FORENSIC SITE INVESTIGATION AND INSTRUMENTATION

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Abstract
This paper discusses the cause of geotechnical failure and its effect, the common type of site investigation techniques and instrumentations to investigate the geotechnical failures. Examples of the methods and their limitations are also given.

Keywords: Geotechnical failures; Geotechnical investigation; Instrumentation

1. INTRODUCTION

Land for development is becoming scarce. Land that is used to be called unsuitable for development such as swampy land, hilly land and ex-mining land are being utilized. This contributes to the many cases of geotechnical failures.

Failure is defined as behaviour not in agreement with the expected conditions of stability, or as lacking freedom from necessary repair, or non-compliance with the desired use and occupancy of the completed structures (Jacob Feld, 1968).

In Malaysia, failures such as the collapse of the Highland Tower and Royal Belum State Park Administration Complex in Pulau Banding showed the extreme extend that geotechnical failure can cause to structures.

The engineering fraternity has a lot to learn from the cases of geotechnical failures in the country. However most of the reports will be shrouded in secrecy as report of failure might lead to litigation and embarrassment to various parties. The investigation may also be time consuming and expensive.

2. CAUSES OF GEOTECHNICAL FAILURE

The cause of failure can be due to human factors and technical shortfalls. The human factors can be due to the following:

i) ignorance
ii) carelessness
iii) false economy
iv) greed
v) attitude

Technical shortfalls can be due to the limitation in the following activities:

i) Site investigation
ii) Design assumption
iii) Detailing

iv) Specification
v) Construction methodology

Possible cause and effect of building failure is provided in Attachment A.

3. FAILURE ACTION PLAN

Whenever failure occurs, clear steps need to be followed by site engineers responsible for the work. The typical steps are as follows:

i) Identify the symptoms. This can be cracks, settlement, tilting and translation.
ii) Report the failure.
iii) Monitor of situation. Monitor until the failure phenomenon is identified and addressed.
iv) Collect the necessary information. This includes:
   a) Structure details
   b) Site information
   c) Description of problem and distress
   d) Foundation detail
   e) Construction record
   f) External and environmental factors

Forensic investigation needs to be pursued by the engineer responsible for the work. The investigation will include the following steps:

i) Collection and review of available data. This data represents the reports and plans that were generated during the design and construction of the project. Typical documents are provided in Attachment B.
ii) Planning and implementation of soil investigation and instrumentation work.
iii) Preparation of forensic report identifying the possible cause of failure and recommended remedial works concept.
iv) Design or remedial work. Normally, permanent remedial work shall not proceed unless the forensic study has clearly establishes the cause of failure. This is to prevent recurrence of the failure. .

4. SITE INVESTIGATION

Site investigation work consists of surface investigation and soil investigation. The two activities will help to assess the general site conditions and identify the possible geotechnical problems, and determine the stratigraphy and pertinent properties of the underlying soil. The guideline for these are provided in BS 5930.

Soil investigation has been identified as the main factor contributing to:

i) Many geotechnical failures. It is not listed in Attachment A as normally it is identified as unpredictable circumstances.
ii) Construction disputes, significant delay and increased in construction cost.
iii) Unnecessary over-designed foundations

Typical soil investigation work for failure investigations are as per the following:

i) Soil boring with Standard Penetration Test (SPT)
ii) Mackintosh Probe (MP)
iii) Cone penetration test (CPT)
iv) Disturbed sampling
v) Undisturbed sampling
vi) Index property tests
vii) 1-Dimensional consolidation test.
viii) Triaxial Compressive Strength Test

5. GEOTECHNICAL INSTRUMENTATION

Geotechnical instrumentations are commonly used for the following:

i) To determine site condition such as pore water pressure, permeability of the soil, stability of the slope, embankment and retaining wall.
ii) To verify design parameters. The performance of soil can be verified and design parameters modified if necessary.
iii) As construction control. As an example is to determine how fast construction should be allowed to proceed.
iv) Evidence in a legal proceeding.

Typical geotechnical instrumentation needs, available instruments and their application are tabulated below (Table 5.1):

Table 5.1: Instruments and their application

Parameter	**Instrument**	**Application**
Pore water pressure	Standpipe piezomter Vibrating wire piezometer	Embankment construction, slope, retaining wall, dewatering
Lateral deformation	Inclinomter Extensometer	Slope, embankment, sheet pile wall
Vertical deformation	Magnet extensometer settlement gauge, settlement marker, displacement marker	Embankment, excavation, foundation.
Loads and strains	Hydraulic jacks, strain gauges, load cells	Foundations, retaining walls
Earth pressure	Membrane type pressure gauge	Embankment, slopes

With the advance in information technology and electronic engineering, real time monitoring system (RTMS) is now available which should provide an early warning system during construction and post construction stage. Nevertheless, as a general rule, it is a sound instrumentation policy to utilize the simplest type of instrumentation system that will enable the desired data to be obtained (DiBiaglio, 1996).

6. INTERPRETATIONS

Interpretation of soil investigation and instrumentation are fundamental to the success of any forensic investigation work.

Typical analysis required from geotechnical instrumentation work is provided in the following Table 6.1.

Table 6.1: Analysis of Instruments

Structure	**Deformation**	**Instrument Readings**	**Analysis**
Embankments	Vertical	Settlement gauges	Asaoka Plot (1978)
	Lateral	Settlement gauge; inclinometer	Matsuo Plot (1977)
	Pore water pressure	Piezometer	Changes in pore water
Slope	Lateral	Inclinometer	Time Plot
Pile	Vertical	Load cells	Chin Method (1978)
	Vertical	Strain gauges	Elastic compression

Table 6.2 below provides the analysis of what can go wrong in any forensic investigation. These are common errors found in the site investigation and instrumentation work.

Table 6.2: What can go wrong analysiss

Data	**What can go wrong**	**Impact**
SPT records	SPT blow counts counting error	Pile foundation design
	Soil description error	Replacement soil (sand layer) may not be present
CPT records	Manual records or processed records	Soil strength (residual or not)
MP records	Obstruction by hard objects	Incorrect interpretation of soil strength
Liquid Limit	Typographical error	Incorrect calculation of the consolidation settlement.
Surface markers	Monitoring of vertical movement but erosion and lateral movement is larger	Small vertical movement observed but cracks could be observed at adjacent floor slab.
Inclinometer	Change in base reading	Cumulative movement cannot be ascertained
	Equipment error	May cause error in determining the total movement
1-Dimensional Consolidation Test	Test loads	Incorrect estimation of settlement

In addition, levels are keys in getting the correct geotechnical instrumentation results. As such, it is paramount that they are checked whenever results are received for consistency and agreement with basic soil mechanics fundamentals.

7. CONCLUDING REMARKS

Geotechnical engineering is a field where we turn art into science. We need to appreciate and understand the art before we could significantly progress in the field of geotechnical engineering.

Geotechnical failures are common. One may well say that the human factor contribution is due to failure to appreciate the art and science of the field.

In geotechnical forensic area, due to the possible litigation process involved, defined steps need to be taken to ensure all possibilities have been considered.

Site investigation and instrumentation are the 'CSI' tools of the geotechnical engineer. As such geotechnical engineers need to be well equipped with knowledge, experience and skill in this area. As a start, correct selection of site investigation and instrumentations techniques will help to solve the 'mysteries' of failure.

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Attachment A

Cause	Effect							
	Foundation		**Settlement**			**Slope**		**Vibration**
	Struct.	**B_rng**	**Total Settle.**	**Diff. Settle**	**Tilt**	**Slope**	**Lateral Supp.**	**Liquef_n**
Lower load		X	X	X	X			
Lateral load		X					X	
Uplift load		X						
Dynamic load			X	X	X			X
Negative Skin			X	X	X			
Hydrostatic pressure	X							
Foundation RL		X	X	X	X			
Close to slope		X				X		
Many foundation type			X	X	X			
Pile durability	X	X	X					
Varying pile length				X	X			
Bakau pile above water	X							
Untreated timber	X							
Excessive bearing allowed		X	X	X	X			
Unequal pressure		X	X	X	X			
Additional load		X	X	X	X			
Close spacing of friction piles		X	X	X				
Poor compaction		X						
Unsuitable material		X						
Bottom heave in excavation		X		X	X			

Unsupported excavation			X	X	X		X	
Dewatering		X		X				
Water ponding		X		X				
Concrete quality	X			X				
Steel reinforcement	X			X				
Timber quality	X			X				
Bored pile quality	X			X	X			
Pile handling	X			X	X			
Hard driving	X	X		X	X			
Pile out of position		X		X	X			
Not properly bedded piles		X		X	X			
Heaving of pile in group		X		X	X			
Failed joints	X			X	X			
Insufficient length		X						
Deep excavation							X	
Earthquake								X
Vibration due to surrounding activity								X

Attachment B

Project Phase	Type of Document
Design	Design reports: geotechnical reports, planning reports, feasibility studies
	Design calculation and analysis
	Computer program used for the design
	Design specification
	Applicable building codes
	Shop drawings and design plans
Construction	Construction reports: Inspection reports, field memos, laboratory test reports, mill certificates
	Contract documents
	Construction specification
	Project payment information
	Change orders
	Relevant project correspondence
	As built drawings
	Photographs
Post-construction	Post construction reports: Maintenance reports, modification documents, reports on specific problems, repair reports , photographs
Technical data	Records: Weather report, seismic activity
	Reference: Geologic maps, topographic map and aerial photographs
	Technical publications: Journals, papers, articles that describe similar failures