation point should not be less than one in two following values: 10 times of diameter under the pile depth and 6 m. However, for construction applying pile group, investigation depth under pile cap should not be smaller than 2 times of the maximum width of the pile group, except when piles are designed to resist on stone or to rail in stone. Otherwise, each investigation point should be drilled into soil with a depth not less than 6m or 3 times of pile diameter.

2.1.5. Investigation methods for designing

- Drilling.
- Soil sampling and water sampling for tests
- Standard penetration test (SPT)
- County penetration test (CPT)
- Shearing test
- Underground water observation test
- Transversal compressing test in boring hole
- Tests for defining pile bearing load and construction capability….

2.1.6. Parameters required for design:

- N_{SPT} index in accordance with depth
- Resistance value at pile cap, q_c and side friction, f_s in term of depth
- Shearing resistance value, c_u
- Water condition under soil
- Soil physical-mechanical norms, corrosion capability of soil and water.

2.2. Investigation for neighboring constructions

There should be investigation for neighboring constructions (such as buildings, bridges, underground constructions, technical pipe systems…) so that a suitable designing and constructing solution is archived to avoid unexpected effects on those constructions' applications. Investigation method should be decided and supposed by consultant engineer.

3. Basic principles for calculation

3.1. General requirements

3.1.1. Pile and pile foundation are designed to ultimate states which are divided into 2 following groups:

Group 1 including calculations for:

- Limit bearing load of pile on soil foundation condition
- Durability of material for pile and pile work.
- Stability of pile and foundation

Group 2 including calculations for:

- Settlement of pile and foundation
- Pile and foundation offset
- Formation and extension of crack inside pile and pile work by reinforcing concrete structure.

Note:

1) *When there is weak soil under pile cap, it will be tested with bearing load to ensure for pile safe condition.*
2) *For piles in over-ground pile work or long and thin piles going through a weak soil layer with bearing load less than 50 kPa (or un-drained shearing resistance not over than 10k Pa), maximum compressing load of the pile should be tested.*
3) *For piles on slope or on boundary of excavation pot, it should be needed to test pile and foundation stability. If there is any strict regulation applied for offset, it should be tested, too.*
4) *Reinforcing concrete for crack calculation and crack extension of pile and pile work is designed by current standard for concrete structure.*

3.1.2. Load used for the first ultimate state is group of basic load and special load (earthquake, wind…) and for the second ultimate state is the group of basic load and standard load as specified in regulation for load and effect.

3.1.3. Each design solution should:

a) Meet all requirements for limit status as specified.

b) Have the safe factor for pile material and foundation soil to be proper.

c) Be economically and technically feasible and safe for neighboring constructions.

3.1.4. Settlement observation should be carried periodically for those constructions which have following conditions, until a stable settlement is set:

– Important constructions.
– Constructions with complex geology status.
– Constructions applied new pile driving method.

3.2. Pile selection

3.2.1. Pile selection should be based on article 3.1.3, with special attention to be paid on following main points:

- Construction characteristics
- Typical conditions of foundation soil and underground water.
- Other conditions at construction site (tolerable noise and vibration, surrounding constructions' status, underground system and other requirements for environmental sanitation…)
- Contractor's construction capability
- Construction speed and required time for completion
- Investor's money.

3.2.2. It should be needed to well understand application of each pile type as well as capacity of constructions tools and construction units' experience, especially for cast-in-place piling method. There should be at least 2 solutions to compare feasibility and technical and economic efficiency for selection.

Note:

1) *In terms of construction method, piles can be classified into 3 main types:*
   a) *Piles with great displacement during construction are general piles which are piled by driving, compressing or vibrating.*
   b) *Piles with small displacement during construction include open-profile steel piles, hollow piles or those which are piled by driving, compressing and vibrating into soil with bore diameter smaller than pile section dimension.*
   c) *Replacement piles are cast-in-place piles or those piled by driving, compressing and vibrating with bore diameter greater and including pile section dimension.*
2) *When pile with great displacement is used, attention should be paid on possibly bad effects on neighboring constructions and pre-built piles caused by vertical displacement and offset of soil base. These changes can make previously constructed piles to be pushed and have exceeded offset as required.*
   The change of soil during piling process should be added in designing for pile group. Above conditions can be avoided by applying piles with small displacement, pre-boring or applying cast-in-place pile.
3) *When cast-in-place piles are used in saturated loose earth, ground water and especially pressure water, pile quality and bearing load of soil surrounding pile can be affected. On the other hand, water in loose earth can have effect on concrete cure, then, pile liner should be applied to protect pile.*
4) *It must be needed not to use vibrating method for piling when near constructions on sandy land or loose earth, saturated water…to protect those neighboring constructions' pile foundation.*

3.3. Pile material intension

3.3.1. General principles

Pre-cast piles should be designed to bear with intension caused during craning progress, transportation, installation and should be able for load bearing with proper safe factor. For cast-in-place piles, to ensure for intension bearing capability, attention should be paid to drill hole bottom, pile vertical position, pile body dimension and concrete uniformity and compactness.

3.3.2. Pile stress

Maximum stress should not be over than:

- For concrete pile: 0.33 f_c;
- For concrete pile with pre-stress: 0.33 f_c – 0.27 f_{pc};

- For H steel and round piles without cast-in-place concrete: $0.25f_y$;
- For round steel cast-in-place piles: $0.25\ f_y + 0.40\ f_c$;

Maximum stress (pile driving process can generate compressing stress wave and tensile stress) should not be greater than:

- For concrete pile: $0.85\ f_c$ (in terms of compressing stress wave)
  $0.70\ f_Y$ (in terms of tensile stress wave)
- For concrete pile with pre-stress: $0.85\ f_c - f_{pc}$ (in terms of compressing stress wave)
  $f_c + f_{pc}$ (in terms of tensile stress wave)
- For steel piles: $0.90f_y$ (for both compressing and tensile stress waves);

Note:

1) *If pile cap surface is not perpendicular with falling direction of the hammer, a transversal force will appear causing pile bending moment which will affect against hammer and make pile leaning.*
2) *If pile cross section is not great enough, pile cap material will be damaged. This usually happens with wooden and steel piles which are directly driven without pile cap. However, the same situation can happen when pile cap material does not cover the whole cap section.*
3) *Pile cap can also be damaged if pile is driven through a hard soil layer or tight sandy layer in a long time. This can also happen with pile cap driven into stone or gravel earth.*
4) *Hammer with weight lighter than pile weight and from high falling distance can cause great contact stress damaging pile cap. In general, hammer weight and pile weight is not less than 0.25 in ratio depending on type of hammer.*
5) *For construction on weak soil, too great hammer falling distance can generate tensile stress damaging the pile.*

3.3.3. Pre-cast steel concrete piles

Piles are designed to bear with tensions usually occurring during loading, transporting 0and driving process.

a) Concrete

Concrete for pile should be made as specified in current standards for designing concrete structure. It should be able to bear with corrosive agents available in soil environment.

Depending on pile working condition, minimum classification for pile concrete can be specified as in Table 3.1

Table 3.1: Minimum mark for pile concrete

Condition	Concrete classification (MPa)
Pile is driven to minimum height	40
Pile is driven in easy and normal condition	25

b) Steel reinforcement

Pile reinforcement should meet all quality requirements to bear internal intension during loading, transporting process and to bear with tensile stress and bending moment from upper construction as well as other possible tensile stress generating in basement uplifting when driving next piles.

Main reinforcement should be built in the whole pile length. In constraint situation that the main steel core must be joined, the junction must follow the standards of steel joining and arrangement.

When bearing moment needs to be increased, there will be reinforcement for pile cap so proper that sudden disconnection of the steel reinforcement does not crack under vibration during pile driving process.

Longitudinal reinforcement is defined by calculation with steel content not less than 0.8% and a diameter not less than 14 mm. For following situations and especially for tall building constructions, steel content may be up to 1% to 1.2%:

– Pile cap goes through hard soil
– Pile thinness L/d >60
– Pile designed load too great while number of single pile less than 3.

Stirrup plays very important role in bearing with arising tension during pile driving process. Stirrup can be hooked, closed or spiral. Excluding the case when special junctions and flange are used for pile caps, tension can be distributed during the driving process. At a position where the distance equals to 3 times in length of the pile small side from its two caps, stirrup content should not be less than 0.6% volume value of the above area.

Stirrup in piles will have total cross section not less than 0.2% and with a distance not over than 1/2 of pile cross section. There should not be any sudden changes in areas which have different distance of stirrup.

c) Pile point

Pile point may be flat or acute. Pile point should be made by steel or cast iron when piling through stone, gravel or binder soil to protect concrete from being destroyed. Pile point is not needed to be acute when piling in homogeneous clay soil.

d) Pile binding

There should not be over 2 connections on a pile (except compressed piles). For piles with over 2 connections, safe factor for load bearing should be increased. In general, pile connections should be done by welding. Protection solutions should be included for connections in corrosive environment soil.

e) Pile cap cutting

When pile is not driven to designing depth, pile cap should be cut to a height so that pile concrete is within a certain height from 5 to 10 cm for pile-work connection. Steel reinforcement should meet all design requirements. When cutting pile cap, pile concrete should not be crack, otherwise, the crack should be removed and mended by new concrete.

g) Pile extension

In the situation when pile needs to be extended while pile caps not having special junctions, it is needed to partly break concrete reinforcement at the pile cap at least 200 mm and avoid destroying pile concrete structure. Main steel structure is welded as stated in steel welding standard. Without welding machine, junctions can be made by binding with a tie length no less than 40 times of steel reinforcement diameter.

3.3.4. Pre-stressed concrete pile

Design for pre-stressed concrete pile should meet requirements as specified in current standards for designing concrete pile. Special attention should also be paid to:

- Anti-corrosion protection
- Restraining cracks generating in pile construction
- Applying hammers with great ratio of hammer weight to pile weight and small hammer falling distance to prevent pile damage.

3.3.5. Steel piles

Steel piles usually consist of open cross section ones as H-steel pile, I-steel pile or those with close cross section as round pile and box pile. Ratio between outer diameter and pile wall thickness should not be over than 100 and the minimum thickness of pile wall should be 8 mm.

a) Steel

Steel for piles should meet all requirements in current standards for steel or other ones as required by designer.

b) Cast-in-place concrete

When a closed cross section pile is fully or partly filled with cast-in-place concrete for load bearing, the amount of cement in concrete structure should not less than 300 kg/m^3 and the sagging should not less than 75 mm.

c) Design

c_1. Load transmission into pile

Construction load will be transmitted into pile via steel concrete pile work with a pile length clamped into pile work. The pile work should be thick enough and covered with steel net or steel plate on pile point to avoid punch. For pile clamped into pile work, the steel surface should be cleaned. If construction load is designed for cast-in-place concrete in box pile or closed cross section pile, allowable pre-tension on concrete should be designed as specified in current standards for concrete reinforcement.

c_2. Anti-corrosion

Anti-corrosion solution should be required in corrosive environment as specified in standards for anti-corrosion of steel. Steel thickness is defined based on corrosion rate and expected durability of construction with an anti-corrosion reservation of 2 mm.

d) Pile point

Piles with open cross section are not required to have points. When piles are driven into hard soil and with long driving time, pile points should be reinforced with steel plate to increase the hardness. Special point design is needed for piles driven into stone. For piles with closed cross section, if it needs to fill the pile bottom, the process will be carried out by steel plate, cast iron or pre-cast steel.

3.3.6. Cast-in-place pile

Cast-in-place piles are those which are driven into soil through pre-built holes and then are filled with reinforced or un-reinforced concrete. Holes are built by drilling, piping or other digging methods. Cast-in-place piles with diameter less than and including 600 mm is called small diameter piles while those with diameter over 600 mm is called great diameter cast-in-place piles.

Both designer and constructor should fully understand about foundation soil and characteristic of technology intended to apply to ensure for pile quality.

a) Concrete

Concrete for cast-in-place piles are common concrete. Besides condition on concrete strength, it is needed to have great slump to ensure concrete continuity.

Concrete slump is reflected in Table 3.2. Concrete classification for cast-in-place piles should not be less than 20 MPa.

Table 3.2. – Concrete slump for Cast-in-place pile

Condition	Slump (cm)
Free concrete placement in water condition, with great steel distance for concrete to displace easily	7.5 ÷ 12.5
Steel distance not great enough for concrete displacement when pile is in temporary wall. Pile diameter is less than 600 mm	10 ÷ 17.5
Concrete placement in water or in bentonite solvent via tremie pipe.	> 15

In general, concrete for cast-in-place pile will have a cement content no less than 350 kg/m^3. Proper additives can be added to avoid segregation of concrete because of high slump index and exsiccosis in summer weather.

b) Steel reinforcement

Longitudinal steel reinforcement of cast-in-place piles is defined by calculation, which should meet following requirements:

- For cast-in-place piles which bear tensile force, longitudinal steel reinforcement should be all over the length of pile. When connection is required, welding process should follow all load requirements. For small withdrawal force, the steel reinforcement is arranged to necessary depth so that tensile force completely disappears under performance of pile friction.
- For piles which bear longitudinal load, steel content should not less than 0.2 to 0.4% with diameter of the steel reinforcement no less than 10 mm and is distributed evenly within the pile perimeter. For piles which bear transversal load, steel content should not less than 0.4% to 0.65%.

Stirrup of cast-in-place piles is usually from ∅6÷∅10 with distance from 200÷300 mm. A single ring weld or continuous spiral weld can also be used. If the steel cage is over than 4m, to increase construction strength and monolithic, steel rings ∅12 can be used with distance 2 m from each other and these steel rings can also be used to stick saddles for steel protection.

The thickness of protection layer for longitudinal steel of cast-in-place should not be less than 50 mm.

In general, cast-in-place piles are driven into holes built from high level ground with inside soil being pushed out. Soil expansion during construction process will cause pile tensile force until the pile is added with enough force. Therefore, longitudinal steel reinforcement should be arranged properly enough to bear with above tensile force until this force completely disappears under upper construction load.

3.4. Axial longitudinal compressed piles

In general, these piles are completely vertical driven into soil. When bearing load for pile material is defined, it is not needed to take pile stability into account. For piles driven into weak soil (un-drained shearing resistance less than 10 kPa), it is necessary to take pile stability into account.

3.5. Transversally compressed piles

Vertically driven piles may bear transversal load if pile work is over ground, upper structure is transversally compressed or if there is a transversal thrust or earthquake load. In this situation, transversal compressed load should be accounted due to its bad effect on pile performance.

3.6. Oblique piles

Oblique piles are used when transversal load is great. When calculating load, these piles are considered to be axial working piles and are defined by geometric or analytic methods. However, there is usually a moment affecting the piles of which the strength depends on settlement of pile group, oblique status of piles and type of connection between pile and pile work.

3.7. Eccentric bearing piles

In general, load at pile bottom is eccentric load or transversal load with a small moment compared with vertical load. In addition, when piles are not driven in right place, eccentricity of pile group can be increased and this means there is always a certain eccentric value that the piles should be designed properly to bear with above loads.

3.8. Withdrawal bearing piles

Piles which bear withdrawal load such as anchoring piles or piles of tower constructions when vertical load is smaller compared with transversal load and moment. In these cases, piles are designed as tensile bearing load. For steel reinforcing piles, the reinforcement will bear total withdrawal load. Because of crack usually happening with anchoring piles, special attention should be paid to corrosive factors which can destroy pile reinforcement and affect pile bearing load capability.

3.9. Pile group

3.9.1. Pile driving process

When working with pile group, due to the fact that piles can usually be lifted or transversally, attention should be paid to pile selection, distance among piles and construction steps. For sand, clay or gravel foundation soil, all piles in a group can be driven to designed depth with the order starting inside out from the middle of the pile group. Boring method can also be used if required. For construction of pile groups which are near to sheeting piles or existing constructions, the driving process should be started firstly with nearby piles to avoid destruction. In this case, cast-in-place pile is the most proper solution.

3.9.2. Pile gap

Pile gap in a group depends on foundation soil condition, the treatment with different pile in group and the construction cost.

The gap should be so proper to minimize pile lifting and to maximize bearing load. It should also be proper to drive all piles to designed depth without damaging other neighboring piles and constructions. Pile gap and dimension are also affected by cost for pile work and braced foundation.

Pile gap can be determined by:

a) Construction method (compressing pile or cast-in-place pile)

b) Bearing load of pile group

In general, centre distance between 2 neighboring piles can be determined by:

- Pile friction is not less than 3d
- Bearing pile is not less than 2d
- Belled-out pile not less than 1.5 belled-out diameter D or D + 1 m (when D >2m)

3.9.3. Group effect

Due to co-effect among piles in group, the settlement and bearing load capability of a pile group will be different compared with a single pile. This effect should be mentioned in designing piles. Depth and effective area under pile group depend on group dimension and load strength.

3.9.4. Settlement of pile group

Group with great number of piles will have greater settlement compared with group with small pile number in the same condition of foundation soil and tension. When estimating settlement, conventional foundation is usually applied with area determined depending on pile working condition.

3.9.5. Pile group load bearing capability

In loose earth, pile group bearing capability can be greater than total bearing load of single piles in the group due to compressing of foundation soil.

In binder soil, pile group bearing capability can be less than total bearing load of all single piles in the group, depending on pile gaps in the group, soil characteristics, pile work hardness and load transferring of piles to soil.

For resistance piles, group bearing load is equal to total bearing capability of all single piles. Piles in eccentric bearing load should be arranged so that the total load is nearest to center of pile group face.

3.10. Negative friction

Negative friction reduces pile bearing capability, especially cast-in-place piles. Therefore, it should be taken into account when determining pile bearing load in these following situations:

- Incomplete cohesion of modern deposit and natural deposit.
- Tightness increasing of coarse grain under dynamic force
- Wet settlement of submerged soil
- Effective stress increasing in soil due to reduction of underground water
- Site lifting to a thickness over than 1 m
- Additional load greater than 20kPa
- Soil volume reducing due to decay of organic components in soil

3.11. Pile work

Pile work is usually steel reinforced with design as a structure bearing load of construction and pile resistance force. Depending on relationship of piles in pile work, it can be considered as an independent structure, a flat structure or a space structure.

3.12. Pile and pile work link

Pile can be bind with pile work by flange or clamp. For flanged link, pile should be pushed into pile work with a depth from 5 to10 cm. It is not needed to lengthen the pile steel reinforcement.

For clamped link, clamped length or steel reinforcement of the pile should be as specified in standards for steel and steel reinforcement structure. For pre-stressed concrete pile, it is required to build a differential steel structure for clamping instead of using its own structure.

Arising moment at the link should be included in clamped link.

3.13. Safe factor

Following safe factors should be applied in designing pile foundation:

a) Safe factor for material of pile and pile work such as structure components, as specified in standards for steel or steel reinforced concrete structure.

b) Safe factor for determining load bearing of foundation soil should include natural state of soil, reliability of determining method and working condition of the construction.

Applied safe factors are usually within 1.2 to 3.0 as stated in Annex A, B, C, D and E.

Note:

1) When there is any special requirement for absolute settlement and deflect settlement (less than general requirement), safe factor should be above upper bound value. When settlement is not decisive factor for designing, a safe factor under lower bound can be used.

2) A great safe factor should be used when pile bears great blow stress, fluctuation stress, repeated load or similar loads which can decrease soil strength in bearing process.

3) For pile group, guidelines in article 3.9 should be considered when designing. It should be needed to consider the working condition of soil-pile package and total load bearing of every single pile in a pile group when estimating bearing load of a group. Settlement of the pile group should also be included in calculation.

4) For cast-in-place with great diameter, difference of the relationship between load and settlement of pile point resistance and side friction should be included in calculation. This difference is reflected by different safe factors for pile points and pile sides in load calculation.,

4. Load bearing capability of single pile

4.1. General requirements

4.1.1. Load bearing capability of pile is defined on:

a) Foundation soil index determined from tests in laboratory or at site (see Annex A, B, C)

b) Steady load tests (see annex E)

c) Dynamic load tests (see annex D)

Note:

1) Among above methods, pile testing by steady load gives the most reliable results.

2) Result of test by dynamic load should be adjusted as test by steady load.

3) Experience knowledge can be applied in preliminary design for similar soil and construction characteristics.

4.1.2. Allowable bearing load of a single pile on foundation soil can be determined by the same formula as follows:

$$Q_a = \frac{Q_u}{FS} \qquad (4.1)$$

Note: Some values of safe factor are proposed in annexes enclosed with this standard.

4.1.3. Pile calculations based on material strength should be defined as stated in standards for steel or steel reinforced structure. In compressed situation, pile is considered to be clamped steadily in soil from a distance of L_c to pile bottom (see annex G).

4.1.4. Allowable bearing load of single pile is the minimum value got in calculation specified in article 4.1.2. and 4.1.3.

4.2. Compressed bearing load of single pile

4.2.1. Compressed load on pile should be:

$$N \le Q_a \qquad (4.2)$$

Where Q_a is the value got from calculation in 4.1.4 article.

4.2.2. Minimum bearing load of pile consists of resistance force at pile point and pile side friction:

$$Q_u = Q_p + Q \qquad (4.3)$$

Note:

1)Pile weight should be considered as a load when pile has negative friction.

2) For pile acting as a resisting pile, side friction can be excluded except if there is not negative friction.

4.3. Withdrawal bearing load of single pile

4.3.1. Withdrawal bearing load on single pile should meet following requirement:

$$N_k \le Q_{ak} \qquad (4.4)$$

Where Q_{ak} is determined as specified in 4.1.4

4.3.2. Minimum withdrawal bearing load is total side friction added with its own weight:

$$Q_{uk} = Q_{sk} + W \qquad (4.5)$$

Note: Some methods for calculating pile withdrawal bearing load are given in Annex A and B.

4.4. Transversal bearing load of pile

4.4.1. Transversal bearing load H on pile should be:

$$H \le Q_{uh} \qquad (4.6)$$

Where Q_{uh} as specified in 4.1.4.

4.4.2. Minimum transversal bearing load is defined when pile bears tensile moment, transversal force and vertical load as well as resistance force of soil.

Note:

1) It is needed to include effect of pile and pile work link in calculation.

2) Some methods for calculating pile transversal bearing load are provided in Annex G.

4.5. Pile load bearing test

Pile bearing load test should be carried out by an independent and experienced testing organization following all requirements in current standards for pile testing TCVN 88:1982.

4.5.1. Pile dynamic testing

4.5.1.1. Pile dynamic testing and static testing are used to find out a suitable driving process and to define pile bearing load.

4.5.1.2. There are two common dynamic tests:

a- Dynamic formula can be used to estimate refusal load for pile driving test (see Annex D).

b- Theory of tension wave transmission can be used for results of strain measurement and displacement accelerator of pile cap as specified in ASTM D4945-89.

Note: Results of strain measurement and displacement accelerator of pile in driving process can be used to determine defects during the process or to test the pile length.

4.5.1.3. Dynamic tests by measuring refusal load should be carried out as stated in current standards for testing pile with number of testing piles up to 1% of the total number of the construction but not less than 5 piles.

4.5.2. Pile county tests

4.5.2.1. This testing method consists of:

- Vertical compressing test.
- Vertically withdrawal test.
- Transversally compressing force perpendicular with pile axes

Note: Depending on requirements, test can be carried out for a single pile or a group.

4.5.2.2. Number of piles for testing in investigation phase (before designing) is selected as stated in current standards for pile testing and base on following requirements:

- Foundation soil conditions and soil thickness in the structure.
- Construction's scale and role.
- Experience with every type of pile in local foundation soil condition.
- Pile construction technology
- Estimated number of piles for the whole construction.

4.5.2.3. Piles for testing should be arranged at testing soil points having typical characteristics of the construction.

4.5.2.4. Testing pile construction should be carried out by tools and procedures intended to apply for mass construction.

4.5.2.5. Pile testing procedure is planned by consultant unit based on foundation soil characteristic, construction load and meets all requirements of current standards for pile testing.

4.5.2.6. Addition test can be given to some other piles during construction process and before construction acceptance. Number and position of piles in addition test is defined in tracking documents of construction surveyor.

Note:

1) *Testing load in county compressing test in this phase should be greater than designed bearing load of pile and decided by designing consultant.*
2) *Evaluation of pile construction should be presented in article 7 of this standard.*

5. Pile foundation estimation in accordance with strain

5.1. Estimation of deformed pile foundation friction is reflected in absolute settlement, deflect settlement, transversal displacement, transversal and spiral. Typical strain should meet requirement as follows:

$$S \leq S_{gh} \qquad (5.1)$$

In which, S is known as any calculated strain which is needed for consideration while S_{gh} is allowable value of that strain.

Note:

1. Strain characteristics listed above (see annex H) can be:

- *Absolute settlement of each individual foundation S_i;*
- *Medium settlement of construction base S_{tb}*
- *Relative deflect $\Delta S/L$ of two neighboring foundations, which is the ratio between the difference of the two vertical displacement to their distance L.*
- *Inclination i of foundation or construction in general – which is the ratio between the difference of settlement at outer boundary of foundation with foundation width or length.*
- *Relative deflection or camber f/L – which is the ratio between deflection arrow f with length of bind construction.*
- *Round of binding length $\rho = 1/R$*
- *Construction relative twist angle $v = \Delta\beta/L$.*
- *Foundation offset u, v.v*

2. For long-term constructions, settlement as function of time should be calculated. It can be excluded pile foundation settlement if it does not affect construction.

3. Limit value of above strain characteristics can change when applying a construction solution which is to reduce compressing settlement and foundation unconformity as well as when applying any solution to reduce construction sensitivity toward basement strain.

5.2. Foundation pile estimation in accordance with strain should be carried out in every type of soil except when pile rests on coarse soil, coarse-grained sand and flint clay. The calculation is also required for pile bearing transversal load causing considerable offset.

5.3. Load for calculating strain is the group load on foundation, even warehouse basement or equipments surrounding the foundation. When basement is raised up to 2 m and consists a weak soil layer over than 30mm or when arising an additional pressure by underground water, these should be included in calculation of foundation.

Note:

1) *In general, it is not needed to estimate pile foundation settlement for resistance pile, withdrawal bearing single pile and withdrawal bearing pile group because its strain shall be clearly ensured in calculation.*
2) *Settlement of bearing pile foundation is mainly due to elastic strain of pile material under construction load. This settlement can be determined by settlement of a single pile from calculation of permanent compressing load with load at pile cap, or it can be determined by the method presented in Annex H.*

3) *It is not required to estimate settlement of railway abutment with span less than 50m and roadway abutment with span less than 100m which are of non-bearing structure. When need to estimate settlement of abutment, method in article 2 of this note can be applied with following addition:*

   a) *Pile of abutment works as bearing pile*

   b) *Pile center gap over than 6d*

   c) *Number of vertical pile rows not over 3 rows.*

4) *Calculation of pile foundation for abutment and drain system should be carried out in accordance with limitation of strength and settlement and transversal displacement of abutment cop*

5.4. Depending on foundation dimension and pile arrangement, estimation of foundation settlement can be settlement of pile group, pile tape, or single pile.

5.4.1. Settlement of pile group (when piles are arranged under bridge axle or abutment…) is usually calculated basing on foundation dimension in reference with related load. Foundation depth and dimension change due to specific condition of foundation soil (see Annex H).

5.4.2. Settlement of pile tape (when piles are arranged under strip foundation in one or two rows with pile gap within 3 to 4d) is calculated as flat theory mathematic problem (see Annex H)

5.4.3. Pile shaft settlement (when piles are evenly distributed under strip foundation with dimension over than 10x10m) can be calculated by lineal strain layer (see Annex H)

5.4.4. Single pile settlement (usually cast-in-place piles with or without belled-out bottom) is calculated by theory of space semi-strain or by site county compressing test.

6. Pile foundation design

6.1. General requirements:

6.1.1. Load in designing pile foundation should follow article 3.1.2 in this standard.

6.1.2. When designing pile foundation, it is needed to complete these following tasks:

- Collecting and examining data of foundation soil and upper structure.
- Load and total load on foundation bearing the same effect and load change during application of the structure.
- Foundation type having the same relatively absolute limitation strain.
- Selecting pile foundation type and bearing soil for installing pile point; determining pile dimension and arranging pile in foundation.

6.1.3. Design for pile work should meet all requirements as specified in standards for designing steel reinforcement structure, including testing for break-through, shearing force and binding tension of pile work.

6.1.4. Pile work and pile binding as in 3.11 and 3.12 of this standard.

6.1.5. Depth of pile work bottom is defined depending on underground designing solution for buildings and constructions (with basement or service cellar) and depending on scraping design of the site (unearthing or raising) while pile work thickness is defined as specified in standard for designing steel reinforcement concrete.

6.1.6. Calculated load on pile N should be defined when foundation is considered to be a structure to bear vertical, transversal and binding load. Vertical load on each pile in a group of vertical piles is defined by following formula:

$$N = \frac{P}{n} \pm \frac{Mx \cdot y}{\Sigma y_i^2} \pm \frac{My \cdot x}{\Sigma x_i^2} \qquad (6.1)$$

Where:

P – Vertical load on pile group, kN

Mx, My – Calculating moments in reference with main axles x and y of the foundation base from high level of pile work bottom, kNm;

x_i and y_i: i pile coordination, m

x and y: pile coordination where load on pile is calculated, m

Note:

1) Load among piles of a over-ground pile work is distributed as stated in 6.2.5 of this standard.

2) For oblique pile, load on piles is distributed as specified in this reference for the frame structure.

6.1.7. Transversal force on every single pile in a group of vertical piles with transversal cross section is evenly distributed on each pile.

6.2. Designing characteristic for bridge foundation and irrigation structure

6.2.1. In general, oblique pile is preferable solution for bridge foundation and irrigation structure with great transversal force. Pile foundation of bridge abutment should have some piles inclined toward the river. Pile foundation of bridge abutment with over-ground pile work should be arranged with four-way oblique piles together with vertical piles.

6.2.2. For abutment foundation and bridge column foundation, it is needed to design with following additional requirements due to their working environment condition:

a) It is needed to include soil corrosion and erosion when designing pile foundation structure and pile point depth.

b) Piles for abutment should be tested under soil transversal force.

c) Piles can be resisted on or driven into stone. Piles may not be clamped into stone if they take over all binding moment in nonabrasive deposit on stone surface. Otherwise, piles should be driven into soil with a depth not less than 0.5 m for a compressing resistance force of stone over than 50MPa and this depth will not be less than 1 m compared with the rest stone.

Note: Specific calculations can be seen in article A.2 of the Annex A in this standard.

6.2. Designing bridge pile foundation should be such that:

a) Pile work dimensions (or steel concrete reinforcement dimension) should be designed so that the distance from pile work boundary to the nearest pile is not less than 0.25 m (boundary to boundary gap).

b) For pile with dimension over than 2 m, it is not needed to have excessive boundary.

6.2.4. Calculation of pile work bottom of bridge abutment should be included with water depth, erosion stated in 6.2.2 and bearing load as well as the durability of foundation in local weather condition.

6.2.5. Load arrangement among piles of over-ground pile work should be defined as the frame structure.

6.2.6. Pile foundation of abutment and centre piles on lean-to roof should be checked with deep slip resistance stability.

6.3. Pile foundation design in earthquake condition

6.3.1. Designing pile foundation in earthquake condition should meet all requirements in this standard as well as to meet requirements for construction in earthquake condition stated in the standard for load and load effect.

6.3.2. Designing for pile foundation of building should include earthquake effect calculated by special load. Attention should be paid to

a) Define pile bearing load under compressing load and withdrawal load as specified in this standard.

b) Examine pile in term of material strength under effect of calculated loads (stress, bending moment and transversal force)

c) Examine soil stability in condition to minimize load transmission to load via pile sides.

Note: When determining calculation value of earthquake load on construction structure, over-ground pile foundation should be considered as the last frame layer.

6.4. Pile foundation designing for overhead transmission line

6.4.1. All content in chapter 2 of this standard should be strictly followed when carrying out investigation for geological condition of overhead transmission line of which electric posts having great transition. In other situations, investigation process can be carried out with at least 3 surveyor points for each kilometer in length.

Note: Classification of overhead transmission line and transition distance is made as stated in standard for electric installation.

6.4.2. Boring hole depth is determined as follows:

a) For intermediate pier: 2 m deeper downward pile point.

b) For angle pier: 4 m deeper downward pile point.

6.4.3. Pile foundation for power towers and outdoor power stations can be used in all soil conditions.

6.4.4. Needle pile, wedge pile and spindle pile should not be used for foundation of transmission line column.

6.4.5. For piles bearing transversal force or withdrawal load, driven depth should not less than 4 m into soil and no less than 3 m for foundation of wooden column.

6.4.6. Calculation of pile foundation load of overhead transmission line shall not be presented in Annex K.

6.5. Pile foundation design in some other special conditions:

6.5.1. Pile foundation in peat soil and filled soil should be designed with soil negative friction to be taken into account.

6.5.2. For wet settlement soil, design should be carried out under condition that the soil is completely wet in water saturating level $G \geq 0.8$.

When carrying out investigation for geological conditions in wet settlement soil, it is necessary to clarify the type of soil and classify the soil layer with a relative wet settlement $\delta_s < 0.02$ at pressure p = 3kg/cm^2.

6.5.3. For wet settlement soil and other types of soil of which strength and strain are reduced in wet condition, piles should be penetrated through all layers and driven into the un-damped settlement layer when each layer's thickness is up to 30 cm.

6.5.4. When designing pile foundation for swelling soil, piles should be completely or party penetrated through all swelling soil layers (with the pile point directly lean against soil face). However, it is required to calculate pile foundation in limitation condition with inclusion of pile county compressing result and pile emergence when soil is swelled.

6.5.5. For swelling soil, besides all general requirements stated in this standard, it is required to follow all addition guidelines as follows:

a) Pile county penetration test is taken on wet soil and complete high level of soil surface should be defined for swelling condition.

b) Pile county test is taken first by increasing load on piles driven in natural wetness, until the load equals to expected load in calculation. After load increasing, soil should be wetted and pile displacement should be defined.

c) Together with stopping soil swelling process, pile testing should be carried out with the same method as for common soil.

6.5.6. When designing pile foundation in mining area, besides all general requirements stated in this standard, it is required to follow all regulations stated in standards for designing construction in mining exploitation area. In specifically, in addition to application of nominative references in this standard, documents on mining geological investigation and soil assumed strain should also be applied.

6.5.7. Calculation of pile foundation of constructions in mining exploitation areas should follow limitation status by special load, including all effect of foundation strain caused during the exploitation process.

6.5.8. Other calculation method of pile foundation in wet settlement, swelling soil or mining exploitation soil area can be seen in SNiP 2.02.03-85 and other related documents.

7. **Technical requirements on pile quality evaluation**

7.1. Hammered and compressed pile

7.1.1. It is needed to have a construction plan and pile quality management before construction. Management document should include:

- Pile type, pile structure and pile casting document of producer.
- Pile position and allowable difference.
- Pile length, pile point high level and intended pile cap
- Pile numbers
- Pile driving/compressing step
- Main requirement for driving/compressing equipments. When necessary, some main parameters of equipments can be tested before mass construction.
- Expected difficulties during construction process and solution.
- Pile allowable bearing load.

7.1.2. During driving/compressing process, it is needed to build a construction book for every single pile.

7.1.3. Pile tracking document should include:

- Pile type and pile driving equipment
- Type designation number.
- Pile producing date and area.
- Pile cross section, steel reinforcement length and type (for steel reinforcement pile)
- Construction time (date, time of beginning and completion) and arising problems during construction process and solution.
- For driving pile, it is needed to clearly note values of hammer weight, falling height, numbers of blow, resistance force. For compressing pile, it is needed to note in detail compressing force for each pile and the last force.
- Arising obstacles in construction
- Difference of real position, deflection and high level of pile point and pile head

7.1.4. Pile construction tracking document should be kept as regulated by the State. As-built drawing should be kept in a long time.

7.1.5. Construction quality test should be added if the investigation proves that piles are not qualified enough. Necessary tests include:

- Re-investigation of foundation soil
- Re-driving pile if bearing pile is upraised when driving neighboring piles
- Pile defect checking
- Load bearing test
- Pile material test (strength and compactness)

7.2. Cast-in-place pile

7.2.1. It is required to have a construction program and pile quality management solution before any construction implementation. The documents should refer to:

- Pile types and structure.
- Allowable position and difference
- Pile length, pile point height level and estimated pile head.
- Pile number
- Pile construction order
- Pre-treatment of equipments and construction technology before mass implementation
- Pile load bearing capability and percent of pile needing to test for quality.
- Difficulties during construction process and solution

7.2.2. Construction of all piles should be carefully followed and tracked. Each pile should have a record document, with signatures of related parties.

7.2.3. Pile tracking document should present:

- Pile type and holing equipment
- Pile symbol
- Pile diameter, length and the hole bottom purity and inclination of boring hole.

- Construction time (date, hour of beginning and completion) and especially arising risks during construction and solution.
- Steel reinforcement type
- Concrete mark classification, slump, volume and concrete casting method
- Ratio, pH, viscosity and grain components of boring solution (if any)
- Mortar or concrete pumping pressure, internal and external diameter of pump pipe.
- Soil layers encountered during boring and washing processes.
- Obstacles during construction.
- Difference of real position and height level of pile point and pile cap.
- Pile quality testing result as regulated by quality management program

7.2.4. Pile construction tracking document should be kept as regulated by the State.

7.2.5. Additional tests can be carried out if pile quality is not good enough. These tests include:

- Re-investigation of soil
- Test for pile material conformity by indirect methods (ultra-sound, vibration, low strain and high strain)
- Pile concrete sampling to directly test concrete quality, including concrete strength.
- Geometric dimensions (diameters, depth…)
- Pile load bearing capability test.

Note: Construction quality testing should be carried out as specified in TCXD 206:1998 "Cast-in-place piles – Requirements for construction quality".

Annex A

Determination of pile bearing load in accordance with foundation soil mechanical condition (SNiP 2.02.03.85)

A.1. Physical-mechanical condition used for calculation in this annex is defined as stated in TCVN 4195:1995 ÷ TCVN 4202: 1995 – Construction soil.

Allowable load of a single pile is calculated as follows:

$$Q_a = \frac{Q_{tc}}{k_{tc}} \qquad \text{(A.1a)}$$

Where:

Q_a – Allowable load in accordance with foundation soil calculated as stated in this annex/

Q_{tc} – Standard load in accordance with foundation soil of a single pile

k_{tc} – Safe factor, which is:

1.2 – if bearing load equals to pile county compressing force at site.

1.25 – if bearing load from high strain dynamic test includes soil elastic strain or equals to soil testing result at site by testing pile.

1.4 – If bearing load is calculated, also by high strain dynamic test but not including soil elastic strain.

1.4 (1.250 – for abutment with low pile work, friction pile or bearing pile; for over-ground pile work – only when pile bears with vertical load and independent with number of piles in the foundation;

For low pile work or over-ground pile work which leans on high strain soil or for compressed friction pile and for any pile work of which piles bear withdrawal load, k_{tc} value will be:

- For foundation with over 21 piles: k_{tc} = 1.4 (1.25)
- For foundation with 11 to 20 piles: k_{tc} = 1.55 (1.4)
- For foundation with 6 to 10 piles: k_{tc} = 1.65 (1.5)
- For foundation with 1 to 5 piles: k_{tc} = 1.75 (1.6)

Of which, the number in blanket refers to k_{tc} value when pile bearing load is calculated from site county compressed test.

Note:

1) *If wind load and pier load can be included in calculation of pile foundation, it is capable to increase assumed load on boundary pile up to 20% (except for pile foundation of power transmission line).*

   When piles of pier foundation under effect of external load build up one or more rows, and when load by wind, fleet loading or by braking is considered in calculation (added or excluded), pile assumed load can be increased up to 10% for 4-pile row and up to 20% for over 8-pile rows. If number of piles is within these numbers (from 4 to 8 piles), then the load increasing percent will be defined by

2) *For foundation with only 1 pile, with bearing load over 60 tons (600kN) or one cast-in-place pile with load over 250 tons (2500kN), then:*

   k_{tc} *= 1.4 – If bearing load is defined by pile county load test.*

   k_{tc} *= 1.6 – If bearing load is defined by other methods.*

k_{tc} = 1 – For pile foundation having great strength and limiting settlement over or including 30 cm (with number of piles over than 100), if pile bearing load is define by county load test.

A.2. Standard bearing load of pile resting on less compressed soil (when E_s =500 kg/cm^2) is defined as:

$$Q_{tc} = mq_pA_p \qquad (A.1)$$

Where:

m – Working condition factor of pile in soil, m= 1

A_p – Pile section leaning on soil, for pile with solid section, this value is equal to pile cross section; for hollow round pile and column pile, this value is equal to non-cast pile cross section or equal to the whole pile cross section when casting concrete to a height no less than 3 times of pile diameter.

q_p- Soil load bearing at pile point T/m^2 calculated as follows:

a) For all types of piles with pile heads against stone or coarse grain (carved stone, gravel, ballast or sandy gravel clay) or piles on hard clay (except for soil with saturation G < 0.85 and swelling soil), q_p = 2000 T/m^2;

b) For cast-in-place pile, concrete hollow pile which are clamped into non-decomposition stone (without additional weak layer), this value should not be smaller than 0.5 m as following formula:

$$q_p = \frac{q_{pn}^{tc}}{k_d}\left(\frac{h_3}{d_3} + 1,5\right) \qquad (A.2)$$

Where:

q_{pn}^{tc} - Stone standard axial compressed bearing capacity (in average) in saturated condition, t/m^2.

k_d - Soil safe factor, equal to 1.4

h_3 – Assumed depth into stone, m

d_3 -Clamped diameter into stone, m

c) For hollow pile resting against flat stone surface which is covered by a non-erosion soil with a thickness not over 3 times of pile diameter, this value is calculated by following formula:

$$q_p = \frac{q_{pn}^{tc}}{k_d} \qquad (A.3)$$

In which, q_{pn}^{tc} and k_d have the same role as in formula (A.2)

Note: when pile rests on non-decomposition stone or washable soil, soil standard resistance force q_{pn}^{tc} should base on semi-compressing test or county testing results,

A.3. Standard bearing load of friction pile driven by hammering of which cross section is 0.8m, with compressing force, is defined by following formula:

$$Q_{tc} = m(m_R q_p A_p + u\sum m_f f_{si} l_i) \qquad (A.4)$$

Where:

q_p and f_s – load bearing at pile point and pile side section, as values in Table A.1 and A.2

m – Working condition factor of pile in soil, equals to 1.0

m_R, m_{lv}- Working condition factors of soil at pile point and pile side section including effect of driving method on soil estimated resistance, defined as in Table A.3.

In formula (A.4), total soil bearing load is the sum of load on all soil layer through which the pile is driven. If the soil basement needs to be scraped or be washed out, total estimated resistance force of all soil layers under the scraping level should be calculated.

Note:

1) Load bearing capability of belled-out pile when being calculated by formula (A.4): perimeter u at the pile column is cross section perimeter and perimeter at the belled-out section is the cross section perimeter of that part.

Table A_1 – Soil resistance force at pile point q_p

Pile point depth, m	Soil resistance force at point of hammered pile and non-concrete pile, q_p, T/m^2						
	Of sandy soil, medium solid						
	Gravel	Coarse	-	Medium coarse	Fine	Dust	-
	Of clay when consistence index I_L equals to:						
	0	0.1	0.2	0.3	0.4	0.5	0.6
3	750	660 (400)	300	310 (200)	200 (120)	110	60
4	830	680 (510)	380	320 (250)	210 (160)	125	70
5	880	700 (620)	400	340 (280)	220 (200)	130	80
7	970	730 (690)	430	370 (330)	240 (220)	14	85
10	1050	770 (730)	500	400 (350)	260 (240)	150	90
15	1170	820 (750)	560	440 (400)	290	165	100
20	1260	850	620	480 (450)	320	180	110
25	1340	900	680	520	350	195	12
30	1420	950	740	650	380	210	130
35	1500	1000	800	600	410	225	140

Table A.2 - Side friction f_s

Average depth of soil layer, m	Side friction of pile, f_s, T/m^2								
	Of sandy soil, medium solid								
	Coarse and medium coarse	Fine	Dust	-	-	-	-	-	-
	Of clay when consistence index I_L equals to:								
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

1	3.5	2.3	1.5	1.2	0.5	0.4	0.4	0.3	0.2
2	4.2	3	2.1	1.7	1.2	0.7	0.5	0.4	0.4
3	4.8	3.5	2.5	2	1.1	0.8	0.7	0.6	0.5
4	5.3	3.8	2.7	2.2	1.6	0.9	0.8	0.7	0.6
5	5.6	4	2.9	2.4	1.7	1	0.8	0.7	0.6
6	5.8	4.2	3.1	2.5	1.8	1	0.8	0.7	0.6
8	6.2	4.4	3.3	2.6	1.9	1	0.8	0.7	0.6
10	6.5	4.6	3.4	2.7	1.9	1	0.8	0.7	0.6
15	7.2	5.1	3.8	2.8	2	1.1	0.8	0.7	0.6
20	7.9	5.6	4.1	3	2	1.2	0.8	0.7	0.6
25	8.6	6.1	4.4	3.2	2	1.2	0.8	0.7	0.6
30	9.3	6.6	4.7	3.4	2.1	1.2	0.9	0.8	0.7
35	10	7	5	3.6	2.2	1.3	0.9	0.8	0.7

Note for Table A.1 and A.2

1) *For fraction values of q_p in Table A.1, numerator refers to sand value and denominator is of clay.*
2) *In table A.1 and A.2, pile depth is the average depth of the soil when it is scraped or raised up to 3 m. In this case, the depth is in natural terrain characteristic. When the soil is scraped or raised up from 3 to 10 m, reference height will be higher 3 m than the scraped soil or lower 3 m than the raised soil.*

   Depth for driving pile in wet area should consider the capability when soil is washed at estimated flood.

   Piles designed for roads over spillways should have point depth (in Table A.1) as depth of natural terrain at construction foundation.
3) *For intermediate values of depth and consistence index I, q_p and f_s in Table A.1 and A.2 should be defined by interpolation method.*
4) *Estimated resistance force q_p can be used as in Table A.1 if pile driven depth into soil is washed or scraped not less than:*
   - *For irrigation constructions: 4m*
   - *For buildings and other constructions: 3m*
5) *When defining side friction f_s as stated in Table A.2, foundation soil is divided into small conformity layer with thickness not over than 2m.*
6) *Estimated side friction f_s of coarse-grained sand should be increased 30% in comparison with values stated in Table A.2.*

Table A.3 – m_R and m_f coefficients

Pile driving method	Soil working condition coefficients independently in calculation of pile bearing load	
	Under pile point m_R	At pile side section m_f
1. Driving of solid pile and hollow pile with crowned point by air-hammer (flying), machine hammer and diesel hammer	1	1
2. Driving piles by boring with pile point depth not less than 1 m under boring hole, with boring diameter: a) Equal to column side b) 5 cm smaller than column pile side c) 15 cm smaller than column pile side or round pile diameter (for transmission line)	 1 1 1	 0.5 0.6 1
3. Driving with wash pile into sandy soil with condition		

that pile is driven at final m length without water washing	1	0.9
4. Driving by vibrating into: a) Sandy soil and medium flint sand - Coarse and medium coarse - Fine - Dust b) Clay with consistence I_l = 0.5: - Semi- sandy soil -Semi-clay soil - Clay c) Clay with consistence $I_l \leq 0$	 1.2 1.1 1 0.9 0.8 0.7 1	 1 1 1 0.9 0.9 0.9 1
5. Open point hollow pile driven by any hammer a) Hollow pile diameter ≤ 40cm b) Hollow pile diameter > 40cm	 1 0.7	 1 1
6. Round hollow pile with covered point, driven by any method to a depth ≥ 10cm and then belling out the pile point by bombing in sandy soil or clay with consistence $I_l \leq 0.5$ when belled-out diameter equal to: a) 1m, independent with mentioned type of soil. b) 1.5m in sandy soil and semi-sandy soil c) 1.5m in clay and semi-clay soil	 0.9 0.8 0.7	 1 1 1

Note: Coefficients m_R and m_f at article 4 in Table A.3 for clay with consistence 0.5 > I_l >0 determined by interpolation.

A.4. For hammered piles of which pile point rests on relative tight sand I_D < 1/3 or clay with consistence I_L> 0.6, pile bearing load should be defined by result from pile county test.

A.5. Calculation of bearing load of wedge pile, needle pile and lozenge pile driven through sand and clay should include additional arising load of soil at pile side which is the resistance depending on strain module from compressing test in laboratory, defined by:

$$Q_{tc} = m[q_p A_p + \sum l_i (u_i f_i + u_{oi} i_c E_j k'_i \xi_p)] \quad (A.5)$$

Where:

m, q_p, A_p, l_l and fi – The same symbols in formula (A.4)

u_i - External perimeter of i cross section of pile, m;

u_{oi} – Total sides of cross section i, in meter, with inclination toward pile column

i_c – Inclination of pile lateral surface, defined by quotient of half length of cross top section and end section on length of the inclination side.

E_i – Strain module of i layer around pile lateral surface, T/m^2, defined by soil compressing test.

k'_i – Factor, defined as stated in Table A.4

ξ_p - rheological factor, equal to 0.8

Note: For lozenge piles, total resistance of soil at pile lateral surface with counter inclination in formula A.5 will not be considered.

Table A.4 – Coefficient k'$_i$

Type of soil	Coefficient k'$_i$
Sandy and semi-sandy soil	0.5
Semi –clay soil	0.6
Clay soil: when plasticity index I_P = 18	0.7
When plasticity index I_p = 25	0.9
Note: For clay with plasticity index 18< I_P < 25, k'$_i$ is determined by interpolation method.	

A.6. Pile withdrawal bearing load is defined as follows:

$$Q^k_{tc} = mu\sum m_i l_i f_i \quad (A.6)$$

Where:

u, m_f, f_i and l_i – The same symbols as in formula (A.4)

m – Working condition coefficient for pile hammered into a depth less than 4m is 0.6, at the depth ≥ 4m is 0.8 for all types of building and construction, except for foundation of overhead power transmission line.

A.7. Bearing load of belled-out and nonbelled-out cast-in-place piles and bearing load of centrally compressed piles is defined as follows:

$$Q_{tc} = m(m_R q_p A_p + u\sum m_f f_i l_i \quad (A.7)$$

Where:

m – Working environment coefficient, when pile rests on clay with saturation G< 0.85, m = 0.8. For other condition, m=1

m_R – Working condition coefficient of soil under pile point. m_R =1 for all conditions, except when pile is belled out by bombing (in this case, m_R = 1.3) and when pile is belled out by underwater concrete (in this case m_R =0.9)

q_p – Bearing load of soil under pile point, t/m^2 in accordance with A.8 and A.9 of this standard.

A_p – Pile point area, m^2, defined as follows:

a) For unbelled-out cast-in-place pile and for column pile, this area is equal to pile cross section area.

b) For belled-out cast-in-place pile, this area is equal to pile cross section of the belled-out area at the maximum diameter.

c) For cast-in-place hollow pile, this area is equal to pile cross section including pile wall

d) For pile containing soil (without concrete casting), this area is equal to pile wall cross section area.

m_f – Working condition coefficient of soil at pile side, depending on boring method, as stated in Table A.5

f_i – Side friction of i soil layer at pile side, T/m^2, as stated in Table A.2

Note: Friction of sand layer at belled-out pile side is calculated from the scraped surface to relative depth of the cross of pile column with an imaginative cone and generating curve on expanded line to form an angle $\varphi_1/2$ with pile column, of which φ_1 is the relative estimated value of soil internal friction. Estimate values y, φ and C of foundation soil are calculated under requirements of standard for designing building foundation and construction, with application of *safe factor equally 1.1 for φ_I and 1.5 for C_I. For clay, it is needed to include side friction on the whole estimated length of pile.*

Table A.5 – Coefficient m_f values

Type of pile and construction methods	Working condition coefficient m_f of soil			
	Sand	Semi-sand	Semi-clay	Clay
1	2	3	4	5
1. Pile constructed by hammering a close steel column and withdrawing the columns when placing concrete	0.8	0.8	0.8	0.7
2. Compressed vibration cast-in-place pile	0.9	0.9	0.9	0.9
3. Cast-in-place pile including belled-out pile, with concrete casting process when:				
a) No water in boring hole (dry method) or when using resistance pile	0.7	0.7	0.7	0.6
b) Under water or by using clay solution	0.6	0.6	0.6	0.6
c) Solid concrete compound placing into pile with compacting (dry method)	0.8	0.8	0.8	0.7
4. Hollow pile driven by vibrating with extracting soil	1	0.9	0.7	0.6
5. Pile column	0.8	0.8	0.8	0.7
6. Cast-in-place pile, hollow pile, pile driving without water in boring hole	0.9	0.8	0.8	0.7
7. Bored pile with resistance column against concrete or concrete pumping with pressure 2 to 4 atm	0.9	0.8	0.8	0.8

A.8 Soil bearing load q_p, T/m^2 under cast-in-place pile column and pile driven with extracting soil before concrete casting, should be:

a) For coarse-grained sand and for sandy soil with belled-out and nonbelled-out piles, for pile driven with totally empty of soil in its column, the soil bearing load will be calculated as in formula (A.8). For pile driven with original volume of soil in its column at a height ≥ 0.5m – this value will be calculated as in formula (A.9):

$$q_p = 0{,}75\beta(\gamma'_I d_p A_k^o + \alpha \gamma_I L B_k^o) \quad \text{(A.8)}$$

$$q_p = \beta(\gamma'_I d_p A_k^o + \alpha \gamma_I L B_k^o) \quad \text{(A.9)}$$

Where:

$\beta, A_k^o, \alpha B_k^o$ - Non-dimensional coefficients as in Table A.6

y'_I - Estimated value of soil volume mass, t/m^3 under pile point (in saturation soil, it is needed to include water floating resistance force)

y_I – Estimated average value (in layers) of soil volume mass, t/m^3 above pile point (in saturation soil, it is needed to include water floating resistance force)

L – Pile length, m

d_p – pile diameter, m of cast-in-place pile or pile bottom (without belled-out process)

b) For clay, when pile is belled-out or nonbelled-out, or hollow pile with extracting soil (partly or totally) and concrete casting into pile column, soil bearing load should have values as stated in Table A.7.

Note: Principles in Article A.8 should be applied when depth of pile into soil is not less than pile diameter (or belled-out section), but not less than 2 m.

Table A.6 – Coefficients of formula (A.8) and (A.9)

Coefficient symbols		A^o_k, B_k^o, α and β values when estimated value of internal friction φ_1 , degree								
		23	25	27	29	31	33	35	37	39
A^o_k		9,5	12,6	17,3	24,4	34,6	48,6	71,3	108	163
B^o_k		18,6	24,8	32,8	45,5	64	87,6	127	185	260
α, if $\frac{L}{dp}$	4	0,78	0,79	0,8	0,82	0,84	0,85	0,85	0,86	0,87
	5	0,75	0,76	0,77	0,79	0,81	0,82	0,83	0,84	0,85
	7,5	0,68	0,7	0,7	0,74	0,76	0,78	0,8	0,82	0,84
	10	0,62	0,65	0,67	0,7	0,73	0,75	0,77	0,79	0,81
	12,5	0,58	0,64	0,63	0,67	0,7	0,73	0,75	0,7	0,80
	15	0,55	0,58	0,61	0,65	0,68	0,71	0,73	0,76	0,79
	17,5	0,51	0,55	0,58	0,62	0,66	0,69	0,72	0,75	0,78
	20	0,49	0,53	0,57	0,61	0,65	0,68	0,72	0,75	0,78
	22,5	0,46	0,51	0,55	0,6	0,64	0,67	0,71	0,74	0,77
	⩾ 25	0,44	0,49	0,54	0,59	0,63	0,67	0,7	0,74	0,77
β if d_p=	⩽ 0,8m	0,31	0,31	0,29	0,27	0,26	0,25	0,24	0,28	0,28
	< 4m	0,25	0,21	0,23	0,22	0,21	0,20	0,19	0,18	0,17

A.9. Load bearing q_p, T/m^2 of soil under non-casting pile point which has soil lasting to final phase until pile is driven with a height ≥0.5 m (with condition that the soil is formed by soil with the same characteristic with soil at pile point), should be values as stated in Table A.1 of this Annex if the working condition mentions to pile driving method as in article 4, Table A.3 and if estimated resistance in this case is pile wall cross section area.

A.10. Maximum withdrawal bearing load of cast-in-place pile is defined by:

$$Q_{uk} = m.u\sum m_f f_i l_i + W \qquad \text{(A.10)}$$

Where:

m – The same function in formula (A.6)

u, m_f, f_i and l_i – The same function symbols in formula (A.7)

Table A.7 – q_p values

Pile point depth h, m	Load bearing capacity, q_p, T/m^2 under casting pile point with and without belled-out bottom, column pile and pile driven with concrete casting after extracting soil, in clay with consistence index I_L equal to:						
	0	0.1	0.2	0.3	0.4	0.5	0.6
3	85	75	65	50	10	30	25
5	100	85	75	65	50	40	35
7	115	100	85	75	60	50	45
10	135	120	105	95	80	70	60
12	155	140	125	110	95	80	70
15	180	165	150	130	100	100	80
18	210	190	170	150	130	115	95
20	230	240	190	165	145	125	105
30	330	300	260	230	200	-	-
40	450	400	350	300	250	-	-

Note (for Table A.7):

For abutment foundation, q_p values presented in Table A.7 should:

a) Increasing (for abutment in water area) to a value of 1.5 ($y_n h_n$) of which:

y_n – Specific weight of water, 1 T/m^3;

h_n – Water layer height, m, including level in dry season to washing level in estimated flooding.

b) Decreasing when soil void ratio e>0.6 when q_p value in Table A.7 should be multiplied by decreasing coefficient m defined by interpolation among values m =1 for e =0.6 and m =0.6 for e =1.1

Annex B

Determination of pile bearing load in accordance with foundation soil strength

B.1. General requirements

B.1.1. Pile maximum bearing load is determined by:

$$Q_u = A_s f_s + A_p q_p \qquad (B.1)$$

B.1.2. Allowable bearing load of pile is determined by:

$$Q_a = \frac{Q_s}{FS_s} + \frac{Q_p}{FS_p} \qquad (B.2)$$

Where:

FS_s – Safe factor for side friction components, equal to 1.5 – 2.0

FS_p - Safe factor for resistance force under pile point, equal to 2.0-3.0

B.1.3. General formula for calculating side friction on pile:

$$f_s = c_a + \sigma'_h \tan \varphi_a \qquad (B.3)$$

Where:

C_a – Binding force among pile and soil, T/m^2, with concrete reinforcement pile, $c_a = c$, for steel, $c_a = 0.7c$, of which c is binding force of foundation soil.

σ'_h - Effective stress perpendicular with pile side, T/m^2

φ_a – Friction angle between pile and foundation soil; for concrete reinforcement pile driven by hammering, $\varphi_a = \varphi$, for steel pile, $\varphi_a = 0.7\varphi$, of which φ is the inner friction of foundation soil.

B.1.4. Bearing load of soil under pile point is calculated by:

$$q_p = cN_c + \sigma'_{vp} N_q + \gamma d_p N_\gamma \qquad (B4)$$

Where:

c – Soil binding force, T/m^2

σ'_{vp} – Effective stress in vertical direction at pile point depth caused by soil mass itself, T/m^2

N_c, N_q, N_y – Load bearing coefficient, depending on soil inner friction, pile point shape and pile construction method.

y - Soil volume mass at pile point depth, T/m^3.

B.2. Pile maximum bearing load in binding soil is determined by :

$$Q_u = A_s \alpha c_u + A_p N_c c_u \qquad (B.5)$$

Where:

c_u – Un-drained shearing resistance force of foundation soil, T/m^2

α – Non-dimensional coefficient, for hammered pile in B.1 figure and for cast-in-place, this value is 0.3 - 0.45 in solid clay and is 0.6-0.8 in soft clay.

N_c – Bearing load coefficient, equal to 9.0 for hammered pile in natural clay and 6.0 for cast-in-place pile.

Note:

1) *Safe factor when calculating pile bearing load as formula (B.5), equal to 2.0 – 3.0*

2) Maximum value of αc_u in formula (B.5), equal to 1kg/cm^2.

B.3. Pile maximum bearing load in loose earth is determined as following formula:

$$Q_u = A_s K_s \sigma'_v \tan\varphi_a + A_p \sigma'_{vp} N_q \quad \text{(B.6)}$$

Where:

K_s – Transversal load coefficient in soil rest state, as presented in Figure B.2

σ'_v – Effective stress at estimated depth of side friction on pile, t/m^2

φ_a – Friction angle between foundation soil and pile

σ'_{vp} - Effective stress in vertical direction at pile point, T/m^2

N_q – Load bearing coefficient, determined as in Figure B.3

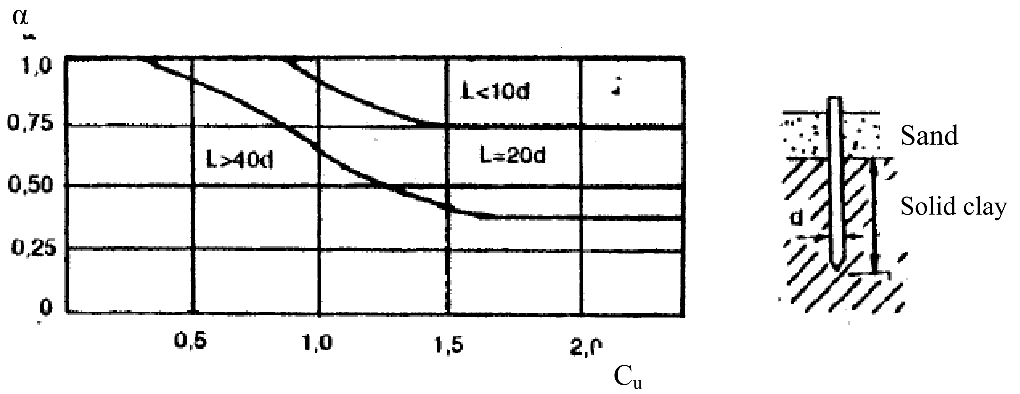
B.3.1. Load bearing under pile point and side friction on pile in loose earth at depths greater than minimum depth, z_c, m, equal to relative values in minimum depth, as follows:

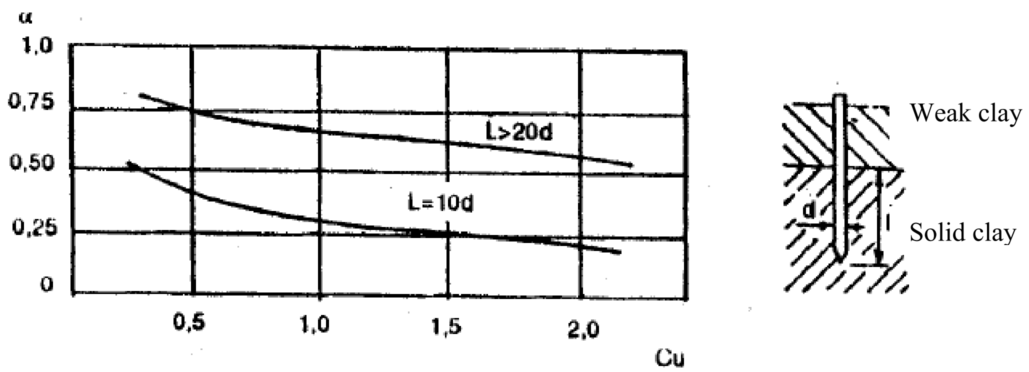
$$f_s\ (z > z_c) = f_s(z = z_c)$$

$$q_p\ (z > z_c) = q_p(z = z_c)$$

Note: Minimum depth z_c is defined by inner friction of foundation soil (Figure B.4)

B.3.2. Safe factor for formula B.6 is equal to 2.0 -3.0





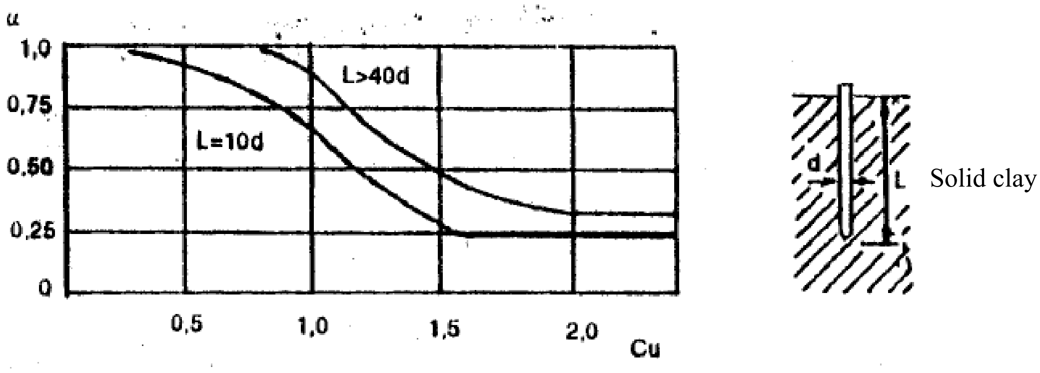


Figure B.1: Relationship of α - c_u

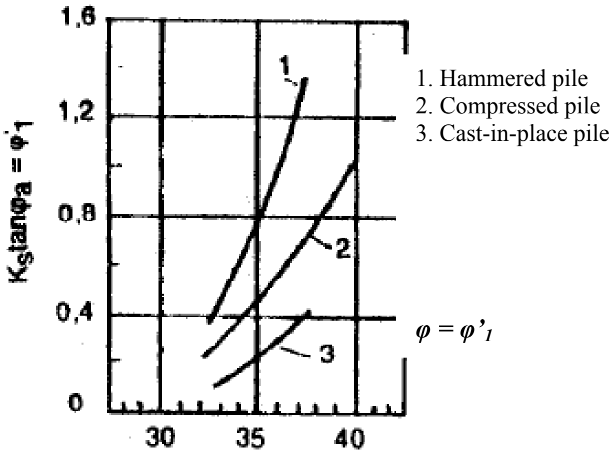


Figure B.2: Relationship of $K_s tan\varphi_a$ and φ

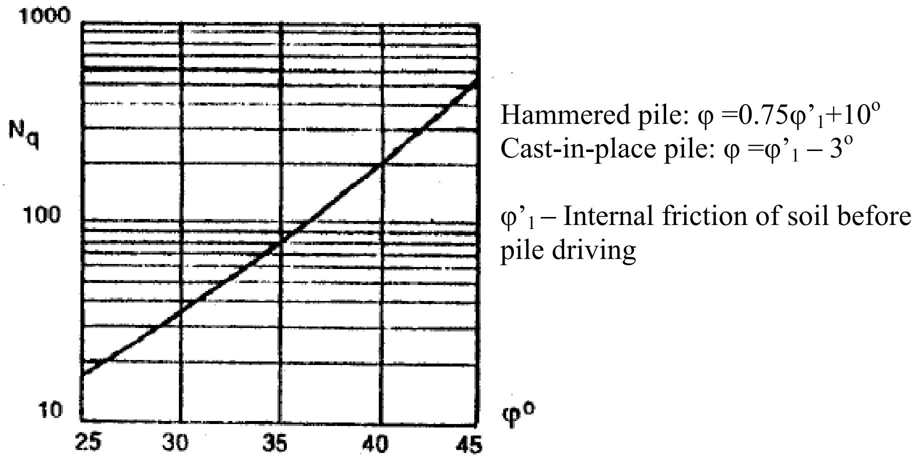
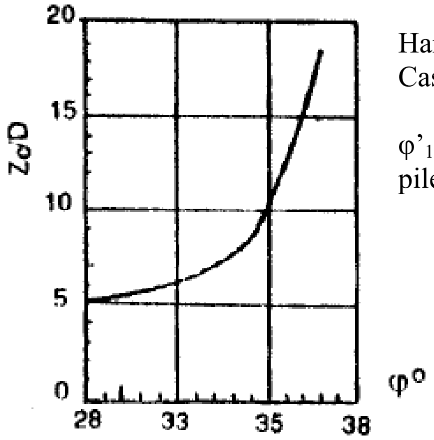


Figure B3: N_q coefficient



Hammered pile: $\varphi = (\varphi'_1+40)/2$
Cast-in-place pile: $\varphi = \varphi'_1 - 3^o$

φ'_1 – Internal friction of soil before pile driving

Figure B4: Relationships of z_c/d and φ

Annex C

Determination of pile bearing load by penetration test

C.1. Calculation by county penetration test result

C.1.1. Pile bearing load is calculated basing on penetration resistance at pile point q_c.

C.1.2. Standard penetration equipment should be used with nose cone diameter equals to 35.7 mm, nose cone acute angle equals to 60°. Otherwise, penetration equipment values should be exchanged relatively basing on relations defined for each equipment.

C.1.3. Calculation method is the same in Standard TCXD 174:1989

C.1.3.1. Pile clamped depth z_c is the maximum depth, if exceeding this value, pile bearing load will stay the same value when:

- Single layer foundation soil: z_c =6d, of which d is cross section side or pile cross section diameter.
- For multi layer foundation soil:

$z_c = 3d$ when $\sigma_v > 0.1$ MPa

$z_c = 3d + 6d$ when $\sigma_v < 0.1$ MPa (with σ_v referring to soil column pressure)

C.1.3.2. Maximum resistance force at pile point is defined as follows:

$$Q_p = A_p.q_p \qquad (C.11)$$

Value of q_p is defined as:

$$q_p = K_c\overline{q_c} \qquad (C.12)$$

Where:

K_c – Load bearing coefficient, as presented in Table C.1

$\overline{q_c}$ - Average penetration resistance, within 3d upper and 3d lower of pile point.

C.1.3.3. Minimum resistance of pile lateral surface is determined by:

$$Q_s = u\sum h_{si}f_{si} \qquad (C.13)$$

Where:

h_{si} – Pile length in i soil layer, m u – Pile section perimeter, m

f_{si} – unit side friction at i soil layer, defined by penetration resistance at pile point q_c as following formula:

$$f_{si} = \frac{q_{ci}}{\alpha_i} \qquad (C.1.4)$$

In which, α_i is coefficient, as presented in Table C.1

C.1.4.4. Allowable load bearing of a single pile is determined by minimum bearing load as stated above divides to safe factor FS = 2 to 3

C.1.5. Correlated experiment between penetration resistance q_c and foundation soil physical mechanical characteristics.

C.1.5.1. Correlation between internal friction of loose earth φ with penetration resistance q_c, defined as in Table C.2

Table C.2 – Correlation between q_c and φ

q_c (10^5Pa)	Φ (degree) at the depth	
	2m	≥ 5m
10	28	26
20	30	28
40	32	30
70	34	32
120	36	34
200	38	36
300	40	38

C.1.5.2. Correlation of penetration resistance q_c and un-drained shearing resistance of binding soil, c_u, is determined by:

$$c_u = \frac{q_c - \sigma_v}{15} \qquad (C.1.5)$$

Where σ_v is vertical pressure caused by soil mass itself.

Table C.1 – Coefficient K_c and α

Soil type	Resistance force at pile point q_c (***) (kPa)	K_c coefficient		α coefficient				Maximum value q_c (kPa)			
				Cast-in-place pile		Hammered pile		Cast-in-place pile		Hammered pile	
		Cast-in-place pile	Hammered pile	Concrete wall	Steel wall	Concrete wall	Steel wall	Concrete wall	Steel wall	Concrete wall	Steel wall
Quick clay, muddy soil (*)	<2000	0.4	0.5	30	30	30	30	15	15	15	15
Medium solid clay	2000-5000	0.35	0.45	40	80	40	80	(80) 35	(80) 35	(80) 35	35
Clay, solid to very solid	>5000	0.45	0.55	60	120	60	120	(80) 35	(80) 35	(80) 35	35
Drift sand	0-2500	0.4	0.5	(60)** 120	150	(60) 80	(120) 60	35	35	35	35
Medium compact sand	2500-10000	0.4	0.5	(100) 180	(200) 250	1000	(200) 250	(120) 80	(80) 35	(120) 80	80
Compact to extreme compact sand	>10000	0.3	0.4	150	300 (200)	150	300 (200)	(150) 120	(120) 80	(150) 80	120
Chalk (soft stone)	>5000	0.2	0.4	100	120	100	120	35	35	35	35
Decayed chalk, debris	>5000	0.2	0.3	60	80	60	80	(150) 120	(120) 80	(150) 120	120

Note:

** It is needed to pay special attention to side friction value of pile in soft and muddy clay soil because of their settlement and negative friction due to even a small load or even with their internal load.*

*** Values in blankets can be:*

- For cast-in-place piles with well kept wall and when construction not damaging pile wall and high quality concrete.

- For hammered pile of which effect is to compact the soil in driving process

**** Penetration resistance value in Table C.1 correlated to simple nose cone.*

C.2. Calculation of pile bearing load in accordance with standard penetration test result

C.2.1. Standard penetration test result (SPT) in loose earth can be used for calculation of pile bearing load (Meyerhof, 1956).

C.2.2. Pile maximum bearing load is determined by formula of Meyerhof (1956)

$$Q_u = K_1 N A_p + K_2 N_{tb} A_s \quad \text{(C.2.1)}$$

Where:

N – SPT average index within 1d under pile point and 4d above pile point

A_p – Area of pile cross section, m^2

N_{tb} – SPT average along pile column within loose earth area.

A_s – Area of pile side section within loose earth area, m^2

K_1 – Coefficient, equal to 400 for hammered pile and 120 for cast-in-lace pile

K_2 – Coefficient, equal to 2.0 for hammered pile and 1.0 for cast-in-place pile

Safe factor applied when calculating pile bearing load is equal to 2.5 -3.0

C.2.3. Pile bearing load can be calculated by Japanese equation as follows:

$$Q_a = \frac{1}{3}\{\alpha N_a A_p + (0{,}2 N_s L_s + C L_c)\pi d\} \quad \text{(C.2.2)}$$

Where:

N_a – SPT index of soil under pile point

N_s – SPT index of soil surrounding pile column

L_s – Pile length section in sand, m

L_c – Pile length section in clay, m

α – Coefficient, depending on pile construction method:

- Concrete steel reinforcement pile driven by hammering: α = 30

- Cast-in-place pile: α =15

Annex D

Determination of pile bearing load by dynamic equation

D.1. Determination of pile bearing load by dynamic equation should use formula of Gersevanov (Article D.2) or Hilley (Article D.3 in this Annex.

D.2. Determination of pile bearing load by Gersevanov's formula:

Allowable bearing load:

$$Q_a = \frac{Q_{tc}}{k_{tc}} \qquad \text{(D.1a)}$$

Where:

Q_{tc} – Standard bearing load determined by dynamic equation of Gersevanov, T

k_{tc} - Safe factor, defined as in Article A.1, Annex A,

D.2.1. Pile standard bearing load from dynamic test can be determined by:

$$Q_{tc} = \frac{Q_u}{k_d} \qquad \text{(D.1)}$$

Where:

Q_u – Maximum bearing load, T, determined by formula D.2 or D.3

k_d – Soil safe factor, as presented in Article D.2.2 in this Annex

D.2.2. When piles are tested in the same soil condition with number less than 6 piles, $Q_u = Q_{u\,min}$ and k_d =1.0

When piles are tested in the same soil condition, with number equal to or more than 6 piles, maximum bearing load Q_u will be defined based on statistic results of specific values of pile bearing load as in test.

D.2.3. In dynamic driving test, if the real resistance (calculated) $e_r \geq 0.002$m, Q_u will be calculated by:

$$Q_u = \frac{nFM}{2}\left[\sqrt{1 + \frac{4Э_p}{nFe_f} \cdot \frac{W_n + \varepsilon^2 (W_c + W_1)}{W_n + W_c + W_1}} - 1\right] \qquad \text{(D.2)}$$

If resistance force measured in reality $e_f < 0.002$m, it should be consider to use hammer with big blow for driving pile, then $e_f \geq 0.002$m. If pile driving equipment can not be changed and elastic resistance force is measured, minimum bearing load will be calculated by:

$$Q_u = \frac{1}{2\theta} \cdot \frac{2e_f + c}{e_f + c}\left[\sqrt{\frac{1 + 8Э_p (e_f + c}{(2e_f + c)^2} \cdot \frac{W}{W + W_c}\theta} - 1\right] \qquad \text{(D.3)}$$

Where:

p – coefficient, equal to 150t/m^2 for concrete steel reinforcement pile with pile cap.

F – Area limited by internal perimeter of pile cross section

M- Coefficient, equal to 1.0 when driving by hammer, for driving by vibrating, this value will be as stated in Table D.1, depending on type of soil under pile point.

$Э_р$ - Estimated energy of a hammer blow, t.m, with values as in Table D.2 or estimated energy of a driving machine by vibration – as in Table D.3

e_f – Real resistance force, equal to pile settlement by a hammer blow; for vibrating method, it will be pile settlement made by a machine capacity in a 1 minute, m

c – Pile elastic resistance force (elastic displacement of soil versus pile), defined by a resistance force tester.

W – Blowing weight of hammer, T

W_c – Weight of pile and pile cap, T

W_1 – Weight of lining pile (when driven by vibrating W_1=0), T

W_n- Weight of hammer or vibrating machine, T

ε – Blowing recover coefficient, when piles and steel concrete reinforcement piles are driven by hammer' blows with wooden cap, ε^2=0.2; when pile driven by vibrating, ε^2=0

θ - Coefficient, l/t, defined by following formula:

$$\theta = \frac{1}{4}\left(\frac{n_o}{F} + \frac{n_h}{\Omega}\right)\frac{W}{W + W_c}\sqrt{2g(H - h)} \qquad \text{(D.4)}$$

n_o, n_h – Coefficient of transformation from dynamic resistance to county resistance, with value for soil under pile point: n_o=0.0025 s.m/T and for soil at pile side n_h = 0.25s.m/T

Ω - Area of pile side contacting with soil, m^2

g- gravity accelerator, equal to 9.81 m/s^2

h – Bounce height of hammer, for diesel hammer, h =0.5m, for other types of hammer: h=0

H – Real falling height level of hammer, m

Note:

1) Values of W_n, W, W_c and W_1 applied in above formulas do not include overloaded coefficient.

2) When there is a difference over than 1.4 times between pile bearing load determined by formulas (D.2) and (D.3) with the value determined basing on soil physical mechanical characteristic, an additional county compressing test should be required.

Table D.1 – M coefficient

Type of soil under pile point	M coefficient
1. Gravel	1.3
2. Medium coarse sand, medium compact and semi-solid	1.2
3. Medium compact fine sand	1.1
4. Medium compact dust sand	1.0
5. Semi-plastic clay, Loam and solid clay	0.9
6. Loam and semi solid clay	0.8
7. Loam and dry plastic clay	0.7
Note: In compact sand, value of M coefficient in term 2, 3 and 4 should be increased 60% and in county penetration, should be increased 100%.	

Table D.2 – Estimated energy Э_P of hammer

Type of hammer	Estimated energy of hammer blow Э_P, Tm
1. Monkey hammer or single-acting hammer	WH
2. Diesel pipe hammer	0.9WH
3. Single-acting diesel hammer	0.4VH
4. Diesel hammer with rechecking method by single acting before blowing	W(H-h)
Note: At term 4, h is the first bouncing height of diesel hammer caused by air, which is determined by measurement, m. For preliminary calculation, it can be considered that h =0.6m for column hammer and h =0.4m for pipe hammer	

Table D.3 – Estimated energy Э_P of vibrating hammer

Stimulating force of vibrating machine, T	10	20	30	40	50	60	70	80
Estimated energy corresponding with vibrating effect Э_P, Tm	4.5	9	13	17.5	22	26.5	31	35

D.3. Hilley's dynamic equation

D.3.1. Minimum bearing load is calculated by formula:

$$Q_u = \frac{kWh}{e_f + 1/2(c_1 + c_2 + c_3)} \cdot \frac{W + e^2 W_c}{W + W_c} \qquad \text{(D.4)}$$

Where:

k – Mechanical efficiency of hammer. Here below are some values suggested for use:

- 100% for freely falling, automatically controlled and diesel hammers
- 75% for freely falling hammers lifted by cable
- 75% to 85% for steam single-acting hammer

W – Weight of driving hammer, T

W_c – Weight of blowing hammer, T

h – Hammer falling height, m

e – Recovery coefficient with some values as follows:

+ For steel sealed pile cap: e =0.55

+ For pile with wood cushioned pile cap: e=0.4

+ For steel concrete reinforcement pile, wood cushioned pile cap: e =0.25

e_f – Pile settlement under one hammer blow in testing (resistance), m

c_1 – Elastic strain of pile cap, pile cap cushion and lining pile, m

c_2 - Pile plastic strain, m

$$C_2 = \frac{Q_u L}{AE}$$

c_3 – Deformation/strain of foundation soil, usually equal to 0.005m

A – Area of pile cross section, m^2.

E – Elastic module of pile material, T/m^2

D.3.2. Safe factor when applying Hilley's formula: $F_s \geq 3.0$

Annex E

Determination of bearing load by pile county compressing method

E.1. The procedure of county compressing test for determining pile bearing load will be carried out under agreement with investor or investor's consultant.

E.2. Selection of procedure to apply should take into account all characteristic of natural conditions, construction load and design's requirements.

E.3. Method in SNiP 2.02.03.85:

E.3.1. Pile allowable vertical load bearing is calculated by following formula:

$$Q_a = \frac{Q_{tc}}{k_{tc}} \quad (E.1)$$

Where:

Q_a – Pile allowable load bearing capability

Q_{tc} – Pile standard load bearing capability defined from result of Standard TCXD 88:1982

k_{tc} – Safe factor, defined as in Article A.1, Annex A.

E.3.2. Pile standard load bearing capability defined by tests with compressing, withdrawal and transversal load is determined by formula as follows:

$$Q_{tc} = m \frac{Q_u}{k_d} \quad (E.2)$$

Where:

m – Working condition coefficient for all types of building and construction, except for open power transmission line, which shall be:

m =1.0 for vertically or transversally compressed pile

m=0.8 for withdrawal pile when its depth into soil ≥4m

m = 0.6 for withdrawal pile when its depth into soil <4m

Q_u – Pile maximum bearing load, t, defined as through article E.3.3 to E.3.5 in this standard.

k_d – Safe factor in accordance with soil condition, as in E.3.3 of this standard.

E.3.3. When piles tested in the same soil condition, with the number less than 6 piles, $Q_u = Q_{u.mm}$ and safe factor $k_d = 1$

When piles tested in the same soil condition, with the number over or including 6 piles, Q_u should be determined by statistic result.

E.3.4. Limited resistance force Q_u of pile is defined as follows (Figure E.1)

- As the load causing continually increasing settlement
- As the value corresponding with settlement ξS_{gh} in the rest situation:

$$\Delta = \xi S_{gh} \tag{E.3}$$

Where:

S_{gh} – Average limited settlement value in standards for foundation design, which is stated in designing task or follows requirements of standards for building and constructions when designing foundation.

ξ - Transferring coefficient from testing settlement to long-term settlement, in general, ξ = 0.1. When there is sufficient testing and settlement surveyor database, it is reasonable if ξ =0.2

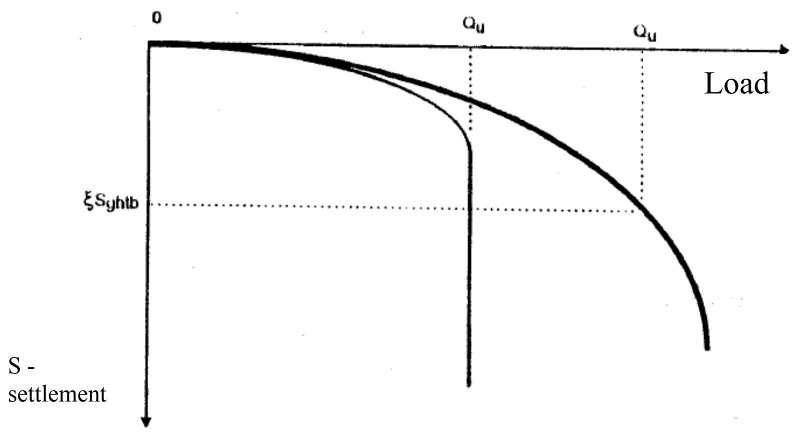


Figure E.1: Calculation of Q_u with formula (E.1)

If settlement calculated in formula (E.3) is greater than 40mm, pile maximum bearing load Q_u should be calculated at a load corresponding with Δ =40mm.

For bridges, pile maximum bearing load in compressed condition should be less than 1 level compared with the load under which:

a) Settlement increases under 1-level increasing load (at the total settlement over than 40mm), exceeding 5 times compared with settlement of previous increasing load.
b) Settlement does not disappear after a diurnal period of time or more (at the total settlement over than 40mm)

During the test, if maximum load is equal to or greater than $1.5Q_{tc}$ (of which Q_{tc} is pile bearing load determined by formulas in Annex A) while pile settlement is less than value determined by formula (E.3) and less than 40mm (for bridges), then pile maximum bearing load will be the maximum load having from the test.

Note: Load values for pile county compressing test are usually suggested within 1/10 to 1/15 of pile estimated maximum load.

E.3.5. When testing pile with transversal county load or withdrawal load, limited load of pile (stated in article E.3.3 of this Annex) will be the load under which pile displacement increases unceasingly.

Note: Results of transversal county test can be used for determination of allowable load from permissible transversal strain of buildings and constructions. Such loads can have values at which pile transversal strain is at soil surface when testing by allowable limited value but not over than 10mm.

E.4. Some common methods can be used for determination of pile limited bearing load when destructive test can not be applied, especially for pile with great diameter.

E.4.1. Testing methods in Canadian Foundation Engineering Manual (1985)

Pile limited bearing load is the load determined at the crossed point of diagram of relationship between load and settlement with a line (Figure E.2):

$$S_f = \delta + d/30 \quad \text{(E.4)}$$

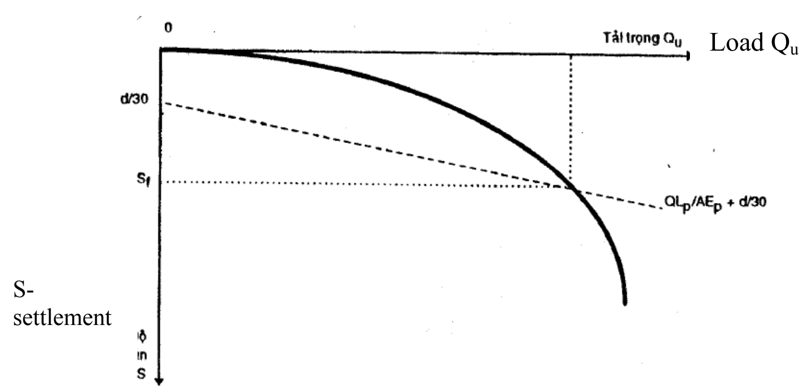


Figure E.2: Method to determine Q_u as in formula (E4)

Where:

S_f – Settlement at destructive load, m

δ - Elastic strain of pile, m:

$$\delta = \frac{QL_p}{AE_p} \quad \text{(E.5)}$$

Q – Load on pile, T

L_p – Pile length, m

A – Area of pile cross section, m^2

E_p – Elastic module of pile material, T/m^2

E.4.2. Davisson's method: Pile limited bearing load is the load corresponding with settlement on load curve – settlement calculated in county test:

$$S_f = \frac{QL_p}{E_p A} + 0{,}0038 + \frac{d}{120}\ (m) \quad (E.6)$$

E.4.3. For long pile, limited bearing load in accordance with settlement:

- When $L_p/d > 80$: $S_f = \frac{2QL_P}{3E_P A} = 0.0038 + 0.02$ (m) (E.7)

- When $Lp/d > 100$: $S_f = 60$ to 80mm (E.8)

Note: The determination of S_f mentioned in E4.2 and E.4.3 is carried similarly to the way presented in E4.1.

E.4.4. Allowable compressed load is calculated by:

$$Q_a = \frac{Q_u}{FS} \quad (E.9)$$

E.4.5. Safe factor is generally FS≥ 2.0. Greater safe factor should be needed for following conditions

- For friction piles in binding soil
- For limited numbers of testing pile in complex geological conditions.
- For piles in loose earth, with bearing load decreasing with the time
- For the requirement to ensure for settlement.

Annex G

Pile calculation under vertical load, transversal load and moment

Calculation method in SNiP II-17-77

G.1. Pile calculations, under the load of vertical load, transversal load and moment in diagram G.1, include:

a) Offset, Δ_n and deflection angle ψ of pile cap should meet following requirement:

$$\Delta_n \le S_{gh} \quad (G.1)$$

$$\psi \le \psi_{gh} \quad (G.2)$$

Where:

Δ_n and ψ - Calculated values of offset, m and deflection angle, radian, of the pile cap, are determined by guidelines in Article G.4 in this Annex.

S_{gh} and ψ_{gh} - Allowable values of offset, m and deflection angle, radian of the pile cap, specified by designing task for building and construction.

b) Calculation of stability of foundation soil around pile should be carried out as required by G.6 of this Annex.

c) Checking pile section in accordance with material durability, the first limiting state and the second one under the load of vertical force, binding moment and transversal load.

Estimated values of binding moment, transversal load and vertical load on different pile cross section are determined as in Article G.7 of this Annex. For piles clamped tightly into pile work, deflection angle ψ =0 and clamped moment is calculated as in G.8 article of this annex.

Note: For pile with cross section d≤ 0.6m and length into soil over than 10d, it is not required to calculate stability of foundation soil around it, except when piles are driven into mud or clay at quick state.

G.2. When calculating transversal load, soil surrounding the pile should be considered to be a linear elastic strain environment characterized by soil factor C_z (T/m^3)

Without experimental data, it can be able to calculate C_z of soil surrounding pile by following formula:

$$C_z = K.z \qquad (G.3)$$

Where:

K – Ratio coefficient, T/m^4, as stated in Table G.1

Z – Depth of pile cross section point, m, from the ground base for over-ground pile work or from pile work bottom for low pile work.

Table G.1 – Ratio coefficient K

Type of soil surrounding pile and its characteristics	Ratio coefficient K, T/m^4 for pile	
	Hammered pile	Cast-in-place, hollow and bearing piles
Clay, quasi-liquid loam ($0.75<I_L \leq 1$)	65-250	50-200
Clay, soft-plastic loam ($0.5<I_L \leq 0.75$), plastic loam ($0 \leq I_L \leq 1$), dust sand ($0.6 \leq e \leq 0.8$)	200-500	200-400
Clay, semi-plastic loam and semi-solid ($0 \leq I_L \leq 0.5$), solid loam ($I_L<0$), grain sand ($0.6 \leq e \leq 0.75$), medium sand ($0.55 \leq e \leq 0.7$),	500-800	400-600
Clay and solid loam ($I_L<0$), coarse grained sand ($0.55 \leq e \leq 0.7$),	800-1300	600-1000
Note: *1.Smaller value of K coefficient in Table G.1 similar to great value of consistence coefficient I_L of clay and void ratio e of sandy soil, which is given in blanket while greater value of K similar to small value of I_L and e. For soil with I_L and e at medium values, K coefficient is determined by interpolation method.* *2. K coefficient for flint sand should be greater 30% compared with the maximum value in table for clay soil.*		

G.3. All calculations are carried out in depth of pile section in soil, z_c and depth of pile driving, L_e, determined by following formula:

$$z_e = \alpha_{bd} z \qquad (G.4)$$

$$L_c = \alpha_{bd} L \qquad (G.5)$$

Where:

z and L – Real depth and length of pile section into soil (pile point), from soil surface for over-ground pile work and from bottom for low pile work, m:

α_{bd} – Strain coefficient, l/m, defined by following formula:

$$\alpha_{bd} = \sqrt[5]{\frac{K \cdot b_c}{E_b I}} \qquad (G.6)$$

Where:

K – The same function symbol in formula (G.3)

E_b – Initial elastic module of pile concrete when compressing and withdrawing, T/m^2, as in standard for designing of steel concrete reinforcement structure.

I – Inertial moment of pile cross section, m^4

b_c- Pile conventional width, m, defined as follows:

+ when $d \geq 0.8$, $b_c = d+1$m

+ when $d < 0.8$m, $b_c = 1.5d + 0.5$m

G.4. Calculation of pile offset at pile work bottom and deflection by following formulas:

$$\Delta_n = y_o + \psi_o l_o + \frac{H l_o^3}{3E_b I} + \frac{M l_o^2}{2E_b I} \qquad (G.7)$$

$$\psi = \psi_o + \frac{H l_o^2}{2E_b I} + \frac{M l_o}{E_b I} \qquad (G.8)$$

Where:

H and M – Estimated values of shearing force, T and binding moment, T.m at pile cap (see Figure G.1)

l_o – Pile length section, m, equal to the distance from pile work bottom to ground surface

y_o and ψ_o – Offset, m and deflection angle of pile cross section, radian, at ground surface for over-ground pile work and at bottom for low pile work, which are defined as in Article G.5 of this Annex.

Note: All values in this annex are considered to be positive values if:

- *Moment and transversal force at pile cap: Moment is clockwise direction and transversal load is toward the right side.*
- *Moment and shearing force at lower part of shearing section: moment is clockwise and transversal load is toward the right side.*
- *Deflection angle and offset of pile section: the angle is clockwise and offset is toward the right side.*

G.5. Determination of offset, y_o, m and deflection angle □$_o$, radian, by following formulas:

$$y_o = H_o \delta_{HH} + M_o \delta_{HM} \qquad (G.9)$$

$$\psi_o = H_o \delta_{MH} + M_o \delta_{MM} \qquad (G.10)$$

Where:

H_o- Estimated value of shearing force, T, H_o=H

M_o- Binding moment, T.m; M_o= M+Hl_o;

δ_{HH}– Offset of cross section, m/T, because H_o =1 (Figure G.2a).

δ_{HM} - Offset of cross section, l/T, because M_o =1 (Figure G.2b).

δ_{MH} – Deflection angle of cross section, l/T, because H_o =1 (Figure G.2a).

δ_{MM} - Deflection angle of cross section, l/(T.m) because moment M_o =1 (Figure G.2b)

Offset δ_{HH}, δ_{MH} = δ_{HM} and δ_{MM} are determined as follows:

$$\delta_{HH} = \frac{1}{\alpha_{bd}^3 E_b I} A_o \quad \text{(G.11)}$$

$$\delta_{MH} = \delta_{HM} = \frac{1}{\alpha_{bd}^2 E_b I} B_o \quad \text{(G.12)}$$

$$\delta_{MM} = \frac{1}{\alpha_{bd} E_b I} C_o \quad \text{(G.13)}$$

Where:

A_o, B_o, C_o – Non-dimensional coefficients in Table G.2, depending on pile depth in soil L_c which is determined by formula G.5. When L_c is within the two values in Table G.2, an adjacent value should be used for list checking.

Table G.2 – Values of A_o, B_o and C_o

l_e	Pile rested on soil			Pile rested on stone			Pile clamped into stone		
	A_0	Bo	Co	A_0	Bo	Co	A_0	Bo	Co
0,5	72,004	192,026	576,243	48,006	96,037	192,291	0,042	0,125	0,500
0,6	50,007	111,149	278,069	33,344	55,609	92,942	0,072	0,180	0,600
0,7	36,745	70,023	150,278	24,507	35,059	50,387	0,114	0,244	0,699
0,8	28,140	46,943	88,279	18,775	23,533	29,763	0,170	0,319	0,798
0,9	22,244	33,008	55,307	14,851	16,582	18,814	0,241	0,402	0,896
1	18,03	24,106	36,486	12,049	12,149	12,582	0,329	0,494	0,992
1,1	14.916	18.160	25,123	9,983	9,196	8,836	0,434	0,593	1,086
1,2	12.552	14.041	17,944	8,418	7,159	6,485	0,556	0,698	1,176
1,3	10.717	11.103	13,235	7,208	5,713	4,957	0,695	0,807	1,262
1,4	9.266	8.954	10,050	6,257	4,664	3,937	0,849	0,918	1,342
1,5	8.101	7.349	7,838	5,498	3,889	3,240	1,014	1,020	1,415
1,6	7.151	6.129	6,268	4,887	3,308	2,758	1,186	1,434	1,480
1,7	6,375	5,189	5,133	4,391	2,868	2,419	1,361	1,232	1,535
1,8	5,730	4,456	4,299	3,985	2,533	2,181	1,532	1,321	1,581
1,9	5,190	3,878	3,679	3,653	2,277	2,012	1,693	1,397	1,617
2	4,737	3,418	3,213	3,381	2,081	1,891	1,841	1,460	1,644
2,2	4,032	2,756	2,591	2,977	1,819	1,758	2,08	1,545	1,675
2,4	3,526	2,327	2,227	2,743	1,673	1,701	2,21	1,586	1,685
2,6	3,163	2,048	2,013	2,548	1,600	1,687	2,330	1,596	1,687
2,8	2,905	1,869	1,889	2,453	1,572	1,693	2,371	1,593	1,687
3	2,727	1,758	1,818	2,406	1,568	1,707	2,385	1,586	1,691
3,5	2,502	1,641	1,757	2,394	1,597	1,739	2,389	1,584	1,711
≥ 4	2,441	1,621	1,751	2,419	1,618	1,750	2,401	1,600	1,732

G.6. When calculating stability of soil surrounding pile, it is needed to test limiting state of estimated pressure σ_z on soil at pile side as following:

$$\sigma_z \leq \eta_1 \eta_2 \frac{4}{\cos\varphi_1} (\sigma'_v \cdot tg\varphi_1 + \xi C_1) \qquad (G.14)$$

Where:

σ_z – Estimated pressure on soil, T/m^2 at pile side, determined by formula (G.16) at the depth of z, m, from ground surface for over-ground pile work or pile work bottom for low pile work:

a) when $L_e \leq 2.5$, at depth of z =L/3 and z=L

b) when $L_e > 2.5$, at the depth of $z=0.85/\alpha_{bd}$, of which α_{bd} is determined by formula (G.6)

y_1 – Soil estimated volume mass, T/m^3

σ'_v – Effective stress in perpendicular direction in soil at z depth, T/m^2

φ_1, C_1 – Estimated value of inner friction angle, degree and binding force, T/m^2

ξ – Coefficient, equal to 0.6 for cast-in-place pile and hollow pile and equal to 0.3 for the rest type of pile.

η_1 - Coefficient, equal to 1, for foundation of defending construction, this coefficient is equal to 0.7

η_2 - Coefficient, including permanent load in total load and defined by following formula:

$$\eta_2 = \frac{M_p + M_v}{\bar{n}M_p + M_v} \qquad \text{(G.15)}$$

Where:

M_p – Moment of external permanent load, calculated at foundation section at pile point, T.m

M_v – Moment of temporary load, T.m

$\bar{n}$, coefficient, equal to 2.5, except for:

a) Important constructions

+ when $L_e \leq 2.5$, $\bar{n}$ =4

+ when $L_e \geq 5$, $\bar{n}$=2.5

+ when L_e is within above values, $\bar{n}$ will be calculated by interpolation.

b) For foundation with 1 row of pile bearing vertically eccentric load, $\bar{n}$ should be equal to 4, independently with L_e

Note: If transversal load on soil, σ_z does not meet requirement stated in (G.14) but there is still pile material load bearing capability and pile offset is less than allowable displacement for pile depth L_e>2.5, then coefficient should be recalculated with reducing ratio factor K (in article G.2 of this standard). For new value of K, it is needed to test pile material strength and pile offset should base on conditions in (G.14)

G.7. Estimated pressure, σ_z, T/m^2, shearing force Q_z, T in pile section should be calculated by:

$$\sigma_z = \frac{K}{\alpha_{bd}} z_e \left(y_o A_1 - \frac{\psi_o}{\alpha_{bd}} B_1 + \frac{M_o}{\alpha_{bd}^2 EI} C_1 + \frac{H_o}{\alpha_{bd}^3 E_b I} D_1 \right); \qquad \text{(G.16)}$$

$$M_z = \alpha_{bd}^2 E_b I y_o A_3 - \alpha_{bd} E_b I \psi_o B_3 + M_o C_3 + \frac{H_o}{\alpha_{bd}} D_3; \qquad \text{(G.17)}$$

$$Q_z = \alpha_{bd}^3 E_b I y_o A_4 - \alpha_{bd}^2 E_b I \psi_o B_4 + \alpha_{bd} M_o C_4 + H_o D_4; \qquad \text{(G.18)}$$

$$N_z = N \tag{G.19}$$

Where:

K – Ratio coefficient calculated in Table G.1 of this Annex

α_{bd}, E_b, I – The same function symbols in formula (G.6)

z_c – Depth calculated in formula (G.4) depending on depth in reality z at which σ_z, M_z, Q_z are calculated.

H_o, M_o, y_o and □$_o$ have the same meaning in article G.4 and G.5 of this Annex.

A_1, B_1, C_1 and D_1
A_3, B_3, C_3 and D_3 } Coefficients as in Table (G.3)
A_4, B_4, C_4 and D_4

N – Vertical estimated load at pile cap.

Table G.3 – Values of A, B, C and D

Z_e	Coefficients											
	A_1	B1	C1	D1	A3	B3	C3	D3	A_4	B_4	C_4	D4
0	1,000	0	0	0	0	0	1,000	0	0	0	0	1,000
0,1	1,000	0,100	0,005	0	0	0	1,000	0,100	-0,005	0	0	1,000
0,2	1,000	0,200	0,020	0,001	-0,001	0	1,000	0,200	-0,020	-0,003	0	1,000
0,3	1,000	0,300	0,045	0,005	-0,005	-0,001	1,000	0,300	-0,045	-0,009	-0,001	1,000
0,4	1,000	0,400	0,080	0,011	-0,011	-0,002	1,000	0,400	-0,080	-0,021	-0,003	1,000
0,5	1,000	0,500	0,125	0,021	-0,021	-0,005	0,999	0,500	-0,125	-0,042	-0,008	0,999
0,6	0,999	0,600	0,180	0,036	-0,036	-0,011	0,998	0,600	-0,180	-0,072	-0,016	0,997
0,7	0,999	0,700	0,245	0,057	-0,057	-0,020	0,996	0,699	-0,245	-0,114	-0,030	0,994
0,8	0,997	0,799	0,320	0,085	-0,085	-0,034	0,992	0,799	-0,320	-0,171	-0,051	0,989
0,9	0,995	0,899	0,405	0,121	-0,121	-0,055	0,985	0,897	-0,404	-0,243	-0,082	0,980
1,0	0,992	0,997	0,499	0,167	-0,167	-0,083	0,975	0,994	-0,499	-0,333	-0,125	0,967
1,1	0,987	1,095	0,604	0,222	-0,222	-0,122	0,960	1,090	-0,603	-0,443	-0,183	0,946
1,2	0,979	1,192	0,718	0,288	-0,287	-0,173	0,938	1,183	-0,716	-0,575	-0,259	0,917
1,3	0,969	1,287	0,841	0,365	-0,365	-0,238	0,907	1,273	-0,838	-0,730	-0,356	0,876
1,4	0,955	1,379	0,974	0,456	-0,455	-0,319	0,866	1,358	-0,967	-0,910	-0,479	0,821
1,5	0,937	1,468	1,115	0,560	-0,559	-0,420	0,881	1,437	-1,105	-1,116	-0,630	0,747
1,6	0,913	1,553	1,264	0,678	-0,676	-0,543	0,739	1,507	-1,248	-1,350	-0,815	0,652
1,7	0,882	1,633	1,421	0,812	-0,808	-0,691	0,646	1,566	-1,396	-1,643	-1,036	0,529
1,8	0,848	1,706	1,584	0,961	-0,956	-0,867	0,530	1,612	-1,547	-1,906	-1,299	0,374
1,9	0,795	1,770	1,752	1,126	-1,118	-1,074	0,385	1,640	-1,699	-2,227	-1,608	0,181
2,0	0,735	1,823	1,924	1,308	-1,295	-1,314	0,207	1,646	-1,848	-2,578	-1,966	-0,057
2,2	0,575	1,887	2,272	1,720	-1,693	-1,906	-0,271	1,575	-2,125	-3,360	-2,849	-0,692
2,4	0,347	1,874	2,609	2,105	-2,141	-2,663	-0,941	1,352	-2,339	-4,228	-3,973	-1,592
2,6	0,033	1,755	2,907	2,724	-2,621	-3,600	-1,877	0,917	-2,437	-5,140	-5,355	-2,821
2,8	-0,385	1,490	3,128	3,288	-3,103	-4,718	-3,408	0,197	-2,346	-6,023	-6,990	-4,445
3,0	-0,928	1,037	3,225	3,858	-3,541	-6,000	-4,688	-0,891	-1,969	-6,765	-8,840	-6,520
3,5	-2,928	-1,272	2,463	4,980	-3,919	-9,544	-10,34	-5,854	1,074	-6,789	-13,692	-13,826
4,0	-5,853	-5,941	-0,927	4,548	-1,614	-11,731	-17,919	-15,076	9,244	-0,358	-15,611	-23,140

G.8. Estimated clamping moment, M_{ng}, T.m for pile tightly clamped into pile work without rotation should be calculated as follows:

$$M_{ng} = -\frac{\delta_{MH} + l_o\delta_{MM} + \dfrac{l_o^2}{2E_bI}}{\delta_{MM} + \dfrac{l_o}{E_bI}}H \qquad (G.20)$$

In this formula, all symbols are the same function and meaning with symbols in above listed formulas. “Negative signal – ” means that transversal load H goes from left to the right, clamping moment on pile is anticlockwise.

Determination of transversal bearing load by Brome’s method (1964)

G.9. Depending on pile strength and foundation pressure distribution, pile will have allowable limited load in different cases. For solid pile, bearing load only depends on foundation load while for soft pile, it completely depends on pile material binging.

Calculation formulas and diagrams are built up for piles in binding soil or loose earth.

G.9.1. Pile in binding soil

a) “Solid” pile: Limited bearing load, H_u is calculated basing on relationship diagram of pile relative clamped pile L/d and relative limited bearing load, $H_u/C_u.d^2$ (Figure G.3a). Clamped link of pile and pile work also need to include in calculation.

b) “Soft” pile: Limited bearing load, H_u, calculated basing on relationship diagram of pile material limited binding force $M_u/c_u.d^3$ and relative bearing load, H_u/c_ud^2 (Figure G.3b)

G.9.2. Pile in loose earth

a) “Solid” pile: Limited bearing load, H_u is calculated basing on relationship diagram of pile relative clamped pile L/d and relative limited bearing load, $H_u/K_p\gamma d^3$ (Figure G.4a). Clamped link of pile and pile work also need to include in calculation.

b) “Soft” pile: Limited bearing load, H_u, calculated basing on relationship diagram of pile material limited binding force $M_u/K_p\gamma.d^4$ and relative bearing load, $H_u/K_p\gamma d^3$ (Figure G.4b)

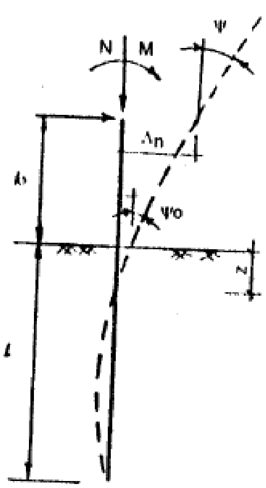


Figure G.1: Pile load diagram

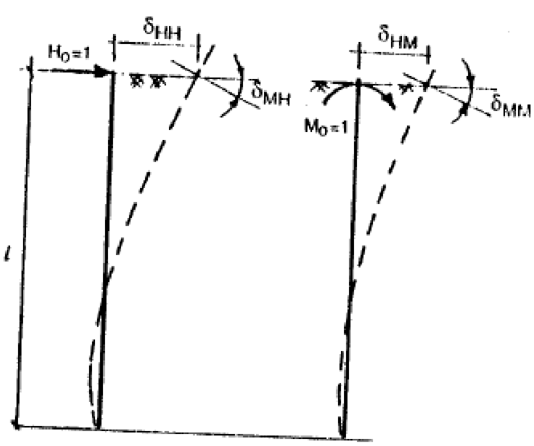


Figure G.2: Displacement diagram of pile
a – Under H_o=0 at ground surface
b- Under M_o=1

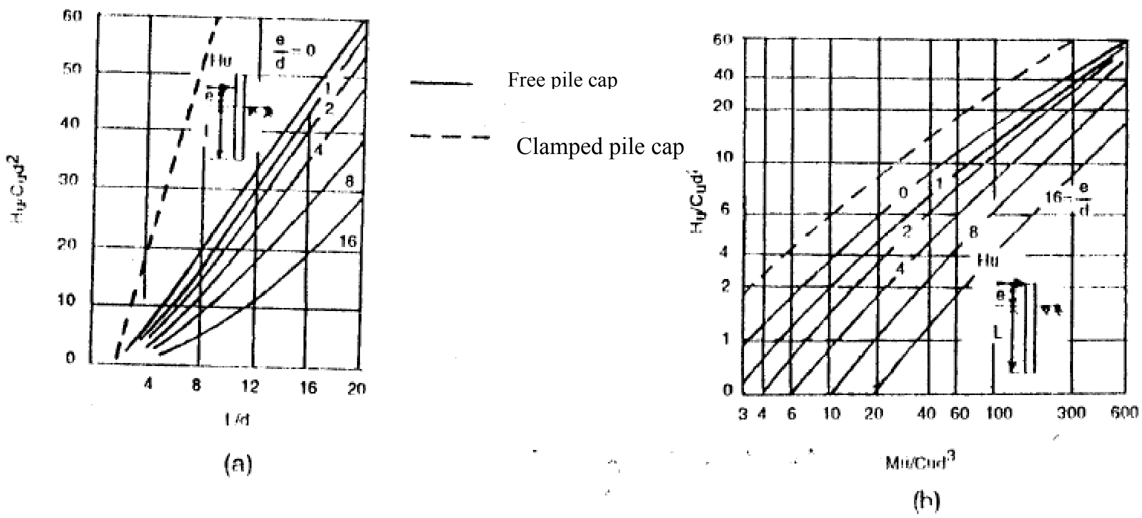


Figure G.3 – Pile transversal load bearing in binding soil

a – Short pile; b- Long pile

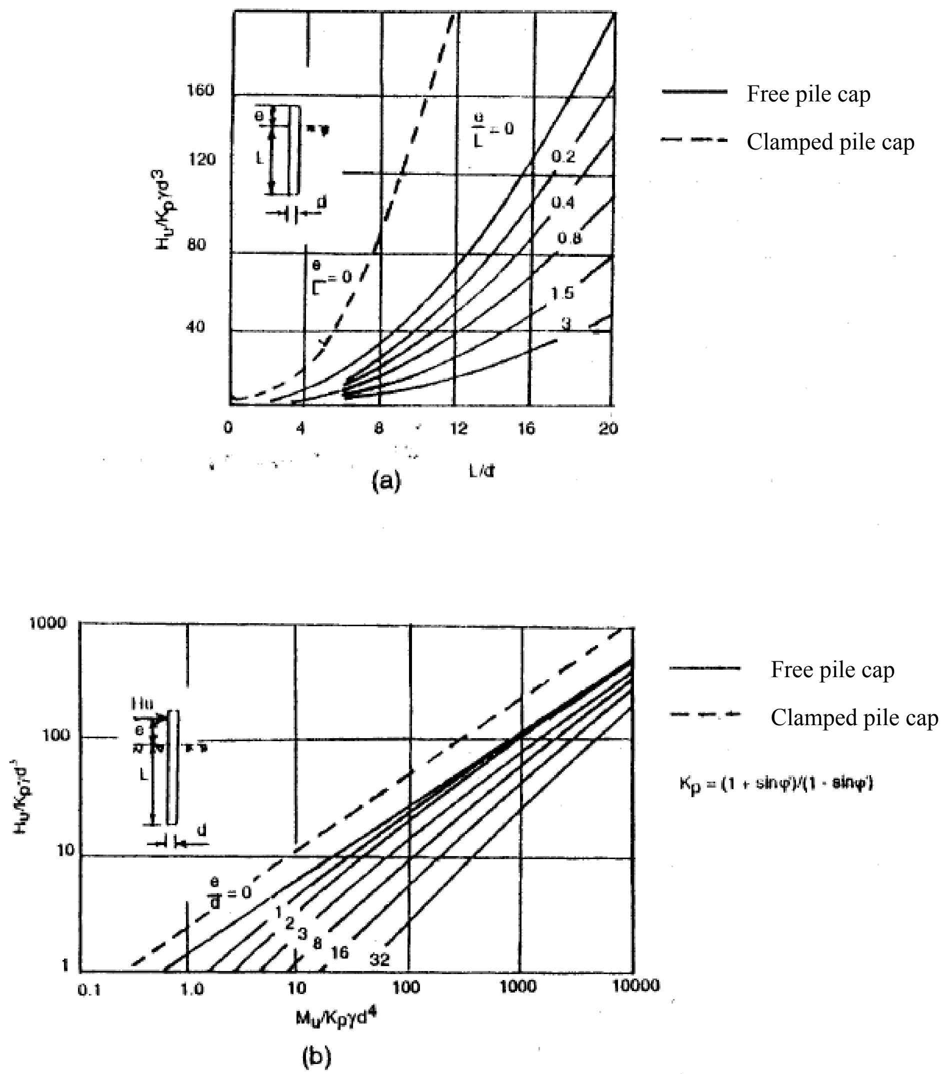


Figure G.4: Pile transversal load bearing in loose earth

a- Short pile b – Long pile

Annex H

Determination of settlement of pile foundation

H.1. Settlement of single pile foundation

Settlement of single pile through a soil layer with shearing module G_1, MPa (T/m^2) and Poisson's ratio v_1 and resting on a soil layer considered to be semi –space linear strain soil characterized by shearing module G_2 and Poisson's ratio v_2 is calculated by following formula under the condition that pile load $N \le Q_a$ and $L_p/d>5$, $G_1L_p/G_2d>1$.

a) For unbelled-out single pile:

$$S = \beta \frac{N}{G_1 L_p} \qquad (H.1)$$

Where:

N – Vertical load on pile, MN (tons)

β – Coefficient, defined by:

$$\beta = \frac{\beta'}{\lambda_1} + \frac{1-(\beta'/\alpha')}{æ}$$

Of which:

$\beta' = 0.17 \times \ln (k_v G_1 L_p/G_2 d)$ – Coefficient for pile with absolute strength ($EA = \infty$)

$\alpha' = 0.17 \times \ln(k_{v1} L_p/d)$ – Coefficient for homogeneous foundation base with characteristic of G_1 and v_1

$æ = EA/G_1 L_p^2$ – Pile relative solidness

λ_1 – Coefficient, determining settlement increase of compressed pile, calculated by:

$$\lambda_1 = \frac{2.12\, æ^{3/4}}{1 + 2.12\, æ^{3/4}}$$

k_v, k_{v1} – Coefficients, determined by:

$k_v = 2.82 - 3.78v + 2.18v^2$

alternatively with $v = (v_1+v_2)/2$ and $v=v_1$

Q_{tc} – Pile bearing load, determined as stated in Annex A

b) For belled-out single pile

$$S = \frac{0{,}22N}{G_2 d_b} + \frac{N L_p}{EA} \qquad (H.2)$$

Where:

d_b – Belled –out diameter of pile

G_1 and v_1 are average values for all soil layers in pile driving depth while G_2 and v_2 are within 10 pile diameter or pile belled-out diameter (for belled-out pile) from pile point downward, with condition that soil under pile point is not muddy or quick peat.

H.2. Determination of pile group settlement

H.2.1. Pile group settlement is estimated based on conventional foundation model. There are two ways for determining a conventional foundation:

Solution *1°*: Conventional foundation boundary (Figure H1)

- The lower is AC surface throughout of the pile point, considered as foundation bottom
- The upper is BD, surface of scraping, with AB =L corresponding to foundation depth.
- The lateral is vertical surfaces AB and CD through outer boundary of side pile row at a distance of $L_{tb}tg(\varphi^{tb}/4)$ but not over 2d (d is diameter or right angle side) when there is a dust clay layer under pile point, with consistence $I_L > 0.6$. If oblique piles are used, they will go through those above vertical surfaces.

$$\varphi^{tb} = \frac{\sum \varphi_i \times l_i}{L_{tb}}$$

Where:

φ_i – Internal friction angle of soil layer with thickness l_i

L_{tb} – Pile driven depth in soil layer, from pile work bottom, $L_{tb} = \sum l_i$.

Note:

1. *If pile is driven into a weak soil layer (mud, peat…) with a thickness over than 30 cm, conventional foundation dimension will be decreased by taking L_{tb} as the value of distance from pile point to bottom of the weak soil*
2. *Weight of conventional foundation is sum of weight of pile, pile work and soil within the foundation.*

Solution 2°

a) Boundary of conventional foundation when foundation soil is homogeneous

The determination process will be taken in the same way presented in Solution 1° but the open angle will be 30° for all type of soil from the depth of $2L_{tb}/3$ (Figure H.2)

b) Boundary of conventional foundation when piles go through some weak soil layers on a solid base

The determination process will be taken in the same way presented in Solution 1° but the open angle will be 30° for soil from the depth of $2L_1/3$ to L_1 for pile at the last weak soil layer (Figure H.3)

c) Boundary of conventional foundation when foundation soil is within pile length with different layers of different load bearing capability

- Width and length of foundation are bottom sides of a cubic of which a belled-out side is ¼ compared with vertical surface of oblique pile row to a depth of $2L_p/3$ downward to the surface of pile point at which the open angle is 30° (Figure H.4)

- Depth for conventional foundation is at surface of pile point.

H.2.2. Additional stress in foundation soil under pile point can be calculated by Boussinesq's solution with assumption that conventional foundation lies in a semi elastic space surface.

H.2.3. Settlement of a conventional foundation is determined by traditional methods for shallow foundation on natural soil base

H.3. Settlement of pile strip foundation

H.3.1. Settlement S, m, of strip foundation with 1 or 2 rows of pile (when pile gap is 3d to 4d) is determined by following formula:

$$S = \frac{p(1-\nu^2)}{\pi E}\delta_0 \qquad (H.3)$$

Where:

p – Load evenly distributed on a meter length kN./m (kg/cm), including foundation mass in the soil block and the pile with order as follows: The upper is foundation base, the neighboring is vertical surfaces through outer pile row and the lower is surface going through pile point.

E, v – Value of strain module kPa (kg/cm^2) and soil Poisson's ratio within thickness of compressed soil under pile point.

δ_o – As in the diagram (see figure) depending on Poisson's factor, is exchangeable width of foundation $Б = b/h$(where b – foundation width to outer edge of boundary pile row)

h – pile driven depth and thickness of compressed soil H_c/h (H_c is the thickness of compressed soil determined in the same condition with the determination of settlement for foundation at natural base)

Value of δ_o is determined by diagram as follows: On the reference system, through points respectively with H_c/h, drawing a line parallel with abscissa axis to cut with corresponding curve $Б$, from this cross point, drawing another line perpendicular to *v* line and then creating a parallel line with abscissa axis toward and cutting with vertical axis. The archived result then will be value of δ_o

Table H.2 – Limited basement strain (according SNiP 2.02.01.83)

Constructions	Relative deflection settlement $(\Delta S/L)_u$	Inclination i_u	Average settlement S_u or maximum, S_{max} (in blanket), cm
1. One-floor houses and civil multi-floor buildings with complete frame by:			
- Steel concrete reinforcement	0.002	-	(8)
- Steel	0.004	-	(12)
2. Houses and building structure without internal stress by uneven settlement	0.006	-	(15)
3. Non-frame multi-floors buildings with stress bearing walls:			
- By large plates	0.0016	0.0005	10
- By large block or non-steel brick wall	0.0020	0.0005	10
-the same above structure but with steel reinforcement	0.0024	0.0005	15
4. Constructions with balanced steel concrete reinforcement:			
- Working house and structure silo placed at the link on a same strip foundation	-	0.003	40
-The same character with above but with a building block structure.	-	0.003	30
-Independent silo with cast-in-place block structure.	-	0.004	40
- The same character with mentioned above but with a building block structure.	-	0.004	30
- Independent working house	-	0.004	25
5, Chimney structure with height H, m			
- $H \leq 100$ m	-	0.005	40
- $100 < H < 200$	-	1/(2H)	30
- $200 < H \leq 300$	-	1/(2H)	20
- $H > 300$	-	1/(2H)	10
6. Structures with height up to 100 m, excluding those mentioned above in 4 and 5	-	0.004	20
7. Communication line constructions, antenna:			

- Grounded station	-	0.002	20
- Ground isolated broadcasting station	-	0.001	10
- Broadcasting station	0.002	-	-
- Short wave broadcasting station	0.0025	-	-
- Individual stations	0.001	-	-
8. Overhead power transmission line column			
- Intermediary tower	0.003	0.003	-
- Anchoring, angle anchoring tower, intermediary angle tower, curve tower, main gate of open type distributor	0.0025	0.0025	-
- Special transmission tower	0.002	0.002	-

Note: for Table H.2:

1) Relative limited rise of building stated in 3 in the Table is equal to 0.5 $(\Delta S/L)_u$

2) When determining relative deflection settlement $(\Delta S/L)$ *in article 8 in the Table, L is considered to be the distance between 2 axes of foundation block in transversal load direction, and to be the distance between axes of compressed foundation to the anchor, for line stretching tower.*

3) If foundation soil consists of horizontal layers (with slope not over than 0.1), allowable limited value of maximum and average settlement can be increased to 20%

4)For construction types referred in 2 and 3 articles above with strip foundation, limited value of allowable average settlement should be increase 1.5 times

5) With experience from practice for different constructions, other limited strain values can be used instead of values stated in this Table

Table H.3 – Limited angle strain

(Skempton and McDonald, 1956; Bjerrum, 1963 and Wroth, 1975)

f/L	Limited state of constructions
1/5000	Observable small crackle in brick structures without steel concrete reinforcement, bent walls.
1/3000	Observable cracks on bearing walls
1/1000	Observable cracks on frame brick walls
1/750	Real limitation to avoid unbalance of high accuracy machines.
1/600	Allowable overstress in inclination structures considerably increasing
1/500	Real limitation to avoid terrible cracks in frame houses and modern constructions.
1/300	Destructive effect on construction frame and large plate walls, causing difficulties for performance of high cranes
1/250	Considerable inclination in multi-floor buildings

1/150	Destructive effect on structure of most of constructions

Note for Table H.3:

1) For common constructions, limited angle strain is smaller than 1/500

2) It is needed to avoid destruction when cracks are observed if angle strain is less than 1/1000

3) Construction damage rarely happens at the value f/L <1/150

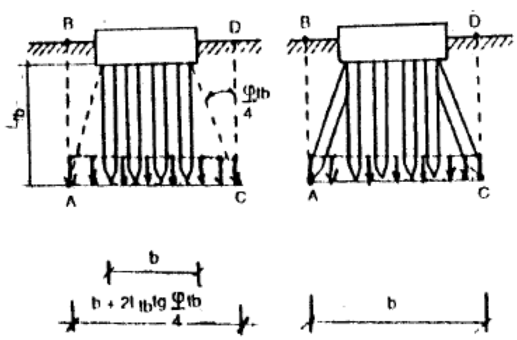


Figure H.1: Conventional foundation dimensions determined by solution 1°

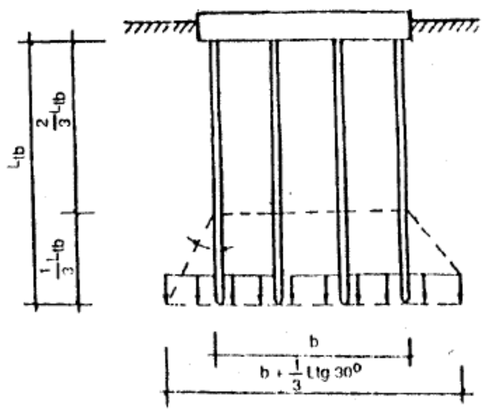


Figure H.2: Conventional foundation dimensions determined by solution 2° for homogeneous foundation soil

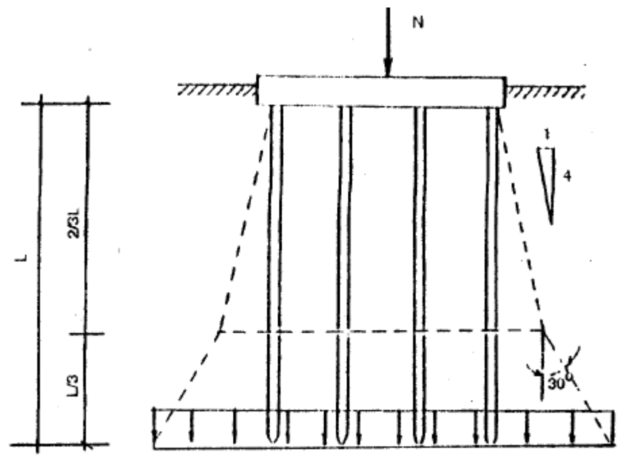


Figure H.3: *Conventional foundation dimensions determined by solution 2° for weak soil foundation*

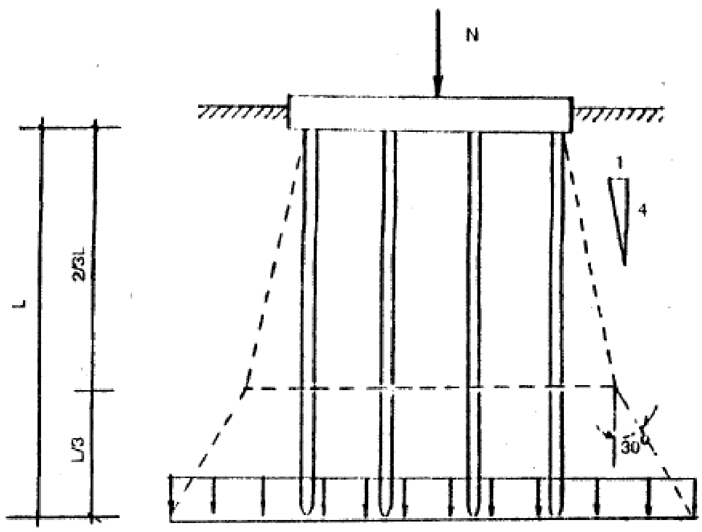


Figure H.4: Foundation dimension determined by solution 2° for multi-layer soil

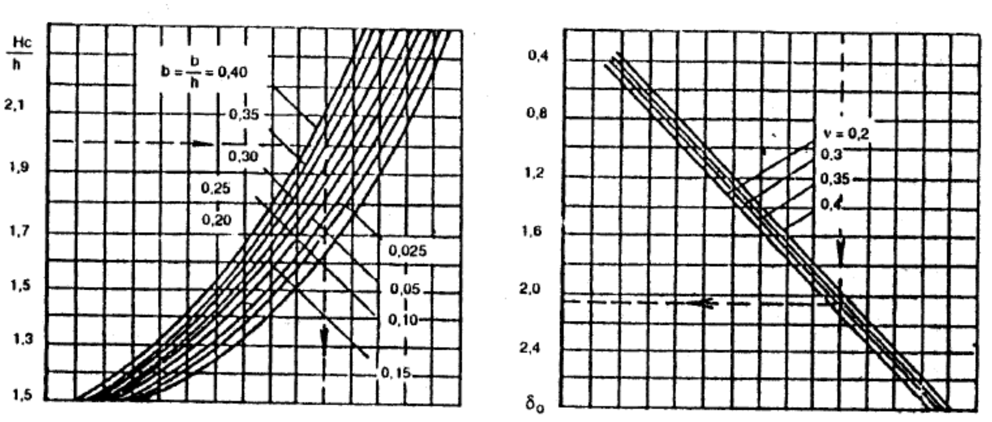


Figure H.5: Diagram for determining δ_o

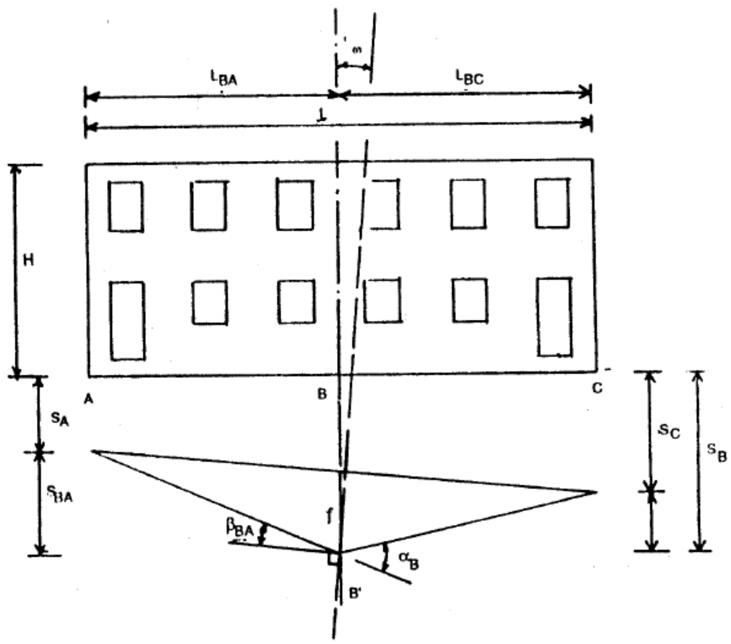


Figure H.6: Definitions and symbols for foundation strain

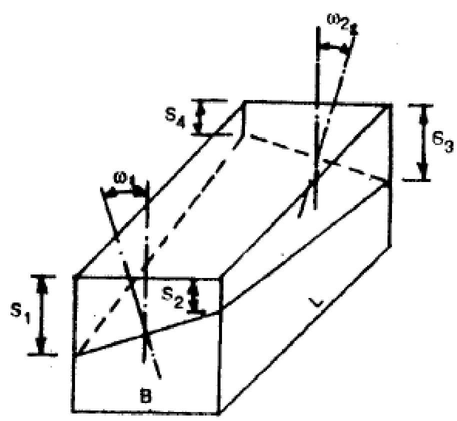


Figure H.7: *Settlement diagram causing construction torsion*

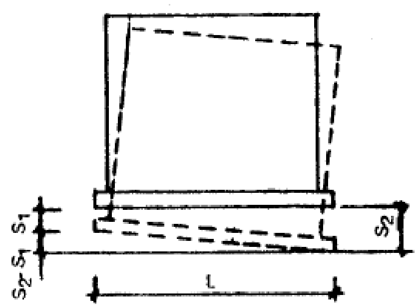


Figure H.8 : *Inclination of solid foundation constructions*

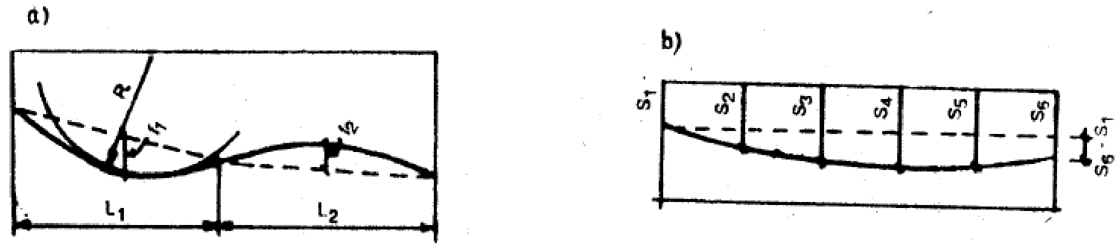


Figure H9: *a) Rising diagram of construction*

b) Complex strain diagram

Annex I

Characteristics of pile foundation design in earthquake areas

I.1. When calculating pile bearing load under withdrawal or compressing force, q_p and f_i values should be multiplied by m_{cl} and m_{c2} factors which reduce working condition of soil and which are presented in Table I.1, except when pile rests on stone and coarse-grained soil,

Value q_p should also be multiplied with working condition m_{c3} =1 when $L_e \geq 3$ and m_{c3} =0.9 when $L_e<3$, of which L_e is pile exchangeable length calculated as in Annex G. Pile side friction, f_i within the distance from ground surface to the depth h_u should be equal to 0:

$$h_u = \frac{4}{\alpha_{bd}} \qquad (I.1)$$

Where:

α_{bd} – strain factor, determined by formula (G.6) in Annex G of this standard.

I.2. When calculating in condition with limited load on soil through pile side section, as stated in Annex G, estimated internal friction φ_1 should decrease as follows: for estimated earthquake 7.2, 8-4 and 9-7 in intensity.

I.3. For calculation of abutment bridges, if there are earthquake effects on pile clamping condition in saturated sand, clay, semi-quick clay or semi-quick sand, then K coefficient in Table G.1, Annex G shall decrease 30%.

When calculating pile load bearing with effect of transversal load, short-term effect of earthquake should be included by increasing 30% for coefficient η_2, and in the case when one row pile in foundation bears load at perpendicular surface of that row, η_2 will be increased to 10%.

I.4. Pile bearing load, Q_{tc}, T under compressing and vertical withdrawal load in site test should be calculated with effect of earthquake to be included in following formula:

$$Q_{tc} = k_c.Q_u \qquad (1.2)$$

Where:

k_c – Coefficient, equal to ratio between pile compressed bearing load Q_u gotten from I.1 and I.2 of this annex included with earthquake effect and values gotten from calculation in chapter 4 of the Standard (excluding earthquake effect).

Q_u- Pile maximum bearing load, T, determined by dynamic, county or county penetration tests as stated in Chapter 4 (excluding earthquake effects)

Table I.1 – Coefficients m_{c1} and m_{c2}

Estimated earthquake level	Working condition coefficient m_{c1} for adjusting q_p in soil:						Working condition coefficient m_{c2} for adjusting f_l, in soil:				
	Compact sand		Medium-compact sand		Dust sand at consistence		Compact and medium compact sand		Dust sand at consistence		
	Wet and little wet	Saturated	Wet and little wet	Saturated	$I_L<0$	$0 \le I_L \le 0.5$	Wet and little wet	Saturated	$I_L<0$	$0 \le I_L \le 0.75$	$0.75 \le I_L < 1$
7	1 --- 0.9	0.9 ------ -	0.95 ------ 0.85	0.8 ------ -	1 ----- 1	0.95 ----- 0.90	0.95 ----- 0.85	0.90 ------ -	0.95 ----- -	0.85 ------ 0.80	0.75 ----- 0.75
8	0.9 ----- 0.8	0.8 ----- -	0.85 ------ 0.75	0.7 ------ -	0.95 ----- 0.95	0.90 ----- 0.80	0.85 ----- 0.75	0.80 ----- -	0.9 ----- 0.8	0.80 ----- 0.70	0.70 ------ 0.65
9	0.8 ---- 0.7	0.7 -----	0.75 ------ 0.60	-	0.9 ----- 0.85	0.85 ----- 0.70	0.75 ------ 0.65	0.70 -----	0.85 ------ 0.65	0.70 ------ 0.60	0.60 ------

Note: Numerator values are used for hammered piles and denominator values are for cast-in-place piles

Table K.1 – m_g coefficient

Type of foundation, soil and load	Additional working condition coefficient m_g when pile length:			
	L > 25d	L <25d and ratios		
		$\frac{H}{N} \le 0,1$	$\frac{H}{N} = 0,4$	$\frac{H}{N} = 0,6$
1. Foundation under intermediary standard column when calculating:				
a) Single pile bearing withdrawal force:				
- in sand and semi sand	0.9	0.9	0.8	0.55
- in clay and semi clay				
When $I_L \le 0$	1.15	1.15	1.05	0.7
When $I_L > 0.6$	1.5	1.5	1.5	0.9
b) Single pile bearing compressing force and pile in pile group bearing withdrawal force				
- in sand and semi sand	0.9	0.9	0.9	0.9
- in clay and semi clay				
When $I_L \le 0$	1.15	0	1.15	1.15

When I_L> 0.6	1.50	1.50	1.50	1.50
2. Foundation under anchoring, under angle column, at end points, under great transferring column when calculating:				
a) Single pile bearing withdrawal force:				
- in sand and semi sand	0.8	0.8	0.7	0.6
- in clay and semi clay	1.0	1.0	0.9	0.6
b) Single pile bearing compressing force and pile in pile group bearing withdrawal force				
- in sand and semi sand	0.8	0.8	0.8	0.8
- in clay and semi clay	1.0	1.0	1.0	1.0
c) Single pile bearing compressing force in all types of soil	1.0	1.0	1.0	1.0

Note:

1) In Table K.1, symbols have meaning as follows:

d – Round pile diameter, side of square pile or longest side of rectangular section pile.

H – Estimated transversal load

N- Estimated vertical load

2) When driving single pile with inclination angle over 10^o *toward transversal load, working condition coefficient* m_g *will be the same value with value for vertical pile in a pile group (term 1b and 2b in Table K.1)*