FEDERATION OF MYANMAR ENGINEERING SOCIETIES

PHC Spun Pile Manufacturing, Construction, and its Application

Presented By
Soe Soe Tin

2nd August 2025

Objective of the Topic of this Seminar

1.**Educational Value**: Discussing PHC spun piles provides insights into new technologies and methodologies that attendees may not be familiar with, enhancing their technical knowledge.

2.**Industry Application**: Highlighting real-world applications and case studies can illustrate best practices and innovations in foundation engineering and construction.

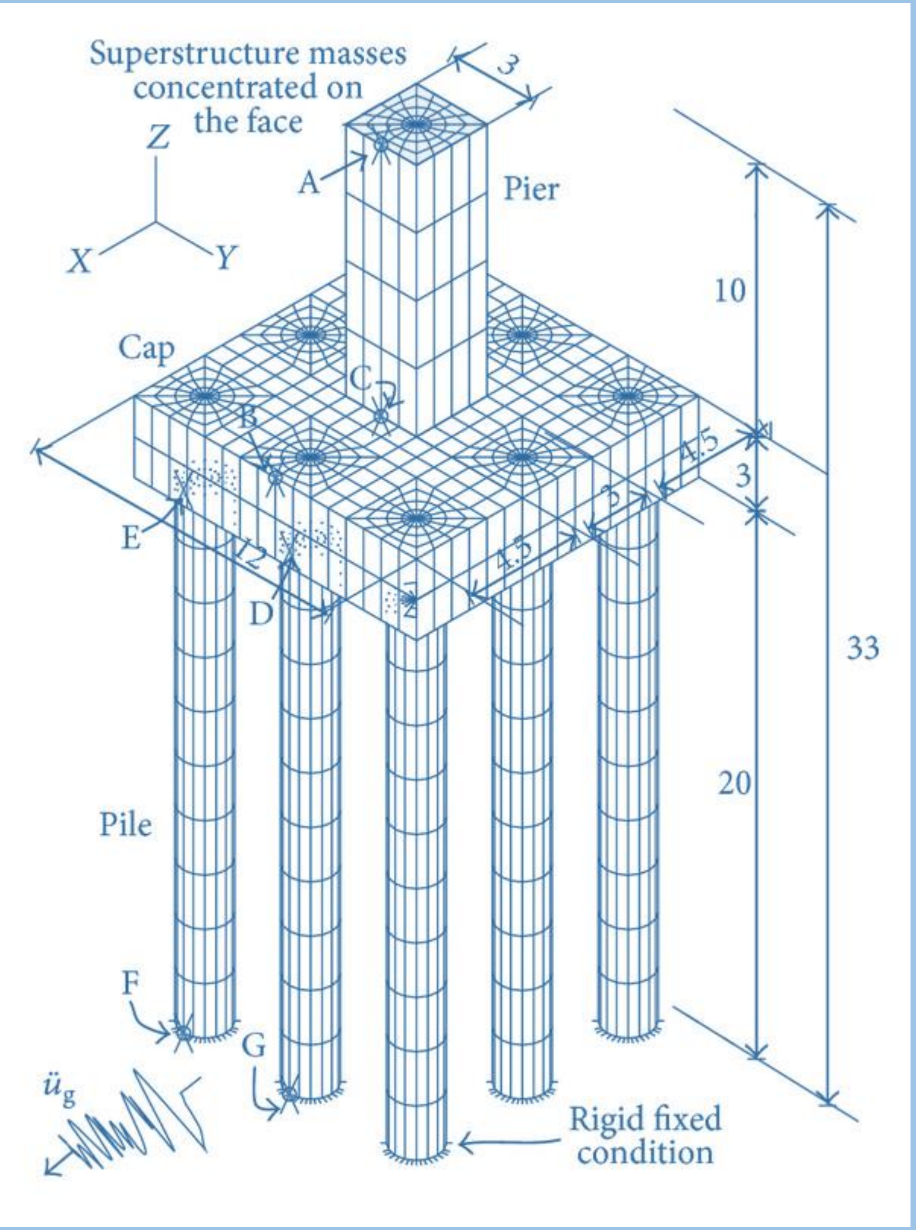
3.**Networking Opportunities**: Many professionals in the construction industry may be interested in PHC technology, offering networking opportunities among specialists in this field.

4.**Promoting Sustainable Practices**: Given their efficient manufacturing processes and reduced environmental impact compared to traditional piling techniques, PHC piles symbolize advancements in sustainable construction practices.

Including PHC Spun Pile Manufacturing and its various applications in this seminar is not just appropriate but potentially vital for both educational and professional development within the construction and civil engineering community. It addresses current demands in infrastructure development and promotes up-to-date engineering practices.

Content

1.0 Overview of Pile Foundations



1.1 Overview of Pile Foundations

- The concept of pile foundations dates back to ancient times when timber piles were manually driven into the ground to create stable bases for structures near water bodies.

- Important developments in pile foundation technology began with notable innovations, such as Christoffoer Polhem's invention of pile-driving equipment in 1740.

- Steel piles have been used since 1800, and Concrete piles since about 1900.

1.2 Classification of Pile

- **Based on Material**
  - Steel Piles, Concrete Piles, Timber Piles, Composite Piles.
- **Based on Load Transfer**
  - End Bearing Piles, Friction Piles, Combined End bearing and Friction Piles
- **Based on Method of Installation**
  - Driven Piles, Driven Cast-in-situ Piles, Bored and Cast-in-situ Piles, Screw Piles, Jacked Piles.
- **Based on Use**
  - Load Bearing Piles, Compaction Piles, Sheet Piles, Fender Piles, Anchor Piles.
- **Based on Displacement of Soil**
  - Displacement Piles, Non-Displacement Piles.

1.3 Different Types of Pile Based on Material

Timber Pile

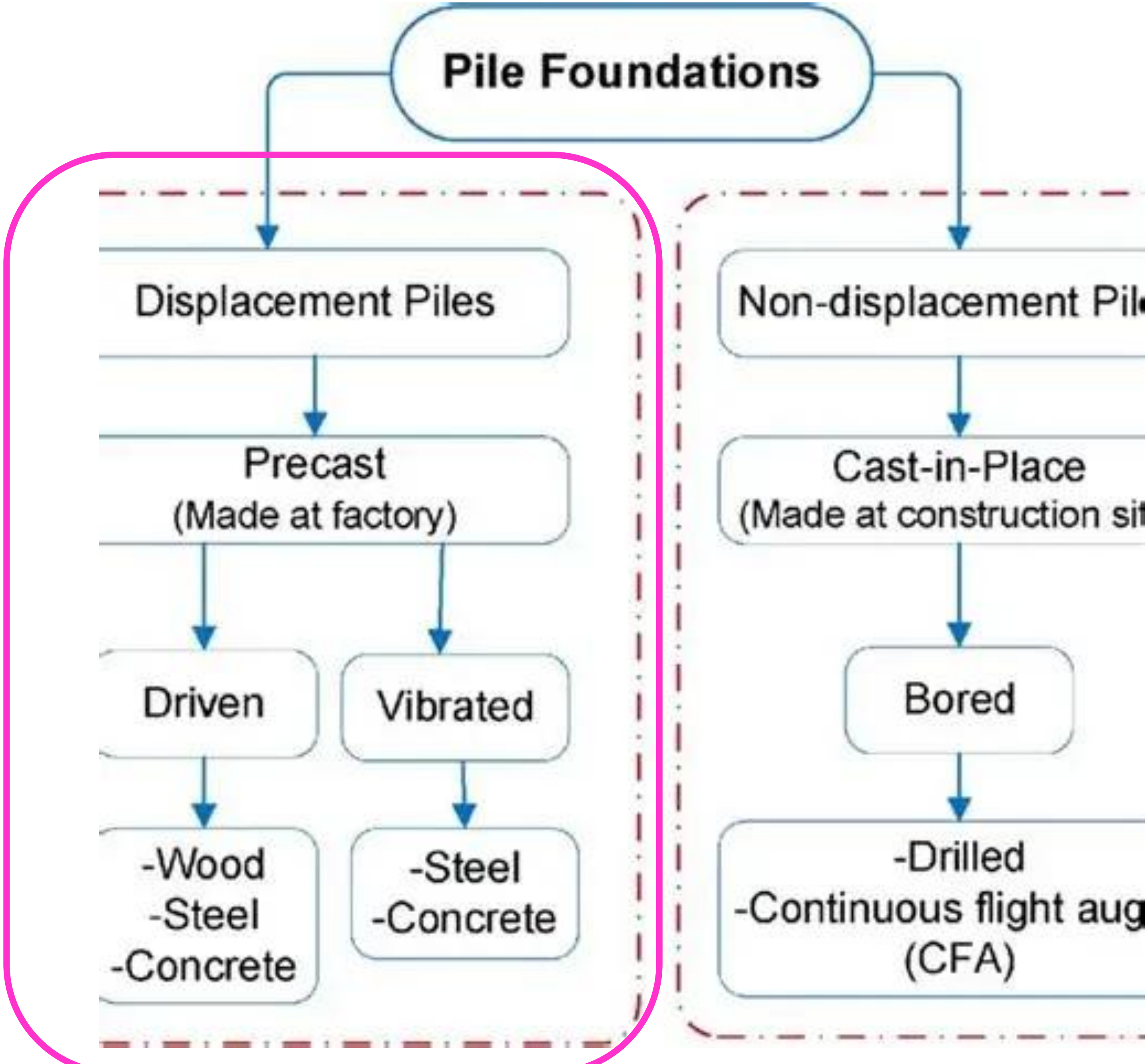
Steel H-Pile

Steel Pipe-Pile

Plastic Pile

Precast / Pre-stressed Concrete Pile

PHC Spun Pile


Pile Foundations
Displacement Piles
Precast
(Made at factory)
Driven
Vibrated
-Wood
-Steel
-Concrete
-Steel
-Concrete
Non-displacement Pil
Cast-in-Place
(Made at construction sit
Bored
-Drilled
-Continuous flight aug
(CFA)

1.4 Comparison of Precast Concrete and Prestressed Concrete Pile

Feature	Precast Concrete Piles	Prestressed Concrete Piles	Spun (Prestressed Centrifugal) Concrete Piles
Manufacturing	Poured and cured in molds under controlled conditions	Same, but with prestressing tendons tensioned during casting	Cast by centrifugal spinning in rotating molds with prestressing
Typical Concrete Strength	Normal to high strength (~30-50 MPa)	High strength (50-70+ MPa)	Very high strength (50-75+ MPa), highly dense
Cross-section	Various (rectangular, square, octagonal, circular)	Mostly rectangular or circular	Circular hollow tubular sections
Weight	Heavier, solid sections	Reduced due to prestressing, smaller sections possible	Lighter due to hollow form and compacted concrete
Durability	Good, depending on mix and curing	Very high, low permeability, crack resistant	Excellent impermeability and durability

1. Precast Concrete Piles

- **Manufacturing Process:**
  - Cast in a controlled factory environment using reusable molds.
  - Concrete is poured and cured under monitored conditions.
  - Can be reinforced with conventional steel rebar.
  - Shapes vary: circular, square, octagonal, tapered or uniform cross-section.
  - Quality control is facilitated by inspection at all stages before shipment.
- **Materials:**
  - Usually normal or high-strength concrete.
  - Reinforcement consists of standard steel bars.
  - Concrete mix designed for durability but without pre-stressing.
- **Production Advantages:**
  - Controlled curing increases product uniformity.
  - Readily available in various sizes.
  - Cost-effective for many applications.
- **Challenges:**
  - Heavier due to lack of pre-stressing—requires significant handling equipment.
  - Risk of cracking during transportation and installation.
  - Requires additional reinforcement to resist handling and driving stresses.

Precast Concrete Pile Production

2. Pre-stressed Concrete Piles

Manufacturing Process:

- Similar factory casting as precast but with pre-stressing tendons (high-strength steel strands or wires) tensioned before or during concrete placement.
- Tendons released after curing to induce compressive stress in concrete.
- Often steam cured or given special treatments to achieve high strength (up to ~10,000 psi / 70 MPa or higher).

Materials:

- High-performance concrete with low permeability.
- High-tensile pre-stressing strands or cables embedded within.
- Reinforcement also placed for additional tensile strength.

Production Advantages:

- Superior crack control due to induced compressive stresses.
- Smaller cross sections possible with higher load capacities.
- Enhanced durability and resistance to corrosion, especially in marine or aggressive environments.
- Enables longer lengths and larger diameters; pre-stressing strands increase axial and flexural capacity.

Challenges:

- More complex manufacturing process requiring precise tensioning equipment.
- Higher material and production costs than conventional precast piles.
- Requires specialized knowledge for design and quality control.

Pre-stressed Concrete Pile Production

3. Spun (Pre-stressed Centrifugal) Concrete Piles

Manufacturing Process:

- Produced by centrifugal casting, spinning the concrete inside a rotating mold.
- This spinning compacts the concrete and removes excess water, creating very dense, high-strength concrete.
- Tendons or pre-stressing wires are tensioned and embedded during spinning.
- Curing often done by steam under controlled temperature and pressure.

Materials:

- High-strength concrete (around 50 to 75 MPa or more).
- Pre-stressing wires or strands arranged cylindrically.
- Often hollow tubular sections (closed-ended), reducing weight.

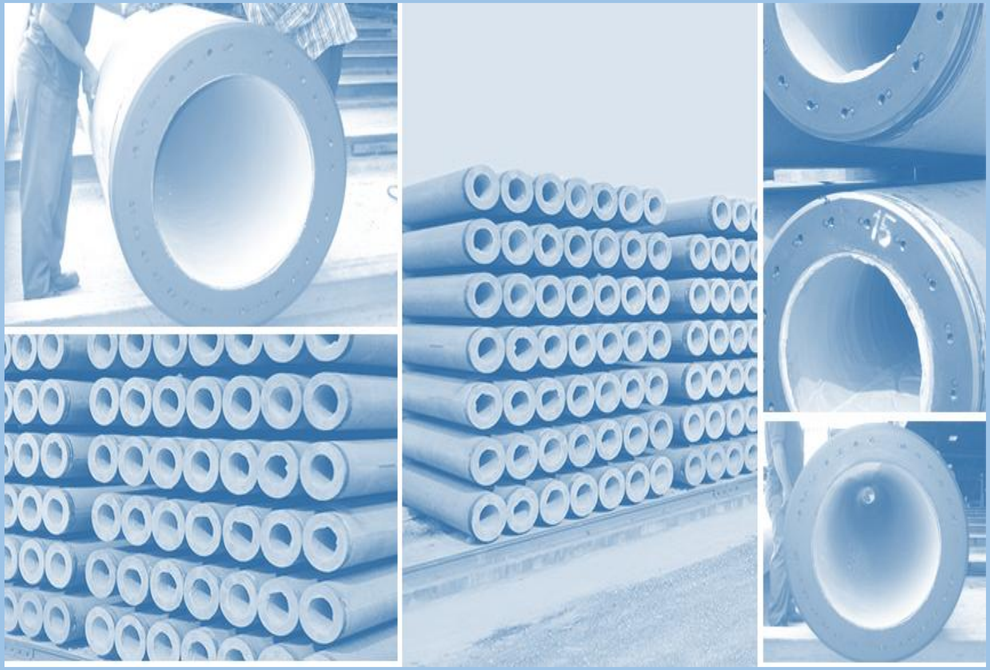
Production Advantages:

- Produces very dense, crack-free concrete with high tensile strength.
- Hollow tubular form reduces weight, making transportation and handling easier.
- Superior durability and impermeability, especially suited for marine environments.
- Pre-stressing combined with centrifugal compaction enhances resistance to tensile cracking during transportation and pile driving.
- Allows welding of flange connections for pile splicing.

Challenges:

- Requires specialized centrifugal spinning equipment and skill.
- Typically limited to circular or cylindrical cross sections.
- Potential for brittle failure unless adequately confined, so external confinement or concrete infill may be required in seismic or high-load scenarios.
- Less suitable for very boulder-filled ground unless pre-boring is done.

2.0 Pre-stressed Concrete piles and Spun Pile



2.1 Prestressed Concrete Piles

- Prestressed concrete piles are extensively employed throughout the world in marine structures and foundations.
- The advantages they offer are their strength in bearing and bending, their durability and their economy.
- In recent years, prestressed concrete piles have broken through into new fields of utilization. This is partly a result of their demonstrated economy in mass production, and partly because of their technical properties and performance.

1. Concentrically loaded short column

a. Design load based on ultimate load

$$N = N_u/S$$
$$= (Kf'_c - 0.60f_e)\,A_c/S$$

where N = allowable bearing load for design

N_u = ultimate bearing load

S = factor of safety, usually 2.5, 3 or 4

K = coefficient of uniformity, assumed by some to be 0.85, especially for piles cast vertically and up to 1.0 for piles cast horizontally

f_e = effective prestress after losses

A_c = cross-sectional area of concrete

f'_c = 28-day strength (6 x 12-in. cylinders)

The Japanese on the other hand, use the following formula for the ultimate strength of piles prestressed with bars:

$$N_u = (f_c - f_e)\,(A_c + nA_s)$$

where n = secant modular ratio, about 6.5 at ultimate conditions.

b. Design load based on allowable stress in pile. Most codes specify stress values ranging from $0.20f'_c$ to $0.33f'_c$. Based on recent studies and evaluation, the author recommends

$$N = (0.30f'_c - 0.25f_e)\,A_c$$

For the usual case, this reduces to $N = 0.275f'_c\,A_c$.

2. Concentrically loaded long column

a. Ultimate load. For long columns where buckling may occur, Euler's formula may be used. For pin-ended conditions, the effective length, L, shall be the full length of the pile. For piles fully fixed at one end and hinged at the other, L can be taken as 0.7 of the length between hinge and point of fixity. For piles fully fixed at both ends, assume L to be 0.5 of the length.

b. Design load. A safety factor of 2 is generally considered sufficient for buckling load. Design loads should be based on the short column value up to $L/r = 60$ and a straight-line function used between $L/r = 60$ and $L/r = 120$. For L/r greater than 120, the pile should be investigated for elastic stability, taking into account the effect of creep and deflection.

3. Moment-resisting capacity

a. Ultimate. This is approximately given by these formulae (for the typical prestressed pile design and materials):

$M_u = 0.37\ dA_s f'_s$ for solid square piles

$M_u = 0.32\ dA_s f'_s$ for solid circular and octagonal piles

$M_u = 0.38\ dA_s f'_s$ for hollow square piles

$M_u = 0.32\ dA_s f'_s$ for hollow circular and octagonal piles

where A_s = total steel area of all tendons

f'_s = ultimate strength of tendons

d = diameter of pile

M_u = ultimate moment capacity

A safety factor of 2 should be applied for normal loading; for seismic or wind loading, the factor is 1.5.

b. Elastic theory. Determine allowable tension, f_t, in the concrete. This may be taken as 0, as 0.5 modulus of rupture, or as 0.8 modulus of rupture, depending on frequency of load, exposure, corrosive conditions, etc.

$$M = (f_c + f_t)\,Z$$

where M = allowable moment

Z = section modulus of pile

4. Combined moment and direct load

The existence of direct load generally increases the moment capacity within the elastic range, by adding to the available compressive stress (prestress plus stress due to direct load) to resist tensile fiber stress. The ultimate moment capacity of the pile is reduced by direct load.

Typical load-moment interaction diagrams are shown in Fig. 3. It can be roughly estimated that, for a typical foundation pile carrying 60 per cent of the allowable axial load, the

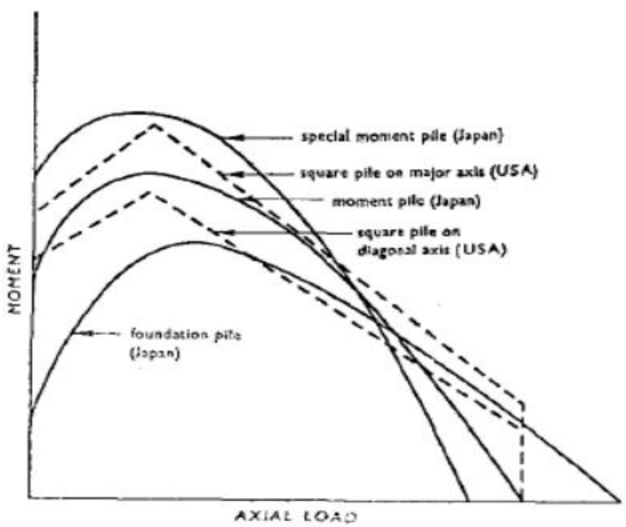


Fig. 3. Typical load-moment interaction curves for prestressed concrete piles

ultimate moment capacity is given by $M_u = 0.29dA_sf'_s$ for solid square piles and by $M_u = 0.25dA_sf'_s$ for round piles. For hollow piles, the lever arms are $0.30d$ and $0.26d$, respectively.

At the pile head, where combined moment and direct load may be critical, the favorable effect of transfer length (i.e. prestress varying from zero to full over the transfer length) may be taken into account.

Permanent bending loads may be imposed by:

- Dead weight of a raking pile
- Lateral load of soil
- Eccentricity of axial load
- Rigid frame action (i.e. structural bending moments imposed).

Transient bending moments may be imposed by:

- Waves and currents
- Ice
- Lateral forces from ships or barges
- Wind on structure
- Seismic forces.

For many of these transient loads, allowable stresses may be increased by one-third.

- Prestressed concrete piles have been extensively employed in both highly developed and less developed countries, and in a variety of environments including sub-arctic, tropical and desert.

- In Japan alone, there are 45 factories producing 1,000,000 tons of foundation piles annually, while in the USA more than 2,000,000 m (6,560,000 ft.) annual production is divided between marine and foundation construction. Prestressed concrete piles support major bridges and wharves in Australia, New Zealand, Peru, Ecuador, Venezuela, Netherlands, Kuwait, Norway, Spain, Italy, Singapore, Malaysia, Sweden, USSR, Canada, England and USA, to name but a few countries in order to illustrate the wide range of application in different economies and climates.

- Prestressed concrete piles have been constructed in the form of cylindrical piles up to 4 m (13.1 ft.) in diameter, as used on the Osterschelde Bridge in the Netherlands, and up to 70 m (230 ft.) long, as employed in off-shore platforms in the Gulf of Maracaibo, Venezuela.

- Prestressed piles have been driven in increments, spliced together during driving to form foundation piling up to 60 m (197 ft.) long to support multi- story buildings in Honolulu and New Orleans.

- Prestressed concrete piles are being increasingly used to resist uplift (tension), bending and dynamic loads. They are acting as fender piling to resist ship impact on harbor structures in Kuwait, Singapore and California and as protective fenders for major bridge piers. Prestressed sheet piles are widely employed as retaining structures for quay walls and bulkheads.

The Japanese National Report asserts the following advantages for prestressed piling:

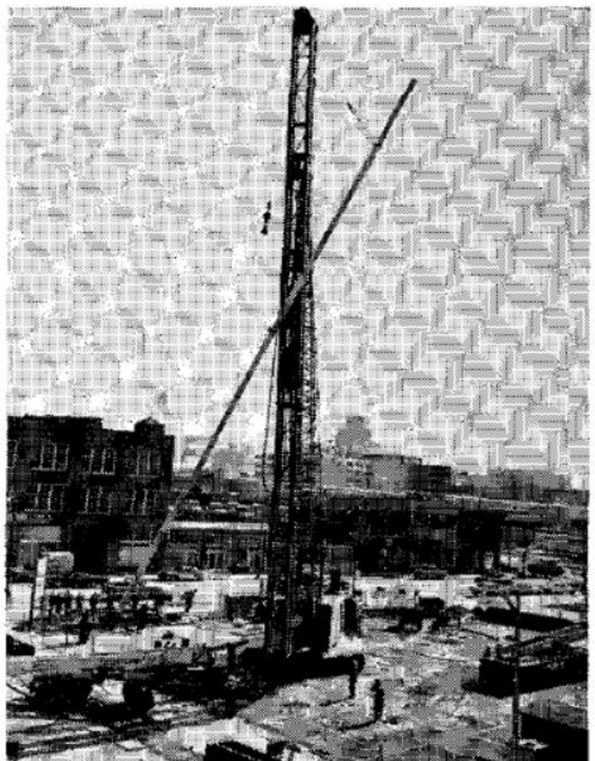
- Crack-free under handling and driving
- Can be economically designed for given loads and moment
- Uniform high quality, high strength concrete
- Readily spliced and connected

The USA report adds:

- High load-carrying capacity
- Durability
- Ease of handling, transportation and pitching
- Ability to take hard driving and penetrate hard material
- High column strength and ability to resist moment or combined moment and bearing
- Ability to take uplift
- Economy.

- In some parts of the United States, there has been a trend towards manufacturing and driving prestressed foundation piling in single long lengths without splices, even for buildings in crowded cities (see below Fig.). Thus piles 40 m (131 ft.) long have been installed for major buildings in San Francisco and Boston.

- High-capacity prestressed concrete piles are particularly advantageous for deep foundations with heavy loads in weak soils. They can be driven successfully through riprap and debris, or through hard strata such as coral, and can penetrate soft or partially decomposed rock.



Long foundation pile (without splices) being used for construction in an American city

- The design of prestressed concrete piles requires consideration of handling, transportation, pitching, driving, permanent loads (both axial and bending), and transient bending loads. Each of these requires an propriate consideration of allowable stresses and, in certain cases, of allowable deflections.
- As a general rule, prestressed piles should be basically designed for the permanently installed condition and then checked for transient bending loads, e.g. seismic or wind. A certain minimum prestress and a certain minimum amount of spiral binding are required for successful installation.

2.2 History of Spun Pile

SPUN PILES have emerged as a significant innovation in foundation engineering, primarily as pre-stressed concrete piles developed for strong load-bearing capacity.

Development of Spun Piles: Spun piles, a specific type of **prestressed concrete pile with a hollow circular section**, became prominent in construction from the **1950s onwards.** It is introduced in 1950 by the Raymond Concrete Pile Company.

Overview of Spun Piles

2.3 Overview of Spun Piles

- **Definition:** PHC piles are Hollow, Precast, Prestressed Concrete piles with circular hollow sections, originally developed in Japan in the 1970s to provide strong foundations in **earthquake-prone regions**.

- **Manufacture:** Produced by prestressing steel strands within cylindrical molds, followed by spinning centrifugal casting and steam curing to achieve dense, high-strength concrete (concrete strengths around 80–100 MPa typical).

- **Dimensions:** Typically range from 300 mm to 1200 mm in outside diameter, adhering often to Japan Industrial Standard (JIS) 5335:2010.

The dimensions of spun pile

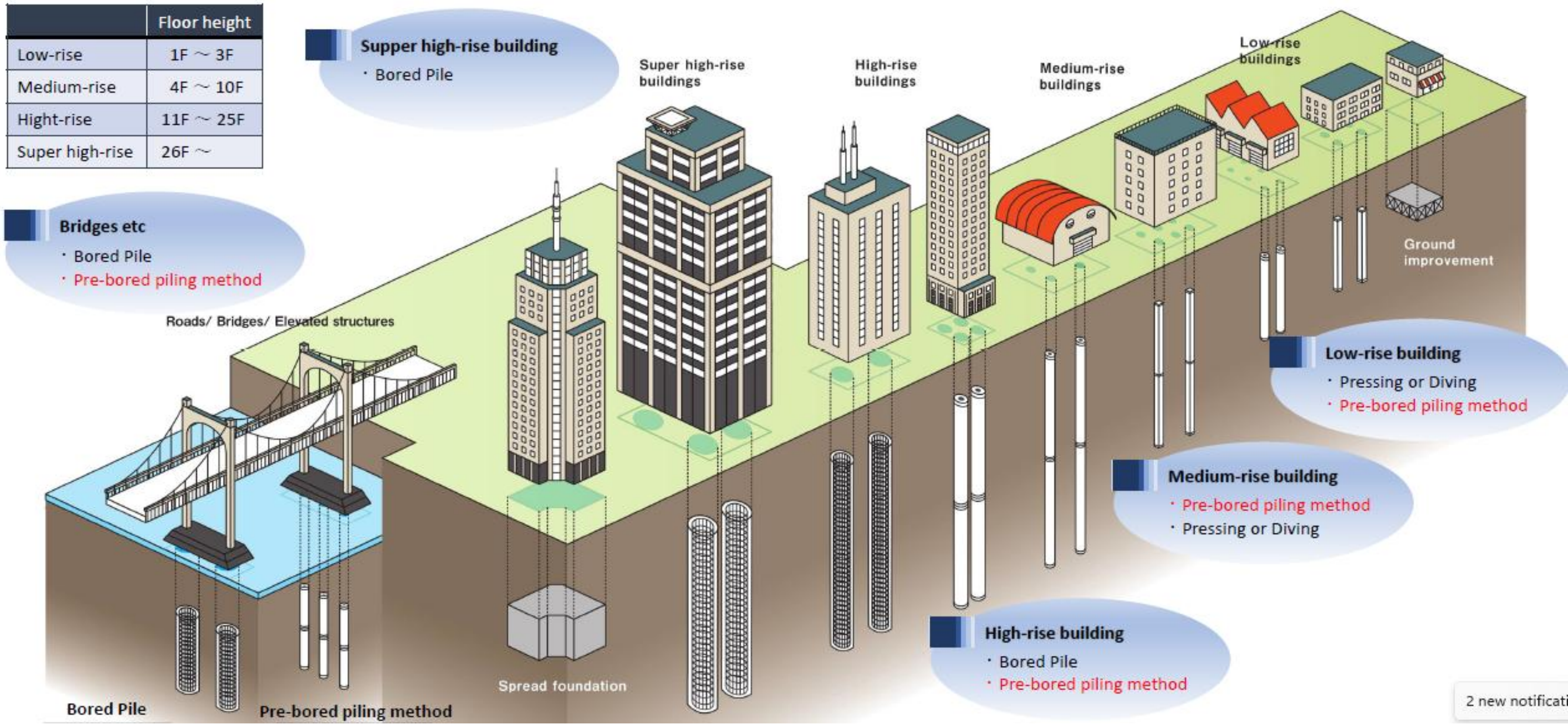
Outside diameter / mm	Thickness / mm
300	60
350	65
400	75
450	80
500	90
600	100
700	110
800	120
1000	140
1200	150

- **Applications:** Commonly used as deep foundations for high-rise buildings, bridges, petroleum tanks, marine structures, and infrastructure requiring high load capacity and durability.

- **Advantages:** High tensile and bending strength, excellent durability (high resistance to cracking, chemical attack, and corrosion), lightweight relative to their strength, fast installation, and economical over lifespan.

2.4 Foundation Construction Coverage

	Floor height
Low-rise	1F ~ 3F
Medium-rise	4F ~ 10F
Hight-rise	11F ~ 25F
Super high-rise	26F ~



2.5 Code , Standard , Specification and Testing

ACI 543R-12

Guide to Design, Manufacture, and Installation of Concrete Piles

Reported by ACI Committee 543

American Concrete Institute®

JIS

JAPANESE INDUSTRIAL STANDARD

Translated and Published by Japanese Standards Association

JIS A 5373 : 2010

(JPCC/JSA)

Precast prestressed concrete products

JIS

UDC 624.155.113.012.46 : 666.982.4.033.17 : 666.982.4.033.4

UNCONTROLLED

JAPANESE INDUSTRIAL STANDARD

Pretensioned Spun Concrete Piles

JIS A 5335-1987

JIS 5335

1. Scope

This Japanese Industrial Standard specifies the prestressed concrete piles manufactured by pretensioning and spinning process, hereinafter referred to as the "PC Piles".

Remark: In this Standard, the units and numerical values given in { } are in accordance with the International System of Units (SI), and are given for reference only.

2. Classification

The PC piles shall be classified by the outside diameter into 300 mm, 350 mm, 400mm, 450 mm, 500 mm, 600 mm, 700 mm, 800 mm, 1000 mm and 1200 mm, and the piles of respective outside diameters shall further be classified into Class A, Class B and Class C depending on the value of cracking bending moment.

3. Quality

3.1 Appearance The PC piles shall be free from defects such as detrimental flaws or cracks.

3.2 Bending Strength

3.2.1 Main Body The main body of the PC piles shall be subjected to the bending strength test specified in 8.1, and shall withstand the cracking bending moment given in Table 1 without showing any cracks.

The breaking bending moment shall be not less than 1.5 times the cracking bending moment given in Table 1 for Class A, not less than 1.8 times for Class B and not less than 2.0 times for Class C.

Table 1. Cracking Bending Moment

Outside diameter mm	Class	Cracking bending moment tf·m{kN·m}	Outside diameter mm	Class	Cracking bending moment tf·m{kN·m}
300	A	2.5{ 24.5 }	450	A	7.5{ 73.6}
	B	3.5{ 34.3 }		B	11.0{107.9}
	C	4.0{ 39.2}		C	12.5{122.6}
350	A	3.5{ 34.3}	500	A	10.5{103.0}
	B	5.0{ 49.0}		B	15.0{147.1}
	C	6.0{ 58.8}		C	17.0{166.7}
400	A	5.5{ 53.9}	600	A	17.0{166.7}
	B	7.5{ 73.6}		B	25.0{245.2}
	C	9.0{ 88.3}		C	29.0{284.4}

Applicable Standards and Reference Standard: See page 10.

Table 1 (Continued)

Outside diameter mm	Class	Cracking bending moment tf·m {kN·m}	Outside diameter mm	Class	Cracking bending moment ft·m {kN·m}
700	A	27.0{ 264.8 }	1000	A	75.0{ 735.5}
	B	38.0{ 372.7 }		B	105.0{1029.6}
	C	45.0{ 441.3 }		C	120.0{1176.8}
800	A	40.0{ 392.3 }	1200	A	120.0{1176.8}
	B	55.0{ 539.4 }		B	170.0{1667.1}
	C	65.0{ 637.4 }		C	200.0{1961.3}

3.2.2 Jointing End The bending strength of jointing end shall be equal to or higher than the breaking bending strength selected from the bending strengths specified in 3.2.1.

4. Construction

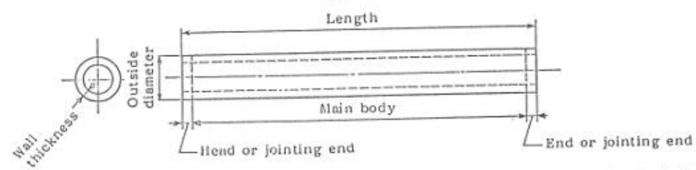
4.1 Construction of End Portion The construction of the end portion of PC piles shall be such that it can transmit the load safely to the foundation soil.

4.2 Construction of Head Portion The construction of the head portion of PC piles shall be such that it does not provide any hindrance in the piling operation.

5. Shape and Dimensions

5.1 Shape The PC pile shall be composed of the main body of hollow cylindrical shape as shown in Fig. 1, and shall have the suitable end, jointing end or head, as necessary. The outside diameter and wall thickness of main body shall be uniform at any cross section over the whole length.

Fig. 1



Remarks 1. Lengths of the end, jointing end and head are included in the total length.

2. The length of an end fitting attached after the fabrication of the PC pile shall not be included in the length thereof.

3. There are various types of ends, e.g., closed type, open type, etc.

4. An upper or intermediate pile may be utilized as a lower pile by providing an end portion.

5.2 Dimensions The dimensions of the PC piles shall conform to Table 2 and the dimensional tolerances to Table 3.

Table 2. Dimensions

Outside diameter mm	Thickness mm	Class	Length m 7	8	9	10	11	12	13	14	15
300	60	A B C	○	○	○	○	○	○	○		
350	65	A B C	○	○	○	○	○	○	○	○	○
400	75	A B C	○	○	○	○	○	○	○	○	○
450	80	A B C	○	○	○	○	○	○	○	○	○
500	90	A B C	○	○	○	○	○	○	○	○	○
600	100	A B C	○	○	○	○	○	○	○	○	○
700	110	A B C	○	○	○	○	○	○	○		
800	120	A B C	○	○	○	○					
1 000	140	A B C	○	○	○	○					
1 200	150	A B C	○	○							

Remark: Subject to the agreement between the parties concerned, the lengths of 5 m and 6 m can be applied.

Table 3. Dimensional Tolerances

Unit: mm

Item / Outside diameter	Length	Outside diameter	Wall thickness
300 to 600	± 0.3 (%) of the length of PC pile	+ 5 - 2	+ not specified 0
700 to 1000		+ 7 - 4	

Remarks 1. The outside diameter of PC pile is defined as the average of two measurements taken along the axis at right angle to each other in a cross section.

2. The wall thickness of PC pile is defined as the average of four measurements taken along the axis at right angle to each other in a cross section.

3. The tolerance of the outside diameter of the jointing end portion shall be $^{+0.5}_{-3}$ mm with respect to the outside diameter of PC pile specified in Table 2.

8. Bending Strength Test

8.1 The bending strength test of main body shall be made by the application of vertical load P to the centre of the span, on the PC pile laid on two supports which has a span equal to 3/5 of its length, as shown in Fig. 2.

Any countermeasure may be taken to prevent the occurrence of local fractures at the loading or supporting points before the PC pile breaks by bending.

The bending moment shall be calculated from the following equation:

$$M=\frac{1}{40}g_n mL+\frac{P}{4}\left(\frac{3}{5}L-1\right)$$

where M : bending moment (tf·m){kN·m}

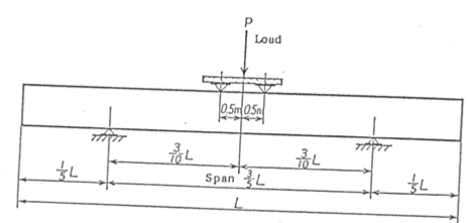
g_n : acceleration due to gravity (1 tf/t){9.81 m/s²}

m : mass of PC pile (t) (see Reference Table)

L : length of PC pile (m)

P : load (tf) {kN}

Fig. 2. Loading Method



9.2 Appearance, Shape and Dimensions The inspection on appearance and shape shall be made for all products and the inspection for dimensions shall be made for the piles sampled from a set of PC piles, and when the requirements of 3.1 and 5. are satisfied, this set shall be acceptable as a whole. Number of PC piles included in set and number of PC piles to be sampled are decided in accordance with the agreement between the parties concerned in delivery.

9.3 Bending Strength of Main Body and Jointing End

9.3.1 The cracking inspection for main body shall be made by making the cracking test in accordance with 8.1 for the two PC piles sampled from a lot of PC piles, and the whole lot shall be decided as acceptable, if both two meet the requirements of 3.2. In the case where either of the two fails to meet the requirements of 3.2, additional four piles sampled from the lot shall be subjected to cracking test, and the whole lot shall be decided as acceptable, if all the four meet the requirements. The size of lot shall be determined upon agreement between the parties concerned.

9.3.2 In the destructive inspection of main body, either of the initial two samples shall be tested in accordance with 8.2, and the whole lot shall be decided as acceptable, if they meet the requirements of 3.2.

The destructive inspection may be omitted, subject to an agreement between the parties concerned.

9.3.3 The jointing end shall be inspected similarly to the main body. This inspection, however, may be omitted, subject to an agreement between the parties concerned.

9.4 Arrangement of PC Steels and Reinforcement The inspection on arrangement of the PC steels and reinforcement shall be made for the PC pile which has been subjected to the destructive inspection in accordance with 9.3.2, and the arrangement shall be decided as acceptable, if it meets the requirements of 7.1.

On that occasion, the wall thickness of the broken part in the PC pile shall also be inspected.

10. Designation

The PC piles shall be designated in the order of the symbol PC indicating pretensioned spun concrete pile, classification, outside diameter (mm) and length (m).

Example: PC-A 500-11

11. Marking

The PC piles shall be marked with the following particulars:

(1) Designation

(2) Manufacturer's name or its abbreviation

(3) Name or abbreviation of manufacturing works

(4) Date of forming

Reference: The following Reference Table shows the long term acceptable axial loads and the masses of the PC piles for the reference of practical use.

The mass of PC piles have been calculated from the following equation, on the assumption that the mass for unit volume of PC pile is 2.6 t/m^3 and $\pi = 3.14$, and rounded off to the second decimal place in accordance with JIS Z 8401.

$$m = 2.6\pi t(D - t)L$$

where
- m : mass (t)
- D : outside diameter (m)
- t : wall thickness (m)
- L : length (m)

Reference Table

Outside diameter mm \ Length m	Mass t									Long term allowable axial load tf (kN)		
	7	8	9	10	11	12	13	14	15	Class A	Class B	Class C
300	0.82	0.94	1.06	1.18	1.29	1.41	1.53			50 (490)	45 (441)	40 (392)
350	1.06	1.21	1.36	1.51	1.66	1.81	1.97	2.12	2.27	60 (588)	55 (539)	55 (539)
400	1.39	1.59	1.79	1.99	2.19	2.39	2.59	2.79	2.98	80 (785)	75 (736)	70 (686)
450	1.69	1.93	2.17	2.42	2.66	2.90	3.14	3.38	3.62	100 (981)	90 (883)	85 (834)
500	2.11	2.41	2.71	3.01	3.31	3.62	3.92	4.22	4.52	125 (1 226)	115 (1 128)	105 (1 030)
600	2.86	3.27	3.67	4.08	4.49	4.90	5.31	5.71	6.12	170 (1 667)	155 (1 520)	145 (1 422)
700	3.71	4.24	4.77	5.30	5.83	6.36	6.89			220 (2 158)	200 (1 961)	190 (1 863)
800	4.66	5.33	6.00	6.66						280 (2 746)	250 (2 452)	235 (2 305)
1 000	6.88	7.86	8.85	9.83						415 (4 070)	370 (3 629)	350 (3 432)
1 200	9.00	10.29								540 (5 296)	490 (4 805)	465 (4 560)

JIS 5373

About PC Products by JIS 5373

3.1 Group I

PC products whose conformity with the stated performance is confirmed by actual results, which are manufactured based on such specification, and whose recommended specifications are indicated in Annexes

3.2 Group II

PC products whose performance and specifications are defined by the agreement between the parties concerned with delivery and which are manufactured based on such specifications

4 Classification

PC products shall be classified as specified in table 1 by the application.

Products shall be classified into Group I and Group II according to the determination method of performance and specifications.

Table 1 Classification of PC products

Classification	Applicable clause in Annex
Poles	See **A.2**.
Bridges	See **B.2**.
Retaining walls	See **C.2**.
Covered conduits	See **D.2**.
Piles	See **E.2**.
Other products Example: Disaster prevention facilities	Shall be subjected to the agreement between the parties concerned with delivery.
NOTE: Group I is listed in the recommended specifications of Annexes; however, Group II has no recommended specifications.	

HOLLOW SPUN PILES

Annex E (normative)
Piles

E.1 Outline

This Annex specifies Group I and Group II of piles which are used mainly for the foundation piles among the PC products specified in this Standard.

E.2 Classification

The classification of piles shall be as specified in table E.1.

In addition, Group I shall be as specified in table E.2.

Table E.1 Classification of piles

Major division	Minor division
Piles	Prestressed concrete pile (PC pile, ST pile, knot pile)
	Prestressed reinforced concrete pile (PRC pile, PRC knot pile)
	Others

Table E.2 Classification of Group I of piles

Classification	Division by external diameter mm	Division by effective prestress N/mm^2	Detail
Prestressed concrete pile (PC pile, ST pile, knot pile)	300 to 1 200	4.0 to 10.0	See recommended specification E-1.

— The effective prestress shall be obtained by calculation. The calculated value shall be in the range of ±5 % of each value.

— The PC pile has the same cross section over the entire length. The ST pile is a PC pile having the cross section which enlarges toward on one end. The knot pile is a PC pile of which the body is provided with knots.

NOTE : The piles of external diameter exceeding 1 200 mm may be adopted. In this case, performance values shall be according subject to the agreement between the parties concerned with delivery.

E.3.1 Performance of body of piles

The performance of body of piles shall conform to the provisions of table E.3.
In addition, the performance items of Group II shall be subjected to the agreement between the parties concerned with delivery.

Table E.3 Performance of body of piles

Performance item	Performance	Performance check method
Service stage performance	Shall be safe to the regular load assumed at the time of use, and crack width shall be less than the permissible value.	See design document or **E.6**.
End stage performance [a)]	Shall not break due to the load assumed at the time of end stage.	See design document or **E.6**.
Durability [b)]	Durability shall be secured against deterioration assumed.	See design document or actual results.
Workability	Workability for transportation, installation, assembly, etc. shall be secured.	See design document or actual results

Notes a) Confirmation of the end stage performance shall be made when requested by the purchaser.

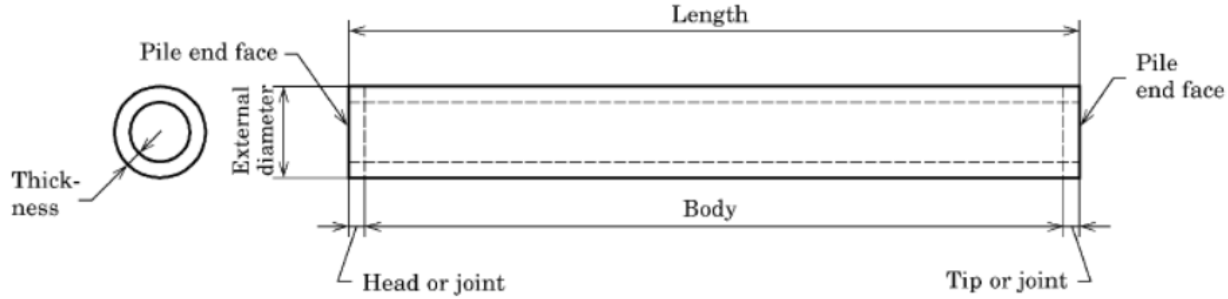
b) Durability may be confirmed by the actual results of such similar products as are equivalent in terms of water-cement ratio and/or covering of reinforcing bar, etc.

E.3.2 Performance of joint part

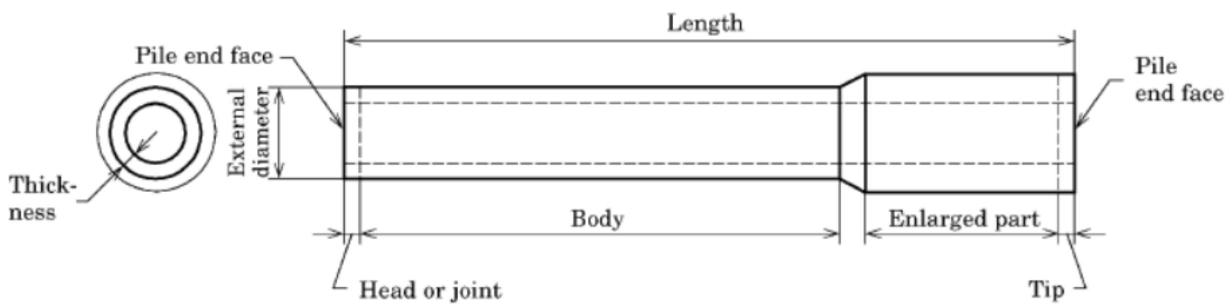
The performance of joint part shall be as follows.

a) **Bending strength of joint part :** The joint part shall not break when it is sub jected to the break bending moment of the end stage performance for the body specified in E.3.1.

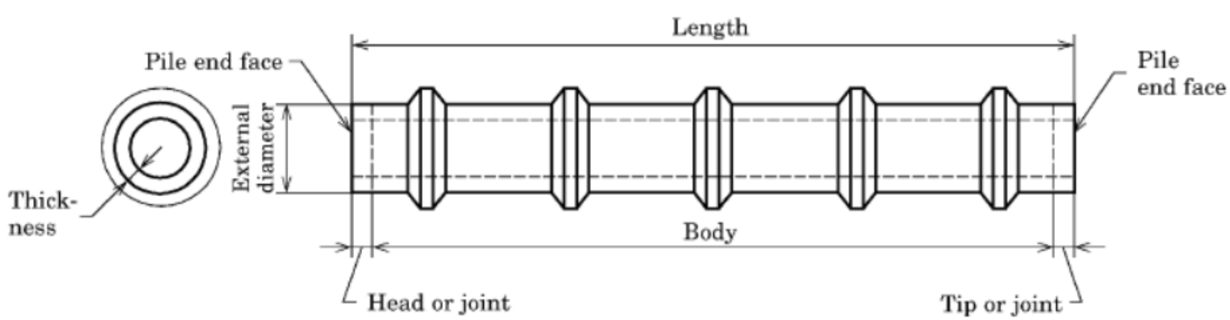
b) **Connectivity (squareness of joint end face) :** The joint end face shall be at right angles with the pile axis line within the deviation of 1mm per 300 mm.



a) PC pile, PRC pile



b) ST pile



c) Knot pile

Figure E.1 Example of shapes of piles

E.4 Shape, dimensions and dimensional tolerances

The shape, dimensions and dimensional tolerances of piles shall be as follows. As to Group I, if the design concept is not different, and if the performance (quality) and the performance (quality) check method are the same, the reference dimension may be changed within ±10 % in response to the purchaser's demand, provided that the necessary performance (quality) is satisfied.

a) **Shape** An example of shapes of piles is shown in figure E.1.

A PC pile and a PRC pile have a hollow cylinder body, having a suitable tip, a joint or a head, if needed. An ST pile has a diameter enlarged part at its end. The maximum length of the diameter enlarged part shall be twice the external diameter of the diameter enlarged part. Also, an ST pile may be provided with a suitable tip, a joint or a head, if needed. Moreover, a knot pile is a PC pile of which the body is provided with knots. The outside diameter of the knot part shall be in the range in which the performance of the body is not compromised. Also, the knot pile may be provided with a suitable tip, a joint or a head, if needed.

b) **Dimensions and dimensional tolerances** The dimensions and dimensional tolerances of the products classified into Group I shall be as specified in table E.4. The dimensions and dimensional tolerances of the products classified into Group II shall be subjected to the agreement between the parties concerned with delivery.

Table E.4 Dimensions and dimensional tolerances of piles

Classification		External diameter mm		Thickness mm	Length m
Prestressed concrete piles (PC piles, ST piles, knot piles)	Dimensions	300 to less than 700	700 to 1 200	60 to 230	4 to 15
	Tolerances	+5 −2	+7 −4	+Not specified −0	±0.3 (%) of length
— The length of a pile shall be designated in increments of 1 m. — The outside diameter of a pile shall be the average of two values measured along the axis perpendicular to a cross section of the body. — The thickness of a pile shall be the average of four values measured along the axis perpendicular to a cross section of end face of the body.					

E.5 Bar arrangement (position of prestressing tendon and reinforcing bar)

The bar arrangement shall be as specified in **JIS A 5364** and a design document. However, according to the agreement between the parties concerned with delivery, the bar arrangement other than that of the recommended specification may be adopted in the range in which the product performance (including the provisions of **E.3**) is not compromised. For the bar arrangement of the piles, the manufacturer shall define the bar arrangement so as to satisfy **E.3** for each product.

E.6 Test Method

6.1. Compressive Strength Test
6.2. Bending Strength Test
6.3. Axial Tension Bending Strength Test
6.4. Shear Strength Test

E.6.1 Compressive strength test

The compressive strength test shall be as specified in **JIS A 1132** and **JIS A 1108**, or **JIS A 1136**.

E 6.2. Bending Strength Test

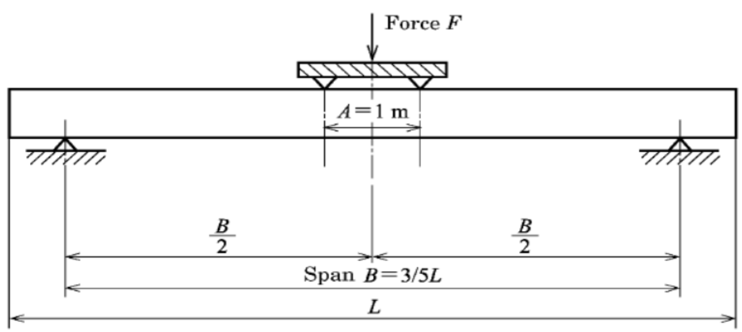


Figure E.2 Loading method of bending strength test

$$F = \frac{8M - mg(2B - L)}{2(B - A)}$$

where,
F : loading force (kN)
M : bending moment (kN·m)
m : mass of pile (t)
g : standard acceleration of gravity (9.81 m/s²)
B : span (m)
L : length of pile (m)
A : bending span (m) $A = 1.0$

E 6.3. Axial Tension Bending Strength Test

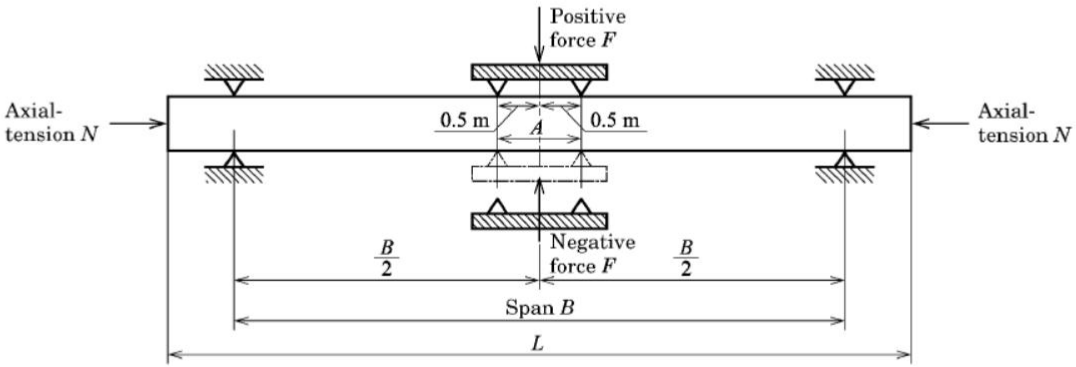


Figure E.3 Loading method of axial-tension bending strength test

In the case of a positive force,

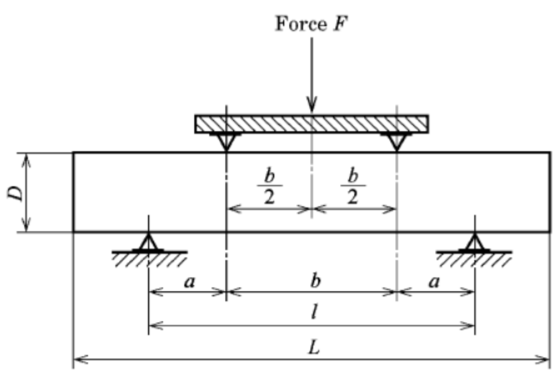
$$F = \frac{8M - mg(2B - L) - 8\delta N}{2(B - A)}$$

In the case of a negative force,

$$-F = \frac{-8M - mg(2A - L) + 8\delta N}{2(B - A)} - mg$$

where,
- F : loading force (kN)
- M : bending moment (kN·m)
- m : mass of pile (see values in of recommended specification E-1 table 5) (t)
- g : standard acceleration of gravity (9.81 m/s²)
- L : length of pile (m)
- B : span (m) $B \geq 7.0$
- δ : relative deflection of centre part (m)
- N : axial-tension (kN)
- A : bending span (m) $A = 1.0$

E 6.4. Shear Strength Test



b : bending span (loading span) (m) $b = 1.0$

a : shearing span (m) $a = 1.0D$

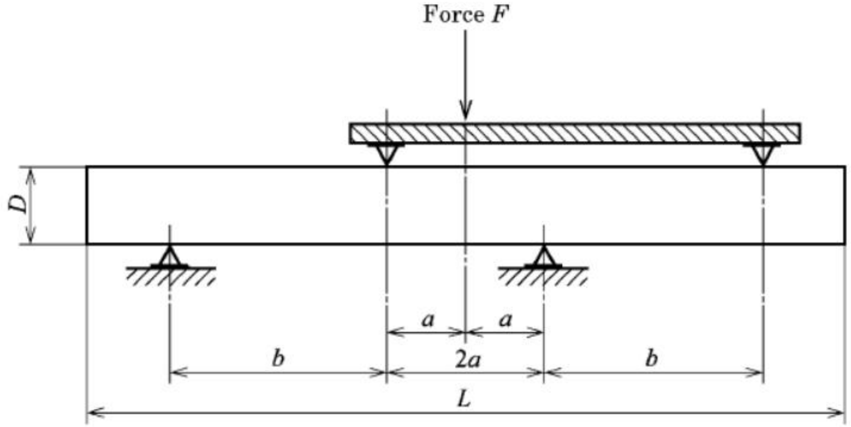
D : external diameter (m)

Figure E.4 Loading method of shear strength test (loading by simple beam form)

$$F = 2Q$$

where,
- F : loading force (kN)
- Q : shear strength (kN)

E.6.4. Shear Strength Test



$$F = \frac{Q(2a+b)}{b}$$

where, F : loading force (kN)

Q : shear strength (kN)

b : distance between loading point and outside fulcrum (m)

a : shearing span (m) $a = D - t/2$

t : thickness (m)

D : external diameter (m)

b : bending span (loading span) (m) $b = 1.0$

a : shearing span (m) $a = 1.0D$

D : external diameter (m)

Figure E.5 Loading method of shear strength test (loading by overhang beam form)

E.6.5 Measuring method of squareness of joint end face

For the measurement of squareness of the joint end face, a square shall be set as it in line with the axis of external diameter of a pile, and the amount of inclinations about the external diameter of a pile shall be measured.

E.7 Quality of concrete

E.7.1 Material and production method

The material for concrete and the production method shall be as specified in **JIS A 5364**.

E.7.2 Compressive strength

The compressive strength of concrete shall be verified by the compressive strength of the sample which has been processed by the same curing as the product or the compressive strength which has been controlled properly. When the predetermined material aging is finished, the strength shall be 80 N/mm^2 or more for the effective prestress of 4.0 N/mm^2, and the strength shall be 85 N/mm^2 or more for the effective prestress of over 4.0 N/mm^2. Moreover, the compressive strength at the time of prestress introduction shall be 40 N/mm^2 or more.

In addition, products of Group II shall be subjected to the agreement between the parties concerned with delivery and the compressive strength of concrete may be as specified in Annex A of **JIS A 5364**.

E.8 Inspections

Inspections shall be as specified in **JIS A 5365** and the following.

a) **Final inspection** The final inspection of piles shall be conducted for the appearance, performance, shape and dimensions, and shall be as follows.

1) **Appearance** For the appearance, it shall be a 100 % inspection or a sampling inspection in consideration of the characteristics of product, manufacturing method, production quantity, etc.

2) **Performance, shape and dimensions** For the performance, shape and dimensions, the inspection shall be a sampling inspection.

When the performance is inspected by a sample as alternative characteristics, the correlation between the sample and the product shall be established.

3) **Size of inspection lot** The size of inspection lot shall be determined by the manufacturer in consideration of the characteristics of product, manufacturing method, production quantity, production period, ordered quantity, etc.

Any product in the inspection lot shall have the same characteristics, and shall be manufactured using the same materials, concrete mix proportion and manufacturing process, etc.

b) **Delivery inspection** The delivery inspection of piles shall be conducted for the appearance, shape and dimensions. The size of inspection lot and the sampling method shall be subjected to the agreement between the parties concerned with delivery, and shall be specified by the purchaser. The delivery inspection may be omitted subjected to the agreement between the parties concerned with delivery.

E.9 Marking

The marking items on piles shall be the following as specified in **JIS A 5361**. Moreover, the PC pile, ST pile and knot pile among the piles manufactured by centrifugal force compaction shall be marked as PHC.

a) Classification or its abbreviation

b) Manufacturer's name or its abbreviation

c) Date of manufacture or its abbreviation

E.10 Others (recommended specification)

Group I of covered conduits is shown in table E.5.

Table E.5 Recommended specification

Structure-specific product group standard		Recommended specification
JIS A 5373	Annex E Piles	Recommended specification E-1 Prestressed concrete piles

Specification 1

Specification of the PHC

	Pile diameter (mm)	Concrete Strength (Mpa)	Type	Thickness (mm)	PC steel bar: Diameter (mm)	PC steel bar: Number	PC steel bar: Diameter of cage (mm)	Pile weight (ton/ m)	Cross sectional area ×10² (mm²)	Conversion cross section area ×10² (mm²)	Geometric moment of inertia ×10⁴ (mm⁴)	Conversion Geometric moment of inertia ×10⁴ (mm⁴)	Conversion section coefficient ×10³ (mm³)	Amount of prestress (Mpa)	Standard bending moment: Cracking (kN·m)	Standard bending moment: Breaking (kN·m)	Standard bearing capacity, Safety factor : 3.5: Long-term (kN)	Standard bearing capacity, Safety factor : 3.5: Short-term (kN)	Shearing Strength (kN)	Tensile Strength (kN)	Length (m)
	D	Fc		t			PCD		Ao	Ae	Io	Ie	Ze	σce	Mc	Mu	N	2N			L
Normal	300	80	A	60	7.1	6	240	0.119	452	462	34,607	35,336	2,355	4.0	25.9	39.0	872	1,744	101	231	6～12
			B		9.0	8				474		36,169	2,411	8.0	36.1	70.4	704	1,408	128	474	6～15
			C		9.0	10				479		36,560	2,437	10.0	41.4	82.1	616	1,232	139	599	
	350		A	60	7.1	7	290	0.142	546	558	59,925	61,167	3,495	4.0	38.4	55.0	1,053	2,106	121	279	6～12
			B		9.0	10				573		62,776	3,587	8.0	53.8	105.3	852	1,704	152	573	6～15
			C		9.0	12				579		63,346	3,619	10.0	61.5	120.2	744	1,488	166	723	
	400		A	65	7.1	10	335	0.179	684	700	99,576	101,944	5,097	4.0	56.0	87.9	1,321	2,642	151	350	6～13
			B		9.0	12				716		104,142	5,207	8.0	78.1	148.4	1,064	2,128	190	716	
			C		10.7	11				726		105,492	5,274	10.0	89.6	177.7	933	1,866	207	907	
	500		A	80	9.0	9	420	0.274	1,055	1,079	241,198	246,581	9,863	4.0	108.4	161.8	2,036	4,072	232	539	6～15
			B		10.7	14				1,109		253,032	10,121	8.0	151.8	300.0	1,648	3,296	293	1,109	
			C		10.7	17				1,120		255,568	10,222	10.0	173.7	344.3	1,440	2,880	319	1,400	
	600		A	90	9.0	12	510	0.374	1,441	1,474	483,427	494,008	16,466	4.0	181.1	263.2	2,780	5,560	317	737	6～15
			B		10.7	18				1,510		505,861	16,862	8.0	252.9	479.2	2,244	4,488	400	1,510	
			C		10.7	23				1,530		512,093	17,069	10.0	290.1	570.1	1,967	3,934	435	1,912	
Special	400	80	A	80	7.1	10	335	0.209	804	821	109,377	111,745	5,587	3.5	58.9	88.2	1,585	3,170	174	364	6～15
			B		9.0	12				836		113,943	5,697	7.0	79.9	149.1	1,324	2,649	217	735	
			C		10.7	11				846		115,293	5,764	8.8	91.1	180.0	1,189	2,379	235	931	
	500		A	100	9.0	9	420	0324	1,256	1,281	267,035	272,417	10,896	3.4	114.3	162.2	2,480	4,960	270	559	6～15
			B		10.7	14				1,310		278,869	11,154	6.9	155.8	302.2	2,081	4,163	338	1,141	
			C		10.7	17				1,321		281,405	11,256	8.7	176.9	349.2	1,868	3,736	367	1,441	
	600		A	110	9.0	12	510	0.436	1,693	1,725	533,818	544,399	18,146	3.5	191.2	263.7	3,333	6,667	363	763	6～15
			B		10.7	18				1,762		556,252	18,541	7.0	260.3	482.3	2,787	5,574	453	1,551	
			C		10.7	23				1,781		562,484	18,749	8.8	296.7	578.2	2,499	4,998	493	1,966	

Specification 2

Formula for calculating Working Load

$$Rma = (Fc/Sm - \sigma e) \times Ae$$

Rma：Working Load (kN)
Fc：Concrete Strength(Mpa)
Sm：Safety factor ・・・【3.5】
σe：Effective Prestress(Mpa)
Ae：Conversion Cross-sectional area(mm^2)

Ae=Ac+As(Es/Ec-1)
Ec=37,000N/mm2(70N)
Ec=38,000N/mm2(80N)
Es=200,000N/mm2

The Standard of JIS A 5373

Standard Bending capacity (Long-term)

$$N = \{(Fc / S - \sigma ce) \times Ae\} / 100$$

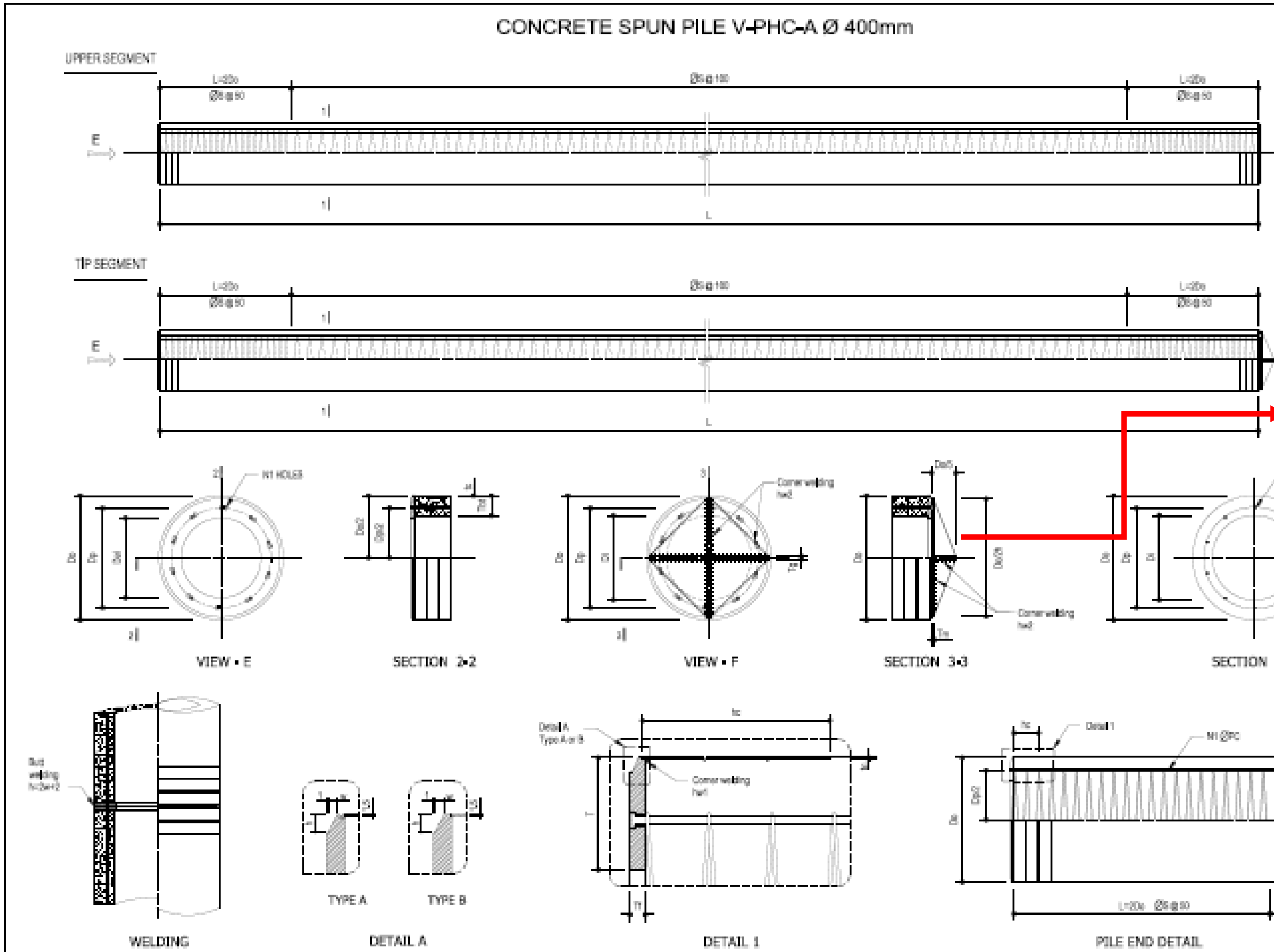
S : Safety factor (3.5)

Standard bending moment (Cracking)

$$M = \{Ie / ro \times (7 + \sigma ce)\} / 100$$

ro : D / 2

Spun Pile Drawing (Sample)

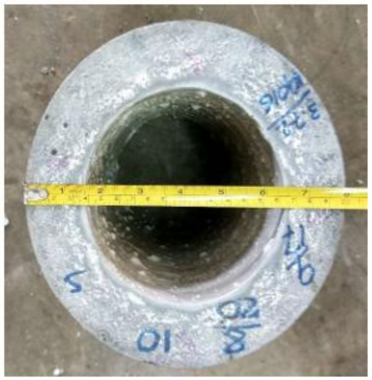


LENGTH	DIMENSION					CLASS	PC BAR		STANDARD BENDING MOMENT		CAL AXIAL BEARING CAPACITY		TENSION CAPACITY	SHEAR CAPACITY	SPIRAL			END FLANGE		COLLAR		DETAIL A			PILE TIP			WORKING LOAD
L (m)	Do (mm)	Dp (mm)	Di (mm)	Dsl (mm)	Ths (mm)	A	Diameter ØPC(mm)	N1 (nos)	Mcr (kN.m)	Mu (kN.m)	Rsl (kN)	Ras (kN)	Qat (kN)	Qas (kN)	Diameter (mm)	@End (mm)	@Middle (mm)	Thickness Tf(mm)	Width T(mm)	Height hc(mm)	Thickness tc(mm)	w (mm)	h (mm)	hwf (mm)	Tm (mm)	Tg (mm)	hw2 (mm)	120 (T)
6~15	400	335	270	270	65		7.1	10	56.2	87.3	1321	2642	350	151	3	50	100	12	65	100	1.5	5	0.5	1	6	10	5	

Compressive Strength Test

Compressive Strength Test Condition of PHC Cylindar Pile
(Spun Result)

Test Specification ……….. JIS A 1136
*Strength = Load /crossectional area *1000 = 1555.8/ 19016.34*1000*
Test result = 81.81 Mpa



Test piece

Test piece

Compressive strength test

Test result

Compressive Strength Test Condition of PHC Cylindar Pile
(Spun Result)

1. Take sample (Spun Type)
2. Measure the dimensions,- concrete thickness at four points and calculate average thickness of these sample- height of these sample
3. calculate the crossectional area
4. Test these sample with compression test machine
5. Take data ,applied load ,at crack point
6. Calculate the compressive strength (Mpa

Slump Test

Bending Strength Test

Bending Strength Test Report

for

Spun Pile (D500mm , Type B)

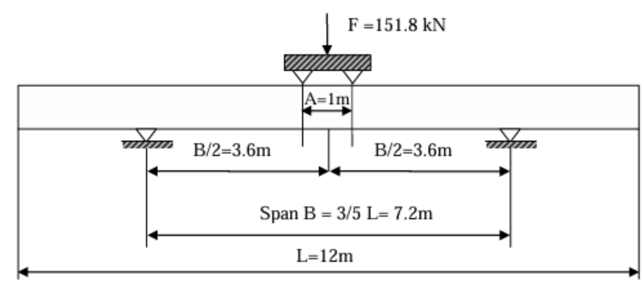
1. Project information

Project	=	Development of Container Terminal Project, Ahlone Port, Yangon, Myanmar
Employer	=	Adani Yangon International Terminal Co., Ltd
EPC Contractor	=	ITD Cementation India Limited
Pile Contractor	=	Myanmar V-Pile Co., Ltd

2. Test pile details

Pile type	=	Prestress spun pile (PHC pile)
Pile Dia & Type	=	500mm, B
Compressive strenght	=	80 N/mm2
Length	=	12m
Test location	=	VJP factory, Thilawa

3. Testing Diagram



4. Calculating of Cracking Load of Dia 500mm, B PHC Pile , L = 12m

The loading force F shall be calculated from the bending moment according to the following formula:

$F = \frac{40M - gmL}{2(3L - 5A)}$ = 151.8 kN (Cracking standard value)

F = loading force (kN)
M = bending moment (kN.m)
m = mass of pile (ton)
L = length of pile (m)
A = bending span
g = gravity acceleration

5. Load Calculation Table

Bending test report of the 80N/㎟ PHC pile

1.Specification of the test body

VJP. Co. ltd

Diameter (mm)	Type	Length L(m)	Span l (m)	Weight m (t)	Product date	Test date	Age (date)	Product No.
500	B	12m	7.2m	3.288	27-May-20	16-Jun-20	20	1036

Factory Manager	Quality GL	staff
on behalf of		

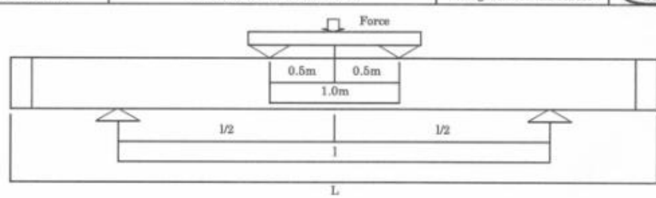
2.The outward appearance and size test result of the test body

Unit:(mm)

Inspection item		Standard value	A permissible difference	Actual value	Judgment
outward appearance		There is not a harmful wound		There is not a wound · There is a wound	Good · NG
Size	Diameter	500	+5mm, -2mm 1565 ~ 1586	Circumference : 1581 Diameter : 503.2	
	Length	12,000	± 0.3 % 11964 ~ 12036	11,982	
	Thickness	80	+There is no rule -0mm	1. 91 2. 89 3. 90 4. 91 Ave 90.25	

3.Bending proof stress test result

Test method	Test is based on JIS A 5373	Judgment of the result	Good NG



Calculation formula of Loading force $F = \frac{8M \cdot mg(2l \cdot L)}{2(l \cdot b)}$

36

Bending span b=1.0(m)

Earth gravity acceleration g : 9.81(m/s²)

	Crack inspection		Final inspection	
	Moment Mcr(kN · m)	Force Fcr (kN)	Moment Mu (kN·m)	Force Fu (kN)
Desing value	151.8	91.7	300.0	187.3
Actual value	155.4	94.0		
Actual value/Desing value	1.02	—		—

Force (kN)	Moment (kN·m)	Remarks
0.00	9.7	
26.50	50.8	
52.00	90.3	
76.00	127.5	
91.70	151.8	Crack Standard value (no crack)
94.0	155.4	There is no crack . Pass the test

6. Comparison of Force and Moment result

BENDING TEST RECORD AT SPUN PILE FACTORY, SEZ THILAWA ZONE A, THANLYIN TOWNSHIP

D 500B -12m

Date : 16.6.2020

Step	Force	Moment KN.m	Inspection Crack / Break	Action Jackup	Load Cell	Test Pile
1	0	9.7		Jackup		
2	26.6	50.9		Jackup		
3	52	90.3		Jackup		
4	76.1	127.6		Jackup		
5	91.7	151.9	Standard Crack Value (No Crack)	Jackup		
6	94.9	156.8	No Crack Pass The Test	Jackup		

7. Reference testing photos

The reference photo of testing can be seen as per below photos:

3.0 Seismic Performance and Improvement of PHC Pile

3.1 Structural and Material Characteristics Relevant to Earthquake Loads

Prestressing: PHC piles are prestressed with high-strength steel strands, applying compressive stress to concrete, which enhances resistance to tensile forces induced by bending during seismic activity.

Concrete Quality: Centrifugal casting and steam curing produce very dense, low-permeability concrete resistant to deterioration over time.

Reinforcement: Use of spiral wire or steel bars as confinement helps resist shear and flexural stresses.

Joint and Tip Durability: Pile tips may be reinforced with steel shoes or additional spiral reinforcement to prevent damage during driving and under seismic forces.

Earthquake Load Considerations and Seismic Performance

Primary Seismic Concern: Earthquakes impose significant lateral (horizontal) loads, causing bending moments and tensile stresses in piles.

Failure Modes: Common failure patterns observed in earthquakes is bending damage, often due to tensile fracture of prestressed tendons.

Ductility: PHC piles show varying ductility depending on reinforcement type; those reinforced with steel bars and strands exhibit better load stability and energy dissipation after cracking compared to those with only steel reinforcement.

Stiffness Degradation: Repeated seismic cycles increase cracks and plastic deformation, reducing stiffness; coatings like BFRP can help maintain stiffness and elastic behavior.

Energy Dissipation: Enhanced by ductility and reinforcement detailing, improving pile resilience to cyclic seismic loads.

Experimental Findings: Low-cycle loading tests indicate that PHC piles wrapped with BFRP or reinforced with steel strands and bars show superior bearing capacity, better hysteretic behavior, and slower stiffness degradation compared to conventional steel reinforced piles.

1. Overview of PHC Pile Foundations in Seismic Context

PHC (Prestressed High-Strength Concrete) piles are widely used deep foundation elements owing to their **high bearing capacity**, quality control, and efficiency in construction. They are especially prevalent in bridge piers, viaducts, and soft soil areas.

Seismic design of PHC piles is critical because, despite their strength, PHC piles exhibit **limited ductility** and tend to behave in a **brittle manner** under seismic excitations. The main damage mode is often **bending failure** due to seismic lateral forces, and tendons inside the pile can fracture under cyclic loads.

2. Seismic Behavior and Failure Mechanisms of PHC Piles

Past earthquake observations (e.g., Kobe 1995) demonstrate that PHC piles fail predominantly by **bending damage** at regions of maximum moment, especially at the pile head and at soil layer transitions.

Damage modes include **fracture of prestressing tendons, concrete crushing, buckling of reinforcement, and cracks** in the pile shaft.

•Due to the **limited energy dissipation capacity** and **stiffness degradation** under cyclic loading, PHC piles must be designed considering their vulnerability to **brittle failures** during major seismic events.

3. Design Considerations for PHC Piles in Seismic Zones

a) Seismic Load Estimation and Soil Profile Analysis

•Seismic load effects on PHC piles depend on:

- **Seismic zone classification** indicating regional seismic hazard.
- **Soil conditions**, especially liquefiable vs. non-liquefiable soils that influence lateral load and pile response.
- **Groundwater table** and soil layering affect liquefaction potential and thus pile bending demands.

•Codes of practice such as **IS 1893 (India)**, **Eurocode 8**, **NEHRP,ASCE** and **Japanese codes and Local code** provide guidelines on seismic load determination, including consideration of **base shear**, **bending moments from soil-structure interaction**, and **liquefaction potential**.

b) Fundamental Failure Mechanisms Under Seismic Loading

PHC pile design must consider multiple mechanisms:

1. **Inertial Bending** (due to superstructure seismic inertia forces)
2. **Kinematic Bending** (due to soil motion/wave propagation)
3. **Lateral Spreading Bending** (especially with liquefaction)
4. **Buckling Instability** (in long slender piles, especially with loss of lateral soil support)
5. **Settlement and End Bearing Failure**
6. **Dynamic Failure** (changes in stiffness/frequency under seismic loading)

4. Experimental and Numerical Findings

- Low-cycle cyclic loading tests show:
    - PHC piles reinforced with **steel strands and steel bars** demonstrate improved seismic performance compared to traditional reinforced PHC piles.
    - Application of **BFRP/CFRP wrapping** significantly enhances bearing capacity and ductility by limiting crack propagation and stiffness degradation.
    - Stiffness degradation and energy dissipation characteristics vary markedly depending on reinforcement type and detailing.
- Finite element models incorporating soil-pile interaction (via p-y springs or more advanced CDP models) capture nonlinear seismic response and help design safe and economical PHC pile foundations.

5. Practical Design Recommendations

- Conduct **site-specific seismic hazard and detailed geotechnical investigations**, including liquefaction potential assessment using methods like **Idriss & Boulanger**.

- Estimate seismic loads on super-structure per relevant codes; model load transfer to piles considering **both inertial and kinematic interactions**.

- Design PHC piles with appropriate **reinforcement types**, consider **steel strands or BFRP/CFRP wrapping** to improve seismic ductility and strength.

5. Practical Design Recommendations

- Avoid brittle failure by providing adequate **transverse reinforcement** and considering **plastic hinge formation locations**.

- For liquefiable soils, **ignore shaft friction within liquefied layers**, increase pile embedment or length accordingly, and design piles as columns subjected to bending and buckling under reduced lateral soil support.

- Implement **structural mitigation systems** (e.g., steel bracing, shear panel dampers) in pile-supported superstructures, especially viaducts, to reduce seismic damage and drift.

Summary

PHC piles require careful seismic design to mitigate their innate brittleness, focusing on soil-pile interaction, liquefaction effects, and advanced reinforcement techniques. International best practices emphasize conservative treatment of soil capacity under seismic load, detailed failure mechanism consideration, and enhanced ductility measures (e.g., steel strands, BFRP/CFRP polymer wrapping, and seismic dampers).

Design Recommendations and Standards

- Reinforcement Modification: To improve seismic resilience, longitudinal reinforcement and confinement (e.g., spiral reinforcement pitch, use of hybrid fibers) can be increased or optimized.

- Axial Load and Bending Moments: Design should account for combined axial compression and cyclic horizontal loads; PHC piles typically have greater bending moment capacity than bored or precast piles.

- Material Choice: Use of appropriate cement types (Type II, III, or V depending on sulfate/chloride exposure), blended cements with supplementary cementitious materials for enhanced durability.

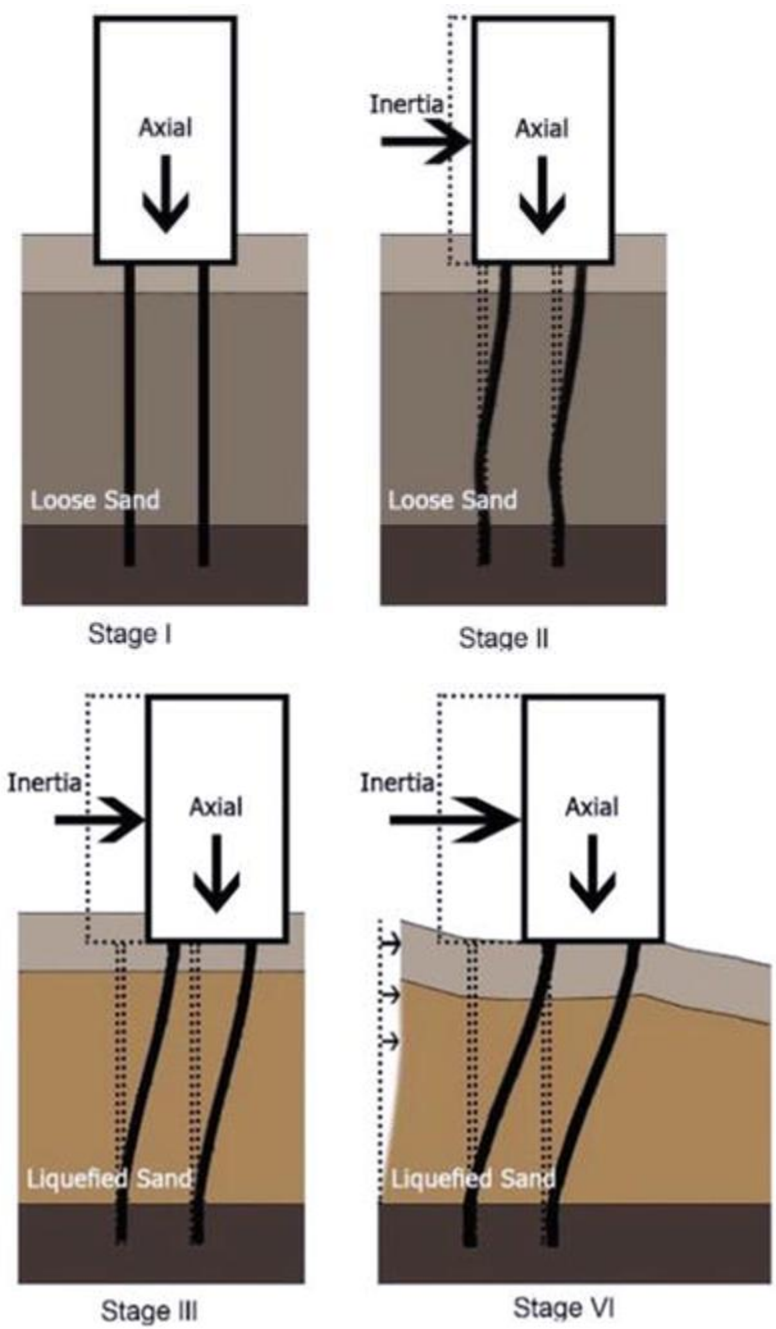
- Installation and Handling: PHC piles must be designed to withstand tensile stresses and impacts during transportation and driving.

- Codes and Specifications: Compliance with relevant standards such as JIS A 5335, MS 1214, BS 8004, and ACI 543R, considering seismic detailing provisions where applicable.

Summary of Practical Benefits of PHC Piles in Seismic Areas

- High strength concrete and prestressed steel provide excellent resistance to bending, tensile, and shear forces induced by earthquakes.
- Dense concrete and prestressing reduce cracking, enhancing durability under seismic and environmental loads.
- Ability to modify reinforcement details (e.g., use of BFRP/CFRP wrap, hybrid bars) improves ductility, energy dissipation, and overall seismic performance.
- Proven track record in Japan and other seismic regions for over 40 years as safe and economical foundation solutions.
- In conclusion, PHC piles represent an advanced, durable, and seismic-resistant foundation technology. Their prestressed high-strength concrete composition and optimized reinforcement schemes provide improved performance against earthquake-induced bending and lateral loads, supporting structural safety in seismic regions.

Failure Mode of PHC Piles




(a) Compressive failure


(b) Shear failure

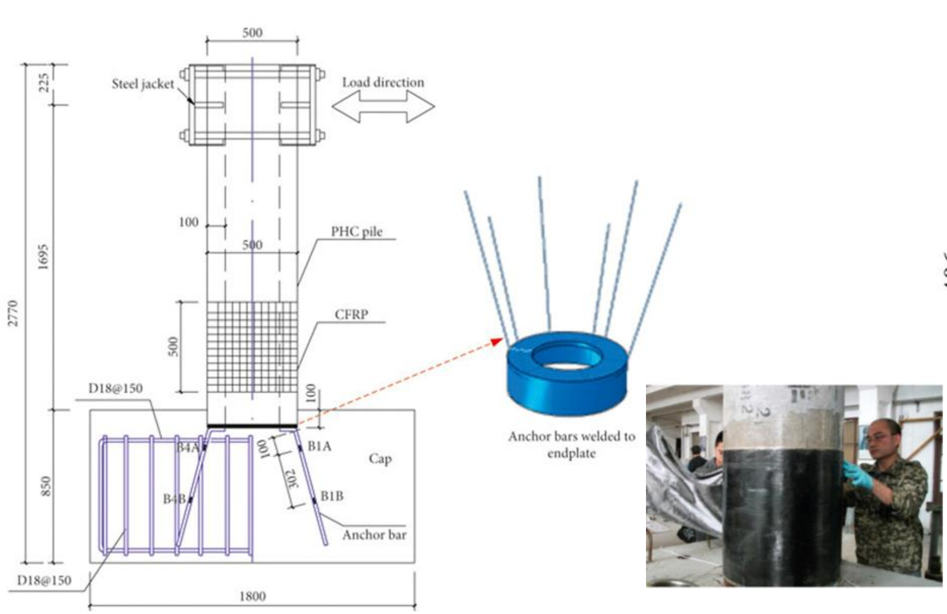

(c) Shear and compressive failure


(d) flexure failure

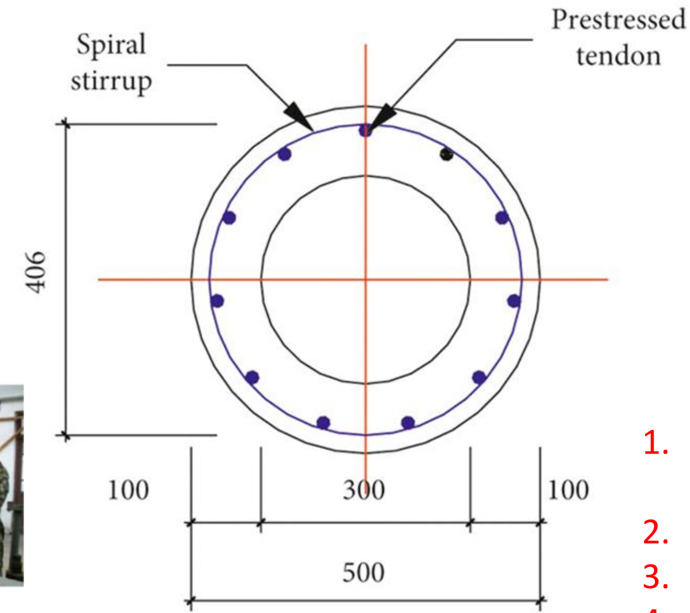
Seismic Performance of PHC pile and Pile Cap Connection

- The flexural and shear performance on the mixed-reinforced PHC piles and found that the flexural performance of the PHC pile was improved, but non-prestressed tendons reduced the deformation of the pile under shear. Extensive laboratory component tests of PHC and PRC piles were conducted. These results indicated that axial load, longitudinal reinforcement ratio, and prestressed reinforcement ratio significantly role increased the bearing capacity and seismic performance of PHC piles

- That the addition of non-prestressed reinforcement could significantly improve the seismic performance and deformation capacity of PHC piles.

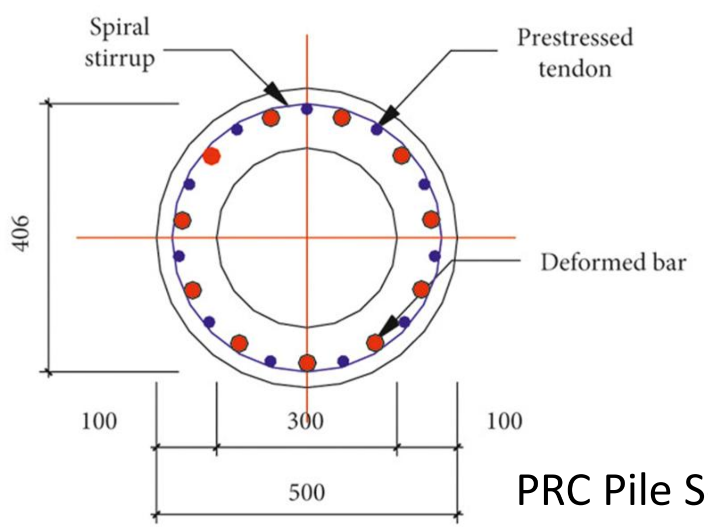


The connection Between Pile and Pile Cap



PHC Pile Section

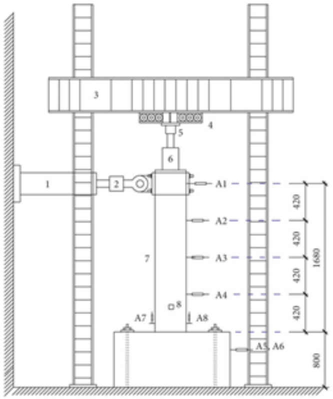
1. Prestressed bar
2. CFRP
3. Anchor bar
4. Stirrups

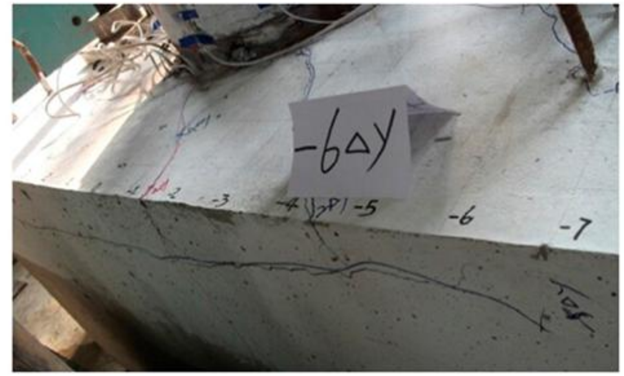


PRC Pile Section

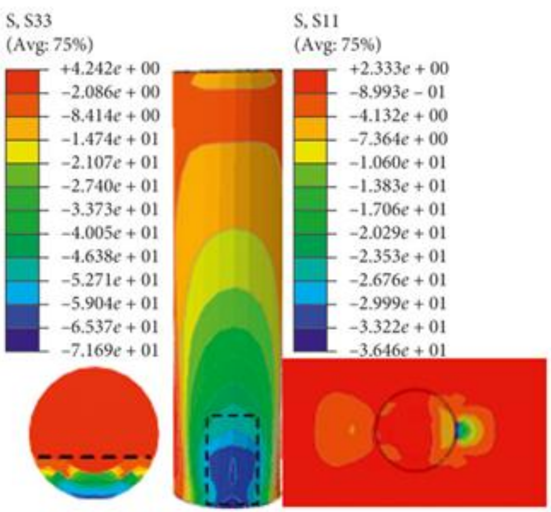
Specimen	*D* (mm)	*t* (mm)	Prestressing bars	Stirrup	Anchor bars	Improved measure of PHC pile
CT-7	500	100	11**A**9.0	**A**5@80	6B18	—
CT-8	500	100	11A9.0	A5@80	6B18	Three layers of CFRP
CT-9	500	100	11A9.0	A5@80	6B18	Volume fiber content 1.0%
CT-10	500	100	11A9.0	A5@80	6B18	11**B**14

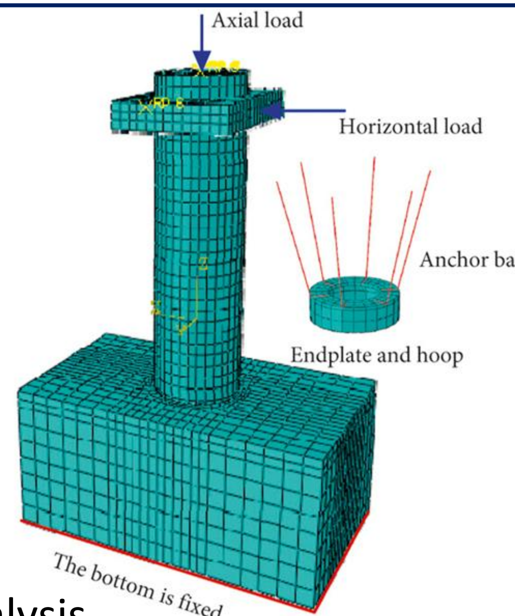
Steel	*d* (mm)	f_y (MPa)	f_u (MPa)	E_s (MPa)
Prestressing tendon	**A**9.0	—	1560	2.0×10^5
Deformed steel bars	**B**14	403	600	2.0×10^5
	B18	352	583	2.0×10^5
Stirrup	**A**5	—	601	2.0×10^5



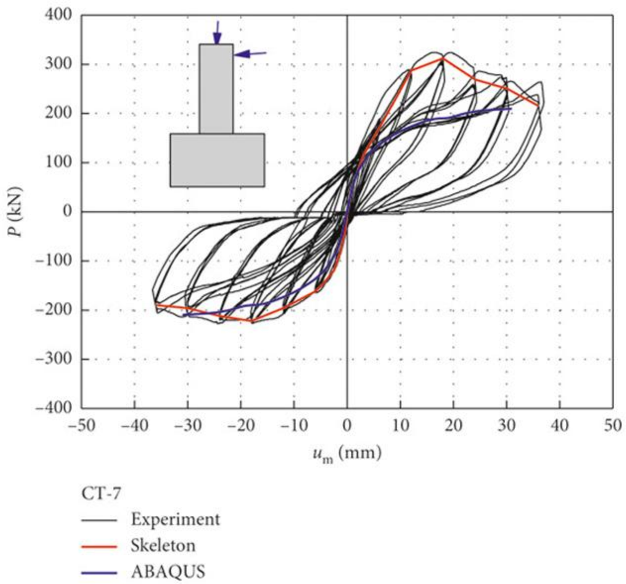


Experimental Method





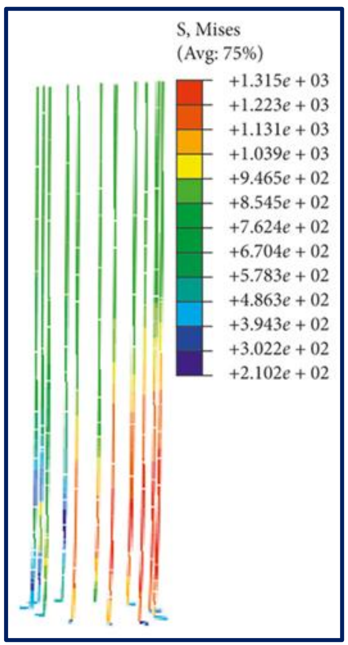
Finite Element Analysis

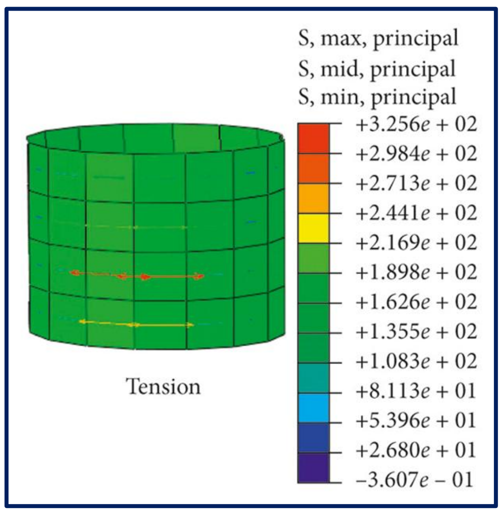


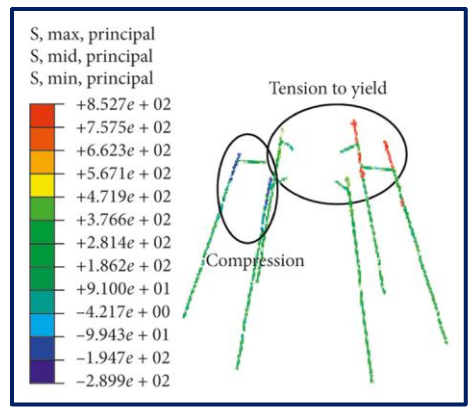
Comparison Between Experimental and Finite Element Analysis results.

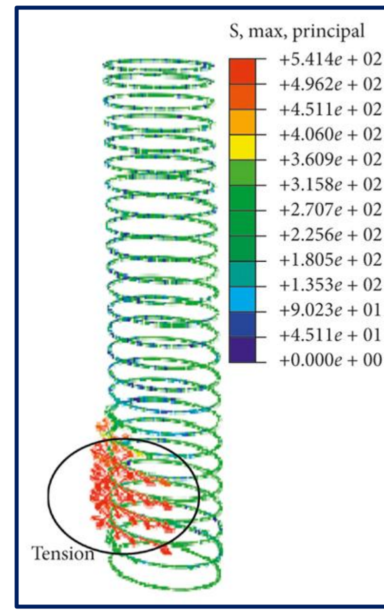
Specimen	P_{Eu} (kN)		P_{Fu} (kN)		P_{Eu}/P_{Fu}	
	Forward	Reverse	Forward	Reverse	Forward	Reverse
CT-7	312	−215	218	−218	0.70	1.01
CT-8	246	−273	293	−293	1.19	1.07
CT-9	273	−170	225	−225	0.82	1.32
CT-10	232	−324	281	−281	1.21	0.87

Note. P_{Eu} is the experimental result and P_{Fu} is the finite element analysis result.









1. Prestressed bar

2. CFRP

3. Anchor bar

4. Stirrups

13 Stories Building Failure in Shanghai

(a)

(b)

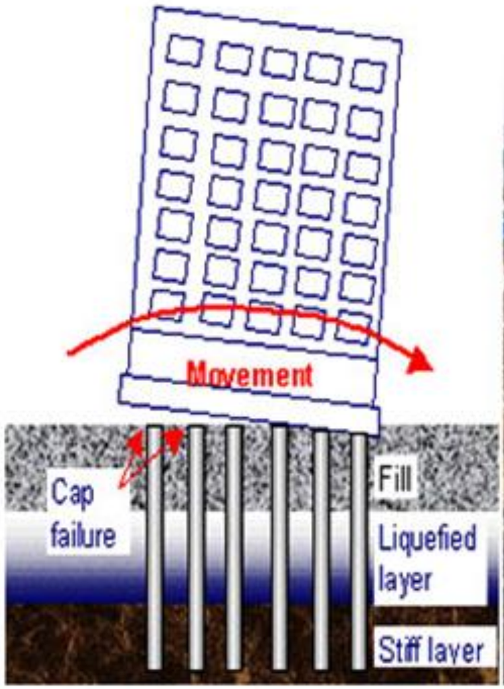
(c)

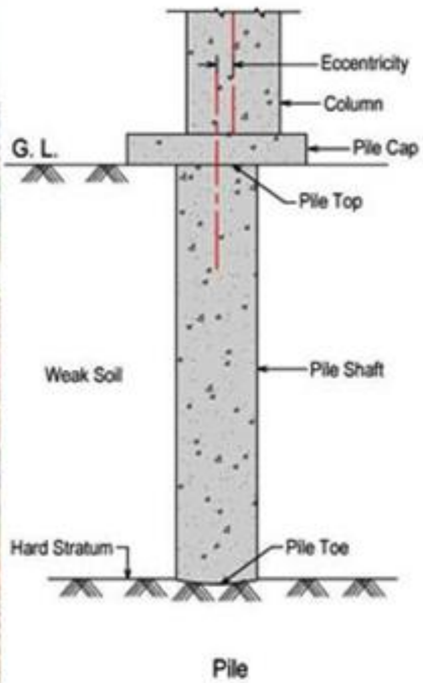
(d)

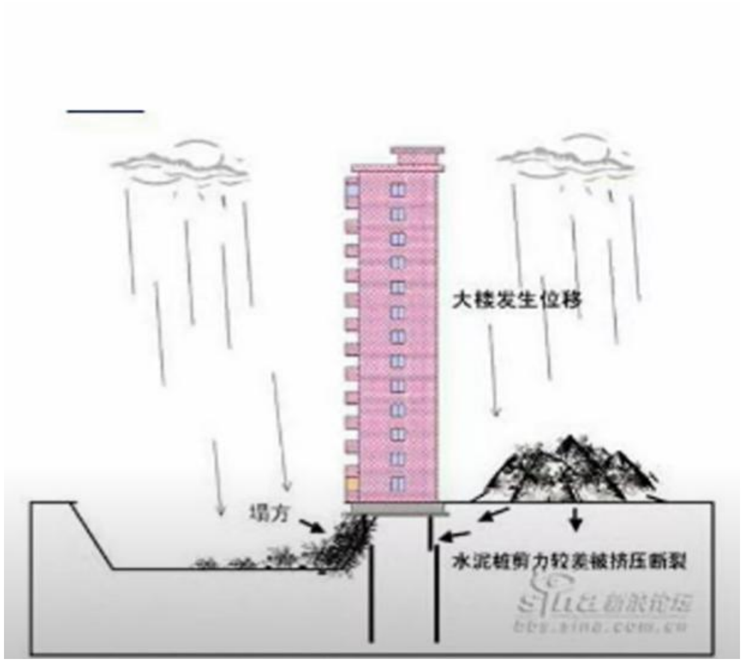
(e)

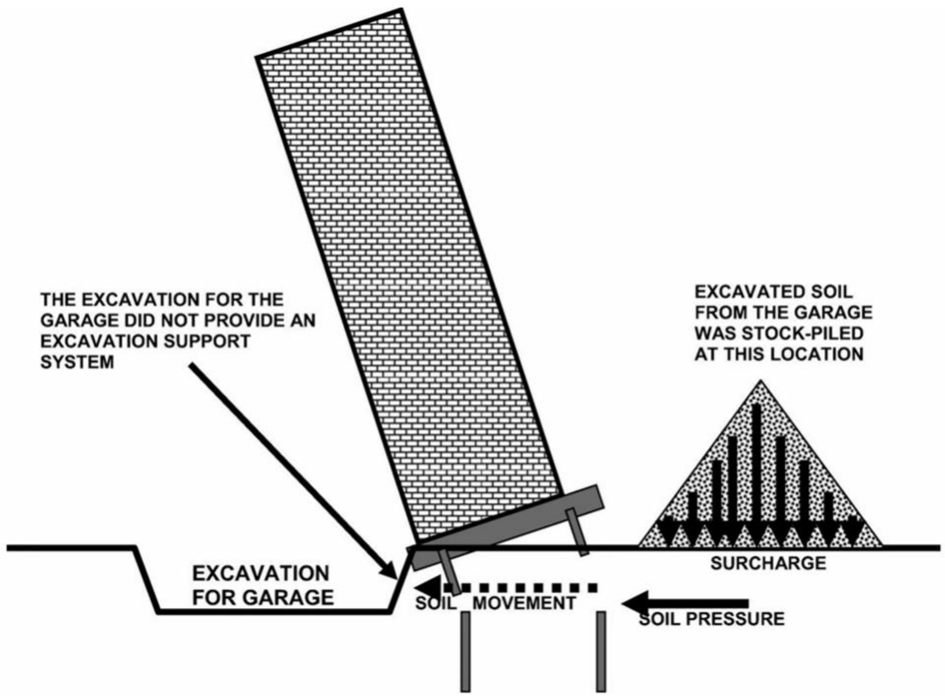
(f)

Reasons for concrete pile foundation failure?



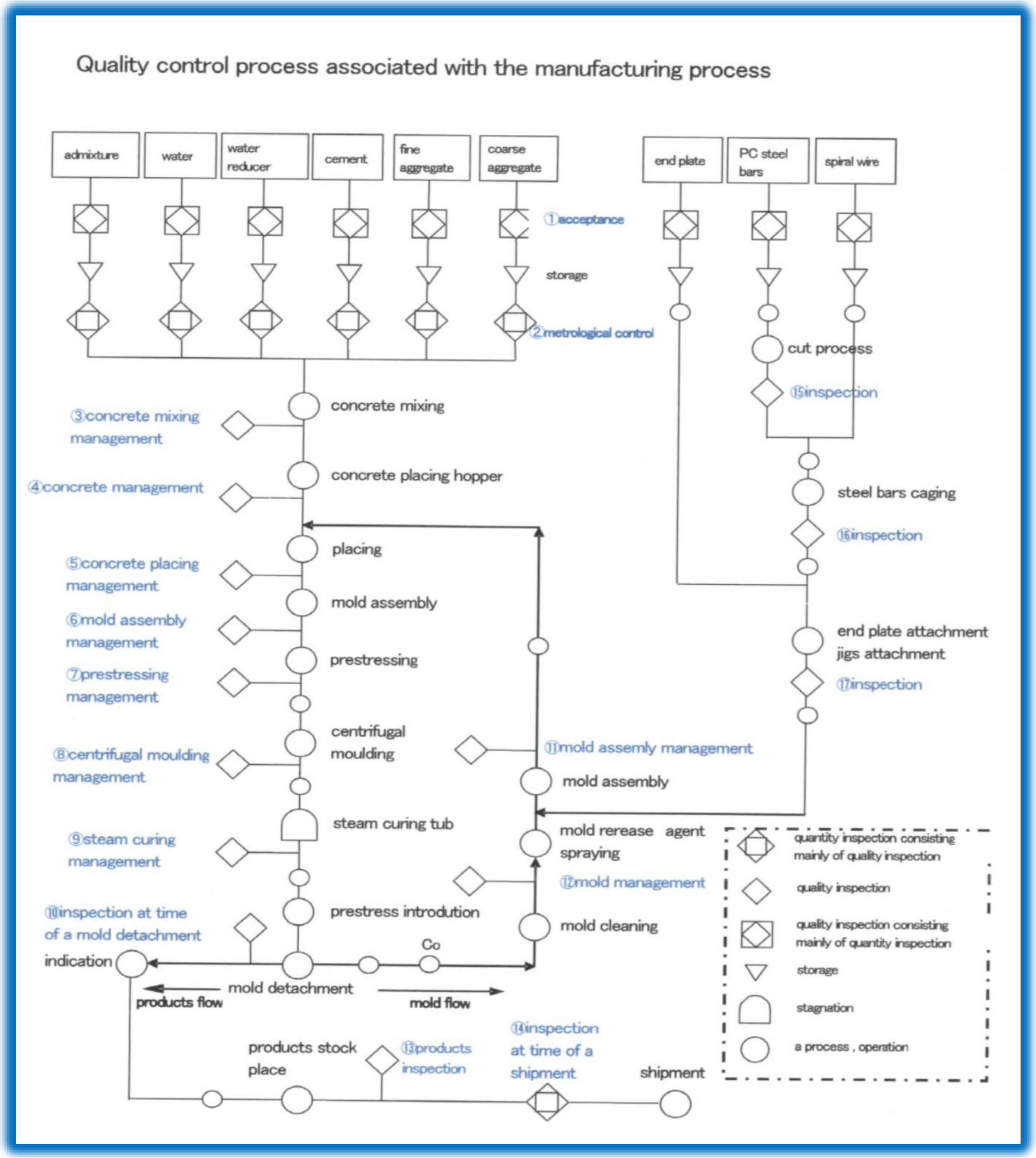



大楼发生位移
塌方
水泥桩剪力较差被挤压断裂


THE EXCAVATION FOR THE GARAGE DID NOT PROVIDE AN EXCAVATION SUPPORT SYSTEM
EXCAVATED SOIL FROM THE GARAGE WAS STOCK-PILED AT THIS LOCATION
EXCAVATION FOR GARAGE
SURCHARGE
SOIL MOVEMENT
SOIL PRESSURE

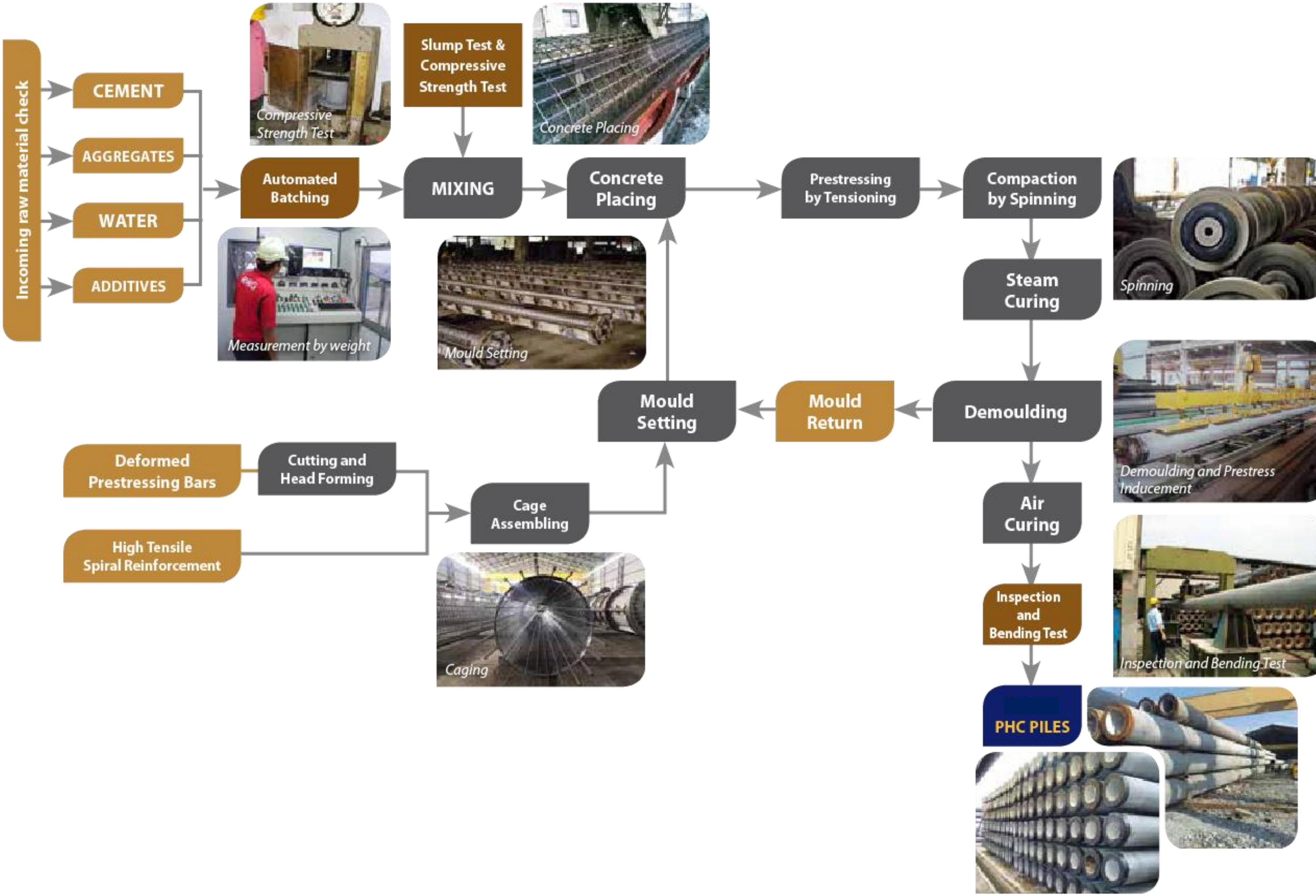
4.0 PHC Spun Pile Manufacturing

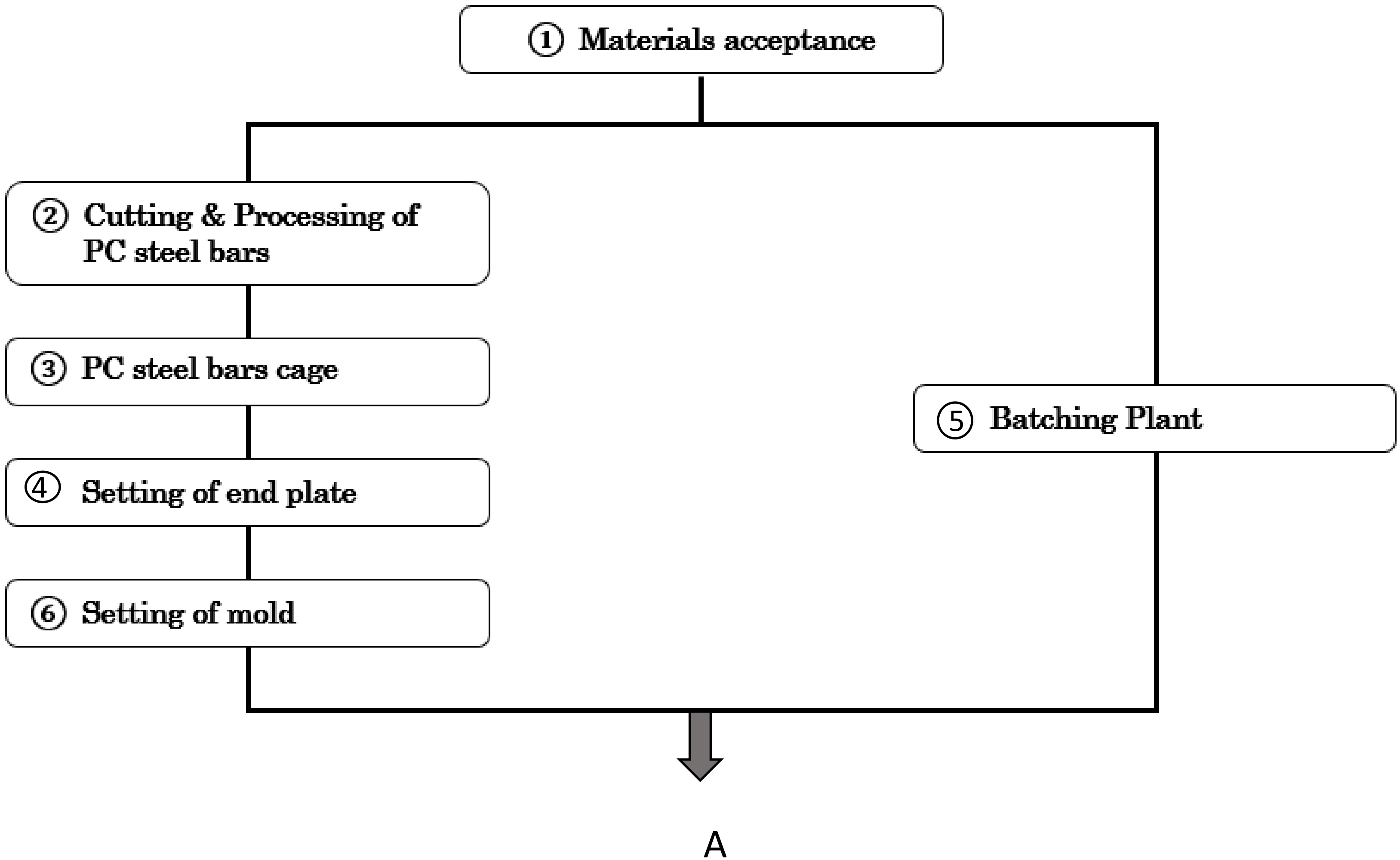
4.1 Quality Control Process

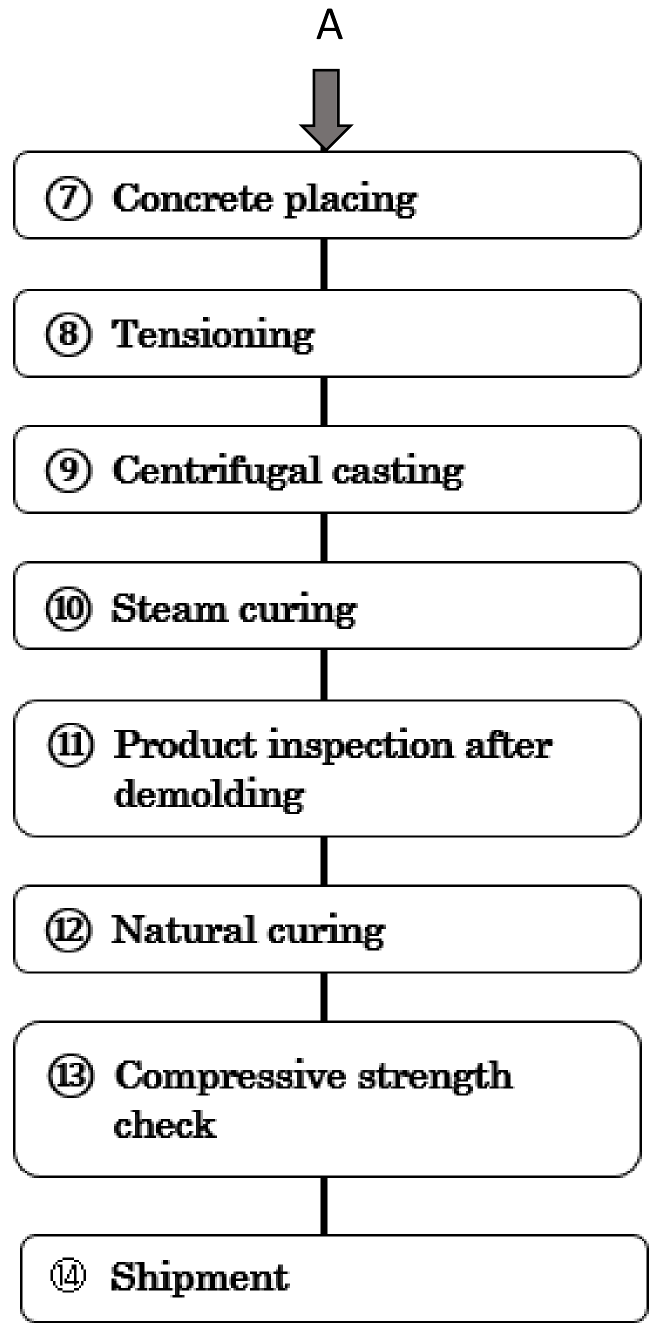


4.2 Manufacturing Process

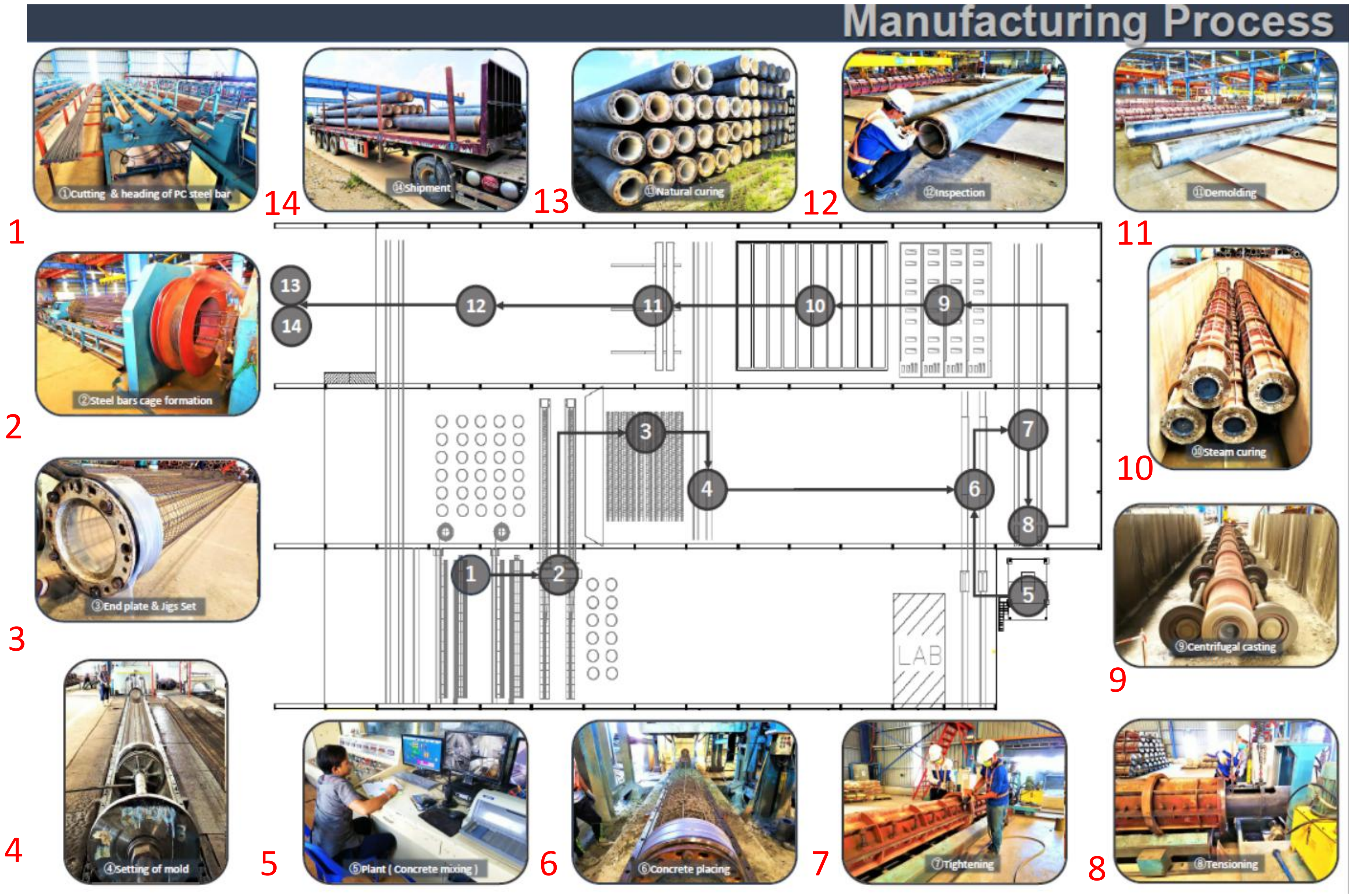
Flow Chart




① Materials acceptance
② Cutting & Processing of PC steel bars
③ PC steel bars cage
④ Setting of end plate
⑥ Setting of mold
⑤ Batching Plant
A


A
⑦ Concrete placing
⑧ Tensioning
⑨ Centrifugal casting
⑩ Steam curing
⑪ Product inspection after demolding
⑫ Natural curing
⑬ Compressive strength check
⑭ Shipment

Manufacturing Process (Factory Floor Plan)



GENERAL SPECIFICATION

Materials Specifications

Cement : SCG Cement / Double Rhino Cement

Coarse Aggregates : Chippings under-20mm or under-15mm fresh granite

Fine Aggregates : Sand

Prestressing steel : High frequency induction heat-treated bars

Wire : Spring wire

Concrete Strength

Minimum concrete strength = 70~80N/mm ^{2}

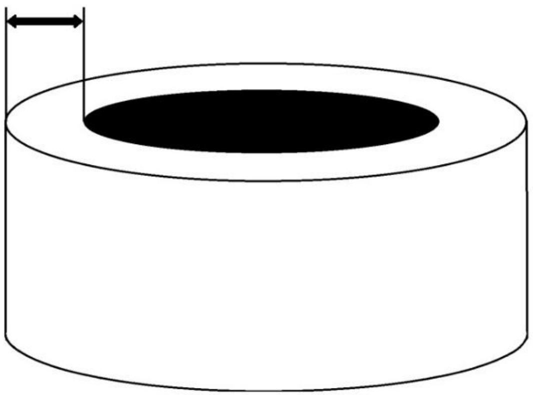
Pile Connection Joint

Three type of joint . There are – Welding joint , Steel plate screw joint , Hydraulic press joint.

In current time we are using welding joint only.

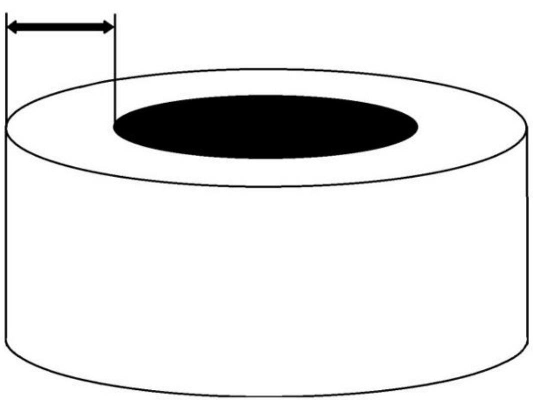
PHC Pile production work process

- PHC Pile size production in Factory



Basic Concrete Thickness

Basic Diameter (mm)	Weight per 1m (t/m)	Thickness (mm)
300	0.119t	60
350	0.142t	60
400	0.179t	65
500	0.274t	80
600	0.374t	90



Special concrete thickness

Basic Diameter (mm)	Weight per 1m (t/m)	Thickness (mm)
300	0.132t	70
350	0.160t	70
400	0.209t	80
500	0.324t	100
600	0.436t	110

FEATURES Of PHC Pile

- High Bending Moment and Crack Resistance.
- A reinforced PHC pile is highly resistance to earthquakes.
- 70~80 N/mm ^{2} concrete strength.
- Prestressed .(Pre- Tension)

Spun Pile

Material and equipment checking

- Before starting the work inspection will check the material and equipment such as Cement , Fine aggregate , Coarse aggregate ,Water , Chemical, PC steel Bar , Steel Wire ,Mould , Safety equipment of worker and crane lifting wire etc.
- PPE (Personal Protective Equipment) inspection , occupational accidental prevent.
- Check aggregate surface moisture and must be inspected material situation.
- Material inspection , can control the quality of product.

PC Steel checking

PPE inspection

PC steel bar cutting and Heading

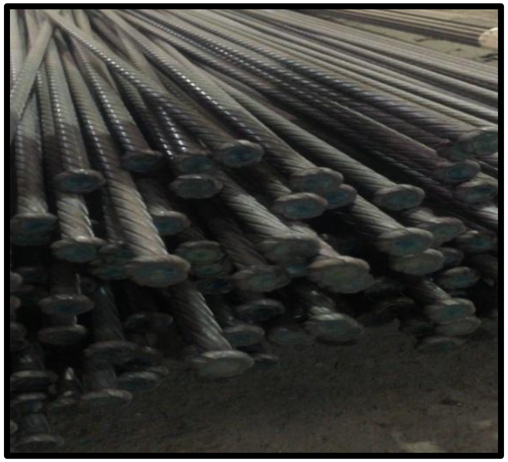
- PC steel bar is used for prestressed and placed into the PHC pile.

PC Bar Cutting machine

PC requirements of the lengths, diameters and can control the machine by manual.

To connect the end plate and prestress.

Heading machine



After heading processed finish

Cage Making

- The following machine with a PC steel bar which together Spring wire automatic welding machine.

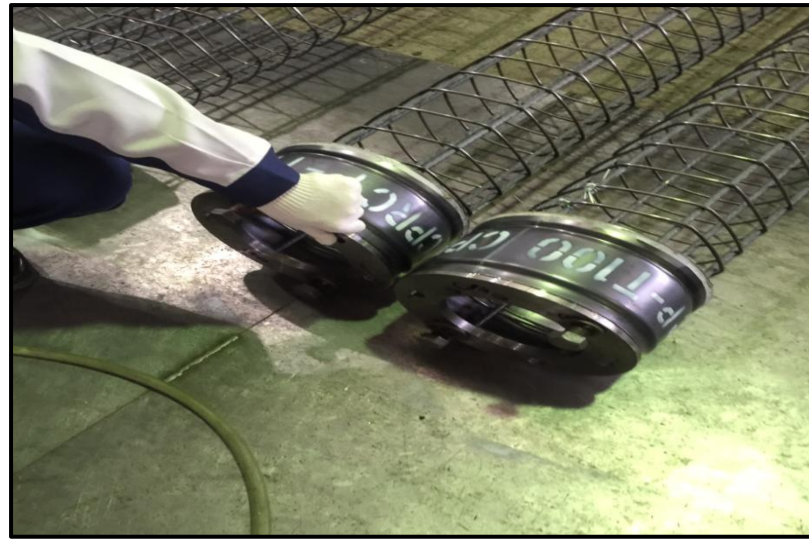
Automatic welding machine

Connected the steel bar with both end

Set end plate and steel cage

- Before connection with end plate, tie with spring wire and PC steel bar by automatic rebar tying machine. Setting the end plate both end of pile steel cage.

Rebar tying

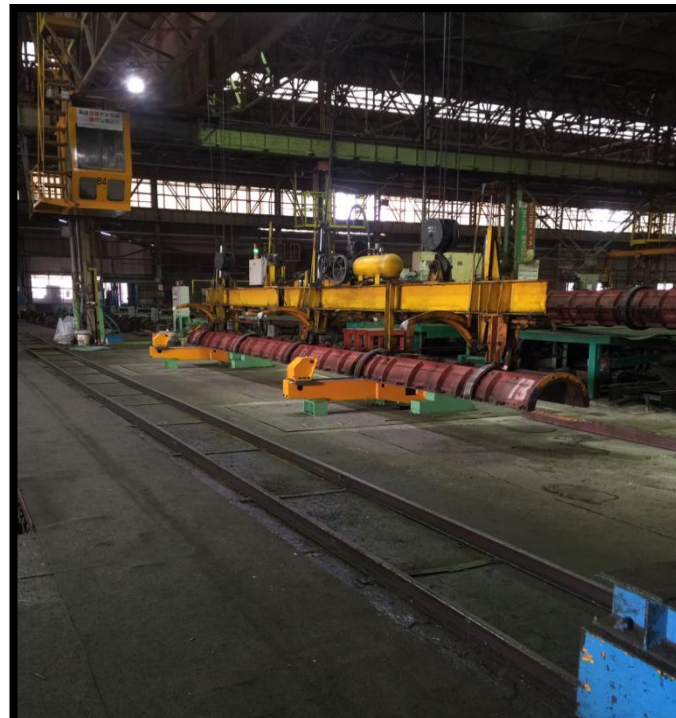


End plate and PC cage connect

Mould Cleaning

- The concrete residues and dirty thing removed on the mould.
- Used by mould oil for cleaning.
- Upper mould and lower mould must clean inside.
- Used machine to turn back and clean the upper mould.

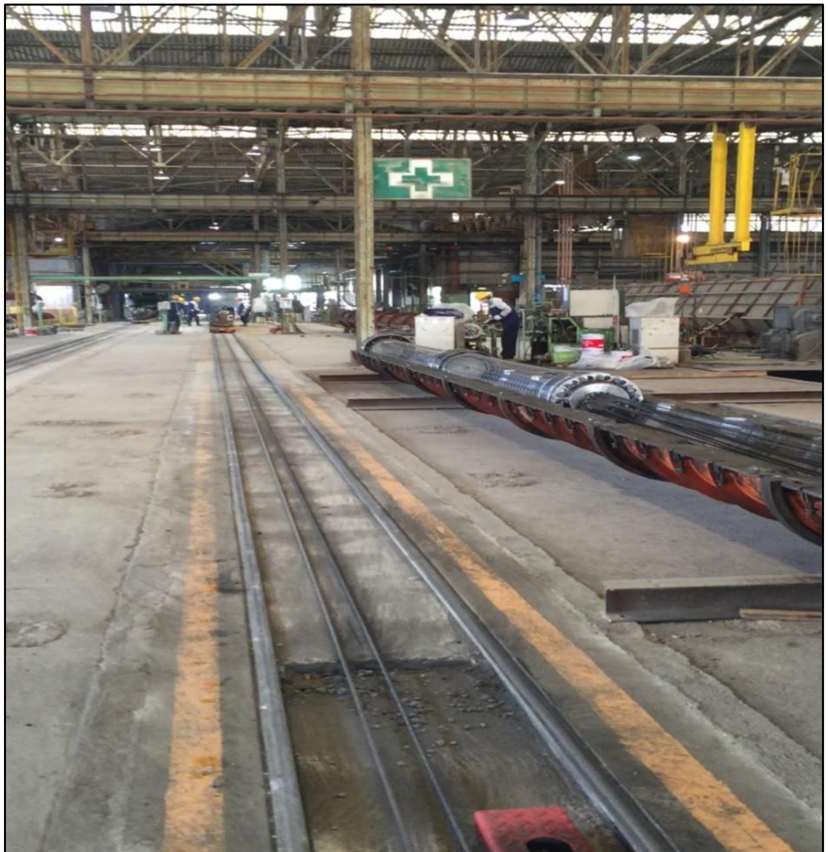
mould Oil spray



Upper mould turn back machine

Setting the steel cage in the form

- After finished the mould cleaning, steel cage set into the mould.
- Ready to cast the concrete.

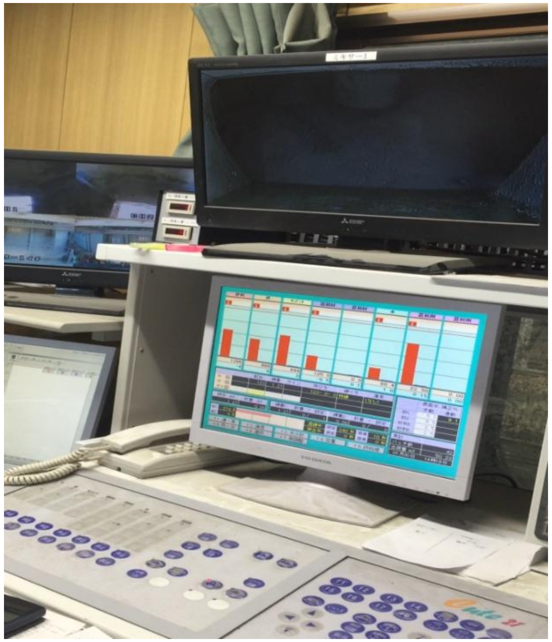


Setting the steel cage in the mould

Mixer control operator room

- Mixer operator check and control the concrete mixing and measure the material.
- Once mixing sets concrete with soft or hard touch looks trial.
- Check the CCTV with concrete mixing in the mixer.
- Control by manual for mixing.

Check concrete by CCTV



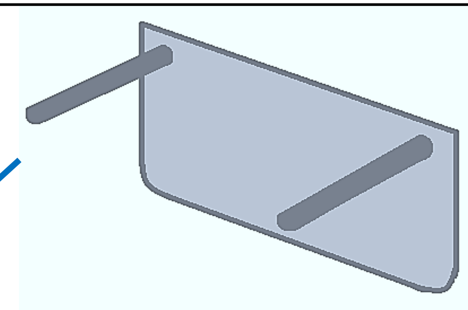
Control the mixing

Measure the cement

Concrete casting

- Need to control man powers
- The worker must to do ensure the concrete not to remained on the lower mould.

Concrete casting in the mould

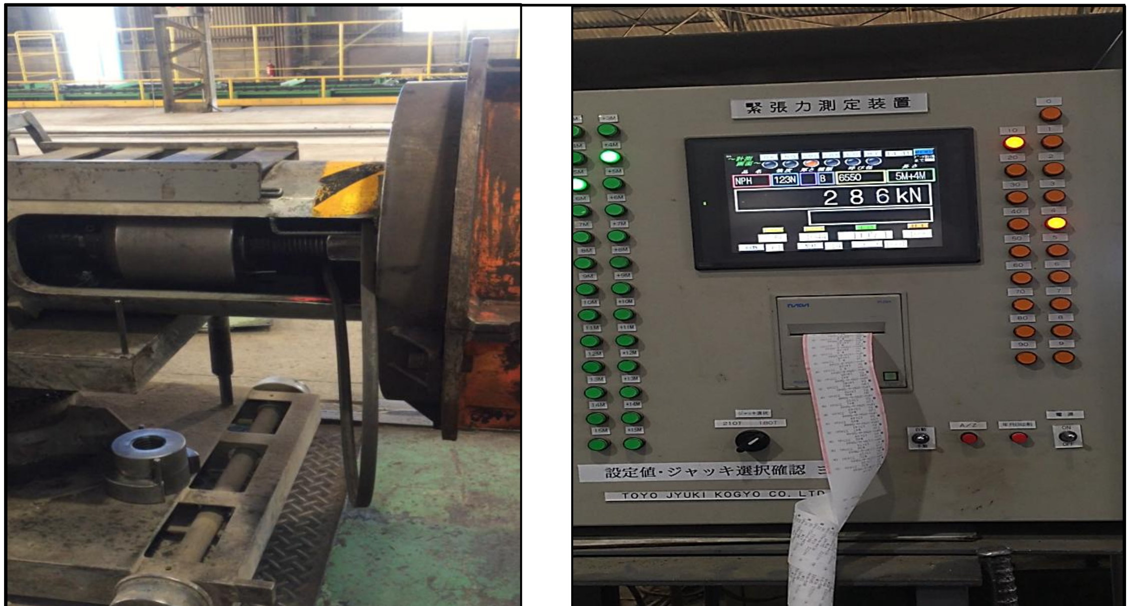


Concrete situated

Remove the concrete on the lower mould

Pre-Tension

- Before Tension ,upper and lower formwork fitting.
- After mould fitting finished , pre-tensions the PC



Prestressed machine

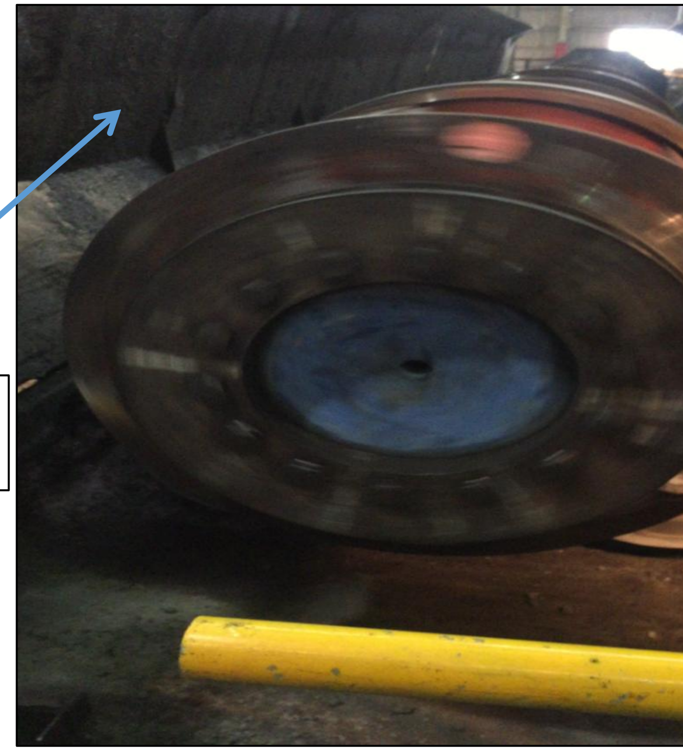
Fitting the formwork

- Tension force will be different depend on dimension and types of Pile.

Pile Spinning

- PHC pile in the middle of the hollow are due to centrifugal rotating.
- Centrifugal machine can spin four step of rotation speed.
- Rotation can control clockwise and anti-clockwise both for.

Covers of centrifugal machine



Centrifugal machine

Rotation the pile

Steam curing

- After finish the centrifugal rotation, Concrete to dry by steam curing.
- Place the pile in the concrete tank and cover.
- Curing time in 8 hours.

Curing tank

Distillation the pile

Steam curing control machine

Demoulding

- After the curing finished, take the pile extraction in the form.
- Lift the pile with vacuum crane from the formwork.

Vacuum crane

Pile inspection

- Inspect and repair the pile body.
- Label on the pile and QC pass symbol on the pile body.
- Inspect the end plate deviation.

Pile label

End plate deviation check
(check both end)

Compression test

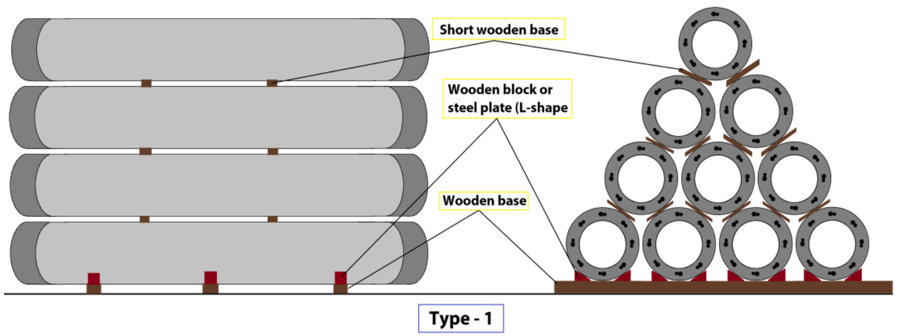
- Test concrete strength of casting in pile. Take the concrete from mixer by weight.
- Test target concrete strength . Result for concrete strength data.
- Distillation with steam curing system.

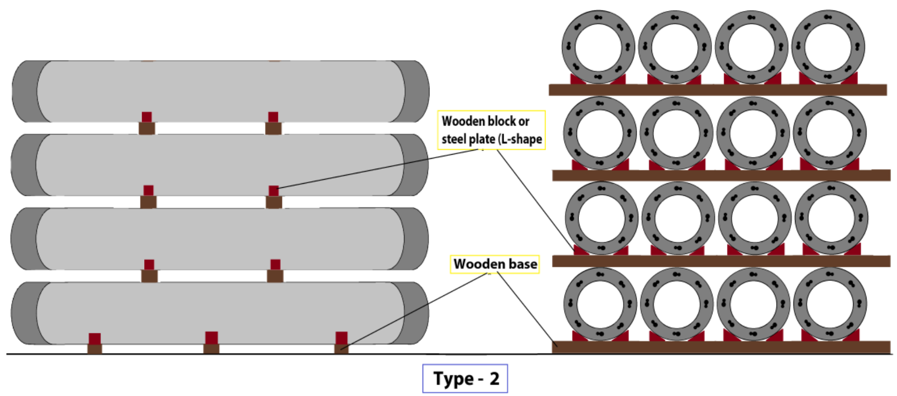
Compression test machine
and cylinder type

Mould and spinning machine

Place the Pile

- After demolding placing the pile in the factory.





Type -1

Type-2

Shipment Inspection and Shipping


COFFEE BREAK