PERFORMANCE OF PULLOUT RESISTANCE OF ANCHORED EARTH
SYSTEM BY FIELD PULLOUT TEST

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ABSTRACT

Anchored Earth System had been developed from combination of the techniques used in reinforced earth and soil anchoring. Instead of using steel strip as a reinforcement, Anchored Earth System consist of round steel bar (tendon) with precast concrete block attached at the free end of each of the reinforcing steel bars, and it is backfilled with granular material or suitable earth fill. This research project can be considered a case study of anchored reinforced soil wall which investigates the performance of Anchored Earth System due to its pullout capacity. In this study, pullout resistance which contributed by friction between the backfill material and the shaft surface of reinforcing tendon, and the passive earth pressure against the concrete anchor block, can be evaluated through pullout tests. The main problems to be studied in this project are the results obtained from field pullout test are different from the calculated theoretical values and there is a non-zero intercept at relationship of pullout force against overburden pressure. The field pullout tests were carried out in three conditions: i) with reinforcing tendon only; ii) with anchor block only; and iii) with both reinforcing tendon and anchor block together in order to determine the sharing of resistance in the system. The pullout test was also done under soaked condition. The average interaction coefficient $\alpha' = 1.99$ and bearing factor $\beta = 6.32$ were determined by back analysis. It was found that the sharing of load between the tendon and the anchor block in anchored earth system is not equal, but most of the resistance is contributed by the bearing passive of anchor block where approximately 30% of resistance contributed by residual frictional resistance and 70% contributed by peak bearing passive resistance. The pullout resistance in soaked condition observed to be lower than in unsoaked condition due to the increase in pore water pressure that reduced the shear resistance.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>i</td>
<td></td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ii</td>
<td></td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
<td></td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
<td></td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
<td></td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
<td></td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
<td></td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
<td></td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xii</td>
<td></td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>xv</td>
<td></td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>xviii</td>
<td></td>
</tr>
</tbody>
</table>

1 **INTRODUCTION**

1.1 Introduction 1

1.2 Historical Background of Reinforced Soil Wall 2

1.3 Problem Statement 5

1.4 Aim and Objectives 6

1.5 Scope of Work 6

2 **LITERATURE REVIEW**

2.1 Introduction 8

2.2 Anchored Earth System 9

2.3 Basic Mechanics and Concept of Reinforced Earth 12

   2.1.1 Anisotropic Cohesion Concept 13
2.1.2 Enhance Cohesion Concept 15
2.4 Stress-strain Relationship of Reinforced Soil 16
2.5 Principle of Reinforced Soil 19
2.6 Rankine Theory of Earth Pressure 21
2.7 Internal Stability 23
2.7.1 Tension Failure of the Reinforcement (Structural Failure) 24
2.7.2 Pullout Failure of the Reinforcement (Geotechnical Failure) 25
2.8 Factor Affecting Pullout Response 26
2.9 Pullout Test of Reinforced Soil Wall 29
2.10 Pullout Test of Geosynthetics 33
2.11 Pullout Test of Anchor 41
2.12 Laboratory and Field Pullout Test Done by Other Researcher 45

3 RESEARCH METHODOLOGY
3.1 Introduction 52
3.2 Equipment Setting Out 55
3.3 Test Procedure 55
3.4 Test Schedule 57
3.4.1 Pullout Test of Reinforcing Bar Only 57
3.4.2 Pullout Test of Anchor Block Only (with bar isolated from friction using pipe sleeve) 59
3.4.3 Pullout Test of Anchor Block and Reinforcing Bar 60
3.5 Laboratory and Field Density Test 62
3.6 Pullout Test in Soaked Condition 65

4 DATA COLLECTION AND ANALYSIS
4.1 Introduction 69
4.2 Evaluation of Pullout Force 71
4.3 Pullout Test with Reinforcing Bar Only 87
4.3.1 Test 1-1 87
4.3.2 Test 1-2 88
4.3.3 Test 1-3 88
4.3.4 Test 1-4 89
4.3.5 Test 1-5 89
4.3.6 Test 1-6 89
4.4 Pullout Test with Anchor Block Only 90
  4.4.1 Test 2-1 91
  4.4.2 Test 2-2 91
  4.4.3 Test 2-3 91
  4.4.4 Test 2-4 92
  4.4.5 Test 2-5 92
  4.4.6 Test 2-6 92
4.5 Pullout Test of Combination of Tendon and Anchor Block 93
  4.5.1 Test 3-1 93
  4.5.2 Test 3-2 94
  4.5.3 Test 3-3 94
  4.5.4 Test 3-4 94
  4.5.5 Test 3-5 95
  4.5.6 Test 3-6 95

5 RESULTS AND DISCUSSIONS

5.1 Introduction 96
5.2 Back Analysis of the Bearing Factor $B$ and Interaction Coefficient $\alpha'$ 96
5.3 Frictional Resistance 98
5.4 Bearing Passive Resistance 103
5.5 Combination of Frictional Resistance and Bearing Passive Resistance (Anchored Earth Wall System) 105
5.6 Pullout Test under Soaked Condition 119
6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction 127
6.2 Conclusions 127
6.3 Recommendations for Further Future Study 128

LIST OF REFERENCES 129

APPENDICES
APPENDIX A – Pullout Data 139
APPENDIX B – Laboratory Test Results 169
## LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Pullout test of reinforcing bar only (from Lee, 2006)</td>
<td>46</td>
</tr>
<tr>
<td>2.2</td>
<td>Pullout test of anchorage block only (from Lee, 2006)</td>
<td>46</td>
</tr>
<tr>
<td>2.3</td>
<td>Pullout test of anchor block and reinforcing bar (from Lee, 2006)</td>
<td>46</td>
</tr>
<tr>
<td>3.1</td>
<td>Reinforcing bar pulled out resistance test schedule</td>
<td>58</td>
</tr>
<tr>
<td>3.2</td>
<td>Pullout Test of Anchor Block Only (with bar isolated from friction using pipe sleeve)</td>
<td>59</td>
</tr>
<tr>
<td>3.3</td>
<td>Anchored Earth System Pullout Resistance Test Schedule</td>
<td>60</td>
</tr>
<tr>
<td>3.4</td>
<td>Field density test results</td>
<td>64</td>
</tr>
<tr>
<td>3.5</td>
<td>Summary of the laboratory test result for sand</td>
<td>64</td>
</tr>
<tr>
<td>3.6</td>
<td>Schematic diagram of pullout test schedule</td>
<td>68</td>
</tr>
<tr>
<td>4.1</td>
<td>Pullout Test Results</td>
<td>70</td>
</tr>
<tr>
<td>5.1</td>
<td>Residual strength of reinforcing tendon</td>
<td>107</td>
</tr>
<tr>
<td>5.2</td>
<td>Table of summary for pullout test of reinforcing bar only</td>
<td>114</td>
</tr>
<tr>
<td>5.3</td>
<td>Table of summary for pullout test of anchor block only</td>
<td>115</td>
</tr>
<tr>
<td>5.4</td>
<td>Table of summary for pullout test of reinforcing bar and anchor block</td>
<td>115</td>
</tr>
<tr>
<td>5.5</td>
<td>Contribution of residual frictional resistance and peak bearing passive resistance in the anchored earth system</td>
<td>117</td>
</tr>
<tr>
<td>5.6</td>
<td>Summary of pullout test results under soaked condition</td>
<td>120</td>
</tr>
<tr>
<td>5.7</td>
<td>Comparison of field pullout resistance and calculated pullout resistance under soaked condition</td>
<td>120</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The earliest reinforced soil structure, Ziggurat in Mesopotamia</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>The timber wharf</td>
<td>3</td>
</tr>
<tr>
<td>1.3</td>
<td>Munster earth retaining structure</td>
<td>4</td>
</tr>
<tr>
<td>1.4</td>
<td>Coyne retaining wall</td>
<td>4</td>
</tr>
<tr>
<td>2.1</td>
<td>Load transferred in anchored earth wall</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>Pullout resistance in Anchored Earth System</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>State of stress in Reinforced Earth</td>
<td>13</td>
</tr>
<tr>
<td>2.4</td>
<td>Reinforced and unreinforced sand in triaxial test</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>(Schlosser <em>et al.</em> 1972: In Pokharel, 1995)</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Anisotropic Cohesion Concept</td>
<td>15</td>
</tr>
<tr>
<td>2.6</td>
<td>Enhanced Cohesion Concept</td>
<td>16</td>
</tr>
<tr>
<td>2.7</td>
<td>Mohr Circle of stress and strain rate</td>
<td>17</td>
</tr>
<tr>
<td>2.8</td>
<td>$\alpha$ and $\beta$ characteristics of reinforced fill produced by</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>wall rotating about A (After Milligan 1974)</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>$\alpha$ and $\beta$ characteristics of reinforced fill</td>
<td>18</td>
</tr>
<tr>
<td>2.10</td>
<td>Idealized zero extension characteristics with $\beta$ direction</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>aligned with the horizontal reinforcement (After Bassett and Last, 1978)</td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>Contact in between particle grains and reinforcing elements</td>
<td>20</td>
</tr>
<tr>
<td>2.12</td>
<td>Tension created by grains and reinforcing elements</td>
<td>20</td>
</tr>
<tr>
<td>2.13</td>
<td>Wall surface with active and passive case</td>
<td>21</td>
</tr>
<tr>
<td>2.14</td>
<td>State of plastic equilibrium</td>
<td>22</td>
</tr>
<tr>
<td>2.15</td>
<td>Active and Passive Rankine State</td>
<td>22</td>
</tr>
<tr>
<td>2.16</td>
<td>Schematic diagram of tension failure</td>
<td>24</td>
</tr>
<tr>
<td>2.17</td>
<td>Schematic diagram of pullout failure</td>
<td>25</td>
</tr>
</tbody>
</table>
2.18 Pullout test in Reinforced earth walls – influence of the nature of the strip surface (After Schlosser and Elias, 1978) 28
2.19 Interaction mechanism in a reinforced soil wall (modified from Palmeira and Milligan, 1989) 29
2.20 Conceptual diagram on pullout tests for soil-reinforcement (from Gurung and Iwao, 1999) 30
2.21 Bearing capacity failure (After Peterson and Anderson, 1980) 35
2.22 Punching shear failure (After Jewell et al. 1984) 35
2.23 Overview of reinforcing bar with expanded toe (Hayashi et al., 2007) 43
2.24 Calculated pullout strength $P_d$ and measured ultimate pullout resistance $P_u$. (from Hayashi et al. 2007) 44
2.25 Relationship between the vertical stress at the toe section $\sigma_v$ and the pullout resistance at yield $P_y$, the ultimate pullout resistance $P_u$ and the calculated pullout resistance $P_d$ for fine sand. (Hayashi et al. 2007) 45
2.26 Constrained dilantancy (from Lo et al., 2004) 50
3.1 Flow chart of methodology 53
3.2 Schematic diagram of pullout test set-up 55
3.3 Typical cross section of anchored earth wall with pullout test equipment 56
3.4 Schematic diagram of pullout test of reinforcing bar only 58
3.5 Schematic diagram of pullout test of anchor block only (with bar isolated from friction using pipe sleeve) 59
3.6 Schematic diagram of pullout test of anchor block and reinforcing bar 60
3.7 Schematic diagram of rear elevation of the pullout test location 61
3.8 Grain size distribution of backfill material of pullout test 62
3.9 Shear box test result 63
3.10 Plan view of anchored earth wall under soaked condition 65
3.11 Side view of anchored earth wall under soaked condition 66
3.12 Front view of anchored earth wall under soaked condition 66
3.13 Setting out of pullout test under soaked condition 67
4.1 Load deformation curve for Test 1-1, 2-1, and 3-1
4.2 Plot history curve for Test 1-1, 2-1, 3-1
4.3 Load displacement curve for Test 1-2, 2-2, 3-2
4.4 Plot history curve for Test 1-2, 2-2, and 3-2
4.5 Load deformation curve for Test 1-3, 2-3, 3-3
4.6 Plot history curve for Test 1-3, 2-3, and 3-3
4.7 Load deformation curve for Test 1-4, 2-4, 3-4
4.8 Plot history curve for Test 1-4, 2-4, and 3-4
4.9 Load deformation curve for Test 1-5, 2-5, and 3-5
4.10 Plot history curve for Test 1-5, 2-5, and 3-5
4.11 Load deformation curve for Test 1-6, 2-6, and 3-6
4.12 Plot history curve for Test 1-6, 2-6, and 3-6
4.13 Pullout force against displacement (for tendon only)
4.14 Pullout force against displacement (for anchor block only)
4.15 Pullout force against displacement (for both tendon and anchor block)
5.1 Default values for pullout friction factor (from AASHTO)
5.2 Graph ultimate pullout resistance against overburden (tendon only)
5.3 Schematic sketch of frictional resistance equation
5.4 Graph ultimate pullout resistance against overburden (anchor block only)
5.5 Graph ultimate resistance against overburden (tendon + anchor block)
5.6 Graph residual resistance against overburden (tendon only)
5.7 Schematic sketch of pullout resistance against displacement for all pullout test conducted.
5.8 Load deformation curve for pullout test under soaked condition
5.9 History curve for pullout test under soaked condition
5.10 Graph ultimate pullout resistance against overburden under soaked condition
LIST OF SYMBOLS

\[ A \] – Facing area of anchor block
\[ A_s \] – Friction area
\[ A_p \] – Projected area of the expanded toe towards the pullout direction
\[ B \] – Width
\[ B_a \] – Long term width of anchor head
\[ B_s \] – Long term horizontal projection area of shaft or loop
\[ C \] – Constant
\[ c \] – Cohesion
\[ D \] – Diameter of tendon
\[ d \] – Depth
\[ F_A \] – Bearing passive resistance
\[ F_R \] – Shaft friction resistance
\[ F^* \] – Pullout resistance factor
\[ F_a \] – Force resulting from adhesion mobilization
\[ F_p \] – Resulting force due to passive resistance
\[ F_{sg} \] – Resulting force due to friction mobilization
\[ F_t \] – Pullout force
\[ F_{qg} \] – Force coefficient
\[ F_1, F_2 \] – Tension force
\[ F_{corr} \] – Corrected pullout force
\[ F_{dum} \] – Dummy pullout force
\[ F_{max} \] – Maximum pullout force recorded
\[ f \] – Friction coefficient between grains and reinforcement
Soil-geosynthetic pullout interaction coefficient
Partial material factor
Pullout friction coefficient
Height
Coefficient of passive earth pressure
Coefficient of pressure at rest
Length of tendon
Length of anchor shaft beyond the potential failure plane
Gradient of graph
Bearing capacity factor
Number of transverse member
Ultimate pullout load
Bearing resistance
Pullout strength
Frictional resistance
Passive pressure
Pullout resistance
Shaft or loop resistance
Ultimate pullout resistance
Pullout resistance at yield
Modification factor
Ultimate bearing capacity
Horizontal confining pressure at expanded toe
Pullout resistance
Long term height of anchor head
Interaction coefficient
Bearing factor
Skin friction angle between reinforcement and soil
Major principle strain
Minor principle strain
Friction angle
\begin{itemize}
\item \( \gamma \) – Unit weight of soil
\item \( \varphi' \) – Peak angle of shearing resistance under effective stress condition
\item \( \mu \) – Coefficient of soil/reinforcement friction
\item \( \mu_s/G_{SY} \) – Soil-geosynthetic interface apparent coefficient of friction
\item \( \tau \) – Maximum shear strength
\item \( \tau_f \) – Failure shear stress
\item \( \sigma_a' \) – Average normal stress
\item \( \sigma_n' \) – Normal effective stress
\item \( \sigma_v' \) – Overburden pressure
\item \( \sigma_{ij}' \) – Vertical applied pressure
\item \( \sigma_{vo} \) – Normal stress
\item \( \sigma_x \) – Horizontal stress
\item \( \sigma_y \) – Increased normal stress due to shearing
\item \( \sigma_z \) – Vertical stress
\item \( \sigma_1 \) – Major principle stress
\item \( \sigma_3 \) – Minor principle stress
\end{itemize}
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Pullout Data</td>
<td>139</td>
</tr>
<tr>
<td>B</td>
<td>Laboratory Test Results</td>
<td>169</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Introduction

Retaining wall is a structure that provides vertical or nearly vertical support to a differential level of masses of soil and holds back soil from another structure such as buildings on top, and it may prevent slope instability or erosion from happening. The supported material is termed as backfill. Retaining walls generally can be classified to various types: (i) Gravity Wall, which rely on their own self-weight or any soil resting on top for the sustainable of stability against the horizontal lateral earth pressure; (ii) Semi-gravity Wall, with minimum amount of reinforcing steel in order to minimize the wall size; (iii) Cantilever Wall, which derives part of its stability from the weight of the soil located above the footing at the back of the wall; and (iv) Counterfort Wall, that consist of counterfort that tie the wall and base slab together in order to reduce the shear and bending moments. The failure of a retaining wall may usually caused by tilting or sliding along the base which parallel to its original position. Each of the failure type as mentioned above is associated with a downward movement which is named as wedge-shaped body of soil or the sliding wedge.

Reinforced soil wall is a combination of soil and reinforcing element. Each of the elements has their own properties and strength. The fundamental is the reinforcing elements embedded in soil contribute tensile strength to soil. The
interaction between reinforcing elements and soil through friction or adhesion thereby provide tension and shear to strengthening the soil.

1.2 Historical Background of Reinforced Soil Wall

The concept of earth reinforcement is the basic principles illustrated naturally by animals and birds and the action of tree roots. It is believed that the earliest reinforced soil wall concept was first applied in the ancient time. During the ancient times, the brick was made with straw reinforcement by the Egyptians. One of an earlies reinforced soil structures, Ziggurat of the ancient city of Dur-Kurigatuz as shown in Figure 1.1, which was built by the Babylonians since 2500 BC was reinforced with woven mats of reed laid horizontally on a layer of sand and gravel at vertical spacing varying between 0.5 and 2.0 m (Lee, 2006).

![Ziggurat of ancient city of Dur-Kurigatuz](image)

**Figure 1.1** The earliest reinforced soil structure, Ziggurat in Mesopotamia (Lee, 2006).

In fact, many parts of Asia are using bamboo and straw to strengthen soil mass. Natural materials were used as reinforcement to construct a large portion of the Great Wall of China. In the Gansu province for instance, some section of Great
Wall were built using loess soil, which was reinforced with reeds and twigs at every 150mm lift (Lim, 2003).

The timber wharf shown in Figure 1.2, parts of which have been preserved in the Thames mud for 1200 years is believed built by Romans (Jones, 1985). The structure was formed from oak baulks and having a vertical face held in place by timber reinforcing elements embedded in the backfill.

![Figure 1.2 The timber wharf (Jones, 1985).](image)

In year 1822, Col. Pasley (Jones, 1985) successfully introduced a form of reinforced soil for military construction in the British Army he proved that significant reduction is possible in the lateral pressure acting on the retaining walls if the backfill were reinforced by horizontal layers of brushwood, wooden planks or canvas.

The modern concept of reinforced soil structure was made by Munster in year 1925 (Jones, 1985). An earth retaining wall using an array of wooden reinforcing members and a light facing was produced by Munster. The systems created by Munster are still valid and become the core of one of the reinforced soil
construction techniques among the many. The following Figure 1.3 is the diagram of Munster earth retaining structure.

![Figure 1.3 Munster earth retaining structure (Jones, 1985).](image)

During 1930s, Andre Coyne (Jones, 1985) had introduced a type of engineered reinforced soil wall Mur Echelle (ladder wall). The ladder wall consists of a mass granular filling unified by a row of tie members each having a small end anchors, together with a thin cladding membrane. The use of ladder wall was not widely used due to the reason of World War II (Lee, 2006). The following Figure 1.4 is the diagram of Coyne retaining wall.

![Figure 1.4 Coyne retaining wall (Jones, 1985).](image)
The reinforced soil concept was applicable and growth throughout the world after the French Architect, Henri Vidal invented the Reinforced Earth. The first Reinforced Earth was constructed in 1966 in Pyrenees Mountains of France (Lee, 2006). The Reinforced Earth wall using flat metallic strips to strengthen the soil mass. The reinforcing strips interact with the soil through interface friction and allow the soil mass to be kept stable even with a near vertical face. The successful application of Vidal’s concept has led to development of better reinforcement materials and has been widely used today.

After the success of invention of Reinforced Earth Wall, several other proprietary and non-proprietary systems have been developed and used. Among them are Hilfiker Retaining Wall (FHWA-RD-89-043, 1989), which uses welded wire mesh type and facing system developed in the mid of 1970’s, VSL Retained Earth (FHWA-RD-89-043, 1989) which using steel strips of steel grid as reinforcement, geotextile reinforced soil wall which is well developed since 1980 (FHWA-RD-89-043, 1989) etc. Anchored Earth System is one of the reinforced soil systems that modified from Reinforced Earth System.

1.3 Problem Statement

One of the internal stability of Anchored Earth System is governed by pullout resistance developed by frictional shaft surface along the reinforcing bar and passive earth pressure against anchor block. The shear strength of the frictional component should be fully relies on the parameter friction angle, $\phi'$, if all the parameter is set to be constant for comparison purposes. However, the result obtained from field pullout test is different from the theoretical value calculated and there is a non-zero intercept at relationship of pullout force against overburden pressure. Besides, the filed test results obtained might have discrepancies because is beyond the control.
1.4  **Aim and Objectives**

The purposes of this study carried out are:

(i) To evaluate the sharing of pullout resistance between reinforcing tendon and concrete anchor block.

(ii) To compare the performance under soaked and unsoaked condition.

(iii) To find the interaction coefficient $\alpha'$ and $\beta$ in comparison with design code.

1.5  **Scope of Work**

The first step in the research project is to review of background of technical literature which inclusive the field and laboratory pullout test that have been carried out by other researchers to understand the concept and development of reinforced soil.

This research project can be considered a case study of anchored reinforced soil wall which investigate the performance of Anchored Earth System due to its pullout capacity. The field pullout test was carried out by using same type of backfilling, which is river sand with friction angle of 36°, reinforcing tendon of 20 mm in diameter and 6.4 m in length with anchor block size of 200 mm x 200 mm at the free end of the reinforcing tendon. The test was done by constant pulling rate of 0.3 mm per minutes until the reinforcing tendon failed as breaking or pullout. The mentioned pullout rate is suggested by Roads and Traffic Authority of New South Wales (RTA). In fact the pullout rate of 0.3 mm per minutes may still too high but due to the practicality of the field test, it may not allow the pullout rate to be reduced much further. The pullout rate shall not be too high to avoid the build up of pore water pressure and a sudden friction during the pullout test.
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