PERFORMANCE OF UNPAVED ROAD WITH DIFFERENT SOFT CLAY REINFORCEMENT

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ABSTRACT

This research, in general, aim to evaluate the performance of full-scale unpaved road on bamboo geotextile composite reinforced soft clay (unpaved road BGC) and high strength geotextile reinforced soft clay (unpaved road HSG), compared to the unpaved constructed on un-reinforced soft clay (unpaved road UR). The soft soil is natural poor in strength but high in compressibility and cannot support heavy load such as building and dynamic load from heavy vehicle. This condition can be a problem to people for transporting agriculture products. The objective of this research to determine the effect on settlement and pore water pressure with partial removal of surcharge, to determine and compare the dynamic load effect on ground condition of reinforced with high strength geotextile and bamboo-geotextile composite. The full-scale unpaved road constructed at RECESS. Three sections of road consist of bamboo-geotextile reinforced, high strength geotextile reinforced and unreinforced (control) was constructed and each section is 10 m length and 16 m width with 5 m length of buffer zones separating each section. The dynamic load from truck has been applied on each section and the installed instrumentation has been measure data for studying the effects of distribution dynamic load on rural road. The instrumentations that were installed at study location are inclinometers, piezometers, and hydrostatic profilers in order to monitor road performance. Effects of dynamic load has been monitored in 2 parts i.e. first part is before applied dynamic load, second part is after applied dynamic load. The four conclusions of this research are effect of partial removal of surcharge on embankment the reverse consolidation of soil has been occurs, the HSG rebound about 10%, BGC rebound about 11% and UR rebound about 8%, reverse consolidation occurs at negative excess pore water pressure, Settlement difference at maximum of passes for BGC compared to UR is a 23% lower than UR. While settlement differences HSG was 26% lower than the UR, Lateral movement different at BGC compare to UR which about 24% lower than UR. While for HSG has 38% lower than UR, Excess pore

water pressure different at 3 meter depth at BGC compare to UR which about 23% lower than UR.While for HSG has 73% lower than UR. This means that the settlement, lateral movement and pore water pressure at the HSG is smaller than the other soil reinforcement.

ABSTRAK

Kajian ini, secara umum, bertujuan untuk menilai prestasi jalan tidak berturap skala penuh pada Komposit Buluh-Geotekstil (jalan tidak berturap BGC) dan tanah liat lembut diperkukuh dengan geotekstil berkekuatan tinggi (jalan tidak berturap HSG), berbanding dengan tanah liat lembut tidak diperkukuh (jalan tidak berturap UR). Tanah liat lembut semulajadi yang lemah dalam kekuatan tetapi tinggi dalam kebolehmampatan dan tidak boleh menyokong beban berat seperti bangunan dan beban dinamik dari kenderaan berat. Keadaan ini boleh mendatangkan masalah kepada orang untuk mengangkut produk pertanian. Kajian ini bertujuan untuk menentukan kesan ke atas pemendapan dan tekanan air liang dengan pemotongan sebahagian surcaj, Untuk menentukan dan membandingkan kesan beban dinamik keatas keadaan bawah tanah yang diperkukuh dengan geotekstil kekuatan tinggi (jalan tidak berturap HSG) dan komposit buluh-geotekstil (jalan tidak berturap BGC). Jalan tidak berturap skala penuh ini dibina di RECESS. Tiga bahagian jalan terdiri daripada tetulang buluh-geotekstil, geotekstil kekuatan tinggi dan tanpa tetulang (kawalan) telah dibina dan setiap bahagian ialah 10 m panjang dan 16 meter lebar dengan panjang 5 m zon penampan yang memisahkan setiap bahagian. Beban dinamik dari trak telah digunakan pada setiap bahagian dan instrumentasi yang dipasang telah mencerap data untuk mengkaji kesan beban dinamik di jalan raya luar bandar. Instrumen yang telah dipasang di lokasi kajian adalah alat *inclinometer, piezometer, and hydrostatic profiler* untuk memantau prestasi jalan raya. Kesan beban dinamik telah dipantau dalam 2 bahagian iaitu bahagian pertama sebelum beban dinamik dikenakan, bahagian kedua selepas beban dinamik dikenakan keatas jalan. Empat kesimpulan didalam kajian ini telah dibuat pertama adalah kesan pemotongan sebahagian surcaj keatas tambakkan menyebabkan berlakunya *reverse consolidation* dimana HSG telah *rebound* sebanyak 10% manakala untuk BGC telah *rebound* sebanyak 11% dan UR telah rebound sebanyak 8%. *Reverse consolidation* ini berlaku pada negatif tekanan air liang. Perbezaan pemendapan pada maksimum

passes pada BGC berbanding UR adalah 23% lebih rendah daripada UR, manakala perbezaan pemendapan pada HSG adalah 26% lebih rendah daripada UR. Perbezaan pergerakan sisi di BGC berbanding untuk UR kira-kira 24% lebih rendah daripada UR, manakala bagi HSG mempunyai 38% lebih rendah daripada UR. Perbezaan tekana air liang pada 3 meter di BGCberbanding dengan UR kira-kira 23% lebih rendah daripada UR, Manakala bagi HSG mempunyai 73% lebih rendah daripada UR. Ini bermakna bahawa pemendapan, pergerakkan sisi dan tekanan air liang pada HSG adalah lebih kecil daripada tetulang tanah lain.

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Unpaved road is important for land communication. In rural areas, unpaved road is important mean to deliver agriculture products. As this agriculture product comprise mainly from product such as oil palm, coconut, pineapples and rubber which requires heavy vehicle to transporting agriculture products, so will become problem if that unpaved road in a situation bad such as muddy, smooth and wet when rainy season. Unpaved road damage also gave problem to people from trip comfort aspect, safety and facility to produce agriculture products. This problem is causes by the characteristics of soft soil are high compressibility, low shear strength and low permeability. Compare to other type of soils, the strength development of soft soil is time dependent. General construction problems in this deposit are insufficient bearing capacity, excessive post construction settlement and instability on excavation and embankment forming (Mat Nor, 2008).

There are methods to improve soft soil such as electro osmosis, lime stabilization, dynamic deep compaction, vibratory compaction, stone columns, dynamic compaction, grouting, vertical drained, static loading and preloading. The methods mentioned are very costly and require a lot of time to strengthen the soft foundation soil. To overcome these difficulties, soil reinforcement was introduced as one of alternative way in unpaved road construction over soft clay that are efficient than other method. Soil reinforcement is a technique where soil is being strengthened by tensile elements such as metal rods or strips, non-biodegradable fabrics, geotextile, granular materials and bamboo (Das, 2004).

1.2 Statement of Problem

Batu Pahat area is categorized as soft clay area and with high ground water level. This would be affected to unpaved road construction at the rural areas, unpaved road or plantation road is important to transporting agriculture products. Therefore, when unpaved roads experience damages like pothole, muddy, and slippery after rainy season and heavy vehicles used to deliver agriculture products, it directly affect the safety, economy and social life of the users (Mat Nor, 2008). The application of bamboo to improve the bearing capacity and reduce the settlement of soil has been proved to be an economical alternative approach for soil improvement. With high tensile strength and good bending properties, bamboo is suitable to be used as an earth reinforcing material. (Hasnita, 2009)

However, there is no proper guideline on the construction using this technique. Therefore, this research is to evaluate the performance of full-scale unpaved road on bamboo geotextile composite reinforced soft clay and high strength geotextile reinforced soft clay, compared to the unpaved road constructed on un-reinforced soft clay. With the results, a new alternative for a cost effective solution for bearing capacity problem of soft clay could be used with more confidence backed by a proper charts and guidelines.

1.3 Aim and Objectives of Research

The aim of this study is to evaluate the performance of unpaved road with different soft clay reinforcements. In order to achieve that, two objectives have to be fulfilled:

(a) To determine the effect on settlement and pore water pressure with partial removal of surcharge.
(b) To determine and compare the dynamic load effect on ground condition of reinforced with high strength geotextile and bamboo-geotextile composite.

1.4 Scope and Limitation

The study focuses on full-scale unpaved road constructed at the Research Centre of Soft Soil Engineering (RECESS), Universiti Tun Hussien Onn Malaysia (UTHM), Batu Pahat, Johor for full scale test under the Short Term Grant (STG) phase 3/2011: Vot 0911 funding by UTHM. This research is a collaborative research between Universiti Teknologi Malaysia (UTM) and UTHM.

Three sections of road consist of bamboo-geotextile reinforced, high strength geotextile reinforced and unreinforced (control) has been constructed and each section is 10 m length and 16 m width with 5 m length of buffer zones separating each section.

The dynamic load from lorry (10 tons) has been applied on each section and the instrumentation was installed to measure data for studying the effects of dynamic load on rural road. Maintenance of the existing instrumentations has been conducted at study location are they inclinometers, piezometers, and hydrostatic profilers in order to monitor road performance. The effects of dynamic load has been monitored in 2 parts i.e. first part before applying dynamic load, second part after the dynamic load has been applied, The location of the instrumentation are as shown in Figure 1.1 and 1.2.

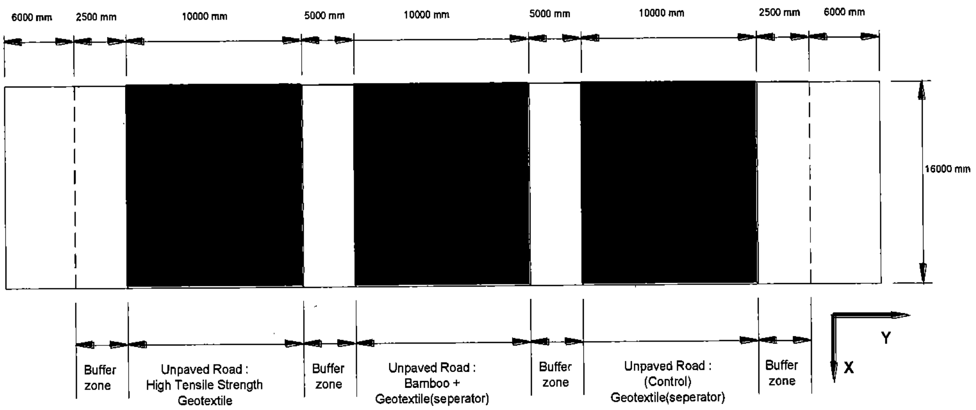
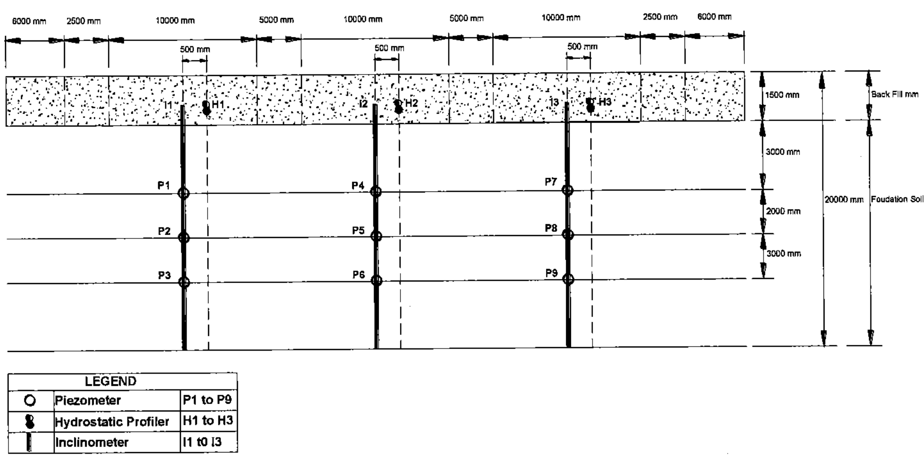
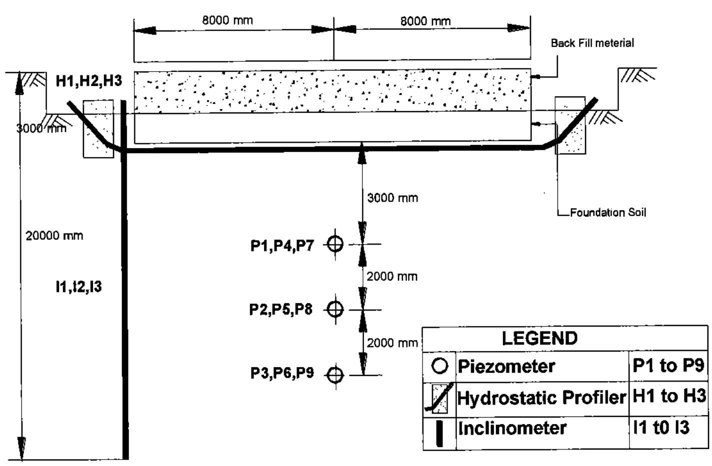


Figure 1.1: Layout of Unpaved Road



a) Cross section X-X



b) Cross section Y-Y

Figure 1.2: Arrangement of instrumentation

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In general, this chapter studies have show the soft clay, problem of clay soil, geotextile, bamboo properties of geotextile and bamboo, factor affecting the life of an unpaved road which geotextile and bamboo as a earth-reinforcing material. This chapter also reviews relevant research work on soft clay reinforcement.

2.2 Soft clay

Clay deposits have a high rate of sedimentation and it had been placed during the period between 12,000 and 5,000 years ago (Leroueil *et al.*, 1990). Soft clay presents several challenges for the geotechnical engineers whereby these problems being transformed to stability and settlement within the soft soil. The deposit of soft clay in Southeast Asia is as shown in Figure 2.1.

However, these soft clays lead serious problems of stability and settlement when construction takes place on this type of soil. Terzaghi and Peck (1967) stated that very soft clay have very low shear strength which less than 25 kPa, and the soft clay shear strength is between 25 kPa to 50 kPa.

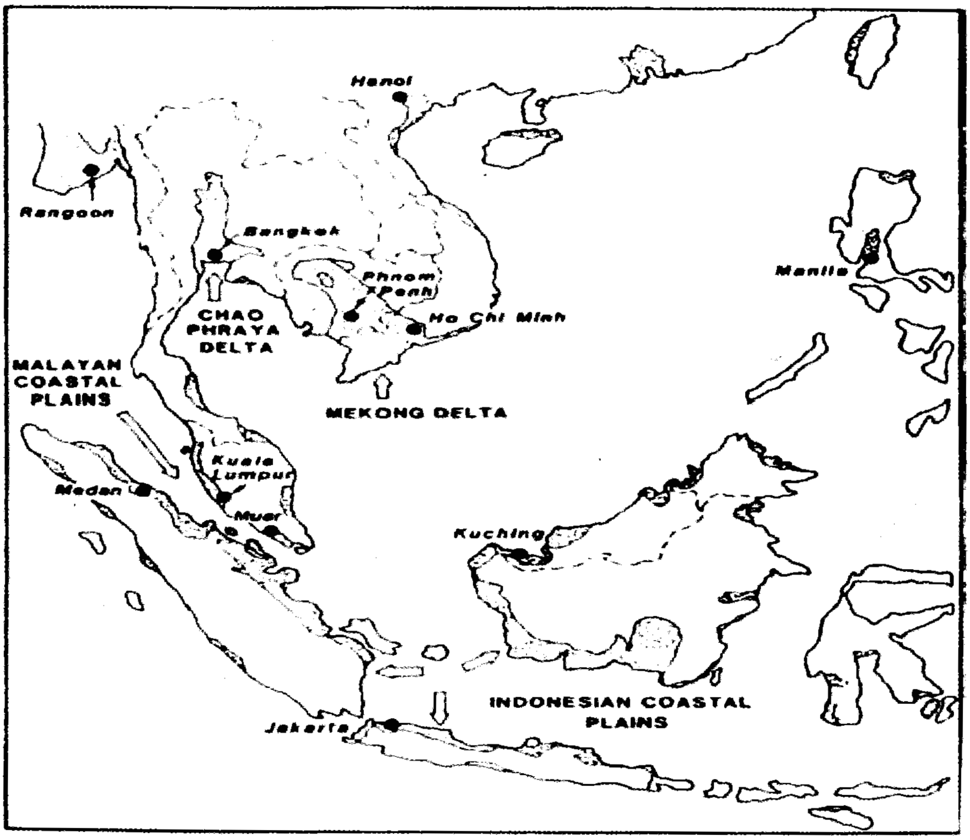


Figure 2.1: Soft clay deposits of Southeast Asia
(Brand and Premchitt, 1989)

2.2.1 Problem of Clay Soil

Saturated cohesive soil can be susceptible to a large amount of settlement from structural loads. It is usually the direct weight of the structure that causes settlement of the cohesive soil. However, secondary influences such as the lowering of the groundwater table can also lead to settlement of cohesive soils. The soil parameters normally employed and characterized in soft soil problems are:

i. Classification and Index Properties, and Natural Moisture Content

ii. Undrained Shear Strength (S_u)

iii. Pre-Consolidation Pressure (σ_p)

iv. Compression Index (C_c) and the Coefficient of Volume Change (m_v)

v. Coefficient of Consolidation (c_v)

The parameters are very important in analyzing the behavior of this soil so that it can carry extra loads subjected to the soils. These nature creatures are widely found in Malaysia along the coastal plains area and with the increasing economic development over the soil; studies were carried out to determine the typical values of the soils that can contribute to the failure of the soil structure. (Hasnita, 2009)

For the soft marine clay in Malaysia, Broms (1990) has reported that typical moisture contents ranges from 60% to 80%. This is different to what has Ting *et al.* (1988) and Chen *et al.* (2003) reported; where the moisture content is typically about 80% to 130% in Penang area and 50% to 100% in Klang area respectively. Brand *et al.* (1989) reported that the Muar clay has the natural water content as high as 100% and generally exceeds the liquid limit. It is also very common that the moisture content of the soft clay especially near to the ground level to be higher than the liquid limit.

The in-situ undrained shear strength, S_u of soft clay can be directly measured using field vane shear test. The S_u is generally increasing with depth. Typically the vane shear test results for clay at Klang areas are about 5kPa at depth 2m to 50kPa at depth 18m (Chen *et al.*, 2003). This is quite similar to Muar Clay and Juru Clay where the S_u ranges between 10kPa at depth 2m to 35kPa at depth 18m, and 10kPa to 30kPa at depth 12m respectively. Soil compress elastically under light loads but then as shifts and rearrange to allow increasing amounts of settlement. This stage of settlement is attributed to primary consolidation, where the rate of settlement is controlled by the time required to squeeze the pore water out. The most useful compressibility parameters to monitor the consolidation process are compression index (C_c), recompression index (C_r) and coefficient of consolidation (c_v).

The compressibility of the soft layers can also be represented using the compression ratio ($C_c/1+e_o$). For Juru Trial Embankment, Huat *et al.*, (1995) found out that the compression ratio is in the region of 0.4 to 0.6 and Ting *et al.*, (1988) reported that the coastal plain areas of Sarawak and Sabah has the average values of $C_c/1+e_o$ vary within a narrow range from about 0.3 in the upper layers to about 0.1 in the lower layers. Terzaghi and Peck (1967) proposed an empirical correlation between C_c and Liquid Limit, w_L for clays of low to medium sensitivity and w_L up to 100% as follow:

$C_c = 0.009\ (w_L - 10)$ (2.1)

Where w_L = Liquid Limit

As for clay from Klang areas, Huat *et al.* (1995) proposed the following relationship for Klang Clay.

$C_c = 0.005\ (w_L + 71.8)$ (2.2)

Where w_L = Liquid Limit

This is because of the sensitivity for Klang Clay is usually range around 3 to 8 and higher C_c values are expected. Another important parameter is coefficient of consolidation, c_v where it measure time taken for a soil to consolidate. Values of c_v are different with types of soft clay. This is proofed by foundation soil found for Juru Trial Embankment and Muar Trial Embankment, where the c_v varies from 0.3 to 0.4 m2/year (Huat *et al.,* 1995) and c_v values range up to about 14 m^2/year (Balasubramaniam, 1989) respectively. Rowe, 1972 stated that laboratory determined c_v value, however, are underestimate the rate of settlement, since the laboratory permeabilities are much lower than the field values because of the soil macro-structure. Hence, in common practice for design c_v values are multiplied by 3 to 10 of those measured in oedometer tests. (Brend *et al*, 1989)

2.3 Geotextile

Geotextile is one of geosynthetic groups and has been used since the early 1970's by civil engineer to perform several major functions in geotechnical (soil) structures (Holtz, 2001). ASTM defines geotextiles as a permeable geosynthetic comprised solely of textiles. Geotextiles perform several functions in geotechnical engineering applications. The major characteristic of geotextiles is that they are porous to liquid flow across their manufactured planes and also within their thickness, but to widely varying degrees. According to Mohd Zulkifli (2009), geotextile can perform as a filter, drainage, separation, erosion control, sediment control, reinforcement and moisture barrier (when impregnated with asphalt).

2.3.1 Properties of Geotextile

The properties of geotextile were tested and given by Tencate Sdn Bhd in Baktiar, 2012. Table 2.1 shows the properties of geotextile used in this study which is PEC100 that used as reinforcement at high strength geotextile reinforced embankment and TS40 used as separator at control embankment

Table 2.1: Properties of PEC100 and TS40 (Bakhtiar 2012)

Properties	**PEC100**	**TS40**
Tensile strength	100 kN/m	13.5 kN/m
Tensile elongation	10%	75%
Horizontal flow rate (20 kPa)	30×10^{-7} m^2/sec	24.5×10^{-7} m^2/sec
Normal mass (g/m^2)	505	192.5

2.4 Bamboo

2.4.1 Properties of Bamboo

2.4.1.1 Physical Properties

The amount of moisture in bamboo varies within and between the species, height and age of the living culm. The moisture content has a similar influence on the strength of the bamboo as it has in timber. Generally, in the dry condition the strength is higher than in the green condition. For some Malaysia bamboos, moisture content is about 30% to 130%. However the density of bamboo varies from about 0.5g/cm3 to 0.9g/cm3 with the outer culm having a far higher density than the inner part (Hasnita, 2009). Moisture content and density of selected species of bamboo are tabulated in Table 2.2.

Table 2.2: Physical properties of some Malaysian bamboos (FRIM, 1995)

Species	Moisture content (%)	Density (g/cm^3)
Buluh Duri	57 - 97	0.43 – 0.60
Buluh Minyak	79 – 118	0.27 – 0.57
Buluh Galah	92 – 132	0.44 – 0.58
Buluh Betong	28 – 105	0.55 – 0.78
Buluh Semantan	79 – 108	0.47 – 0.60
Buluh Beting	30 – 77	0.65 – 0.94

According to Siopongco and Munandar, (1987), the differences in moisture content due to seasons are greater than variations due to age. Internodes contain 2% to 7% more moisture than the nodes. Green moisture content of six Philippine species studied ranged from 95% to 174% with an average of 125% and their relative density or specific gravity varied from 0.461 to 0.626 averaging 0.542, as tabulated in Table 2.3. As reported in 1983 DBR experiment (in Siopongco and Munandar, 1987), the specific gravity of three species of Indonesian bamboo (Gigantochloa apus, Gigantochloa verticillata and Dendrocalamus asper) ranged between 0.67 to 0.72 with moisture content ranged in between 10.04% to 10.81%.

Table 2.3: Physical properties of six Philippine bamboos (Espiloy *et al.,* 1985) (in Siopongco and Munandar, 1987)

Scientific Name	Moisture Content (%)	Specific Gravity
Bambusa blumeana	136	0.503
Bambusa vulgaris	95	0.626
Dendrocalamus latiflorus	108	0.575
Gigantochloa aspera	119	0.547
Gigantochloa levis	117	0.541
Schizostachyum lima	174	0.461

2.4.1.2 Mechanical Properties

The strength of bamboo depends on the species and on its age, moisture content, density and culm height. The mechanical properties of bamboo vary with the age of the bamboo and the height of the culm, as mentioned by Chauhan (2000) (in Li, 2004). However, higher moisture content will decrease the strength of bamboo (Prawirohatmodjo 1990) (in Lybeer, 2005). The strength of this material also related to its density. The density of bamboo varies approximately from 0.5 to 0.9 g/cm³ but can differ considerably within the culm (increase with the height of the culm) and between species (Siti & Abd. Latif 1992;Jamaludin *et al.* 1995; Kabir *et al.* 1996; Subyakto 1996) (in Lybeer, 2005).

As the bamboo becomes older, the strength properties increase. This is probably due to the hardening of the culm walls as the bamboo matures in about 3 to 5 years, by which time it would reached its maximum strength (Lee *et al.,* 1997) (in Khatib, 2009). On the other hand, Wong (1995) states that culms take 2 to 6 years to mature which depends on the species. According to Limaye, (1952) (in FRIM, 1995), young bamboo with higher moisture content shows greater increase in strength on drying than the older culms.

Abang Ali (1984) presented a comparison between bamboo and the more common engineering materials, as tabulated in Table 2.4. It was found that bamboo is very strong in tension, with a few species having tensile strength as high as that for mild steel. The ratio of tensile to compressive strength of bamboo can be as high as seven times. FRIM (1995) has conducted an experiment on selected Malaysian bamboo to evaluate the mechanical properties of bamboo, as shown in Table 2.5. The bending stress at proportional limit was ranged from 21MPa to 49MPa and it shows the differences in static bending strengths of specimens (Table 2.5). For the three species of Indonesian bamboos (*Gigantochloa Apus, Gigantochloa verticillata* and *Dendrocalamus asper*) where the age of bamboo was more than three years were tested to assess its mechanical properties and Table 2.6 shows the test results (Siopongco and Munandar, 1987). It can be seen that bamboo has more strength in tension compared to bending strength. According to Ghavami (2005), the tensile strength of bamboo is relatively high and can reach 370MPa. This makes bamboo an attractive alternative to steel in tensile loading applications.

Table 2.4: Typical materials properties of bamboo compared with mild steel, concrete and timber (Abang Ali, 1984)

Material	Ultimate Strength (N/mm^2)		Tensile-Compressive Strength ratio, σ_t/σ_c	Modulus of Elasticity (kN/mm^2)
	Tension, σ_t	Compression, σ_c		
Mild Steel	480	-	1.0	210
Concrete	2-4	25-55	0.1	10-17
Timber	20-110	50-100	1.1	8-13
Bamboo	180-440	38-65	4.8-7.1	7-20

Table 2.5: Strengths of some Malaysian bamboos (FRIM, 1995)

Species	Compression Parallel to grain (MPa)	Static bending		
		Modulus of rupture (MPa)	Modulus of elasticity (MPa)	Stress at proportional limit (MPa)
Buluh Duri	19.5 – 28.5	43.1 – 156.4	2.6 – 5.6	21.2 – 38.9
Buluh Minyak	20.5 – 30.0	46.1 – 78.4	4.1 – 8.1	28.7 – 42.6
Buluh Betong	28.3 – 34.6	48.9 – 122.4	3.8 – 8.8	32.2 – 46.8
Buluh Semantan	21.6 – 32.3	35.9 – 68.9	3.7 – 5.9	31.1 – 42.2
Buluh Beting	37.3 – 42.8	37.6 – 119.4	3.7 – 6.5	35.7 – 48.7

Table 2.6: Mechanical properties of Indonesian bamboos (Gigantochloa apus, Gigantochloa verticillata and Dendrocalamus asper) (Siopongco and Munandar, 1987)

Properties	Range
Tensile strength	118-275MPa
Bending strength	78.5-196MPa
Compression strength	49.9-58.8MPa
Modulus of Elasticity in Tension	8.73-31.38GPa
Modulus of Elasticity in Bending	5.59-21.18GPa
Tensile strain	3.7-24.4kPa

2.4.2 Specialty of Bamboo

Bamboo had been extended from traditional societies used on material construction and handicraft to food and feed as described by Dannenmann *et al.* (2007). Research developed by them shows that if the bamboo is harvested systematically, bamboo can have the potential as a bamboo bio-fuel and therefore can generate an income to poor farmers. Nowadays most of bamboo production is for handicraft goods like bamboo baskets, blinds, furniture, chopsticks and etc. Ghavami *et al.* (2003) and, Krause and Ghavami (2009) agreed that bamboo had an excellent mechanical properties that can be considered as a composite material and as a results it can reduce the need on steel for construction materials.

2.4.3 Weakness of Bamboo

Although the bamboo shows a lot of the specialty, unfortunately bamboo also has a weakness on pathologies. According to Krause and Ghavami (2009), bamboo is easy to be influenced by insect and fungi attack, the degradation of lignin when exposed to UV rays, low shear resistance and geometric problems. Once cracking occurred on bamboo and then the compression load applied, the premature flexurecompression failure will be faced. They generally show the bamboo culms crack along their longitudinal fibres occurred due to environmental temperature and humidity. Figure 2.2 shows the cracking occurred on bamboo culm.

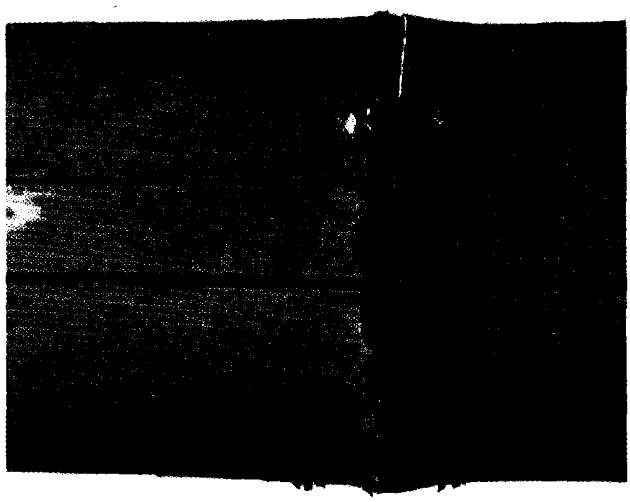


Figure 2.2: Longitudinal cracks on bamboo culm (Krause and Ghavami, 2009)

2.5 Factors Affecting the Life of an Unpaved Road

There are five major factors that affect the ability of an unpaved (as well as paved) roadway to survive and serve the needs of the traveling public over a long and useful life. Table 2.7 shows factors affecting the life of an unpaved road (MDEPB and U.S. EPA, 2001).

Table 2.7: Factors Affecting the Life of an Unpaved Road

Factor	**Affect**
Traffic Loads	Road damage typically depends on the number and weight of heavy trucks using a road, not the number of lighter vehicles.
Subgrade Quality	Unpaved roads need a good subgrade to help carry heavy loads and support the surface. A properly constructed subgrade can greatly influence road performance and life.
Workmanship and Construction Practices	Using quality materials and following proper construction practices can greatly increase the life of an unpaved road.
Maintenance Program	Unpaved roads require routine and preventative maintenance on a regular basis. The idea is to spot the "possible" problem before it gets to be a "real" problem. Spend a few dollars *now* to prevent major repair costs *later*.

2.6 Performance of Embankment on Bamboo-Geotextile Composite Reinforced Soft Clay

Bakhtiar, 2012 successfully constructed embankment on bamboo-geotextile composite reinforced soft clay. The monitoring through the instrumentation installed at the embankment are analyzed and discussed. For the performance, only performances in term of settlement, lateral movement and excess pore pressure had been discussed. Hence, only three (3) instrumentation results from Bakhtiar, 2012 which were settlement gauges, inclinometer and piezometer were shown.

2.6.1 Summary of Settlement Results for Previous Research

Summary of results on the settlement of embankments obtained using various instrumentations at the centre point of the embankments is shown in Table 2.8. At the end of embankment construction, the settlement measured by hydrostatic profiler and liquid settlement system was quite the same except for UR embankment which showed a deviation of more than 100 mm. For the condition after the construction both BGC and UR embankments showed the same trend of settlement measured by hydrostatic profiler and surface settlement marker, though with a difference of about 100 mm. (Bakhtiar 2012)

Table 2.8: Summary results on the settlement of embankments obtained using various in strumentations at the centre point of the embankments (Bakhtiar 2012)

No	Embankment	Settlement (mm)					
		End of Construction (Day 17)			End of Monitoring (Day 418) – End of Construction		
		Hydrostatic Profiler	Liquid Settlement System	Surface Settlement Marker	Hydrostatic Profiler	Liquid Settlement System	Surface Settlement Marker
1	BGC	258	232	0.0	330	25 *(Day 23)*	440
2	UR	331	443		413	0 *(Day 17)*	510
3	HSG	141	147		458	238 *(Day 183)*	481

Figure 2.3 shows the variation of the height and settlement of embankment with time. The height was measured by surface settlement marker, while the settlements were by hydrostatic profiler and liquid settlement system. Overall results indicate that BGC reinforced system had reduced the immediate settlement of BGC embankment as well as the consolidation settlement by comparing with the results of unreinforced embankment. However the reduction achieved, particularly during construction was smaller than HSG embankment. (Bakhtiar 2012)

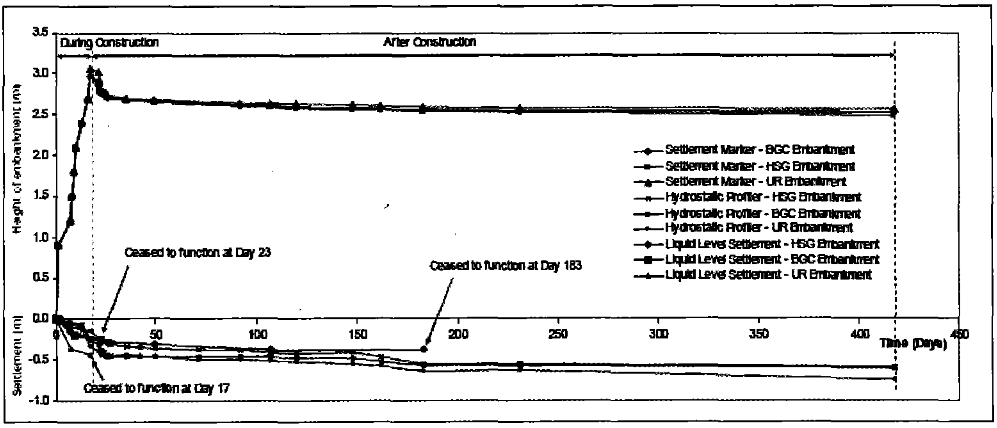


Figure 2.3: Variation of the height and settlement of embankment with time (Bakhtiar 2012)

2.6.2 Lateral Movements

Based on Figure 2.4 and Table 2.9, it is observed that UR embankment recorded a maximum lateral movement of more than 100 mm at the end of Day 418. This corresponded to an average of 0.13 mm/day. Until Day 230 (the last day reading before instrumentation ceased to function), 42 mm of lateral movement was observed for HSG embankment. This corresponded to the same 0.13 mm/day rate of settlement shown by UR embankment. (Bakhtiar 2012)

Table 2.9: Summary results from inclinometer for lateral movement at the left toe of Embankment (Bakhtiar 2012)

No	Embankment	End of Construction (Day 17)			End of Monitoring (Day 418)		
		Maximum lateral movement (mm)	Depth at maximum lateral movement	Rate of movement (mm/day)	Maximum lateral movement (mm)	Depth at maximum lateral movement	Rate of movement (mm/day)
1	BGC	21.3	1.5 m	1.25	63.9	1.5 m	0.1
2	UR	49.3	1.0 m	2.9	100.7	1.5 m	0.13
3	HSG	13.6	1.0 m	0.8	42.0 (Day 230)	1.5 m	0.13

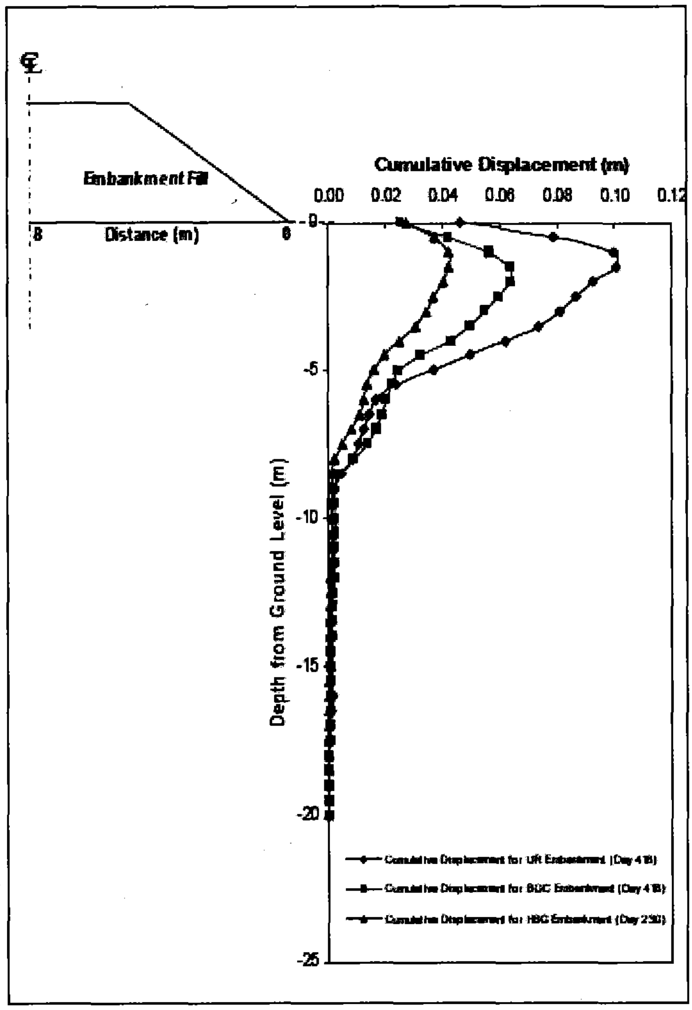


Figure 2.4: Cumulative displacement profile for all embankments at Day 418 (Bakhtiar 2012)

Based on the lateral movements occurred at the BGC, UR and HSG embankments, it was noticed that the maximum lateral movement on the BGC embankment occurred at 1.5 m depth throughout the monitoring periods. However, for UR and HSG embankment, the maximum lateral movement occurred at 1.0 m depth during construction period but the maximum lateral displacement occurred at 1.5 mdepth on Day 418. This condition indicates that BGC system was able to retain the movement at the same depth for along period compared with geotextile. (Bakhtiar 2012)

2.6.3 Development of Excess Pore Water Pressure

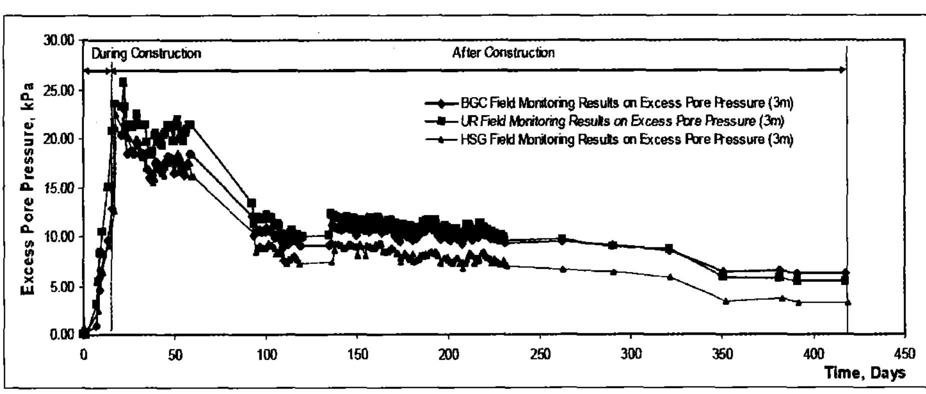
From Figure 2.5, it was observed that the excess pore pressure at the end of the construction of UR embankment was 23.47 kPa, recorded at 3 m depth piezometer. However, the maximum excess pore pressure of occurred for UR Embankment was on Day 22. The same trend measured at BGC embankment. The HSG embankment shows the maximum excess pore pressure occurred at the end of construction of the embankment.

The rate of increased in pore pressure development was 1.38 kPa/day. At the end of monitoring (Day 418), the excess pore pressure under UR embankment was 5.45 kPa and dissipated at the rate of 0.045/day.

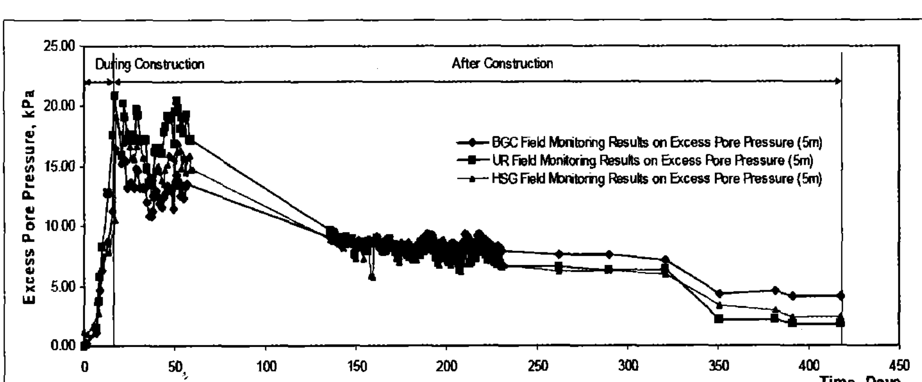
From both results on excess pore pressure for BGC and UR embankments, the results showed insignificant different in the excess pore pressure profile. The higher rate of dissipation of excess pore pressure was recorded at UR embankment compared with BGC embankment. From the rate of excess pore pressure measured from BGC and UR embankment, it shows that the BGC system that combined low strength geotextile with bamboo arranged in square pattern behaved as a floating system. As a result, the BGC system decreased the overburden pressures from embankment fill at the same depth of piezometer in UR embankment. It can be seen from the rate of the excess pore pressure at the construction stage. The excess pore pressure below BGC embankment increased at a small rate compared with UR embankment. BGC embankment where the bamboo provided the tensile and bending strength had given an additional support for embankment fill. For the pore pressure under HSG embankment at 3 m depths, the pattern of the pore pressure is quite similar with BGC and also UR embankment.

In HSG embankment, for 17 days of construction periods, the excess pore pressure increased rapidly with embankment height and achieved the maximum excess pore pressure at 2.968 m height with 22.49 kPa. After the completion of embankment construction, the dissipation of pore pressure that occurred at 3 m below HSG embankment dissipated at different rate compared with UR and BGC embankments. The excess pore pressure for HSG embankment had been recorded as 3.30 kPa at the end of monitoring works (418 Days). Hence, the rate of dissipation of pore pressure was measured at 0.048 kPa/day. The rate of dissipation was quite the same with dissipation at UR embankment at range 0.04 kPa/day to 0.05 kPa/day. This condition occurred because the UR and HSG embankment were using the same material (geotextile) which provided the tensile strength only. However, the properties of geotextile using PEC 100 provide higher horizontal flow rate at 30x10-7 m2/sec compared with TS 40 geotextile only 24.5x10-7 m2/sec. Differ from BGC embankment, the use of bamboo decreased the area of the geotextile for dissipation of the pore pressure due to the properties of bamboo which cannot act as drainage system. As a result, the rate of the dissipation of excess pore pressure becomes small.

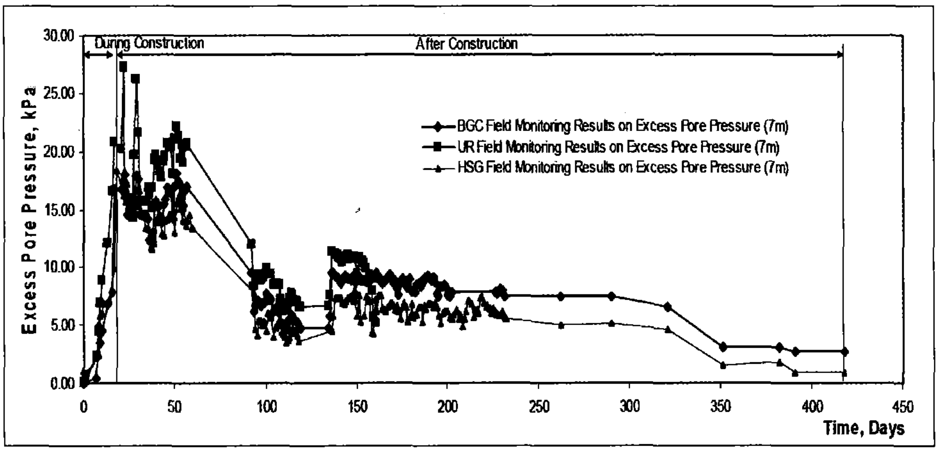
At Day 418 of monitoring, the dissipation of excess pore pressure seemed to be already small. Through time, the dissipation of pore pressure will achieve the minimum value of excess pore pressure (≈0 Kpa) pressure is expected to stop. The long period of dissipation of pore pressure shows that the soil was characterized by the low permeability of the soil, hence taking longer time for consolidation to occur. (Bakhtiar 2012)



(a) 3 m depth below ground level



(b) 5 m depth below ground level



(c) 7 m depth below ground level

Figure 2.5: Excess pore pressure at the centre of embankments (Bakhtiar 2012)

2.7 Relevant Previous Research Findings

Hasnita (2009) has tried to determine the performance of the embankment with or without BGC reinforcement to the soils. A measurement using hydrostatic profiler at the bottom of the embankments show that throughout 120 days of monitoring the settlement, it is found that BGC reinforced embankment settled with total settlement of 0.462m at the centerline of the embankment. (Refer to Table 2.30)

Mohd Zulkifli (2009) has tried to determine the performance of the embankment with or without high strength geotextile reinforcement to the soils. A measurement using hydrostatic profiler at the bottom of the embankments show that throughout 121 days of monitoring the settlement, it is found that high strength geotextile reinforced embankment settled with total settlement of 0.424 m at the centerline of the embankment. (Refer to Table 2.30)

Table 2.30: Previous research about methods to improve soft soil by using soil reinforcement

Tesis	Item	Control Embankment	BGC Reinforcement Embankment	HSG Reinforcement Embankment
Mohd Zulkifli(2009)	**1) Type of Loading :**	Static Loading		Static Loading
	2) Settlement under the embankment :			
	i) End of Construction	0.331 m		0.141 m
	ii) After Construction (103 day)	0.201 m		0.283 m
	iii)Total Settlement	0.532 m		0.424 m
	2) Settlement Marker :			
	i) Total Settlement	0.555 m		0.446 m
	3) Lateral Movement			
	i) End of Construction	5.44 mm at depth 2 m		1.16 mm at depth 2.5m
	ii) After Construction (103 days)	11.2 mm at depth 4.5 m		4.53 mm at depth 4.5 m
	4) Excess Pore Pressure:(At 3 m depth)			
	i) End of Construction	23.47 kpa		22.49 kpa
	ii) After Construction (103 days)	12.3 kpa		8.29 kpa
[redacted]	**1) Type of Loading :**	Static Loading	Static Loading	
	2) Settlement under the embankment :			
	i) End of Construction	0.331 m	0.258 m	
	ii) After Construction (103 day)	0.201 m	0.204 m	
	iii)Total Settlement	0.532 m	0.462 m	
	2) Settlement Marker :			
	i) Total Settlement	0.532 m	0.462 m	
	3) Lateral Movement			
	i) End of Construction	4.88 mm at depth 4 m	2.63 mm at depth 3.5 m	
	ii) After Construction (103 days)	11.19 mm at depth 4.5 m	8.07 mm at depth 4.5 m	
	4) Excess Pore Pressure:(At 3 m depth)			
	i) End of Construction	23.47 kpa	23.47 kpa	
	ii) After Construction (103 days)	12.3 kpa	12.3 kpa	

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This section discusses the research methodology that includes five phases the first phase literature search testing, second phase data collection, third phase construction work, fourth phase analysis of results program and the last phase reporting of results. The research works started with literature review for more understanding and determine the requirements work need to be done. After that the construction of road started with cutting process of the existing embankment and maintenance process of existing instrument. The cutting work will be carried out in order to modify the existing embankment to be the demonstration road.

The monitoring process has been carried out to evaluate the performance of the road before and after applying the dynamic loading. The research methodology outline to be carried out in this study is as illustrated in Figure 3.1

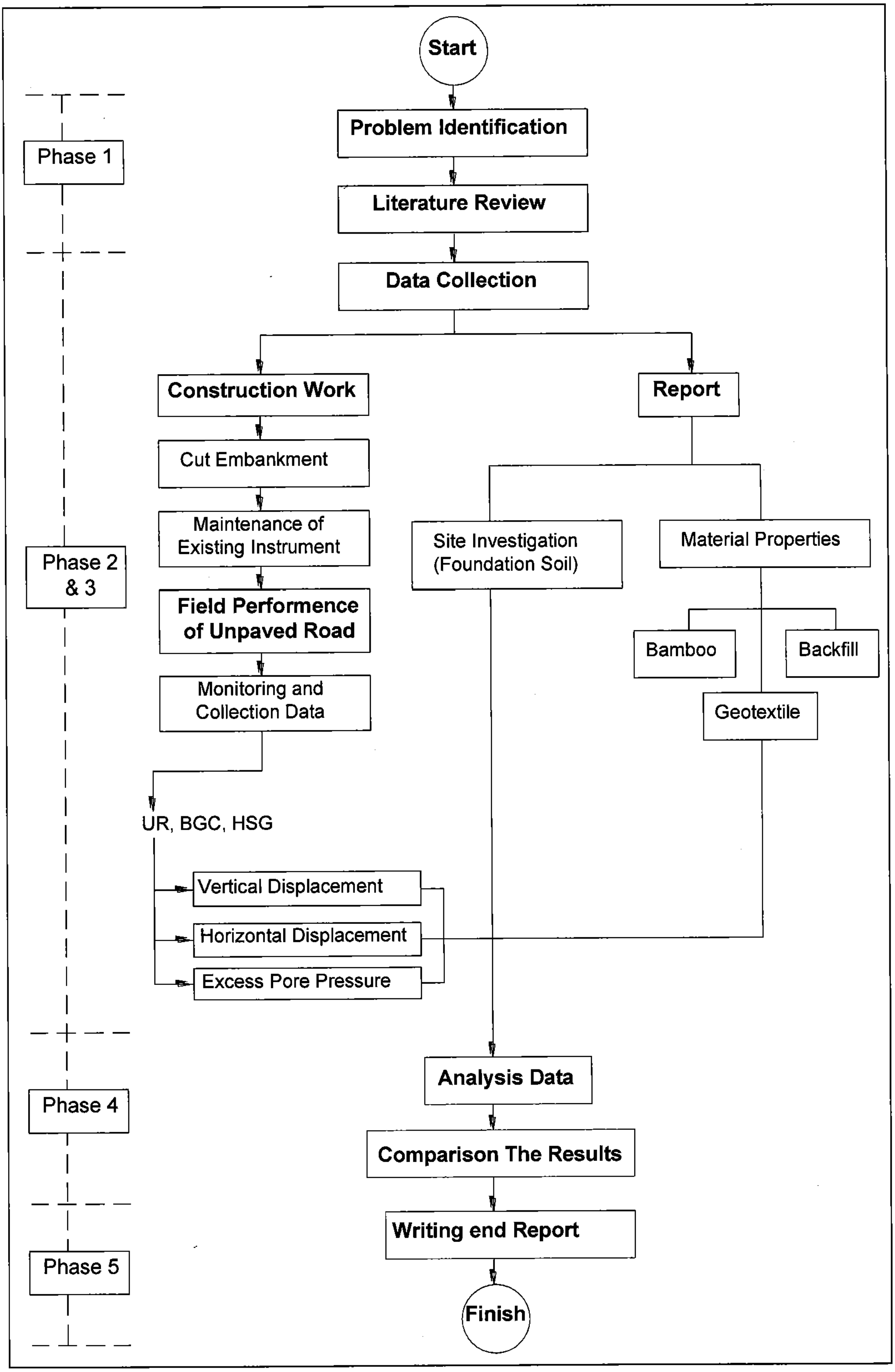


Figure 3.1: Methodology of Research

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