

ENGINEERING STANDARD
FOR
PILES

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1. SCOPE

This Engineering Standard provides basic requirements governing the design and the selection of piling materials for land and marine construction. It applies to structural steel, steel pipe (plain or filled with concrete), cast-in-place concrete, precast concrete, timber, composite and caisson type piles.

Where necessary, guidance for the protection of steel piles and preservance of timber piles has been provided.

This Standard does not cover sheet piling. For the design requirements of sheet piling, reference is made to IPS-E-CE-140 "Retaining Walls".

Throughout this Standard, the symbol AR denotes Authorized Representative of the Owner.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant.

NIGC-TREATING PLANT, Vol. I:

Clause 102.7	"Piling-Equipment and Material Specifications"
Clause 103.1	"Piling-Design Criteria"

ACI STANDARD (AMERICAN CONCRETE INSTITUTE)

318	"Building Code Requirements for Reinforced Concrete"
543-74	"Recommendations for Design, Manufacture, (reaffirmed 1980) and Installation of Concrete Piles"

AISC SPECIFICATION (AMERICAN INSTITUTE FOR STEEL CONSTRUCTION)

"Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings"

API STANDARD (AMERICAN PETROLEUM INSTITUTE)

5 L	"Line Pipe"
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ASTM STANDARDS (AMERICAN SOCIETY FOR TESTING AND MATERIALS)

A 36	"Specification for Structural Steel"
A 252	"Specification for Welded and Seamless Steel Pipe Piles"
A 283	"Specification for Low and Intermediate Tensile Strength Carbon Steel Plates"
A 416	"Specification for Uncoated Seven-wire Stress-relieved Steel Strand for Prestressed Concrete"
A 572/A 572M	"Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality"
A 633/A 633M	"Specifications for Normalized High-Strength Low-Alloy Structural Steel"
C 150	"Specification for Portland Cement"
D 25	"Specification for Round Timber Piles"
D 2899	"Establishing Design / Stresses for Round Timber Piles"
D 1143	"Method of Testing Piles under Static Axial Compressive Load"
D 3689	"Method of Testing Individual Piles Under Static Axial Tensile Load"

AWPA STANDARD (AMERICAN WATER AND POWER ASSOCIATION)

C 3	"Piles-Preservative Treatment by Pressure Processes"
M 4	"Care of Preservative-Treated Wood Products"

**ANSI/AWS CODE (AMERICAN NATIONAL STANDARD INSTITUTE /
AMERICAN WELDING SOCIETY)**

D 1.1	"Structural Welding Code"
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SSPC SPECIFICATION

SP 5	"White Metal Blast Cleaning"
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UNIFORM BUILDING CODE

UBC-88	"Section 2908: Piles-General Requirements"
	"Section 2909: Specific Pile Requirements"

STANDARD BUILDING CODE

SBC-1988 edition	"Section 1303: Piles"
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BSI (BRITISH STANDARDS INSTITUTION)

BS 12:1978	"Portland Cement (Ordinary and Rapid Hardening).
BS 146: Part 2:1973	"Portland-Blastfurnace Cement."
BS 5896:1980	"Steel Wire for Prestressed Concrete."

3. NOMENCLATURE

Throughout this Standard, the following symbols are used:

F_y or f_y	= specified yield strength of reinforcement in MPa.
f_c	= specified compression strength of concrete in MPa.

4. UNITS

International System of Units (SI) in accordance with IPS-E-GN-100 shall be used.

5. PRIOR TO PILING: FOUNDATION INVESTIGATION**5.1 General**

The classification of the soil at each site shall be determined by a recognized soil engineering laboratory.

5.2 Investigation

The classification shall be based on observation and any necessary tests of the materials disclosed by borings or excavations made in appropriate locations. Additional studies may be necessary to evaluate soil strength, the effect of moisture variation on soil-bearing capacity, compressibility and expansiveness.

5.3 Reports

The soil classification and design bearing capacity shall be shown on the plans. The AR shall require submission of a written report of the investigation which shall include, but need not be limited to, the following information:

- a)** A plot showing the location of all test borings and/or excavations.
- b)** Descriptions and classifications of the materials encountered.
- c)** Elevation of the water table, if encountered.
- d)** Recommendations for foundation type and design criteria including bearing capacity, provisions to minimize the effects of expansive soils and the effects of adjacent loads.
- e)** Expected total and differential settlement. (See also Sub-clause 6.1)

5.4 Expansive Soils

When expansive soils are present, the AR may require that special provisions be made in the foundation design and construction to safeguard against damage due to this expansiveness. He may require a special investigation and report to provide this design and construction criteria.

5.5 Adjacent Loads

Where footings are placed at varying elevations the effect of adjacent loads shall be included in the foundation design.

5.6 Drainage

Provisions shall be made for the control and drainage of surface water around structures.

5.7 Plans and Drawings

5.7.1 Piling plans

The piling shall be based on calculations and data as specified in IPS-E-CE-500: "Loads".

5.7.2 Piling drawings

The drawing shall include:

- The location of all piles, whereby raking piles, if any, shall be clearly indicated with reference level(s) for setting out.
- The required minimum ultimate bearing capacity(ies) of the piles.
- The required minimum penetration depth(s) and, if the characteristics of piles and the driving equipment are known, the minimum number of blows of the hammer per 300 mm penetration.
- General notes and reference drawings, and cut-off levels of the piles.

6. GENERAL REQUIREMENTS FOR PILING

6.1 General

Pile foundations shall be designed and installed on the basis of a foundation investigation as defined in Clause 5.

The investigation and report provisions of Clause 5 shall be expanded to include but not be limited to the following:

- a) Recommended pile types and installed capacities. For additional information concerning choice of piles, see Appendix A, and for typical pile characteristics and uses, see Table B-1 of Appendix B.
- b) Driving criteria.
- c) Installation and field inspection procedures.
- d) Pile load test requirements.
- e) Durability of pile materials.
- f) Designation of bearing stratum or strata.

6.2 Interconnection

Individual pile caps and caissons of every structure subjected to seismic forces shall be interconnected by ties. Such ties shall be capable of resisting, in tension or compression, a minimum horizontal force equal to 10 percent of the larger column vertical load.

6.3 Column Action

All piles standing unbraced in air, water or material not capable of lateral support, shall conform with the applicable column formula as specified in IPS-E-CE-200: Concrete Structures, and IPS-E-CE-210: Steel Structures.

Such piles driven into firm ground may be considered fixed and laterally supported at 1.5 meter below the ground surface and in soft material at 3 meters below the ground surface unless otherwise prescribed by the AR after a foundation investigation by an approved soil engineering laboratory.

6.4 Group Action

The bearing capacity of a pile group consisting of end bearing piles or piles driven into granular strata at normal spacing may be considered at least equal to the sum of the bearing capacities of the individual piles. The bearing capacity of a friction pile group in cohesive soil should be checked by evaluating the shear strength and bearing capacity of the soil and by considering that the pile group is supported by shear on the periphery of the group and by end bearing on the base area of the group. The use of group reduction formulas based on spacing and number of piles is not recommended.

6.5 Jetting

Jetting shall not be used except where and as specifically permitted by the AR. When used, jetting shall be carried out in such a manner that the carrying capacity of existing piles and structures shall not be impaired. After withdrawal of the jet, piles shall be driven down until the required resistance is obtained.

All piles placed with the aid of jets shall be firmly seated by driving with a hammer without jetting, until at least an additional 1.5 m of penetration is secured, or until refusal is reached.

Acceptable procedures for water-jetting are as follows:

- a) A minimum of two water jet pipes placed symmetrically about the pile and operated simultaneously.
- b) If approved by AR, a method entailing water jet pipe encased in the pile may be used.

6.6 Protection of Pile Materials

Where the boring records of site conditions indicate possible deleterious action on pile materials because of soil constituents, changing water levels or other factors, such materials shall be adequately protected by methods or processes approved by the AR.

The effectiveness of such methods or processes for the particular purpose shall have been thoroughly established by satisfactory service records or other evidence which demonstrates the effectiveness of such protective measures.

6.7 Pile Caps

Pile caps shall be of reinforced concrete. The soil immediately below the pile cap shall not be considered as carrying any vertical load. The tops of all piles shall be embedded not less than 75 mm into pile caps and the caps shall extend at least 100 mm beyond the edges of all piles. The tops of all piles shall be cut back to sound material before capping.

6.8 Allowable Pile Loads

6.8.1 Determination of allowable loads

The allowable axial and lateral loads on piles shall be determined by an approved formula, load tests or method of analysis.

6.8.2 Piles in subsiding areas

Where piles are driven through subsiding fills or other subsiding strata and derive support from underlying firmer materials, the downward frictional forces which are imposed on piles by the subsiding upper strata shall be included in the design.

6.8.3 Driving formula

The allowable compressive load on any pile when determined by the application of an approved driving formula shall not exceed 36 metric tons. The formula load shall be determined for gravity-drop or power-actuated hammers and the hammer energy used shall be the maximum consistent with the size, strength and weight of the driven piles. The use of a follower shall be permitted only with the approval of the AR. The introduction of fresh hammer cushion or pile cushion material just prior to final penetration shall not be permitted.

6.8.4 Load tests

When greater compressive loads per pile than permitted by sub-clause 6.8.3 are desired or when the design load for any pile foundation is in doubt, control test piles shall be tested in accordance with ASTM D 1143. At least one pile shall be test loaded in each area of uniform subsoil conditions.

In subsequent driving of the balance of foundation piles, all piles shall be deemed to have a supporting capacity equal to the control pile when such piles are of the same type, size and relative length as the test pile, are installed using the same or comparable methods and equipment as the test pile, are installed in similar subsoil conditions as the test pile and when the rate of penetration of such piles is equal to or less than that of the test pile through a comparable driving distance.




6.8.5 Allowable lateral load

When required by the design, the lateral load capacity of a single pile or a pile group shall be determined by an approved method of analysis or by lateral load tests to at least twice the proposed design working load. The resulting allowable load shall be not more than one-half of that test load which produces a gross lateral movement of 25 mm at the ground surface.

6.8.6 Batter or raking piles

When large lateral loads are to be resisted by a pile group, it is recommended to consider the use of piles driven at a slope with the vertical, i.e. batter or raking piles. For the purpose of design, batter piles are assumed to carry all lateral loads.

When batter piles are used together with vertical piles, the design of the foundation structure should consider that the batter piles will accept a portion of the vertical load. The inclination and position of the batter piling should be selected such that when a lateral load is applied, the resultant of the lateral and vertical loadings is axial and the effects of bending moments are kept to a minimum.

The acceptable range for pile batters is from 1 horizontal to 12 vertical (¹²) to a batter of 5 to 12 (¹²). It should be noted that in case the batter exceeds 1 to 4 (⁴), the driving may require special equipment with the resulting increased cost.

6.8.7 Uplift capacity

When required by the design, the uplift capacity of a single pile shall be determined in accordance with ASTM D 3689 or an approved method of analysis based upon a minimum factor of safety of three. The maximum allowable uplift load shall be one-half that load which produces an upward movement of the pile but equal to the gross elastic extension of the pile plus 2.54 mm. For pile groups subjected to uplift, the allowable working uplift load for the group shall be the lesser of:

- a) The proposed individual pile uplift working load times the number of piles in the group, or
- b) Two-thirds of the effective weight of the pile group and the soil contained within a block defined by the perimeter of the group and the length of the pile.

6.8.8 Bearing capacity

Individual piles and groups of piles shall develop ultimate load capacities of at least twice the design working loads in the designated bearing layers. Analysis shall show that no soil layer underlying the designated bearing layers causes the bearing capacity safety factor to be less than two.

6.8.9 Bent piles

The load carrying capacity of piles discovered to have a sharp or sweeping bend may be determined by an approved method of analysis or by load testing a representative pile.

6.8.10 Overloads on piles

The maximum compressive load on any pile due to mislocation shall not exceed 110% of the allowable design load.

6.9 Pile Spacing

A general rule for minimum pile spacing is 2½ times the average diameter for round or octagonal piles and 2 times the diagonal dimension of square piles. However regardless of pile size, a minimum distance between piles is usually specified. Spacing is measured from center to center of the piles.

Several factors should be considered in establishing the pile spacing. For example, the following considerations might require an increase in the normal pile spacing:

- a) For piles deriving their principal support by friction.
- b) For extremely long piles, especially if they are flexible in order to minimize tip interference.
- c) For uncased cast-in-place concrete piles where pile driving could damage adjacent unset concrete shafts
- d) For piles carrying very high loads.
- e) For piles that are driven in obstructed ground.
- f) Where group capacity governs.
- g) Where passive soil pressures are considered a major factor in developing pile lateral load capacity.
- h) Where excessive ground heave conditions exist.

Special installation methods could be used as an alternative to increasing pile spacing. For example, predrilling for cases (b), (e), and (h) above; or staggered driving sequence for case (c). Closer than normal spacing might be permitted for end bearing piles installed in predrilled holes.

Under special conditions, the pile spacing might be determined by the available area for the required number of piles.

7. STEEL PILES

7.1 General

This Clause gives guidance on the selection of material and engineering design for structural steel piles, steel pipe piles and concrete-filled steel pipe piles.

7.2 Materials

7.2.1 Structural steel piles

Structural steel piles shall consist of rolled H-sections in accordance with ASTM-A 36.

7.2.2 Steel pipe piles

Steel pipe piles shall be per ASTM A 252 Gr 2 or 3, API 5L Gr B. and the following:

- a)** Strength of welds (shop and field) including the type of joint preparation and percent penetration shall be developed for the specific application and submitted to the AR for approval. Welding procedure and welder qualification shall be per AWS D1.1.
- b)** Complete penetration welds are required for all piles which will be subjected to tensile or flexural stresses.
- c)** Pipe smaller than 200 mm NPS shall not be used.
- d)** A minimum corrosion allowance of 1.5 mm shall be added to the calculated wall thickness.
- e)** Minimum pipe wall thickness shall be as given in Table 1.

The values shown include 1.5 mm (1/16 in.) corrosion allowance:

TABLE 1 - MINIMUM PIPE WALL THICKNESS

NOMINAL PIPE SIZE		WALL THICKNESS	
mm	(in)	mm	(in)
200	(8)	7.92	(0.312)
250	(10)	8.74	(0.344)
300	(12)	9.53	(0.375)
350	(14)	9.53	(0.375)
400	(16)	11.13	(0.438)
450	(18)	11.13	(0.438)
500 or larger	(20)	12.70	(0.500)

f) High strength alloy steel material. ASTM A 633/A 633M Gr. D (including Supplementary Requirements), or A 572/A 572M type 3 is acceptable. Proposals to use other steels shall be submitted for approval by the AR. Proposal information shall include complete details of materials welding procedures, postweld heat treatment , inspection methods and acceptance criteria.

7.2.3 Concrete filled steel pipe and tube piles

Steel pipe and tube piles shall conform to one of the following specifications: ASTM A 252, ASTM A 283.

Concrete shall conform to sub-clause 8.1.1. The maximum size coarse aggregate shall be 19 mm. The concrete-filled steel pipe piles shall have an ultimate compressive strength f'_c of not less than 17.2 MPa.

7.2.4 Cathodic protection and protective coating

7.2.4.1 Cathodic protection

For the need and specifications concerning cathodic protection of steel H-piles and steel pipe piles, reference is made to IPS-E-TP-720: "Electrochemical Protection".

7.2.4.2 Protective coatings

The need for protective coatings on steel piles for land structures (pipe and structural) will be specified. Steel piles for marine facilities (fresh water or salt water) shall be coated. As required, coatings shall be per the following table 2:

TABLE 2 - COATINGS

SERVICE	PROTECTIVE COATING SYSTEM
<p>a. LAND STRUCTURES:</p> <p>PILES SHALL BE COATED FROM 600 mm BELOW PERMANENT GROUND WATER LEVEL TO TOP OF PILE, OR FROM 1.5 m BELOW GRADE TO TOP OF PILE, WHICHEVER IS LESS.</p> <p>b. MARINE FACILITIES:</p> <p>COAT PILES IN ZONE FROM 1.5 m BELOW HARBOR BOTTOM TO TOP OF PILE.</p>	<p>1. SURFACE PREPARATION BY WHITE METAL BLAST CLEANING.</p> <p>2. COAL TAR - POLYAMIDE EPOXY COATING-2 COATS NORMAL DRY FILM THICKNESS EACH COAT TO BE 200 μm.</p>

7.3 Design Requirements

7.3.1 General

Steel piles shall not be used when the conditions of the soil and/or the ground water may cause corrosion of steel. The design of pile(s) shall be subject to AR's approval.

7.3.2 Allowable stresses

7.3.2.1 Structural steel

The allowable stresses shall not exceed 0.35 of the minimum specified yield strength F_y , provided such yield strength shall not be assumed greater than 250 MPa for computational purposes.

7.3.2.2 Steel pipe piles

For the allowable stresses of steel pipe pile, see sub-clause 4.3.2.1 except that the specified yield strength, F_y , for welded seamless steel pipe piles shall be 240 MPa according to ASTM A252, Grade 2.

7.3.2.3 Concrete-filled steel pipe piles

The allowable design compressive stress in the concrete shall not exceed $0.33 f'_c$. The allowable design compressive stress in the steel shall not exceed 88 MPa.

7.3.3 Minimum dimensions

7.3.3.1 H-piles

Sections of H-piles shall comply with the followings:

- 1) The flange projections shall not exceed 14 times the minimum thickness of metal in either the flange or the web and the flange widths shall be not less than 80% of the depth of the section.
- 2) The nominal depth in the direction of the web shall be not less than 200 mm.
- 3) Flanges and web shall have a minimum nominal thickness of 9.5 mm.

7.3.3.2 Steel pipe piles

Steel pipe piles driven open ended shall have a nominal outside diameter of not less than 250 mm and a minimum wall thickness of 6.4 mm for diameters less than 350 mm and a minimum wall thickness of 9.5 mm for diameters 350 mm and over. Pipe of less wall thickness may be driven open ended if a suitable cutting shoe is provided.

7.3.3.3 Concrete-filled steel pipe piles

Piles shall have a nominal outside diameter of not less than 200 mm and a minimum wall thickness in accordance with sub-clause 7.3.3.2 except that for mandrel driven pipe piles the minimum wall thickness may be 2.5 mm.

Reinforcement steel shall conform to sub-clause 8.1.2. Reinforcement shall not be placed within 25 mm of the steel casing.

8. CAST-IN-PLACE CONCRETE PILES

8.1 General

8.1.1 Material

Concrete piles cast in place against earth in drilled or bored holes shall be made in such a manner as to ensure the exclusion of any foreign matter and to secure a full-sized shaft. The length of such piles shall be limited to not more than 30 times the average diameter.

The selection of type of cast-in-place concrete piles shall be based on competent soil investigations.

When concrete is placed through a funnel hopper at the top of the pile, the concrete mix shall be designed and proportioned so as to produce a cohesive workable mix having a slump of not less than 100 mm and not more than 150 mm. If concrete is to be pumped, the mix design including slump shall be adjusted to produce a pumpable concrete.

Concrete for piles shall have a minimum 28 days compressive strength of 21 MPa. Where soil investigations indicate the likelihood of considerable sulfate attack, consideration shall be given to the use of Type II or Type V Portland Cement as specified in ASTM C 150 Specifications for Portland Cement.

Piles may be either of the permanent or removable steel shell type, may be open or closed end and may be of plain or reinforced concrete.

8.1.2 Reinforcement

Except for steel dowels embedded 1.50 m or less in the pile and as provided in 8.2, reinforcement when required shall be assembled and tied together and shall be placed in the pile as a unit before the reinforced portion of the pile is filled with concrete.

8.2 Drilled or Augered Uncased Piles

8.2.1 Allowable stresses

The allowable design stress in the concrete of drilled uncased piles shall not exceed $0.33 f'_c$. The allowable design stress in the concrete of augered cast-in-place piles shall not exceed $0.25 f'_c$.

8.2.2 Dimensions

The pile length shall not exceed 30 times the average diameter. The minimum diameter shall be 300 mm.

Exception:

The length of pile shall be permitted to exceed 30 times the diameter, provided the design and installation of the pile foundation is under the direct supervision of an approved soil engineering laboratory knowledgeable in the field of soil mechanics and pile foundations, which shall certify that the piles as installed satisfy the design criteria.

8.2.3 If concrete is placed by pumping through a hollow-stem auger, the auger shall not be permitted to rotate during withdrawal and shall be withdrawn in a steady continuous motion. Concreting pumping pressures shall be measured and shall be maintained high enough at all times to offset hydrostatic and lateral earth pressures. Concrete volumes shall be measured to insure that the volume of concrete placed in each pile is equal to or greater than the theoretical volume of the hole created by the auger. If the installation process of any pile is interrupted or a loss of concreting pressure occurs, the pile shall be redrilled to original depth and reformed. Augered cast-in-place piles shall not be installed within 6 pile diameters center to center of a pile filled with concrete less than 24 hours old unless approved by the AR. If the concrete level in any completed pile drops, the pile shall be rejected and replaced.

8.2.4 Reinforcement

For piles installed with a hollow stem auger, longitudinal steel reinforcement may be placed without lateral ties, provided it is placed through ducts in the auger prior to filling the pile with concrete. All pile reinforcement shall have a concrete cover of not less than 64 mm.

8.3 Driven Uncased Piles

8.3.1 Allowable stress

The allowable design stress in the concrete shall not exceed $0.25 f'_c$ applied to a cross sectional area not greater than the inside area of the drive casing or mandrel.

8.3.2 Dimensions

The pile length shall not exceed 30 times the average diameter. The minimum diameter shall be 300 mm.

8.3.3 Concrete cover

All pile reinforcement shall have a concrete cover of not less than 64 mm measured from the inside face of the drive casing or mandrel.

8.4 Enlarged Base Piles

8.4.1 Materials

Materials for enlarged base piles shall have similar specifications with Sub-clause 8.1.1 of this Standard for cast-in-place concrete piles with the following clarifications:

- a) The maximum size for coarse aggregate for all concrete shall be 20 mm.
- b) Compacted concrete shall have No slump.*

* No-slump concrete refers to concrete with a consistency corresponding to a slump of 25 mm or less. No-slump concrete is very dry, yet it must be sufficiently workable so that it can be placed and consolidated with the equipment to be used on the job.

8.4.2 Allowable stress

The allowable design compressive stress in the concrete shall not exceed $0.25 f'_c$ except that where the concrete is placed in a permanent steel casing the allowable concrete stress may be increased to $0.33 f'_c$.

8.4.3 Bearing capacity

Pile bearing capacity shall be verified by load tests in accordance with Sub-clause 6.3.8.

8.4.4 Concrete cover

The minimum concrete cover shall be 60 mm for uncased shafts and 25 mm for cased shafts.

8.5 Steel Cased Piles

8.5.1 Material

Pile shells or casings shall be of steel and shall be sufficiently strong to resist collapse and sufficiently water tight to exclude any foreign materials during the placing of concrete. Steel shells shall have a sealed tip with a diameter of not less than 200 mm.

8.5.2 Allowable stresses

The allowable design compressive stress in the concrete shall not exceed $0.33 f'_c$ except that the allowable concrete stress may be increased to a maximum value of $0.40 f'_c$ for that portion of the pile meeting the following conditions:

- 1) The thickness of the steel shell is not less than 2.0 mm minimum.
- 2) The shell is seamless or is provided with seams of strength equal to the basic material and is of a configuration which will provide confinement to the cast in place concrete.
- 3) The ratio of steel yield strength, f_y , to design, f'_c , shall be not less than six.
- 4) The nominal pile diameter is not greater than 400 mm.

8.5.3 Reinforcement

Reinforcement shall not be placed within 25 mm of the steel shell. Reinforcing shall be considered necessary only for unsupported pile lengths or when the pile is designed to resist uplift or unbalanced lateral loads.

9. PRECAST CONCRETE PILES

9.1 General

9.1.1 Design and manufacture

All piles shall be designed and manufactured in accordance with accepted practice and to resist all stresses induced by handling, driving and service loads. The minimum lateral dimension shall be 200 mm. All corners of square piles shall be chamfered. Longitudinal steel shall be arranged in a symmetrical pattern and shall be laterally tied with steel ties or wire spiral spaced not more than 76 mm apart center-to-center for a distance of 600 mm from the ends of the pile and not more than 150 mm elsewhere except that at the ends of each pile the first five ties or spirals shall be spaced 25 mm center to center.

9.2 Reinforced Piles

9.2.1 Design

The minimum amount of longitudinal reinforcement expressed as a percentage of the gross cross-sectional area of the pile shall be 1% for piles 12 m. and shorter and 1 ½% for piles longer than 12 m. and shall consist of at least four bars.

9.2.2 Material

Concrete for precast concrete piles shall have a minimum 28 days compressive strength of 31 MPa. Where sub-surface investigations indicate the likelihood of considerable sulfate attack, consideration shall be given to the use of Type II or Type V Portland Cement as specified in ASTM C150-Specifications for Portland Cement.

9.2.3 Allowable stress

The allowable compressive stress in the concrete shall not exceed $0.33 f'_c$ applied to the gross cross sectional area of the pile.

9.2.4 Reinforcement

The steel reinforcing shall be so designed that the stresses will remain within the permissible limits under all loading conditions, including those due to the handling of the piles.

9.2.5 Concrete cover

9.2.5.1 Reinforcement for piles cast in the field and also for piles not manufactured under plant control conditions shall have a concrete cover of not less than 50 mm.

9.2.5.2 Reinforcement for piles manufactured under plant control conditions shall have a concrete cover of not less than 32 mm for 15 mm bars and smaller, and not less than 38 mm for 19 mm through 43 mm bars except that longitudinal bars spaced less than 38 mm clear distance apart shall be considered bundled bars for which the minimum concrete cover shall be equal to that for equivalent diameter of the bundled bars.

9.2.5.3 Reinforcement for all piles exposed to seawater shall have a concrete cover of not less than 76 mm.

9.3 Prestressed Concrete Piles

9.3.1 General

In cases where hard driving through dense layers is to be expected, prestressed concrete piles shall be specified to minimize the chance of cracks from tensile shock waves.

Also for reasons other than above, prestressed concrete piles may be advantageously used and shall therefore be considered in piling design.

9.3.2 Material

a) Concrete quality

The concrete shall contain at least 420 kg cement per m^3 concrete in place.

All concrete shall have a 28 day specified compressive strength f'_c of not less than 34.5 MPa.

b) Aggregates

The maximum size of the coarse aggregate shall not exceed 25 mm.

c) Prestressing wires

Prestressing wires shall be of high tensile steel in accordance with ASTM A 416. Oil tempered prestressing wires shall not be used.

9.3.3 Allowable stress

The maximum allowable design compressive stress f_c in concrete shall be determined as follows:

$$f_c = 0.33 f'_c - 0.27 f_{pc}$$

Where:

f_{pc} = The effective prestress stress on the gross section.

Under normal load conditions the stress in the prestressing wires shall not exceed one-half of their guaranteed ultimate tensile strength.

9.3.4 Concrete cover

All prestressing steel and pile reinforcement shall have a concrete cover of not less than 30 mm for square piles of 300 mm or smaller size and 40 mm for larger piles except that for piles exposed to seawater, the minimum protective concrete cover shall be not less than 75 mm.

10. TIMBER (WOODEN) PILES

10.1 Material

Except where untreated piles are permitted, wood piles shall be pressure treated in accordance with Sub-clause 10.2. Untreated piles may be used only when it has been established that the cutoff will be below lowest groundwater level assumed to exist during the life of the structure. Every wood pile shall conform to ASTM D 25.

10.2 Preservative Treatment

10.2.1 Timber piles used to support permanent structures shall be treated in accordance with this section unless it is established that the tops of untreated timber piles will be below lowest ground water level assumed to exist during the life of the structure.

10.2.2 Preservative and minimum final retention shall be in accordance with AWPAC Standard C3.

10.2.3 Preservative and minimum final retention for sawn timber piles shall be in accordance with AWPAC Standard C24.

10.2.4 When timber piles are used in salt water, the treatment shall conform to AWPB MP1, MP2, or MP4.

10.2.5 Pile cut-offs shall be treated in accordance with AWPAC M4.

10.3 Allowable Stresses

Allowable working stresses for wood piles shall be per ASTM D 2899 except values for allowable compressive strength shall not exceed the following Table 3:

TABLE 3

TYPE OF WOOD	ALLOWABLE COMPRESSIVE STRENGTH MPa
BALD CYPRESS, COASTAL REGION DOUGLAS FIR, HICKORY, WHITE OAK, AND OTHER WOODS OF COMPARABLE STRENGTH	5.52
CEDAR, MOUNTAIN REGION DOUGLAS FIR, WESTERN HEMLOCK, AND OTHER WOODS OF COMPARABLE STRENGTH	4.14

Note:

The allowable pile loading for wood piles shall not exceed 18 metric tons for 150 mm piles and 23 metric tons for 200 mm piles.

10.4 End Bearing Piles

Any sudden decrease in driving resistance of an end bearing timber pile shall be investigated with regard to the possibility of damage and if the sudden decrease in driving resistance cannot be correlated to bearing data, the pile shall be removed for inspection or rejected.

10.5 Other Requirements

- When driven, the entire pile shall be permanently below water or ground water level.
- If the foundation base level is to be above water or ground water level , the wooden piles shall be provided with reinforced concrete top sections of sufficient length to ensure that the wooden part remains permanently below water or ground water level.
- The piles and the concrete top sections shall be rigidly connected and this connection shall be able to withstand a bending moment equal to that which can be taken by the pile proper.
- These piles may only be used for the support of light structures, e.g. pipe bridges, light vessels, pump foundations, etc.

11. COMPOSITE PILES

11.1 Design

Composite piles are used in ground conditions where conventional piles are unsuitable or uneconomical. They may consist of a combination of bored and driven piles, or driven piles embodying two types of material. A frequently used type of composite pile is the concrete and timber pile. This type combines the cheapness and ease of handling of the timber pile with the durability of the concrete pile. The susceptibility of the former to decay above the ground water table has already been mentioned. Thus the timber pile is terminated below lowest ground water level and the upper portion formed in concrete.

Another method of composite piling is to use a hollow precast concrete driven section which remains in position after a timber pile has been driven down the interior to the required penetration. Composite steel H-section and concrete piles can be driven in a similar manner to concrete and timber piles. The concrete portion is used in the zone above and immediately below ground level which is most susceptible to corrosion. The design of such composite piles should provide a rigid connection between the two components.

11.2 Limitation of Load

The maximum allowable load shall be limited by the capacity of the weakest section incorporated in the pile.

11.3 Splices

Splices between concrete section and steel or wood sections shall be designed to prevent separation of the sections both before and after the concrete portion has been set, and to insure the alignment and transmission of the total pile load. Splices shall be designed to resist uplift due to upheaval during driving of adjacent piles and shall develop the full compressive strength and not less than 50% of the strength in tension and bending of the weaker section.

12. CAISSON PILES

12.1 Definition

Caissons are deep foundation units which often function similar to piles. However, these are essentially end-bearing units and designed as deep footings combined with concrete shafts to carry the structure loads to the bearing stratum.

Caisson piles shall consist of a shaft section of concrete filled pipe extending to bedrock with an uncased socket drilled into the bedrock and filled with concrete. The caisson pile shall have a full length structural steel core or a stub core installed in the rock socket and extending into the pipe portion a distance equal to the socket depth.

12.2 Design

The depth of the rock socket shall be sufficient to develop the full load bearing capacity of the caisson pile with a minimum factor of safety of two but the depth shall be not less than the outside diameter of the pipe. The design of the rock socket may be predicated on the sum of the allowable bearing pressure on the bottom of the socket plus bond along the sides of the socket. The minimum outside diameter of the caisson pile shall be 460 mm and the diameter of the rock socket shall be approximately equal to the inside diameter of the pipe.

12.3 Material

Pipe and steel cores shall conform to the material requirements of Sub-clause 7.2.2.

Pipe shall have a minimum wall thickness of 9.5 mm and shall be fitted with a suitable steel driving shoe welded to the bottom of the pipe. All concrete shall have a 28 day specified compressive strength f'_c of not less than 28 MPa. The concrete mix shall be designed and proportioned so as to produce a cohesive workable mix with a slump of from 100 to 150 mm.

12.4 Structural Core

The gross plan area of the structural steel core shall not exceed 25% of the gross caisson section. The minimum clearance between the structural core and the pipe shall be 50 mm. If cores are to be spliced, the ends shall be milled or ground to provide full contact and shall be full depth welded.

12.5 Allowable Stresses

The allowable design compressive stresses shall not exceed the following:

Concrete, $0.33 f'_c$; steel pipe, $0.35 f_y$; structural steel core, $0.50 f_y$.

APPENDICES

APPENDIX A CHOICE OF PILES

CHOICE OF TYPE

Piles may be divided into three main types, depending on their effect on the soil as shown in Fig. A-1. These are as follows:

- a) Large displacement piles. These include all types of solid pile, including timber and precast concrete and steel or concrete tubes closed at the lower end by a shoe or plug, which may either be left in place or extruded to form an enlarged foot.
- b) Small displacement piles. These include rolled steel sections, such as H piles, open-ended tubes and hollow sections if the ground enters freely during driving.

However, it should be recognized that open-ended tubes and hollow sections frequently plug and become displacement piles particularly in cohesive soils. H-piles may behave similarly.

- c) Replacement piles. These are formed by boring or other methods of excavation; the borehole may be lined with a casing or tube that is either left in place or extracted as the hole is filled.

When considering a bored pile in soft or granular ground especially when water-bearing, particular care will need to be taken to ensure the integrity of the pile shaft and to avoid:

- 1) disturbance causing instability of the bearing stratum and the surrounding ground;
- 2) an inflow of water which could cause a disturbance to the bearing stratum or the surrounding ground;
- 3) an inflow of water or soil causing damage to the unset concrete in the pile or piles recently installed nearby.

When a displacement pile is installed, its volume has to be accommodated below the ground surface by vertical and lateral displacements of the soil. Effects of consequential heave or compaction may be unacceptable to adjacent structures.

In some soils the vertical and lateral displacement or heave resulting from subsequent piling may carry with it piles that have already been installed. This may cause end bearing piles to be lifted off their bearing stratum. If lifting is suspected, careful levelling from a datum unaffected by the piling should be made on the heads of piles already driven before and after driving subsequent piles. Risen piles which depend largely on end bearing and which are capable of being redriven should be redriven to the specified resistance.

Driven cast in situ piles should not normally be redriven after concreting and should be replaced or supplemented or the required resistance developed by pre-loading the piles.

The soil around a driven pile is disturbed during installation and with a pile group the volume of soil affected may be considerable. Mitigation of this effect can be obtained by the use of small displacement piles, or by pre-boring over part of the depth of displacement piles or, if the ground conditions are suitable, by the use of bored piles. Where large displacement piles are to be employed in ground liable to heave, the effects on adjacent piles and structures can usually be minimized by working outward from the center of a group or by commencing with the piles adjacent to the structure and progressing away from it.

Where vibration or noise has to be reduced to a minimum, piles formed by augering are generally preferable. However, piles driven under carefully controlled conditions do not necessarily cause appreciable vibration and may then be used safely under skilled supervision. When working near existing structures which are founded on loose sands or silts, particularly if these are saturated, it is essential to avoid the use of methods which cause dangerous vibrations, because these may have the effect of temporarily reducing the shear strength of the ground beneath the adjoining foundations.

Rapid settlement may also occur due to consolidation of loose sands and silts. If bored piles are used in loose sands and silts, care should be taken to prevent inflow of soil into the boreholes, as this might cause loss of support by the removal of soil from beneath adjacent foundations or create unstable water-filled cavities outside the pile shaft, leading to voids in the shaft during concreting or the washing out of cement.

Where headroom is limited, a pile installed in sections by jacking it into the ground may be used, for example where underpinning is to be carried out, but care is required to ensure that the reaction available is adequate. Some rigs for installing bored piles and some proprietary rigs for driven piles are also capable of working in confined headroom.

Whilst they are rarely used, screw piles are suitable for the construction of structures such as wharves, piers and jetties where there is soft alluvial soil to a considerable depth.

They may also be used to withstand uplift forces.

Timber piles may be used in permanent work where the conditions are such that deterioration will not occur.

(to be continued)

APPENDIX A (continued)

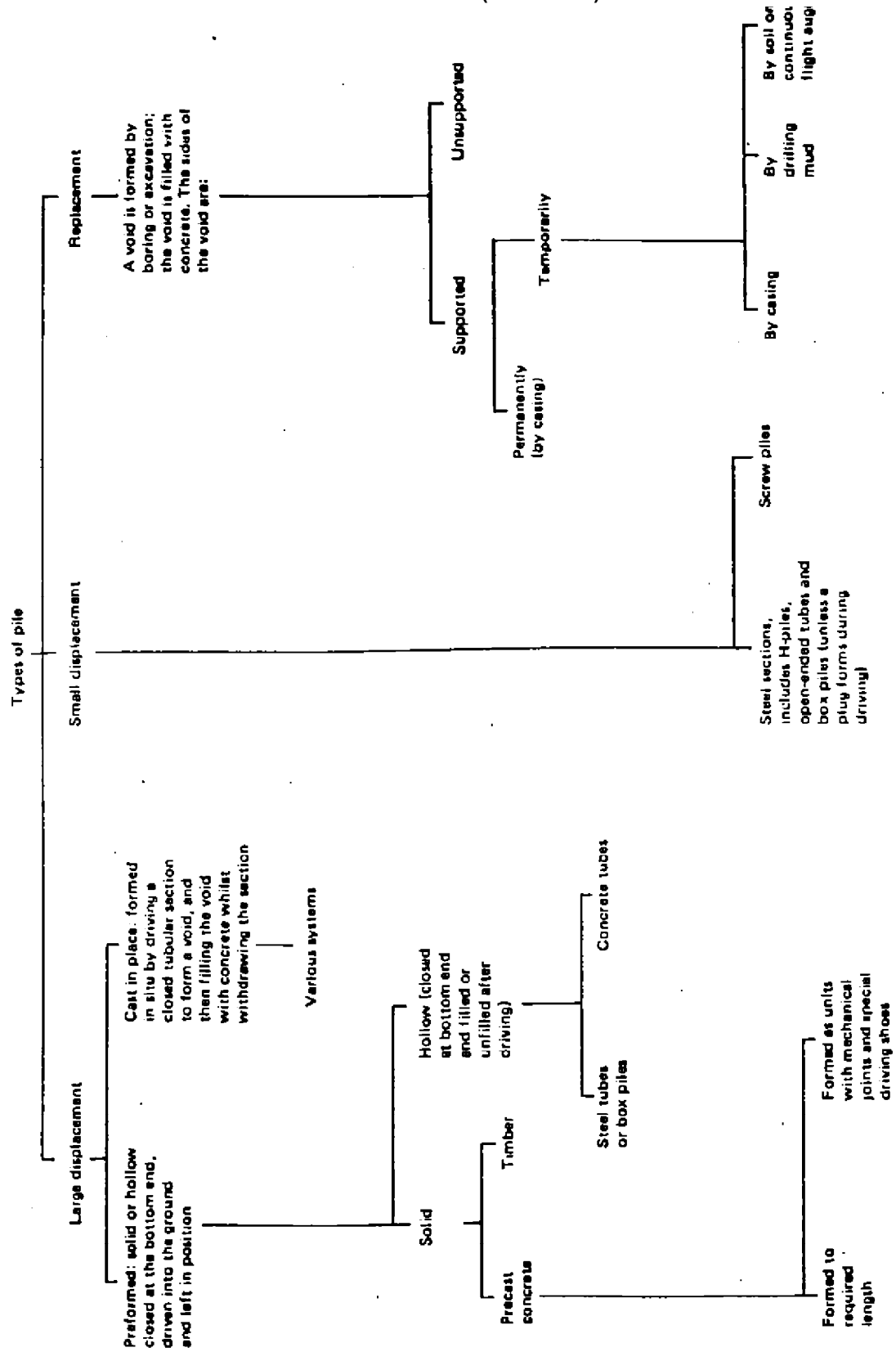


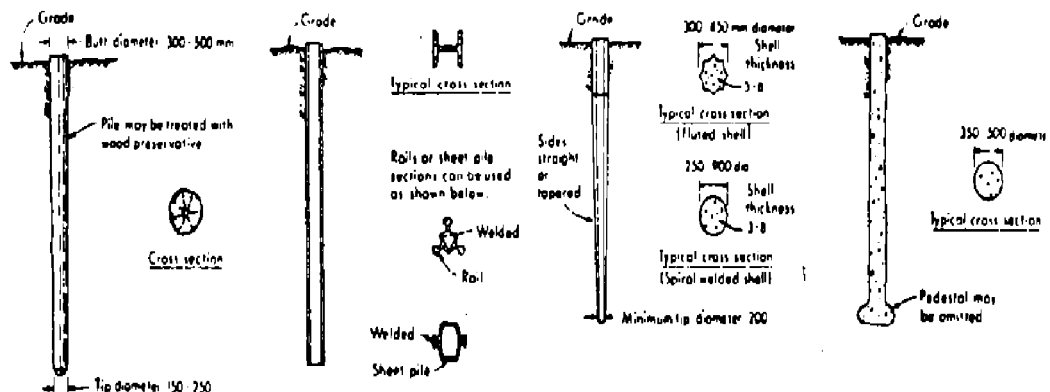
Fig. A-1: Types of pile

APPENDIX B TYPICAL PILE CHARACTERISTICS AND USES

TABLE B-1

Pile type	Timber	Steel	Cast-in-place concrete piles (shells driven without mandrel)	Cast-in-place concrete piles (shells withdrawn)
Maximum length	33 m	Practically unlimited	45 m	36 m
Optimum length	9-20	12-30	9-25	8-12
Applicable material specifications	ASTM-D25 for piles; P1-34 for quality of creosote; C1-60 for creosote treatment (Standards of American Wood Preservers Assoc.)	ASTM-A36 for structural sections ASTM-A1 for rail sections	ACI	ACI
Recommended maximum stresses	Measured at midpoint of length: 4-6 MPa for cedar, western hemlock, Norway pine, spruce, and depending on Grade 5-8 MPa for southern pine, Douglas fir, oak, cypress, hickory	$f_t = 65 \text{ MPa}$ $f_c = 85$ $f_t = 140$ $f_c = 0.33-0.5 f_t$	$0.33 f_t$; $0.4 f_t$ if shell gage ≤ 14 ; shell stress = $0.33 f_t$ if thickness of shell $\geq 3 \text{ mm}$	$0.25-0.33 f_t$
Maximum load for usual conditions	270 kN	Maximum allowable stress \times cross section	900 kN	1300 kN
Optimum-load range	130-225	350-1050	450-700	350-900
Disadvantages	Difficult to splice Vulnerable to damage in hard driving Vulnerable to decay unless treated when piles are intermittently submerged	Vulnerable to corrosion HP section may be damaged or deflected by major obstructions	Hard to splice after concreting Considerable displacement	Concrete should be placed in dry More than average dependence on quality of workmanship
Advantages	Comparatively low initial cost Permanently submerged piles are resistant to decay Easy to handle	Easy to splice High capacity Small displacement Able to penetrate through light obstructions	Can be redriven Shell not easily damaged	Initial economy
Remarks	Best suited for friction pile in granular material	Best suited for end bearing on rock Reduce allowable capacity for corrosive locations	Best suited for friction piles of medium length	Allowable load on pedestal pile is controlled by bearing capacity of stratum immediately below pile

Typical illustrations



(to be continued)

Pile type	Concrete-filled steel pipe piles	Composite piles	Precast concrete (including prestressed)	Cast in place (thin shell driven with mandrel)	Auger placed pressure-injected concrete (grout) piles
Maximum length	Practically unlimited	55 m	30 m for precast 60 m for prestressed	30 m for straight sections 12 m for tapered sections	9-25 m
Optimum length	12-36	18-36	12-15 for precast 18-30 for prestressed	12-18 for straight 5-12 for tapered	12-18
Applicable material specifications	ASTM A36 for core ASTM A252 for pipe ACI Code 318 for concrete	ACI Code 318 for concrete ASTM A36 for structural section ASTM A252 for steel pipe ASTM D25 for timber	ASTM A15 reinforcing steel ASTM A82 cold-drawn wire ACI Code 318 for concrete	ACI	See ACI
Recommended maximum stresses	0.40 f_c reinforcement < 205 MPa 0.50 f_c for core < 175 MPa 0.33 f_c for concrete	Same as concrete in other piles Same as steel in other piles Same as timber piles for wood composite	0.33 f_c unless local building code is less 0.4 f_c for reinforced unless prestressed	0.33 f_c ; if $f_c = 0.4 f_c$ if shell gage is ≤ 14 use $f_c = 0.35 f_c$ if shell thickness ≥ 3 mm	0.225-0.40 f_c
Maximum load for usual conditions	1800 kN without cores 18 000 kN for large sections with steel cores	1800 kN	8500 kN for prestressed 900 kN for precast	675 kN	700 kN
Optimum-load range	700-1300 without cores 4500-14 000 with cores	250-725	350-3500	250-550	350-550
Disadvantages	High initial cost Displacement for closed-end pipe	Difficult to attain good joint between two materials	Difficult to handle unless prestressed High initial cost Considerable displacement Prestressed difficult to splice	Difficult to splice after concreting Redriving not recommended Thin shell vulnerable during driving Considerable displacement	Dependence on workmanship Not suitable in compressible soil
Advantages	Best control during installation No displacement for open-end installation Open-end pipe best against obstructions High load capacities Easy to splice	Considerable length can be provided at comparatively low cost	High load capacities Corrosion resistance can be attained Hard driving possible	Initial economy Tapered sections provide higher bearing resistance in granular stratum	Freedom from noise and vibration Economy High skin friction No splicing
Remarks	Provides high bending resistance where unsupported length is loaded laterally	The weakness of any material used shall govern allowable stresses and capacity	Cylinder piles in particular are suited for bending resistance	Best suited for medium-load friction piles in granular materials	Patented method

Figure 10.1 illustrates various types of piles, showing their typical cross sections and dimensions. The figure is divided into several sections:

- Plain pipe pile:** Shows a cross section of a plain pipe pile with a shell thickness $h = 12$. The diameter is specified as 300-900 mm. The end closure may be omitted.
- Pipe pile with core:** Shows a cross section of a pipe pile with a core. The diameter is specified as 300-900 mm.
- Typical combinations:** Shows three typical combinations of piles:
 - Cased or uncased concrete.
 - Concrete filled steel shell.
 - Timber.
- Steel pipe concrete-filled:** Shows a cross section of a steel pipe concrete-filled pile. The diameter is specified as 300-600 mm. The reinforcing may be pre-stressed.
- Corrugated shell:** Shows a cross section of a corrugated shell. The diameter is specified as 200-450 mm. The thickness is specified as 10 ga to 7 ga. The sides are straight or tapered.

The figure also includes labels for 'Grade' and 'Rock'.