A Case Study of Foundation Failure in The Existing Residential Building

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Abstract

Excellent building performance during its lifetime cannot be separated from foundation contribution as ground structure that provides stability and support. Foundation intercepts the loads from superstructure and transferring the loads by spreading them over a large enough area to utilize the maximum soil resistance. All loads and forces transferred to the underlying soil will result in some movement, allowable movement. Foundation which experienced movement more than they can resist will cause failure, foundation failure. Distortion and damage from the superstructure is appearing due to the failure. Remedial action will aid the problem and increase the performance of structure to prevent further failure. This research study involves a case of foundation failure. The case is appearing in existing residential building. The study consists of site investigation to determine the site condition, the types and causes of foundation failure, damaged occurred on site and also the types of remedial works carried out. All the types of failure have very strong connection with the soil, because the soil behaviors determine the stability of foundation structure. In the case study, ground settlement is occurred because the soil has low strength stability. The soil contains of clay/silt material which is unsuitable and has low bearing capacity to carry the loads. The ground settlement has produce large and a lot of damages in the residences structure. The remedial work has carried out by underpinning method using combination of micro pile and beam, and also ground stabilization using pressure grouting. From the remedial work that has carried out, it shows there is no more movement in the building. The technique of underpinning has good impact to stabilize the foundation structure.

Keywords : *foundation, failure, remedial works*

Abstrak

Kinerja bangunan yang sangat baik semasa penyelenggaraan tidak dapat dipisahkan dari kontribusi struktur pondasi sebagai struktur dasar yang memberikan dukungan dan stabilitas. Pondasi menerima beban dari bangunan atas dan mentransfer beban dengan menyebarkannya di wilayah yang cukup besar dengan memanfaatkan ketahanan tanah maksimum. Semua beban dan tekanan yang disalurkan ke tanah akan menghasilkan beberapa pergerakan yaitu pegerakan yang diijinkan. Pondasi yang mengalami pergerakan melebihi kemampuannya dalam menahan beban akan menyebabkan kegagalan pondasi. Distorsi dan kerusakan dari superstruktur timbul akibat kegagalan yang terjadi.Tindakan perbaikan akan membantu masalah dan meningkatkan kinerja struktur untuk mencegah kegagalan lanjut. Penelitian ini melibatkan kasus kegagalan pondasi yang terjadi di bangunan perumahan. Penelitian ini terdiri dari investigasi tapak untuk mengetahui kondisi, jenis dan penyebab kegagalan pondasi , kerusakan yang terjadi dilapangan dan jenis perbaikan pekerjaan yang dilaksanakan. Semua kegagalan yang terjadi memiliki ikatan yang kuat dengan kondisi tanah, karena perilaku tanah menetukan stabilitas struktur pondasi. Pada studi kasus ini penurunan tanah terjadi karena kekuatan stabilitas tanah yang rendah. tanahnya mengandung bahan tanah liat / lumpur yang tidak cocok dan memiliki daya dukung yang rendah untuk membawa beban .Penurunan tanah yang terjadi telah menghasilkan banyak kerusakan struktur pada perumahan. Pekerjaan-pekerjaan perbaikan dilakukan dengan metode underpinning menggunakan kombinasi antara micro pile dan balok serta stabilisasi tanah menggunakan pressure grouting. Dari pekerjaan perbaikan yang dilakukan memperlihatakan tidak adanya lagi pergerakan pada bangunan dan teknik underpinning memiliki dampak yang baik menstabilkan struktur pondasi.

Kata kunci : Pondasi, kegagalan, kerja perbaikan

I. INTRODUCTION

Basic principle of a building is to unite all of the structure as a nation to carry and transfer the loads all together and propositional into the ground. Foundation is the supporting link between the building and the ground. They will transfer the loads from the walls, floors and roof into the ground. These foundations will act as a support to intercept loads and forces from building structure, afterward divert and spread them over a large enough area to utilize the maximum allowable resistance of the soil. All loads transferred to the underlying soils will result some movement. Normally there is allowable movement that has been determined by the geotechnical engineer and also by applicable building code. But, when the support are failed to carry and resist the loads forces and the soil pressure excess the limit, eventual failure of foundation is unavoidable. Foundation movement possibly causing distortion and damage when the building cannot withstand the movement because exceeds the tolerable limit of distortion of the building. Identification of the damages is very important to detect the types of failure occurred, because when the failure is take place, it will require immediate attention and investigation about the causes of foundation failure and what types of failures that appears to get the possibility of repairing and remedial work for the damage.

1.1 PROBLEM STATEMENT

Foundation of the building also designed by considering the site condition and environmental factors besides concerning the loads carried out to avoid the failures. Foundation movement, such as settlement is the problem often occurred to the building such as residential building. Because of the movement, failures are take place and deformation of the building is unavoidable. Cracks in wall, floor and other defects in structural building will appear. The defects become larger if the foundation movement becomes worse. Not all occupants are alert for the occurrence, when they notice the damage, patching the wall cracks will be one of the solution for several occupants. This condition will give impact and can be dangerous to the building occupant; also caused the loss when the building is collapse. That is why the knowledge about foundation failure is very important for people, because to avoid the unwanted things take place. Identifying the types, the sources or causes and defects of foundation failure is very significant, by knowing all of this, anticipation will obtain earlier to determine what the most suitable remedial works can be apply.

1.2 AIM

The aim throughout this research is to learn and understand the various causes and categories of the foundations failures including the types of repair and remedial works. By this understanding, hopefully be able to increase the knowledge of people about the damage causing by the failure to get early action and know how to prevent before it become more seriously.

1.3 OBJECTIVES

To achieve the purposes, several objectives of this dissertation can be affirmed as below:

1. To identify the types of foundation failures, the causes, and structural defects due to the failure in the residential building;
2. To identify the types of remedial work and repair techniques to overcome the problems of foundation failures;

3. To Identify and determine the failures in an actual case of foundation failures in the residential building and the remedial works have been done.
4. To identify and propose the methods of maintenance in existing residential building to prevent the similar foundation failure in the future.

1.4 SCOPE OF RESEARCH

The scope of research can be identified as literature review on the types of foundation, foundation failures, the causes; types of defect occurred and types of remedial works. An observation through a case study of foundation failures is carry out in existing residential building, and known occurred in 88 Unit Houses Taman Tunas Muda on lot 6034, Mukim 12, Daerah Barat Daya, and Penang. The scope of case study consists of the analysis based on site and building condition when failure is occurred. The types of failure, causes, and defect will be determined through the analysis and assessment, and identification the types of remedial work has been done, including the suggestion of suitable methods of foundation maintenance in residential building to prevent the similar failures.

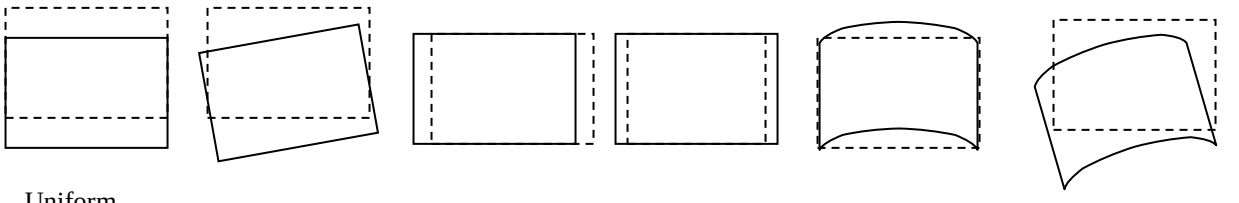
II. FOUNDATION FAILURES AND REMEDIAL WORKS

The failure of foundation will bring the unexpected result to the building structure. Deficient performance in the form of unacceptable deformation will leading to cracks, moisture penetration and other serviceability problems (JF and KL.C, 1997).

2.1 THE TYPES OF FOUNDATION FAILURES

2.1.1 Settlement

Settlement is movements of the ground followed by footings because of the unreliable or weak ground by carrying loads from the structure or resulting from soil moisture changes. When the ground movement excesses the acceptable limit, it will result in foundation failure (JF and KL.C, 1997). The characteristic of movement happened in the natural ground and fill material where the existing building is laid There are several types of movement that has been recognized as uniform settlement (or heave), uniform horizontal displacement, extension (or compression) differential horizontal displacement, and differential settlement.



(Source: Attewell and Taylor, 1984)

Figure II.1 Components of Movement

2.2 THE CAUSES OF FOUNDATION FAILURES

Foundation failures may result from wide range of factors, all of these factors have big influenced to the stability of foundation. I have divided it in to 4 major factors that have contributes to the foundation failures.

Environmental Factor	Design Deficiency	Construction Faults	Lack of Maintenance
Soil Behavior 1. Abnormal soil Moisture at the time foundation is poured. 2. Frost heave and permafrost 3. Decay of organic material in fills 4. Loss of soil moisture 5. Removal of water (drain) 6. Addition of water (collapsing soil) Vegetation Weather Condition Natural Hazard	1. Soil Creep. 1. Error in design concepts 2. Lack of structural redundancy 3. Failure to consider a load or a combination of loads 4. Deficient connection details 5. Calculation error 6. Misuse of computer	Poor workmanship. 1. Undercompaction. 2. Overcompaction 3. Concrete foundation settlement cracking Procedural deficiencies Poor control material and Material deficiencies Cold Pour Joints in concrete foundations Concrete/Masonry shrinkage cracks Holes and penetrations in concrete foundations.	Slab/Foundation Movement Caused By Plumbing Leaks Foundation Upheaval Caused by Poor Drainage

Source : (Freeman TJ, et al. 1997). (Robert W, 1997). weight (Lee HS and George CS, 1993), (www.foundationrepair.org, 04/24/08), (www.foundationrepair.org, 04/24/08) (Roxanna M, 2003), (Alan C, 1990), (Jacob and Kenneth, 1997).

2.3 THE CATEGORIES OF DAMAGE

- Structural Cracks
  The location of the cracks is as important as their physical appearance. Foundation movement often results in crack at weak points, such as window openings and doors, (Freeman TJ, et al. 1994)
- Opening distortion
  Foundation movement tents to distort openings and often causes doors and windows to stick. In some cases the distortion may also affect partitions, ceilings, floors and the roof.

- Floor movement/Uneven Floor
  The initial effect due to foundation movement and unstable soil beneath are bulging of the floor (Attewell and Taylor, 1984).

2.4 TYPES OF REMEDIAL WORKS

Remedial procedures depend upon both environmental factor such as soil behavior and the type of foundation.

2.4.1 Site Investigation

Site Investigation work is very important to collect appropriate information to determine the site condition. From there, the consultant will make the decision and assumption about the work that need to carry out to overcome the failures. The steps of site investigation generally consist of the point stated below;

2.4.2 Testing and Monitoring

Testing and monitoring is very important to identify the accurate ground condition. Site monitoring is divide into 3(three) categories; Monitoring to establish cause of damage, monitoring to measure rate of movement and monitoring to check success of remedial action. (Freeman TJ, et al, 1994).

2.4.3 Shoring

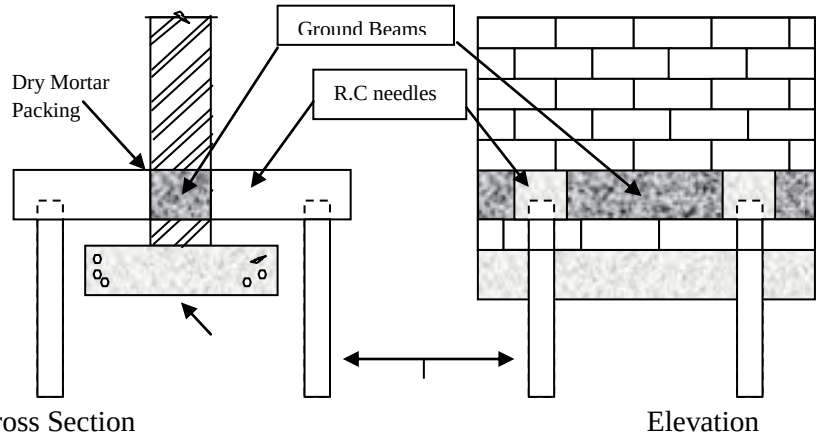
Where a building or structure is in poor condition due to settlement, and underpinning has to be carried out to limit or to arrest resulting movements, external shoring will probably be required. The main shoring members can be of timber, steel or scaffolding. Where timber is used, swelling and shrinking will take place and provision should be made, in the shape of hardwood wedges, to allow for any adjustment which will be required

2.4.4 Underpinning

Underpinning is the process of modifying an existing foundation system by extending it to or into subsurface strata that are deeper and more stable than the near surface soil that supports the existing foundation system (www.foundationrepair.org, 04/27/08).

Methods of underpinning strip Foundation

- Traditional Underpinning
- Pynford Stool Method
- Jacked Pile Underpinning
- Needle (beams) and Piles, etc.



(Referred to Freeman TJ et al, 1994)

Figure II.2 Underpinning with vertical mini-piles and needle beams

Methods of underpinning Pad Foundations or column Bases

- Temporary support to column

Before underpinning, the columns must be relieved on their loads by dead shores erected under all beams bearing on them. Reinforced concrete columns and break piers can be supported by means of a horizontal yoke formed of two pairs of rolled steel beams positioned in chases on the sides of the columns (Lee HS and George CS, 1993).

- Needle and Piles

The column loading is transferred from the collar to cross beams or needles which in turn transmit the load to the ground at a safe distance from the proposed underpinning excavations. One end of the needle is usually made to rest on a concrete bearing pad on a firm support and then loads is distributed to a safe bearing stratum with a hydraulic jack on a precast or bored pile.

Basement or Foundation wall repair

The first repair example involves the construction of a new member inside the original wall, Sometimes refer to as a "sister" wall. The structural load is ultimately transferred to this assertion. No effort is made to plumb or reinforce the existing basement foundation wall.

Ground Improvement

Ground improvement usually referred to the stabilization of soil to improve the natural soil properties in order to provide more adequate resistance to erosion, loading capacity, water seepage and other environmental forces (Robert WB, 1997).

- Chemical grouting
- Jet Grouting

III. METHODOLOGY OF THE RESEARCH STUDY

3.1 Introduction

The case study is a project **"Ground Settlement Problems and Building Cracks Assessment at 88 Unit Houses Taman Tunas Muda on Lot 6034, Mukim 12, Daerah Barat Daya, Penang".** This Project is carried out in existing residential Houses Taman Tunas Muda owned by Developer Sri Tunas Harta Sdn. Bhd. The contractor involved in the housing development is also under the owner itself that is Sri Tunas Sdn Bhd. The complex of houses was constructed between 1998 and 2002 and consists of 88 units single storey of Terrace houses. The area of the houses is used to be paddy field, and the buildings is constructed and supported by reinforced concrete piles as the foundation structure.

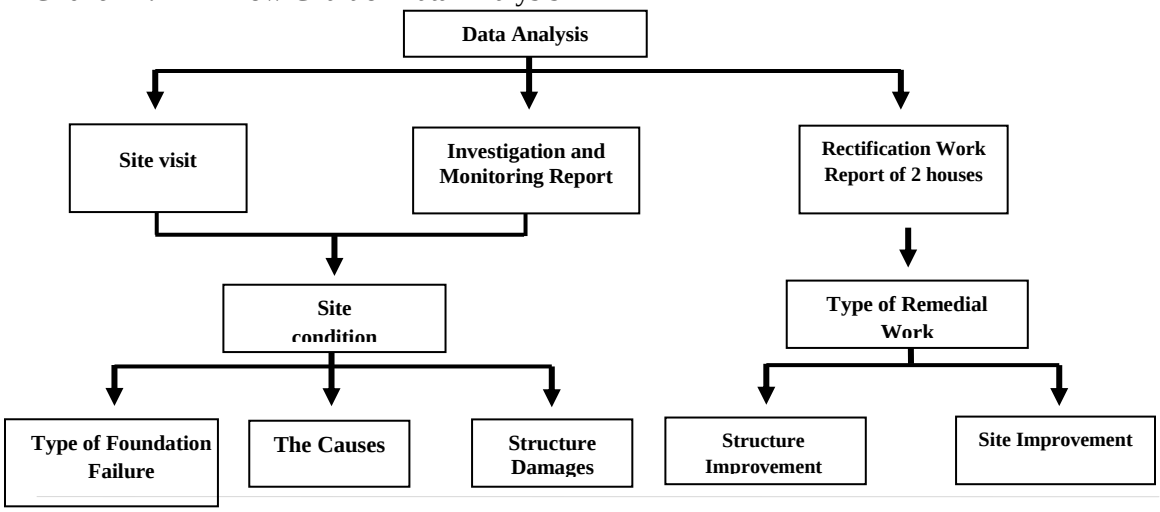
3.2 PROJECT BACKGROUND

The structural damages in the residential area were encounter in 2004, when there were complaints by the occupant to the developer, reported that damages appear in their residence. The damages consist of appeared cracks on the wall, beam, column and aprons and there were ground surfaces also settle at that time. Based on information derived from the occupant, the developer carried out the site inspection to assess the damage, and then they attempted to fix the problem on site by repaired damages. But the repaired structure cannot resist, and later on the damaged continuing occurred.

3.3 SITE PROJECT CONDITION

The residences is landing on paddy area, constructed on earth filled area and based on information collected from SI report, up to 1.5 m fills of soil had to be placed. The original ground level is 12 m and required to achieve 13.5 m expected final ground level. The building is constructed on 150mm x 150mm square reinforced concrete piles driven down to a maximum depth of 6m and 18m (Ikram SI report, 2006).

Chart III.1 Flow Chart of Data Analysis



IV. DISCUSSION AND RESULT

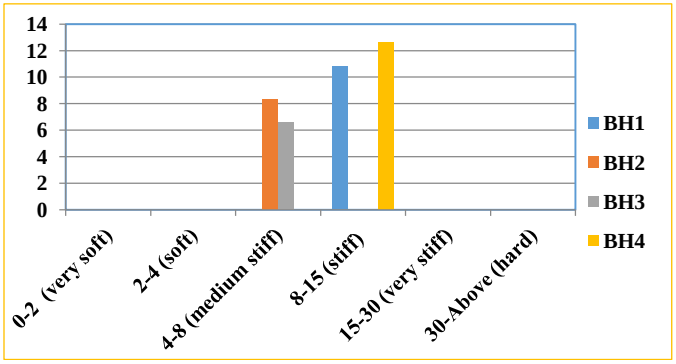
Site Investigation Works.

Deep Boring test

In this project, IKRAM consultant using Rotary Wash Boring method and Rotary Core Drilling to performed the boreholes. Samples was taking by continues sampling, the initial site investigation that was conducted by KGA Engineering Sdn. Bhd comprised of 6 (six) numbers of boreholes and drilled down to a maximum depth of 30.45m.

Standard Penetration Test

The test performed by follow British Standard 1377 test 19. SPT test was performed to collect the information about bearing capacities of the soil. The samples in the tube (75) mm dropped into bore hole 450 deep using boring rig (63.5 kg), and take the note in each 7.5 cm gap until 45 cm. and the N value determined by the amount of blow for penetration tube sampler from 15 cm to 45 cm. The SPT test was carried out at every 1.0m until 6.0m depth and after that 1.5 m interval to acquire N values. From data report, the number of SPT that have been carried out is about (73) numbers of SPT. Based on data in deep boring log and SPT graph (Appendix B) it shows that the soil has low bearing capacity based on low SPT value. The soil that has low bearing capacity and low strength to resist the loads has the chance to settle. Chart below shows the result value of S.P.T test until the depth of 18 m from BH1-BH4 taken from S.P.T plot data.



(Source: IKRAM Site Investigation Report Volume II, 2006)

Chart IV.3 Average S.P.T. value

The chart shows the average N value until the deep of 18 m. the N value of soil is placed between medium stiff to stiff. In my opinion, this value shows medium strength for soil to carry the loads from the structure above. But in this case, the background of site is paddy area and filled with 1.5 m compacted soil, so, the average N value of the the soil is not adequate to carry heavy loads from the structure especially the soils in BH3.

Vane Shear Test

The test is performed based on British Standard test 18. It is suitable for soft soil to solid one or if N value is 2 or less. The procedures is 2 bladed vane with size 6.35cm x 12.7cm inserted into a soil at the foot of a borehole, it is rotated by a rod at the surface with a measure force until the soil is shrink. This in-situ soil test gives shear strength that have been found to give consistent result.

Analysis and discussion

The ground water levels are susceptible to change in the rainy season. Usually the ground water level will increase in the rainy seasons and decrease in the dry season. It useful to monitor and records the groundwater level in longer period because the fluctuations of ground water level maybe the evident. Charts below are taken from the two sets of reading from the standpipes that the ground is seemed to stabilize between 1.38m to 1.78m below the ground level. High ground water level or unstable water table will disturb the characteristic of the soil and reduce the strength of that soil to carry the load, especially when the type of soil is expansive soil. Because this kind of soil is very easy to shrink in dry condition and also expand when in high moisture content.

Boreholes Sampling.

Obtained from this boring test is 8 undisturbed samples and 62 disturbed sample to test in the laboratory

Soil strength test

- One dimensional consolidation
- Consolidated Undrained Tri axial

4.4.1.b Site Monitoring

The purpose of site monitoring is to verify the cause of damage and determine the rate of movement on the site. IKRAM consultant has divided the monitoring works into; cracks measurement, measurement of soil and building settlement and monitoring of groundwater elevation.

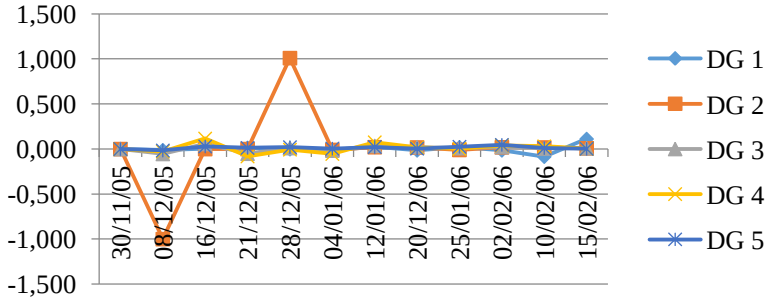
Crack and settlement monitoring project is implemented in the house no 32A and no. 36. All the monitoring works was recorded in every week and the length of monitoring period is 3 months. The monitoring works is start from 03 November 2005 until 2 February 2006.

Analysis and discussion

Demec Gauge can measure very accurately and this equipment is to measuring very small movement. For this crack monitoring Plastic Tell Tale is the equipment to measure, this equipment is very flexible because the reading can be taken without limiting time and no need additional equipment. The result for this monitoring taken from IKRAM consultant Monitoring Report shows below;

ANALYSIS DATA FROM CRACK MEASUREMENT RESULTS

UNIT NO. 32 : CRACK MONITORING BY DEMEC GAUGE



Graph IV.2 measurement result in unit 32 using demec gauge

The graph showed the overall result of cracks monitoring in house no.32 using demec gauge. It shows that the crack is quite stable and sometimes there is no movement at all, but from the value of cracks we can see that the movement influenced to the opening of the crack in building.

4.5 REMEDIAL WORKS

Based on Site Investigation works result and monitoring program carried out by IKRAM Sdn. Bhd. Consultant, it shows that the performance of building is decreased and the foundations of the buildings must be properly supported (underpinned), the structures damaged need to repaired and patch up. In September 2006, IHSAN Sdn Bhd, was appointed to carry out pilot test on two (2) units, namely house no. 40 and no.42. Lintang Bayan 8 (plan showed in appendix J) to observe and study the actual problem site problem and find out the results based on study and assumption. Based on study IHSAN Sdn Bhd has divided the remedial work into 3 parts and also carried out site monitoring during the remedial work. List below is shows the scope of remedial work has been done by IHSAN consultant.

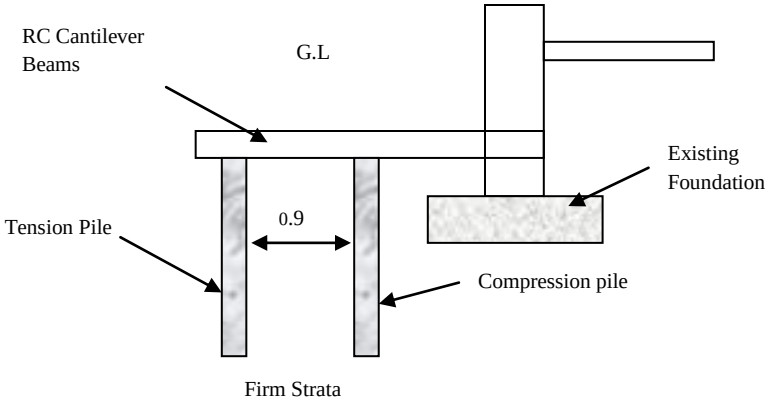
- Underpinning works
- Pressure grouting works

All the works started on 25th May 2007 and was completed on 9th July 2007.

4.5.1 *Underpinning works*

Based on previous site investigation, the building is laid down on 150mm x 150mm square reinforced concrete piles driven down to a maximum depth of 6m and 18m (Ikram SI report, 2006). Because large ground settlement occurred, the stability of foundation has change failed to resist the load pressure due to large movement. During observation, IHSAN consultant has found out that since the ground beams were sitting directly to single pile cap and the brick wall is supported on the ground beam, cracks appears on the wall and this symptom influenced to other structure nearest then the damages start continuing. IHSAN consultant also found out that the pile cap also experienced the cracks because of the movement. Based on study, IHSAN consultant has design and proposed the type of underpinning being used. The combination of cantilever beam and 150mm diameter micropile with 18m length was used to underpinning the existing single pilecap foundation to overcome the problem (Ihsan Rectification works report, 2007) .

Figure below showed the combination of cantilever beam and micropile with length 150mm diameter that being used to overcome the foundation failure.



SECTION OVERVIEW
(Source: Ihsan Rectification work Report,2007)

Figure III.25 Sectional View of underpinning work.

This method is combination between pile foundation and beam, this type of underpinning usually used for low-rise building. This each piles will take greater load once their underpinned. Usually the normal pile is used, depend on loads being carry, and for this pilot test IHSAN consultant has chose micro pile to support the cantilever beam. Micropile sized 150mm diameter was proposed to transfer the load from every pile cap. Explanation below showed the procedures of underpinning process based on Rectification works Report.

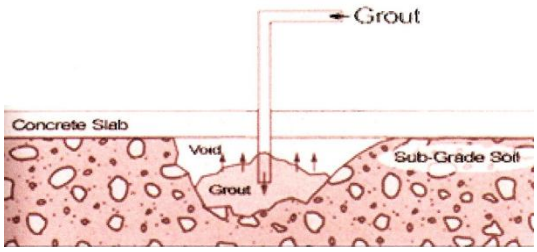
Underpinning Procedures:

- For pilot test purposes, there are two micropiles was used, compression and tension micropiles, but, the
  compression piles just only driven and drilled into the soil. The depth of drilling process is 18 meter. Figure below is showed boring process for micropiles driven into the soil using micropiles machine.
- The load from the existing foundation is then transferred into the new pile using a cantilever beam of 230x600mm
  deep. The bar size is 4Y32 for top and 3Y25 for bottom. With R10-100c/c shear links (Ihsan Rectification work Report, 2007).

From report data, there are eight (8) nos. of micropile can be driven. From the preliminary plans there were twelve (12) nos. of micropile have been proposed. From the data I have collected; the micropile is one of efficient structure foundation compare to other type of piles foundation, besides its smaller than other type of pile, it also easy to carry and placed the pile because it usually used small drilling equipment and machine and cheaper than other type of common piles for foundation.

4.5.2 *Pressure Grouting*

Because of the ground settlement, the ground floor slab become suspended, there are empty space which is have to fill in, this empty space (void) introduce the cracks to the ground floor slab because the floor cannot resist the pressure from upward and the loads also. The void is being confirmed below the slab after site inspection.To fill this void, IHSAN consultant has decided to use pressure grouting to fill the void area under the ground slab. Pressure grouting technique is by injecting the cement slurry to the ground using pump equipment. This method is a common method to stabilize the ground. Pressure grouting has chosen because it's more economical to solve the problem. Base on data collected, pressure grouting also can improve the stability of the ground to support structure above. Pressure grouting was carried out in 29 June 2007 and 4th July 2007 using grade 30 concrete epoxy mortar flow for unit 40 and unit 42. Below is showed the schematic of pressure grouting and diagram of pressure grouting work.



(Source: Ihsan Rectification work Report, 2007)

Figure III.34 The schematic of pressure grouting.

V. RESULT AND CONCLUSION

All the types of failure have very strong connection with the soil, because the soil behaviors determine the stability of building foundation and the long term performance of the building. The failures of foundation have large impact to the performance of building structure. Distortion and deflection will occur if the foundation is not stable and slightly move. It will create damages to the structure, such as cracks on the wall, beam, and floor and become a problem to the occupants. This problem need to be solve, and remedial work are the option to repair the failure.

5.1 MAINTENANCE TO PREVENT FOUNDATION FAILURE

Foundation is the supporting link between the building and the ground. They transmit the structure into the ground. But at the same time they transfer any ground movement back to the structure. If the foundation failed to transfer this movement it will effect on distortion and will produce damage to the building structure. This movement related to soil behavior including the bearing capacity of the soil to resist the loads from structure. To prevent the movement take place or minimal to reduce the movement itself, proper maintenance for soil and foundation stability is very important. Below are the methods that can be used to prevent the existing foundation from the failure;

Understanding the important of Foundation structure maintenance

The knowledge about the importance of foundation structure is essential to be spread wider, especially for ordinary peoples, who are having no relation in this building behavior. The occupant, building owner and also tenant, have to know the condition of their building structure or houses and know how to maintain the stability and performance of structure itself.

Site Inspection and Monitoring

Regularly Site inspection is quite important to locate whether there is damage appears in the building structure. The inspection will maintain the performance of building structure because if there is any sign or notice small scale of damages or crack appears on the wall or column, there will be early action taken. And if the damaged become larger, find out the expert to find the solution. The site inspection can be done by self or by the building inspector. The inspection can be done at least once in 6 month or once a year. It's already adequate and can maintain the stability of the structure itself. It also can reduce the risk of failure.

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