



Faculty of Engineering

**The Use of Lightweight Foamed Concrete as Fill Material for
Road Embankment on Soft Ground in Sarawak**

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The Use of Lightweight Foamed Concrete as Fill Material for Road Embankment on Soft Ground in Sarawak

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Settlements are the main problem on soft ground construction in Sarawak. The research is to study the feasibility of using foamed concrete (FC) as fill material for road embankment on soft soil and peat soil (soft ground) by replacement method. This study focuses mainly on the idea of innovative “floating road embankment” on soft ground by density and bearing capacity comparisons. There are three (3) main approaches to be solved before applying on construction field, which is FC mixing techniques, appropriate properties of FC and FC road embankment design procedure. A new innovative mixing technique that could produce big volume mixing is developed. The technique is focused on the sequence of mixing, whereby adding water will be the last part of the mixing to avoid segregation. This technique also found that horizontal shaft mixer could produce the FC with no segregation. To perform the replacement, the research focuses on density at between 700-1300 kg/m³, where it is almost similar to the density of the soft soil and peat soil. It is found that workability is “just right” when the FC can perform self-compacting. The range of workability for small scale (less than 100 litres) and big scale production (more than 100 litres) are respectively at 13-16 cm and 16-19 cm. FC compressive strength shall not be less than 1 kN/m², which is better strength than normal soil and enough for supporting the load and resist the vehicles vibrations. The study also found that water-cement ratio at 0.2-0.3 could produce strength at the range of 1-3 kN/m². The additional admixture like Polyvinyl alcohol (PVA) and quarry dust could increase the strength highly at 300% and 60% respectively, but PVA is difficult to produce and is costly. The result of FC shrinkages is only 0.156%, which could be neglected in the production of FC. At the final stages of the research, the design procedure is developed and the lightweight embankment is applied on field at allowed settlement range. Finally the “lightweight FC road embankment” is successfully produced with saving time and cost.

Keywords: Foam concrete, density, workability, strength, settlement

***Cadangan Kajian Kepada Kegunaan Konkrit Berbuih Ringan Sebagai Bahan
Penambakan Kepada Tambalan Jalan Di Atas Tanah Lembut Di Sarawak***

ABSTRAK

Pemendapan adalah masalah utama dalam pembinaan di atas kawasan tanah lembut di Sarawak. Kajian ini adalah untuk mengkaji kemungkinan menggunakan konkrit berbuih (FC) sebagai bahan pengisi untuk tambakan jalan di atas tanah lembut dan tanah gambut (soft ground) dengan kaedah penggantian. Kajian ini memfokuskan pada idea inovatif "tambak jalan terapung" berdasarkan perbandingan kepadatan dan daya galas. Terdapat tiga (3) pendekatan utama untuk diselesaikan sebelum pengaplikasian di tapak pembinaan, iaitu teknik pencampuran FC, sifat-sifat FC yang sesuai dan FC prosedur rekabentuk tambakan jalan. Teknik pencampuran inovatif baru yang dapat menghasilkan FC dalam isipadu yang besar. Teknik ini tertumpu pada urutan pencampuran, penambahkan air merupakan bahagian terakhir pencampuran untuk mengelakkan pemisahan. Teknik ini juga mendapati bahawa pengaduan aci mendatar dapat menghasilkan FC tanpa pemisahan. Untuk melakukan penggantian, penelitian ini memfokuskan pada ketumpatan di antara 700-1300 kg/m³, di mana ini merupakan ketumpatan yang paling dekat dengan tanah lembut dan tanah gambut. Didapati bahawa kebolehkerjaan "tepat" berlaku apabila FC dapat melakukan pemadatan diri. Julat kebolehkerjaan untuk skala kecil (kurang dari 100 liter) dan skala besar (lebih dari 100 liter) masing-masing adalah pada 12-16 cm dan 16-19 cm. Kekuatan mampatan FC tidak boleh kurang dari 1 kN/m², kerana kekuatan ini adalah lebih baik daripada kekuatan tanah biasa dan mencukupi untuk menyokong beban dan menahan getaran kenderaan. Kajian ini juga mendapati bahawa nisbah air-simen pada 0.2-0.3 dapat menghasilkan kekuatan pada 1-3 kN/m². Campuran tambahan seperti alkohol polivinil (PVA) dan debu kuari boleh meningkatkan kekuatan dalam 300% dan 60% masing-masing,

tetapi PVA sukar dihasilkan dan mahal. Pengecutan FC menunjukkan hanya 0.156% dan ini dapat diabaikan semasa penghasilan FC. Pada tahap akhir kajian ini, prosedur reka bentuk dihasilkan dan tambakan jalan ringan yang dibina di tapak pada julat pemendapan yang dibenarkan. Akhirnya "jalan raya FC ringan" berjaya dihasilkan dengan menjimatkan masa dan kos.

Kata kunci: *Konkrit berbuih, ketumpatan, kebolehkerjaan, kekuatan, mendapan*

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LIST OF ABBREVIATIONS

A	Area
ACC	Autoclaved Aerated Concrete
BS	British Standards
g	Gram
GTL	Paraffin Oil
kg	Kilogram
L, H, W	Length, Height, Width
M	Mass
m	Meter
m ²	Meter square
m ³	Cubic meter
mm	Millimeters
N	Newton
PFA	Pulverized Fly Ash
PVA	Polyvinyl Alcohol
SP	Super Plasticiser
UNIMAS	Universiti Malaysia Sarawak
%	Percent (or percentage)
θ	Degree of Rotation

CHAPTER 1

INTRODUCTION

1.1 General

Construction on soft ground area is a major problem in Sarawak, with problems like excessive settlement that could occur either during or after the construction phase due to its low bearing capacity. Road designers have also avoided constructing road and realigning the road alignment on these difficult areas. However, with rapid development and high demand, it is no longer possible to avoid road construction altogether in these areas. For example the coastal road requires alignment to pass through vast areas of soft ground zone in Samarahan, Sarikei, Sibu, Mukah and many other divisions in Sarawak.

It is high time that researchers work on new innovation in designing road on soft ground. The existing conventional design (refer Table 1.5) is well accepted by the industries but lacks quality and standard. Often, the construction cost becomes overly high and maintenance cost would also be an annual burden (refer Section 1.3.2).

1.2 Example of Problematic Soft Ground

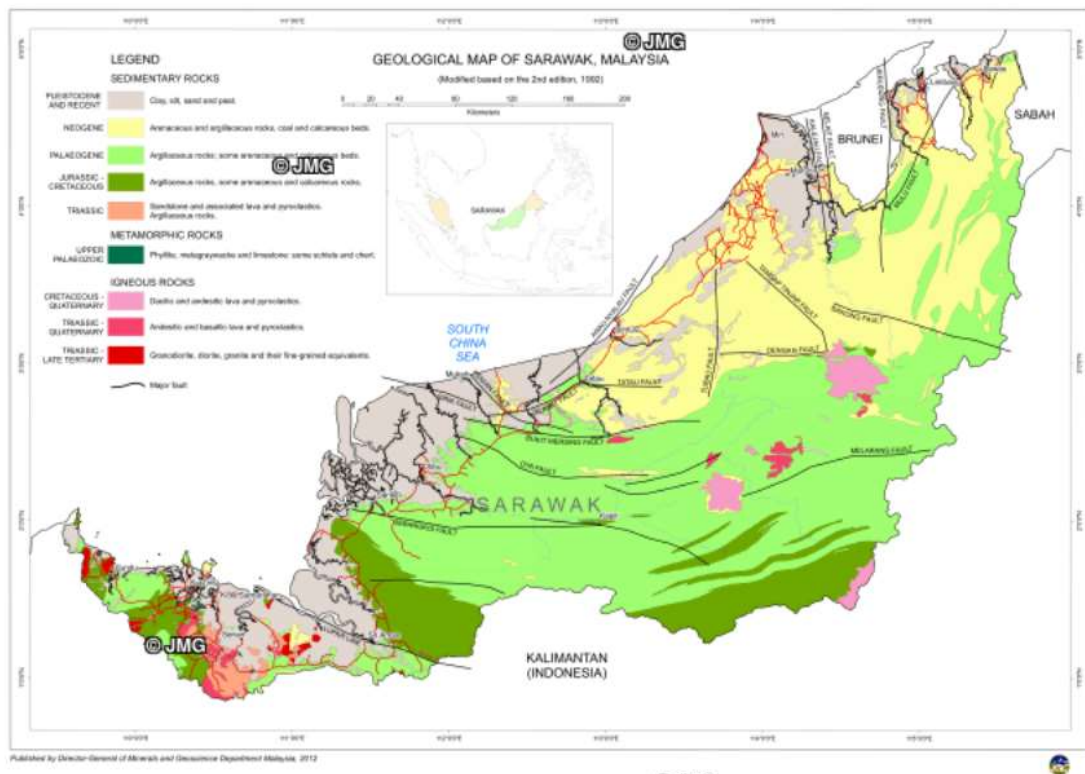


Figure 1.1: Geology map of Sarawak (JMG, 1992)

Soft ground is referring to soft soil (clay, silt and sand) and peat soil, which refers at coastal corridors, low lands and offshore areas of Sarawak as shown on the latest geology map of Sarawak in Figure 1.1. The soil is categorised as organic soil when its organic content is at a range of 20% to 75% and categorised as peat soil when its organic is more than 75%. In most area of Sarawak, peat soil can be found on top of soft soil with a typical depth between 3-6 m. Soft soil and peat soil are characterized as a organic soil with low shear strength. The shear strength of the soft soil is reported to be less than 40 kPa with an organic content greater than 20% of the total weight, while the shear strength of peat is almost 0 kPa.

1.2.1 Example of Problematic Soft Soil – Marine Clay

Marine clay is an organic soft soil that is often described as problematic soil due to its high settlement and high instability, poor soil properties that are not suitable for engineering requirements, uncertainty of performance, low unconfined compressive strength of between 25 to 50 kPa and flat or featureless surface (Ali & Aminaton, 2017). Rahman et al., (2013) and Shahri and Chan (2015), reported that marine clay in Malaysia had a fine content of 24% and 26%, respectively. However, marine clay in Sarawak is consist of clay, silt and sand with density at $2400 \text{ kg/m}^3 - 2600 \text{ kg/m}^3$ and its physical properties shown in Table 1.1 (Ahmad & Harahap, 2016) and Figure 1.2.

Table 1.1: Physical and index properties of some studies on marine clay in Sarawak

Sand (%)	Silt (%)	Clay (%)	Moisture content (%)	Specific Gravity (Gs)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (IP)
5 - 12	35 - 63	25 -60	24.2 – 65.2	2.4 – 2.66	54 - 56	30 - 36	19 - 25



Figure 1.2: Marine clay at Sg Bako road, Kuching

1.2.2 Example of Problematic Peat Soil

Besides of marine clay, peat soil is also known as a problematic soft soil in construction, Sarawak, the biggest state in Malaysia, has a total peat area 69.08% which is the largest in the country as shown in Table 1.2 (Melling, 2016).

Table 1.2: Peatland distribution in Malaysia (Melling, 2016)

No	State	Total Peat Area (Ha)	Percentage (%)	No	State	Total Peat Area (Ha)	Percentage (%)
1.	Sarawak	1,697,847	69.08	6.	Terengganu	84,693	3.45
2.	Selangor	164,708	6.70	7.	Perak	69,597	2.83
3.	Pahang	164,113	6.68	8.	Kelantan	9,146	0.37
4.	Johor	143,974	5.86	9.	Negeri Sembilan	6,245	0.25
5.	Sabah	116,965	4.76	10.	Federal Territory	381	0.02
					Total	2,457,669	100.00

Peat area covers 13% of the Sarawak as shown in Table 1.3, Sibul/ Mukah, Sri Aman/ Betong and Miri are reported to have the largest peat area and more than 80% of Sarawak peat land is classified as deep peat with more than 3 m depth, and 21 m depth in some areas in Sibul and Miri. Generally, the peat soil is widely deposited in the State of Sarawak (Taib et al., 2016), especially at 2-4 km from the coast.

The physical and geochemical properties of peat soil from different districts in Sarawak have a bulk density at the range from 1300 kg/m³ to 1700 kg/m³ (Huat, 2004).

Table 1.3: Estimated peatland areas in Sarawak (Wetlands International, 2010)

Area	Total Peat Area (ha)	%	Area	Total Peat Area (ha)	%
Sibu/ Mukah	600,387	35.36	Sarikei	74,414	4.38
Sri Aman/ Betong	340,374	20.05	Limbang	34,730	2.05
Miri	295,995	17.43	Kuching	26,827	1.58
Samarahan	165,581	9.75	Kapit	2,097	0.12
Bintulu	157,422	9.27	Total	1,697,847	100.00

Carlson et al., (2015) mentioned that most water table of the peat soil is always high in between 40 – 50 cm below the surface, Figure 1.3 shows a photo taken in Lingga, Sarawak which reflects a water table 40 – 50 cm at most peat soil area of Sarawak.



Figure 1.3: Peat soil in Sarawak

1.3 Settlement on Soft Ground

As mentioned earlier, soft soil and peat soil (soft ground) have generally been recognized as a problematic soil in differential and excessive settlement. There are many projects developed in the soft ground area such as Asajaya Samarahan, Maluddam Betong, Sibu Airport Road and Matu Daro area. Figure 1.4 shows the settlement on a building built on peat soil in Sadong Jaya, Samarahan.



Figure 1.4: Settlement by water drain out

Settlements vary from the type and depth of the soil and also the height of the water table. Some results show that the settlement is half of the fill placement thickness and settlement will continue over the years. Figure 1.5 illustrates a case of settlement versus time for road construction works on peat soil in Kuching, Sarawak.

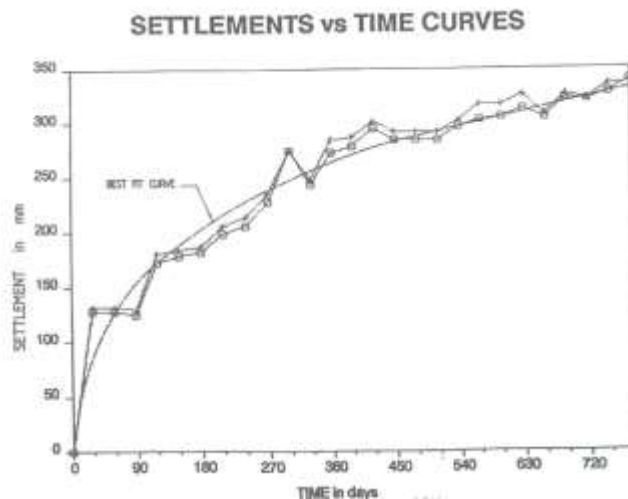


Figure 1.5: Settlement versus Time Curves for Kuching and most places in Sarawak (Jon, 1989)

In most areas, it is predicted that the total consolidation or settlements is 400 mm or more and would take more than seven (7) years until completion with treatment by surcharging method with 1.25 m additional soil in 8 m deep of peat soil (CREAM, 2015).

1.3.1 Damages of the Road by Settlements

There are variations of failures occur caused by settlements like cracking and distortion as shown in Table 1.4.

Table 1.4: Types of road damages caused by settlements (Jayakumar & Lee, 2015)

No.	Types of Damages	Descriptions
1.	Cracking	Damages that occurs in the surface layer of the road are divided into 9 (nine) types of cracks are: hair cracking, alligator cracks, edge cracks, edge joint cracks, lane joint cracks, widening cracks, reflection cracks, shrinkage cracks and slippage cracks could be because the soil road base is less stable, poor surrounding drainage system, job execution and paving material, and other possible factors that exceed the load capacity of the road traffic.

Table 1.4 continued

2.	Distortion	Deformation caused by the compaction of the road embankment soil is not properly done, resulting damage by additional traffic load. Types and causes of distortion must be known to determine the appropriate type of repair.
----	------------	---

Figure 1.6 shows the cracking on the road surface caused by settlement in Maluddam, Sarawak.



a. Cracking on road pavement



b. Distortion on road pavement

Figure 1.6: Type of road damaged by settlement of peat soil in Sarawak

1.3.2 Cost of Road Maintenance

A total of 31,780 km of road have been completed in Sarawak (MIPD, 2019) with a total sum of road maintenance estimated at RM 500 million per annum based on JKR Sarawak estimation in year 2020. Therefore the price of maintenance per month is RM 42 million.

Based on the super impose of Road Maps and Geological Maps of Sarawak as shown in Figure 1.7, it is estimated the road built on soft ground is approximately 1040 km. Therefore, approximately RM 16 million is spent annually on road maintenance for road built on soft ground.

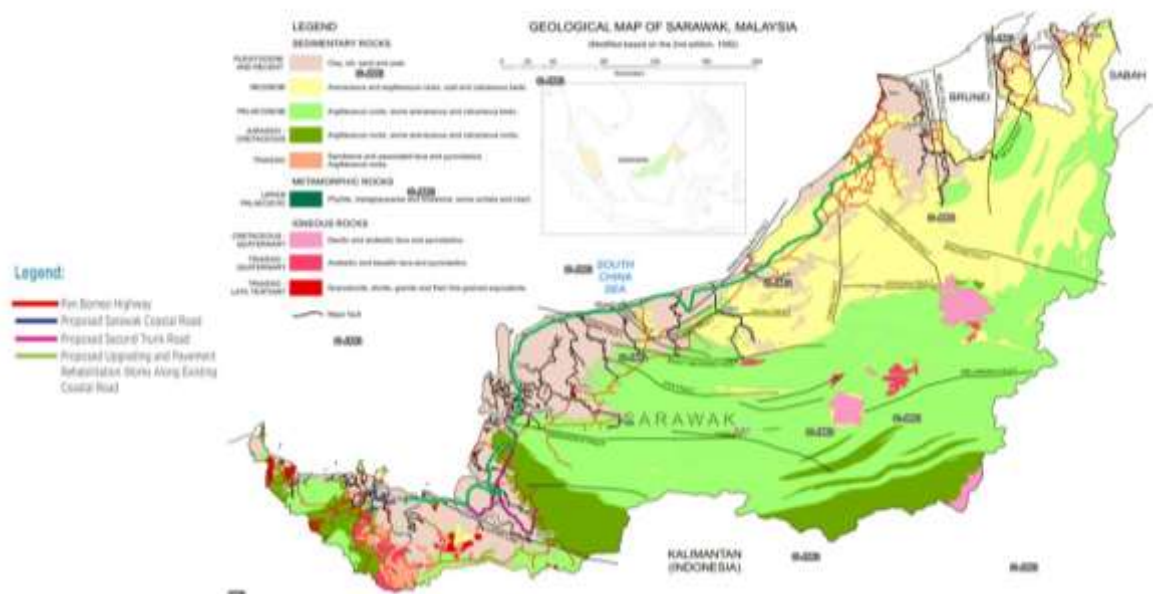


Figure 1.7: Most coastal road in Sarawak is built on soft soil

1.3.3 Estimated Number of Road Accidents caused by Poor Road Condition

Sarawak has recorded 19,581 cases of road accident between January to November in 2019 (Lee, 2020) with total fatalities of 329 cases. Based on JPJ Sarawak report, 10% of

accidents are caused by poor road condition, which means poor condition of the road built on soft ground is likely not the main cause of accident (Zulazhar, 2014).

1.4 Conventional Method of Road Construction on Soft Ground

The guideline as shown in Figure 1.8 has been identified and used by industry, it consists of several of construction practices to address settlements issues of road construction on soft ground.



Figure 1.8: Guideline for construction on peat and organic soil in Malaysia (CREAM, 2015)

There are two (2) conventional methods widely used in road construction on soft ground to eliminate the settlement of road based on the guidelines as shown in Table 1.5.

Table 1.5: Type of problems encountered when constructing embankments on soft soil or peat soil (CREAM, 2015)

No	Method	Engineering problems	Effects, methods and techniques discussed
1.	Remove, replacement and surcharging method	Preparation for access on soft soil or peat soil	• Built a surface drainage of soft ground by 1 m to drain out the water • Built the access road on top of soft ground
		Fill materials and method of fill placement	• Sand or soil fill material • Dumped away unwanted soil and replace with fill material
		Settlement	• Pre-loading (Surcharging)
2.	Piling	Pile embankments	• Suspended working platform is required • High-density concrete pile to overcome acidic conditions • Requires longer pile to set

Method no. 1 could be the most common method in construction industries. However, Vincent (2016) mentioned that the lack of proper drainage system to lower the ground water table, inadequate surcharging for long term consolidation and insufficient soil investigation during construction are the main reasons that contribute to road settlements or damage as described in Section 1.3. The most efficient method is method no.2 (piling method). However, it is too costly to be implemented on soft soil if the hard layer is very deep.

1.5 Research Significance

An idea on load reduction method such as a floating road embankment is proposed, which is based on the principle of buoyancy, where a lightweight material is used to replace the soft soil or peat soil in the same or less density. This proposed idea comes from floating timber track as shown in Figure 1.9. The aim of this idea is to reduce the bulk of construction works such as earth fill, excavation, replacement and piling works and ultimately save on the construction cost.



Figure 1.9: Floating timber track on peat area

In this research, lightweight foamed concrete is proposed as the floating road embankment. This will be studied in length in the upcoming chapters.

1.6 Innovation of Construction on soft Soil and Peat Soil

This research attempts to innovate the conventional method of “remove and replace” by introducing foamed concrete in the design with the aim to mitigate the settlement problem.

The design method is presented based on a previous study by Lai (2011). The laboratory data and results had proven the feasibility of the use of foamed concrete in soil replacement but has yet to be applied on actual project.

Concrete is one of the most important material used in construction, which is made by mixing cement, aggregate, water and admixtures. It has high compressive strength, durability and low maintenance. However, it is considered a heavy construction material. Many researchers had conducted research works to reduce the weight of concrete.

The first lightweight foamed concrete was introduced in the 1923. It was initially used as an insulating material. Due to improvements throughout the past 20 years a better production equipment and quality foam agents has been use in production of foam concrete in large scale.

The innovation of this research is to apply load reduction method with an idea to replace the soft soil or peat soil by using lightweight foamed concrete as road embankment fill material and create an undisturbed condition to the peat surrounding environment as shown in Figure 1.10.

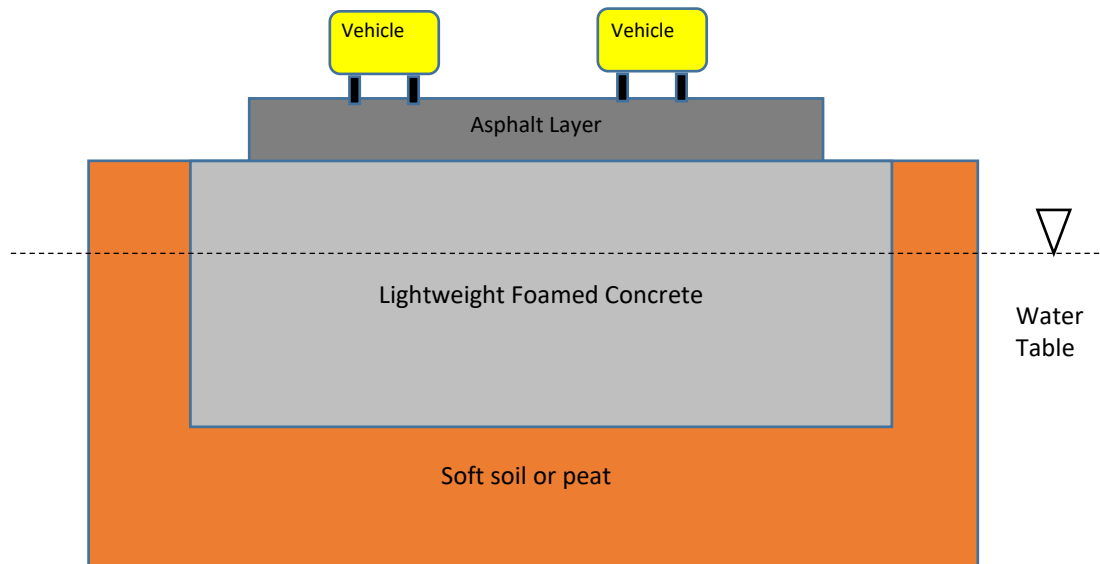
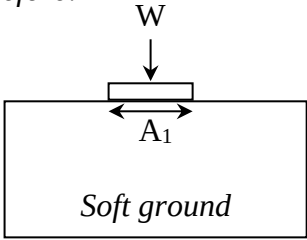
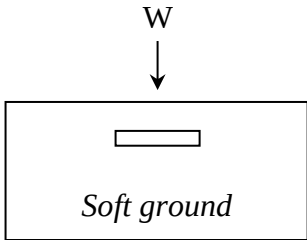
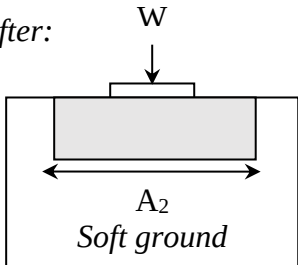
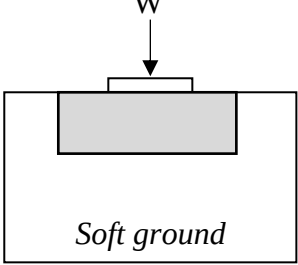
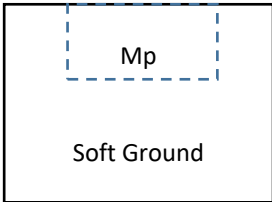
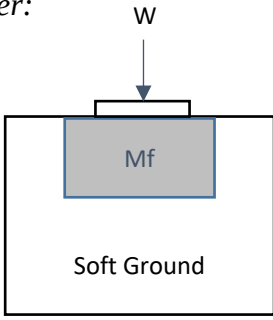


Figure 1.10: Conceptual diagram showing foamed concrete replacement method

This innovation is to study the method to achieve the soft soil or peat soil replacement by applying the principle of equilibrium and buoyancy. Table 1.6 explains the proposed alternative method and system, which though enlargement of area and buoyancy effect achieved its purpose.

Table 1.6: The concept for the proposed method and system

Principle	Description
1. Enlargement of area (Load spreading)	<i>Before:</i>   Vehicle Load = W, Road area = A_1; Thus, Stress, $\sigma_1 = W/A_1$ For a smaller road area A_1, its means total settlement is greater and leads to more significant differential settlement. <i>After:</i>   Load = W, Area = A_2; Thus, Stress, $\sigma_2 = W/A_2$ Larger area Foamed concrete A_2, it means less total settlement and leads to less significant differential settlement. Conclusion: If $A_2 > A_1$; Therefore, $\sigma_2 < \sigma_1$
2. Buoyancy effect (Load reduction)	<i>Before:</i>  <i>After:</i>  Excavated mass, $M_p =$ Load Vehicle, W + Mass foamed concrete, M_f Conclusion: $W + M_f < M_p$, less settlement

In conclusion, these two principles are to prevent settlement by enlarging the base surface area and reducing the stress or load imposed to foamed concrete.

It is expected that the use of lightweight material on peat replacement will be able to mitigate the settlement problem. In this research, the main target is to reduce the settlement of soil at post-construction period. According to (CREAM, 2015) on settlement, a value of 400 mm in 7 years is considered acceptable.

1.7 Design of Road Embankment by using the Reduction Method

In previous work by Lai (2011), the design calculation procedure had been proposed. Figure 1.11 shows the proposed cross section for road embankment from the research work.

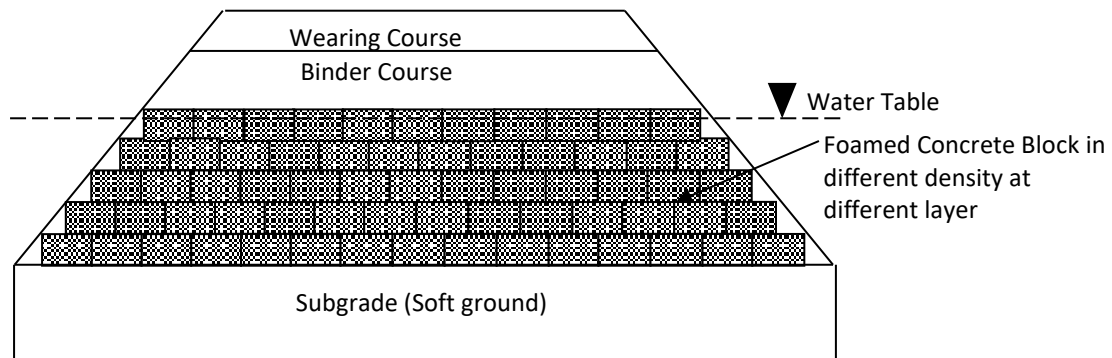


Figure 1.11: Proposed foamed concrete foundation (road embankment) for soil replacement on peatland in Sarawak.

The design calculation procedure is based on “soil replacement method” as shown in Table 1.6, where the total mass of excavated soft ground is replaced with equal or less than the total mass of vehicle, road furniture, road pavement and mass of foamed concrete. By using this method, the replacement material will not sink due to equilibrium.

This design also be enhanced by supported bearing capacity of soil ground at certain depth. It is believed that there are certain resistance bearing capacity for soft soil or peat soil although in small amount. The bearing capacity could be determined by soil investigation (soft soil) described in Chapter 2 or equation by other researcher (peat soil).

In view of total mass of vehicle, road furniture and road pavement are decided at the preliminary design stages. The only variable able to change is the mass of foamed concrete material. This research study focuses on the production of the required mass of foamed concrete to meet the replacement target. Figure 1.12 shows the proposed design spreadsheet for road embankment on soft ground, in which the following parameters need to be considered: -

- | | |
|---|---|
| a. Density of soft soil or peat soil: | Determine from site |
| b. Height of water table: | Can submerge whole foamed concrete foundation |
| c. Density of foamed concrete: | 700 - 1300 kg/m ³ |
| d. Strength of foamed concrete: | Minimum 1-3 N/mm ² |
| e. Load distribution angle:
(Crack angle of foamed concrete during ultimate compressive strength- form lab data) | 25° - 35° |

DESIGN OF FOAMED CONCRETE SUBGRADE ON SOFT SOIL

Loading

Vehicle	10 tons	98.10 kN
Contract Point	2	49.05 kN
Point load vehicle to road (Assume to 1m²)	49.05 kN/m²	
Premix	100 mm	0.10 m
Premix Density	2.3 tons/m ³	22.56 kN/m ³
Loading premix to road	2.26 kN/m²	
Aggregate (20mm)	250 mm	0.25 m
Aggregate Density	1.8 tons/m ³	17.66 kN/m ³
Loading Aggregate to road	4.41 kN/m²	
Chipping (5mm)	100 mm	0.10 m
Chipping Density	1.8 tons/m ³	17.66 kN/m ³
Loading Chipping to road	1.77 kN/m²	
Total Loading	57.49 kN/m²	
Width of road	9 m	
Length of road	25 m	
Area of road	225.00 m ²	
Total Loading	12934.49 kN	
Total Loading + Additional load	13138.44 kN	

Volume of foamed concrete for carrying total Loding

Density of foamed concrete	1100 kg/m ³			
Water absorption	35 %			
Density foamed concrete + Water	1485 kg/m ³			
Allow Density	1300 kg/m ³			
Extra Density	185 kg/m ³	203.95 kN		
Degree of load distribution, ϕ	30 °			
Height, H	17.00 m			
Lt=	9.00 m			
Lb= Lt+2(H*Tan(ϕ))	28.63 m			
Volume of foamed concrete	2878.69 m ³			
Allow loading (Based on lab, 0.001m ³ could taken 5N with rotation <1°)	14393.44 kN	>	13138.44 kN	(OK)
Length, L	18.81 m			
Moment, NL (Actual)	247199.11 kNm			
Moment, NL (Allow)	270811.92 kNm	>	247199.11 kN	(OK)
Cube selected	H L W			
	750 mm 1000 mm 500 mm			
Nos of cube in Height	23 nos			
Nos of cube in Top	9 nos			
Nos of cube in Bottom	29 nos			
Total of Cube	426 nos	50.00	21324 nos	

Check bearing capacity

Bearing capacity, $y=7.68+0.44H$ (From others research)	15.16 kN/m ²			
Actual bearing capacity require	50.20 kN/m ²	>	15.16 kN/m ²	(OK)

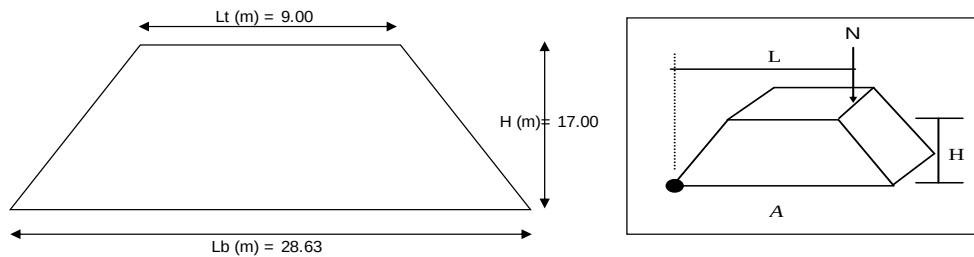


Figure 1.12: The design spreadsheet developed to calculate the size of the foamed concrete foundation (Lai, 2011)

The design parameters and calculation spreadsheet had been reviewed, modified and simplified as follows:-

- Lightweight platform is proposed and supported by the buoyancy force, so no huge excavation is needed.
- Checking on road tilting (moment) by vehicle is not required, due to very small figure as compare to the load imposed to whole foamed concrete embankment system. In addition, the buoyancy force could assist in stabilizing the tilting.

Section 3.3 (a) will further elaborate this modified method call partially foamed concrete method. In Section 7.4, a design spreadsheet calculation for foamed concrete embankment using the partially foamed concrete method suitable for soft soil and peat soil is developed.

1.8 Research Problems

It is the intention of this research to introduce new materials as fill material in the construction of road on soft ground. The design procedures have been outlined in previous study and will be used as a guide in this work. The main challenge will be to produce the big volume of foamed concrete as required in the design pilot project in Chapter 7.

There are a few problems that would occur at the earlier stage of production of foamed concrete, such as the difficulty to achieving the target density due to the inability to control the foam and moisture content in the mix, unknown workability to control the foamed concrete flow, low compressive strength and frequent occurrence segregation and shrinkage.

Although compressive strength is not expected to be as high as the normal concrete, the minimum requirements must be achieved. It must not crush under the pressure of stem rollers trucks and other vehicles.

Mixing technique is important in affecting the achievement of five (5) elements of foamed concrete such as density, workability, shrinkage, strength and volume. The research work involved investigation on the mixing technique that could produce foamed concrete in stable shape, without shrinkage, with strength and ease of casting. There are no exact mixing technique for reference in producing foamed concrete, and the only references is based on normal concrete mixing technique with entering foam bubbles (Jalal et al.2017) which mentioned the mixing technique as follow:-

- a. The desired ratio of cement, sand and fly ash, and water are thoroughly mixed together with high-speed impellers. Slurry is dropped into a buffer tank, which is continuously agitated to prevent it from segregation.
- b. The pre-formed foam is generated in specialized foam production equipment. Foaming agent and water is mixed in a separate tank and compressed air is supplied to it based on the amount of foam required. The pre-formed foam is then injected to slurry to produce the foamed concrete.

An in-depth understanding of mix ingredients and consequential properties of foamed concrete is important for use as fill material in road construction. These are the pre-requisites before embarking on any pilot projects. The final outcome of the work will be the proof that the use of foamed concrete in construction could mitigate the settlement problem.

Finally, the cost of production will be another obstacle as ingredients cost for foamed concrete are expensive. In addition, in producing good quality foamed concrete, concrete technologist prefer the use of various admixtures to achieve the desired properties. However, admixtures cost will be a burden to production cost.

1.9 Objectives of the Study

This study attempts to provide a new alternative approach to construction on soft ground as mentioned in Section 1.6. The concept is to take advantage of the soil condition to support road design. Foamed concrete is one of the fundamental materials that will be used in this study. This study attempts to replace the soft soil or peat soil with foamed concrete as fill material with the following objectives:-

- a. To investigate the factors that affects quality of foamed concrete at a density around $700 - 1300 \text{ kg/m}^3$. Where to study the mixing technique that can produce foamed concrete with optimum strength of $1 - 3 \text{ N/mm}^2$ and to investigate the ideal workability of foamed concrete
- b. To transfer the method of production of foamed concrete from small scale (laboratory mixing) to big scale plant mixing). At this stage, the shrinkage of foamed concrete is attempt to minimize, which is not more than 2.0% of foamed concrete sample depth.
- c. To design a road embankment using foamed concrete as fill material. To study the settlement of foamed concrete road embankment

1.10 Study Approach

This study is to solve the soft ground settlement problem in road construction. The foamed concrete road embankment is the main target in this study. A practical foamed concrete, method of mixing and design method will be looked into in this study. A “foamed concrete road embankment (fill material) design procedure will be developed at the final stages of the study. There are a few stages of the study to sub-objective for achieve the main objective as mentioned in Section 1.9 of this study and described in Table 1.7.

Table 1.7: Targeted stages to achieve study sub-objectives

Main objective	Stage	Milestones	Sub-objective target
1.9 (a)	1	Optimum mix proportion	Small scale study in the laboratory to obtain an optimum mix proportion.
1.9 (a)	2	Practical mixing Technique	To obtain a good sequence of mixing method.
1.9 (a)	3	Foamed concrete Properties	To identify the optimum fresh and harden properties of foamed concrete to fit the purpose as filler.
1.9 (b)	4	Mass Production	To produce a big volume of foam concrete.
1.9 (c)	5	Design of embankment	To design the foamed concrete road embankment.
1.9 (c)	6	Pilot project	To apply the foamed concrete road embankment on the project site and conduct data collection.

1.11 Limitation of the Study

A few limitations had been encountered in this study based on the worst soil ground condition (peat soil condition) in Sarawak:-

- a) Foamed concrete density is limited at a range of $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$, due to density limitation of peat soil is not more than 1300 kg/m^3 . Therefore, any foamed concrete less than 700 kg/m^3 is believed to be having no strength and brittle.
- b) The compressive strength of foamed concrete is limited between $1\text{-}3 \text{ N/mm}^2$. This strength is better than the unconfined strength of any type of soil with a strength less than 1 N/mm^2 .

1.12 Layout of Thesis

The thesis layout consists of eight (8) chapters. Chapter 1 presents the background of the soft ground and the objectives of the study, where readers will understand the geographical and problematic nature of soft soil in construction industries. Chapter 2

presents a review of the literature on soft ground and foamed concrete. This chapter will further elaborate the properties of soft soil and peat soil and understand the lightweight foamed concrete replacement on soft ground in the construction area. Chapter 3 describes the research experimental program and method of experiments. This chapter is to describe the sequence of foamed concrete production and the method of replacing the soft soil and peat soil. Chapter 4 presents the innovative mixing technique to produce foamed concrete. This chapter will describe in details the technicality to produce the foamed concrete. Chapter 5 explains how to achieve the target strength of foamed concrete. In this chapter, the optimum mix proportional will attempted using consistent parameters such as compressive strength, cement and sand ratio, water-cement ratio, water absorption rate and others. Chapter 6 describes the transfer from small laboratory scale to the mass production for industrial scale of foamed concrete. This chapter will discuss the change of foamed concrete production parameters due to mass production. Chapter 7 describes the results of the production on site. This chapter will discuss the design of foamed concrete road embankment and the settlement changes in time. The last chapter, which is Chapter 8 is the conclusion on the feasibility of the foamed concrete replacement technique and cost of industries production of foamed concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Soft Ground Construction Method

As mentioned in Chapter 1, soft ground construction is very problematic due to settlements. There are many methods that have been practiced over the years in the construction field to overcome the settlement problems. This Chapter will discuss in detail two (2) common conventional methods as mentioned in Table 1.5 and non-conventional deep soil stabilization method, which is recently years has been used in Sarawak's construction industry. Deep soil stabilization method has not been applied to replace unwanted soil with foamed concrete, but a method that is used in soft ground construction. The literature reviews will briefly introduce this method for understand the soft ground construction method.

2.1.1 Remove, Replacement and Surcharging Method

Removed, replacement and surcharging method is the simplest and most reliable technique if constructed properly. This method is to remove and replace the unwanted soft soil or peat soil with a suitable fill material, such as sand or other suitable soil as shown in Figure 2.1. The bamboo mattress shown in Figure 2.2 is to provide a platform for laying geotextile on it. Bamboo mattress and geotextile function like surface reinforcement (Huat et al., 2014), which provide reinforcement to resist bending moment for the fill material on top of it. Geotextile is also used as a separator to separate the soft ground and fill material. Normally this method is carried out on the earthwork which without soil improvement works

to the original ground at the early stage of construction, and this tend to result in the embankment stability problem, such as bearing capacity failure and dramatic differential settlement in the long run especially in area with water table that changes rapidly. This method is difficult to construct and take longer time to complete, and particularly involves the long surcharging period. The duration of construction is taken into account in the gap analysis for the new innovation method in section 2.13 (a).



Figure 2.1: Unwanted peat soil has been excavated then filled with sand
(Photo taken at Matang road construction site)



Figure 2.2: Bamboo mattress that has been tie together
(Photo taken at Pusa road construction site)

A layer of suitable material is laid over the geotextile as a working platform as shown in Figure 2.3.



Figure 2.3: Installation of geotextile and sand platform
(Photo taken at Sri Aman road construction site)

In some cases, prefabricated vertical drain (PVD) and surcharging are needed to fasten the consolidation process. Kjellman (1952) introduced the first prototype of a prefabricated vertical drain made entirely of cardboard. Figure 2.4 shows the process of discharging groundwater by surcharging with PVD.

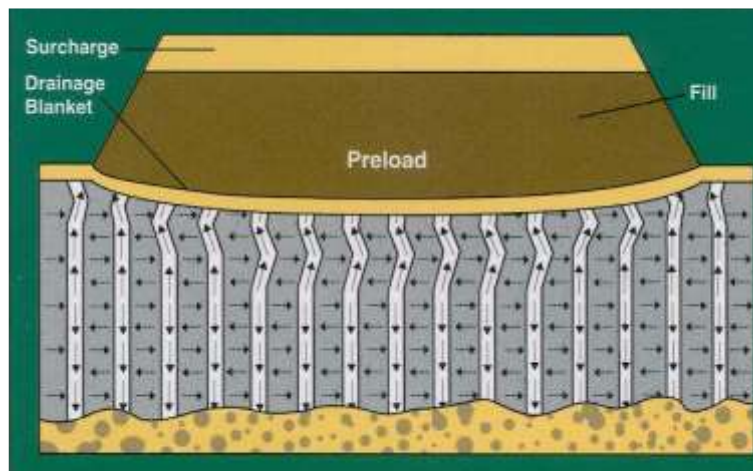


Figure 2.4: Groundwater dissipates through PVD (Gue, 2012)

Groundwater will be discharged through the PVD to the drainage blanket. Figure 2.5 shows the installation of the PVD before the surcharge layer.



Figure 2.5: Installed PVD
(Photo taken at Betong road construction site)

Figure 2.6 shows a layer of geotextile is installed in between the filled surcharge layer and the top of PVD. The period of surcharge is normally between 6 –12 months.



Figure 2.6: Sand filled to surcharge level
(Photo taken at Samarahan road construction site)

Peter (2015) mentioned PVD will accelerate the settlement to achieve the final settlement 100 times faster as described in Figure 2.7.

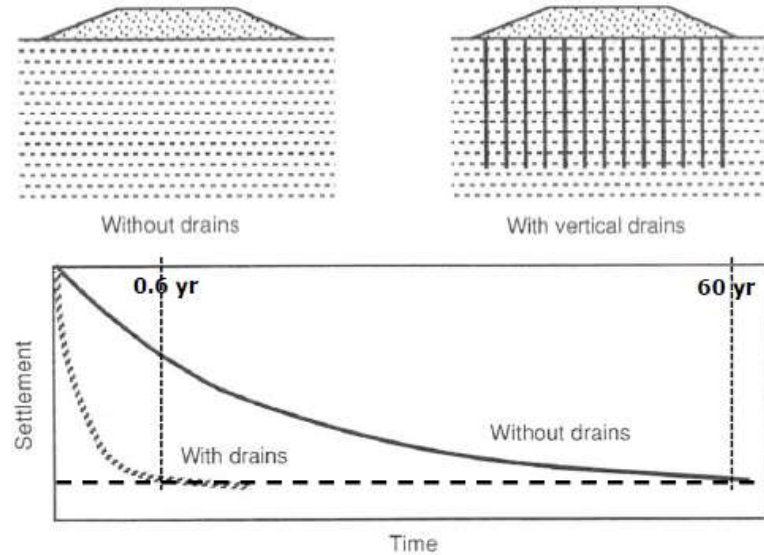


Figure 2.7: Prefabricated vertical drain (PVD) accelerates the settlement but not reducing the final settlement

2.1.2 Piling Method

Piled foundation provides support to the structure, transfers the loads from the structure to the hard strata layer. Piling method is the fastest method with high bearing capacity at very small settlements (Baoyun et al., 2020) to address settlement problem especially on peat area. Normally this method is costly due to the depth of hard strata layer. Basically, there are two (2) types of piles as shown in Figure 2.8, which is displacement and non-displacement piles.

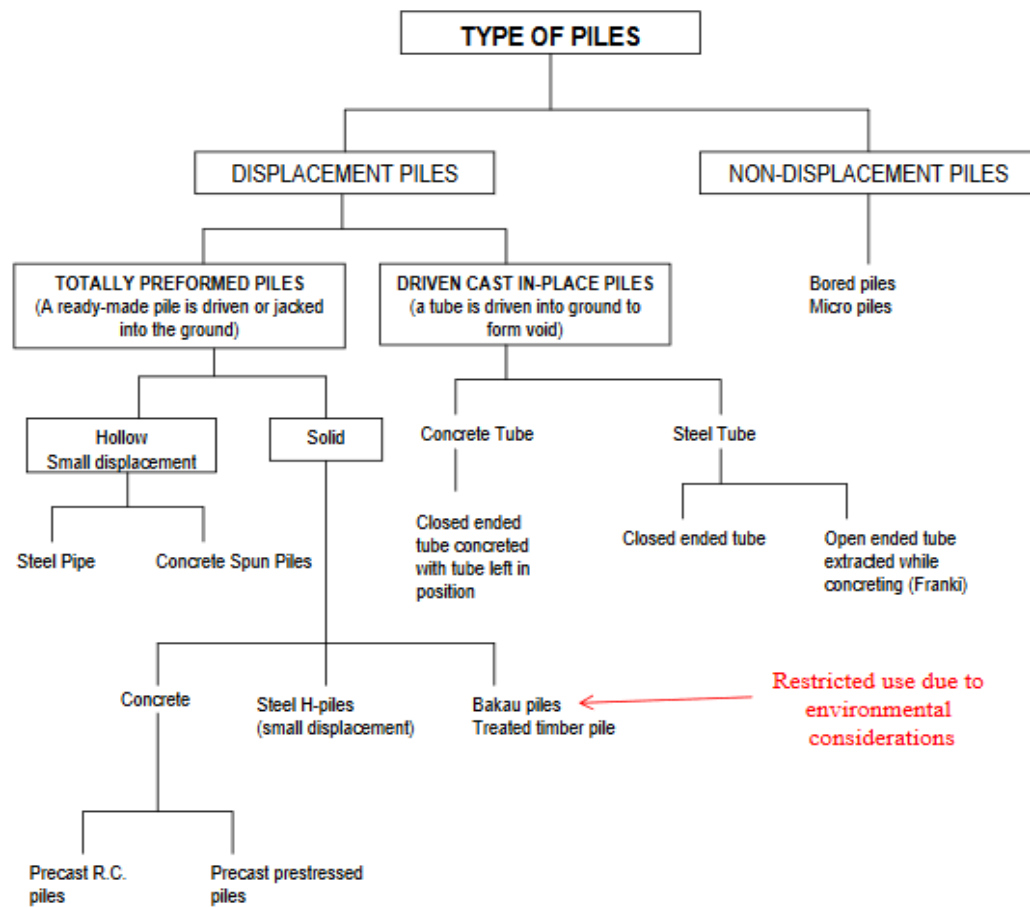


Figure 2.8: Classification of piles (Gue, 2020)

From Figure 2.8, this research study will only discuss three (3) types of piles which are widely used in soft ground construction such as preformed piles, cast-in-place piles – micro piles, and bored piles.

a. Preformed Piles

Preformed pile or precast piles like timber pile (Bakau Pile and Belian Pile), concrete piles (RC Square Pile and Spun Pile) and steel pile (H Pile, Pipe Pile and Seet Pile) are normally found in the construction industry. Reinforced concrete piles (RC piles) have been widely used in peat soil foundation. Piles are driven into the granular soils by using a hammer and displacing the equal volume of soil. Most of the piles are driven until the hard strata

layer (end-bearing Pile). Figure 2.9 shows the normal practice in the construction site for piling installation process.

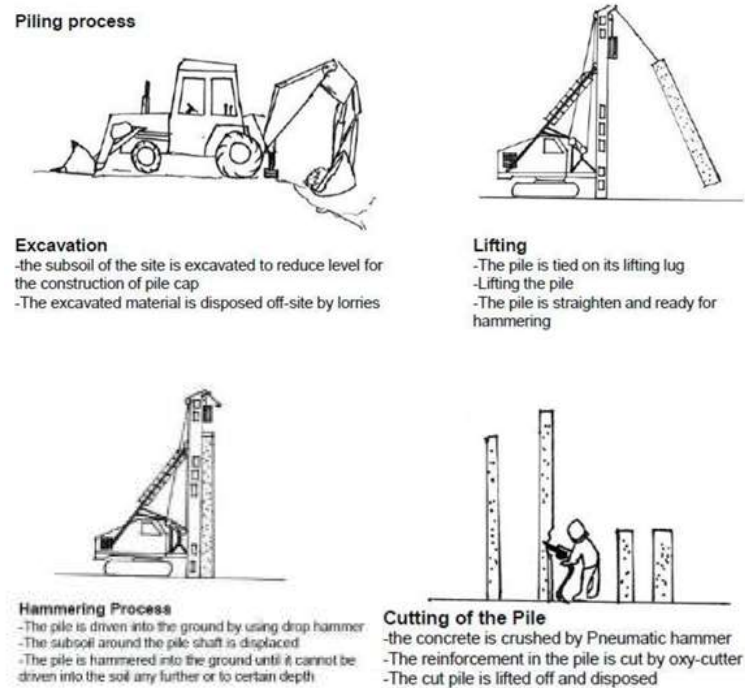


Figure 2.9: Piling installation process (JKR SRO, 2020).

Piling on site has to strictly follow the pile set criteria and the pile set record is used for analysing the set as shown in Figure 2.10.



Figure 2.10: Installation of the pile at site and piling record (Photo taken at project site Santubong)

The advantages of using driven piles are:

- i. Piles can be pre-fabricated in any size and length to suit the project and can easily be installed once on site.
- ii. The displacement of driven piles could increase the bearing capacity of the pile due to friction of the pile surface and soil surrounding.
- iii. Their high lateral and bending moment can resist soil lateral movement and protect soil run off.
- iv. The installation is easy by using moveable piling equipment.

The disadvantages of using driven piles are:

- i. Advance planning is required for the handling and driving of pile by the heavy piling equipment on site,
- ii. Precast piles must be adequately reinforced to withstand handling stresses during transportation and installation.
- iii. Driven piles may not be suitable where the ground has poor drainage qualities, and where staging is needed for piling rig.
- iv. Driven piles can be noisy to install and vibration can result in noise pollutions and damages to nearby structure.

b. Cast-in-place piles

Cast-in-place pile or also known as micropile (without casing), are used in moderate soft clay area like marine clay where the wall of soil would not collapse after drilling. These piles are constructed by drilling holes in the ground to the required depth and then filling with reinforcements concrete. The size of micropile is normally less than 300 mm diameter.

The sequence of installation micropile is shown in Figure 2.11, which follow the FHWA manual (2005).

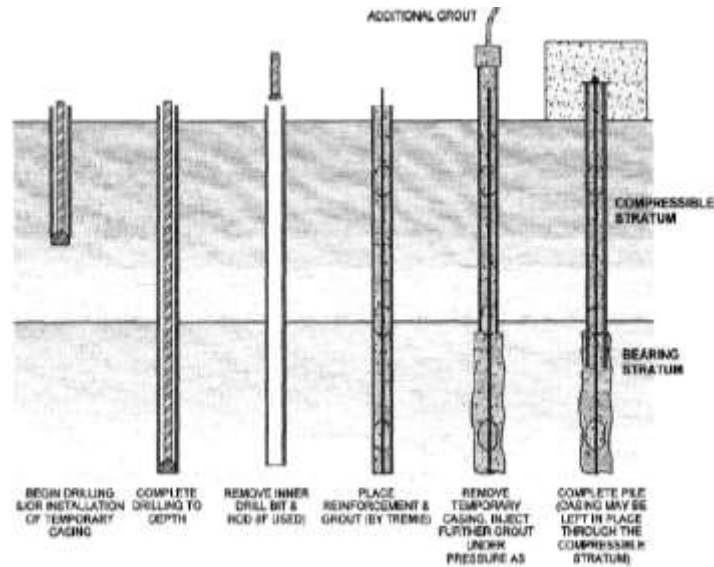


Figure 2.11: Typical micropile construction sequence (FHWA, 2005)

c. Bored Piles

Bored piles are used in very soft clay where the wall of soil can easily collapse after drilling. Steel pipe pile as casing will press into the soil then followed by drilling the internal soil and washing out the internal soil or muck. Reinforcement will be installed into the steel pipe then followed by pouring down concrete grout. The size of bored piles is normally more than 300 mm diameter. The process of installation of the bored pile is the same as micropile.

Figure 2.12 shown the installation of bored pile at a project site.



(a)

(b)



(c)

(d)

Figure 2.12: (a) Installing the temporary casing into the ground with vibro hammer
(b) Pumping grout into the borepile hole (c) Installation of reinforcement
(d) Grouting. (Photo taken at project site Padawan)

This piling method is expensive and difficult in the construct of working platform for piling rig. This shall be taken into account in the gap analysis. The advantages of using driven piles are:

- i. Micro pile and bored pile method produce minimal vibration and noise pollution.

- ii. The pile is casting by cement grout which has minimizes the void in the harden concrete and no jointing in between the pile length.
- iii. The pile length can be adjusted to suit varying ground conditions and can be installed in very large diameters.
- iv. The soil sample from drill level can be inspected and determine the bearing capacity in situ.
- v. Quality of piles material is controlled and not affected by handling or driving conditions.

The disadvantages of using driven piles are:

- i. This method is costly and take longer time to install.
- ii. The drilling method used depends greatly on the type of soil, and the contractor needs to perform a comprehensive analysis of the soil to pick the best drilling method to minimize the disturbance.

2.1.3 Deep Soil Stabilization

Deep soil stabilization can be used to stabilise a wide range of soils, including soft soil and peat soil to provide a hardened platform for road base construction (Michał, 2016). This method is to plump the grout into a certain depth of ground by high pressure, then forcing the grout to mix with the soil underneath to form stabilized soil column as shown in Figure 2.13. The material for grout are cement, lime and fly ash, each with its own function:-

- The hardening (setting) of cement will enclose the soil as a glue, but it will not change the structure of soil (Khan et.al, 2015).

- Lime stabilization may refer to the pozzolanic reaction in which pozzolana materials react with lime in the presence of water to produce cementitious compounds (Ronoh, 2014).
- Fly ash can react chemically to form a cementitious compound that contributes to improved strength of soft soil (Pandian, 2013)

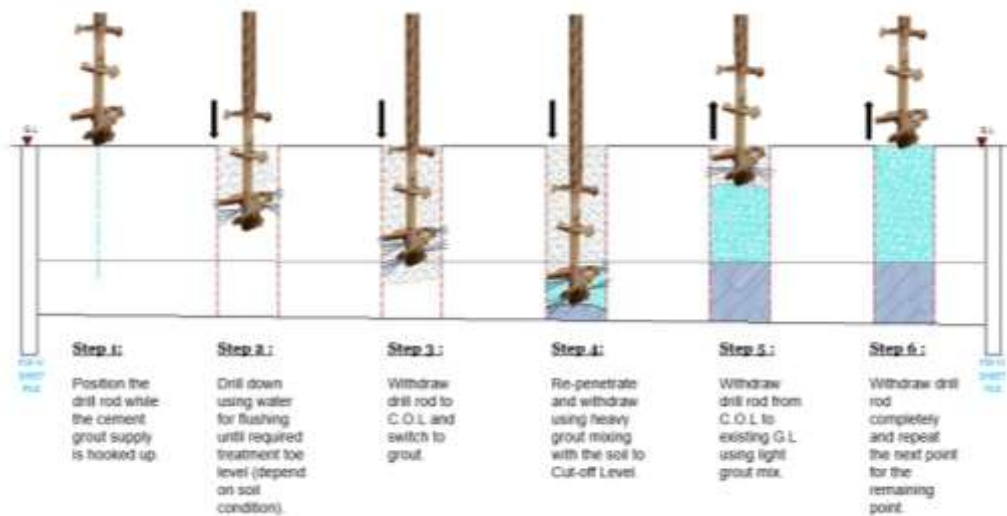
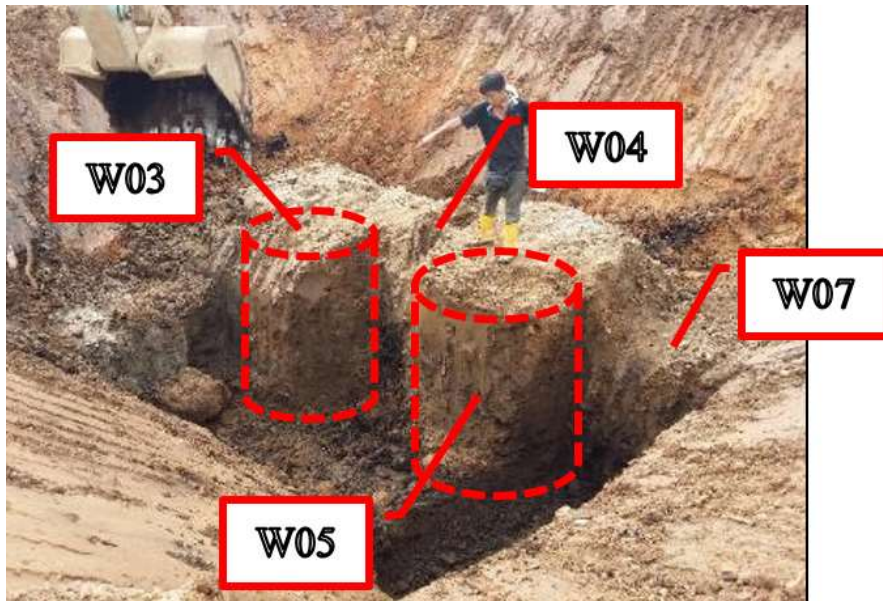


Figure 2.13: Deep soil stabilization sequence (ZYG, 1997)

The deep soil stabilization sample is taken to ensure the quality meets the requirement as shown in Figure 2.14. Figure 2.14 (a) shows four (4) deep soil stabilization that had been constructed, namely W3, W4, W5 and W7. The soil column is presented as the cylinder shape drawn at W3 and W5. The samples are core and test for compressive strength as shown in Figure 2.14 (b) and (c).



(a)



(b)



(c)

Figure 2.14: (a) Exposed deep soil stabilization, (b) Core sampling and (c) Compressive test
(Photo taken at a project site in Matang)

2.2 Soils Investigation on Peat

Soil investigation is important to obtain the geotechnical properties of peat and to determine the method of construction on soft ground based on its localized geotechnical properties. Peat samples and site profile are taken from the site by several methods like visual inspection, auger, borehole (SPT) and Mackintosh probe for further investigation at the laboratory to determine the soil info such as shear strength and bearing capacity. Bearing capacity can be determined as illustrated in Figure 2.15, where MS 2038 Site Investigations-Code of Practice (2006) is referred for this purpose.

Table 3.1 Relationship between S.P.T, J.K.R. probe and unconfined compressive strength of clay			
N (blows/ft)	Consistency	Unconfined Compressive Strength (Ton/Sq.ft)	J.K.R. probe blows/ft
2	very soft	< 0.25	< 10
2-4	soft	0.25 - 0.50	10 - 20
4-8	medium (firm)	0.50 - 1.00	20 - 40
8-15	stiff	1.00 - 2.00	40 - 70
15-30	very stiff	2.00 - 4.00	70 - 100
30	hard	> 4.00	> 100

Table 3.2 Relationship between S.P.T, J.K.R. probe and allowable soil pressure for sand			
N (blows/ft)	Relative density	Allowable Soil pressure* (ton/sq.ft)	J.K.R. probe blows/ft
0 - 4	very loose	Not suitable	< 10
4 - 10	loose	0 - 0.8	10 - 30
10 - 30	medium	0.8 - 2.8	30 - 80
30 - 50	dense	2.8 - 4.7	80 - 110
over 50	very dense	> 4.7	> 110

* After Terzaghi and Peck 1967

Figure 2.15: Soil investigation indicator for soils bearing capacity

The basic geotechnical properties of peat soil in Sarawak such as moisture content, organic content and bulk density have been described in Table 1.5 in Chapter 1. This research study mainly focuses on few soft ground geotechnical parameters such as density, moisture content and bearing capacity.

2.3 Load Reduction Method

Section 1.7 in Chapter 1 has briefed on the load reduction method which is the main focus of this thesis, where besides lightweight foamed concrete, there are many other lightweight materials used to perform loads reduction method on peat area construction. All those lightweight material are targeted to reduce the consolidation stress with reduction in the total embankment load and minimising the settlements. There are three (3) types of lightweight materials for road construction that have been used in load reduction method as described below.

2.3.1 Rubberized Lightweight Concrete

According to JPJ report, Malaysia has 31.2 million registered vehicle as at 31 December 2019 (Anthony, 2020). The scrap tire or waste tire are estimated at 311,337 tonnes annually. The relevant statistical data is shown in Appendix B. With this unlimited resources, researchers had conducted a study to reuse these scrap tires for engineering purposes, by crumbling the tires into powder to be mixed in concrete with the right proportion to produce lightweight concrete as shown in Figure 2.16.



Figure 2.16: Scrap tire is crumbled into powder for casting in concrete

2.3.1.1 Mixing with Crumbled Tires

The density of crumble tires is around 1025 kg/m^3 , which is very light compared to soft soil and peat soil density with water absorption range between 2% to 4.3%. Table 2.1 shows the mix proportion of concrete used to study the effect of volume of crumbed tires on the compressive strength of concrete (Antil, 2014).

Table 2.1: Mix proportion use for crumbled tyre

Water (Litre)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
191.58	425.73	574.51	1202.55

Table 2.2: Compressive strength with various percentage of crumbled tires
(Antil, 2014).

No.	Percentage of crumbled tires	Slump (mm)	Density (kg/m^3)	Compressive strength (N/mm^2)
1	0%	45	1517.7	36.2
2	5%	48	1512.0	32.2
3	10%	49	1506.3	27.7
4	15%	40	1500.7	24.8
5	20%	35	1495.0	22.7

The results in Table 2.2 proved that addition crumbled tires will decrease the density and strength of lightweight rubberized concrete. Research is still ongoing to apply the use of rubberized concrete in soft soil or peat replacement. However, the study on lightweight rubberized concrete is only at initial stage.

2.3.2 Expanded Poly-Styrene Block (EPS)

Nowadays, load reduction method is the main focus in road construction. Expanded Polystyrene Fill (EPS) also commonly known as “geofoam” is a lightweight (normal density range of 11 to 46 kg/m³) and rigid closed-cell polystyrene foam. These characteristics make EPS blocks suitable materials for the construction of road embankments. EPS is low-density cellular plastic blocks, which can be used as a lightweight and environmentally safe fill material. Moreover, EPS geofoam qualifies as an excellent time-saving and cost-effective method in a wide range of transportation-related applications such as road embankments, temporary access road for strategic projects, bridge abutments, lightweight filling, and landslide areas with weak soils (Autelitano et al., 2017). The first pioneering projects for road embankment was constructed in 1972 (Aabøe and Frydenlund, 2011). EPS geofoam as a lightweight fill material was first introduced in 1992 in Malaysia.

The EPS blocks used for road construction shall meet the following physical requirements stated in Table 2.3.

Table 2.3: The physical requirements for EPS block

Minimum Physical Properties			
ASTM D 1622	Density		0.2 kN/m ³
ASTM D 1621	Compression Strength	At 1% Deformation	40 kPa
		At 10% Deformation	110 kPa
ASTM C 203	Flexural Strength		207 kPa

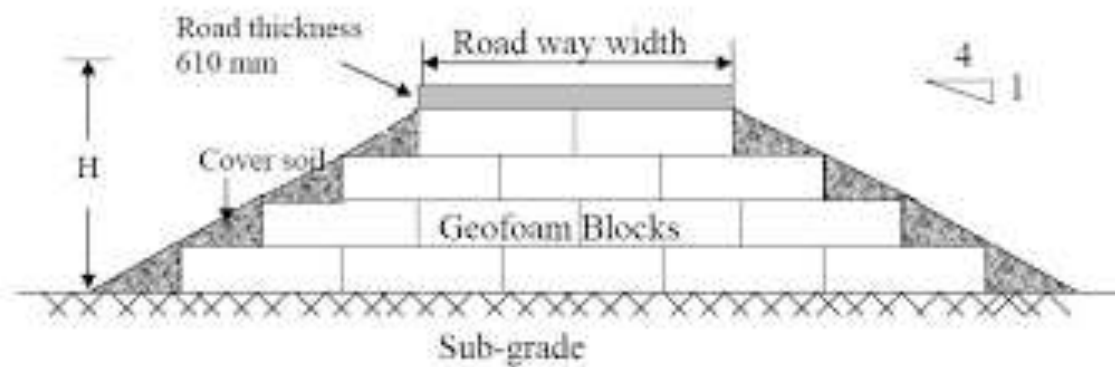


Figure 2.17: The use of EPS as a lightweight fill material (Matthew et al., 2017)

Figure 2.17 describes how the EPS can be used as filling material in soil replacement. The basic principle of EPS construction method is to make the incremental stress in the substrata due to embankment loads as small as possible. The benefit of using EPS is:-

- Transportability and reusability– can be easily moved to sites.
- Ease of construction –easy to assemble and dismantle and requires little excavation.
- Cost reduction – the cost shall be lower than the pile foundation.
- It is capable in reducing the pressure exert in soil.
- It is rigid, thus, could prevent or reduce the differential settlement.

2.3.3 Foamed Concrete as Construction Material

Foamed concrete is a type of lightweight porous concrete in which the distribution of uniform air bubbles is throughout the mass of concrete. Foamed concrete is produced by mechanical mixing of foam and concrete. Figure 2.18 shows the basic ingredients forming the foamed concrete.

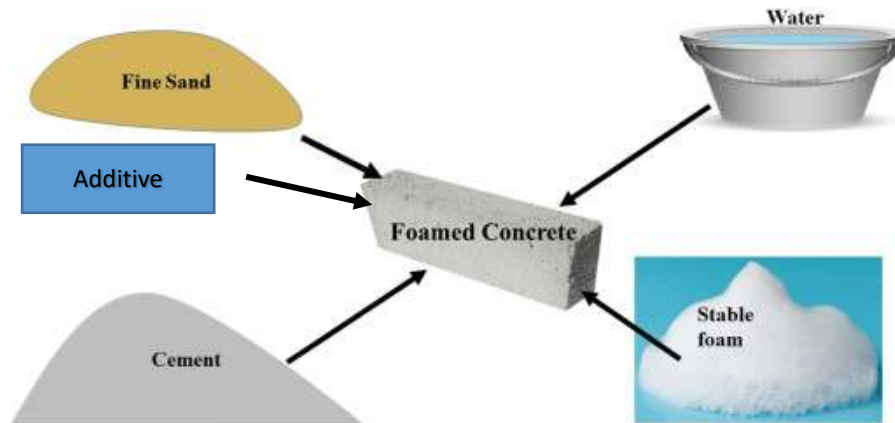


Figure 2.18: Overall view for the production of foamed concrete (Nagesh, 2020)

To enhance the quality of foamed concrete especially on its compressive strength, admixtures are added, eg. PVA (polyvinyl alcohol), Paraffin Oil (GTL) and quarry dust other types of admixtures. The effect of admixtures to compressive strength will be discussed in Chapter 3.

2.4 Foamed Concrete as Fill Material

As mentioned in Section 2.3, this research is to study the feasibility of foamed concrete to replace peat as fill material. The advantages of foamed concrete as fill material are:-

- a) Time and cost saving due to no surcharging and removal activities.
- b) Weight reductions from 10% to 87% over standard dense weight concrete.
- c) Economical in transportation, lower crane capacity required and reduction in manpower.
- d) Can be sawn by hand, sculptured and penetrated by nails and screws.
- e) Easy to combine other materials in the mix, such as quarry dust.
- f) Environmental friendly.

The method of producing foamed concrete will be further explained in Chapter 3.

2.5 Different Methods of lightweight Concrete Production

Lightweight concrete is used to minimize the self-weight of structures and reduce the dependence on bid volume of natural resources. There are three (3) main types of lightweight concrete, which are autoclaved aerated concrete, lightweight aggregate concrete and foamed concrete.

a. Autoclaved Aerated Concrete (ACC)

Generally, the production of autoclaved aerated concrete (AAC) involves the use of chemical such as quartz sand, calcined gypsum, lime (mineral) and/or cement and water as a binding agent. Aluminium powder is used at a rate of 0.05 - 0.08% by volume. In some countries, like India and China, fly ash generated from coal fire power plants and having 50 - 65% silica content is blended into AAC.

When AAC is mixed, calcium hydroxide will react to aluminium powder and water then discharges hydrogen. The hydrogen gas will form bubbles evenly in the fresh concrete with average bubble size of 3 mm diameter. This chemical reaction contributes 20% of voids to AAC or more, depending on its design density. The hydrogen gas will be replaced by air voids. AAC could achieved 8 MPa, approximately 50% of the compressive strength of regular concrete. Figure 2.19 shows the AAC block which can easily be found in the market.



Figure 2.19: Autoclaved Aerated Concrete

b. Lightweight Aggregate Concrete

The most popular way of achieving structural LWC is by using natural lightweight aggregates and manufactured lightweight aggregate. Utilization of lightweight aggregate (LWA) in concrete is mainly to reduce the self-weight of concrete, which then reduces the dimension of foundation and that results in cost saving (Hama, 2017) as shown in Figure 2.20. Normally, lightweight aggregate with bulk density less than 1120 kg/m^3 is used as a raw material in the manufacture of lightweight concrete. It is also used in the production of lightweight masonry blocks to improve thermal, insulating, and nailing characteristics of these building materials.



Figure 2.20: Lightweight Aggregate Concrete

Concrete is considered to be lightweight if the density is not more than 2200 kg/m^3 , as compared to normal concrete density between $2300\text{-}2400 \text{ kg/m}^3$ and a proportion of the aggregate, should have a density of less than 2000 kg/m^3 .

There are two types of lightweight aggregate, where categories are based on the type of raw material. The main natural lightweight aggregates raw material such as diatomite, pumice, volcanic cinders, scoria, tuff and artificial lightweight aggregates such as expanded clay, shale, slate, perlite and vermiculite have been used as construction materials (Aslam et al., 2017).

2.6 Research on Foamed Concrete

Now foamed concrete is widely used in the construction sector for both structural and non-structural purposes. The characteristics of foamed concrete are low self-weight, high workability, consists of low compressive strength, minimum consumption of aggregate and has good thermal insulation properties compared to normal concrete. The density is between 400 kg/m^3 to 1600 kg/m^3 which can be applied to structural, partition, insulation and filling grades by using the appropriate composition of foam.

Researchers have made their own way of producing foamed concrete as shown in Table 2.4. These research findings have been adopted and used as guidance to this research study.

Table 2.4: Researcher's findings on producing foamed concrete

Year	Researcher	Research findings
1992	Van Deijk	Foamed concrete is known to have a minimum of 20% by volume of foam in the mortar slurry. The air-pores are initiated by agitating air with a foaming agent diluted with water then the foam was carefully mixed together with cement slurry to form foam concrete.
1993	Karl & Worner	The water requirement for a mix depends upon the composition and use of admixtures and is governed by the consistency and stability of the mix.

Table 2.4 continued

Year	Researcher	Research findings
1998	Byun & Park	Foam is produced to develop void structure in concrete during the mixing process.
2001	Turner	High Alumina and Calcium Sulfoaluminate have been used for decreasing the setting time and to improve the early strength of foamed concrete.
2002	Kersley & Wainwright	Ordinary Portland cement and rapid hardening Portland cement are used for foamed concrete production.
2005	Aldridge	Dry foam is extremely stable and has a size smaller than 1 mm. This makes it easy applied in the base material required in producing a pumpable foamed concrete.
2005	Jones & McCarthy	Super plasticisers can be a possible reason for instability in the foam.
2006	Nambiar & Ramamurthy	At lower water content, the mix is too stiff causing bubbles to break while a high water Content makes the mix too thin to hold the bubbles leading to separation of bubbles from the mix and thus segregation. The lower water content leads to a hard mixture, resulting in bubble bursting. The higher water content causes the mixture become too thin to accommodate bubbles, thereby causing bubbles separating from the mixture.
2009	Ramamurthy et al.	Over the past 30 years, foamed concrete are widely used for the bulk filling. The water requirement for constituent material depends on composition, consistency and stability of the mortar body. The consistency and stability of fresh mixed foamed concrete are important to avoid a separation of artificial air bubbles and cement mortar as well as breaking of the bubbles, which would affect the hardened properties of concrete. Lightweight Foamed Concrete (LFC) is lighter than normal weight concrete. This is because of the existence of artificial air bubbles trapped in cement mortar when the suitable foaming agent is applied.
2011	Zhao et al.	A 900 kg/m ³ foamed concrete by adding expanded perlites; the prepared foamed concrete exhibits a 28 days compressive strength of 3.2 MPa.

Table 2.4 continued

2014	Zhang et al.	The closed air-voids system in foamed concrete is unable to reduce its density and weight and at the same time produces efficient insulation and fire resistance capacity.
2015	Amran et al.,	Lack of coarse aggregates leads to 4 – 10 times higher shrinkage of the foamed concrete than that observed in ordinary concrete. Drying shrinkage decreases with the density reduction.
2016	Huiskes et al.	The strength of foamed concrete is determined by different cementitious materials, cement dosage, mix proportion, water-cement ratio, foam volume, foaming agent, curing method, additive, etc.
2016	Jones et al.	Unstable behaviour of bubbles causes the uneven pore size distribution in foamed concrete.
2017	Tan et al.	Lightweight foamed concrete is low-density foam cellular lightweight concrete, which can perform self-compacting.
2018	Sahu et al.	The foaming agent determines foamed concrete density by controlling generation rate of the bubbles in cement paste. The resin-based was one of the earliest used foaming agents in foam concrete. So far, synthetic, protein-based, composite and synthetic surfactants have been derived and developed, while the most frequently used are synthetic and protein-based ones.
2018	Hajimohammadi et al.	Addition fillers is helpful to improve mix proportion design, long-term strength, and reduce costs. In addition, some fine aggregates such as fine sand, recycled glass powder, and surface modified chip are commonly used for production of high-density foamed concrete.
2019	Sun et al.	The low density and controlled self-weight makes foamed concrete capable for load reduction.
2020	Wang et al.	Foamed concrete is a type of cement mortar containing cement, water, and stable and homogeneous foam introduced using a suitable foaming agent.

2.7 Highlighted Research Parameters

There are few research parameters to be highlighted in this research study, such as density, workability, shrinkage, compressive strength and volume. These parameters will directly be involved and related to the findings of this research study. Water absorption is a parameter which need to be studied to know the percentages of air-void in the foamed concrete.

a. Density of Foamed Concrete

Density is the most important parameter to be investigated to achieve the target density. It is a quite challenge to do the replacement for soft ground with foamed concrete in the same or less density as described in Table 1.6. Density can be measured either in the fresh state or in the hardened state. Fresh density is required for casting control purposes, which could assist to determine the volume of foam to be added into the foamed concrete. Generally, the results of the hardened density may be scattered due to the continued expansion of the foam during casting and breaking of foam during hardening. In theory, the scattered density data illustrates the relationship between fresh density and hardened density, then to other comparisons, such as compressive strength versus density, shrinkage versus density etc. The comparison is important as it can give an idea related to design mix proportion, concrete strength and resistance to permeability. The moisture condition needs to be indicated due to the material of foamed concrete from different sources that will affect the degree of dryness (Ramamurthy et al., 2009).

The density of foamed concrete will increase when foam is continuously added in at low cement/water ratio. But, when additional water is added in the mix, the foam bubbles wall will be stiff and thus the foam bubbles will break due to hydration process. Whereas,

higher water contents will result the mix being too slurry to and segregation of the mix will occur. The optimum water-cement ratio is necessary to be investigated to achieve the target density (Nambiar & Ramamurthy, 2006).

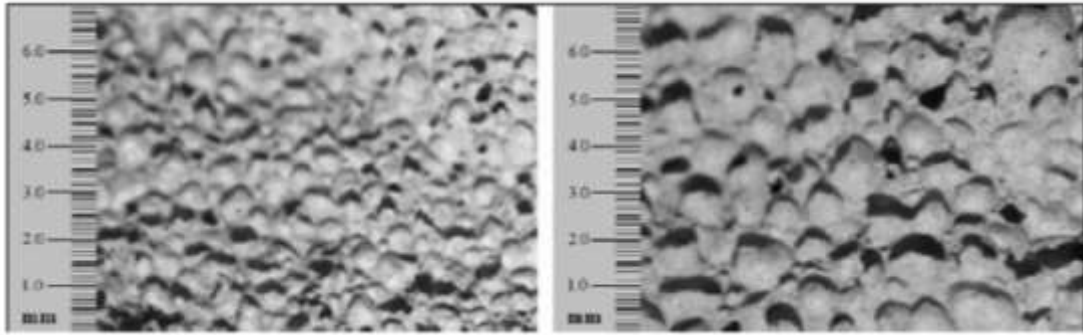


Figure 2.21: Air-Void size for range 1000kg/m³ (left) and 650 kg/m³ (right) densities (Nambiar & Ramamurthy, 2006)

Figure 2.21 shows the different densities of foamed concrete produced different size of air-void. This shows that the size of air-void can represent the foamed concrete density, which the increase of the foam volume will contribute to larger size of air-voids and decrease the density. This happens because of air-void increases the adhesion between the bubbles and solid particles, thus reducing the density (Nambiar & Ramamurthy, 2006).

In some cases, adding of other materials such as quarry dust or fly ash will reduce the density of foamed concrete but will increase the compressive strength of foamed concrete. This is because the fine material will fill in the foam volume and decrease the density, but this will increase the strength of the foamed concrete (Ramamurthy et al., 2009).

b. Compressive Strength

The compressive strength tests were performed according to (BS. 1881: Part 116: 1983). The cubes were tested by using a hydraulic compression machine at a loading rate of

18 MPa per minute. Normally, the compressive test was conducted at ages of 28 days, if required some would conducted in others duration of days.

Compressive strength can be defined as the ability of a concrete specimen to sustain the axial load. The strength of the foamed concrete is affected by the specimen age, water content, ingredient used and method of curing. When the volume of foam increase, the density of foamed concrete and its compressive strength will decrease. Thus, the volume of air-voids and the composition of the paste have an influence on the compressive strength (Kamarulzaman, 2010). The strength of foamed concrete can be determined by various mix design based on quantity or material used such as cement, aggregate, fillers and volume of entrained foam (Aldridge, 2005) as shown in Table 2.5. A reduction in density exponentially and adversely affects the compressive strength (Cong & Chen, 2015).

Table 2.5: Typical foamed concrete properties (Cong & Chen, 2015)

Dry density (kg/m ³)	Compressive strength (N/mm ²)
400	0.5 - 1.0
600	1.0 - 1.5
800	1.5 - 2.0
1000	2.5 - 3.0
1200	4.5 - 5.5
1400	6.0 - 8.0
1600	7.5 - 10.0

The other factors that influence the strength of foamed concrete are water-cement (W/C) ratio, sand-cement ratio (S/C), type of cements and content, air-void size and distribution, type of surfactants (forming agents) and curing regime. Research has shown that an increase in water/cement ratio resulted in a decrease in the compressive strength of concrete (Apebo & Shiwua, 2013). Additionally, the increase in sand fines content has also been found to decrease the compressive strengths of normal concrete (Cho, 2013). While

higher cement position in the mixture, it will lead to the increase in compressive strength but it is not economical. In order to reduce the cement use with the target strength, fly ash will be added in the mixture with a maximum of 35% of the cement weight (NPCA, 2010) Table 2.6 shows the summarization of S/C, W/C and fly ash-cement ratio (F/C).

Table 2.6: Summarization of S/C, W/C and fly ash-cement ratio (F/C).

Researcher	Proportion of cement (kg/m ³) or composition	Ratios			Density range kg/m ³	Compressive strength (28 days) N/mm ²
		Sand/ Cement	Water/ Cement	Fly Ash/ Cement		
Van Deijk (1991)	Cement-sand/ fy ash	-	-	-	280-1200	0.6-10.0 (91 days)
Durack and Weiqing (1998)	270-398	1.23-2.5	0.61-0.82	-	982-1185 (DD)	1.0-6.0
	137-380	-	0.48-0.70	1.48-2.50	541-1003 (DD)	3.0-15.0 (77 days)
Kearsley and Wainwright (2001)	Cement-fly ash Replacement 193-577	-	0.6-1.17	-	1000-1500	2.0-18.0
Jones and McCarthy (2005)	500	1.5-2.3	0.3	-	1400-1800	10.0-26.0
	500	-	0.65-0.83	1.15-1.77	1400-1800	20.0-43.0
Nambiar and Ramamurthy (2006)	Cement-sand mix (coarse)	With filler-cement ratio varied from 1 to 3 and fly ash replacement for sand varied from 0% to 100%			800-1350 (DD)	1.0-7.0
	Cement-sand mix (fine)					2.0-11.0
	Cement-sand fly ash mix				650-1200 (DD)	4.0-19.0

DD: Dry Density

There are few factors that will affect the compressive strength, such as quality of raw materials, water/cement ratio and curing of concrete.

- i. Cement: Provided the cement conforms to the appropriate standard and it has been stored correctly (i.e. in dry conditions), it should be suitable for use in concrete.

- ii. Aggregates: Quality of aggregates, its size, shape, texture, strength etc. determines the strength of concrete. The presence of salts (chlorides and sulphates), silt and clay also reduces the strength of concrete.
- iii. Water: Often, the quality of the water is covered by a clause stating “..the water should be fit for drinking..”. This criterion though is not absolute and reference should be made to respective codes for testing of water construction purpose.
- iv. The relation between water cement ratio and strength of concrete is important. The higher the water/cement ratio, the greater the initial spacing between the cement grains and the greater the volume of residual voids not filled by hydration products. The workability of the concrete is reduced if the water/cement ratio is reduced. A lower water cement ratio means less water, or more cement and lower workability. However if the workability becomes too low the concrete becomes difficult to compact and the strength reduces. For a given set of materials and environment conditions, the strength at any age depends only on the water-cement ratio, provided full compaction can be achieved.

c. Workability

Nabilah & Cher (2016) mentioned a slump 20 cm – 24 cm in workability value is recommended to produce foamed concrete. However, in view of too many variable such as, source of material, foam agent, mix proportion etc., it is difficult to determine a good workability for foamed concrete. Tan et al. (2017) had mentioned as long as foamed concrete can perform self-compacting, the workability is suitable for the mix. Hence, it is important to study the fresh foam concrete spread ability and flowability to perform self-compatibility.

The amount of foam and w/c in the mix is the main factor that influence the workability. The appropriate and constant ratio between the foam, w/c and base mix is call consistency of base mix. Nambiar and Ramamurthy (2006) mentioned that the design density is achieved only at a particular consistency of the base mix. Consistency values either lower (mixture is too stiff causing the bubble to break) or higher (slurry becomes too thin to hold the bubbles resulting in segregation) than this value leads to an increase in density. Thus the “stability of foam concrete”, is the state of the mix at which the density ratio is closer to unity.

From the above, it is evident that the fresh foam concrete is influenced by the foam volume and water-cement ratio with other solid ingredients in the mix. Hajimohammadi et al. (2018) mentioned addition fillers like quarry dust and fly ash will change the foamed concrete quality. Hence the consistency of base mix will change with the influence of composition like filler-cement ratio, fly ash replacement level, water-solids ratio and foam volume. Thus, the appropriate workability values for foam concrete mix are also changed.

Jones and McCarthy (2005) mentioned the consistency of fresh foam concrete involves measurement of spread ability and flowability. Jones et al. (2003) used the Brewer spread test and slump flow test as per BS 4551-1 and Kearsley and Mostert (2005) used the ASTM flow table for hydraulic cement for measuring spread ability.

d. Water Absorption

The transport of aggressive liquids into concrete depends on its permeation characteristics, like permeability, water absorption and sorption. The volume of air-voids directly influences the volume of water absorption of foamed concrete. Water absorption did not react with all voids of foamed concrete because not all of them are interconnected due

to the air being trapped and sealed into the entrained air voids. The difference in water absorption is in response to the densities, where low density will give higher water absorption that is caused by the addition of the foam into the foamed concrete (Richard & Ramli, 2015).

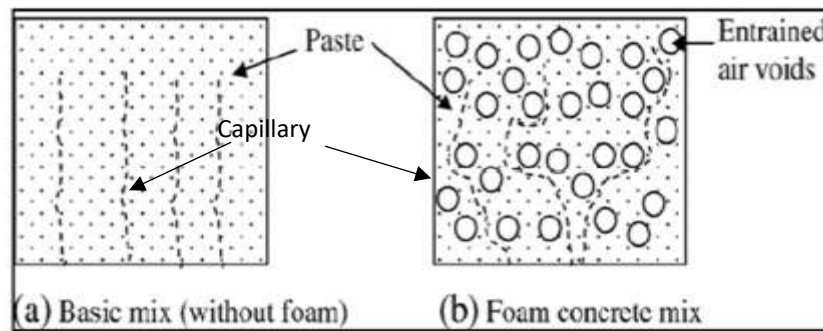


Figure 2.22: Advancement of water into the base mix and corresponding foamed concrete (Nambiar & Ramamurthy, 2006)

Figure 2.22 explained that water absorption is the process of water filling into the air voids by capillary or forced by water pressure. The type of filler influences the absorption of water, such as fly ash that gives a lower range of water absorption percentage because lesser foam volume is needed to achieve the target density. Researchers have proven that fly ash could decrease the percentage of water absorption of foamed concrete (Nambiar & Ramamurthy, 2006). In some cases, the small particles like fine sand or fly ash seal up the air-void wall structure and retard water movement into the closed bubbles structures then reduce the level of water absorption.

2.8 Drying Shrinkage

The volume of foamed concrete will change from fresh to harden (drying shrinkage) as a result of moisture loss during hydration process by removal of absorbed water from the

surface of gel pores (Neville 2010). Foamed concrete possess high drying shrinkage due to the absence of aggregates, up to 10 times greater than normal concrete (Valore, 1954; Jones et al., 2003). Significant reduction in shrinkage is predominantly a function of the physical structure of the hydration product (Ramamurthy & Narayanan, 2000). While Tada and Nakano (1983) attribute the higher shrinkage in aerated concrete to its larger volume of finer pores, Ziembicka (1977) and Georgiades and Ftikos (1991) have related shrinkage to the volume and specific surface of micropores. Schubert (1983) related shrinkage to volume of pores affecting shrinkage, pore distribution and moisture content.

In a comparative study on the shrinkage behaviour with sand and fly ash as filler, mixes with sand exhibited smaller drying shrinkage as the sand particles have higher shrinkage restraining capacity compared to fly ash particles (Jones et al., 2003). Nmai et al. (1997) in a study on new foaming agent for CLSM applications indicated a reduction in shrinkage as density decreases. In addition lightweight aggregate could be used to reduce the shrinkage of foam concrete (Regan & Arasteh, 1990).

2.9 Advantage of Foamed Concrete

Lightweight foamed concrete is a low-density material. It is widely used in load reduction method due to its lightweight nature, easy to install and economical. It has high workability and a self-compacting material, where no vibration is required during concreting. It is excellent in fire resistance, thermal insulation and acoustic, where heat energy and sound wave are diffused much slower in the medium of air porous structure compared to solid state (Kim et al., 2011). Besides that, foamed concrete is a non-hazardous material and reliable quality control and easy to reproduce.

2.10 Disadvantages of Lightweight Foamed Concrete

It is very sensitive to water content in the mixtures. Besides, it is also very difficult to place and finish because of its porosity and easy segregation. In addition, the mixing time is longer than conventional concrete to assure proper mixing. The main disadvantage of foamed concrete is the inability to take consistent compressive strengths and density for all time (Neville, 2010).

2.11 Application of Lightweight Foamed Concrete

Generally, the application of lightweight concrete depends on its density. Lightweight foamed concrete is commonly used for constructions, houses, highway constructions, blinding, void filling, footing, tunnel lining, trench reinstatement, roof insulation and others. Table 2.7 shows the summary of the most common application based on varying density.

Table 2.7: Application of foamed concrete based on varying density (Neville, 2010)

Density (kg/m ³)	Application
300-600	Lightweight and insulating cements for floors foundation, for heating insulation and slope for flat roofs, rigid floor foundation, tennis courts foundation, interspace concrete filling, raceways insulation, thermos insulating blocks, steel structures fireproofing, tunnels and pipelines compensating mass, dump's foundation and covering land reclamation and consolidation underground cavities infill and all types of infill where an elevated thermal insulation is required.
600-900	Stables foundation, industrial foundations, partition and tamponing slabs, ceiling slabs, concrete + lightweight concrete mix panels.
900-1200	Blocks for outside walls, slabs for foundation, concrete and lightweight concrete mixed panels for covering, foundations for elastic floors.

Table 2.7 continued

1200-1700	Prefabricated panels for civil and industrial buildings such as plugging, wall casting, gardens ornaments.
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2.12 Summary

This chapter has discussed the ground improvement and load reduction method, which also described the advantages and disadvantages of each method. Overall, this research is a focus on the use of foamed concrete as fill material because it is easy to obtain the materials, produce, install, cheap and durable. Chapter 3 will further elaborate further on the characteristic of foamed concrete.

2.13 Gap Analysis

This study is important in applying the foamed concrete material in soft ground construction to solve the settlement and stability problem. It is important to fill the gap for conventional method to lightweight foamed concrete method such as:-

- a. Review the soil replacement method.
- b. Reduce the replacement fill material load.
- c. Reduce the settlement of foamed concrete embankment in an acceptable range.
- d. Transfer the laboratory mixing technique to industrial mixing technique.
- e. Minimize the dry shrinkage of foamed concrete.

There are a few methods of producing foamed concrete precast foundation and applying to project site to study the behavior of foamed concrete react to soft ground. At the end of the study, the result could determine the feasibility of foamed concrete foundation or road embankment to replace the unwanted soft ground and support the traffic load above it.

CHAPTER 3

EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 General

As elaborated in Chapter 1 and Chapter 2, this research study is to achieve the replacement of soft soil or peat soil with foamed concrete. This chapter will further explain the method to achieve the target foamed concrete density at $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$, and focusing at $\pm 1000 \text{ kg/m}^3$ to perform the replacement as mentioned in Section 1.6 of Chapter 1. The mix proportion for cement : sand ratio is set at the range of 1:1, 1:2, 1:3 and 1:4. The reason for this density and mix proportion range will be explained in Section 3.2.1.

This research study involves three (3) phases, which is laboratory, industry and field phases. Phase1 involves laboratory experiment mainly to address research objective of Section 1.9(a) for the optimum density and mixing technique. This involved study the behavior of the foamed concrete material and to determine its technical parameter e.g. density, workability, compressive strength in varied mix proportion with or without additive, percentage of water absorption, shrinkage of foamed concrete and others. Phase 2 is to address research objective as mentioned in Section 1.9(b) to produce foamed concrete in mass volume at industry level or concrete batching plant and achieve the minimum shrinkage. Phase 3 is regarded to Section 1.9(c) as field experiments, which is to study the application of foamed concrete as fill material for the road embankment. This phase is to understand the application of foamed concrete against the loading for vehicle, pavement and self-weight in against settlement.

3.2 Research Methodology

Figures 3.1, 3.3 and 3.4 elaborated three (3) phases of experiment that is focused in this research and each phase has been carried out in five (5) stages. This specific experimental program is only for the innovative mixing technique, whereby for the conventional mixing technique, there are no specific experimental program, as the experiment is ad hoc and when necessary only. This section will further elaborate the details in each stages.

3.2.1 Phase 1: Production of Foamed Concrete based on Laboratory Experiments

Section 1.2.1 and 1.2.2 have mentioned the density of soft soil at $2400 \text{ kg/m}^3 - 2600 \text{ kg/m}^3$ and density of peat soil at the range $1300 \text{ kg/m}^3 - 1700 \text{ kg/m}^3$. To perform the replacement by buoyancy or density comparison method, the produced foamed concrete density must always be less than the existing soil. With this, the foamed concrete density is determined at the range of density at $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$, which is good enough as a safe range for the design of foamed concrete embankment later. As the optimum mix proportion for producing foamed concrete is unknown, the range of mix proportion cement to sand ratio at 1:1 to 1:4 has been chosen, as for normal concrete it is believed that a mix proportion after 1:4 is difficult to mix due to it having too much sand and result in low workability, has less strength and is fragile. This phase will also determine a better mixing technique compared to mixing technique that was described by Jalal et al., (2017) in Section 1.8 and Lai (2011). Data for strength, shrinkage, workability, volume will be collected in this phase and analysis of the relationship of density to the data collected will be discussed further in Chapter 4. Further relationship on additional admixture such as polyvinyl alcohol, paraffin oil, quarry dust will be discussed in Chapter 5.

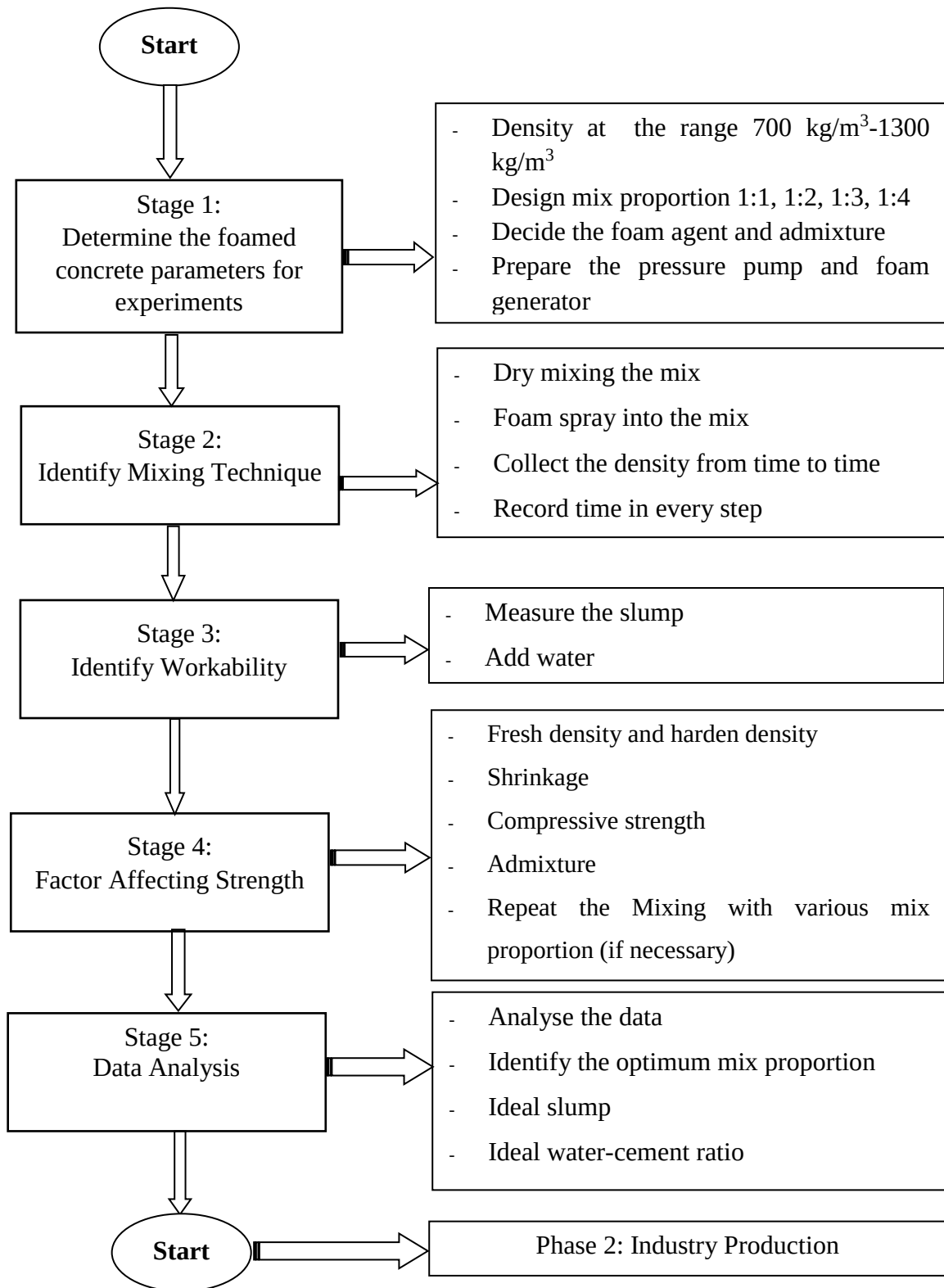


Figure 3.1: Laboratory experimental program

a. Phase 1: Production of foamed concrete based on laboratory experiments

In this phase, numerous numbers of mixes had been conducted in the laboratory in order to produce the foamed concrete to be used on site. A similar method of mixing will be used to produce mass scale production in the factory. Targeted properties of the foamed concrete are based on four (4) criteria as follows:-

i. Density shall be in the range of $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$

As explained in Section 3.2.1, density is the most important criteria in the design. The density of peat is about 1300 kg/m^3 , so the density of foamed concrete must be less or the same as this value. Therefore, the density of foamed concrete must be targeted in between $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$. A density lower than 700 kg/m^3 will be very difficult to achieve and the strength value will be too low.

ii. High workability with Slump in 13 - 16 cm

There is no standard on the workability range for foamed concrete, as it is based on the performance of self-compacting, which it could placed and consolidated homogeneously to fill up the forms completely without extra moisture leaked away. The moisture and the size of the sand material and water – cement ratio is much affecting by the workability. This criteria is measured based on mini slump cone test. Based on previous study by Lai (2011), a slump value of 13 - 16 cm can be performed well on self-compacting ability. However, Nabilah and Cher (2016) recommended a slump at the range of 20 - 24 cm.

iii. Minimum compressive strength at $1 - 3 \text{ kN/m}^2$

Strength is another challenge in the laboratory phase. The use of foam in foamed concrete will lower the strength by increasing the percentage of voids. In the design of foamed concrete as fill material (road embankment), the foamed concrete is not required to

have a high resistance on load bearing as normal structural concrete, where 1 kN/m^2 is considered adequate. The requirement of $1 - 3 \text{ kN/m}^2$ is based on compressive strength comparison, which 1 kN/m^2 is much better than compacted compressive strength for subgrade soil.

The strength at the density range of $700 \text{ kg/m}^3 - 1300 \text{ kg/m}^3$ shall be at least 1 kN/m^2 , additional material like quarry dust and admixture needed to improve the strength if necessary. The purpose of adding material and admixture is to enhance the physical property of the foamed concrete. The recommended admixtures to be used in this research are polyvinyl alcohol (PVA) and paraffin oil (GTL). These admixtures are targeted to increase the strength of the foamed concrete by its own functioning, such as filling up the air-void, reducing the water/cement ratio of the designed mix and etc.

iv. Segregation

Since foamed concrete uses foam in mixing, and it is the lighter ingredient in the mix, any error in production such as water – cement ratio and mixing technique will end up with a segregated mix. A correct mixing technique must be used to produce a non-shrinkage harden foamed concrete.

v. Low shrinkage

Shrinkage is happened due to the losses of moisture during hydration, which not from segregation. In order to ensure the foamed concrete harden in a good shape, the limitation of shrinkage for foamed concrete shall be set. As targeted in research objective in Section 1.9(b), shrinkage shall not be more than 2.0% of foamed concrete sample depth.

b. Improvements in mixing technique

Foamed concrete consists of three (3) basic elements which are cement, sand and foam. The technique of mixing plays a very important role in achieving a good foamed concrete. The sequence of mixing has been the most important technique to consider in produce the desirable foamed concrete.

Preforming method (Pugh, 1996) explained the foam and base mixture (cement and sand and/or fill material) are prepared independently, then mix it together in mixer and add in water. This statement has not clearly described the sequences of mixing. Jalal et al., (2017) have described the mixing sequence and Lai (2011) had explained more on the sequence of mixing as shown in Figure 3.2 that has been used to produce foamed concrete. The dry concrete mix consist of cement and sand constituents for a few minutes and water is added in and they are thoroughly mixed. Then foam is added to the wet slurry and ensure foam has been completely mixed with the mortar until the required density. However, the main problems with this technique is segregation or shrinkage of foamed concrete. This will be further elaborated in Section 4.3.

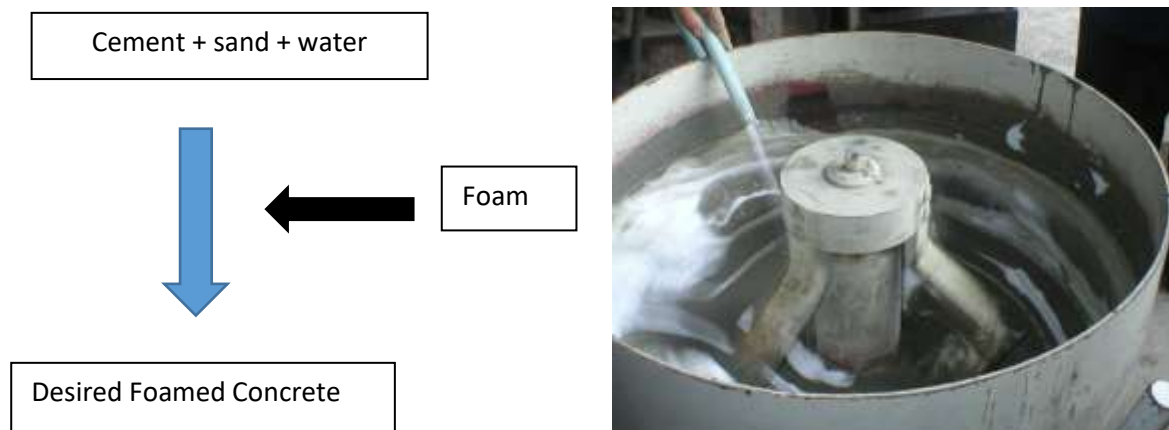


Figure 3.2: Sequence of conventional mixing for foamed concrete

As mentioned in Section 3.2.1 (a-iv), this research study needs to come up with a correct mixing technique to solve the segregation or shrinkage problems. Coincidentally, after a few trial and error mixing tested in the laboratory, a new sequence of mixing is developed using the similar equipment and material. Foam is added into the dry mix to achieve the density followed by water for achieving the workability. This technique is namely new mixing technique or innovative mixing technique.

In this new mixing technique, it is assumed that the moisture provided by the foam itself is sufficient for the hydration process of the dry mix, the dry mix is blended homogeneously with foam to expand the volume of foamed concrete to achieve the target density by ignoring the presence of extra water.

As mentioned in Section 3.2.1 (a-iv), foamed concrete shall having high workability. By this, extra water is added to enable the foamed concrete flow with a great distance in order to perform self-compacting during casting. Based on this, water will only be added after the cement, sand and foam had been homogeneously mixed inside the mixer. Chapter 4 will further discuss the production of foamed concrete by using new mixing technique

c. Target research objective on phase 1

To pursue the research objective, a comprehensive experiment in laboratory based on experimental program in Section 3.2.1 was devised. It was a systematic approach towards achieving several research objective in the work. Table 3.1 shows the laboratory experimented program drafted for this phase.

Table 3.1: Experimental Program in Phase 1

No.	Research objective	Parameters	Values
a.	New mixing technique (Refer Section 1.9a)	Sequences of mixing	To easily reach the density, strength, segregation and shrinkage targeted as in (b), (c) and (e) in this table.
b.	Investigate foamed concrete density (Refer Section 1.9a)	Mixing routine	Density range 700-1300 kg/m ³ , focusing at density at 1000 kg/m ³
c.	Optimum compressive strength (Refer Section 1.9a)	Compressive strength	1 – 3 kN/m ²
d.	Investigate workability (Refer Section 1.9a)	Slump	13 – 16 cm
e.	No segregation and minimise shrinkage (Refer Section 1.9b)	Segregation Percentage of shrinkage	0% 2.0 % of the sample depth

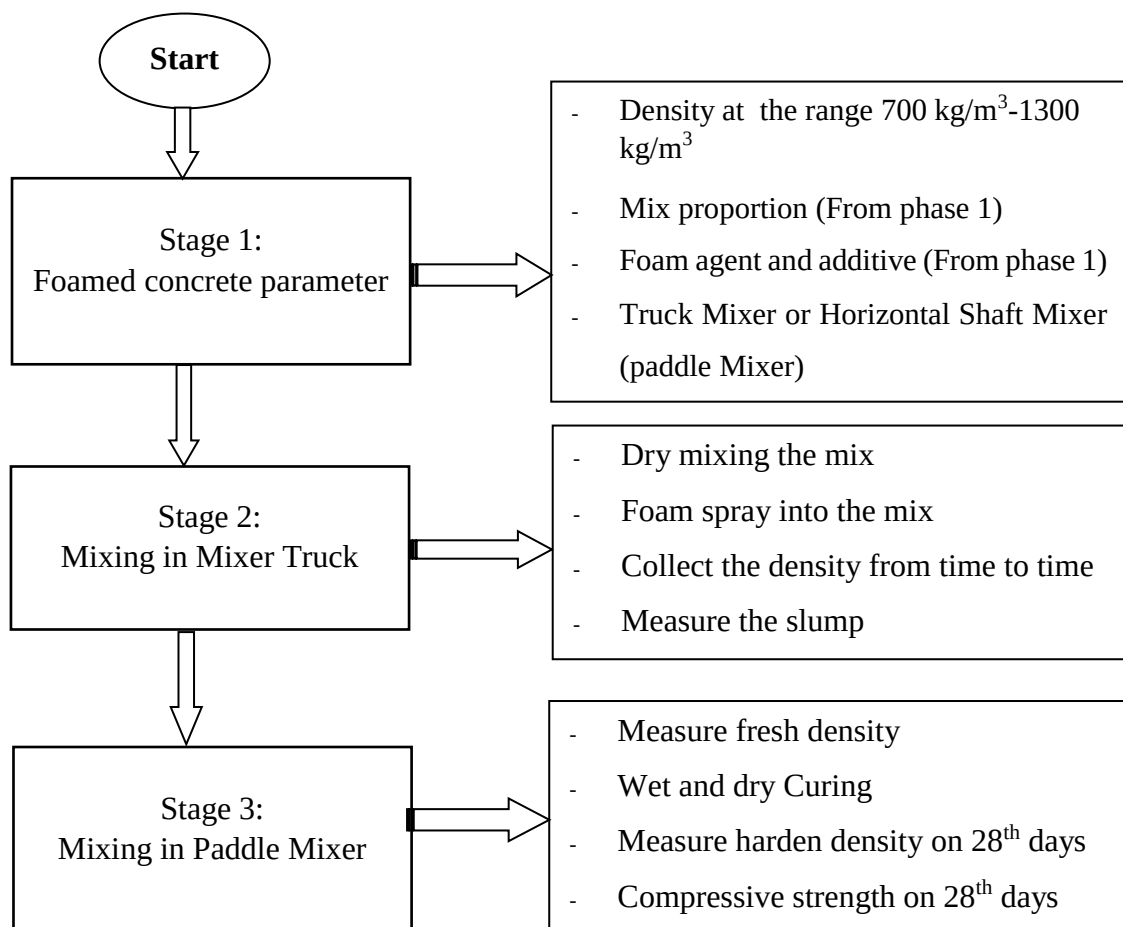
There are five (5) experiments as listed below to investigate the compressive strength of the foamed concrete. The aim of this experiments is to study the foamed concrete from weakness to strength:-

- a) Foamed concrete without admixture.
- b) Foamed concrete without admixture plus quarry dust.
- c) Foamed concrete with polyvinyl alcohol (PVA).
- d) Foamed concrete with paraffin oil (GTL).
- e) Foamed concrete with paraffin oil plus quarry dust.

However the laboratory experiment is only suitable for small scale production with less than 100 litres of foamed concrete. The experiments and result will be further elaborated in Chapter 5 and Chapter 6.

3.2.2 Phase 2: Industry Production for Big Volume Mixing at Industrial Level (Concrete Batching Plant/ Factory)

Phase 2 is the continuing experimental program from Phase 1 at industrial level as shown in Figure 3.3, where big volume of foamed concrete will be produced. In this phase, the data from Phase 1 will be adopted and some are modified to obtain a good quality foamed concrete e.g. density, workability, strength, shrinkage, volume and water absorption to be applied on pilot project site. The mixing machinery has also been investigated for the best production. Same as phase 1, data for strength, shrinkage, workability, volume will be collected on this phase and analysis of the relationship of density to the data collected will be further discussed in Chapter 6. The final information will be analysed and used in pilot project in Phase 3.



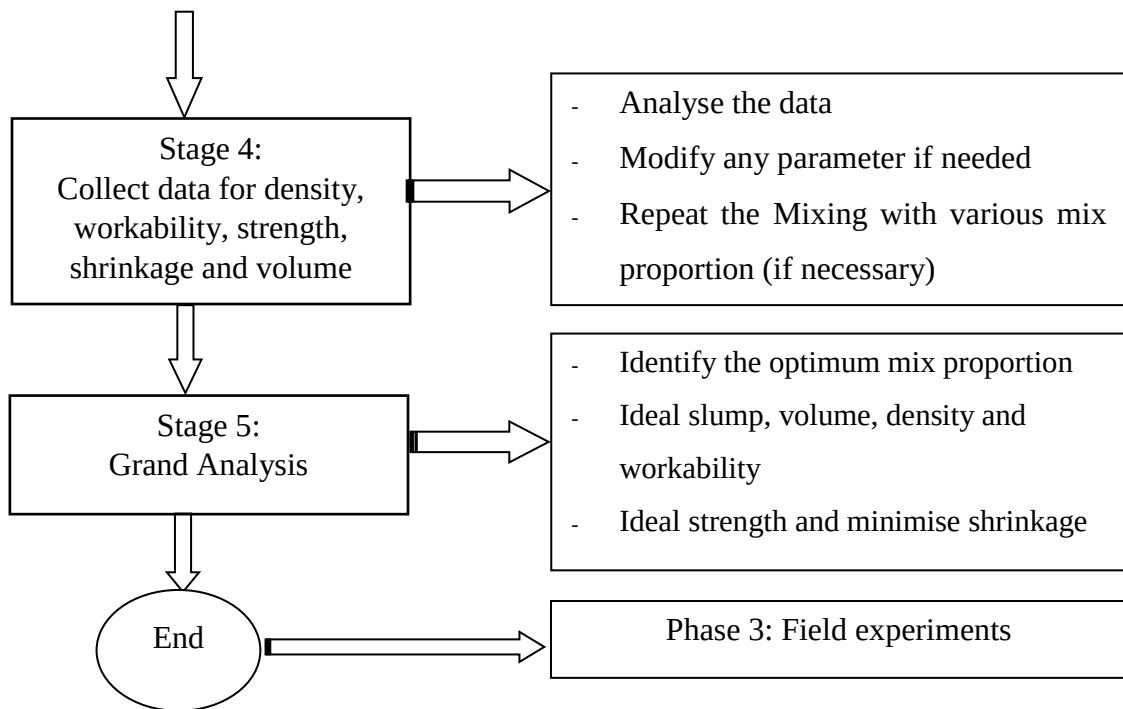


Figure 3.3: Industrial production experimental program

a. Phase 2: Industry Production for Big Volume Mixing

Big volume mixing for more than 100 litres foamed concrete in factory needs to be investigated to understand the feasibility of product foamed concrete that uses the same method for small scale production. There are two (2) methods conducted for big scale mixing as described in Table 3.2:-

- i. Mixer truck mixing.
- ii. Horizontal shaft mixer/ bladder mixer.

Table 3.2: Experimental Programme in Phase 2

Activities	Parameters	Values	Research objective
Ready mixer truck	Mix proportion	S:C ratio at 1:2	
	Density	1000 kg/m ³	Investigate foamed concrete density, optimum compressive strength, Investigate workability, Investigate dry shrinkage
	Volume	5 m ³	
	Strength	3 MPa	
	Workability	14-19 cm	
	Shrinkage	2.0%	
	Segregation	Zero segregation	
Horizontal shaft mixer	Mix proportion	S:C ratio at 1:2	
	Density	1000 kg/m ³	Investigate foamed concrete density, optimum compressive strength, Investigate workability, Investigate dry shrinkage
	Volume	5 m ³	
	Strength	3 MPa	
	Workability	14-19 cm	
	Shrinkage	2.0%	
	Segregation	Zero segregation	
Large size of moulds	Moulds sizes	750 × 750 × 1500 mm	
	Segregation Percentage of Shrinkage	Zero segregation 2.0%	Investigate dry shrinkage

The experimental results will be further elaborated in Chapter 6.

3.2.3 Phase 3: Application and Experiment Foamed Concrete on Construction Field

Phase 3 explains the experimental program of installing the foamed concrete embankment to the pilot project site as shown in Figure 3.4. The aim of this phase is to design the road embankment based on the design procedure. The precast foamed concrete road embankment is casted at the factory and transported to site. The settlement of the road embankment is monitored from the construction until completion.

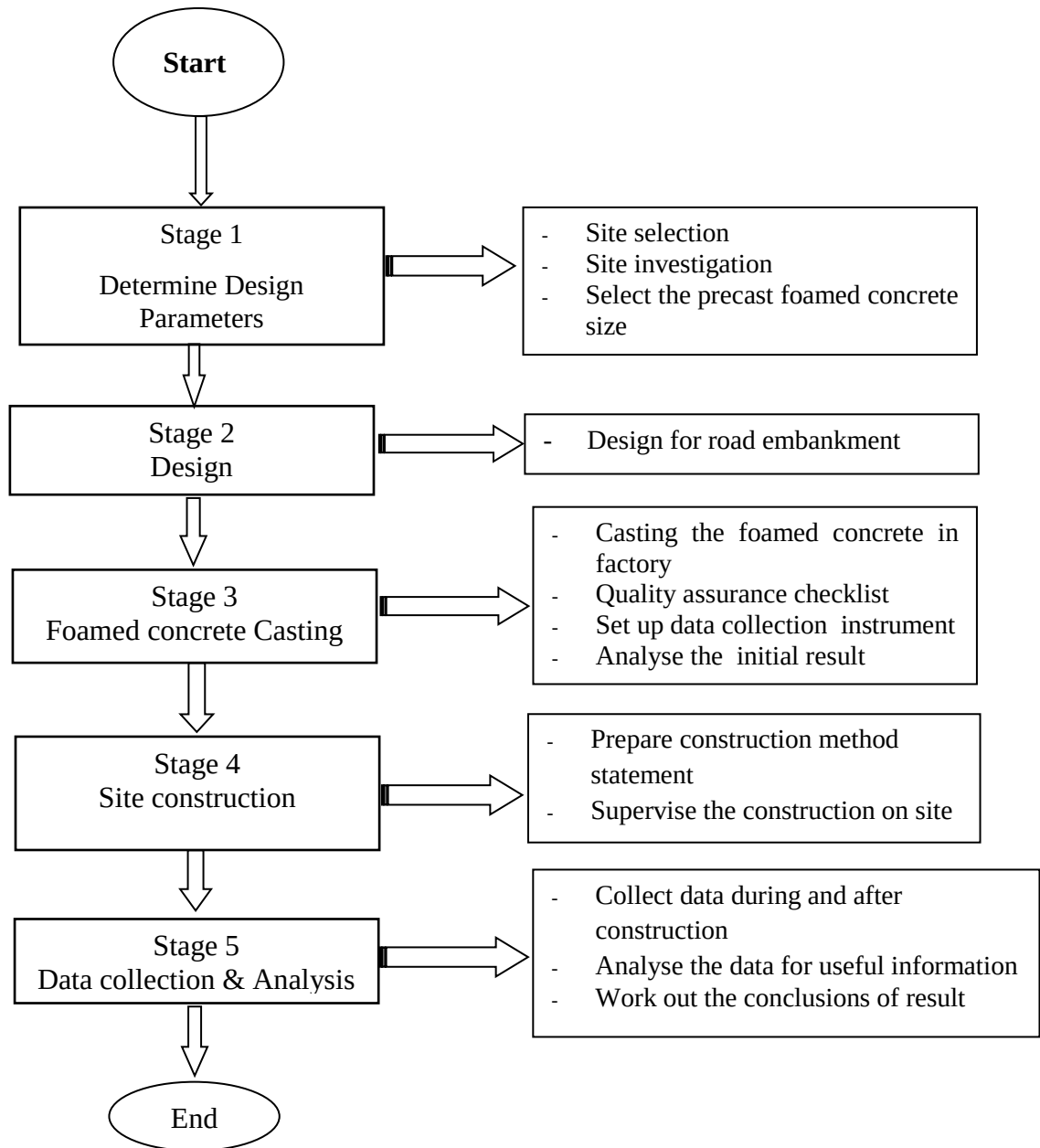


Figure 3.4: Pilot project experimental program

a. Phase 3: Application and Experiment on Foamed Concrete in the Field

Field experiments are conducted following Figure 3.4 to examine the foamed concrete embankment reaction to the soft ground. From the analysis, the researcher will understand the feasibility of foamed concrete used in the road construction. Table 3.3 shows the experimental program related to the research objective.

Table 3.3: Experimental Program in Phase 3 in relation to research objective

No	Activities	Parameters	Values	Research objectives
1.	Site investigation	SPT test or mackintosh probe	Type of soil Density of soil	
2.	Selection and design	Foamed concrete embankment	Size of foamed concrete embankment Density of foamed concrete	To design a road embankment using foamed concrete as fill material (Refer Section 1.9c)
3.	Construction	Constructability	Easy/difficult	
4.	Settlement (Measured by settlement plate)	Settlement of foamed concrete embankment	Control able	To minimize the settlement of foamed concrete road embankment (Refer Section 1.9c)

Settlement is the main issue to be investigated in Phase 3. A number of settlement plates as shown in Figure 3.5 were be installed on pilot project site to monitor the settlement of the foamed concrete embankment.

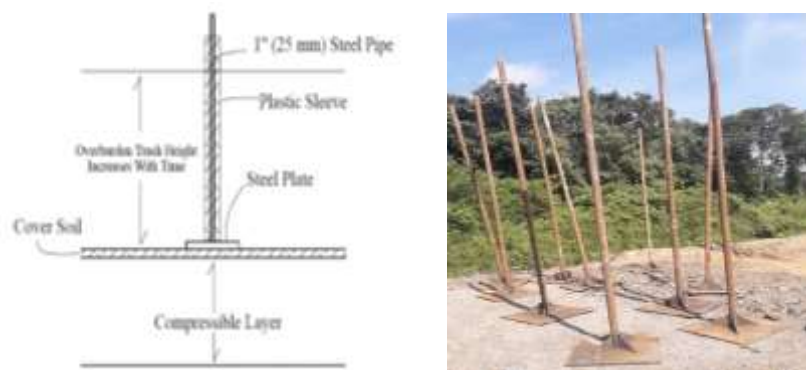


Figure 3.5: Settlement plate

Settlement plates measured at of 300×300 mm should be installed before the filling of the suitable fill material and extended to the road surface by riser pipes, which is protected by PVC pipe cover.

Figure 3.6 shows the settlement plate is installed to monitor the settlement throughout the construction period, the settlement analysis report being produced in weekly or bi-weekly.



Figure 3.6: Monitoring of settlement after reaching the surcharge level by settlement plate (Photo taken at a road construction site at Samarahan)

It is important that the settlement plates be surveyed immediately at the time of installation. The collected settlement data reflects the settlement of the foamed concrete embankment. The settlement results will be further discussed in Chapter 7.

3.3 Design of foamed concrete road embankment

The two (2) methods of the foamed concrete road embankment design are as follows:-

- a. Full Foamed Concrete Method.
- b. Partially Foamed Concrete Method.

a. Full Foamed Concrete Method

Full foamed concrete method is the whole life load (vehicle) and dead load (road pavement, road furniture) calculated to determine the thickness and contact area of foamed concrete as shown in Figure 3.7. The design by Lai (2011) is based on this method.

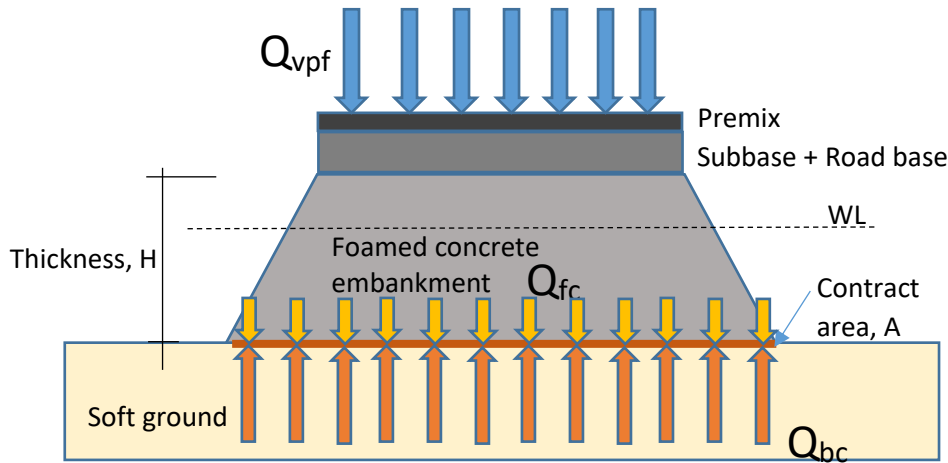


Figure 3.7: Full foamed concrete method

Figure 3.7 explains the calculation as below:-

$$Q_{bc} \geq Q_{vpf} + Q_{fc} \quad (\text{unit kN/m}^2) \quad \text{Equation 3.1}$$

where,

Q_{bc} is bearing capacity of soft ground, the bearing capacity is divided into two:-

- Bearing capacity of soft soil based on site investigation result.
- Bearing capacity of peat is estimated by others researcher finding.

$$\text{Salmah (1992): Bearing capacity, } y = 7.68 + 0.44x \text{ (kN/m}^2\text{)} \quad \text{Equation 3.2}$$

$$x = \text{Water table from surface} \quad y = Q_{bc}$$

Q_{vpf} is total loading for vehicle, road furniture and road pavement (premix, road base and subbase)

Q_{fc} is total mass of foamed concrete road embankment. The total mass of foamed concrete embankment is required to include the total volume of water fill in the air void. This is to estimate the condition of full submerging of the foamed concrete embankment during flooding.

b. Partially Foamed Concrete method

Due to the Full Foamed Concrete embankment method involving big volume of foamed concrete and huge excavation, this method is modified by adding in a floating platform (react as buoyancy force) to reduce the amount of excavation and foamed concrete as shown in Figure 3.8.

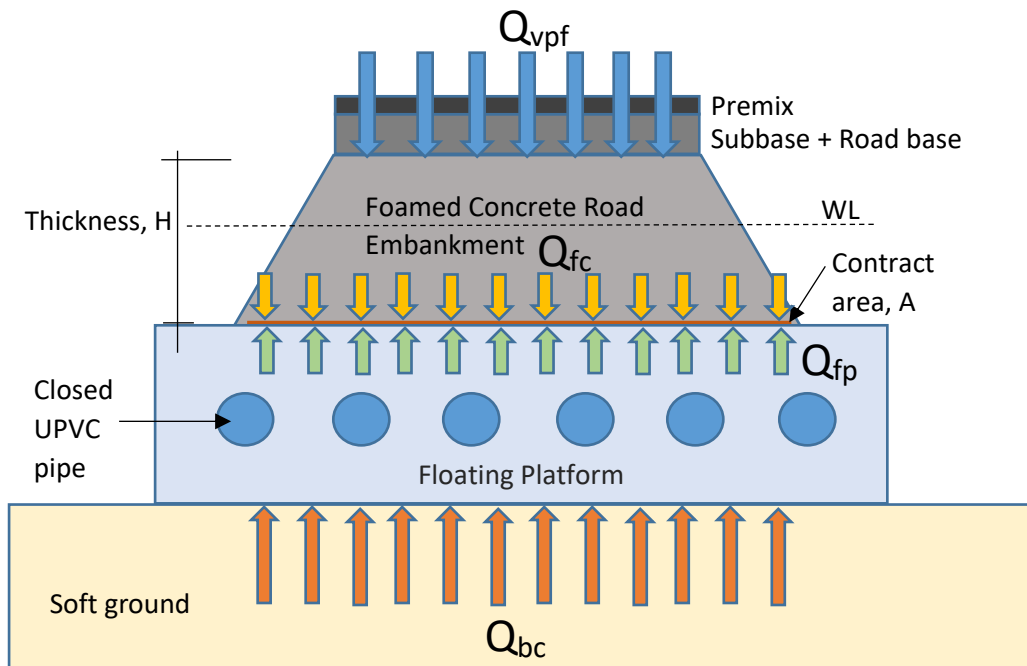


Figure 3.8: Partially foamed concrete method

$$Q_{bc} + Q_{fp} \geq Q_{vpf} + Q_{fc} \quad (\text{unit kN/m}^2) \quad \text{Equation 3.3}$$

where,

Q_{bc} is bearing capacity of soft ground, the bearing capacity of soft ground divided into two:-

- Bearing capacity of soft soil based on site investigation result.
- Bearing capacity of peat is estimated by others researcher finding.

Salmah (1992): Bearing capacity, $y = 7.68 + 0.44x$ (kN/m²) Equation 3.4

x = Water table from surface $y = Q_{bc}$

Q_{vpf} is total loading for vehicle, road furniture and road pavement (premix, road base and subbase)

Q_{fc} is total mass of foamed concrete road embankment. The total mass of foamed concrete road embankment is required to include the total volume of water fill in the air void. This is to estimate the condition of full submerging of the foamed concrete road embankment during flooding.

A proposed road embankment design for this research study will be produced in Section 7.4.

3.4 Equipment used for experiments

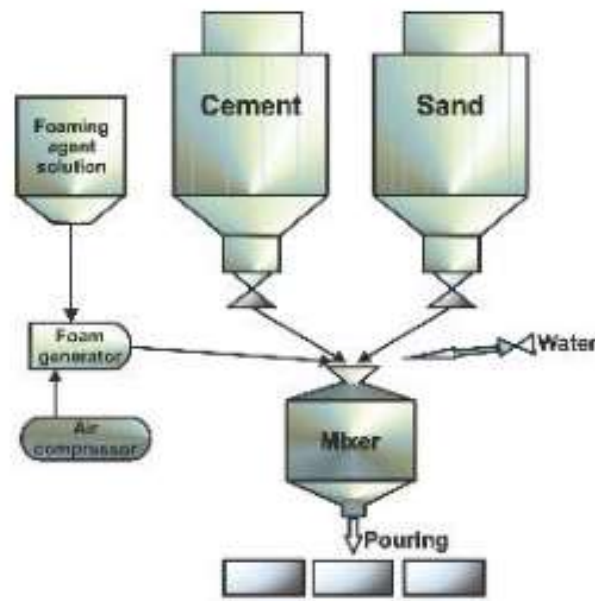


Figure 3.9: Equipment used for experiments

There are few important factors that will affect the quality of the foamed concrete as shown in Figure 3.9 and described as follows:-

a) Air Compressor

Foamed concrete typically has bubbles size from 0.1 mm to 1.5 mm in diameter (Brady & Jones, 2001). An air compressor is the equipment used to compress the diluted foaming agent inside the closed tank turn into bubble. It consists of one number of pressure gauge at each air compressor's pressure and closed tank that is used to measure the pressure. Figure 3.10 shows the air compressor diagram.

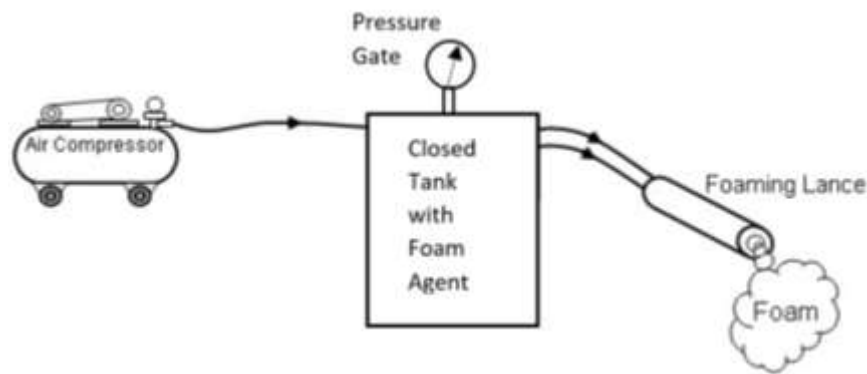


Figure 3.10: Air compressor diagram

Air compressor's pressure is used to control the pressure to the closed tank, while closed tank is used to control the size of the bubble formed from the foaming agent. The pressure for the closed tank is very dependent on the foam agent manufacture details, which normally is not less than 4 bars. Observation from the experiment to the pressure gate at the foam generator is needed if the pressure required for the foam agent is not stated at the technical data. The recommended pressure shall be consistently maintained to produce stable foam bubble. Figure 3.11 show the pressure for a foam generator. Pressure generated from foam generator that is lesser than the required pressure will produce watery foam that can cause the bubble to break easily on the designed mix.



Figure 3.11: Pressure form foam generator

b) Closed tank (Foam Generator)

Foam is produced in a closed tank or foam generator with the size at around 60 liter for laboratory and 1700 litre for factory production. The recommended foam agent water dilute ratio is 1:5 for foam agent softclean AE 27 based on the manufacture details. The water diluted ratio varies for different type of foam agent based on its technical data. It is important to know the volume of foaming agent needed to produce the known volume of foamed concrete for a known density of foamed concrete. The volume of foam is measured based on the height of the foaming agent shown on the plastic tube as the closed tank as shown in Figure 3.12. The recommended diameter of the plastic tube is 10 mm.



Figure 3.12: Equipment used to produce foam and measure the volume of foam

c) **Mini Slump Cone Test**

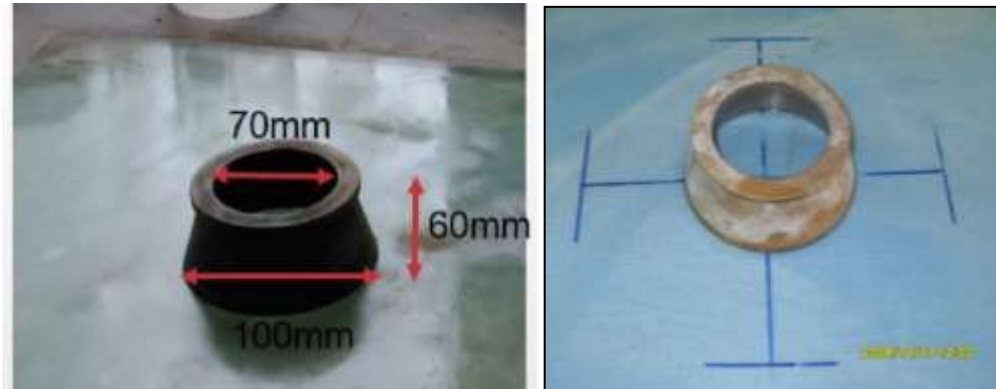


Figure 3.13: Mini slump apparatus

The mini-slump test, originally developed by Kantro (1980), and later modified by Zhor and Bremner (1998), to measure the consistency of flow or workability of self-compacting concrete (SCC). Figure 3.13 shows a mini-slump cone used for mini-slump test. British Standard EN (2016) - slump flow measurement of SCC procedure is used to perform the test, where, the foamed concrete mortar as a type of SCC is filled into the slump cone placed on a flat glass surface, then flattening the mortar surface, before lifting up the cone and leaving the mortar to spread horizontally until it stops as shown in Figure 3.14.



Figure 3.14: Foamed concrete slump measuring

The method of measuring the slump is measured the two diagonal lengths (a and b), then the average figure is taken as the slump of the foamed concrete.

d) Density Measurement

Density of fresh foamed concrete is measured by filling the fresh foamed concrete into the 1000 cm³ plastic cone and then weigh on the scales as shown in Figure 3.15. The density of foamed concrete is simplified to unit kg/m³.



Figure 3.15: Foamed concrete density measurement

e) Curing

Curing is an important process to maintain high moisture and suitable temperature for fresh concrete to ensure hydration process of concrete is continues. Neville (2010) defines curing as procedures used for promoting the hydration of cement and consists of control of temperature and of the moisture movement from and into the concrete. Apart from hardening, curing also minimizes shrinkage and cracking of concrete. Gambhir (1986), defines curing as the process of creation of an environment during a relatively short period immediately after placing and compaction of concrete, favourable to setting and hardening

of concrete. Price (1951) showed that the 28-day compressive strength of concrete cube specimens, continuously moisture cured, had compressive strength 20% higher than those of uncured cubes.

There are two (2) types of curing methods used to cure the fresh foamed concrete, which is wet curing and dry curing. Wet curing involves immersing specimen in a curing tank for compressive test at 7 days and 28 days as shown in Figure 3.16. However, dry curing is the concrete cubes specimens are cure in open air at room temperature for compressive test at 7 days and 28 days.



Figure 3.16: Curing tank

3.5 Materials of Foamed Concrete

As mentioned early in this research study, foamed concrete are set in the range of dry densities (700–1300) kg/m³ and compressive strengths (1–3) N/mm². The compressive strength of foamed concrete formed can be increased by quarry dust, PVA, and GTL, where this increment in strength is to ensure that the foamed concrete is satisfactory to be used for structural applications or load bearing purposes (Karthikeyan et al., 2015). The base material of foamed concrete are cement, sand and water as follows:-

a) Ordinary Portland Cement

Ordinary Portland cement type (I): The chemical and physical properties of this cement conformed to BS-EN 196-1 (2015).



Figure 3.17: Type of cement used in foamed concrete

Figure 3.17 shows the Ordinary Portland Cement (OPC) produced by CMS Cement Sdn. Bhd. under the brand name CMS cement. It complies with MS 522: Part 1: 2007 – CEM 142:5N. It is the most common type of cement used in general concrete construction. All cement from this study is obtained from this source.

OPC is a grey colored powder. It is capable to bond the mineral fragment into a compact whole when mixed with water. This hydration process results in a progressive hardening, stiffening and strength development.

b) Sand

BS 812-103.1:1985 - verifying distribution and particle size is used to verify the natural sand supplied locally to the requirements. The specific gravity of the sand was 2.6.



Figure 3.18: Sieved sand

Figure 3.18 shows the fine sand used in the production of foamed concrete. The dried sand was sieved through a 5 mm sieve in order to remove all unwanted particles before it is stored in the airtight container to prevent atmospheric humidity contact. In order to obtain the best quality of foamed concrete, the recommended sand size to be applied in the designed mix is $0.75\ \mu\text{m}$ as shown in Table 3.4, the light of the sand particle could maintained its floating on the foam and avoiding segregation.

Table 3.4: Results of sieve test of sand sample

Sieve diameter (mm)	Weight retained (g)			Average (g)	% Retained	% Passing
	Sample 1	Sample 2	Sample 3			
1.180	0.00	0.00	0.00	0.00	0.00	100.00
0.600	3.93	4.13	4.39	4.15	2.08	97.92
0.425	38.34	41.72	42.30	40.79	20.39	77.53
0.300	87.91	99.88	99.23	95.67	47.84	29.69
0.150	62.14	47.14	46.83	52.04	26.02	3.67
0.075	6.45	5.86	5.94	6.08	3.04	0.63
pan	1.23	1.27	1.31	1.27	0.63	0
Total	200.00	200.00	200.00	200.00	100.00	

Note: The above sand is provided by UNIMAS laboratory

c) Water

Tap water had been used throughout this study for the production of lightweight foamed concrete. Water is added to ensure the workability of fresh foamed concrete and also for water-cement ratio for foamed concrete. The recommended slump for this study is 13 - 16 cm. So that it can be easily transported, placed and finished without any segregation. The sample of water could be test to ensure it is free from any impurities or other chemicals that can affect the properties of mixtures.

d) Foaming Agent

Foam is a form of stable bubbles produced in foam generator by mixing the foaming agent and water in a specific ratio. The desired density of foamed concrete is governed by the amount of foam added into the cement and sand mixtures. Figure 3.19 shows the foaming agent used in this study.



Figure 3.19: Foaming agent (Softclean 27AE)

In this research, the lightweight concrete is produced using the foamed concrete method, where it is easier to produce and control the quality. The special equipment is also easy to purchase at cheaper cost. A special foaming agent is used in this method. It is aqueous and able to produce air bubbles with a high stability level, resistant to the physical and chemical processes of mixing, placing and hardening. There are two (2) types of foam agents used in this research depending on the size of bubbles to be produced:-

- a. Kao Foam Agent Soft-clean 40AE
- b. Kao Foam Agent Soft-clean 27AE

These foam agent catalogues are shown in Appendix C. Foam agent soft-clean 27AE could produce smaller bubbles compared to foam agent soft-clean 40AE.

e) Quarry Dust

Quarry dust shown in Figure 3.20 can be defined as a by-product of the crushing process during quarrying activity at the quarry site. From the results of the experimental investigation conducted, quarry dust can be used as a partial replacement for fine aggregate which is sand. By replacement of quarry dust, the cost of production can be reduced. In

general, the quarry dust as a sand replacement material shows its mechanical properties could improve the strength for the foamed concrete end product (Lim et al., 2017).



Figure 3.20: Quarry dust used in foamed concrete production

f) Paraffin Liquid (GTL)

According to James (2011) the paraffin liquid is oily, transparent and colourless liquid. It is odourless and colourless at room temperature. James (2011) also stated that the density of the paraffin oil is 800 kg/m^3 . However, when heated it does have a slightly unpleasant petroleum smell. Shell gas-to-liquid (GTL) is a type of paraffin oil, which is colourless and odourless as shown in Figure 3.21. The function of GTL mixed into the foamed concrete is to increase the workability and reduce the water/cement ratio.



Figure 3.21: Paraffin liquid

g) Polyvinyl Alcohol (PVA)

Polyvinyl alcohol as shown in Figure 3.22 is translucent, odourless and it is soluble in water when mixed with hot water (70 to 90 degree Celsius) with proper stirring until it becomes a solution. It is a white colour granular powder. Researchers believe PVA fibres could give higher compressive strength, high elastic modulus and low ductility (Georgiou and Pantazopoulou, 2016) to the concrete. In addition, the PVA fibres also have good chemical resistance, strong corrosion resistance in extreme environments, and high dimensional stability against heat and moisture. The properties of polyvinyl alcohol is shown in Table 3.5.

Table 3.5: Properties polyvinyl alcohol

No.	Particular	Value and Property
1.	Specific Gravity	1.19-1.26
2.	pH	7
3.	Colour	White
4.	Nature	Crystalline



Figure 3.22: Polyvinyl alcohol

3.6 Summary

In conclusion, a series of mixing as shown in Appendix D will be mixing for the foamed concrete study in new mixing technique and the requirements parameter and performance of the foamed concrete for further investigation shall be as the followings:-

- a) Lighter density (700 - 1300 kg/m³).
- b) Slump limited to 13 - 16 cm (small scale).
- c) Minimum compressive strength = 1 - 3 MPa.
- d) Recommended sand size = 0.75 μ m.
- e) Stiff and non-shrink.

However, the performance of the foamed concrete can be further enhanced by adding the additives such as PVA and paraffin oil into the designed mix. This will be further elaborated in Chapter 5.

CHAPTER 4

DETERMING THE OPTIMUM MIX PROPORTION AND MIXING TECHNIQUE

4.1 General

This chapter will further discuss on the mix proportion and mixing technique of foamed concrete as mentioned in Chapter 3. The target of this chapter is to achieve the production method of foamed concrete that can be used for pilot project. The production of foamed concrete must fulfil five (5) main elements, namely density, workability, shrinkage, strength and volume, and also cost effectiveness either in laboratory scale or industrial scale. At the end of this chapter, an optimum mix proportion for foamed concrete will be determined and most importantly is the technique of mixing that allow easy achievement of the two (2) priority elements, which are density and workability. The other three (3) elements will be easier to achieve after the achievements of density and workability.

4.2 Challenge in Mixing Foamed Concrete

The mixing of foamed concrete is not as simple as mixing ordinary concrete. Other than lightweight ingredient such as sand and other filler, the foamed concrete must be homogeneously mixed with air-void (the foam). This is the challenge and effort to ensure homogenous mix during the work to achieve the targeted density and workability.

Foamed concrete is known as a cementitious material at the range of 6% - 35% by volume (Atoyebi et al., 2018) of mechanically entrained foam in the mortar slurry in which air-void are entrapped in the matrix of bubbles produced by suitable foaming agent. According to Van Deijk (1992), the air-voids are initiated by agitating air with a foaming

agent diluted with water. Then the foam is carefully mixed together with cement slurry to form foamed concrete. By this, the technique of mixing plays a very important role in producing a good quality foamed concrete. This chapter will further elaborate the mixing technique and attempt to obtain a better method of mixing.

4.2.1 Factor Affecting Production of Foamed Concrete

There are two (2) factors affecting production of foamed concrete before go deeper into the mixing technique, e.g. closed tank pressure and foam production.

i. Pressure of foam agent inside closed tank

It is known that the closed tank or foam generator pressure is to control the size of the bubble formed from the foaming agent and this pressure is maintained by the air compressor. This is important to ensure the appropriate pressure in the closed tank that could provide the consistent size and stable of foam bubble with consistent volume.

In view the manufacturing details (refer to Appendix C) have only mentioned the cleansoft 27AE foam agent dosage without the closed tank pressure for producing a good bubbles. There are three (3) condition of closed tank pressure been selected for laboratory experiment to determine the good pressure for producing bubbles, which is less than 3 bars, 3 - 5 bars and more than 5 bars. The experiment is conducted and the results are shown in Table 4.1:-

Table 4.1: Effect of foam pressure to foamed concrete

Pressure condition	I	II	III
Condition of foam spraying speed			
	Less than 3 bars (Weak spraying speed)	3 - 5 bars (Moderate spraying speed)	More than 5 bars (Strong spraying speed)
Description	When the pressure of closed tank is less than 3 bars, the speed of foam spray out is weak.	When the pressure of closed tank is at 3 - 5 bars, the speed of foam spray out is sufficient.	When the pressure is more than 5 bars, a stable foam can be produced.
	The foam will separate with water and extra water will leak out from the foam	The foam and water is combined, no extra water will leak out from the foam.	The foam and water is combined, no extra water will leak out from the foam
	-	-	The use of higher pressure often cause mechanical problem with the valves. In few occasion the valve had to be replaced due to faulty parts.

From Table 4.1, pressure of condition II (3 - 5 bars) can provide a satisfactory foam and less maintenance on the equipment. Thus, this research adopts the closed tank pressure at 3 - 5 bars to produce the foam. Figure 4.1 shows the pressure of closed tank is monitored by pressure gauge on the closed tank.

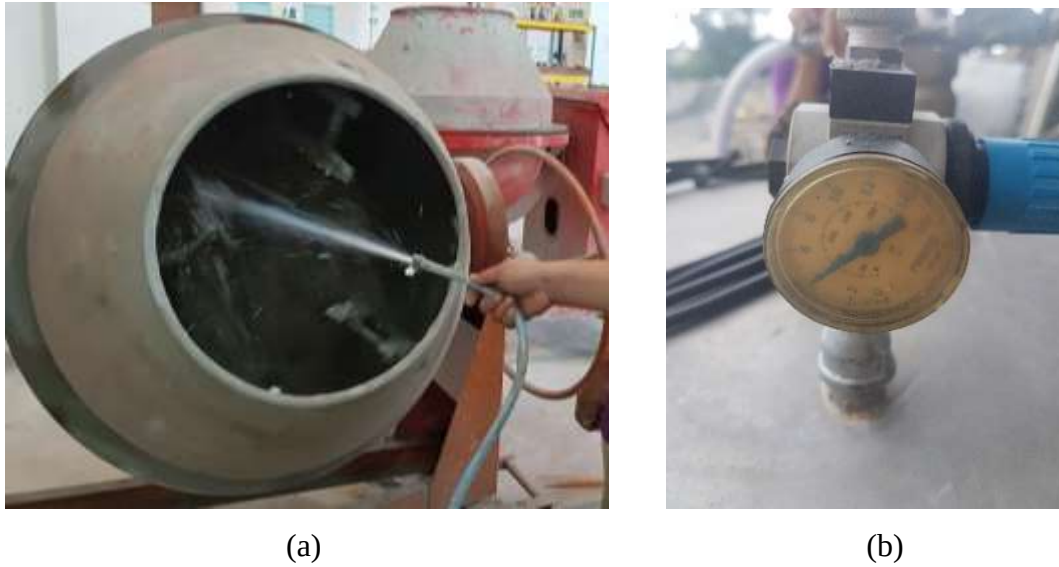


Figure 4.1: (a) Strong pressure foam spread and (b) Pressure gate monitoring

ii. Foam Production

As mentioned in Section 3.5(d), the foam agent is important to the workability of foamed concrete that is presented by slump spread. This dosage and water dilute ratio of foam agent is important to provides a consistent foam bubbles in all mixing, where inconsistent of ratio will affect the workability of produced foamed concrete, thus affecting the quality of five (5) elements of foamed concrete.

The foam agent used is this study is Kao Foam Agent Soft-clean 27AE (refer to Appendix C), the recommended dosage at 0.1 – 0.3 kg used for 100 kg cement but no water dilute ratio is provided. A laboratory experiment is conducted to determine the best water dilute ratio as shown in Table. 4.2. From the comparison of foamed concrete slump (without water-cement ratio) versus different foam agent water dilute ratio, ratio 1:5 could produce a big volume, moderately thick and does not breaks bubble.

Table 4.2: Effect of slump in different foam agent water dilute ratio

Slump condition	I	II	III
Foam agent water dilute ratio	Less than 1:5	1:5	More than 1:5
Condition of foamed concrete			
Type of sump	Not flow and stable	Flow and stable	Flow and watery
Description	To this condition the foam produced consist of moderate volume of foam bubbles but the foamed concrete does not flow due to insufficient water in the diluted foam agent.	To this condition the foam produced consist of big volume of foam bubbles and the foamed concrete could flow due to sufficient water in the diluted foam agent.	To this condition the foam produced consist of little volume of foam bubbles and the foamed concrete could flow more due to too much water in the diluted foam agent.
	The bubble wall is thick and does not breaks.	The bubble wall is moderately thick and does not breaks.	The bubble wall is thin and easy to breaks.

4.3 Mixing Technique

The mixing technique to produce foamed concrete is important to achieve a good production of foamed concrete in the two (2) priority elements; density and workability (include no segregation). There are two (2) mixing technique thus will be elaborated based on the laboratory experiment. The main objective of this section is to understand the mixing technique; the method or sequence of mixing the foamed concrete material. The mix proportion, water-cement ratio and admixture shown in the mixing technique are an experimental example, not the main focus. In a real scenario of foamed concrete production,

the mix proportion, workability and duration of casting will be re-planned based on the foamed concrete end product requirement.

4.3.1 Conventional Mixing Technique

Figure 4.2 shows the details of conventional mixing technique as described in Section 3.2.1(b), which is used in the initial stage of this research. Sand, cement, water and super plasticiser (SP) were mixed prior to adding the foam to produce the foamed concrete to achieve the two (2) priority targeted workability and density. The SP was an admixture used to increase the foamed concrete strength. The work flow is shown in Figure 4.2.

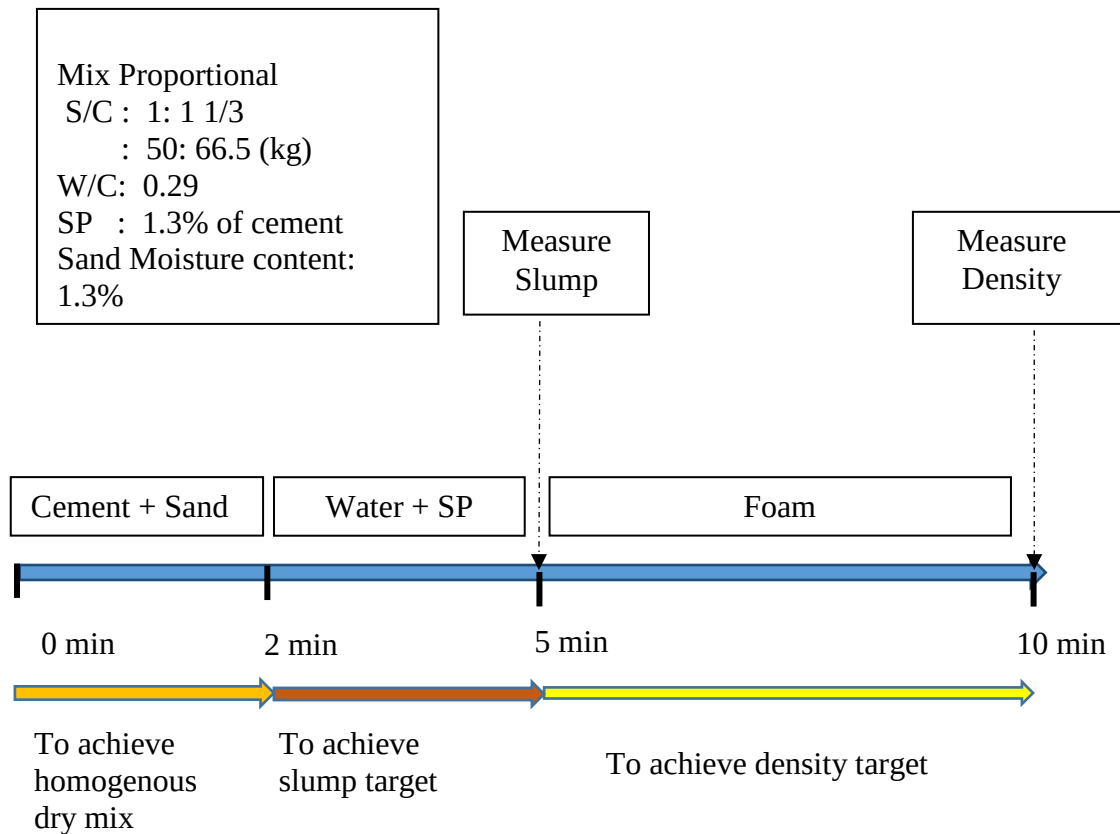


Figure 4.2: Conventional mixing technique

Figure 4.2 describe the conventional mixing technique with its mixing sequence and mixing duration for each stage. There are five (5) stages in the mixing which follow the

mixing sequence and the mixing duration of each stages is based on the duration recorded during experiment. This duration is not a fix figure, where it is changeable and depend much on the design mix e.g. volume, mix proportion, moisture content, target density, target workability etc. for the foamed concrete. In addition, the rotation speed of the drum mixer will also affect the duration of mixing (Hiremath & Yaragal, 2017). Table 4.3 shows the explanation of each stages in the mixing technique.

Table 4.3: Explanation of conventional mixing technique

No	Stages	Description	Duration
1.	Cement + Sand	Cement and sand (dry mix) are mixed inside the drum mixer until homogenous	Recommended 1-2 minutes*
2.	Cement + sand + water + admixture	Water and admixture (SP) is added into the dry mix. The wet mix is mixed inside the drum mixer until becoming homogenous	Recommended 4-6 minutes*
3.	Measure the slump	This stages is to ensure the workability is achieved by adding water slowly until the targeted slump is achieved.	
4.	Cement + sand + Water + admixture + Foam	After the slump is achieved, the foam is added until the targeted density is achieved.	Recommended 4-6 minutes*
5.	Measure the density	The fresh density is measured to predict the hardened density	

Note: * Hiremath and Yaragal (2017)

4.3.1.1 Challenges in Conventional Mixing Technique

Few problems had been identified by using this conventional technique, as discussed in the next paragraph:-

a. Difficulty in Achieving the Targeted Density

Additional foam will reduce the density of the mix, but not all foam bubbles will be turned into air-voids in the solid material. Part of the foam will dilute into the liquid in the cement slurry. It is predicted that more foam needs to be added into the flowable mortar in

order to achieve the targeted density. It would be more challenging to estimate the density at a bigger scale of production. The density will be measured by the method as described in Section 3.5(c) in Chapter 3.

b. Occurrence of Segregation

In the production of foamed concrete by conventional mixing technique, segregation often occurs due to excess moisture from different sources. This caused the segregation between liquid water, foam bubbles and solids fine aggregates, and the surface of foamed concrete will become fragile and has no strength. During segregation, the foam bubbles being the lighter ingredient, have the tendency to move upwards and the heavy material like sand will move downwards. Thus, this separation trends will increase when foam is continuously added into the flowable mortar as shown in Figure 4.3.



Figure 4.3: Foamed concrete with segregation

c. Shrinkage of Harden Foamed Concrete

A problem that often occurs in the production of foamed concrete is the shrinkage of concrete during hardening. The volume of foamed concrete will change from fresh to harden (drying shrinkage) as a result of moisture lost during hydration process.

Figure 4.4 shows most of the foamed concrete samples had shrunk when mixing by using the conventional mixing technique. This can be proven by elaborating the relationship between density and strength as listed in Table 4.5.

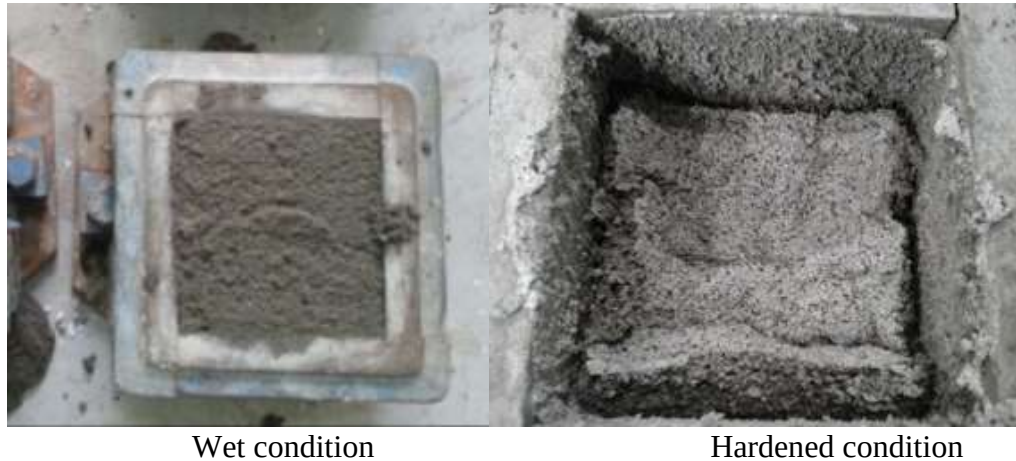


Figure 4.4: Shrinkage occur and volume reduced upon hardening

Shrinkage can be directly measured from the surface of foamed concrete as shown in Figure 4.5 below. Generally, shrinkage of foamed concrete is directly related to the density of foamed concrete due to volume change. The data of shrinkage is taken from the various density of foamed concrete. The shrinkage can be measured from average s from all axis A – A, B – B, C – C and D – D of the cube as shown below:-

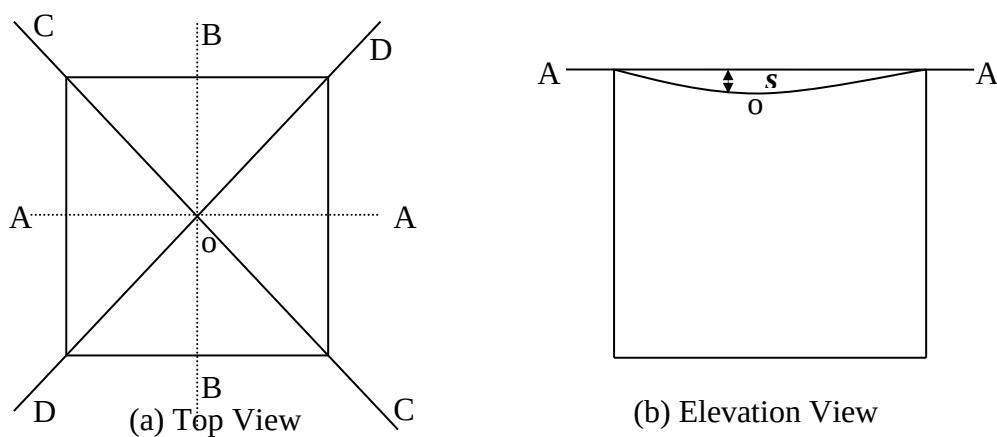


Figure 4.5: Measurement of shrinkage

4.3.1.2 Preliminary Test on Conventional Mixing Technique

The conventional technique is used to mix foamed concrete at low density range of 500-1100 kg/m³. The ingredients requirement is shown in Table 4.4:-

Table 4.4: Mix proportion of conventional mixing technique

Water/cement ratio	Cement ratio	Sand ratio	SP (%)	Foam
0.29	1	1 1/3	1.3	Add until the target density achieved

The foam is continuously added in the mix to achieve the varied density. The shrinkage and strength results were collected and tabled in Table 4.5.

Table 4.5: Shrinkage and strength result for conventional mixing technique

Sample	Density (kg/m ³)	Strength (N/mm ²)	Shrinkage (mm)	Shrinkage (%)
M1-1	516.0	0.00	5.50	3.67
M1-2	550.3	0.00	4.50	3.00
M1-3	589.8	0.00	5.00	3.33
M1-4	595.8	0.00	4.65	3.10
M1-5	642.7	0.00	5.00	3.33
M1-6	646.4	0.00	4.25	2.83
M1-9	674.5	0.20	3.88	2.59
M1-10	671.2	0.00	3.75	2.50
M1-11	735.4	0.15	3.75	2.50
M1-13	807.2	0.00	4.38	2.92
M1-14	832.2	0.15	3.38	2.25
M1-15	851.6	0.35	3.75	2.50
M1-16	986.8	0.27	1.00	0.67
M1-17	991.9	0.04	2.38	1.59
M1-18	997.6	3.81	2.13	1.42
M1-21	1130.7	8.63	0.50	0.33
M1-22	1136.2	9.33	1.00	0.67
M1-24	1151.4	9.15	0.00	0.00

From Table 4.5, there are 24 units of 150 x 150 x 150 mm foamed concrete cube that were taken for shrinkage test, where the shrinkage percentage decreases for density from

500 - 1100 kg/m³ and the highest shrinkage percentage is 3.67%. However the average strength for density below 1000 kg/m³ is almost no strength. Figures 4.6 and 4.7 clarify the relationship between shrinkage and density and strength and density of foamed concrete.

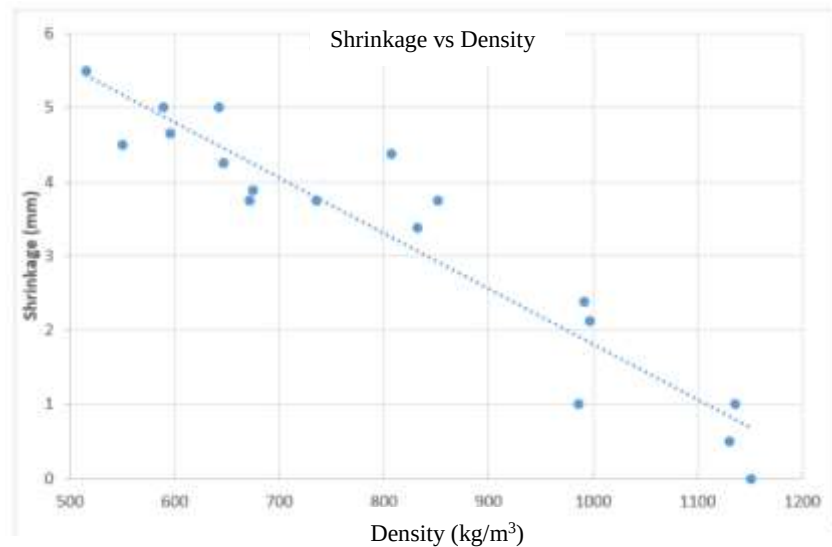


Figure 4.6: Graph of shrinkage vs density of foamed concrete

From Figure 4.6, it is known that the losses of moisture during hydration process (shrinkage) is scattered, however the overall view shows that the shrinkage is directly related to the density, where when the density increased the shrinkage decreased.

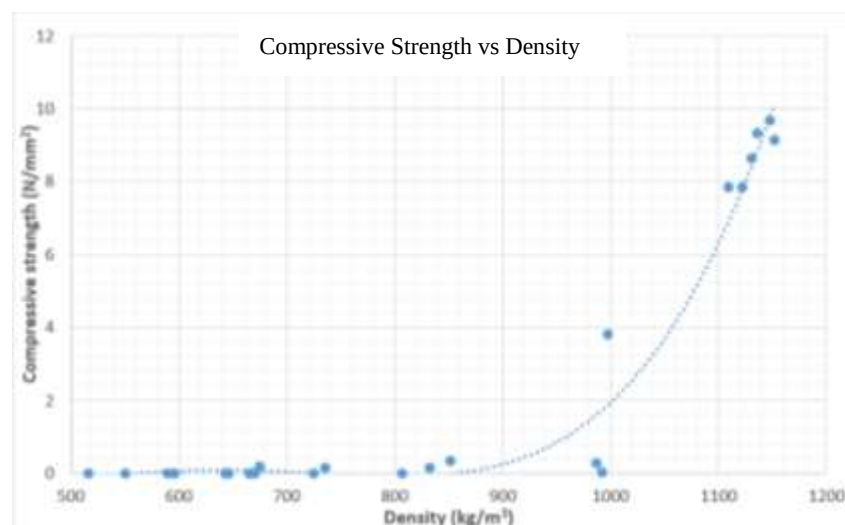


Figure 4.7: Graph of compressive strength vs density of foamed concrete

Figure 4.7 shows the foamed concrete produced by conventional mixing technique has no strength for densities below 1000 kg/m^3 , but the strength is suddenly increased after the density reached 1000 kg/m^3 . This shows that the strength is difficult to achieve if the conventional mixing technique is used for production of foamed concrete below 1000 kg/m^3 .

4.3.1.3 Conclusion on the Conventional Mixing Technique

These finding values for conventional mixing technique are beyond practical sense, where there is no strength for the density below 1000 kg/m^3 . This shows that severe shrinkage will occur at the low density due to high liquid content in the mix. As such, a proper mixing technique is important to be practiced in this research study.

With this, it is proved that the conventional mixing technique is unreliable to achieved targeted density and compressive strength, it only suitable for laboratory experiments (small scale production) with the foamed concrete volume is less than 100 litres only. It is impossible for big scale production by using conventional mixing technique because it is proven difficult to achieve the targeted density and compressive strength due to uncontrolled water in the mix, whereby the particles of the raw materials can be easily submerged due to watery mix and causes segregation. There is a need to review the mixing technique to avoid this segregation and shrinkage problems.

4.3.2 The Innovative Mixing Technique

The previous conventional mixing technique has been discussed on the difficulty to achieve the target density, no segregation, minimize shrinkage and increase the strength. Conventional mixing technique is concluded not recommended for big scale foamed concrete mixing. There are two (2) aspects of mixing that must be considered in order to enhance or modify the conventional mixing technique to new mixing technique, to achieve

the targeted density and workability of foamed concrete. This technique allows the targeted density of foamed concrete to be achieved easily and having an optimum workability.

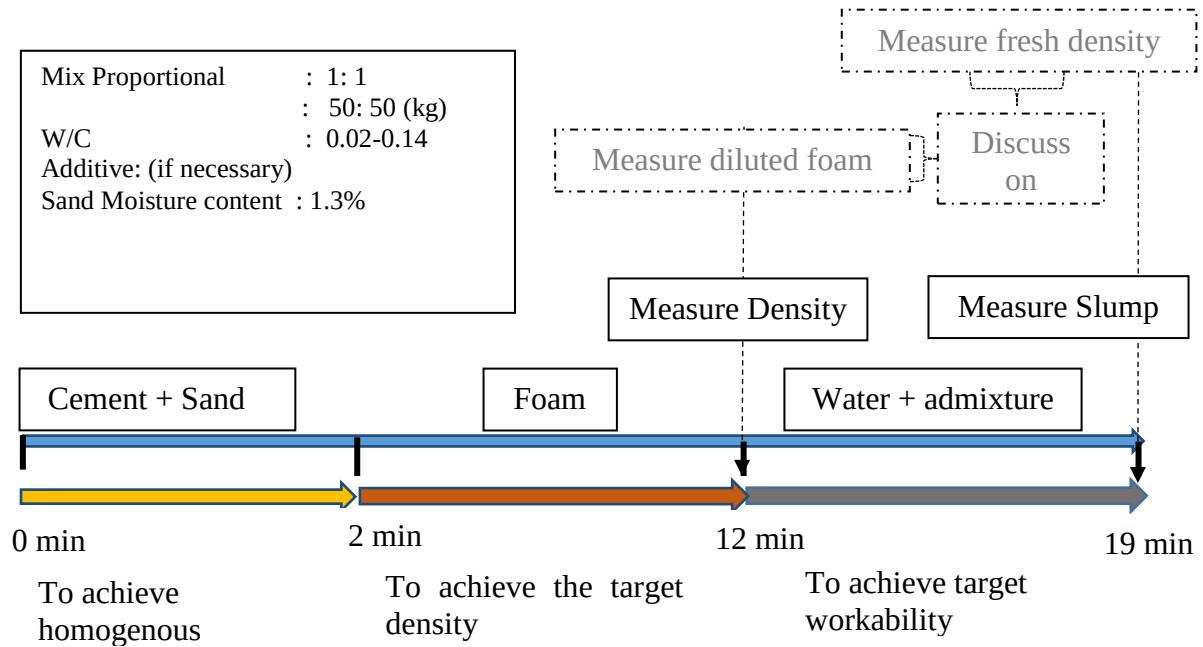


Figure 4.8: Innovative mixing technique

Figure 4.8 describes the innovative mixing technique with its sequence of mixing and mixing duration for each stage. There are also five (5) stages in the mixing according to the mixing sequence and the mixing duration of each stage is based on the duration recorded during experiment. This duration is not a fixed figure, where it is changeable and much dependent on the design mix e.g. volume, mix proportion, moisture content, target density, target workability etc. for the foamed concrete. In addition, the rotation speed of the drum mixer will also affect the duration of mixing. Table 4.6 shows the explanation of each stage in the mixing technique.

Table 4.6: Explanation of innovative mixing technique

Stages	Description	Duration
Cement + sand	Cement and sand are mixed in dry mix inside the drum mixer until homogenous	Recommended 1-2 minutes*
Cement + sand + foam	Foam is added until the targeted density is achieved	Determine from Table 4.7
Measure the density	The fresh density is measured	
Cement + sand + foam + water + admixture	Water and admixture are added into the dry mix. The wet mix is mixed inside the drum mixer until homogenous	Recommended 1-2 minutes*
Measure the slump	This stage is to ensure the workability is achieved by the amount of water is added slowly until the targeted slump achieved	Approximately 1 minute or less for every litre

Note: * Hiremath and Yaragal (2017)

In order to obtain the accurate target density, laboratory experiments are carried out to determine the duration used to spray the foam into 50 kg cement and 50 kg sand mixtures. It is found that the density of the foamed concrete will decrease by 700 kg/m^3 in every 5 minutes interval when foam is sprayed into the mixtures or every 43 second the foamed concrete density will decrease 100 kg/m^3 . Table 4.7 shows how the spray duration relate to the density of the foamed concrete.

Table 4.7: Spray duration vs density of foamed concrete

Conventional Density for the Dry Mix (kg/m^3)	Duration used to Spray the Foam (minutes)	Target Density (kg/m^3)
2400	5	1700
	10	1000
	15	300

Based on the above finding in Table 4.7, to produce foamed concrete density at 1000 kg/m^3 10 minutes spray duration is required. Duration of spraying the foam can also be obtained from Figure 4.9 below.

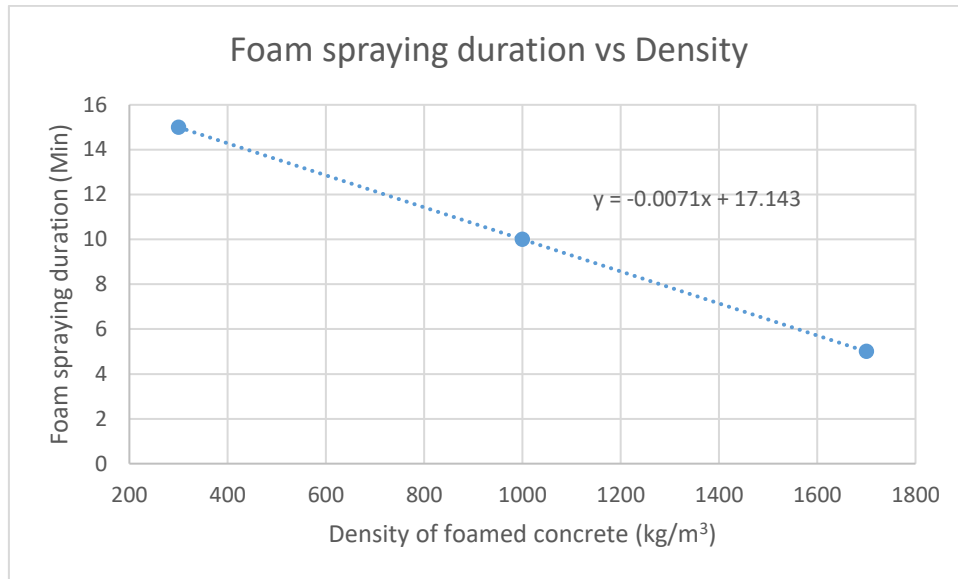


Figure 4.9: Graph of foam spraying duration vs density of foamed concrete

The duration of foam spraying at certain density of foamed concrete is important to estimate the nearest duration for achieving the target density. This will minimize the frequency of stopping the mixer to obtain foamed concrete sample's density. Frequent stopping the mixer is a disturbance, will delay the time of casting the foamed concrete and cause more foam bubbles to break. Different set of mix proportion, cement-sand ratio, cement-sand ratio and mass of the mix are required to produce different set of spray duration versus density of foamed concrete before big volume production.

4.3.2.1 Targeted density of foamed concrete

In the way to simplify the experiment, a different C:S ratio of mix proportion is used for this innovative mixing technique compared to conventional mixing technique. This is because a range of different C:S ratio is proposed for the subsequent experiments eg. 1:1, 1:2, 1:3 and 1:4 the previous experiment has covered the C:S ratio of 1:1 1/3 in the conventional mixing technique. In avoiding too many repeating experiments, the C:S ratio

1:1 is chosen to examine the innovative mixing technique. Table 4.8 shows the foaming duration for the mass of mix proportion is 100 kg and the target density is 1000 kg/m³.

Table 4.8: Foaming duration for innovative mixing technique

Cement (kg)	Sand (kg)	Foam		Water
50	50	Foam is added until the targeted density 1000 kg/m ³ is achieved, and can be estimated by duration of spray of foam from Table 4.7 or Figure 4.9.	10 minutes	Add until the target slump is achieved

Table 4.8 shows the C:S of 50 kg : 50 kg, required 10 minutes of foam spraying duration to reach the target density 1000 kg/m³. The density is required to be re-confirmed by weighing on the scales (see Figure 3.15). From this the duration to achieve the target density in Figure 4.9 is 10 minutes.

4.3.2.2 Targeted Workability of foamed concrete

Foamed concrete workability is measured by slump spread modeled by slump cone test as shown in Figure 3.13 & 3.14. Table 4.9 shows the continue mixing added with water after foam addition. The slump cone experiment was conducted to achieve the workability 13 - 16 cm slump spread by adding water in stages.

Table 4.9: Target slump of innovative mixing technique

Cement (kg)	Sand (kg)	Foam	Water	
50	50	Add until achieved the target density	Add until achieved the target slump	13 - 16 cm (slump spread)

Table 4.9 shows that the slump required is easily achieved by controlling the amount of water added into the mix. The water is added litre by litre as shown in Table 4.10.

Table 4.10: Relationship between slump, strength and water in the mix

Water (Litre)	Slump (cm)	Strength (N/mm ²)
0	10.7	1.25
1	11.5	-
2	12.6	1.13
3	13.0	-
4	14.3	1.08
5	16.7	-
6	17.9	0.40
7	18.4	0.92

The slump flow was measured after water is added at each stage. The slump versus water is measured as shown in Figure 4.10.

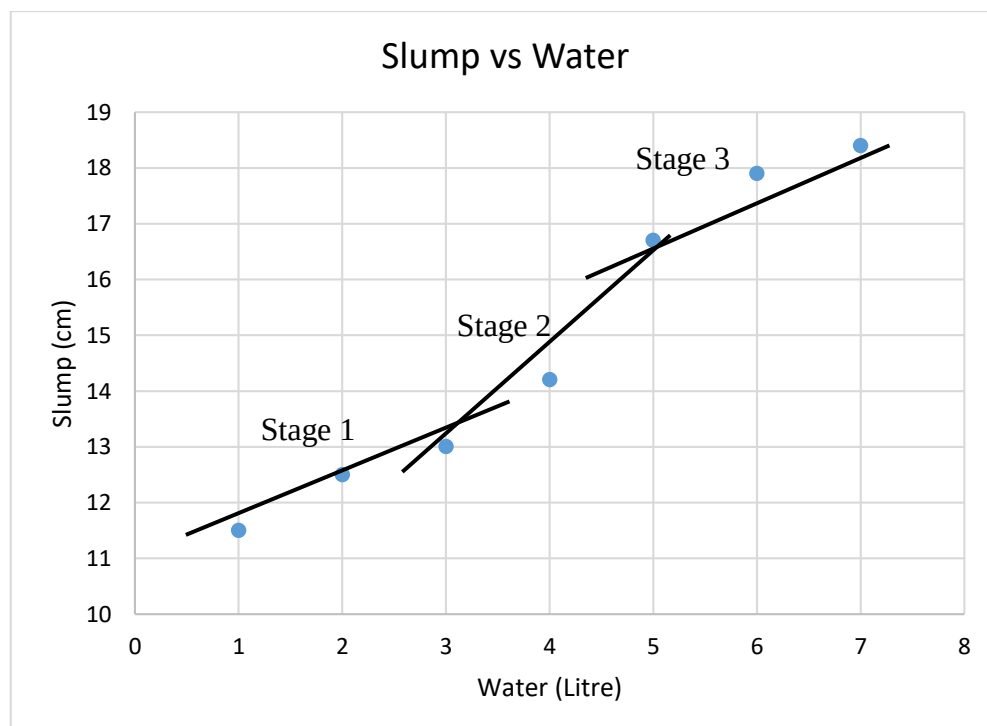


Figure 4.10: Slump vs water content

Based on the experimental results, it is found that workability can be divided into three (3) different stages, which is affected by the amount of water added into the mix as presented in Figure 4.10. These three (3) stages are captured from the experiments as shown in Figure 4.11.



Figure 4.11: Three stages of slump

Stage 1 shows the shape of cone did not change from the original cone shape. This is because the mix is slightly in dry condition. As more water is added in, the shape of cone started to change and flattened out into disc shape, this is considered stage 2. In this stage the mix become slightly wet and started to be flowable. At this point the water added is around 3.5 - 4.7 liters. The amount of water added was used to improve the workability which does not contribute to any change of the concrete density. The final stage 3 involved more water being added, and this caused the mixture to be fully flowable. The original cone shape is totally collapsed and the mix spread out to become flat and thin. Slump spread is measured by the two perpendicular lengths of the slump as captured in Figure 3.5(c).

From Figure 4.10, it is known that that to achieve the slump at 13 cm – 16 cm, the water added is in the range 3.5 – 4.7 liters. The strength of foamed concrete by this innovative mixing technique is also important and need to be investigated. The compressive strength results shown in Table 4.10 presented that amount of water added into the foamed concrete

will affect the foamed concrete strength beside the slump, where the strength will decrease when the amount of water added is increased. However, the most interesting aspect of this experiment is the mixture did not experience any sign of segregation.

4.3.2.3 Dry Shrinkage for Innovative Mixing Technique

The same C:S ratio of 1:1 at 50 kg cement : 50 kg sand with water-cement ratio of 0.10 as shown at Appendix E is cast and shrinkage is investigated with results shown at Table 4.11. It is proven that the average shrinkage at 900 - 1100 kg/m³ is 2.4 mm or 1.6% and at 1100 - 1300 kg/m³ is 1.5 mm or 1.0%. Thus, shrinkage less than 2.0% with fulfill the research objective of Section 1.9(b). With this, shrinkage can be neglected during design stage. A further investigation on shrinkage for massive volume production will be documented in Chapter 6.

Table 4.11: Density of foamed concrete vs shrinkage under innovative mixing technique

Label	Density (kg/m ³)	Shrinkage (mm)	Label	Density (kg/m ³)	Shrinkage (mm)	Label	Density (kg/m ³)	Shrinkage (mm)
M3A-13	900	3	M3A-38	1025	1.5	M3A-54	1101	2.6
M3A-15	907	3	M3A-39	1034	4.5	M3A-55	1105	0
M3A-18	930	2.1	M3A-40	1035	4	M3A-56	1108	2.1
M3A-19	930	3.4	M3A-41	1040	1.5	M3A-57	1112	2.3
M3A-20	931	3	M3A-42	1052	1.2	M3A-58	1113	3
M3A-22	942	2.2	M3A-43	1052	1.2	M3A-59	1114	0
M3A-23	945	2.9	M3A-44	1055	1.3	M3A-60	1138	1.6
M3A-24	947	3.4	M3A-45	1055	4	M3A-61	1155	0
M3A-25	966	2	M3A-46	1059	0	M3A-62	1168	1.7
M3A-26	966	2.1	M3A-47	1061	0.8	M3A-63	1179	1.8
M3A-27	967	5	M3A-48	1067	1.3	M3A-64	1231	2.5
M3A-28	972	2	M3A-49	1068	3.8	M3A-65	1232	2.5
M3A-30	978	3.9	M3A-50	1073	1.3	M3A-66	1233	3.5
M3A-31	978	2.2	M3A-51	1082	3.2	M3A-67	1236	0.1
M3A-32	984	2.5	M3A-52	1082	3	M3A-68	1239	1.7
M3A-33	985	2.4	M3A-53	1098	1.2	M3A-69	1245	0
M3A-35	993	2				M3A-70	1390	0
M3A-37	1020	1.5	Average	1005.3	2.42	Average	1182.2	1.5
Percentage of Shrinkage for height of sample in 150 mm (%)				1000±100	1.6%	1200±100		1.0%

Table 4.11 shows that shrinkage data is scattered, the data is grouped into the range of 50 kg/m³ from 900 -1400 kg/m³, then presented in Table 4.12 and Figure 4.12.

Table 4.12: Relationship between density and shrinkage

Group	Density range (kg/m ³)	Density (kg/m ³)	Average Shrinkage (mm)
M3A-D925	900 – 950	925	2.88
M3A-D975	950 – 1000	975	2.62
M3A-D1025	1000 – 1050	1025	2.60
M3A-D1075	1050 – 1100	1075	1.76
M3A-D1125	1100 – 1150	1125	1.66
M3A-D1175	1150 – 1200	1175	1.17
M3A-D1225	1200 – 1250	1225	1.56
M3A-D1375	1250 – 1400 etc	1400	0

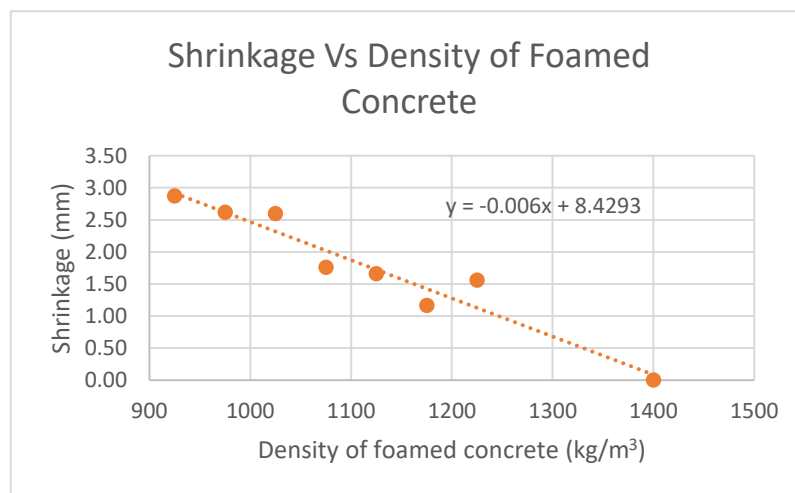


Figure 4.12: The relationship between density of foamed concrete and shrinkage

Experimental results in Figure 4.12 shows the shrinkage will decrease significantly from 3 mm to 0 mm for density of foamed concrete that range from 900 – 1400 kg/m³. Shrinkage can be predicted by using the presented linear equation. The maximum shrinkage 2.88 mm or 1.92% is within the allowance 2% in the research objective in Section 1.9(b). However, the result shows the sample M3A-D1225 is strange, this may be due to the size of sand particle from different sources of sand.

4.3.2.4 Relationship between C:S Ratio to Fresh and Hardened Density

The relationship between fresh density and hardened density is important to determine the change of density of foamed concrete due to deformation from segregation and shrinkages. The water – cement ratio for the experiment is controlled at the range 0.06 - 0.10 as shown in Appendix E. Figure 4.13 shows the relationship between fresh density and hardened density of foamed concrete which have been extracted from Appendix E.

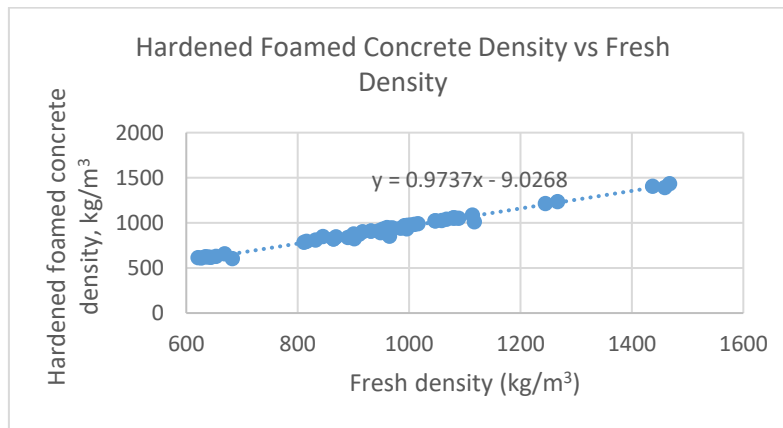


Figure 4.13: The relationship between fresh density and hardened density of foamed concrete.

Figure 4.13 has proven that the percentage loss in density after the foamed concrete harden is constant. Losses of density is on average is 3.61% as shown in Appendix E. This also can confirm that the fresh mix is stable in segregation (if any) and shrinkage from fresh to hardened condition. This finding is to prove that the constant of density due the water losses in hydration process and the research objective 1.9(a) and stage 3 in Table 1.7.

4.4 Classification of the Foamed Concrete Density

The most important aspect of the preliminary results is the measurement of density for foamed concrete. For better understanding, the harden density is written in the range within four categories as shows in Table 4.13.

Table 4.13: Classification of Harden Density of foamed concrete

Category	Density (kg/m ³)	Density Range (kg/m ³)
A	650 – 750	700 ± 50
B	750 – 850	800 ± 50
C	850 – 950	900 ± 50
D	950 – 1050	1000 ± 50
E	1050 – 1150	1100 ± 50
F	1150 – 1250	1200 ± 50
G	1250 – 1350	1300 ± 50

The purpose of the classification is to categorizing the hardened density for further used in the design of road embankment stage, as known fresh density is could not provide consistent density due to decrease in certain percentages when the foamed concrete hardened as shown in Section 4.3.2.4. In the following section, all data of density will follow the similar understanding as in Table 4.13. With this, this research study is focusing is category D, which is in-line with the target density for soft soil and peat soil replacement.

4.5 Summary

This chapter has discussed the suitable pressure for closed tank, water dilute ratio for foam agent, comparison of mixing techniques. Innovative mixing technique is produced to fulfil four (4) important aspects, via, ease of achieving targeted concrete density, workability, no segregation and minimal shrinkage upon hardening. This technique mainly focuses on the sequence of mixing, where the foam is added to obtain the density, thereafter achieving the required workability by adding water into the mixture. At the end of this chapter, the innovative technique is proven to improve the production of foamed concrete significantly and fulfill the aim of ease of achieving target density, workability, no segregation and minimize shrinkage.

CHAPTER 5

FOAMED CONCRETE FOR DESIGNED STRENGTH

5.1 Introduction

Chapter 4 has reported a unique innovative mixing technique to produce foamed concrete, where 3 of the 5 elements have been solved, which is density, workability and shrinkage (include segregation). Strength and volume are the remaining elements that need to be investigated further. This chapter aims to investigate the factors that affect the strength of foamed concrete, as well as to explain the experiments undertaken to produce foamed concrete with considerable target strength. This target strength value should comply with the design requirement of the project in Section 3.4. As mentioned, the target compressive strength of this research is at around $1 - 3 \text{ N/mm}^2$, and it is proven better than the unconfined compressive strength of soil for subgrade in 175 kPa (Noraida et al., 2016).

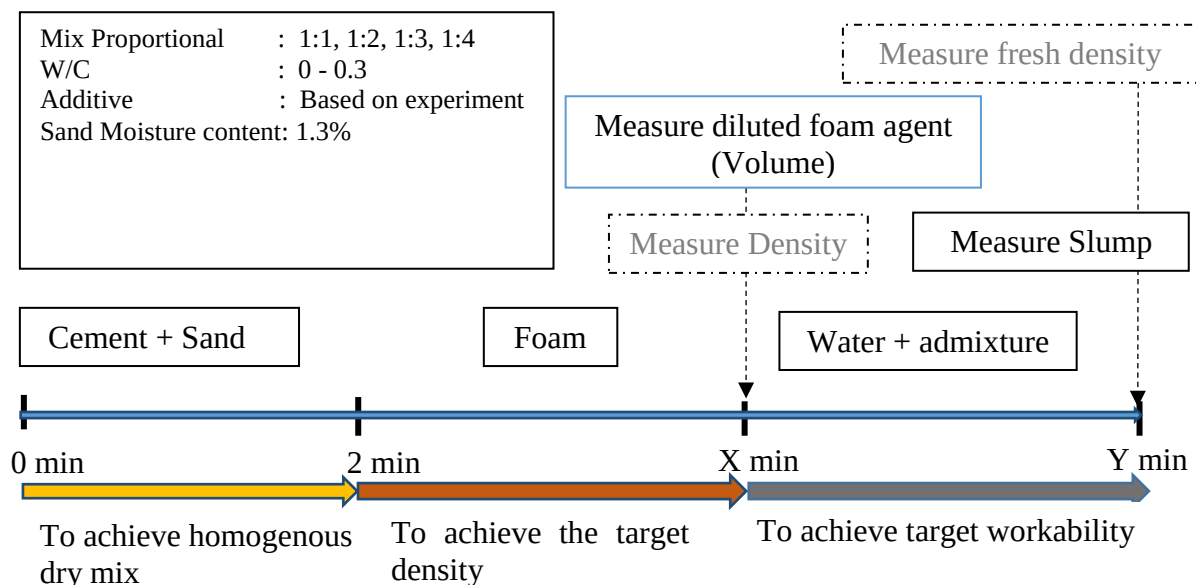
Besides producing foamed concrete with higher compressive strength, this chapter will discuss the use of admixture and method of curing for foamed concrete produced by innovative mixing technique. At the end of this chapter, the reader will understand the procedure to produce foamed concrete to the required strength.

A series of experiments with different cement-sand (C:S) ratio was conducted to investigate the relationship between C:S ratio with strength. It is important that the workability be kept within the same range, where a range in between 13 – 16 cm was used in the experiment. As explained in Chapter 4, this range of workability is at the physical limit of the mix becoming workable. The mix proportion used for the experiments are in C:S

ratio of 1:1, 1:2, 1:3 and 1:4. The innovative mixing technique used for the mixing as shown in Figure 4.8.

5.2 Relationship Between C:S Ratio and Compressive Strength, Volume of Foam and Volume of Foamed Concrete

In this research, it is known that the maximum density of soft soil is 2600 kg/m^3 and peat soil is 1300 kg/m^3 , and in order to achieve the target density of replacement, the fill material shall not be more than 1300 kg/m^3 . In this section, the research work assumed the target density of foamed concrete at $\pm 1000 \text{ kg/m}^3$ (Category D) with variation in workability at between 13 – 16 cm slump. The aim is to correlate the workability of concrete to the compressive strength. An experiment has been carried out to investigate different mix proportion in relation to the strength. The volume of foamed concrete produced and volume of foam agent needed are as shown in the result in Table 5.1. The mix proportion used for the experiments are in the C:S ratio of 1:1, 1:2, 1:3 and 1:4. Water is added until the slump achieves 13 – 16 cm and recorded. Table 5.1 is related to Figure 4.8, where compressive strength test is started after 28 days of casting as shown in Figure 5.1.



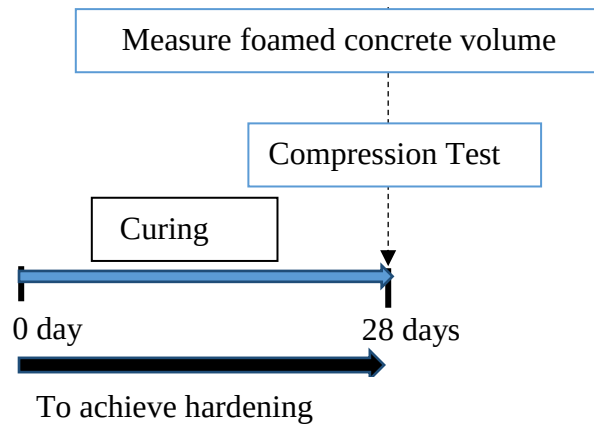


Figure 5.1: Innovative mixing technique with various parameters

Figure 5.1 shows that three (3) additional parameters had been measured during the casting of foamed concrete, which is the volumes of diluted foam agent, volume of foamed concrete and the compression test result.

Table 5.1: The relationship between mix proportions to compressive strength and volume of diluted foam agent

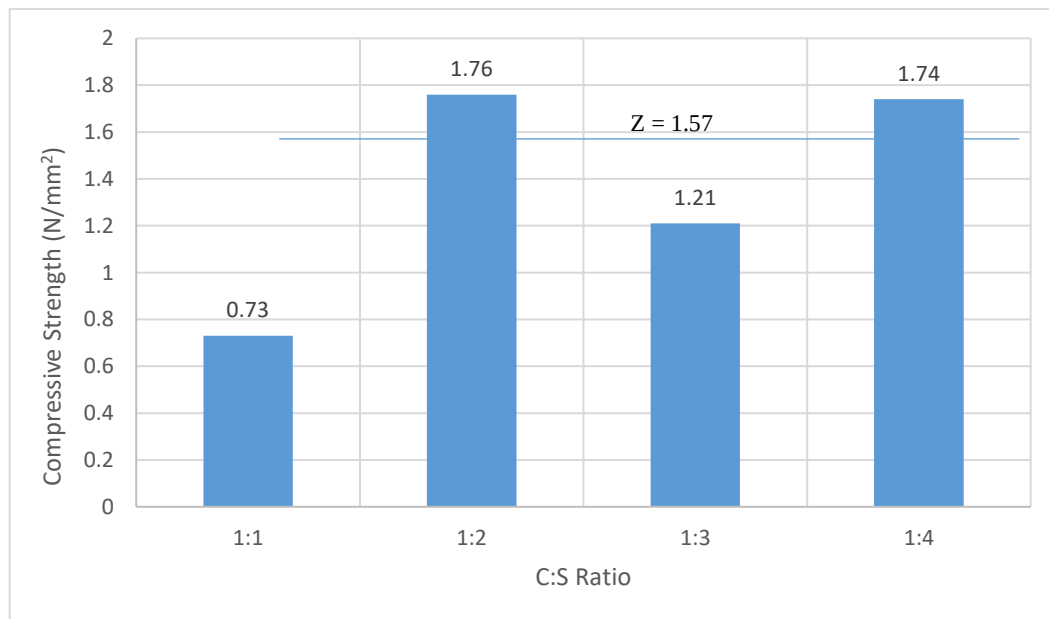
Sample	Cement : Sand ratio	Slump (cm)	Average Slump (cm)	Compressive strength (kg/m ³)	Average Strength (kg/m ³)	Average Foamed Concrete Volume for cement in 50 kg (m ³)	Average diluted Foam agent been used (Litre)
M3A-25	1:1	13.80	13.34	0.65	0.73	0.126	13.16
M3A-27	1:1	13.80		0.20			
M3A-30	1:1	14.50		0.25			
M3A-33	1:1	13.20		0.50			
M3A-35	1:1	12.80		0.40			
M3A-37	1:1	12.80		1.40			
M3A-39	1:1	13.00		1.03			
M3A-41	1:1	12.80		1.40			
M4A-15	1:2	12.80	13.43	1.46	1.76	0.166	7.28
M4A-16	1:2	12.80		1.63			
M4A-17	1:2	13.90		2.02			
M4A-18	1:2	13.90		0.94			
M4A-19	1:2	13.80		2.81			
M4A-20	1:2	13.80		2.97			
M4A-21	1:2	13.20		1.06			
M4A-22	1:2	13.20		1.21			

Table 5.1 continued

M4B-7	1:3	13.20	13.46	0.99	1.21	0.131	6.28
M4B-8	1:3	13.20		1.05			
M4B-9	1:3	13.50		0.98			
M4B-10	1:3	13.50		1.77			
M4B-11	1:3	13.90		1.24			
M4C-6	1:4	12.80	12.82	2.01	1.74	0.228	9.47
M4C-7	1:4	12.80		1.63			
M4C-8	1:4	12.80		1.46			
M4C-9	1:4	12.80		2.05			
M4C-10	1:4	12.90		1.55			

5.2.1 Relationship between Cement-Sand ratio and Compressive Strength

From Table 5.1, the experiment result revealed that the foamed concrete at different C:S ratio can produce various of strength results. Physically, these strength with value at more than 1 N/mm² is sufficient for carry out the compression loading, however the higher the strength the better.

**Figure 5.2:** Graph of compressive strength vs C:S ratio

From Figure 5.2, it is observed that the strength of foamed concrete produced within C:S ratio 1:1 is less than 1 N/mm². Most of the samples with the 1:1 ratio in Table 5.1 did

not have adequate strength despite keeping its shape in the cubical. However, there was almost zero shrinkage upon hardening. This proves that the method of mixing was good and acceptable.

For the C:S ratio 1:2, 1:3 and 1:4, the samples exhibit substantial strength between 1 – 2 N/mm², which was 1.76 N/mm², 1.21 N/mm² and 1.74 N/mm², respectively. There is a little difference in strength between C:S ratio of 1:2 - 1:3 and 1:3 - 1:4 with - 0.55 N/mm² and + 0.53 N/mm², respectively. By this, it is assumed that strength values between 1.0 – 2.0 N/mm² are considerably the same. It can be concluded that an increase in sand does not contribute to the better strength.

For the purpose of this research, a compressive strength of 1 – 2 N/mm² seems inadequate to sustain the dynamic load of vehicles as per objective of study in Section 1.9(a). There is still a need to explore other approaches to achieve a higher strength value as per the results shown in Appendix G.

5.2.2 Relationship between Cement-Sand ratio and Volume of dilute Foam Agent

Table 5.1 shows the volume of foamed concrete is different due to C:S ratio differences. Columns 7 and 8 in Table 5.2 show the pro-rata for columns 5 and 6 to obtain the volume of diluted foam agent for 1 m³ foamed concrete.

Table 5.2: The relationship between mix proportions to volume of diluted foam concrete (See also Appendix F)

No	1	2	3	4	5	6	7	8
	Sand-cement ratio	Cement (kg)	Sand (kg)	Mass of dry mix (kg)	Average Foamed Concrete Volume for every 50 kg cement	Average Foam agent been used (Litre)	Average Foamed Concrete Volume (m ³)	Average diluted Foam agent been used (Litre)
M3A	1:1	50	50	100	0.126	13.16	1	104.44
M4A	1:2	50	100	150	0.166	7.28	1	43.86
M4B	1:3	50	150	200	0.131	6.28	1	47.94
M4C	1:4	50	200	250	0.228	9.47	1	41.53

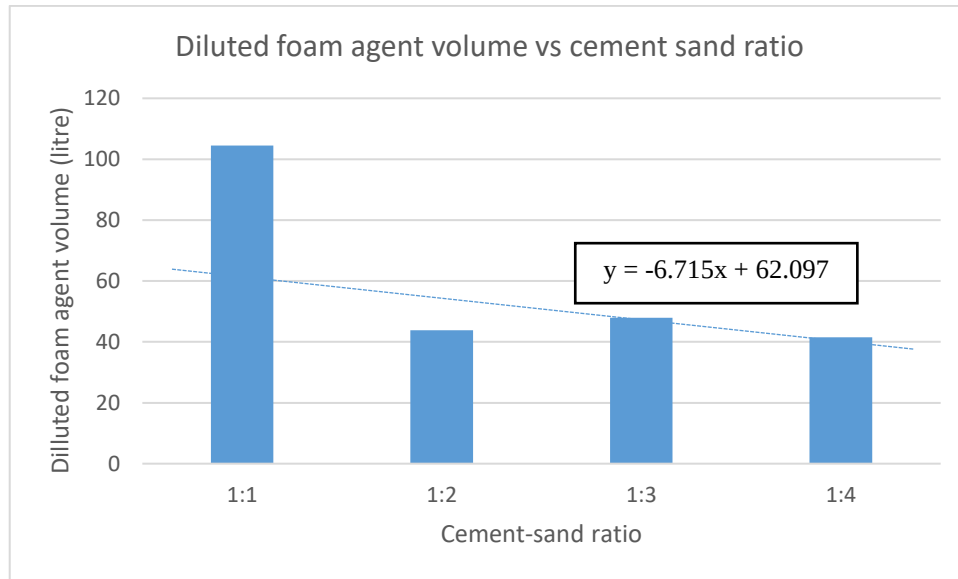


Figure 5.3: Graph of diluted foam agent volume vs C:S ratio

From Table 5.2, there is a direct correlation in the C:S ratio with the diluted foam agent added in the mix for the production of 1 m³ foamed concrete as presented in Figure 5.3.

The workability of the all mixes were kept constant at slump spread 13 – 16 cm, but the result on Figure 5.3 show the difference trend to the volume of foam agent added, where the trend does not show the same pattern between the foam agent volume for C:S ratio 1:1 to others C:S ratio. Where for other C:S ratio e.g. 1:2, 1:3 and 1:4 shows the volume of foam agent at the range 41 – 48 litres could produce 1 m³ of foamed concrete with compressive strength at the range 1 – 2 N/mm². It is believed that some technical error had occurred during the mix of C:S ratio at 1:1 or the sand material is not from the same source.

5.2.3 Relationship between Cement-Sand ratio and Foamed Concrete Volume

The volume of foamed concrete could expand consistently as long as the closed tank (foam generator) provides consistent pressure to the foam agent. There is not easy in

estimated the foam volume, but it is proven that the volume of foamed concrete increase by the increases of the foam volume as shown in Figure 5.4.

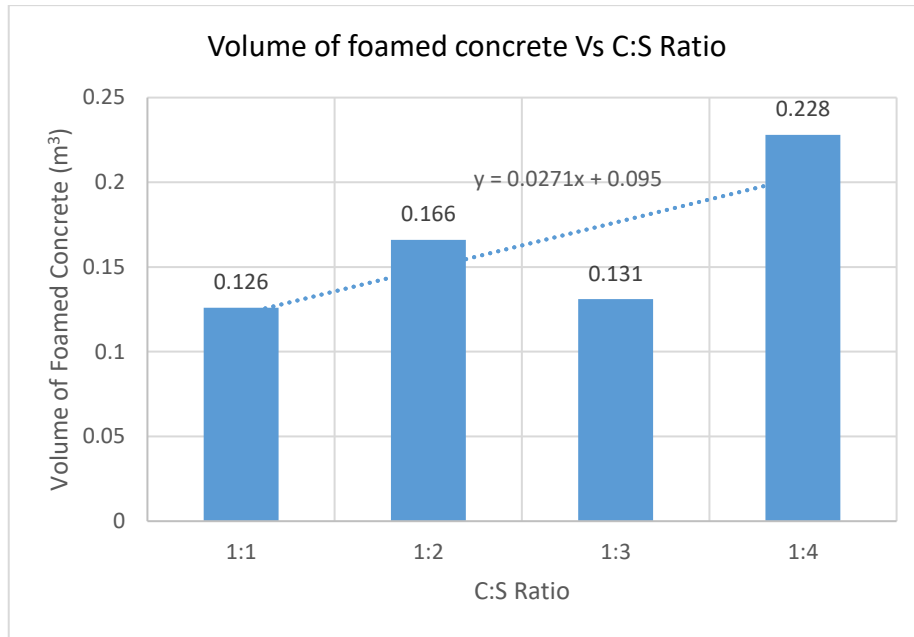


Figure 5.4: Graph of volume of foamed concrete vs C:S ratio

Figure 5.4 shows that the volume of foamed concrete is constantly increased upon the increases of C:S ratio. This proves that the volume of foam is constant and its bubbles does not break in any C:S ratio. And it is believed that the constant volume of foam could produce a good foamed concrete with no shrinkage and this solving the research objective 1.9(b).

5.3 Relationship between Water-Cement ratio and Compressive Strength

Another important parameter to be investigated in producing a good compressive strength of foamed concrete is the water/cement ratio. The data collected from C:S ratio 1:1 to 1:4 at density category D, $\pm 1000 \text{ kg/m}^3$ and range of slump 13 – 16 cm is as shown in Table 5.3 and presented in Figure 5.5. Table 5.3 is adopted from Appendix G.

Table 5.3: The relationship of water-cement ratio to compressive strength

Cement ratio	Sand ratio	Water/cement ratio (w/c)	Average Slump (cm)	Average Compressive Strength (N/mm ²)
1	1	0	14.0	0.4
1	1	0.02	13.1	0.4
1	1	0.04	14.0	0.33
1	1	0.05	13.5	0.26
1	1	0.06	13.8	0.28
1	1	0.08	13.3	0.55
1	1	0.10	13.6	0.6
1	1	0.16	13.4	0.65
1	1	0.22	13.9	1.5
1	1	0.24	14.7	0.9
1	2	0	12.2	0.5
1	2	0.04	13.9	1.05
1	2	0.08	13.7	1.12
1	2	0.10	13.2	1.28
1	2	0.20	13.6	1.62
1	2	0.24	13.9	2.41
1	2	0.28	14.0	1.5
1	3	0	12.0	0.6
1	3	0.16	13.8	0.96
1	3	0.24	13.5	1.07
1	3	0.28	13.7	1.51
1	4	0	13.0	0.6
1	4	0.28	12.9	1.56
1	4	0.30	12.8	2.07

Table 5.3 shows a group of sample at same C:S ratio but different in the total mass, where the results are proved that the compressive strength is consistent, and not affected by the mass of cement and sand material. This also proved that foam bubbles does not break in the variation of the mass of cement and sand material.

Although, the compressive strength results seem a bit scattered, this does not affect the overall trend line to present the relationship between compressive strength to water-cement ratio as shown in Figure 5.5.

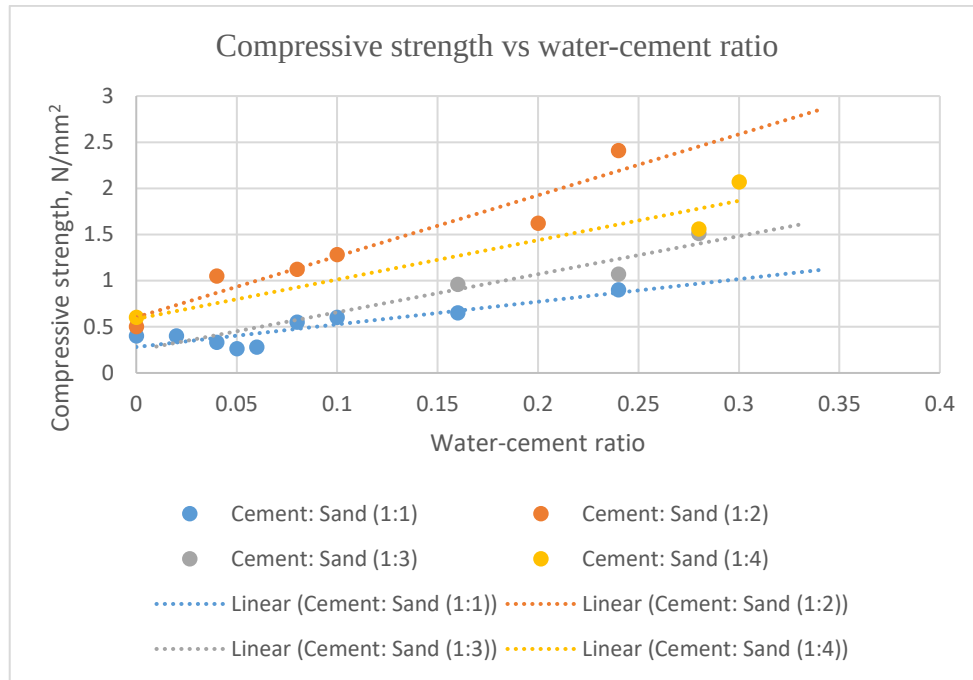


Figure 5.5: Graph of compressive strength vs water-cement ratio

Figure 5.5 explains the best water-cement ratio for achieving a good strength more than 1 N/mm², shall not be less than 0.2. For this experiment the maximum w/c ratio is 0.3. The foamed concrete starts to show segregation when w/c more than 0.35.

The conclusion of this experiment is water/cement ratio plays a very important role in affecting the compressive strength of foamed concrete. W/C in the range of 0.2 - 0.3 is good to achieve higher compressive strength at the range of 1 – 3 N/mm².

Table 5.4: The relationship of high water-cement ratio to compressive strength

Sample	Cement (kg)	Sand (kg)	Cement ratio	Sand ratio	Water (Litre)	Water/cement ratio (w/c)	Slump (cm)	Compressive Strength (N/mm ²)
M4A	50	100	1	2	17.5	0.35	21.00	0.15
M4A	50	100	1	2	19	0.38	22.50	0.00
M4A	50	100	1	2	19.5	0.39	22.30	0.10
M4A	50	100	1	2	20	0.4	21.80	0.00
M4A	50	100	1	2	21	0.42	23.00	0.25

The experiment in Table 5.4 discovers that, when the water-cement ratio increased by more than 0.35 and the slump will start increase significantly. The experiment shows that when the slump reached 210 mm, the foamed concrete will start to shrink and become fragile due to segregation as shown in Figure 5.6.



Figure 5.6: Foamed concrete become fragile with w/c more than 0.35

5.4 Effect of Quarry Dust on Compressive Strength

Based on literature, effects of aggregate type, size, and content on concrete strength and fracture energy, Kozul (1997) reported that the higher the sand content the higher the compressive strength as illustrated in Figure 5.5. The solid content in the mix has a direct relationship to the strength values. This section investigates the need of using admixtures into foamed concrete to improve the strength. The admixture can be categorized into mineral and chemical admixtures.

In this section, the first approach is to use a stronger fine aggregate to add into the mix proportion, where it is projected that the strength will improve with stronger fine

aggregate. The material easily found in industrial practice is quarry dust. Quarry dust is easily found with bulk density in $1300 - 1450 \text{ kg/m}^3$ which is slightly lighter than sand with bulk density $1600 - 1950 \text{ kg/m}^3$. From this, an experiment on quarry dust is needed to investigate its effect on the strength on compared to sand.

The following experiments are aimed to investigating the effect of replacing sand with quarry dust in the production of foamed concrete. In the experiments, the density is kept at 1000 kg/m^3 while slump spread was within the range $130 - 160 \text{ mm}$. In order to achieve the same slump spread the water-cement (w/c) ratio is changed to achieve the target slump. The range of w/c ratio for all experiment is $0.12 - 0.20$ as shown in Table 5.5.

Table 5.5: Compressive Strength for added quarry dust

No	C:S	W/C ratio	Strength with Sand (100%) (kN/m ²)	Average Strength with Sand (100%) (kN/m ²)	Strength with Sand (50%) and Quarry sand (50%) (kN/m ²)	Average Strength with Sand (50%) and Quarry sand (50%) (kN/m ²)	Percentage of Strength Increase (%)
1	1:1	0.10	0.55	0.75	2.22	1.79	238.7
	1:1	0.16	0.92		2.27		
	1:1	0.20	0.65		1.45		
	1:1	0.24	0.86		1.21		
2	1:2	0.10	1.34	1.55	1.46	2.32	49.7
	1:2	0.16	1.83		2.78		
	1:2	0.20	1.62		2.46		
	1:2	0.24	1.41		2.56		
3	1:3	0.10	0.83	0.97	1.14	1.55	59.8
	1:3	0.16	0.96		1.41		
	1:3	0.20	1.02		1.77		
	1:3	0.24	1.07		1.87		
4	1:4	0.10	1.07	1.21	1.26	1.62	33.9
	1:4	0.16	1.21		1.39		
	1:4	0.20	1.13		1.46		
	1:4	0.24	1.42		2.35		

Table 5.5 shows the strength is increased with added quarry sand for all C:S ratio. C:S ratio 1:1 has shown a huge increase of strength by 239%, where this result is considered

to be out of range. However for the C:S ratio 1:2 – 1:4, the strength is increased within a range of 30-60%. Based on these results, it is confirmed that foamed concrete with quarry dust has stronger strength than foamed concrete with sand.

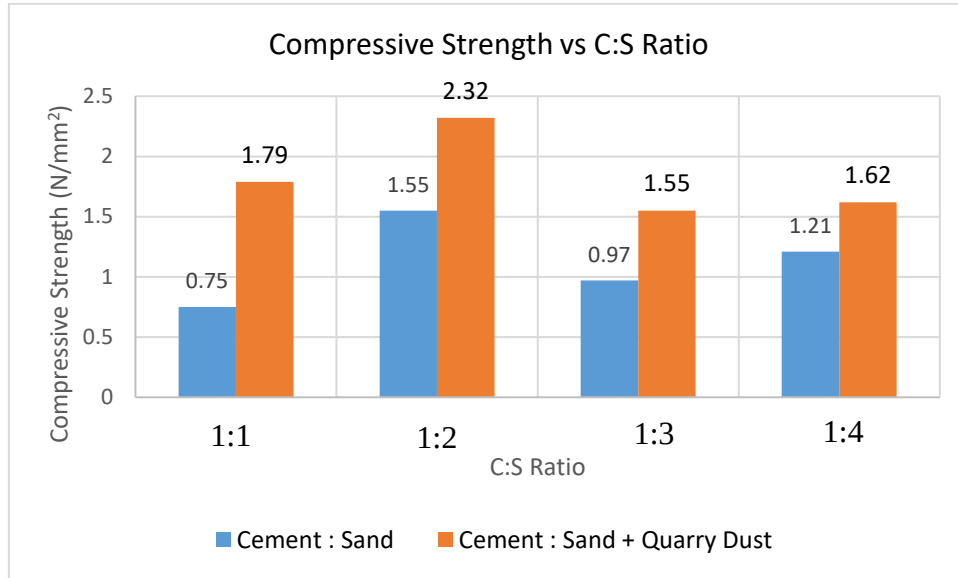


Figure 5.7: Graph of compressive strength versus cement (sand + quarry dust)

Based on Figure 5.7, the control mix which is made up of cement and sand only shows the same trend with the mix added with quarry dust. The C:S ratio 1:1 gives the lowest strength value of 0.75 N/mm², whereby the C:S ratio of 1:2 gives the highest strength value of 1.55 N/mm². This finding is logic, where the higher the C:S ratio, the lower the strength value. However, there is no appropriate explanation yet for the strength pattern of samples with C:S ratio 1:3 and 1:4. The same phenomena also occurs to the control mix added with quarry dust. Further investigations are required and it is beyond the main objectives of this work. The main focus of the present research is to produce foamed concrete of density 1000 kg/m³ with average strength 3 N/mm².

The results of control mixes were compared to the ones with quarry dust 50% replacement fine aggregates. For mixes with 50% quarry dust replacing the sand particles, the strength of samples with S:C ratio 1:1 shows a higher value than the control sample. For

samples with sand only the strength measured is 0.75 N/mm^2 while the sample with 50% quarry dust gave a value of 1.79 N/mm^2 . The presence of a stronger particles in the hardened concrete prove to contribute significantly to the compressive strength. Quarry dust have rougher surfaces, lighter, finer and bigger in volume compared to sand particles. These properties contribute towards better packing model to fill the void within the particles. The same explanation can be applied to samples with C:S ratio 1:3 and 1:4. The strength of the samples with quarry dust are higher than those without quarry dust. For C:S ratio 1:3 and 1:4, the percentage difference are 59.8% and 33.9% respectively.

It is important to note that specimen with the C:S ratio of 1:2 exhibits the greatest strength value. This is consistent with the results in Table 5.1. The volume of mix prepared in the laboratory for C:S ratio 1:2 has given an optimum packing density, where the mortar perform better in enveloping the particles to achieve higher strength. This result concluded that C:S ratio 1:2 is the optimum mix proportion proven in the experiments. The strength value 2.32 N/mm^2 is 49.7% higher than the sample without quarry dust shows strength value 1.55 N/mm^2 .

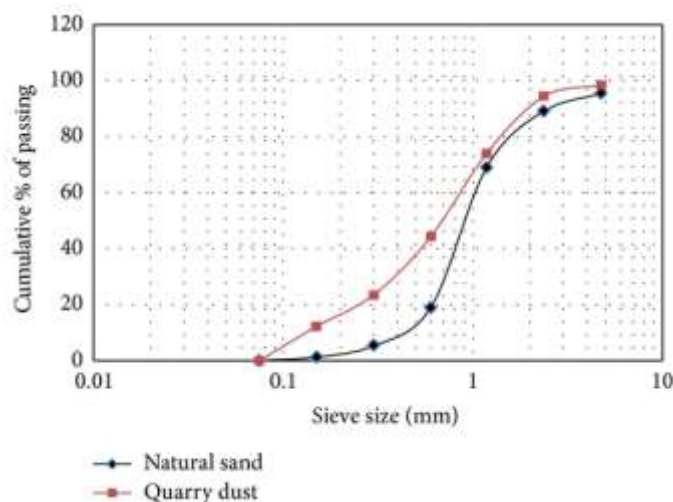


Figure 5.8: The sieve analysis result between natural sand and quarry dust

Figure 5.8 shows the percentage of fine quarry dust is higher than sand. This strength improvement is due to the various size of particle for quarry dust and sand make a good combination and allowed better compaction in the mix. Figure 5.9 explains the quarry dust particle fills up the space between sand particles. Microscopically, hardened foamed concrete has a higher matrix when quarry dust is added compared to sand only in the mix.

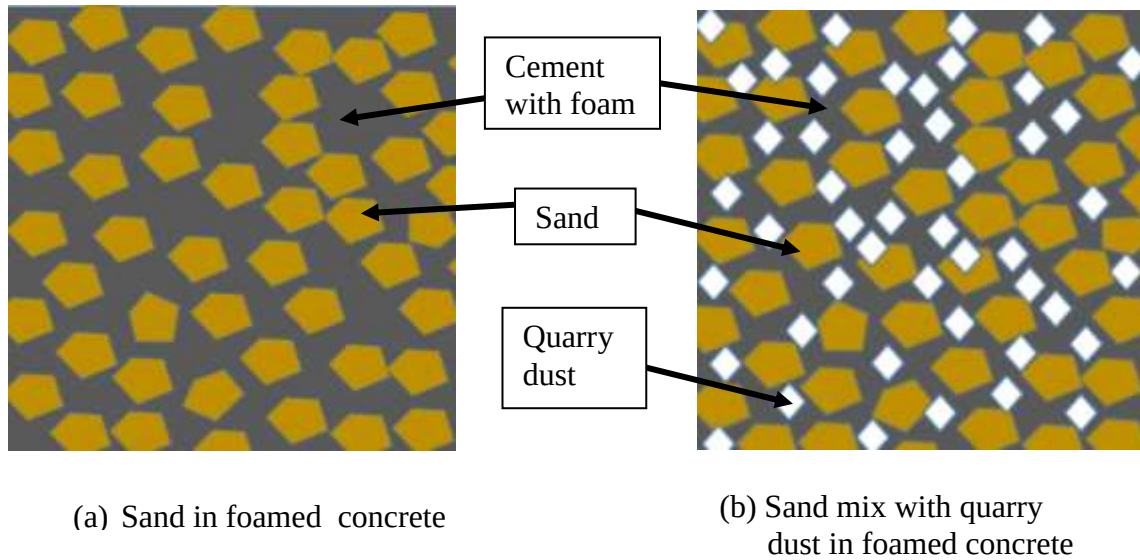


Figure 5.9: Particle contribution schematic for sand and sand plus quarry dust

5.5 Effect of Chemical Admixture on Strength

In this experiment, a chemical binder, polyvinyl alcohol (PVA) is added into the mix. This binder has a strong binding effect on the hardened matrix. PVA is also effective to reduce the water absorption, which reacts as filler to fill up the void in foamed concrete. Previous research by Ummirah (2013) proved that PVA can increase the strength to above 3 N/mm^2 for density 1000 kg/m^3 .

The preparation of PVA was necessary prior to the mix. The PVA used in the industry is a water-soluble synthetic polymer, which is solid in nature and white particle size. It has to be dissolved in boiled water at 100°C and cooled down to room temperature before adding

in the mix as show in Figure 5.10. The mass of PVA and water to dissolve shall be calculated as shown in Table 5.6:-

Table 5.6: Mass of PVA and water to dissolve PVA

Say, to preparation 1% PVA for foamed concrete C:S ratio 1:1 for 50 kg cement and 50 kg sand.		
PVA	1% of 50 kg	500 g
Water to dissolve (1:4)	500 g x 4	2000 g or 2 Litres



Figure 5.10: Melting PVA at laboratory

The experiment proceeds with C:S ratio 1:1 as shown in Table 5.7 with different percentages of PVA. This experiment is an attempt to investigate the effects of PVA on the foamed concrete strength. The w/c is in the range 0.06 – 0.12.

Table 5.7: The effects of PVA in different percentage to the compressive strength of foamed concrete

Label	Cement (kg)	Sand (kg)	PVA (%)	Water Added (Litre)	Slump (cm)	Compressive Strength (N/mm ²)
M3B-P1	100	100	0	6	13.5	0.44
M3B-P2	100	100	0	6	13.5	0.54
M3A-P1	50	50	1	6	13.0	0.89
M3A-P2	50	50	1	6	13.0	1.03
M3A-P3	50	50	2	6	13.0	1.10
M3A-P4	50	50	2	6	13.0	1.24
M3A-P5	50	50	3	6	13.2	1.56

Table 5.7 shows the strength is increases with the increase of PVA in the mix. The w/c ratio is decreased in comparison to w/c to achieve the correct density and workability for foamed concrete without additive in Table 5.2.

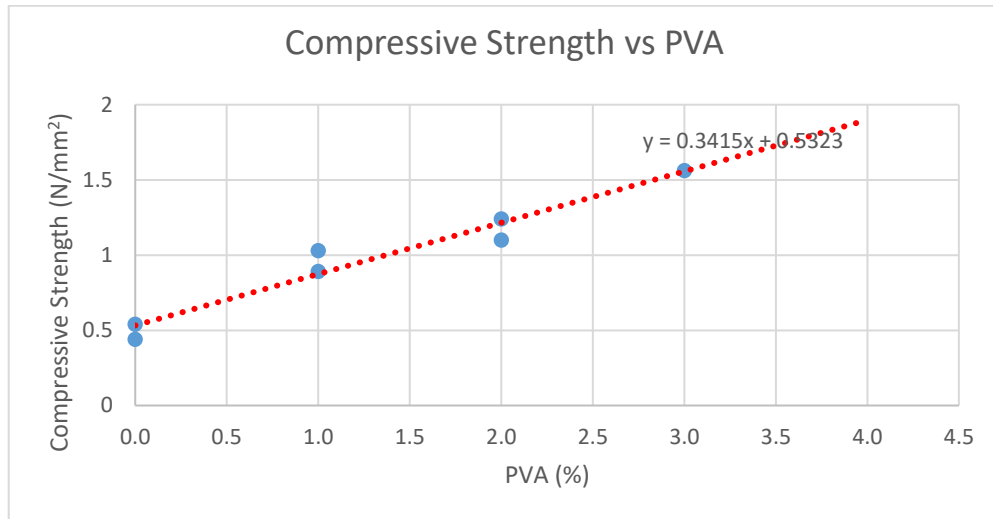


Figure 5.11: Compressive strength vs PVA%

Figure 5.11 attempts to show the relationship between percentages of PVA added in the mix to compressive strength. The relationship is linear showing an increase of PVA% will contribute to the increase in compressive strength. For samples without PVA the strength is less than an average value of 0.49 N/mm² and serve as a control mix. With 1% addition of PVA, the strength increases to 0.96 N/mm², 2% addition of PVA have strength of 1.17 N/mm² and 3% PVA produces strength of 1.56 N/mm². The percentage difference between 0% - 3% PVA is 68%. However, comparatively the increase of strength is achieved but not significant and it is considered high cost by using PVA. In this mix proportion, PVA is introduced as a second binding material other than cement. Hypothetically, it should increase the concrete strength by binding the materials together, sand supposedly contribute towards a stronger bond.

This experiment also concludes that the research approach to gain better strength will be easily achieved through a particle packing model rather than chemical binding

enhancement. It is easier to achieve strength from an optimum C:S ratio (1:2) as compared to adding chemical admixture in the mix.

The conclusion of this experiment is the use of PVA in foamed concrete is expensive and preparation of PVA is not easy for mass production. This method is not economical and not practical.

5.6 Effects of Paraffin liquid on Compressive Strength

The research proceeds into the accessibility of adding paraffin liquid in the mix proportion. Paraffin liquid is a product from the oil and gas industry. It is made up of long chain polymers from the process of gas to liquid technology. The liquid is colourless, odourless and viscous in the physical form. Figure 5.12 shows the paraffin liquid used by this research study.

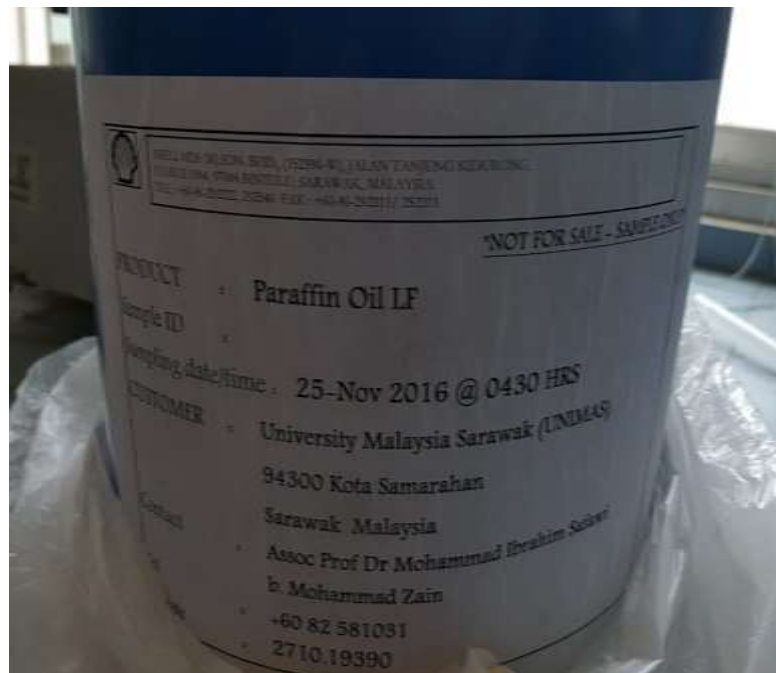


Figure 5.12: Paraffin oil (GTL)

The hypothesis for introducing paraffin liquid is to improve the workability of the mix. Although the mix obtained are considered flowable with a slump spread above 13 cm,

the amount of water added in the mix is low (w/c is low). However, this amount of water should be sufficient for the cement hydrate effectively. Thus, the following experiments are undertaken to pursue this objective. The use of paraffin liquid is going to allow more water added in the mix proportion used as given in Table 5.8.

Table 5.8: The compressive strength vs various C:S ratio in different paraffin liquid percentage

No	C:S	Cement (kg)	Sand (kg)	GTL (%)	GTL (L)	Water (L)	W/C	Slump (cm)	Strength (N/mm ²)	Average Strength (N/mm ²)
M3A-G1	1:1	50	50	0	0	0	0.02	12.0	0	0
M2D-G1	1:1	75	75	1.3	1	6	0.09	13.5	0.2	0.20
M3A-G2	1:1	50	50	2	1	0	0.02	12.0	0.8	0.90
M3A-G 3	1:1	50	50	2	1	0	0.02	12.0	1	
M4A-G1	1:2	50	100	0	0	14	0.28	13.9	1.63	1.63
M4A-G2	1:2	50	100	2	1	10	0.22	14.0	1.46	2.18
M5A-G1	1:2	100	200	2	2	12	0.14	13.8	2.89	
M3B-G1	1:2	50	100	4	2	6	0.16	13.2	1.34	1.34
M4B-G1	1:3	50	150	0	0	14	0.28	13.4	1.77	1.77
M4B-G2	1:3	50	150	2	1	12	0.26	13.6	0.98	1.00
M4B-G3	1:3	50	150	2	1	12	0.26	13.2	1.02	
M4B-G4	1:3	50	150	4	2	8	0.2	14.0	0.94	0.94
M4C-G1	1:4	50	200	0	0	14	0.28	13.4	1.74	1.74
M4C-G2	1:4	50	200	2	1	10	0.22	12.9	1.55	1.55
M4C-G3	1:4	50	200	4	1	10	0.25	12.8	1.65	1.65

The results in Table 5.8 show that water add in the mix will increase the strength. However, adding too much water in mixing foamed concrete will not continuing increase the strength, and will easily cause material segregation. At each of C:S ratio, the paraffin liquid allowed extra water add to increase the workability although is not significant due to low w/c. The strength of foamed concrete not show significant changes by adding the paraffin. Figure 5.13 proved that paraffin liquid will not increase the compressive strength of foamed concrete.

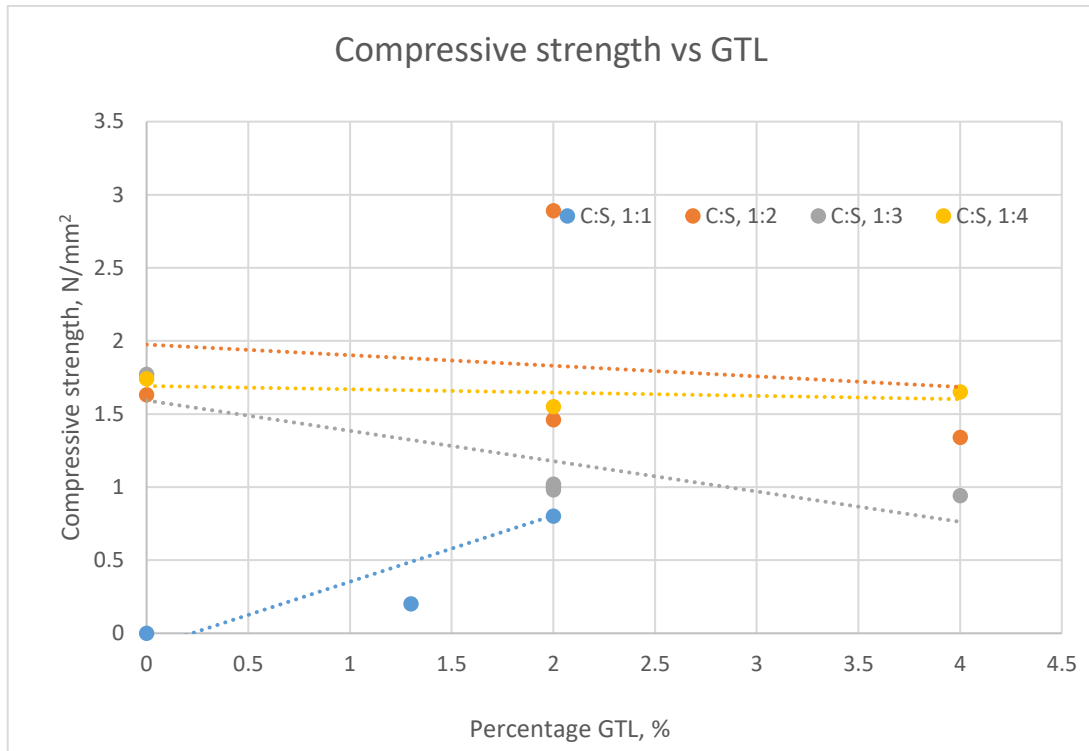


Figure 5.13: Relationship between compressive strength to percentages of GTL

5.6.1 Combination of Quarry Dust and Viscosity Enhancer

The experiment is continued by adding in quarry dust in the mixing with GTL. It was already proven in Section 5.2 that quarry dust contribute to the strength development. Having understood both the role of water and quarry dust in the mix and its contribution toward strength, the mix proportion that is expected to produce a stronger foamed concrete with C:S ratio 1:2, 1:3, 1:4 with larger than usual amount of water added and quarry dust included into the mix.

Table 5.9: Results of compressive strength by adding Quarry dust

Sample	Cement (kg)	Sand (kg)	Quarry Dust (kg)	C:S	GTL (%)	GTL (L)	Water (L)	W/C	Slump (cm)	Strength (N/mm ²)	Strength (N/mm ²)
M7A-G	100	0	100	1:1	2	2	10	0.12	13.5	2.22	2.22
M7B-G	100	100	100	1:2	2	2	2	0.04	13.5	2.40	2.40
M6D-G	50	0	100	1:2	4	2	8	0.20	13.6	3.16	3.16
M6C-G	50	100	50	1:3	4	2	2	0.08	13.9	1.05	1.87
M6B-G	50	75	75	1:3	4	2	12	0.28	13.9	0.94	
M6A-G	50	50	100	1:3	4	2	11	0.26	14.0	3.61	
M6E-G	50	100	100	1:4	2	1	10	0.22	14.2	0.91	1.19
M6E-G	50	100	100	1:4	2	1	10	0.22	12.9	1.46	
M6E-G	50	100	100	1:4	4	2	4	0.12	13.2	0.40	1.54
M6E-G	50	100	100	1:4	4	2	4	0.12	13.2	1.06	
M6E-G	50	100	100	1:4	4	2	4	0.12	14.0	1.14	
M6E-G	50	100	100	1:4	4	2	10	0.24	14.0	1.45	
M6E-G	50	100	100	1:4	4	2	10	0.24	14.0	1.45	
M6E-G	50	100	100	1:4	4	2	10	0.24	14.0	2.27	
M6E-G	50	100	100	1:4	4	2	12	0.28	13.9	2.98	

From Table 5.9, a mix proportion comprising C:S 1:2 - 1:4, after curing for 28 days, the highest strength obtained was 3.16 N/mm². This mix had achieved the strength target of more than 3.0 N/mm². By this, it is proven that adding of quarry dust could increase the strength, but the presence of GTL (paraffin liquid) will not affect the strength of foamed concrete when combining to others material.

5.7 Summary

This chapter has discussed the target foamed concrete for road embankment design is 1 – 3 N/mm². With additional quarry dust, the strength could increase 30 – 60%. The use of GTL could reduce the water-cement ratio, however it maintained the workability. Finally, it is found that wet curing could obtain high strength. The finding in this chapter will be used in the big volume production in Chapter 6 and design part in Chapter 7.

CHAPTER 6

BIG VOLUME PRODUCTION OF FOAMED CONCRETE

6.1 General

In the research, a pilot project will be undertaken to determine the feasibility of using foam concrete as fill material. This soil replacement method has never been used in any real project in Sarawak construction industry. To produce foamed concrete as fill material, a mass amount of foamed concrete is required, with this the next phase of experiment will be to identify the best method of mass producing foamed concrete by using this new innovative mixing technique.

6.2 Criteria for Mass Concreting

On the onset, it is important to evaluate the main outcome to be achieved in the production of foamed concrete in big volume for the pilot project. Mixing in the laboratory and factory pose different challenges and must be tackled first and foremost before undertaking the pilot project. The main criteria are given as follows:-

a. Density

The foamed concrete used in the pilot project fulfil the density targeted in the design steps. The density range at category D is about $1000 \pm 50 \text{ kg/m}^3$. The additional foam bubbles in the mix must be optimized and kept homogeneous. The main difficulty expected is the segregation of materials particularly the sand and cement slurry. It is mentioned in Section 4.3.2, density can be easily obtained in innovative mixing technique. However, the density

of big volume foamed concrete production should also be as easy as production on small scale in laboratory.

b. Workability

In order to make the mix flowable, it must be cohesive and consistent. This can be achieved by ensuring free water is available in fresh condition. Workability of the mix is measured by using mini slump cone. Based on laboratory experiments, the mix is flowable at a slurry spread of 13 – 16 cm and above. The main challenge in fulfilling this target will be the moisture condition of the fine aggregates. In the laboratory, mixing only use dry sand and workability can be controlled easily. The situation for mass concreting in the real plant will be different, as the sand moisture is difficult to predict. The only method is to adjust the amount of water to the dry fresh foamed concrete until it can performed self-compacting. It will not be as simple for mixing in the plant for mass volume in the control range of workability at 13 – 16 cm.

c. Shrinkage

In simple term, shrinkage is a reduction in size due to evaporation of lighter materials, water and foam bubbles. The newly found innovative mixing technique had successfully eliminated this problem from happening in laboratory mixing. However, most of the moulds used in the laboratory is 150 × 150 × 150 mm in size. It is inevitable that the size of mould will also increase manifold in the case of the pilot project required for the precast samples. There should not be any potential for the foam bubbles to flow freely and slowly move vertically to the surface. If this scenario were to occur, the ambient temperature or relative humidity will cause the bubbles to evaporate into the air. Heavier materials like fine aggregates will fill in the voids and settle downwards. Thus, shrinkage will occur if such

scenario prevail. The challenge will be the ability of foam bubbles to be added into the mix must adhere strongly to the surface of fine aggregate particles.

d. Concrete Strength

The strength of hardened foam concrete is related to the mix proportion used. Chapter 5 has explained, the strength of foamed concrete shall be obtained at the range of 1 – 3 N/mm². This is to ensure the produced foamed concrete for pilot project could undertake the same pressures from the fill materials (sand or earth fills) above it. The most critical factor here is the ability of the foam concrete to undertake dynamic loads for heavily loaded trucks or steam rollers during construction stage. It is important that the ingredients are mixed effectively to obtain the targeted strength.

e. Volume of Mix

In laboratory mixing, for a 50 kg mass of cement, the volume of foamed concrete mix produced varied from 100 – 150 litres. The density of mix, ingredient materials used and mixer effectiveness were the controlling variables. In comparison to big volume mix, the above 3 parameters need to be taken into special consideration. Foamed concrete mix is different from a normal mix with respect to total volume because foamed concrete mix expands in volume by the foam bubbles. For an initial density of 1800 – 2000 kg/m³, the volume shall be less than 50 litres. With the addition of foam bubbles the volume can increase 3 – 4 times. Strict control in laboratory mixing had made the production process easy. However, big volume mixing will be challenging for the project. The main target is to achieve 1000 litres (1 m³) per mix. This approach is considered conservative and less risky. The importance of achieving an appropriate volume per mix is due to the economics of foamed concrete. If the volume produced is too little which is less than 1000 litres per mix,

the cost of production will be high. Then the idea of using foamed concrete as fill materials will be too expensive and not practical. This makes the production in big volume mix become more challenging. The method of obtaining foam bubbles and blending of fine bubbles in the mix is important in the process.

All the above criteria will transform the process of mass concreting. The following section will explain the investigation works done. The initial approach was to use ready mix truck to supply the concrete and cast in-situ. As the experiments progressed, few failures were achieved and the idea was not ideal. Subsequently, the idea of factory mix and pre-casting the samples were tested. The results were encouraging and practical to be applied for the pilot project later.

6.3 Producing of Precast Foamed Concrete

There will be two stages of investigation to produce big volume of foamed concrete. This investigation is to understand the difficulty of producing foamed concrete in volume. There are two (2) stages of experiments as shown in Table 6.1 to conduct this investigation as follows:-

Table 6.1: Two (2) stages of experiments producing foamed concrete

Stage	Experiment	Method
1.	Comparison of mixing technique (Laboratory)	Concreting the production of foamed concrete using the conventional technique and new found innovative technique in size $300 \times 300 \times 300$ mm
2.	Comparison of mixer (Concrete plant)	Two (2) types of mixers used to mixing the foamed concrete

The aim of these two (2) experiments is to produce good quality of foamed concrete to supply to pilot project.

6.3.1 Stage 1: Comparison of Mixing Technique

This experiments is to compare the feasibility of two (2) mixing technique in large volume production of foamed concrete. The independent parameter of this experiment is the size of foamed concrete block which is $300 \times 300 \times 300$ mm instead of standard cube $150 \times 150 \times 150$ mm. This purpose of using the bigger block size is to understand further on the changes in volume due to segregation and shrinkage, where the changes may not significant for $150 \times 150 \times 150$ mm block size. The mix proportion for this experiment is 1:2 as shown in Table 6.2.

Table 6.2: Mix proportion for Two (2) mixing techniques

Mix ingredients	
Mix Proportion: (1+ Fly ash 15%) : 2 where, Cement 85 kg, Fly Ash 15 kg and Sand 200 kg.	
Conventional Method	Innovative technique
W/C = 29% SP = 1.3%, so water = 27.7% Slump 17 – 23 cm	Water is added in to achieve the slump 13 – 16 cm

For the mix proportion above, there are a total of 2 batches of mixing foamed concrete cube produced and the experiment results are summarized in Table 6.3:-

Table 6.3: Conventional mixing technique in 300 × 300 × 300 mm mold

Batch	Conventional mixing technique		
	Density (kg/m ³)	Volume of Hardened foamed concrete (m ³)	Shrinkage (mm)
MI-1	945.3	0.0254	18.27
MI-2	959.7	0.0254	17.58
MI-3	965.1	0.0255	16.88
MI-4	988.0	0.0255	16.19
MI-5	997.5	0.0256	15.83
MI-6	997.7	0.0257	14.81
MI-7	999.0	0.0256	15.14
MI-8	1005.1	0.0254	17.91
MI-9	1019.3	0.0253	18.46
MI-10	1026.2	0.0253	19.29
MI-11	1031.6	0.0254	17.91
MI-12	1033.3	0.0255	17.02
MI-13	1047.8	0.0254	18.18
	Average	0.0255	17.19
	Volume change	1-(0.0255/0.0270)	5.73%

Note: 0.027m³ is the volume of 300 x 300 x 300 mm fresh foamed concrete

The results shown that the conventional mixing technique obtain shrinkage on average of 17.19 mm, where the foamed concrete volume is reduced by 5.73%. It is more challenging to use conventional mixing technique to product foamed concrete as explained in Section 4.3.1.1.

Another trial has also been conducted by using conventional mixing technique. There are three (3) layers casting for a cube as show in Figure 6.1. This method could achieve the zero shrinkage it is but a lot of time is wasted as shown in Figure 6.3.



Figure 6.1: Foamed concrete block produced in three-layer by using conventional mixing technique

Due to the shrinkage problem, new mixing technique was innovated as described in Section 4.3.2 and a trial mixing in larger volume $300 \times 300 \times 300$ mm was conducted as shown in Table 6.4 below.

Table 6.4: Innovative mixing technique in $300 \times 300 \times 300$ mm mold

Batch	Innovative mixing technique		
	Density (kg/m^3)	Volume of Hardened foamed concrete (m^3)	Shrinkage (mm)
MV-1	952.93	0.0266	4.91
MV-2	959.11	0.0266	4.79
MV-3	965.31	0.0266	4.65
MV-4	970.71	0.0266	4.62
MV-5	977.95	0.0265	5.19
MV-6	980.98	0.0265	5.41
MV-7	984.43	0.0265	5.34
MV-8	994.61	0.0266	4.57
MV-9	1003.10	0.0266	4.20
MV-10	1013.75	0.0267	3.85
MV-11	1032.39	0.0267	3.50
MV-12	1039.56	0.0266	5.22
MV-13	1046.76	0.0264	6.22
	Average	0.266	4.81
	Volume change	$1-(0.0266/0.0270)$	1.481%

Note: 0.027m³ is the volume of $300 \times 300 \times 300$ mm fresh foamed concrete

Table 6.4 shows the innovative technique is successfully achieved without any shrinkage for bigger volume as shown in Figure 6.2.



Figure 6.2: Foamed concrete block produced by new mixing technique with minimised shrinkage

With this, it is proven that the innovative mixing technique could produce foamed concrete with minimised shrinkage even in big volume. This experiment will be conducted in the factory for production bigger volume for pilot study at the size of precast foamed concrete cube in 500 x 750 x 1500 mm.

6.3.2 Stage 2: Comparison of Mixer

There are two (2) methods that can be conducted for big volume mixing:-

a. Mixing by mixer truck

Mixer truck is used to produce foamed concrete less than 4.5 m^3 . The dry mix is put into the mixer drum then foam and water is added to achieve the density and slump and transfer to casting site. Figure 6.3 shows the big volume mixing in mixer truck.



Figure 6.3: Big volume mixing in mixer truck; (a) mixer truck, (b) spraying the foam into the mixer truck drum, (c) slump measurement and (d) pouring into the formwork

Mixing foamed concrete in mixer truck is difficult due to the inability of mixer drum unable to rotate and distribute the mix evenly and lot of solid material will stick to the mixer drum wall. Normally the drum rotates in 15 rpm during mixing and 2 rpm during transportation. In this situation, it is unable to control the accuracy of the quality of foamed

concrete (w/c and slump) and this creates segregation and fragility often occur by this method as shown in Figure 6.4.



Figure 6.4: Foamed concrete segregation and fragility

b. Horizontal Shaft Mixer

In the concrete plant factory, horizontal shaft mixer is normally used for mixing ordinal concrete. This research has attempted to use horizontal shaft mixer to produce foamed concrete as shown in Figure 6.5. The foamed concrete mixing by batching plant can produce more than 4.5 m³ foamed concrete with average rotation of 12.6 rpm.



(a)



(b)



(c)



(d)

Figure 6.5: Producing foamed concrete in batching plant; (a) Mixing plant, (b) Foam preparation, (c) Horizontal shaft mixer and (d) Transferring into the mixer truck

In this method, the w/c and the slump follow the exact laboratory data. This method produces a good foamed concrete without any segregation and fragility as shown in Figure 6.6.



Figure 6.6: Foamed concrete produced by batching plant

This is to ensure that the final product is complied with the design requirements. From this study, it is figured out that the quality of foamed concrete from big volume mixing may differ from laboratory mixing depending on the transportation duration and segregation of the foam concrete produced in the factory.

After several trial mixes, it is found that the slump shall be adjusted to 18 – 19 cm due to the distance of transportation from the plant.

6.3.3 Findings in Stage 1 and Stage 2

After the experiments, it is found that the new mixing technique can easily produce good quality foamed concrete homogeneously (no segregation) and minimised shrinkage. The mixing in concrete truck is not easy to control the rotation speed and long distance transportation that will cause segregation of foam concrete. Concrete truck will only be used to transport the foamed concrete slurry to the precast mould. The horizontal shaft mixer

normally could provide good quality foamed concrete with slump 18 – 19 cm. The results are shown in Table 6.5.

Table 6.5: Comparison of mix proportion to produce foamed concrete in 0.844 m³

No	C:S ratio	Cement (kg)	Quarry Dust (kg)	Sand (kg)	Fly Ash (kg)	Foam (L)	Water (L)	Compressive strength (N/mm ²)	Average Compressive strength (N/mm ²)
BV-1	1:2.3	283.3	472.3	-	189	108	188	1.40	1.40
								1.57	
								1.23	
BV-2	1:1.8	337.6	472.6	-	135	75	112	1.30	1.41
								1.51	
BV-3	1:2	295.4	590.8	-	-	63	74	1.80	1.84
								2.12	
								1.61	
								2.01	
								1.62	
BV-4	1:3.7	211.3	636.5	141.4	-	43	54	1.81	1.83
								1.56	
								2.11	
BV-5	1:4.4	156.0	-	684.1	24	29	45	1.61	1.75
								2.01	
								1.62	

From Table 6.5, it is known that mix proportion no. 3 which is at C:S ratio 1:2 has produced the highest compressive strength compared to others. Appendix H shows the compressive strength for C:S ratio 1:2 after 743 days with average strength result of 1.8 N/mm². The purpose of compressive test done on 743 days (approximately 2 years) is to find out any changes of strength for more than 28 days and the result has proven that the foamed concrete strength is constant after 28 days and suitable as road embankment material.

In relation to these results, this research study has decided to use C:S ratio in 1:2.or the mix proportion no. BV-3 as shown in Table 6.1 to produce the foamed concrete block in size 750 × 750 × 1500 mm or 0.844 m³ for pilot project.

6.4 Water Absorption

Water absorption is important for foamed concrete embankment design. Table 6.6 has described the percentage of water absorption for mix proportion 1:2 density of 1000 kg/m³ form big volume production.

Table 6.6: Water absorption for mass production in C:S ratio 1:2

No.	Density (kg/m ³)	Water Absorption (%)	No.	Density (kg/m ³)	Water Absorption (%)
1	619.40	70.53%	16	901.90	60.83%
2	630.69	74.80%	17	930.84	51.38%
3	645.21	85.44%	18	948.45	53.77%
4	660.39	82.68%	19	966.07	56.19%
5	680.45	78.66%	20	989.00	57.27%
6	699.63	72.83%	21	1000.90	55.50%
7	712.57	74.18%	22	1016.51	39.12%
8	749.80	73.66%	23	1025.55	45.42%
9	778.74	53.04%	24	1049.41	43.23%
10	782.50	64.00%	25	1180.94	29.19%
11	810.70	55.53%	26	1187.63	34.31%
12	821.71	51.35%	27	1227.00	12.15%
13	856.64	31.35%	28	1241.22	23.14%
14	866.40	39.87%	29	1271.00	24.59%
15	875.85	48.39%	30	1300.00	24.30%

The percentages of water absorption could represent the percentage of air void of the foamed concrete that allow water to fill in. With this, the mass of water and mass of foamed concrete have been combined into one density for calculation in the replacement to soft soil.

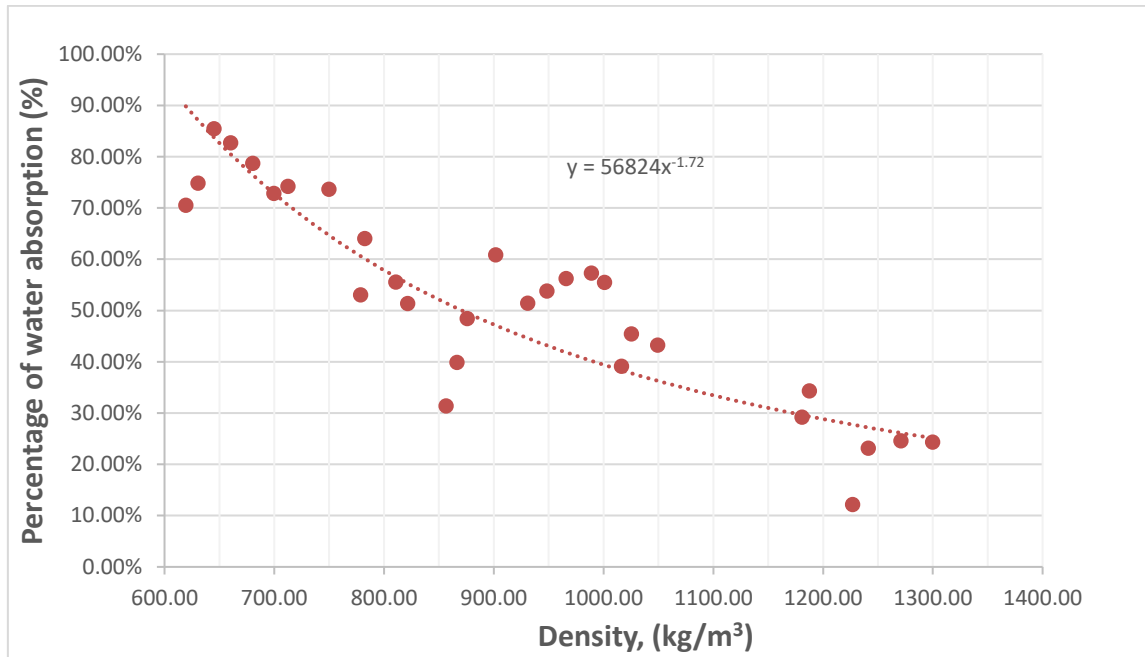


Figure 6.7: Chart of foamed concrete density vs percentage of water absorption

Table 6.5 shows the average water absorption for foamed concrete density from 600 – 1300 kg/m³. Figure 6.7 will be used in all design of foamed concrete embankment.

6.5 Result of Mass Production

From the results, it is proven that the mix 1:2 with density 1000 kg/m³ and slump 18-19 cm with water absorption 39.00% is a good foamed concrete for peat replacement materials. This design mix demonstrates an acceptable compressive strength and range of density which is suitable for mass production for experiment on project site. This mix proportion is also considered low shrinkage, which with average shrinkage is 11.71 mm, this will further elaborate in Section 7.8.1.

This result of new mixing technique was used to produce the lightweight foamed concrete foundation (road embankment) as shown in Figure 6.8 for pilot project.



Figure 6.8: Foamed concrete foundation by new mixing technique

CHAPTER 7

PILOT PROJECT AT SG. BAKO ROAD

7.1 General

This chapter will discuss the use of foamed concrete as a fill material for road embankment on a real project site at Sg. Bako Kuching. The settlement data will be measured and compared based on several types of construction method. This aspect of research is a continuation of the research work by Lai (2011) based on the laboratory works. The researcher produced a model to design the use of foamed concrete as alternative fill material in road construction of soft ground. A pilot project was undertaken to evaluate the constructability and impact of using such fill material.

7.2 Project Brief

The research project is part of the project “Proposed Bridge over Sg. Bako and Access Road to Kpg. Bako, Kuching Division”. This project is implemented by JKR Sarawak with a total road length of 3.512 km, where the road length allocated for research is 75 m as shown in Figure 7.1.

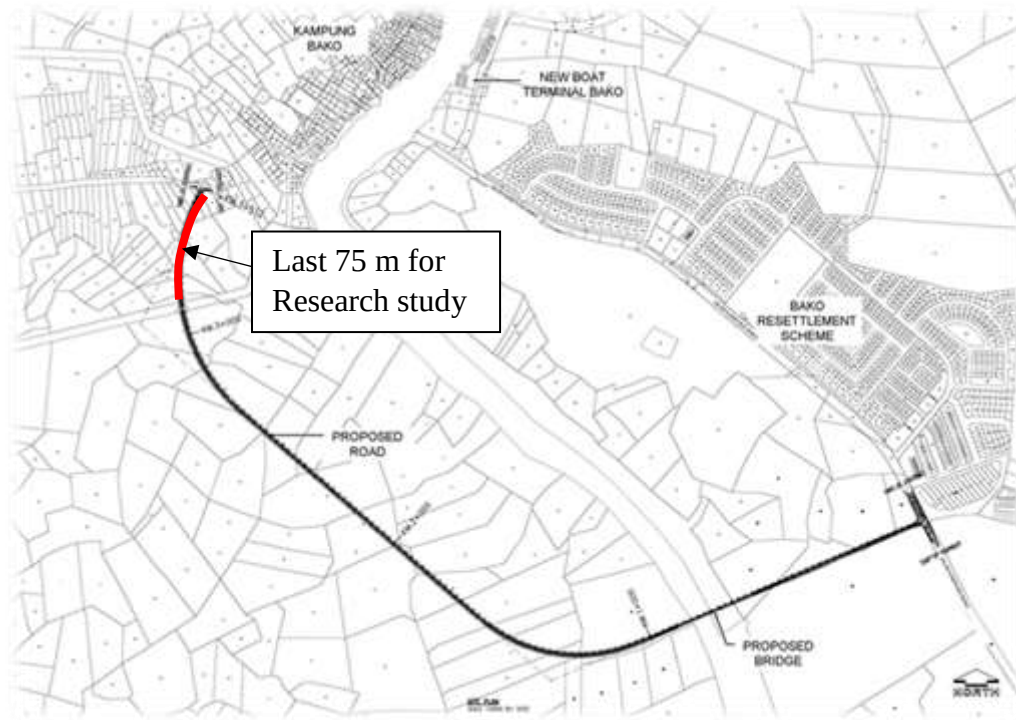


Figure 7.1: The site plan for research study

Table 7.1: Technical information for the project

	DESCRIPTION
Project Site	The proposed road for this project is approximately 3.5 km in length, branching off from the existing Jalan Kampung Bako and connecting via a proposed reinforced concrete bridge crossing Sungai Bako to Kampung Bako.
Design Standard	Road Engineering Association Malaysia (REAM) R3 Road Standard
Design Width	6.0 m wide single carriageway with 2.5 m wide shoulder (inclusive of 0.25 m marginal strip) on each side of proposed carriageway.
Design Tolerance	The proposed road pavement is designed to withstand the equivalent standard axle load (ESAL) of five (5) millions.
Total Length of Road	3,512 m

For the purpose of this research study, there are (4) four types of different design constructed within the 75 m. The total research cost is estimated to be approximately RM 260,000.00 (Refer to Appendix J).

7.3 Site Investigation

Based on the Soil Investigation Report as shown in Figure 7.2, the clay underneath the said 75 m is marine clay, which is a type of soft clay. The water level is at 1.2 m below the ground level. The Mackintosh probe test is used to determine the bearing capacity and the result is shown in Figure 7.2 below:-

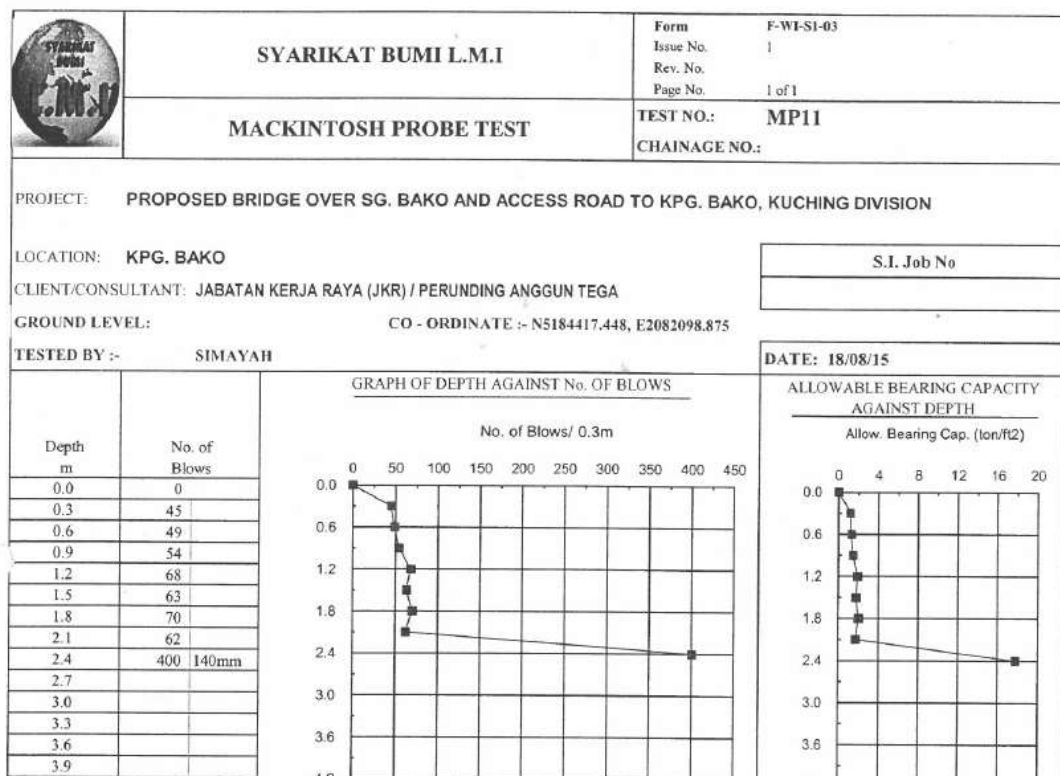


Figure 7.2: SI report for research study

Based on Figure 7.2, the bearing capacity at level 1.2 m is 3 ton/ft² or 0.287 N/mm²

7.4 Design of Road Embankment Using the Replacement Method.

The target in this chapter is to meet the design consideration on road design in peat soil replacement with foamed concrete base. The strength requirement for foamed concrete is 1 - 3 N/mm² with density 1000 kg/m³. This strength is enough for easy for transportation,

lifting and installation of the precast foamed concrete without any damages for the purpose of replacement in peat soil. Figure 7.3 shows the proposed cross section for the road embankment for this research.

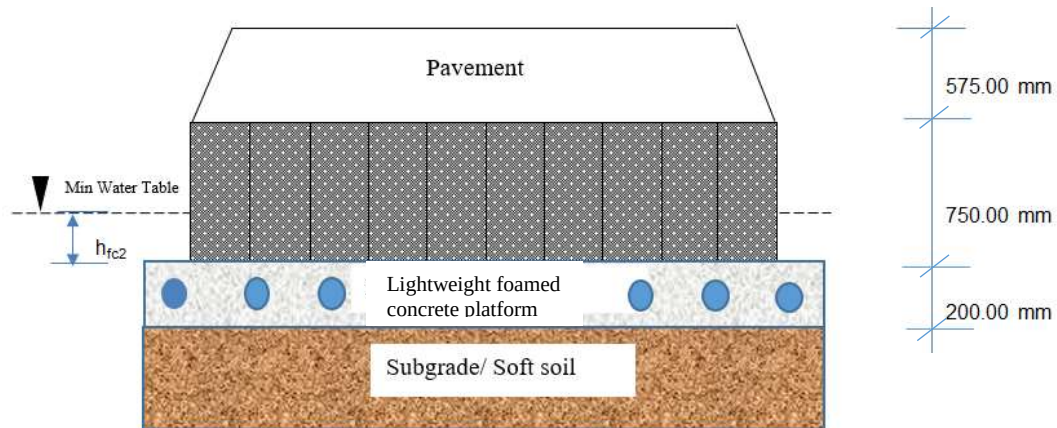


Figure 7.3: Proposed foamed concrete foundation for soil replacement on peatland in Sarawak

Figure 7.3 shows the proposed design for road embankment to replace soft ground, where this design needs to consider a few parameters as follows: -

- | | |
|---------------------------------|--|
| a. Density of soil: | Maximum 1500 kg/m ³ |
| b. Height of water table: | 1.2 m from pavement level |
| c. Density of foamed concrete: | 1000 kg/m ³ |
| d. Strength of foamed concrete: | Minimum 1 - 3 N/mm ² |
| e. Others addition features: | Lightweight platform, pavement and vehicle |

The following design step is produced to calculate the replacement factor and determine the size of the foamed concrete foundation:-

- Calculated total load include vehicle, pavement and foamed concrete
- Calculated the buoyancy force
- Calculated the total loading and volume
- Compare the moment actual to moment allowed.
- Calculated the numbers of precast foamed concrete foundation
- Compare the density and bearing capacity based on site actual density and bearing capacity.

A design spreadsheet is produced to calculate the replacement factor then determine the size of the foamed concrete foundation as shown in Figure 7.4.

DESIGN OF FOAMED CONCRETE EMBANKMENT ON SOFT GROUND

A Loading vehicle plus pavement

Vehicle (Include road furniture)	10 tons	98.10 kN
Contract Point	2	49.05 kN
Vehicle (Include road furniture) to road (Assume to 1m ²), I ₁	49.05 kN/m²	
Premix	100 mm	0.100 m
Premix Density	2.3 tons/m ³	22.56 kN/m ³
Premix load to road, I ₂	2.26 kN/m²	
Road base	250 mm	0.250 m
Aggregate Density	2.6 tons/m ³	25.51 kN/m ³
Road base load to subbase, I ₃	6.38 kN/m²	
Subbase	225 mm	0.225 m
Aggregate Density	2.6 tons/m ³	25.51 kN/m ³
Sub base load to foamed concrete embankment, I ₄	5.74 kN/m²	
Total pavement Load, L_p = I₁+I₂+I₃+I₄	63.42 kN/m²	

Area of road pavement

Width of road pavement (include road shoulder)	13 m
Length of road pavement	12.5 m
Area of road, A ₁	162.50 m²
Total Load for road pavement, L₁ = L_p x A₁	10306.02 kN
	1050368.76 Kg
Pavement thickness, T _p	575.00 mm
Total Volume of pavement, V ₁ =A ₁ x T _p	93.44 m³

Area of road pavement

Width of road pavement (include road shoulder)

[13](#) m

Length of road pavement

[12.5](#) mArea of road, A_1 **162.50 m²****Total Load for road pavement, $L1 = L_p \times A_1$** **10306.02 kN****1050368.76 Kg**Pavement thickness, T_p

575.00 mm

Total Volume of oavement, $V1 = A_1 \times T_p$ **93.44 m³****B Volume of upvc pile**

Cylinder radius

[0.1](#) m

Cylinder length

[1.2](#) m

Nos of cylinder

[60](#) NosVolume of cylinder, $V2$ **2.26 m³****Mass of lightweight platform submerged in water**Height of lightweight platfrom, H_{lwp} [0.2](#) mWidth of lightweight platfrom, W_{lwp} [15](#) mLength of lightweight platfrom, L_{lwp} [12.5](#) mArea of lightweight platfrom, A **187.5 m²****Volume of lightweight platform, $V3$** **37.5 m³**Density of concrete in grade 20, ρ_{c1} [2400.00](#) kg/m³Density of concrete (excluded volume for cylinder upvc pipe), $\rho_{c2} = (V3 - V2/V3) \times \rho_{c1}$ **2255.24 kg/m³**Density of water, ρ_w (input 0 if not lightweight platform)[1000.00](#) kg/m³**Mass of submerged lightweight platform, $L2 = V3(\rho_{c2} - \rho_w) \times 9.81$** **461769.73 kg****C Mass of foamed concrete (FC) embankment above water**Density of foamed concrete, ρ_{fc} [1000](#) kg/m³Height of FC, H_{fc1} [750](#) mmHeight of FC submerged in water, H_{fc2} [0](#) mmHeight FC above water, $H_{fc3} = H_{fc1} - H_{fc2}$

750 mm

Width of FC, W_{fce1} **13 m**Length of FC, L_{fce1} **12.5 m**Area of FC, A_{fce1} **162.5 m²****Total mass of FC above water, $L3 = \rho_{fc} \times H_{fc3} \times A_{fce}$** **121875 kg****Total Volume, $V4 = H_{fc3} \times A_{fce}$** **121.88 m³****D Mass of foamed concrete (FC) embankment in water**Density of foamed concrete, ρ_c [1000](#) kg/m³So, percentage of water absorption, W_A (From Figure 6.7)[39](#) %So, density foamed concrete + water absorption, ρ_{c2} **1390 kg/m³**Height of FC submerged in water, H_{fc4} [0](#) mmWidth of FC, W_{fce2} **13 m**Length of FC, L_{fce2} **12.5 m**Area of FC, A_{fce2} **162.5 m²****Volume of FC submerged in water, $V5$** **0 m³**Density of water, ρ_w 1000.00 kg/m³**Mass of submerged lightweight platform, $L4 = V5(\rho_{c2} - \rho_w) \times 9.81$** **0.00 kg**

E	Total loading, $L = L1+L2+L3+L4$	1634013.48 kg
F	Total Volume, $V = V1+V3+V4+V5$	252.81 m ³
G	<u>FINAL CHECK</u>	
i	<u>Check Bearing Capacity</u>	
	Area bottom lightweight platfrom, A_{blp}	187.50 m ²
	Downward Force at bottom of lightweight platfrom, $DF = L/A_{blp}$	85.49 kN/m ²
		0.89 Ton/ft ²
	Bearing capacity from site investigation at, Q_u at 1.5 m	3.00 Ton/ft ² (OK)
ii	<u>Check Density</u>	
	Average density, L/V	6463.34 kg/m ³
	Density excavated soft ground (from site)	1500.00 kg/m ³ (Not OK)
	Noted: If (1) is "OK", (2) no need to check, the FC will support by the soil bearing capacity. If (1) is "Not OK", (2) Must "OK", so, the FC will react float based on density comparison. If (1) is "Not OK", (2) "Not OK", the design need to review.	

Figure 7.4: The design spreadsheet developed to calculate the size of the foamed concrete foundation

Form the design calculation, the result of checking bearing capacity is “OK”, this means the foamed concrete embankment will not settle further.

From the design spreadsheet at Figure 7.4, the outcome of this foamed concrete with UPVC pipe System is as shown in Figure 7.5 or Appendix K.

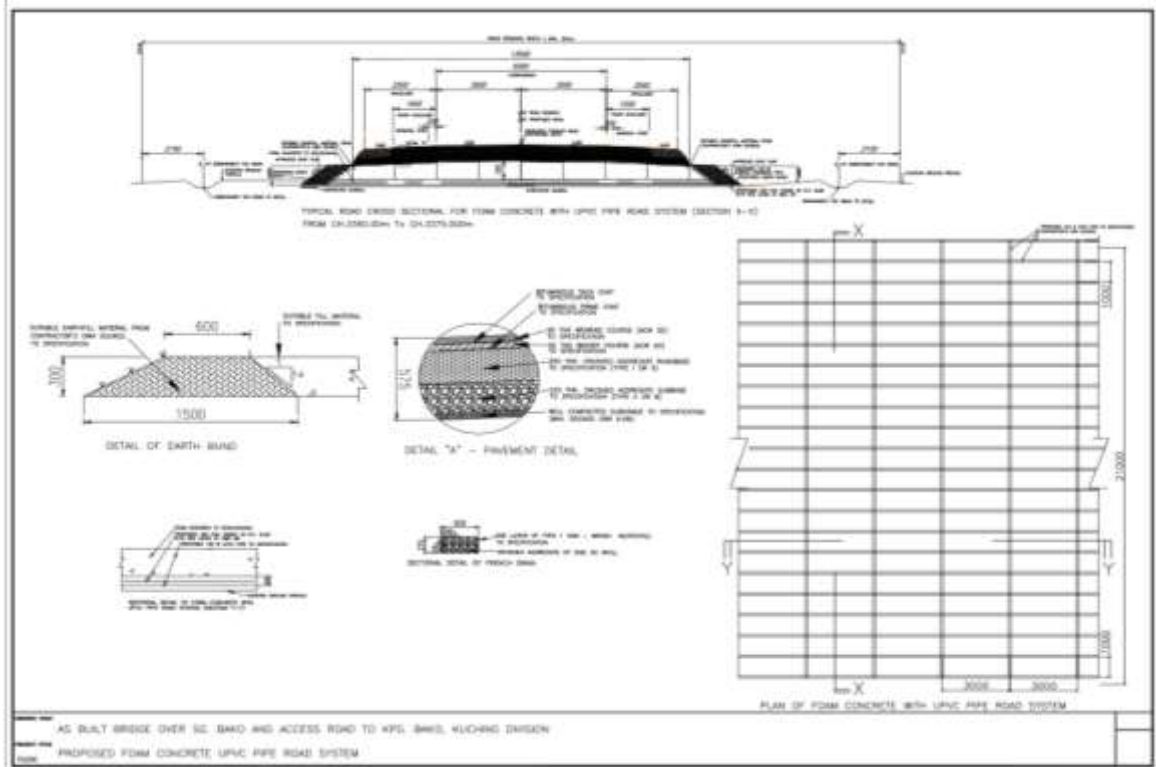


Figure 7.5: Proposed foamed concrete road embankment with UPVC pipe floating system

7.4.1 Summary of Road Embankment Design

The use of lightweight platform is to improve the soil bearing capacity and avoid huge excavation. Lightweight platform is a buoyancy structure that will provide uplift force when submerged in water. The uplift force depends on the depth of water table and the number of UPVC pipe.

The design spreadsheet is suitable for soft soil and peat soil. For foamed concrete road embankment on peat soil, the final checking on density shall be pass. The total average density of the foamed concrete road embankment must be less than the density of surrounding peat soil. However, for soft soil, the total downward load must be less than the bearing capacity underneath. The bearing capacity check must show “OK”.

7.5 Construction of Foamed Concrete Embankment

The final stage of this research study is to construct the foamed concrete embankment based on the design. Figure 7.6 shows the road embankment cross section for the pilot project.

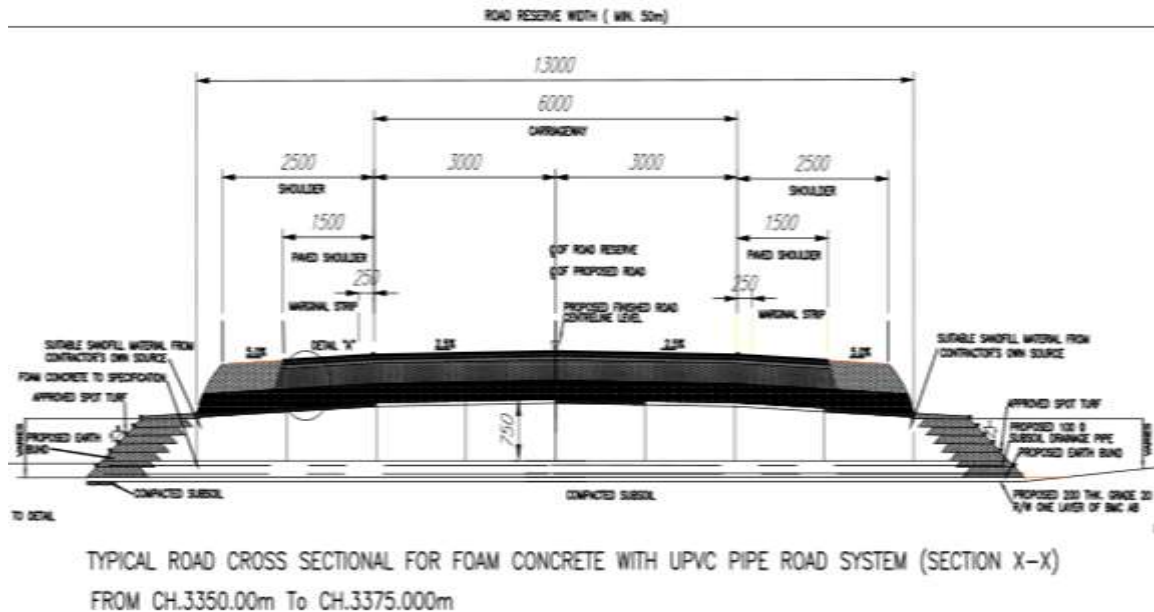


Figure 7.6: Details of foamed concrete embankment

Figure 7.6 shows the cross section of the foamed concrete road for the Bako pilot project. The width of road pavement is 6 m with the allowed research's length of 75 m. On this 75 m, the following four (4) types of design will be undertaken for comparison:-

- Replacement method with PVD, Geotextile and Surcharge
- Replacement with foamed concrete sit on lightweight platform
- Replacement with suitable material sit on lightweight platform
- Replacement with suitable material without soil treatment

The length of each type of design is 25 m as shown in Figure 7.7.

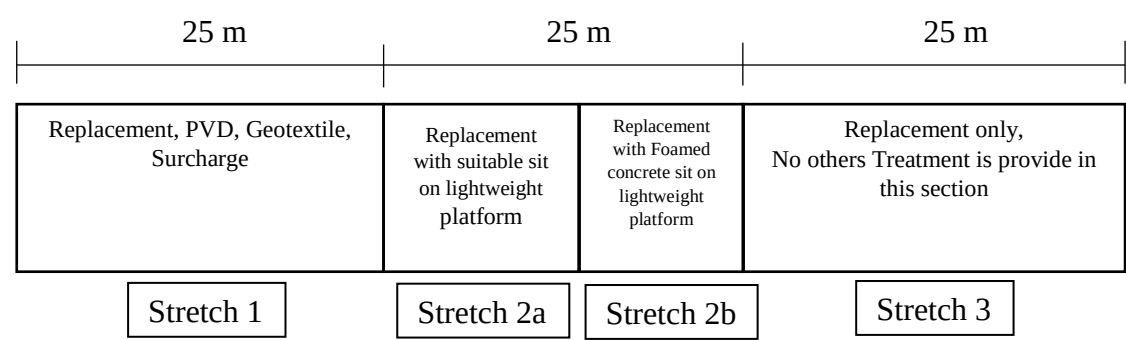


Figure 7.7: Subgrade for 3 different section

There are Six (6) settlements plate installed at stretch 2. Two (2) units of settlement plates were installed at Stretch 1 and 3 for comparison. The area for installation are shown in Figure 7.8 and Figure 7.9.

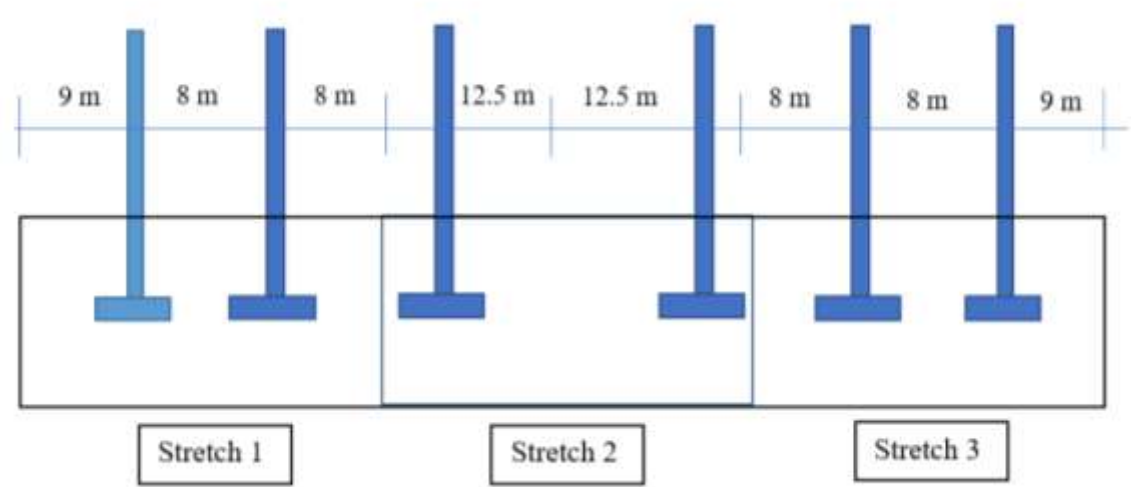


Figure 7.8: Installation of settlement plate at 3 stretches of road embankment

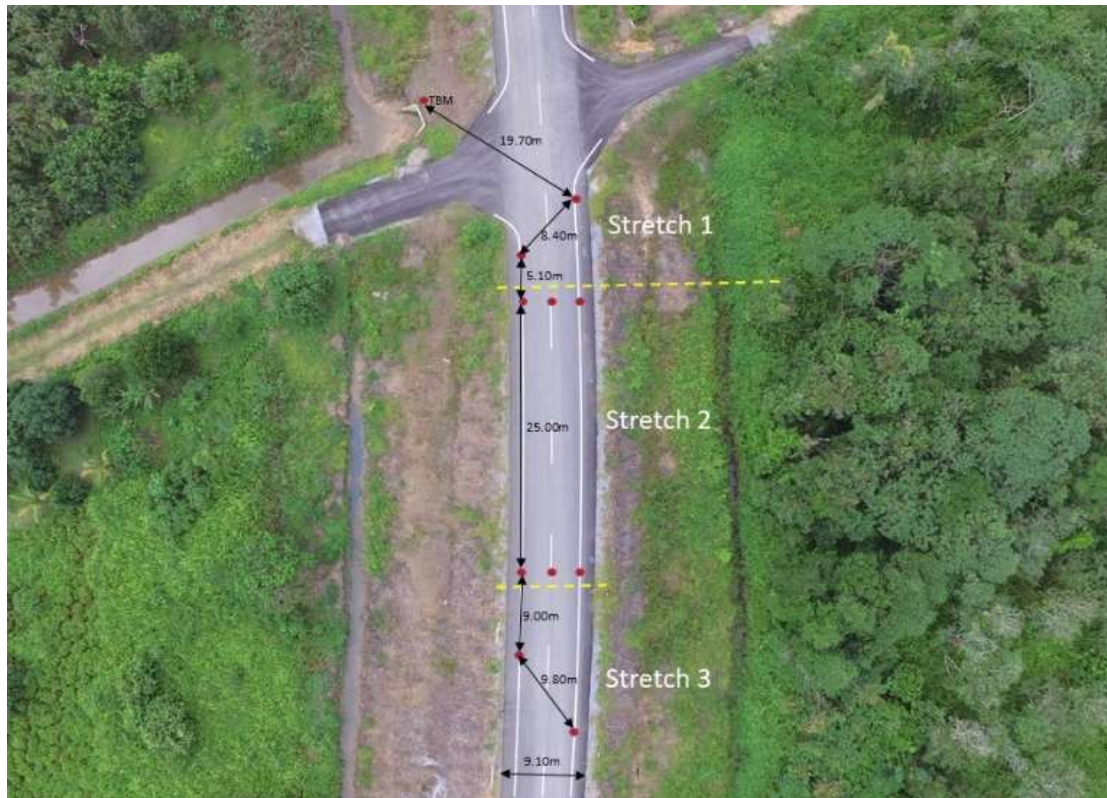


Figure 7.9: Aerial photo shows the location of settlement plate for three (3) different stretches

7.6 Sequence of Placement Foamed Concrete Foundation for Bako Road project

It is decided to use the precast foamed concrete 750 x 750 x 1500 mm for this pilot project due to site constraint and machinery flow on site. Figure 7.10 shows the casting of precast foamed concrete in factory.



Figure 710: The casting of precast foamed concrete in mold

The hardened precast foamed concrete is transported to project site for placement after the site has been set up.



(a) UPVC Pipe installation



(b) Settlement Plate installation



(c) Concreting the base



(d) Levelling Surveying



(e) Installation of Precast foamed concrete



(f) Road completed

Figure 7.11: Placement of foamed concrete block

Figure 7.11 shows the sequence of installation of foamed concrete foundation on site based on drawing in Figure 7.6.

7.7 QAQC Requirement of Foamed Concrete Foundation for Bako Road Project

There are several quality control requirement to be fulfilled at both factory and project site as stated in Appendix I, Figure 7.12 explains the sequence of installation on site Any quality control requirement that are not fulfilled will be rejected and redone.



(a) Level between block shall less than 20 mm



(b) Crack on the block is not allowed



(d) Gap between shall less than 10 mm



(e) Plastic crack shall not more than 5 mm

Figure 7.12: Quality assurance on foamed concrete block after installation

7.8 Results Measured on Pilot Project

As described previously, the purpose of this pilot project is to study and compare the results for four (4) types of design method. There are two (2) parameters that have been measured and collected for results analysis.

7.8.1 Shrinkage

A total 160 numbers of 750 x 750 x 1500 mm foamed concrete block had been measured and the results are shown in Table 7.2.

Table 7.2: The shrinkage for precast foamed concrete block

Row No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	706	741	750	731	742	714	755	750	748	745	746	743	748	746	747	750
2	750	737	750	754	750	715	750	748	750	750	747	748	748	750	749	741
3	739	739	737	738	739	719	730	750	732	737	738	747	750	748	746	739
4	738	746	736	740	747	737	748	743	742	743	743	733	754	744	731	731
5	749	736	735	745	745	735	740	735	725	729	729	720	735	725	725	720
6	751	711	750	739	742	744	733	738	732	729	728	716	735	735	725	694
7	739	739	735	744	747	737	744	724	735	739	749	710	746	748	744	733
8	746	754	743	739	738	740	730	738	732	750	720	728	746	707	716	722
9	739	731	748	723	726	750	722	741	746	742	724	738	740	730	713	726
10	750	729	734	733	720	743	750	731	736	739	712	749	740	735	750	743
Average Height (mm)	740.75	736.25	741.80	738.64	739.59	733.40	740.26	739.80	737.77	740.35	733.62	733.14	744.24	736.82	734.58	729.91
Mould Height (mm)	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00
Average Shrinkage (mm)	9.25	13.75	8.20	11.37	10.41	16.60	9.74	10.20	12.23	9.65	16.38	16.86	5.76	13.18	15.42	20.09
Grand Average Shrinkage (mm)	11.71															

Table 7.2 shows only 11.71 mm for shrinkage from the average 160 numbers of foamed concrete block in total. Therefore the shrinkage is only 1.56%, which can be concluded that the shrinkage can be ignored during the mass production based on this finding.

7.8.2 Settlement

The settlement result were collected during construction stage and after construction stage. There are Four (4) settlements result were taken as described in Figure 7.7, the result being compared to JKR's common use settlements criteria (Cream, 2015) stated as follows to evaluation the acceptable range of settlements.

- i. 10% of total consolidation settlements
- ii. 200 mm over first 3 post construction years
- iii. 400 mm over first 7 post construction years
- iv. Differential settlement 1 : 500

a. Settlement Result During Construction Stage

This settlement result is obtained during construction period. The purpose of the measurement is to know the initial settlement between the three different stretches as shown in Table 7.3.

Table 7.3: Initial settlement result during construction stage

Stretch 1 (With Geotextile and PVD)						Remarks
	4/11/2017	27/1/2018	24/2/2018	23/6/2018	7/10/2018	
1	0.000	0.003	0.006	0.008	0.008	
2	-	-	-	0.000	0.000	
Average	0.000	0.003	0.006	0.008	0.008	
Accumulative settlement (m)	0	-0.003	-0.006	-0.008	-0.008	
Stretch 2a (Slab with soil fill)						
	4/11/2017	27/1/2018	24/2/2018	23/6/2018	7/10/2018	
1	0.000	0.018	0.035	0.040	0.065	
2	0.000	0.005	0.005	0.020	0.020	
3	0.000	0.000	0.001	0.051	0.100	
Average	0.000	0.007	0.013	0.037	0.061	
Accumulative settlement (m)	0	-0.007	-0.013	-0.037	-0.061	
Stretch 2b (Slab with foamed concrete)						
	4/11/2017	27/1/2018	24/2/2018	23/6/2018	7/10/2018	
4	0.000	0.020	0.025	0.095	0.068	
5	0.000	0.015	0.120	0.129	0.150	
6	0.000	0.053	0.054	0.113	0.116	
Average	0.000	0.029	0.066	0.112	0.112	
Accumulative settlement (m)	0	-0.029	-0.066	-0.112	-0.112	
Stretch 3 (No treatment)						
	4/11/2017	27/1/2018	24/2/2018	23/6/2018	7/10/2018	
1	-	-	-	0.000	0.070	
2	-	-	-	0.000	0.230	
Average	-	-	-	0.000	0.150	
Accumulative settlement (m)	-	-	-	0	-0.15	

The results shows stretch 1 only settles in 8 mm for the period of 11 months, while stretch 2a have settled in 61 mm and stretch 2b have settled for 112 mm in 11 months. It is noted that from Figure 7.13, stretch 3 have obtained the highest settlement of average of 150 mm in 3.5 months as described in Table 7.3.

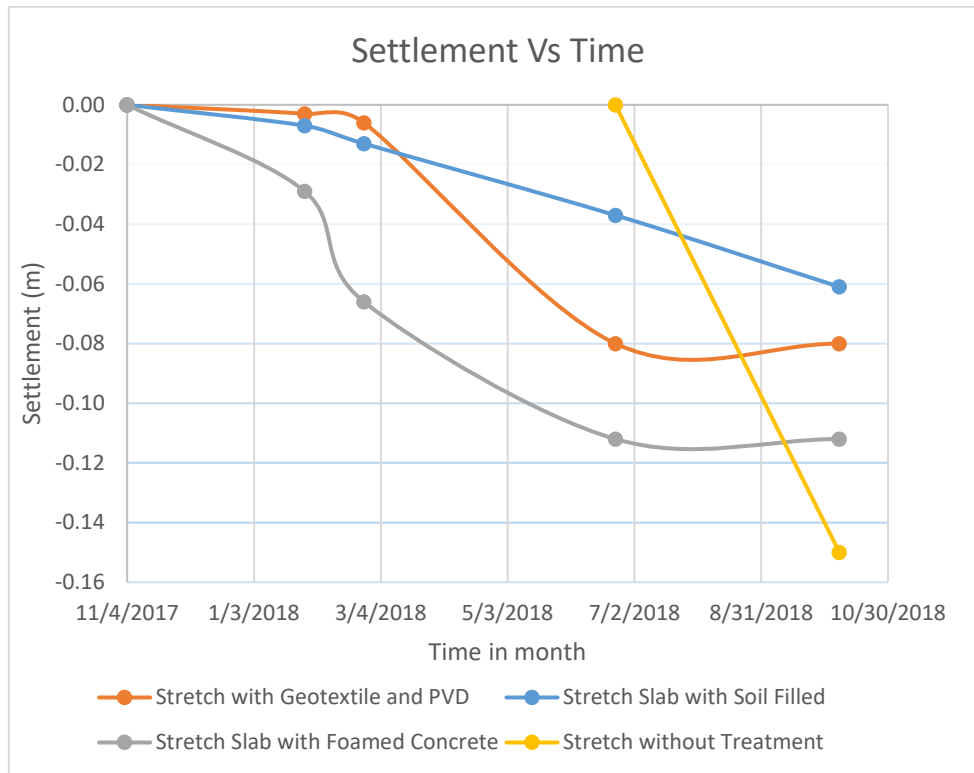


Figure 7.13: Settlement of road embankment in different type of soil treatment

Figure 7.13 also shows that the performance of geotextile and PVD treatment in resist settlement is better than other method. However the settlement gauge was installed during construction stage and soil embankment is affected by heavy machinery from time to time, which may also disturb the settlement gauge and affected the result.

b. Settlement Result After Construction Stages

The settlement results are measured after 4 months of laying the premix, Table 7.4 shows the result of settlement after construction stages.

Table 7.4 Settlement (m) result after construction stage

Stretch 1 (With Geotextile and PVD)				
	4/11/2018	2/1/2019	1/3/2019	Total Settlement
1	0	0.001	0.000	0.001
2	0	0.006	0.006	0.006
			Average	-0.004
Stretch 2a (Slab with soil fill)				
	4/11/2018	2/1/2019	1/3/2019	Total Settlement
1	0	0.002	0.002	0.002
2	0	0.001	0.001	0.003
3	0	0.001	0.001	0.001
			Average	-0.002
Stretch 2b (Slab with foamed concrete)				
4	0	0.002	0.002	0.002
5	0	0.002	0.002	0.002
6	0	0.000	0.000	0.000
			Average	-0.001
Stretch 3 (No treatment)				
	4/11/2018	2/1/2019	1/3/2019	Total Settlement
1	0	0	0.001	0.001
2	0	0	0.001	0.001
			Average	-0.001

Table 7.4 has shown that there is almost no settlement for the four stretch. This may be because of the good compaction of subbase and road base for others stretch. Furthermore, the settlement is predicted to be not significant in such a short period. The continue settlement measurement is need for long term monitoring not less than 7 years.

7.8.3 Settlement Result Analysis

Table 7.5 explains the summary of settlements for both before and after construction stage. It is proven that the conventional design (stretch 1) have the least settlement as compared to others stretch. However the foamed concrete foundation (stretch 2b) has achieved the acceptable range of settlement at primary settlement and subsequent settlement.

Table 7.5: Settlements comparison for several design

Experiments	Design method	Primary Settlement (mm) (12 months)	Subsequent Settlement (mm) (4months)	Settlement Rating
Stretch 1	Replacement, PVD, Geotextile, Surcharge	8	0	I
Stretch 2a	Replacement with suitable material sit on lightweight platform	61	0	II
Stretch 2b	Replacement with foamed concrete sit on lightweight platform	112	0	III
Stretch 3	Replacement with suitable material without soil treatment	150	1.0	IV

This study has categorised the settlement based on rating to identify a suitable method for the construction. The higher rating does not mean that the method is the most suitable, as it also depends on the cost and duration of construction.

Based on this, it is understood that foamed concrete foundation in the rating III, but this method could save surcharging time as compared to convention method in the rating I. In term of settlement, the foamed concrete foundation settlement is within the acceptable range based on JKR's settlement criteria.

7.9 Conclusion

This chapter has discussed Four (4) types of treatment design in settlement, where the settlement result is significant when compared during the construction stage and after construction. Although the foamed concrete embankment may not the lesser settlement solution, it is acceptable for soft soil treatment.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 General

The objective of this research has been achieved through studies on laboratories mixing, industrial mixing and practical application on the project site. These studies are elaborated in details from Chapter 1 to Chapter 7.

8.2 Conclusion

The findings from previous chapter have led to the following conclusions on achieving the research objective:-

- a. The investigating of the foamed concrete density at a certain range is to ensure that at these range the foamed concrete have strength, no segregation, less shrinkage, consistence in volume. By this, the research has found that the best cement-sand ratio is 1:2, it allows density of foamed concrete to produce 700 – 1300 kg/m³ with strength above 1 N/mm². This ratio will be an important factor for the industry phase to produce big volume of foamed concrete at economy scale. Hence, the research must ensure the industrial foamed concrete fulfils the six (6) important criteria as stated below:-
 - i. Density of fresh and harden foamed concrete is related each other's
 - ii. Workability is at allowable level for performed self-compacting and easy casting
 - iii. Shrinkage is consistent to all samples
 - iv. Strength for samples is suitable on transportation and load bearing

- v. Economical for industry phase, where, cheap cost in production
 - vi. Can produce in mass production
- b. A new mixing technique has been found, which could produce big volume of foamed concrete that allows for the target density to be achieved easily. The previous conventional mixing technique has difficulties to estimate the density and caused shrinkage easily. This new technique allows the foamed concrete density be achieved as low as 700 kg/m^3 without exhibiting any shrinkage upon hardening. In some cases, the density could be lowered to 500 kg/m^3 . This technique will be useful when the mass production is required to fulfil the market demand.
- c. This study concludes that the strength of foamed concrete depends directly on the water-cement ratio. Based on this research finding, the w/c range of 0.20 – 0.30 can produce stronger harden foamed concrete. For w/c above 0.30, the strength produced is low and fragile due too much liquid in the mix and the foam bubble float to the surface.
- d. The research has successfully transfer the method of production of foamed concrete from small scale (laboratory mixing) to big scale (plant mixing). Laboratory production of foamed concrete can be done easily in small volume. This research has achieved the production in mass volume by using horizontal shaft mixer at batching plant. The mixing process proved that foamed concrete has been successful produced at the 3 m^3 per mixing. With this, the research has filled the gap for section 2.10(d), where it is successfully transferred the laboratory mixing technique to industrial mixing technique.
- e. The research has successfully minimized the shrinkage of foamed concrete with the overall result of shrinkage for foamed concrete embankment is 11.71 mm or 1.56%, which is not more than 2.0 % of the embankment depth. Therefore, shrinkage could be

assumed to be neglectable in the production. By this, the research has filled the gap for Section 2.10(e), where it has minimized the dry shrinkage of foamed concrete.

- f. As per the design spreadsheet shown on Chapter 7, the research has developed a spreadsheet to design a road embankment using foamed concrete as fill material. The design had encountered the buoyancy force by using the lightweight platform, which is to reduce the huge excavation. With this, the research has filled the gap for Section 2.10(b), where it has successfully reduced the replacement fill material load.
- g. The research has successfully minimized the settlement of foamed concrete road embankment. By comparing the performance of foamed concrete embankment with the others three (3) design, the foamed concrete as fill material had proven to be more practical option in resistance of settlement based on JKR's settlement criteria. The research had fill the gap for section 2.10(c), where reduced the settlement of foamed concrete embankment in the acceptable range.

8.3 Recommendation

Generally, this research study has achieved the target objective as stated in Chapter 1, Section 1.8. However it is noted that a few technical issues needed to be solved by the next researchers as stated below:-

- a. Due to limitation of project site, the pilot study has been implemented on soft soil - marine clay, it is proposed the next research could carry out the study on the worst soft soil condition at deep peat area.
- b. The precast foamed concrete block is used to achieve the replacement objective, as this method is found easy for quality control at factory casting and installation. However this method is restricted for remote area due to transportation. The cast in

situ method is recommended but issue on quality control and mixing plant set up shall be solved in advance.

- c. Finally, investigation on the foamed concrete to able be pumped direct to the construction site is needed to avoid cold joint and ensure the foamed concrete homogeneously, then shorten the placement time.

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APPENDICES

Appendix A: Number of Road Accident Cases by Division in Sarawak,
2005-2013

Division	Year								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
Kuching	6,002	5,850	5,853	6,038	6,417	6,454	6,238	6,575	6,730
Sri Aman	463	479	457	516	555	596	601	633	578
Sibu	1,460	1,665	1,812	2,024	2,100	2,135	2,395	2,329	2,349
Miri	2,940	3,070	3,148	3,103	3,292	3,471	3,505	3,646	3,682
Limbang	287	282	328	274	266	307	336	347	306
Sarikei	290	314	375	469	541	593	663	666	661
Kapit	52	47	42	55	124	146	193	193	143
Samarahan	730	725	851	912	968	1,044	1,157	1,105	1,176
Bintulu	1,516	1,811	1,780	1,608	1,826	1,875	2,082	2,337	2,351
Mukah	243	300	310	290	315	379	565	526	473
Betong	227	251	228	201	251	253	229	221	251
<i>Total</i>	14,210	14,794	15,184	15,499	16,655	17,253	17,964	18,578	18,700

(Source: Sarawak Social Indicators Bulletin)

Appendix B: Statistics Data for Scrap Tyre in Malaysia by JPJ

Table B.1: Projection of the number of the registered vehicle from 2011-2015

Type of vehicles	Total Projection of Vehicle				
	2011	2012	2013	2014	2015
Motorcycle	9,095,971	9,550,770	10,028,308	10,529,724	11,056,210
Motorcar	8,284,202	8,698,412	9,133,332	9,589,999	10,069,499
Mini Bus	62,607	65,737	69,024	72,475	76,099
Bus					
Taxi	79,214	83,174	87,333	91,700	96,285
Hire and Drive Car	16,397	17,217	18,078	18,982	19,931
Vans	837,818	879,709	923,695	969,880	1,018,374
Light trucks (<2.5 tonnes, and non-diesel trucks)					
Lorry (>2.5 tonnes), Trailers and Others					
Light truck	406,192	426,501	447,827	470,218	493,729
Heavy vehicles					
Total	18,782,401	19,721,521	20,707,597	21,742,976	22,830,125

Table B.2: Estimation of annual and daily tonnage for scrap tires generation by categories in Malaysia.

Type of vehicles	Annual Tonnage				Daily Tonnage			
	2007	2008	2009	2010	2007	2008	2009	2010
Motorcycle	17,667	18,839	19,801	20,854	48	52	54	57
Motorcar	91,945	98,653	105,196	112,575	252	270	288	308
Mini Bus	310	320	334	348	1	1	1	1
Bus	7,494	7,733	8,075	8,421	21	21	22	23
Taxi	3,649	3,796	4,024	4,330	10	10	11	12
Hire and Drive Car	577	764	833	926	2	2	2	3
Goods Vehicle	1,730	1,805	1,862	1,930	5	5	5	5
Light trucks (<2.5 tonnes, and non-diesel trucks)	9,515	9,929	10,240	10,614	26	27	28	29
Lorry (>2.5 tonnes), Trailers and Others	59,315	61,897	63,834	66,165	163	170	175	181
Light truck	8,558	8,950	9,284	9,693	23	25	25	27
Heavy vehicles	8,150	8,523	8,842	9,231	22	23	24	25
Total	208,911	221,209	232,325	245,087	572	606	637	671

Table B.3: Projection of annual and daily tonnage of scrap tyres (2011-2015)

Type of vehicles	Annual tonnage					Daily tonnage				
	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
Motorcycle	21,830	22,922	24,068	25,271	26,535	60	63	66	69	73
Motorcar	115,979	121,778	127,867	134,260	140,973	318	334	350	368	386
Mini Bus	368	387	406	426	447	1	1	1	1	1
Bus	8,903	9,348	9,815	10,306	10,821	24	26	27	28	30
Taxi	4,436	4,658	4,891	5,135	5,392	12	13	13	14	15
Hire and Drive Car	918	964	1,012	1,063	1,116	3	3	3	3	3
Vans	2,053	2,155	2,263	2,376	2,495	6	6	6	7	7
Light trucks (<2.5 tonnes, and non-diesel trucks)	11,290	11,854	12,447	13,069	13,723	31	32	34	36	38
Lorry (>2.5 tonnes), Trailers and Others	70,377	73,896	77,590	81,470	85,543	193	202	213	223	234
Light truck	10,236	10,748	11,285	11,849	12,442	28	29	31	32	34
Heavy vehicles	9,749	10,236	10,748	11,285	11,849	27	28	29	31	32
Total	256,138	268,945	282,392	296,512	311,337	702	737	774	812	853

Appendix C: Technical data foaming agent: Softclean 27AE

Kao Industrial (Thailand) Co., Ltd.	
15th Fl., Wave Place Bldg., 55 Wireless Rd., Pathumwan, Bangkok, 10330 Thailand	Tel : +66 (0) 2655-4433 Fax : +66 (0) 2655-4333~5

Technical Information

SOFTCLEAN 27AE

(Foaming Agent for Light Weight Concrete)

【 Introduction 】

SOFTCLEAN 27AE is a new type of foaming agents for lightweight concrete products which has been developed by Kao based on the technique in surface chemistry.

SOFTCLEAN 27AE is designed to be safe, easy in handling, and satisfy the cost performance required in each application field.

【 Applications 】

- Lightweight precast panels
- Foaming mortar for grouting in tunnels and sewerage works
- Foaming mortar for filling underground shelters

【 Special Features 】

1. Liquid form for easy handling
2. Good storage stability (at 0 - 40°C) because no organic solvent is contained
3. Easily soluble in water of wide range of hardness and temperature
4. Total volume does not change after being mixed into cement slurries, mortar, and concrete because the fine and strong foams is obtained
5. No effect on the setting time of cement slurries

【 Product Data & Technical Data 】

Appearance	: Light Yellow Liquid
Active Ingredient	: 25.0 - 29.0 %
pH (5% solution)	: 6.5 - 7.5
Viscosity (CPS)	: 1,000 Max

Method of Application

The standard dosage of SOFTCLEAN 27 AE is 0.1 - 0.3 % by weight of cement.
For example, after 0.1 - 0.3 kg of SOFTCLEAN 27 AE is poured into the mixing water, the whole is transferred into the mixer together with 100 kgs of cement.

Packing

210 kgs net in plastic drum

Appendix D: Test sample labelling indicator

Label	Batch	Cement (kg)	Sand (kg)	Quarry Dust (kg)	Fly Ash (kg)	C:S Ratio
M1	A	12.5	25	-		1:2
M1	B	25	50	-		1:2
M1	C	75	150	-		1:2
M1	D	25	75	-		1:3
M1	E	25	100	-		1:4
M2	A	12.5	12.5	-		1:1
M2	B	20	20	-		1:1
M2	C	25	25	-		1:1
M2	D	75	75	-		1:1
M3	A	50	50	-		1:1
M3	B	100	100	-		1:1
M3	C	150	150	-		1:1
M3	D	200	200	-		1:1
M3	E	300	300	-		1:1
M4	A	50	100	-		1:2
M4	B	50	150	-		1:3
M4	C	50	200	-		1:4
M4	D	50	250	-		1:5
M5	A	100	200	-		1:2
M5	B	100	300	-		1:3
M6	A	50	50	100		1:1:2
M6	B	50	75	75		1:1.5:1.5
M6	C	50	100	50		1:2:2
M6	D	50	0	100		1:0:2
M6	E	50	100	100		1:2:2
M7	A	100	0	100		1:0:1
M7	B	100	100	100		1:1:1
M8	A	75	225	-		1:3

Appendix D show the test sample labelling, there are 45 times mixing (see Appendix E) for the whole research study, each C:S ratio could repeat few time in different mass to obtain the big data for the analyst later.

Appendix E: Data for fresh density vs hardened density for foamed concrete in C:S ratio 1:1

Label - cube no.	Cement	Sand	Water- cement ratio	Fresh Density Foam Concrete (F) (kg/m ³)	Harden Density Foam Concrete (H) (kg/m ³)	Factor H/F
M2B-1	20	20	0.06	621.6	612.6	98.55
M2B-2	20	20	0.06	627.2	608.3	96.99
M2B-3	20	20	0.06	634.3	625.1	98.55
M2B-4	20	20	0.06	638.9	619.4	96.95
M2B-5	20	20	0.06	644.1	615.3	95.53
M2B-6	20	20	0.06	653.5	626.1	95.81
M2B-7	20	20	0.06	669.2	657.4	98.24
M2B-8	20	20	0.06	682.6	603.9	88.47
M3A-1	50	50	0.08	811.6	782.5	96.41
M3A-2	50	50	0.08	816.3	793.8	97.24
M3A-3	50	50	0.08	832.3	809.5	97.26
M3A-9	50	50	0.08	848.1	845.3	100.33
M3A-5	50	50	0.08	864.1	821.0	95.01
M3A-4	50	50	0.08	864.3	820.1	94.89
M3A-8	50	50	0.08	868.7	845.2	97.29
M3A-7	50	50	0.08	890.3	838.2	94.15
M3A-12	50	50	0.08	900.5	876.4	97.32
M3A-6	50	50	0.08	901.5	821.9	91.17
M3A-11	50	50	0.08	910.3	872.9	95.89
M3A-14	50	50	0.08	916.4	901.9	98.42
M3A-15	50	50	0.08	931.4	906.7	97.35
M3A-16	50	50	0.08	945.9	911.1	96.32
M3C-1	150	150	0.10	948.6	891.3	93.96
M3A-17	50	50	0.10	952.6	927.7	97.39
M3A-18	50	50	0.10	955.6	930.4	97.36

Label	Cement	Sand	Water-cement ratio	Fresh Density Foam Concrete (F) (kg/m ³)	Hardened Density Foam Concrete (H) (kg/m ³)	Factor H/F
M3A-23	50	50	0.10	960.2	945.2	98.44
M3A-10	50	50	0.10	965.2	852.1	88.28
M3A-22	50	50	0.10	970.3	942.2	97.10
M3A-21	50	50	0.10	985.2	939.6	95.37
M3A-25	50	50	0.10	992.1	966.2	97.39
M3A-20	50	50	0.10	995.9	930.7	93.45
M3A-28	50	50	0.10	997.3	971.9	97.45
M3A-29	50	50	0.10	1002.7	976.6	97.40
M3A-32	50	50	0.10	1010.0	983.7	97.40
M3A-34	50	50	0.10	1016.3	990.2	97.43
M3A-37	50	50	0.10	1046.6	1019.6	97.42
M3A-38	50	50	0.10	1058.6	1025.2	96.84
M3A-41	50	50	0.10	1067.4	1040.0	97.43
M3A-42	50	50	0.10	1079.5	1051.9	97.44
M3A-43	50	50	0.10	1079.6	1051.9	97.43
M3A-44	50	50	0.10	1082.4	1054.8	97.45
M3B-1	100	100	0.10	1088.9	1050.0	96.43
M3B-2	100	100	0.10	1114.0	1086.7	97.55
M3A-36	50	50	0.10	1117.5	1010.5	90.43
M3B-3	100	100	0.10	1245.0	1214.1	97.52
M3A-67	50	50	0.10	1266.8	1235.6	97.54
M3B-4	100	100	0.10	1437.0	1402.6	97.61
M3A-70	50	50	0.10	1459.0	1389.6	95.24
M3B-5	100	100	0.10	1468.0	1433.6	97.66
				Average		96.39
				Average losses in percentage = 100% - 96.39%		3.61

Appendix E show 49 numbers of foamed concrete cube taken for fresh and hardened density comparison during each mixing. There are only 4 mixing been conduct to obtain the above data.

Appendix F: Volume of Foam agent (without diluted) used in various C:S ratio

Mixing no.	Label	C:S	Cement (kg)	Sand (kg)	Foam agent used (Liter)	Volume of Foamed concrete (m ³)
1	M2A	1:1	12.5	12.5	1.50	0.0075
2	M2A	1:1	12.5	12.5	1.63	0.0063
3	M2C	1:1	25.0	25.0	4.00	0.0316
4	M2C	1:1	25.0	25.0	5.71	0.0363
5	M3A	1:1	50.0	50.0	13.08	0.1266
6	M3A	1:1	50.0	50.0	13.25	0.1266
7	M2D	1:1	75.0	75.0	17.91	0.1580
8	M2D	1:1	75.0	75.0	22.80	0.1590
9	M3B	1:1	100.0	100.0	22.13	0.1660
10	M3B	1:1	100.0	100.0	26.13	0.2080
11	M3D	1:1	200.0	200.0	9.33	0.2589
12	M3D	1:1	200.0	200.0	16.96	0.2218
13	M3E	1:1	300.0	300.0	19.79	0.2605
14	M1A	1:2	12.5	25.0	1.20	0.1045
15	M1B	1:2	25.0	50.0	2.40	0.1350
16	M1B	1:2	25.0	50.0	3.20	0.1645
17	M4A	1:2	50.0	100.0	7.00	0.1561
18	M4A	1:2	50.0	100.0	5.00	0.1635
19	M4A	1:2	50.0	100.0	6.80	0.1682
20	M4A	1:2	50.0	100.0	10.35	0.1750
21	M1C	1:2	75.0	150.0	14.37	0.1830
22	M1C	1:2	75.0	150.0	14.70	0.2118
23	M5A	1:2	100.0	200.0	19.50	0.2618
24	M1D	1:3	25.0	75.0	1.50	0.0983
25	M4B	1:3	50.0	150.0	5.50	0.1080
26	M4B	1:3	50.0	150.0	6.10	0.1195
27	M4B	1:3	50.0	150.0	5.20	0.1288
28	M4B	1:3	50.0	150.0	8.30	0.1366
29	M8A	1:3	75.0	225.0	10.35	0.1632
30	M5B	1:3	100.0	300.0	22.25	0.2250
31	M1E	1:4	25.0	100.0	1.20	0.14550
32	M4C	1:4	50.0	200.0	6.70	0.15610
33	M4C	1:4	50.0	200.0	5.90	0.18329
34	M4C	1:4	50.0	200.0	7.60	0.18978
35	M4C	1:4	50.0	200.0	13.00	0.22170
36	M4C	1:4	50.0	200.0	8.70	0.22110
37	M4C	1:4	50.0	200.0	7.20	0.22905
38	M4C	1:4	50.0	200.0	7.90	0.22257
39	M4C	1:4	50.0	200.0	7.90	0.23896
40	M4C	1:4	50.0	200.0	6.70	0.24137
41	M4C	1:4	50.0	200.0	10.35	0.24150
42	M4C	1:4	50.0	200.0	8.36	0.26375
43	M4C	1:4	50.0	200.0	15.00	0.26550
44	M4C	1:4	50.0	200.0	18.00	0.28330
45	M4D	1:5	50.0	250.0	7.03	0.20400

Appendix F show the quantity of foam agent used and volume of produced foamed concrete on each mixing.

Appendix G: Data of compressive strength in various Cement: Sand ratio

Table G1: Compressive strength for mix proportion Cement: Sand 1:1 in Density 1000 kg/m³

Label – cube no.	Cement (kg)	Sand (kg)	Cement ratio	Sand ratio	Water (Litre)	Water/ cement ratio (w/c)	Slump (cm)	Compressive Strength (kN/m ²)	Average Compressive Strength (kN/m ²)
M2C-1	25	25	1	1	0	0	14	0.3	0.4
M3A-23	50	50	1	1	0	0	14	0.5	
M3B-1	100	100	1	1	2	0.02	13.5	0.4	0.4
M3B-11	100	100	1	1	2	0.02	12.8	0.4	
M3B-2	100	100	1	1	4	0.04	14	0.3	0.33
M3B-3	100	100	1	1	4	0.04	14	0.35	
M3B-10	100	100	1	1	5	0.05	13.5	0.25	0.26
M3B-4	100	100	1	1	5	0.05	13.5	0.27	
M3B-5	100	100	1	1	6	0.06	13.5	0.3	0.28
M3B-6	100	100	1	1	6	0.06	13.5	0.33	
M3B-7	100	100	1	1	6	0.06	13.5	0.24	
M3B-9	100	100	1	1	6	0.06	14.5	0.25	
M2C-2	25	25	1	1	2	0.08	13	0.35	0.55
M2D-1	75	75	1	1	6	0.08	13.5	0.1	
M2D-2	75	75	1	1	6	0.08	14	0.2	
M2D-4	75	75	1	1	6	0.08	13.5	0.2	
M2D-6	75	75	1	1	6	0.08	13.5	0.3	
M3A-24	50	50	1	1	4	0.08	14	0.2	
M3A-27	50	50	1	1	4	0.08	13	0.2	
M3A-33	50	50	1	1	4	0.08	13.2	0.5	
M3A-35	50	50	1	1	4	0.08	13	0.86	
M3A-36	50	50	1	1	4	0.08	13.85	1	
M3A-39	50	50	1	1	4	0.08	13	1.03	
M3A-40	50	50	1	1	4	0.08	13	0.86	
M3A-41	50	50	1	1	4	0.08	12.8	1.4	0.60
M3A-42	50	50	1	1	5	0.1	13.2	0.55	
M3A-43	50	50	1	1	5	0.1	13.8	0.65	0.65
M2A-1	12.5	12.5	1	1	2	0.16	13.6	0.92	
M2C-4	25	25	1	1	4	0.16	14.2	0.38	1.50
M3A-22	50	50	1	1	11	0.22	13.8	1.7	
M3A-44	50	50	1	1	11	0.22	14	1.3	0.90
M2A-2	12.5	12.5	1	1	3	0.24	15.5	0.86	
M2D-7	75	75	1	1	12	0.24	13.9	0.94	

There are few numbers of mixing e.g. M2B (20 kg: 20 kg), M3C (150 kg: 150kg), M3D (200kg: 200 kg) and M3E (300 kg: 300 kg) are no compressive strength result taken, it is mixing for others purpose as experiment for Appendix F. The results have shown few outline data such as M3A-35, M3A-36, M3A-39, M3A-40, M3A-41 and M2A1. It is believed that some technical error had occurred during the mixing or the sand material not from the same source.

Table G2: Compressive strength for mix proportion Cement: Sand 1:2 in Density 1000 kg/m³

Label	Cement (kg)	Sand (kg)	Cement ratio	Sand ratio	Water (Litre)	Water/ cement ratio (w/c)	Slump (cm)	Compressive Strength (kN/m ²)	Average Compressive Strength (kN/m ²)
M4A-1	50	100	1	2	0	0	12	0	0.50
M4A-3	50	100	1	2	0	0	12.5	0.5	
M4A-2	50	100	1	2	0	0	12	1	
M4A-4	50	100	1	2	2	0.04	13.9	1.05	1.05
M4A-5	50	100	1	2	4	0.08	13.2	1.06	1.12
M4A-6	50	100	1	2	4	0.08	14	1.14	
M4A-8	50	100	1	2	4	0.08	13.9	1.24	
M4A-9	50	100	1	2	6	0.1	13.2	1.21	1.28
M4A-7	50	100	1	2	6	0.1	13.2	1.34	
M4A-11	50	100	1	2	10	0.2	14.2	0.91	1.62
M4A-14	50	100	1	2	10	0.2	14	1.42	
M4A-15	50	100	1	2	10	0.2	12.8	1.46	
M4A-16	50	100	1	2	10	0.2	12.8	1.63	
M4A-17	50	100	1	2	10	0.2	13.9	2.02	
M4A-10	50	100	1	2	10	0.2	14	2.27	
M4A-18	50	100	1	2	12	0.24	13.9	0.94	2.41
M4A-19	50	100	1	2	12	0.24	13.8	2.81	
M4A-13	50	100	1	2	12	0.24	13.8	2.89	
M4A-12	50	100	1	2	12	0.24	13.9	2.98	
M4A-21	50	100	1	2	14	0.28	14	1.5	1.5

Table G3: Compressive strength for mix proportion Cement: Sand 1:3 in Density 1000 kg/m³

Label	Cement (kg)	Sand (kg)	Cement ratio	Sand ratio	Water (Litre)	Water/ cement ratio (w/c)	Slump (cm)	Compressive Strength (kN/m ²)	Average Compressive Strength (kN/m ²)
M4B-2	50	150	1	3	0	0	12.0	0.6	0.6
M4B-12	50	150	1	3	8	0.16	13.5	0.98	0.96
M4B-1	50	150	1	3	8	0.16	14	0.94	
M4B-7	50	150	1	3	12	0.24	13.2	0.99	
M4B-8	50	150	1	3	12	0.24	13.2	1.05	1.07
M4B-9	50	150	1	3	12	0.24	14.3	1.21	
M4B-10	50	150	1	3	12	0.24	13.2	1.02	
M4B-10	50	150	1	3	14	0.28	13.9	1.24	1.51
M4B-5	50	150	1	3	14	0.28	13.4	1.77	

Same to Table G1, M1A (12.5 kg: 25 kg), M1B (25 kg: 50kg), M1C (75 kg: 150kg), M5A (100kg: 200 kg) for Table G2 and M1D (25 kg: 75kg), M5B (100 kg: 300 kg) are no compressive strength result taken, it is mixing for others purpose as experiment for Appendix F.

Table G4: Compressive strength for mix proportion Cement: Sand 1:4 in Density 1000 kg/m³

Label	Cement (kg)	Sand (kg)	Cement ratio	Sand ratio	Water (Litre)	Water/ cement ratio (w/c)	Slump (cm)	Compressive Strength (kN/m ²)	Average Compressive Strength (kN/m ²)
M4C-1	50	200	1	4	0	0	12.0	0.6	0.6
M4C-2	50	200	1	4	10	0.28	12.9	1.55	1.56
M4C-3	50	200	1	4	10	0.28	12.8	1.57	
M4C-4	50	200	1	4	15	0.30	12.8	2.01	2.07
M4C-5	50	200	1	4	15	0.30	12.8	2.05	
M4C-6	50	200	1	4	15	0.30	12.8	2.15	

Same to Table G1, M1E (25 kg: 100 kg) is no compressive strength result taken, it is mixing for others purpose as experiment for Appendix F.

Appendix H:

Result of compressive strength after 743 days

GEOSPEC TESTING SDN. BHD. (854673-U)
(Geotechnical, Structural & Material Testing)
Lot 587-588, Lorong Blacksmith 2B, Off Jalan Petanak,
93100 Kuching, Sarawak, East Malaysia.
Tel: 082-428695 Fax: 082-252516
geospec@gmail.com ; www.geospec.com.my

STANDARDS
MALAYSIA
ACCREDITED LABORATORY
MS ISO/IEC 17025
TESTING
SAMM NO. 595

IRAC-IRCA

COMPRESSIVE STRENGTH TEST
(MS EN 12390-3 : 2012)

Lab Ref. : GT/19/KL3906
Customer : Lai Phui Hua
Project : UNIMAS RESEARCH.
Date Received : 2/3/2019
Sample Ref. : 150mm Cube
Grade : N/A.
Tested By : Danny

Report No. : GT/19/KL3906
Page No. : 2 OF 2

Temperature : 27.3°C (Min.) 27.3°C (Max.)
Relative Humidity (RH) : 81% (Min.) 81% (Max.)

Cube No.	Specimen Identification		Age Test (Days)	Cube Dimension			Cube Weight (kg)	Cube Density (kg/m³)	Maximum Load at Failure		Mode of Failure	Measurement Uncertainty (N/mm²)
	Date Cast	Date Test		Length (mm)	Width (mm)	Height (mm)			kN	N/mm²		
1	17/2/2017	2/3/2019	743	151	150	152	4.225	1227	40.4	1.8	a	± 0.02
2	17/2/2017	2/3/2019	743	151	149	152	4.445	1300	38.8	1.7	a	± 0.02
3	17/2/2017	2/3/2019	743	151	150	152	4.375	1271	42.3	1.9	a	± 0.04
									Average Compressive Strength		1.8 N/mm²	

Remarks:

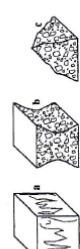


Figure a, b & c : Satisfactory Failure of Cubes



Figure b, c & d : Satisfactory Failure of Cubes

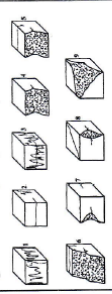


Figure c, d & e : Unsatisfactory Failure of Cubes

Witnessed by: 

Approved Signature: 
Chief Engineer
Lab Engineer
R. Eng. (Road Civil)

Table H1: Data collected from foamed concrete after 743 days casted

Mass in dry (kg)	Mass in Wet (kg)	Density (kg/m³)	Water absorption (cm³)	Cube Volume (cm³)	Water Absorption (%)	Compressive strength (N/mm²)
3.93	4.34	1227	410	3375	12.15	1.79
3.71	4.53	1300	820	3375	24.30	1.72
3.69	4.52	1271	830	3375	24.59	1.88
3.78	4.46	1266	686.67	3375	20.35	1.80

Appendix I: Quality Control for Foamed Concrete at Factory and Site

a. Quality of fresh foamed concrete

- The size of the mould is 750 x 750 x 1000mm
- Three numbers of 100 mm dia UPVC pipe are inserted mid-way of the mould
- Identify the name of foam agent used for mixing is KAO SOFTCLEAN 27AE
- Every mix must be labelled by the date and block number of the samples produced per mix
- The hardened density must be in the range of 1200-1600 kg/m³
- The followability is measured by the standard slump cone with the range of slump spread is 180-190 mm
- Segregation observation on fresh foamed concrete must be done in random
- Visible appearance of bubbles on the surface of the mix must be avoided
- For every 5 m³ mix done 9 samples must be collected for 28-day strength
- The compressive strength of hardened concrete is 1-3 N/mm²

b. Quality of harden foamed concrete

- The size of the foamed concrete is 750 x 750 x 1000 mm
- There should not be drying shrinkage of more than 12 mm upon hardening
- Upon casting the moulds must be covered against direct sunlight and wind
- Curing of the sample is done by air cured
- Special precautions must be given to ensure no plastic cracks formed
- Delivery of dried blocks must be done after 28 days hardening

c. Deliver of harden precast foamed concrete unit

- The concrete slab must achieve 28-days strength before placing the units
- The location of the blocks must be pre-determined and marked on the slab
- Safety precautions must be taken during Lifting the block due to its fragile
- Upon placement of the block care must be taken to ensure it does not crack
- Any visible cracks more than 3 mm will be rejected by the site supervisor
- The maximum distance between two adjacent units is 10 mm
- The sequence of placing must commence from the centre of the slab
- Additional blocks are added in parallel on the left and right toward both ends

d. PRECAST FOAMED CONCRETE PLACING INSPECTION FORM

Table I1: Form for placing precast foamed concrete

PROJECT TITLE:							
Date of casting	Block no	Slump (180 - 250 mm)	Density (1200 - 1600 kg/m ³)	Segregation observation (pass/fail)	28-day Strength (1.5-3.0 MPA)		Shrinkage (< 12 mm)
	Works Components				Acceptable	Not acceptable	Remarks
1	SETTING OUT/POSITION						
	Alignment						
	Level of surface < 20 mm between blocks						
2	PLACEMENT						
	Placing sequence from centre towards both ends						
	Gaps between blocks < 10 mm						
3	SIZE						
	In Dimensions 0.75 m x 0.75 m x 1.5 m						
	No dusting on surface						
4	INSERTS						
	3 nos of 100 mm UPVC pipes						
5	LIFTING CONDITION						
	No cracks upon placement						
Checked by:				Agreed by:			
Signature.....				Signature.....			
Name: UNIMAS Representative				Name: JKR CML Representative			

Form H1 is used as checklist and approval chit for placing foamed concrete block at project Sg. Bako and shows in Figure 7.10.

Appendix J: Estimation of pilot study, work programme's grant chart and S curve

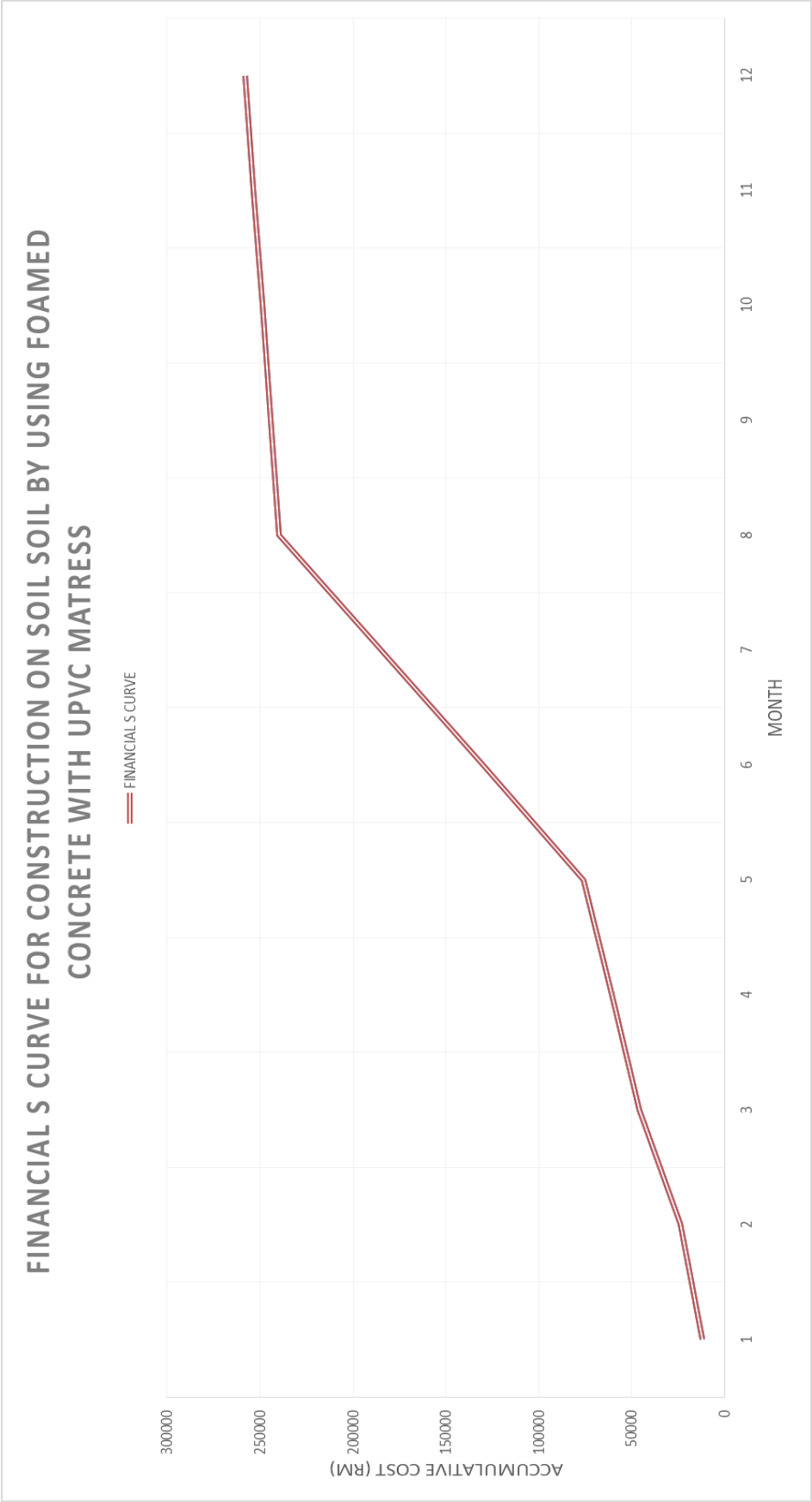
CONSTRUCTION ON SOFT SOIL USING FOAM CONCRETE WITH UPVC MATRESS
At Channel 3350 - 3375 m In 25 m Length and 9 m Width

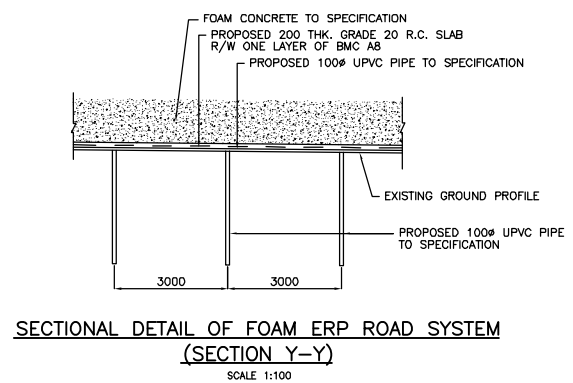
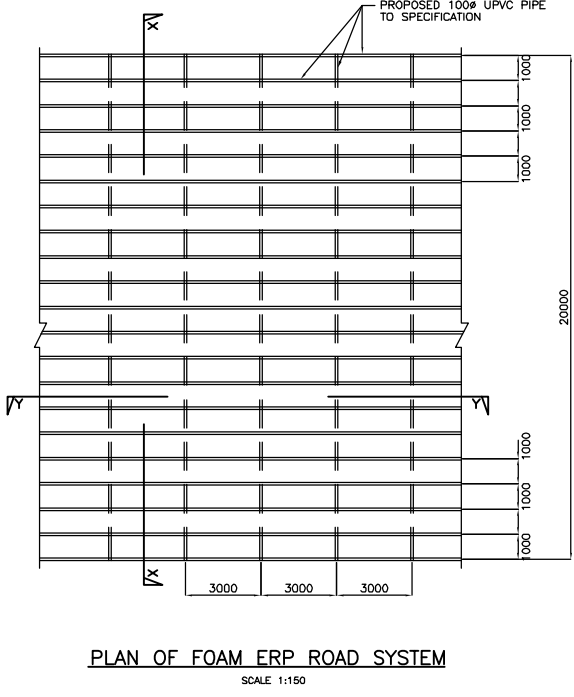
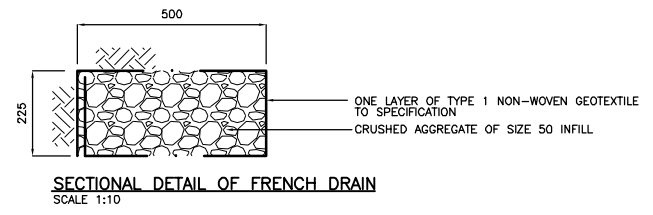
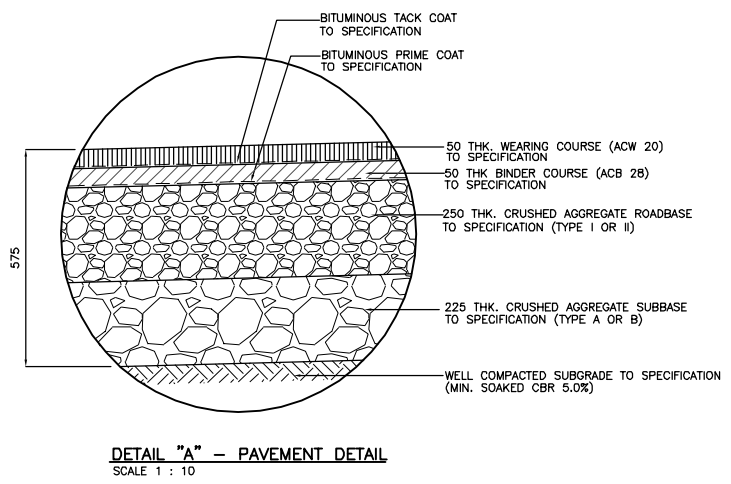
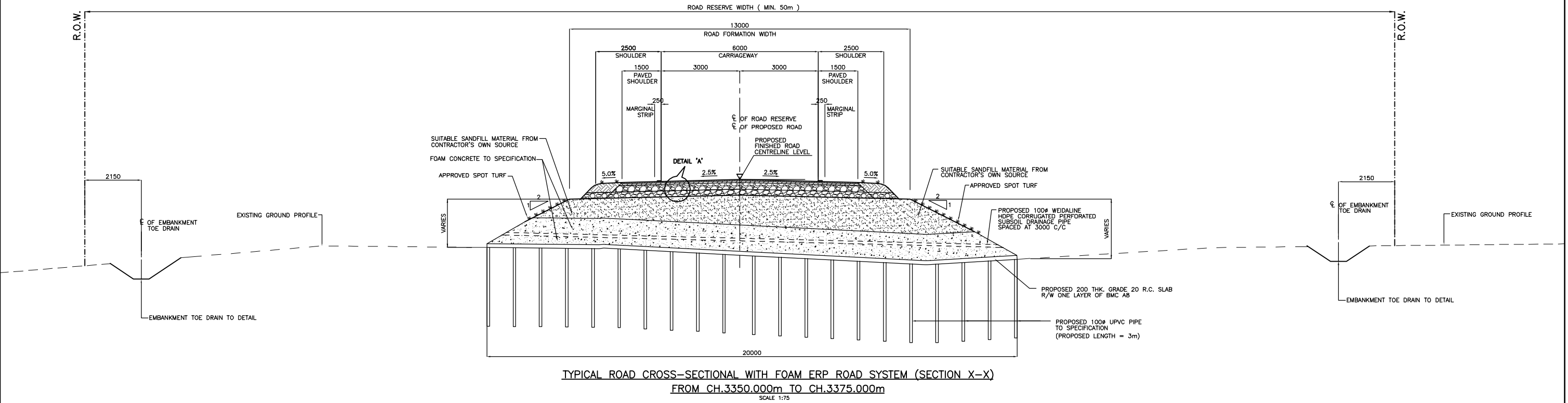
ITEM NO	DESCRIPTION OF WORK	UNIT	QUANTITY	RATE (RM)	AMOUNT (RM)
A	Introduction				
1.0	The purpose of the V.O is for the Reseach by Unimas as using Lightweight Foam Concerete as filling material, which the this method will replace the sand fill, PVD and Surcharge in compare to conventional method.				
2.0	All preliminary like soil investigation, design, consultancy fee, mobilisation, de-mobilization, transportation, management, survey work, excavation and disposal shall be absorpted in the preliminarly and general and existing items of this contract.				
3.0	All road work after sub-base and others work eg drain and etc shall construct as original contract.				
B	Contruction Works (All items in Re-Measurement)				
1.0	UPVC Foundation matress				
1.1	UPVC Pile Foundation Matress System				
	Handle, transport, pitch, drive and install the Single Row UPVC Pile Foundation matress System using penetration method or approved equivalent so as to obtain an integral interlocking pile foundation system				
1.1.1	UPVC Bend 4" diameter in 3.2 mm thk in 6 m lengths C/W Bend, Somet, and Tee as details in drawings. (SOR 2014 BW- E15 + 3%)	Nos	100	219.39	21,939.00
2.0	Foamed Concrete Production				
2.1	Foam Concrete				
2.1.1	Supply, deliver and cast foam concrete with density 1000 kg/m ³ as secified in the drawing. Agree Rate	m ³	450	330.00	148,500.00
3.0	Sub Base				
3.1	Concrete slab in G20 with 150 mm thk c/w 1 layer BMC A8 in 11 m x 50 m (bottom) and 150 mm thk c/w 1 layer BMC A8 in 9 m x 50 m (Top)				
3.1.1	Concrete grade 20 (SOR 2014 CW- B15A + 3%)	m ³	75	282.32	21,174.00
3.1.2	BMC A8 (minimum 3.55 kg/m ²) in (11+9)m x 50 m (SOR 2014 CW - B19 +3%)	m ²	500	19.57	9,785.00
4.0	Sub Soil				
4.1	100 mm Diameter" Weidaline" HDPE corrugated perforated sub-soil drainage pipe laid at level 1/3 height from bottom of ground level. (SOR 2014 BW- E25 + 3%) - (SOR 2014 CW- A10 + 3%) @ (RM 25 x7 m - RM 8 x 4.2 m ²) x1.03 = RM145.64 in 7 m; RM 20.81/m	m	81	20.81	1,685.61
5.0	Research Works (Provisional)				
5.1	Instrumentation (All purchasing of research instructment shall get approval from SO)				35,000.00
5.2	Contingency				20,000.00
TOTAL					258,083.61

Appendix J-1

CONSTRUCTION ON SOFT SOIL USING FOAM CONCRETE WITH UPVC MATRESS
At Channel 3350 - 3375 m in 25 m Length and 9 m Width

ITEM NO	DESCRIPTION OF WORK	UNIT	QUANTITY	RATE (RM)	AMOUNT (RM)	Week	1	2	3	4	5	6	7	8	9	10	11	12
A	Introduction The purpose of the V.O is for the Research by Unimas as using Lightweight Foam Concrete as filling material, which use this method will replace the sand fill, PVD and Surcharge in compare to conventional method. All preliminary like soil investigation, design, consultancy fee, mobilisation, de-mobilisation, transportation, measurement, survey work, excavation and disposal shall be absorbed in the preliminary and general and existing items of this contract. 3.1 All road work after sub-base and others work eg drain and etc shall construct as original contract.																	
B Construction Works (All Items in Re-Measurement)																		
1.1 UPVC Foundation Matress																		
1.1.1	UPVC Pile Foundation Matress System Handle, transport, pitch, drive and install the Single Row UPVC Pile Foundation matress System using penetration method or approved equivalent so as to obtain an integral interlocking pile foundation system UPVC Bend 4" diameter in 3.2 mm thk in 6 m lengths C/W 1.1.1 Bend, Socket, and Tee as details in drawings. (SOR 2014 BW- E15 + 3%)	Nos	100	219.99	21,999.00	3	7313	7313	7313									
2.0 Foamed Concrete Production																		
2.1	Foam Concrete 2.1.1 Supply, deliver and cast foam concrete with density 1000 kg/m ³ as specified in the drawing. Agree Rate	m ³	450	330.00	148,500.00	3						49500	49500	49500				
3.0 Sub Base																		
Concrete slab in G20 with 150 mm thk c/w 1 layer BMC																		
3.1	AS in 11 m x 50 m (bottom) and 150mm thk c/w 1 layer BMC AS in 9 m x 50 m (Top)																	
3.1.1	Concrete grade 20 (SOR 2014 C/W- B15A + 3%)	m ³	75	282.32	21,174.00													
3.1.1	BMC AS (minimum 3.55 kg/m2) in (11-9) m x 50 m (SOR 2014 C/W- B19 +3%)	m ²	500	19.57	9,785.00	3			10319	10320	10320							
4.0 Sub Soil																		
4.1	100mm Diameter Weldline HDPE corrugated perforated sub-soil drainage pipe laid at level 1/2 height from bottom 4.1.1 of ground level (SOR 2014 BW- E15 + 3%) (SOR 2014 C/W- A10 + 3%) @ (RM 25 x 7 m - RM 8 x 4.2 m) 141.03 = RM 145.64 in 7 m; RM 20.81/m	m	81	20.81	1,685.61	2							842.8	842.81				
5.0 Research Works (Provisional)																		
5.1	Instrumentation (All purchasing of research instrument shall get approval from SO)				35,000.00	12	2,916.63	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67	2,916.67
5.2	Contingency				20,000.00	12	1,666.63	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67	1,666.67
				TOTAL	258,083.61		11,886.26	11,886.34	11,886.34	14,903.34	14,903.34	54,083.34	54,926.14	54,926.15	4,583.34	4,583.34	4,583.34	4,583.34
				Percentage			4.61%	9.22%	17.83%	23.60%	29.38%	50.33%	71.61%	92.90%	94.67%	96.45%	98.22%	100.00%





MAJIKAN:		JABATAN KERJA RAYA SARAWAK CAWANGAN JAMBATAN DAN DERMAGA	
NAMA PROJEK:		PROPOSED BRIDGE OVER SG. BAKO AND ACCESS ROAD TO KPG. BAKO, KUCHING DIVISION	
TAJUK LUKISAN:		PROPOSED FOAM ERP ROAD SYSTEM	
TARIKH:	BILANGAN LUKISAN:	REV.	BILANGAN HELAIAN
APRIL 2017		0	