EXPERIMENTAL STUDY ON EFFECT OF END PLATE THICKNESS ON MOMENT CAPACITY AND FAILURE MODE OF RC SQUARE PILE JOINTS

By

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ABSTRACT

Precast reinforced concrete pile length is generally limited to 12 meters due to transportation and handling constraints. Pile joints are needed to lengthen the pile for certain circumstances where pile length exceeding 12 meters is needed. The joints strength should not be less than in all respects to that of the pile section joined. The components of RC square pile joint consist of pile end plate, centering bar, anchor bar and mild steel skirting. The objective of this final year project is to further investigate by means of experiment on the effect of end plate thickness on capacity at both serviceability and ultimate limit states and failure mode of RC pile joints at ultimate limit state. The result obtained shows that increasing of end plate thickness will lead to the higher moment capacity of the pile joints as follows: 4.624 kN m (4 mm end plate), 7.208 kN m (6 mm end plate) and 10.374 kN m (8 mm end plate). The failure modes of specimens differ for different end plate thickness. For the case of 4 mm end plate thickness, specimen failure mode is caused by the local excessive bending at welded connection between anchor bar and the end plate. For 6 mm end plate thickness specimen, the failure mode is mainly due to pull-out failure. Meanwhile, the failure mode for the 8 mm case is classified as failure of RC section.

ABSTRAK

Secara amnya, panjang cerucuk segiempat pratuang bertetulang adalah dihadkan dalam 12 meter disebabkan oleh kekangan penghantaran dan pengurusan. Sambungan cerucuk diperlukan untuk penyambungan cerucuk pada keadaan di mana panjang ceruruk melebihi 12 meter diperlukan. Kekuatan sambungan cerucuk tidak harus kurang daripada seksyen cerucuk yang disambungkan dalam semua konteks. Komponen cerucuk segiempat pratuang bertetulang adalah terdiri daripada plat hujung cerucuk, bar pertengahan, 'anchor bar', dan kambi keluli lembut. Objektif untuk projek tahun akhir ini ialah untuk menjalankan penyiasatan lanjutan melalui eksperimen tentang kesan ketebalan plat hujung cerucuk pada kapasiti sambungan cerucuk pada kedua-dua tahap had perkhidmatan dan tahap had muktamad serta ragam kegagalan sambungan cerucuk segiempat pratuang bertetulang pada tahap had muktamad. Keputusan yang diperolehi telah menunjukkan bahawa pertambahan ketebalan plat hujung cerucuk akan menjadikan sambungan cerucuk mempunyai keupayaan momen yang lebih tinggi seperti yang berikut: 4.624 kN m (4 mm plat hujung), 7.208 kN m (6 mm plat hujung) dan 10.374 kN m (8 mm plat hujung). Ragam kegagalan adalah berbeza untuk spesimen yang berlainan ketebalan plat hujung cerucuk. Ragam kegagalan untuk ketebalan plat hujung cerucuk 4 mm adalah disebabkan oleh lenturan tempatan yang keterlaluan pada sambungan kimpalan antara 'anchor bar' dengan plat hujung. Untuk ketebalan plat hujung cerucuk 6 mm pula, ragam kagagalannya adalah secara amnya disebabkan oleh kegagalan tertarik keluar dari plat hujung. Sementara itu, ragam kegagalan untuk ketebalan plat hujung cerucuk 8 mm boleh dikelaskan sebagai kegagalan keratan pada konkrit bertulang.

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CHAPTER 1

INTRODUCTION

1.1 Background

Piles are long, slender, structural member made of steel, concrete, timber or composite material, which are used to carry and transfer the load of the structure to the bearing ground located at certain depth below ground surface. According to BS 8004: 1986 CL 7.3.2, the three main types of pile are: (a) large displacement piles, (b) small displacement piles and (c) replacement pile, depending on their effect to the soil (Figure 1.1). Pile also can be classified based on the material used and installation method. According to BS 8004:1986, piles can also be divided into the following categories: (i) timber piles, (ii) precast reinforced concrete piles, (iii) prestressed concrete piles, (iv) bored cast-in-place piles and (v) steel bearing piles.

Among all types of pile, precast reinforced concrete piles are the most widely used in our country due to their suitability for supporting building ranging from low rise to medium or high rise under a wide range of soil conditions. They are used in soil conditions which may not be suitable for cast in place piles and in condition where a high resistant to lateral forces is required. Meanwhile, precast piles do have advantages as stated below compare to other type of pile:

- able to improve durability of foundation
- densely compacted elements
- speed up construction progress
- tight tolerance control resulting from factory conditions
- easier for unit inspection
- reduction in temporary formwork (cost and time)

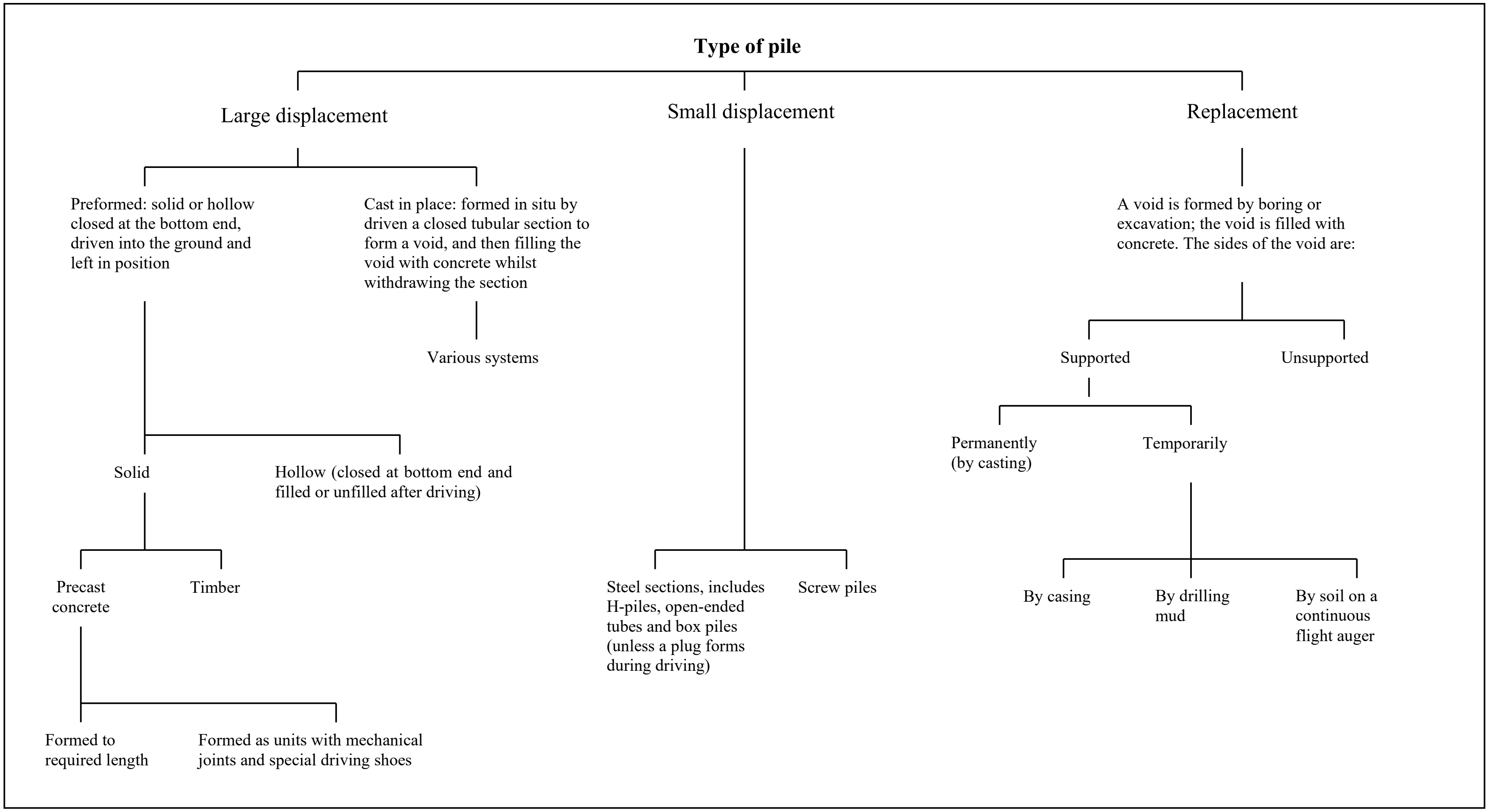


Figure 1.1: Types of pile (BS 8004: 1986)

Usually, square precast concrete piles are used for short and moderate length design. However hexagonal, octagonal or circular piles are usually preferred for long length or piles size larger than 400 mm x 400 mm. Long pile presents problems during handling, transporting and driving. Used of pre-stressed piles or pre-cast jointed piles should be considered when long pile is required in design.

Due to transportation and handling constraints, precast reinforced concrete pile length is generally limited to 12 meter. However, in most of the cases, the pile lengths needed in the construction sites are more than the limitation. Thus, pile joints are introduced to solve this problem. There are two main components of pile joints, male end and female end, which consist of components such as pile end plate, centering bar, anchor bar and mile steel skirting (Figure 1.2 and Figure 1.3).

Figure 1.2: Front view and back view for RC square pile joints (female end)

Figure 1.3: Front view and back view for RC square pile joints (male end)

1.2 Problem statement

There are many manufacturers that produce pre-cast concrete piles in our country such as Hume Industries (Malaysia) Berhad, Bestpile Sdn. Bhd., Associated Concrete Products (M) Sdn. Bhd. (ACP), Universal Concrete Product (M) Sdn. Bhd., Sejati Konkrit Sdn. Bhd. and others. There are various types and sizes of precast concrete piles that are produced by the manufacturers for different construction demand. Among all the products, precast reinforced concrete square pile is highly demanded by the market due to the wide usage range of this kind of pile. Basically, the manufacturers refer to the following design standard and specification as their guideline for precast reinforced concrete square pile:

- BS 8004: 1986

  British Standard Code of Practice for Foundation (Formerly CP 2004)

- BS 8110: Part 1: 1997

  Structural use of concrete

  Part 1: Code of practice for design and construction

- MS 1314: Part 1: 1993

  Specification for Precast Concrete Piles

  Part 1: Standard Design Pre-cast Concrete Piles

- MS 1314: Part 2: 1996

  Specification for Pre-cast Concrete Piles

  Part 2: Special Design Small Pre-cast Concrete Piles

- Manufacturer's own standards

However, according to Neoh (Neoh, 2003), many of the pre-cast concrete piles available in the market do not meet the minimum requirement specified by MS 1314 Part 1. For instance, the percentage of main reinforcement is far less than 1%, MS end plates thickness are far less than 12 mm, centering bar is smaller than 25 mm in diameter and shorter than 300 mm, etc. Most of the manufacturers do not comply exactly with the pile joints specification requirement as stated in Clause 10 of MS 1314: Part 2: 1993, due to many uncertainties about the design specification caused by lack of supporting technical document. Most manufacturers have established their own specification based on experiences from the construction site. Table 1.1 shows a clear comparison among the specification in MS 1314: Part 2: 1993 and specifications of different manufacturers with regards to pile joints details (for 150 mm x 150 mm RC square piles).

Table 1.1 Comparison of pile joint specification according to MS 1314: Part 2: 1993 and pile joints details from local manufacturers

	Centering bar				**Pile end plate**		**Skirting**		**Anchorage/end plate started bar**	
	Diameter (mm)	Length (mm)	M.S Tube Internal diameter (mm)	Protruded length (mm)	Width (mm)	Thickness (mm)	High (mm)	Thickness (mm)	Overall	Length (mm)
MS 1314: Part 2: 1993	16	≥200	-	100	-	10 mm (for normal driving) and 8 mm for hydraulic jacking	50	≥16	-	40d*
Hume Industries (Malaysia) Berhad	20	130	25	80	145	6	50	1.6	4Y10	400
Propile Sdn Bhd	25	150	30	90	-	-	50	3.00	4Y9	-
UCP Universal Concrete Products (M) Sdn Bhd	25	150	30	-	-	6 or 9	-	-	-	-
Sejati Konkrit Sdn. Bhd.	20 or 25	160	25 or 30	100	-	6	MS Collar		4Y9	350

Note: 40d*: 40 times the size of the main reinforcement

On top of that, there is no mandatory law requiring designers to follow the standard that have been developed. However, structural damages to concrete pile that are substandard might occur and the consequences can be very serious.

Base on the above explanation, it is felt that there is a need to develop a systematic investigation about the behaviour and failure modes of pre-cast reinforced concrete pile joint. Realizing this need, the relevant authorities have initiated movement to develop design standards or guidelines that are more scientifically based, logical and reasonable. Both theoretical and experimental investigation need to be carried out in order to produce references and guidelines that can be used in the calculation and determination of the dimensions of the components of the pile joints such as pile end plate thickness, diameter and length of centering bar, thickness and width of steel skirting and diameter and length of anchor bar. Testing programme is needed to educate the users on the proper design of pile joint based on a systematic investigation.

Through literature search, it has been found that no work has been carried out on the behaviour of pile joint. In a first attempts towards obtaining information about behaviour of pile joints, Ong (Ong, 2004) has carried research work to investigate the effect of end plate thickness on the moment capacity of pile joint with partial welding at ultimate limit state. Type of pile considered in the experiment is restricted to 150 mm x 150 mm precast reinforced concrete square pile. The end plate thickness that has been tested was 4 mm, 6 mm and 8 mm. According to the study, the bending strength of pile joints is found to be depended on the pile end plate thickness. The bending strength of the pile joints will be higher, if the end plate thickness is increased. However, such conclusion is based on testing results conducted on pile without skirting with partial welding. The pile joints failure is mainly due to bending failure of the pile end plate especially for those pile specimens without skirting. In Ong's work, two main areas have been identified for further investigation:

1. Effect of end plate thickness with full welding.
2. Pile at both serviceability limit state and ultimate limit state.

1.3 Objective

This final year project is carried out in order to further investigate the effect of end plate thickness on moment capacity and failure mode of RC pile joints. Through the investigation, the effect of end plate thickness on moment capacity at both serviceability and ultimate limit states and failure mode of RC pile joints at ultimate limit state can be determined. It is hoped that the results obtained will be able to provide technical information about the behaviour of precast reinforced concrete pile joints in terms of pile capacity as well as the associated failure mode. Such basic information could then be beneficially employed in the development of specification and guidelines.

1.4 Scope of research

The scope of this research is limited to the determination of the effect of end plate thickness on moment capacity at both serviceability and ultimate limit states and failure mode of RC pile joints at ultimate limit state. The pile type used is restricted to 150 mm x 150 mm precast RC square pile, with total length of 2 m. Only RC square piles with end plate thickness 4 mm, 6 mm and 8 mm are tested. Failure mode of RC pile joints at ultimate limit state and other related data are observed and recorded during the test.

1.5 Layout of thesis

This thesis consists of 5 chapters.

Chapter 1 is Introduction that includes background, problem statements, objective and scope of research.

Chapter 2 consist of section on pile foundation, type of pile, pile joints for precast reinforced concrete square pile.

Chapter 3 is about methodology used in this project that consists of introduction and method for determination of bending strength for the pile joint.

Chapter 4 shows the test result and the discussion.

Chapter 5 gives conclusion about the research study.

CHAPTER 2

PRECAST RC PILE JOINT

2.1 Pile foundation

Piles are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata that having a high bearing capacity. Piles are used to transmit loads to strata beyond the practical reach of shallow foundations due to economic, constructional and soil considerations. In addition to the above application, piles are also used to anchor structures against uplift forces and to assist structures in resisting lateral and overturning forces.

Basically, piles are used for the following purposes:

- To carry the superstructure loads into or through a soil stratum. Both vertical and lateral loads may be involved.
- To resist uplift, or overturning, forces, such as for basement mats below the water table or to support tower legs subjected to overturning from lateral loads such as wind.
- To stiffen the soil beneath machine foundations to control both amplitudes of vibration and the natural frequency of the system.
- To control settlements when spread footings or a mat is on a marginal soil or is underlain by a highly compressible stratum.
- To compact loose, cohesionless deposits through a combination of pile volume displacement and driving vibrators. These piles may be later pulled.
- As an additional safety factor beneath bridge abutment and/or piers, particularly if scour is a potential problem.

- In offshore construction to transmit loads above the water surface through the water and into the underlying soil. This case is one in which partially embedded piling is subjected to vertical (and buckling) as well as lateral loads.

It is important to understand the pile mechanisms of load transfer to the soil. Generally, the piles can be classified as end bearing pile or friction pile depend on the mechanisms of load transfer and soil conditions. End bearing piles are pile that terminate in hard, relatively impenetrable material or soil level such as bedrock or dense sand and gravel within a reasonable depth (see Figure 2.1 (a) and (b)). In the above case, the pile ultimate capacity is derived from the resistance of the stratum at the toe of the pile. Friction pile is used when the impenetrable layer or the bedrock level is not present in a reasonable depth. In this case, most of the pile carrying capacity is derived from skin friction or adhesion between the embedded surface of the pile body and the surrounding soil (Figure 2.1 (c)). However, in most of the situations, the load transfer mechanism of pile is derived from both methods mentioned above.

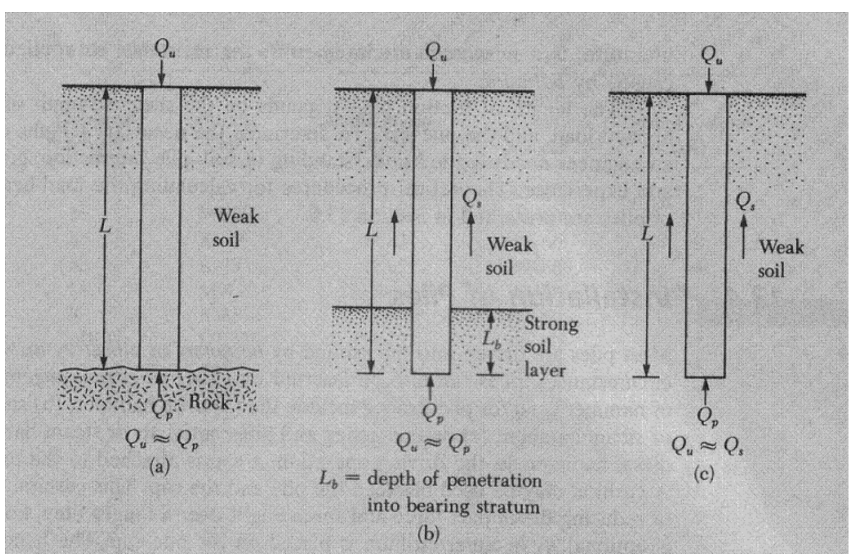


Figure 2.1: (a) and (b) end bearing pile; (c) friction pile
(Source: Braja M.Das (1999), "Fundamentals of Geotechnical Engineering".)

2.2 Type of pile

According to BS 8004: 1986, piles can be classified into the following categories: a) timber piles, b) precast reinforced concrete piles, c) prestressed concrete piles, d) bored cast-in-place piles, and e) steel bearing piles.

2.2.1 Precast reinforced concrete piles

Precast reinforced concrete pile are formed in a central casting yard to the specified length, cured, and then shipped to the construction site. If space is available and a sufficient quantity of piles needed, a casting yard may be provided at the site to reduce transportation cost. Precast piles using ordinary reinforcement are designed to resist bending stresses during pickup and transport to the site and bending moments from lateral loads and to provide sufficient resistance to vertical loads and any tension forces developed during driving. Precast reinforced concrete piles are usually solid square or hexagonal cross section for units of short or moderate length. However due to the requirement of weight-saving, long and large sizes piles (greater than 400 mm) are usually manufactured with a hollow interior in hexagonal, octagonal or circular section. The interior of the piles can be filled with concrete after driving to avoid bursting due to weather expansion. Figure 2.2 shows the fabrication sequence of precast reinforced square piles.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 2.2: (a) and (b) reinforcement and joint detail, (c) and (d) casting and compaction, (d) curing in progress and (f) precast RC square pile

2.3 Pile joints for precast reinforced concrete square pile

Due to logistics and handling constraints, precast reinforced concrete pile length is generally limited to 12 meter. However, in most of the cases, the pile lengths needed in the construction sites are more than the limitation. Thus, pile joints are introduced to solve this problem. There is various type of pile joints used worldwide. Figure 2.3, Figure 2.4 and Figure 2.5 shows the typical pile joints for concrete piles.

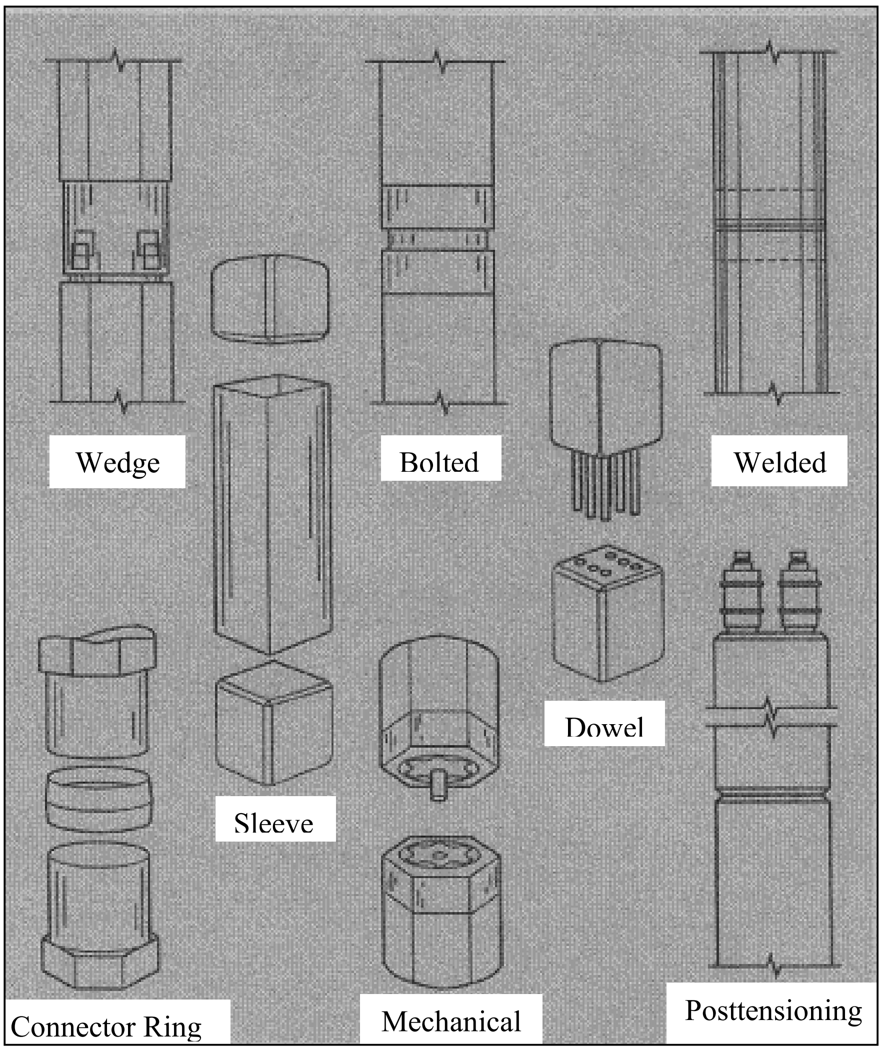


Figure 2.3: Typical pile joints for concrete piles
(Adapted from Precast / Prestressed Concrete Institute)

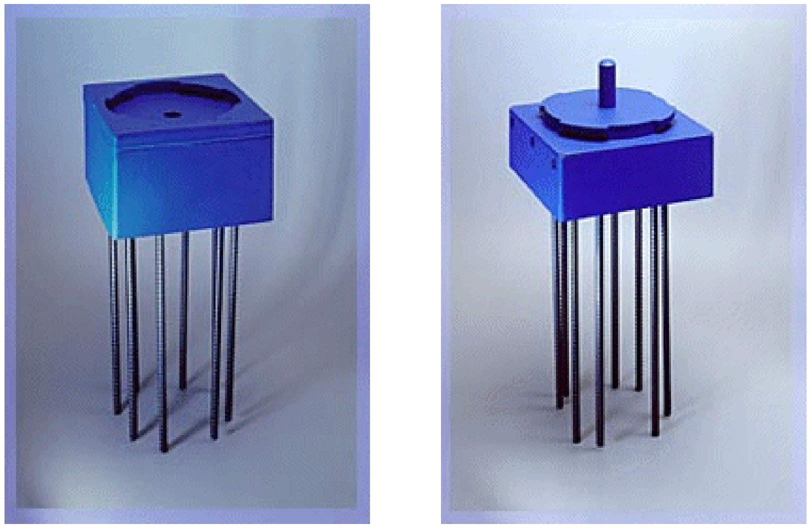


Figure 2.4: Hercules type of pile joint
(Sources: http://www.sbe.napier.ac.uk/projects/piledesign/guide/chapter1.htm)

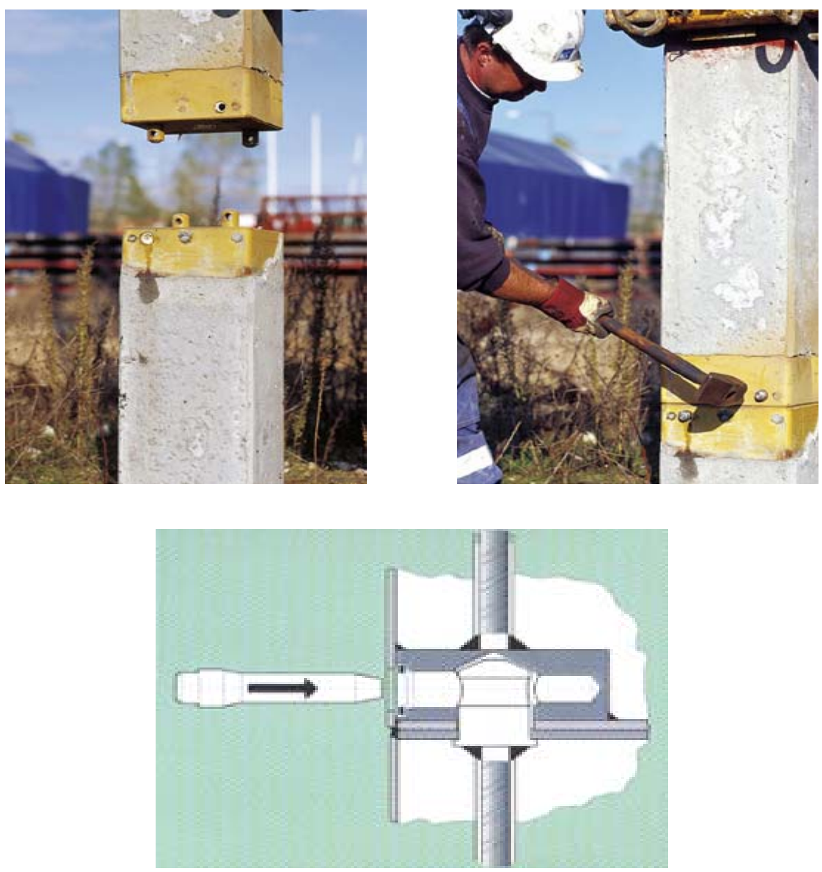


Figure 2.5: Leimat pile joints
(Source: http://www.centrumpaele.dk/uk/koblingerl.htm and http://www.leimey.fit/end/valuohjaimet.htm1)

According to Young (Young, 1981), it is essential that in a joint should possess the following characteristics:

- it should not require any change in the reinforced concrete section which would cause stress concentration
- it should transmit force over the surface of the joints as evenly as in the reinforced concrete section
- it should not be weakened by the process of driving
- it should be made from one type of material only. This is for the purpose of eliminating undesirable electrolytic action, with the exception of parts which may be used as sacrificial anode and are not required in the load-carrying condition

Generally, the joints should be as strong as the pile. Preferably it should have the same moment resistance. The quality of the joints must be high or else a significant amount of energy will be lost during driving.

The precast reinforced concrete square pile joints used in our country consist of pile end plate, anchor bar (started bar), centering bar and mild steel skirting (Figure 2.6). The length of pile is joined together by means of welding around two end plates as shown in Figure 2.7. The pile joints should have sufficient strength to take compression, bending, tension, shear and torsion during driving or jacking and in service. The joints strength should not be less than in all respects to that of the pile section joined (MS 1314: Part 2: 1996 CL 10).

The pile concrete section cannot be joined after set. Thus, the mild steel pile end plates are the only pile joints component that can be joined by welding on site. The pile end plates are held to the pile body by anchor bar. The centering bar is used to ensure the alignment of piles length being joined. It also resists shear force which develops in the pile joint.

Basically, when the four point bending load test is carried out on the precast reinforced concrete square pile, the load transfer path is as shown in Figure 2.8. When load is applied on the pile section, bending moment develops in the pile end plate. Load will be transferred from the welded pile end plate section to the pile end plate body. The load will then be transferred to the anchor bolt which is welded to the end plate. Meanwhile, the load will continue to be transferred to the main reinforcement and the whole concrete section or pile body by means of bonding action between the reinforcement and the mass concrete. Internal stress will develop during the load transmission.

There are a few design calculations available to evaluate the pile joint moment capacities, such as the design ultimate moment at section $M_{u, sec}$, pull-out moment capacity at joint M_{w}, and moment capacity of welded joints M_{wu} for precast reinforced concrete square pile. The corresponding equations for these moments are shown below. The detail calculation for the moment capacities mentioned above which is base on the precast R.C. pile size 150 mm x 150 mm is included in Appendix III.

Ultimate Moment at the section, $M_{u, sec}$ = $0.95 f_y z A_s$ **(2.1)**

where,

f_y is the characteristic strength if concrete of reinforcement,

z is the lever arm and

A_s is the area of tension reinforcement.

Moment capacity of welded joint, M_{wu} = $Q_{wy} \times Z$ **(2.2)**

where,

Q_{wy} is the welded strength and

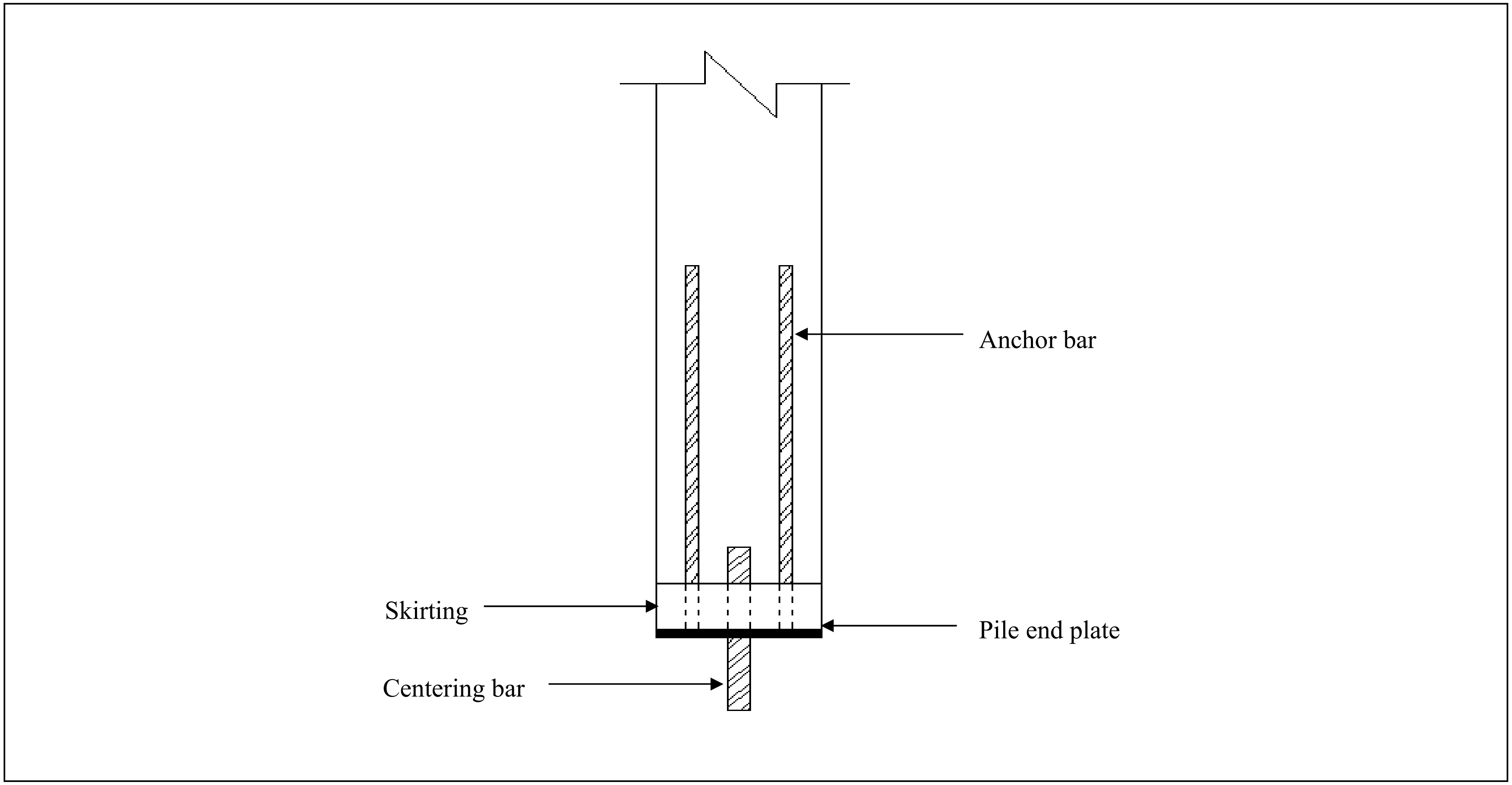
Z is the section modulus of cross section at welded part.

Pull out moment, M_w = $F_w (2z)$ **(2.3)**

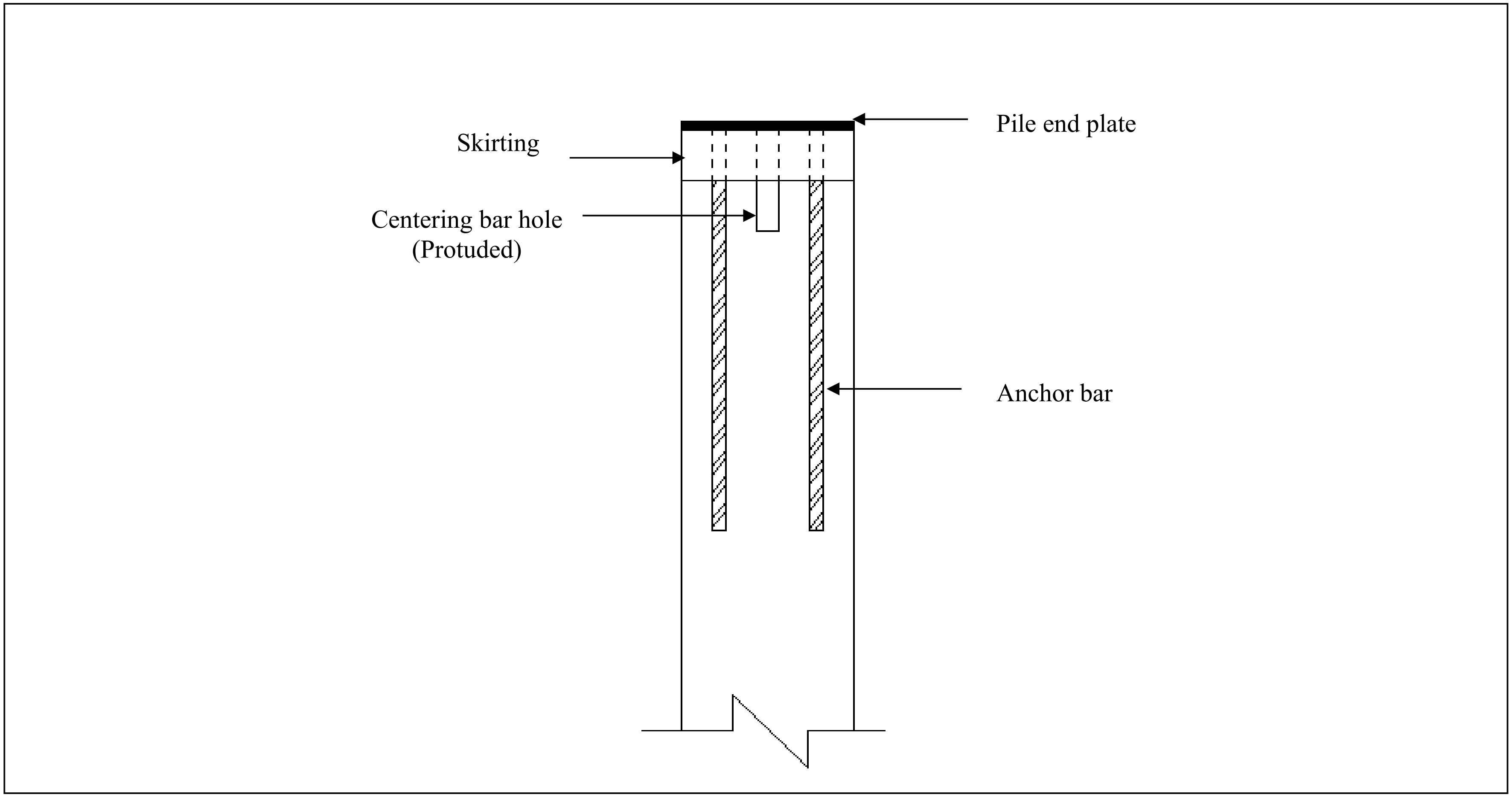
where,

F_w is the pull-out capacity per bar and

z is the lever arm against moment.



(a): Male end
Figure 2.6: Components of precast RC square pile joints



(b): Female end
Figure 2.6: (Continue)

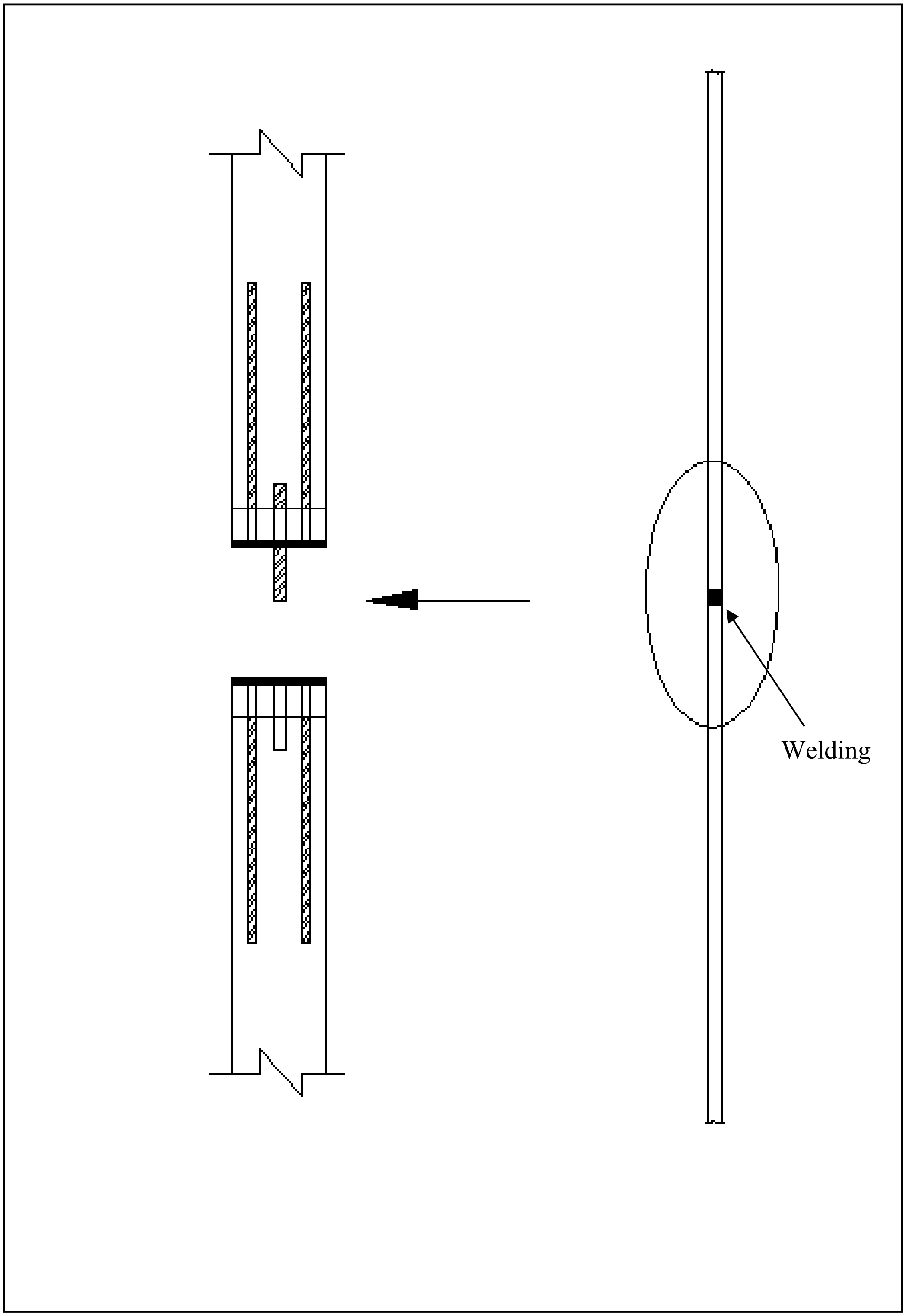
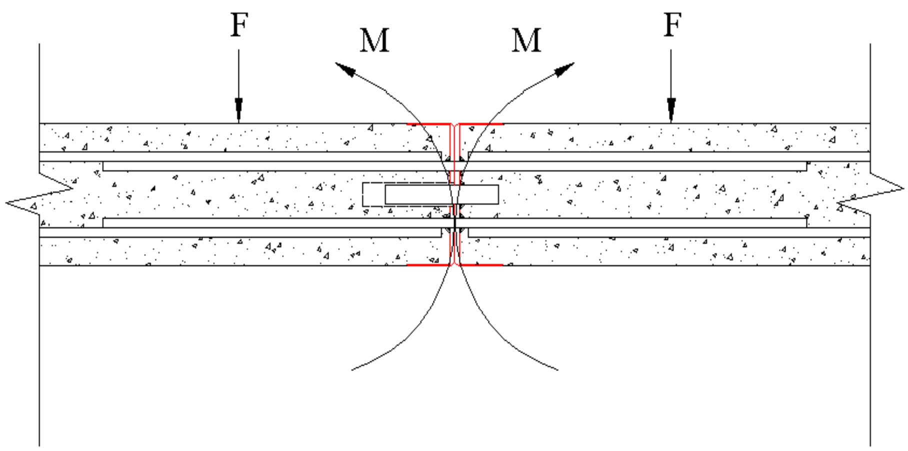
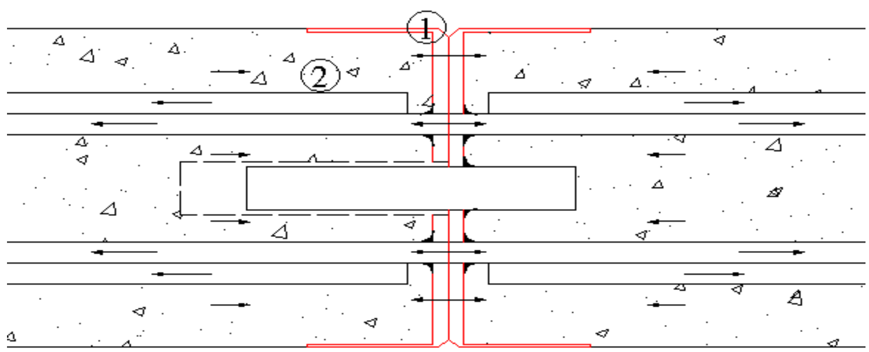


Figure 2.7: Typical precast reinforced concrete square pile joint





Note:

1. Load transfer to end plate on both sides of joints.
2. Load transfer from end plate to anchor bolt, main reinforcement and concrete section.

Figure 2.8: Load transfer path of bending moment applied to the pile joint

CHAPTER 3

METHODOLOGY

3.1 Introduction

Pile are mainly designed to support and transmit various types of load such as compression, tension, axial force, torsion, bending moment and shear force. Pile joint that connects the pile body should at least have the same strength or more compared to the pile body in service. The pile joints should have sufficient strength to resist the compression, bending, tension, shear and torsion during driving or jacking and in service according MS 1314: Part 2: 1996 CL 10.

3.2 Method for determination of bending strength for the pile joint

There is no specific testing method to determine the pile joint bending strength. The bending strength testing for pile joint (MS 1314: Part 2: 1996 CL 9.2) has been adopted as the pile body bending strength test in this project. Generally, the test procedure is based on the procedure stated in MS 1314: Part 2: 1996 Appendix B. The apparatus arrangement is as shown in Figure 3.1. The four point load arrangement is to ensure that causes of failure are only due to the pure bending without the influence of forces such as shear force, torsion or other combination of forces. The bending strength test on pile joints is carried out by determining the cracking bending moment M_s, at serviceability limit state and ultimate bending strength. The ultimate bending strength of pile joint is assumed to be the same as the design ultimate moment $M_{u, sec}$, for the concrete section for the pile body (Equation 3.1). The cracking moment at serviceability limit state is obtained by the ratio of ultimate breaking bending strength to the cracking bending moment M_u/M_s as shown in Equation 3.2 (MS 1314: Part 1: 1996 CL 9).

Ultimate Moment at the section, $M_{u, sec}$ = $0.95 f_y z A_s$ **(3.1)**

where,

f_y is the characteristic strength if concrete of reinforcement,

z is the lever arm and

A_s is the area of tension reinforcement.

$M_u/Ms > 2.0$ **(3.2)**

where,

M_u is the ultimate bending strength and

M_s is the cracking moment at the serviceability limit state.

3.2.1 Apparatus

3.2.1.1 General

The devices for applying the loads consist of two supporting rollers and two load-applying rollers as shown in Figure 3.1 and 3.2.

3.2.1.2 Load control

The load is applied uniformly and control at a rate of 0.06 ± 0.04 N/mm^2 s or 0.1125 kN/s ± 0.075 kN/s.