DESIGN OF LIGHTWEIGHT CONCRETE ARCH TILES AS PERMANENT FORMWORK FOR UPPER FLOOR SLAB BY USING POLYSTYRENE BEADS.

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Report submitted in partial fulfilment of requirements for the award

of the degree of B. Eng. (Hons.) Civil Engineering

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ABSTACT

Nowadays in Malaysia, many contractors and developers are still struggling to catch up with the current pace of development, especially in meeting country's demand, as conventional construction methods still work. Although traditional practice, this conventional method has several disadvantages such as high labor and material costs, and especially, a tendency not to change production of construction waste. Therefore, to overcome these weaknesses, permanent formwork using lightweight concrete is chosen as an alternative solution. In short, the new technology existence in construction to overcome this problem is permanent formwork using lightweight concrete which is more useful than conventional methods in terms of effectiveness of the functions, lighter, safety features and productivity. The main objective of this study is to determine the density and compressive strength of lightweight concrete to be used as arch slab by using polystyrene beads. The tests will be conducted is to find compressive strength and the displacement of the arch slab. All the procedures are prepared accordingly, to assure the research objectives are applicable, and to secure proper sequence and smooth running of the entire flow, from start until end. Six samples will provided, which three of them are 50mm and the rest is 75mm. All six samples of the slab tile are concreted at Heavy Structure Laboratory, Universiti Malaysia Pahang (UMP) and compressive strength test also conducted at same laboratory. Meanwhile the flexural test is conducted at Tensile Laboratory. From the theoretically calculation of arch tile of 50mm arch rise have highest horizontal and vertical force compared than arch rise 75mm with difference average load 1.267kN. While displacement of arch rise 50mm have highest displacement compared than arch tile of 75mm with difference displacement 0.463mm because of its geometry. Meanwhile, the density of fresh concrete with and without EPS also has difference about 68 kg/m^3. As conclusion, EPS can be used as extenuating agent in concrete. However, from the observation, we can hardly distinguish which of this arch tile is stronger. Besides that, the development of the graph pattern for each sample is not consistent, thus explains the indifferences of the load bearing capacity.

ABSTACT

Pada masa kini di Malaysia, ramai kontraktor dan pemaju masih berjuang untuk mengejar ketinggalan dengan kadar semasa pembangunan, khususnya dalam memenuhi permintaan negara, seperti kaedah pembinaan konvensional yang masih bekerja. Walaubagaimanapun amalan tradisional, kaedah konvensional ini mempunyai beberapa kelemahan seperti tenaga buruh dan bahan kos yang tinggi, dan terutamanya, kecenderungan untuk tidak menukar kepada penghasilan sisa pembinaan. Oleh itu, untuk mengatasi kelemahan berkenaan, acuan kekal menggunakan konkrit ringan dipilih sebagai penyelesaian alternatif. Pendek kata, kewujudan teknologi baru dalam pembinaan untuk mengatasi masalah ini adalah acuan kekal menggunakan konkrit ringan yang lebih berguna daripada kaedah konvensional dari segi keberkesanan fungsi, lebih ringan, ciri-ciri keselamatan dan produktiviti. Objektif utama kajian ini adalah untuk menentukan ketumpatan dan kekuatan mampatan konkrit ringan untuk digunakan sebagai papak lengkung dengan menggunakan butiran polisterin. Ujian akan dijalankan adalah untuk mencari kekuatan mampatan dan anjakan papak gerbang. Semua prosedur telah disediakan dengan sewajarnya, untuk memastikan objektif kajian adalah undang, dan untuk mendapatkan urutan yang betul dan berjalan lancar keseluruhan aliran, dari awal hingga akhir. Enam sampel akan disediakan, di mana tiga daripada mereka adalah 50mm dan selebihnya adalah 75 mm. Kesemua enam sampel jubin papak disediakan di Makmal Struktur Berat, Universiti Malaysia Pahang (UMP) dan ujian kekuatan mampatan juga dijalankan di makmal sama. Sementara itu ujian lenturan dijalankan di Makmal tegangan. Dari pengiraan secara teori jubin gerbang 50mm kenaikan lengkung mempunyai daya mendatar dan menegak tertinggi berbanding daripada 75 mm kenaikan lengkung dengan perbezaan beban purata 1.267kN. Walaupun anjakan kenaikan gerbang 75 mm mempunyai anjakan paling tinggi berbanding daripada jubin gerbang 50mm dengan 0.463mm anjakan perbezaan kerana geometri itu. Sementara itu, ketumpatan konkrit segar dengan dan tanpa EPS juga mempunyai perbezaan kira-kira 68 kg/m^3. Kesimpulannya, EPS boleh digunakan sebagai agen peringan dalam konkrit. Walau bagaimanapun, dari pemerhatian, kita boleh tidak membezakan yang mana satu papak gerbang ini adalah lebih kuat. Di samping itu, pembangunan corak graf bagi setiap sampel tidak selaras, dengan itu menerangkan perbezaan keupayaan galas beban.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
EPS	Expended Polystyrene Beads
LVDT	Linear Vertical Displacement Transducer

1.2 Problem Statement

Malaysia's housing policy is to work towards fulfilling the objective of determining the density and compressive strength of lightweight concrete for use as tile arch. However, the supply of houses by both the public and private sectors is still far from meeting the demand, especially in of low cost housing sector. As time and technology advances, many developers and contractors are still found struggling in catching up with the pace of the current development as conventional construction method is still very much employed.

Construction industry is developing rapidly due to increasing human population and current technology. It increases the request for raw materials in concrete production. However, the sources for materials such as granite and gravel are decreasing in day by day. The uses of gravel or granite in concrete works increase the weight of structure. So, it is needed to find an alternative way to reduce construction weight. Thus, the application of lightweight concrete in the construction industry is seen can overcome these problems. Lightweight concrete can produce light structures and it mostly does not use granite or gravel. However, there are some problems to be faced in order to use this concrete.

In order to produce a good quality of lightweight concrete mixture, mixing ratio is very important. The process of mixture especially lightweight concrete that uses lightweight material should be done perfectly so that the concrete produced will in accordance with the targeted quality. This caused the required of skill workers to handle the process. The construction period also can increase because the complicated process of producing the lightweight concrete rather than ordinary concrete.

This research shows that the cost of materials for producing lightweight concrete is expensive. This is because there are several types of lightweight concrete that uses some chemicals lightweight materials to produce low-density and hollow concrete. Material costs are also high for the type of concrete using lightweight aggregates such as expended clay, shale, pulverized fuel, ash, etc. The lightweight aggregate must go through several processes such as crushing and burning which incurs high cost.

1.3 Objective of Study

The objectives of this research are as follows:

1. To determine the density and compressive strength of lightweight concrete to be used as arch slab.
2. To analyze the optimum arch height.

1.4 Scope of Study

This research generally covered the construction of slab for upper floor of a house using permanent formwork application. The main focus is basically on the basis of design and design procedures of the arch pan to determine the density and compressive strength of lightweight concrete to be used as arch slab. These two different density and height of arch that serve as a permanent formwork using lightweight concrete will undergo necessary testing and analysis, both individually and inclusively with the whole slab structure, to establish its adequacy and behavior. Thus recommends the essential and evident basis for its application in slab construction.

precast unit figure 2.1 are used to connect the two layers and make the unit stiff during erection. The heavy weight of the full slab, its low thermal efficiency and the additional cost of the steel trusses needed to connect the two layers are some of the disadvantages of the system.

Developing a new floor slab system to overcome the shortcomings of in situ concrete floor slabs and existing precast floor systems is a challenging task for many researchers. Existing systems have shortcomings such as long construction time, heavy weight, and dependency on heavy equipment at the job site, poor thermal and sound insulation, and high material wastage, dependency on formwork, lack of structural integrity, jointing problems and high cost.

Figure 2.1: Example of Precast Slab

There are two types of permanent formwork. First is structurally participating, which is designed to provide the temporary support for the wet concrete and construction loads and then become part of the permanent works contributing to the strength of the completed element. Second is structurally non-participating, which is designed solely to support the wet concrete and the construction loads.

The application of permanent formwork provides several advantages for construction process. Below are the following:

a) Contracting the workmanship needed on site.

b) Enhancing the potency for standardization and repetition.

c) Allowing off-site modular fabrication followed by scheduled and appropriate deliveries.

d) Accelerating erection times, peculiarly in building works.

e) Doing away with the need to strike formwork and false work.

f) Permitting early access for following or concurrent operations.

g) Snubs the need to reuse formwork.

2.1.2 Lightweight Concrete

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailbility and lessened the dead weight. It is lighter than the conventional concrete. The use of lightweight concrete has been widely spread across countries such as USA, United Kingdom and Sweden (Kamsiah Mohd.Ismail, 2011)

Lightweight concrete has strengths comparable to normal weight concrete, yet is typically 25% to 35% lighter (Fahrizal Zulkarnain, 2008). Lightweight concrete offers flexibility and substantial cost savings by providing: less dead load, improved seismic structural response, better fire ratings, and reduce material cost. Lightweight concrete precast elements offer reduced transportation and placement costs (Kenneth S., 1999)

This fundamental research report is prepared to show activities and progress of the lightweight concrete. Focused are on the performance of polystyrene beads lightweight concrete such as compressive strength and flexural test. Comparisons will make with other height of arch of the lightweight concrete arch slab. According to Bischoff (1990), polystyrene is a vinyl polymer. It is a long hydrocarbon chain with a phenyl group attached to every other carbon atom. Polystyrene is produced by free radical vinyl polymerization from the monomer styrene. Expendable polystyrene (EPS) meanwhile is polystyrene in raw beds being steam-heated, causing it to expand. Polystyrene has been used mainly in cold countries to make concrete blocks for residential purposes.

2.1.3 Arch Concept

For this research, the type of arch chosen is a two pinned symmetrical parabolic arch as shown in Figure 2.1. Below is the parabolic arch equation as Eq. (2.1) :

$$y = \frac{4fx(L-x)}{L^2} \tag{2.1}$$

Where;

h = arch height

L = length of span

y = horizontal distance

x = vertical distance

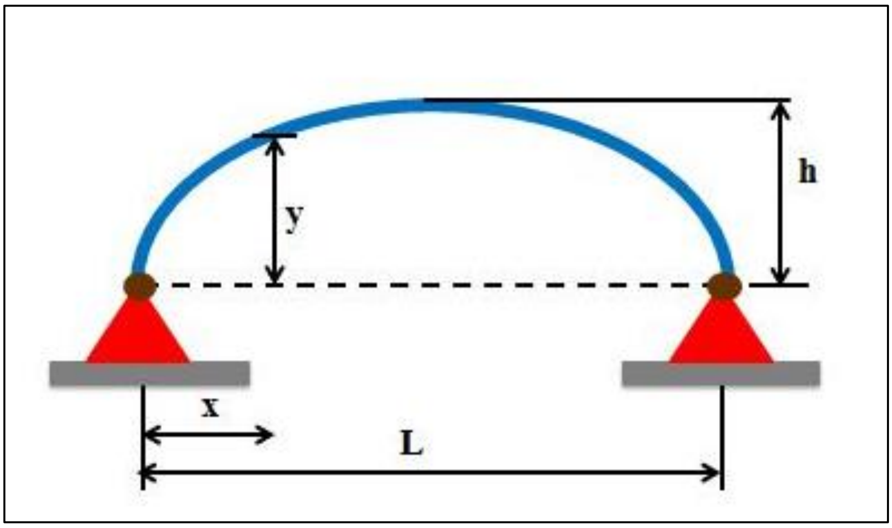

Figure 2.2 : Two pinned symmetrical parabolic arch

A two pinned symmetrical parabolic arch is indeterminate structure; thus to determine the horizontal force at both supports using static equilibrium equation, the pinned support is changed to a roller support to achieve a determinate structure, as shown in Figure 2.2. For this particular case, when load is exerted uniformly or directly at the center, moment is distributed equally; M1 = M2.

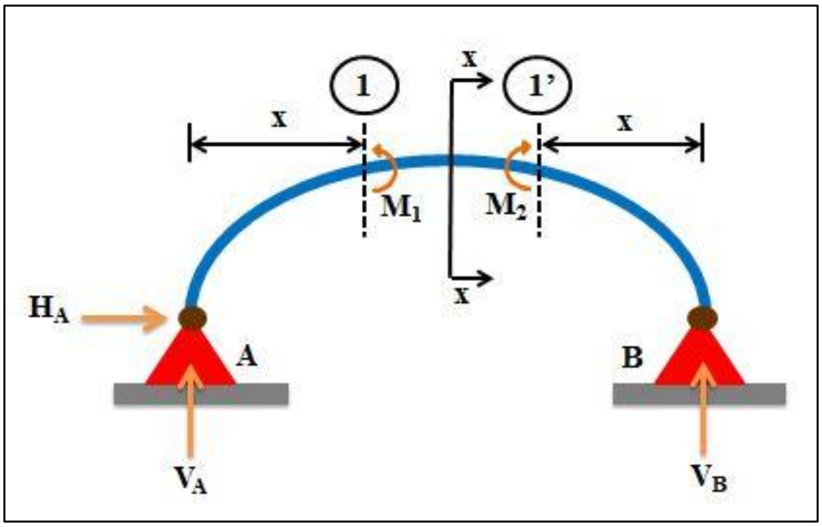

Figure 2.3 : Two pinned symmetrical parabolic arch analysis 1.

Horizontal thrust, H is determined using the formula as Eq. (2.2):

$$\boldsymbol{H = \frac{\int_0^L Mydx}{\int_0^L y^2 dx}} \tag{2.2}$$

For symmetrical arch, $\int_0^L y^2 dx$ can be simplified by using Eq. (2.3):

$$\int_0^L y^2 dx = \frac{8h_2L}{15} \tag{2.3}$$

To determine the thrust (N) and shear force (S) at any given point, Eq. (2.4) and Eq. (2.5) is used; with reference to Figure 2.3.

$$N = H_c \cos\alpha + V_c \sin\alpha \tag{2.4}$$

$$S = -H_c \sin\alpha + V_c \cos\alpha \tag{2.5}$$

Where; $= \frac{dy}{dx}$, in radian

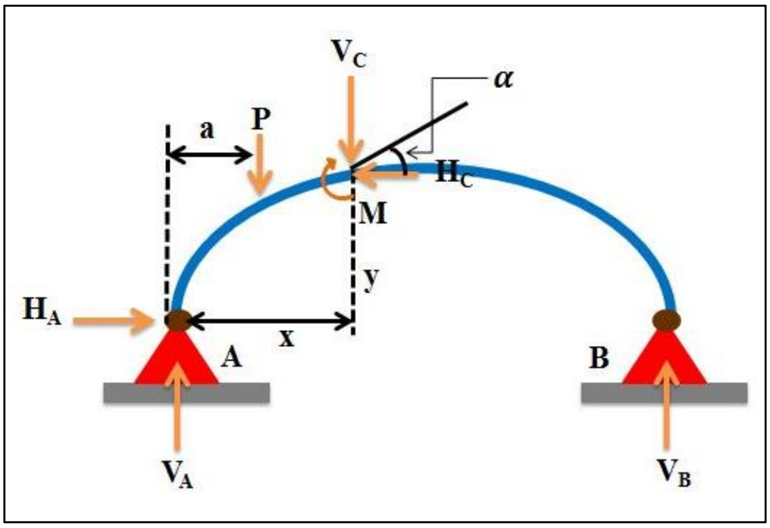

Figure 2.4 : Two pinned symmetrical parabolic arch analysis 2.

In relationship to this research, this conceptual study and procedure provide the essential reference in designing the arch slab and to investigate its behavior when subjected to loading.

2.2 Materials

The materials will be used in this study are cement, silica sand, polystyrene beads and water. The type of cements that will be use is Ordinary Portland Cement (OPC)

2.2.1 Cement

Ordinary Portland Cement (OPC) is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or groundwater. OPC manufactured by Lafarge Malaysia exceeds the quality requirements specified in the Malaysian Standard MS 522 : Part 1: 1989 Specifications for OPC. Cement is commonly used as mortar and in highway construction. Supplier claims that this cement can make higher strength than ordinary cement.

Table 2.1 : Chemical composition of ordinary portland cement and silica fume

Constituent	Ordinary Portland Cement, % by weight
Lime (CaO)	64.64
Silica (SiO2)	21.28
Alumina(Al2O3)	5.60
Iron Oxide(Fe2O3)	3.36
Magnesia(MgO)	2.06
Sulphur Trioxode (SO3)	2.14
N2O	0.05

2.2.2 Silica Sand

Sand for lightweight concrete is used for the entire superstructure except for the pier table segments. The sand uses normal weight and lightweight coarse aggregate to produce concrete that is lower in density. The anticipated higher creep and shrinkage and lower modulus of elasticity characteristics expected with the lightweight concrete, resulted in stringent material properties being specified for construction

2.2.3 Polystyrene Beads

Polystyrene is vinyl polymer. Structurally, it is a long hydrocarbon chain, with a phenyl group attached to every other carbon atom. Polystyrene is produced by free radical vinyl polymerization, from the monomer styrene. Expanded polystyrene (EPS) meanwhile is polystyrene in raw beads being steam-heated, causing it to expand. EPS beads are a type of artificial ultra-lightweight, nonabsorbent aggregates. It can be used to produce low-density concretes required for building applications like cladding panels, curtain walls, composite flooring systems, and load-bearing concrete blocks. There have many sizes of polystyrene beads to be used for certain applications. In this study, size of polystyrene beads used is in a range 1.5-5.0 mm.

According to Chandra and Berntsson (2002), the advantages and disadvantages of lightweight polystyrene concrete are shown in table 2.2.

Table 2.2 : Advantages and disadvantages of lightweight polystyrene concrete.

Concrete Properties	Advantages	Disadvantages
Weight	Light: Down to 600 kg/m^3	
Strength	Ranging from 2 to 20 N/mm2	
Resistance to chemicals		Sensitive to most petroleum product
Field application	Suitable for structural and non-structural members	Not suitable to be as pre stressed
Cost	Less than most available lightweight concretes	
Acoustic resistance	The best among all other lightweight concretes	
Fire resistance	Burning without flames	Starts to evaporate above 300°C
Workability	Very workable at low water-cement ratio	Stable up to 30 minute after mixing
Mix consistency	Consistence for water-cement ratio 0.32 to 0.45	
Thermal insulation	The best among all other lightweight concrete	

2.2.4 Summary Finding

Because there is no research on the use of EPS as a lightweight concrete tile arch. So I have studying of the eight researches on the use of EPS as lightweight concrete. Based on the research I have conducted on the materials used, I have been summarized as shown in Table 2.3. As conclusion, I decided to use the ratio is 1: 2: 5: 0.5 which 1 part cement, 2.5 parts silica sand and 0.5 part is EPS as sand replacement.

Table 2.3 : Summary finding

No.	Author	Method	Recommendation
1	Muhamad Khamal Bin Shamsuri (2011)	Cement : Sand : EPS 1:1.5:1.5 Water/Cement = 0.5 Density = 1512 kg/m3	Use various sizes of polystyrene beads to get more value of compressive strength.
2	Daneti Saradhi Babu	Cement : Sand : EPS 20% : 34% : 46%	-
3	S.G. Park (1999)	Cement = 450 kg/m3 Density = 1000 kg/m3 Sand = 340 kg/m3 EPS = 850 L/m3 Water = 180 L/m3	EPS concrete is very prone to segregation. Care must be taken to ensure that not too much water is added to the mix so as to prevent segregation from occurring.
4	Idawati Ismail (2003)	Cement : Sand : EPS 1:2.5:0.5	1. Density less than recommended density for lightweight concrete which is 1800 kg/m^3 2. Most suitable mix to be used as a load bearing internal wall.
5	Rosli M. F. (2011)	Cement : Sand 1:1 Water/Cement = 0.4 Density = 1000 kg/m3	1. Application of reinforced foam concrete is feasible and contributed to better compressive and flexural strength. 2. EPS replacement, an optimum replacement level of 30% produces best results.
6	Aneke I.F. (2014)	Cement : Sand : EPS 1 : 0.7 : 0.3 Water/Cement = 0.4 Cement/Sand = 0.22 Density = 1264 kg/m^3	1. The UCS of light weight geomaterial is affected by the mix proportion and the cement content. 2. Curing effect on the specimen was very significant even for a short curing age of 7days. 3. Lightweight material can be produced from a mixture of CPS having a density in the ranges of 1750kg/m3-2150kg/m3. 4. 15% cement content increased the UCS of the mix due to cement hydration effect. 5. The density and UCS properties of the geomaterial mix are made flexible by adjusting the CPS material constituent ratios.

Table 2.3 : Continued summary finding

No.	Author	Method	Recommendation
7	Ling I.H (2011)	Cement : Sand : EPS 1:1.5:1.5 water/cement = 0.5 Density = 1838 kg/m3	-
8	Manolia Abed Al-wahab Ali (2012)	Cement : Sand : EPS 1:2.5:0.5 water/cement = 0.325, Density = 1895 kg/m3 Percentage of sand replacement = 16.7%	Density of 1895kg/m3 and compressive strength of 14.65MPa is the most suitable mix to be used for the production of masonry units which are used for load bearing internal wall

2.3 Method

2.3.1 Arch Design

The rise of the arch generally is between 1/3 to 1/4 6 of the span for economy; the smaller value being applicable to relatively larger span and large value for relatively smaller spans. The loads falling upon a minor arch may consists of live loads and dead loads from floors, roofs, walls and other structural elements. These are applied as point loads or as uniform loads fully or partially distributed.

Arch concept was described earlier in design study in permanent formwork. The optimum of height of the concrete arch pan can obtained is 75mm which the design two-pinned symmetrical parabolic arch. Other than that, the height 75mm of the arch pan and size of pan 500mm can successfully without resist 1000N load (Zarriqbar, 2013).

In the research by (Brenden,2010), the higher rises of dimension are more stronger than lower rise of dimension with fixed of measurable height. The sample dimension is fixed size of span 460mm and thickness 20mm, the rise of height first sample is 75mm compared to second sample height is 50mm. This is because sample 75mm possess higher load bearing capacity than sample 50mm.

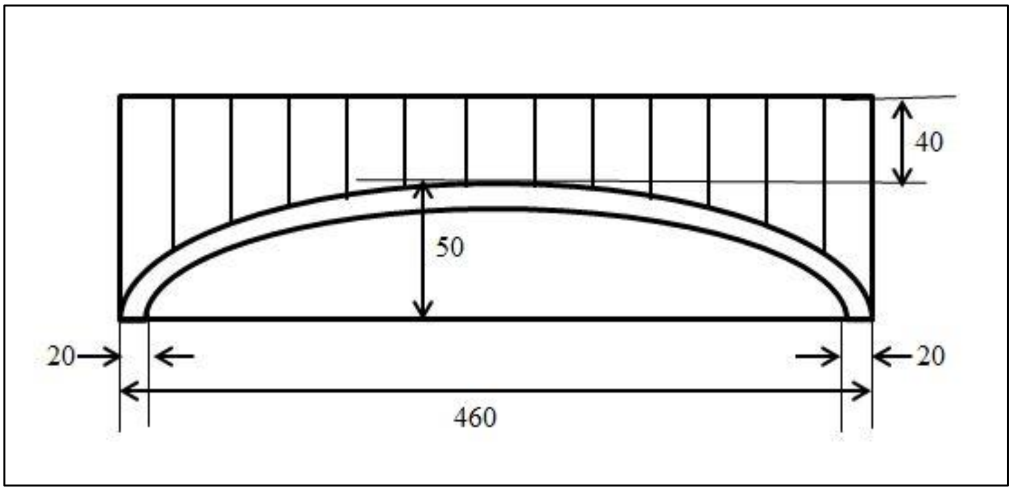

Figure 2.5 : Arch slab height of arch = 50 mm.

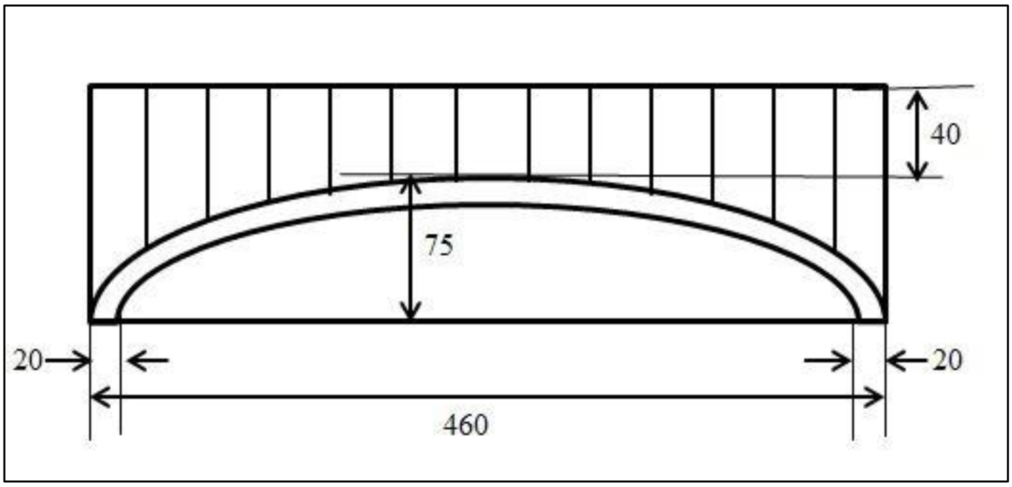

Figure 2.6 : Arch slab height of arch = 75 mm.

2.3.2 Lightweight Concrete Density Design

This research is aimed to determine the suitable density and arch height can be used arch pan that can serve as permanent formwork in this research. Meanwhile, the density can be form for lightweight concrete especially for block construction. For structural concrete, the suitable density from 1000 to 2000 kg/m^3 respectively (Osman Unal, 2007).

In this research, foamed agent will not be used. This is because to see how the condition of polystyrene beads (EPS) in the concrete mixture while in the formwork. Whether the EPS float or not on the structure surface. For the lightweight material, the replacement of fine aggregate by the polystyrene beads reduce the fresh density.

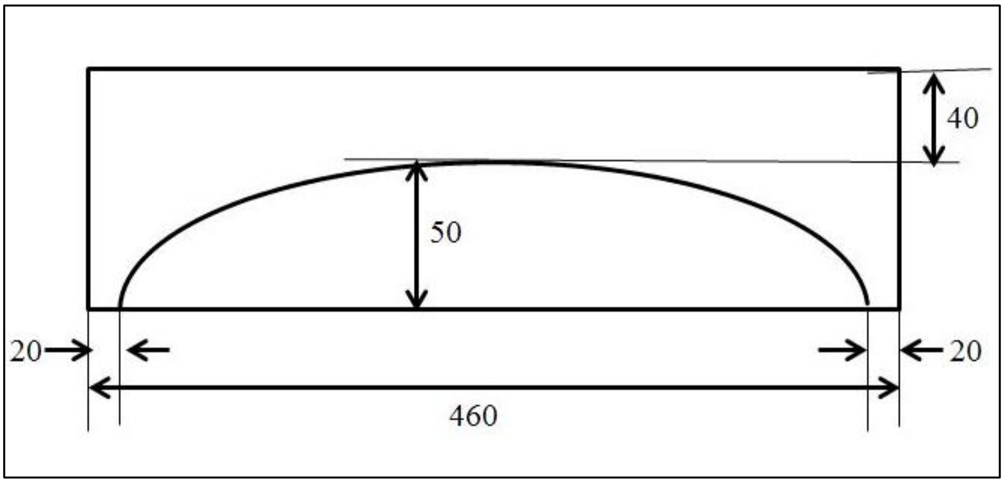

Figure 3.1 : Arch slab 50mm

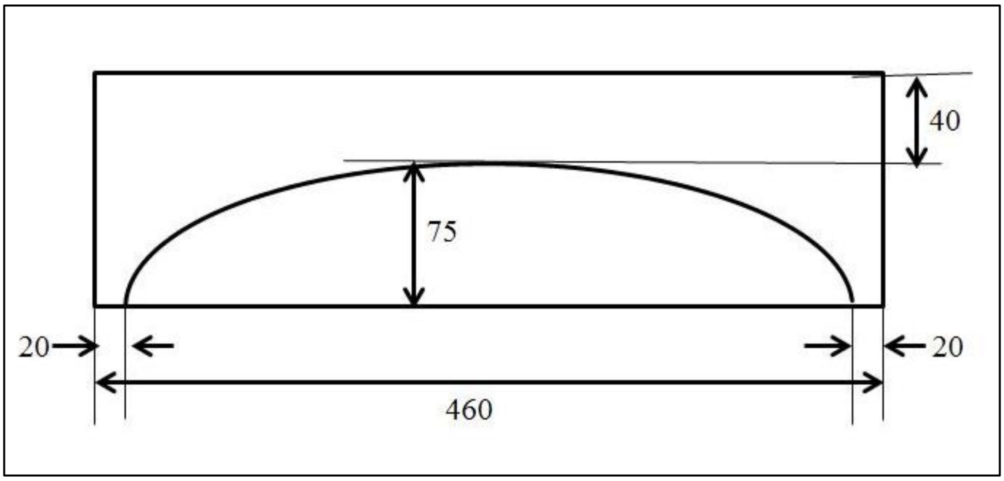

Figure 3.2 : Arch slab 75mm

Besides that, the slab also is designed in accordance to BS 8110: Part 1: 1997 where all required checks are made for shear, moment, deflection and displacement. Load calculation is presented in Appendix A and B. In this research, two slab specimens are constructed; where each slab accommodates the arch slabs of two different arch of rise, as shown in Figure 3.1 and 3.2.

The slab thickness is 40mm, 460mm width, and spans 600mm, which serves as a two-way slab system, as shown in Figure 3.3.

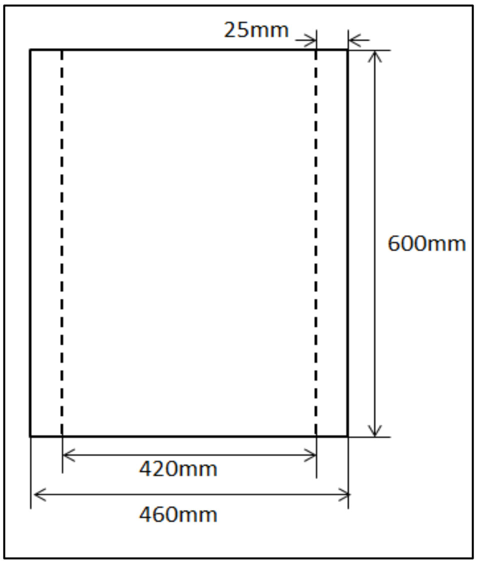

Figure 3.3 : Plan view of arch slab with detail.

For experimentation, the slab is divided into two specimens. The first specimen accommodates the arch slab with arch rise of 75mm, while the second one accommodates the arch slab with the arch rise of 50mm. Prior to testing, each specimen is coated with white paint to aid cracking visibility.

In this particular configuration, the arch slabs indirectly serve as a permanent formwork for the complete slab construction. In terms of structural engineering, these arch slabs transfer the gravity loads, mainly in compression, to the supporting beams.

3.3 Sample of Preparing

The materials used as follows:

1. Ordinary Portland Cement (OPC)
2. Silica sand
3. Polystyrene beads (EPS)

3.4 Experimental Investigation

This experimental investigation is carried out at University Malaysia Pahang (UMP), Faculty of Civil Engineering, in Heavy Structural Laboratory. All materials and apparatus are provided and prepared by the laboratory itself, where all students are permissible to utilize them under the guidance of technicians.

The purpose of laboratory experimentation is to meet the research objectives, primarily to determine the density and compressive strength of lightweight concrete and to analyze the optimum arch height to be used as arch slab as permanent formwork for upper floor slab. Other considerations, such as material proportions and compressive strength of concrete, are also taken into account to provide essential structural basis. In this research, the experimentation that will be included is compressive strength test and flexural test.

In this research, the experimentation is divided into three stages. Which are formwork preparation, concreting, and finally, testing of the specimens. Where the test includes for the final stage is compressive strength test and flexural test.

3.4.1 Formwork Preparation

Formwork is a die or a mold including all supporting structures, used the shape and supports the concrete until it attains sufficient strength to carry its own weight. It should be capable of carrying all imposed dead and live loads apart from its own weight.

Formwork has been used since the beginning of concrete construction. New materials such as steel, plastics and fiberglass are used in formwork. Greater attention is being given to the design, fabrication, erection and dismantling of formwork

There are six sets of formwork are prepared for this research; the three sets are for arch slab 50mm and the rest are for arch slab 75mm. This formwork was made at Carpentry Laboratory, and it’s made from sheets of plywood with thickness 4mm and

12mm. Depending on how much pressure the wet concrete will induce. For instance, plywood with thickness of 4mm is flexible enough to form the curving shape of the arch slab and while plywood with thickness 12mm is used to construct the arch shape rigid rectangular shape and the base of the slab.

Before concreting, each formwork inner surfaces are covered by packing sellotape a few days before and after a few days. A few minutes before concreting, the formwork was coated with lubricant oil to prevent concrete sticking. Formwork preparation is shown in Figure 3.4, 3.5, 3.6 and 3.7.

Figure 3.4 : Plywood cutting for arch slab formwork.

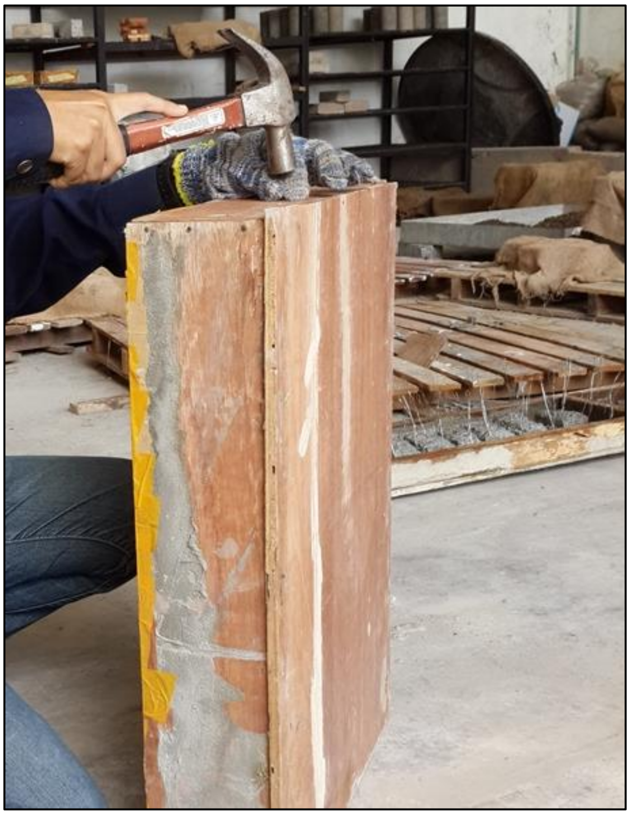

Figure 3.5 : Formwork preparation for arch slab.

Figure 3.6 : Completed arch tile formwork

Figure 3.7 : Oiling works on formwork.

3.4.2 Concrete Works

Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements such as rebar are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone like material with many uses.

In the preparation level, parts for concrete mix must carefully to measure the strength achieve the required strength characteristics, the $20N/mm^2$. This requirement applies to slab as permanent formwork. In addition, water cement ratio also plays an important role, which more water can dilute the concrete mixture, thus reducing its strength; while the lower water content reduces the workability of concrete. Main materials used to build arch slab are ordinary Portland cement (OPC), silica sand, and 16.7% EPS will be replace silica sand.

For this research, the mix proportion was obtained by make some study of previous research about lightweight concrete by using EPS. And I used the most consumption ratio a slight EPS in advance. For the ratio just take the ratio from previous research which is 1:2.5:0.5 where stands for 1 part cement, 2.5 parts sand and 0.5 part EPS. The water-cement ratio is 0.7 for all specimens. But for the calculated coefficients provided by own self determined with the wastage of 30% excess for nine samples of cube molds, used for compressive strength test. Mix proportion for trial mix and arch tile are shown in Table 3.1, and 3.2 respectively

3.4.2.1 Trial Mix Design

But before the actual concrete work done on the slab, as others construction should begin with trial mix design beforehand. This is to ensure that the concrete mix not failed and in right proportion. Good quality concrete starts with the quality of materials, cost effective designs is actually a by the product of selecting the best quality material and good construction practices.

In trial mix design of concrete, the proportion of cement, fine aggregate (silica sand) and water cement ratio is finding out by trial, which gives the maximum weight of the combined of material. The mixture which will give the maximum weight will have the maximum solid matter therefore the least voids and surface area.

In another method of trial mix cement and silica sand are combined in several proportions. The quantity of cement per unit volume of concrete is found to give a certain water-cement ratio for each mixture. The percentage of silica sand is known as optimum percentage.

In this trial mix design, the results will be taken in 3 day, 7 day and 28 day compressive strength results. The laboratory mix design strength will be defined as the mean of the 3 day compressive strength results. The reason why use 3 day as minimum result taken because to find whether the mix design can use for commercial industry in the short time or not.

There are three main stages of trial mix design. They are preparation, mixing and pouring. For the first stage which is preparation, all the mix proportion for trial as shown in table 3.1.

Table 3.1: Mix proportion for casting of trial mix

Volume (m^3)	Cement (kg)	Water (kg)	Silica sand (kg)	EPS (kg)	Percentage of sand replacement (%)	Total (kg)
0.0117	3.71	2.60	13.29	0.01134	16.70	54.65

After preparation stage, the next stage is mixing. Mixing however, ahead the casting work. For the work mixing just need to use manual mixing by hand as shown in Figure 3.8. It is because a volume a slightly and inappropriate use concrete mixer which will only cause a lot of wastage.

Figure 3.8 : Manual mixing by hand concrete mixing for trial mix.

After mixing, concrete is poured into the cube mold size 100mm x 100mm x 100 mm for compressive strength testing. As the concrete being poured, compaction work is ensured. Compaction is essential to prevent the existence of honeycomb and to ensure concrete is firmly spread in the forms. But for this mixture, need to use self-compacted.

Which is use cube test procedure, where need to make 3 layers and 25 blows at every layer as shown in Figure 3.9. This is because, when use vibrator, the EPS will float on the concrete surface.

Figure 3.9 : Blowing step for compacted the concrete in cube mold

3.4.2.2 Slab Concreting

Concreting is one of the critical stages in the construction, but it also is the most important phase in this research and experimentation as well. Good concrete serves as the adequacy reliable for the entire construction process in terms of workability, strength and durability. In this research, the concrete is divided into three main stages which are preparation, mixing and casting stage and level of curing. The preparations of concreting are same as the method like preparation of trial mix design. All the mix proportion for casting of arch slab as shown in table 3.2.

Table 3.2: Mix proportion for casting of arch slab

Volume (m^3)	Cement (kg)	Water (kg)	Silica sand (kg)	EPS (kg)	Percentage of sand replacement (%)	Total (kg)
0.135	43	29.31	153	0.130	16.70	242.14

Next stage after preparation stage is the mixing and pouring. However, mixing will ahead by the casting work. In this research, the concrete is mixed using lightweight concrete mixer for mechanical advantage, where it helps to blend the mixture, especially in large amounts up to $0.5m^3$ in a short period of time to perfect, much better than with manual mixing by hand or normal concrete mixer. The mixing work is as shown in Figure 3.10.

Figure 3.10 : Lightweight concrete mixer of $0.5m^3$ capacity used for lightweight concrete mixing.

The final stage of slab concreting is pouring. Where the concrete will pour into the arch slab formwork as shown in Figure 3.11. As the concrete being poured, compaction work is ensured. Compaction is essential to prevent the existence of honeycomb and to ensure concrete is firmly spread in the forms. But for this mix, where the additional material is EPS we need to use self-compacted. This is because to avoid the EPS from float. And at the same time to make sure the mixture mix with proper. Excess concrete will be poured into cube molds for compressive strength testing. Prepared nine cubes which are three cubes for 3 days, three cubes for 7 days and the rest for 28 days.

Figure 3.11 : Pouring stage of arch slab

Figure 3.12 : Complete casting of slab.

After completion pouring work, screeding and leveling work is to make sure the surface is smooth and flat. When the concrete hardens approximately within 24 to 48 hours, the mold will be removing as shown in Figure 3.13. After the entire arch slab was removed from their molds, wet gunny are then wrapped on top of the concrete surface to vertical for keeping the concrete wet. Wet gunny is one of the methods of water curing. This curing process shall take between 28 days because all the structure will be testing under flexural test on the day 28th. But concrete cube is placed in a curing pool for 3 until 28 days for the same reasons.

Figure 3.13 : Arch slab 50 mm.

3.4.3 Testing

Concrete is tested to ensure that the material that was specified and bought is the same material delivered to the job site. There are a dozen different test methods for freshly mixed concrete and at least another dozen tests for hardened concrete and fresh concrete. But for this research just use hardened concrete test which is Compressive Strength Test and Flexural Test.

Concrete hardens and gains strength as it hydrates. The hydration process continues over a long period of time. It happens rapidly at first and slows down as time goes by. To measure the ultimate strength of concrete would require a wait of several days. This would be impractical, so a time period of 3, 7 and 28 days were selected by specification writing authorities as the age that all concrete should be tested. At this age, a substantial percentage of the hydration has taken place.

In this research, several testing are conducted to achieve the research objectives; in compliance with the experimental procedures, which comprises of testing of concrete, testing of the slab. In general, the first testing is conducted to determine the quality of the material used in example is concrete, in the structure as built; values for the material parameters so obtained may then be used to appraise the structure. The second testing is flexural tests of the slab; conducted to check on either strength or serviceability, and deformation measurements.

3.4.3.1 Compressive Strength Test

This test in carried out to measure the compressive strength of the concrete cubes using a compressive test machine, thus ensuring whether the concrete achieve the desired strength or not. In this research, cube molds dimensioning 100mm x 100mm x 100mm is prepared upon concrete mixing process for slab construction. During casting, excess concrete that is poured in the cube mold is compacted using the self-compacter. After one day, the molds are removed, leaving the concrete cubes in shape. These cubes are then soaked in water 3 to 28 days for curing purpose. After achieving the required duration, these concrete cubes are taken out from the curing pool and left to dry. Later on, each cube is placed is in the compressive test machine for testing. Data is recorded once the tested concrete cube reaches failure.

In this research, 3 day, 7 day and 28 day compressive strength tests were carried out using a compressive test machine as shown in Figure 3.14. Thus ensuring whether the concrete achieve the desired strength or not. In this research, cube molds dimensioning 100mm x 100mm x 100mm is prepared upon concrete mixing process for the arch slabs. Compressive strength test at 3 day, 7 day and 28 day shows similar manner in the increase in strength with respect to EPS contents.

Figure 3.14 : Compressive Strength Test Machine.

Follows are the procedure of compressive strength test:

1. Poured concrete in the cube mold in three layers and compact with 25 strokes using steel rod for 100mm cubes continuously for every layer.
2. Stored the cube in moist at temperature 20°C
3. After one day, the molds are removed, leaving the concrete cubes in shape. These cubes are then soaked in water 3 to 28 days for curing purpose.
4. After achieving the required duration, these concrete cubes are taken out from the curing pool and left to dry for a few minutes.
5. Each cube is placed is in the compressive test machine for testing. Data is recorded once the tested concrete cube reaches failure.

3.4.3.2 Flexural Test

Flexural test objective is to determine the flexural strength of hardened concrete specimen by the use of arch sample with reference to the standardized three points support. This test also will determine the maximum load and displacement. Flexural test is carried out after slab is cured for 28 days, corresponding to its concrete compressive strength test results.

Follows are the procedure of flexural test:

1. Measure the weight and dimension of the arch
2. Indicate the location of supports and loading points of the arch surface.
3. Load the specimen continuously and without shock until rupture occurs.
4. Record the maximum load carried by the specimen during testing and measures the specimen cross section at one of the fracture faces by using data logger.

In this experiment, DARTEC Universal Tensile Machine is used to run the test. The behavior of the structure will be identified according to the mode of failure or arch pan. For this test, several key's equipment are used to run its entire operation. Below are the following:

- Compression Load Cell - A transducer which converts load or force into a measurable electrical output
- Data Logger - A control system that monitors real time measurement
- Linear Vertical Displacement Transducer (LVDT) – An electric device that measures displacement

This test is conducted to determine its behavior under applied loading, particularly concerning its strength and flexural performance. This test is carried out after slab is cured for 28 days, corresponding to its concrete compressive strength test results.

In this particular experiment, DARTEC Universal Tensile Machine as shown in Figure 3.15 and 3.16 is used to run the test. This setup is prior to the loading configuration as shown in Figure 3.16. The purpose of this configuration is to distribute the load uniformly on the slab specimen. A LVDT are placed as shown in Figure 3.17, correspondingly to the configuration, above the rod on the slab. Meanwhile, the load cell is positioned at the center of the slab.

Figure 3.15 : Testing of arch tile setup using Universal Tensile Machine.

Figure 3.16 : Linear Vertical Displacement Transducer (LVDT) is use to measures displacement

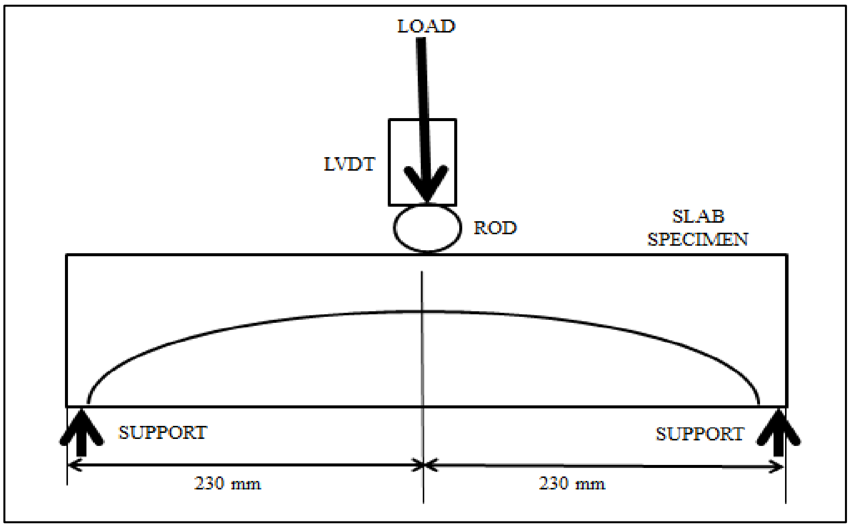

Figure 3.17 : Loading detail for flexural test.

Static load is the type of loading that occurs on the specimen. During this test, the load applied to the rates fixed by computer and associated with a data logging system. The loading will be increase every 0.5 second because more less the time, the result and the cracking will be more visible.

The load is read aloud by technicians to test observers note. As load that has been imposed, the development of cracks is considered timely. The test progress until the specimen failed almost entirely in the graph of the data logging system showed the breakdown or balancing decreases in the growth. Observations end of the specimen was then the pictures for evidence and further analysis.

3.5 Density

The density of both before and after adding mixture is of interest to the parties involved for numerous reasons including its effect on durability, strength and resistance to permeability. And also the density of both fresh concrete with and without EPS and hardened concrete.

The way for determining the density of both types is to enter into the concrete before adding mixture into one liter measuring and weighing as shown in Figure 3.18 and Figure 3.19. And do the second round but repeated the same steps using concrete that has been mixed with the EPS.

Hardened concrete density is determined with the method of weigh all the cube sample and calculates the average weight. After that, the weight are divided the volume of the cube. To determine the density of lightweight concrete sample, the simple calculation is preferred as listed in the Appendix C.

Figure 3.18 : Weigh the fresh concrete.

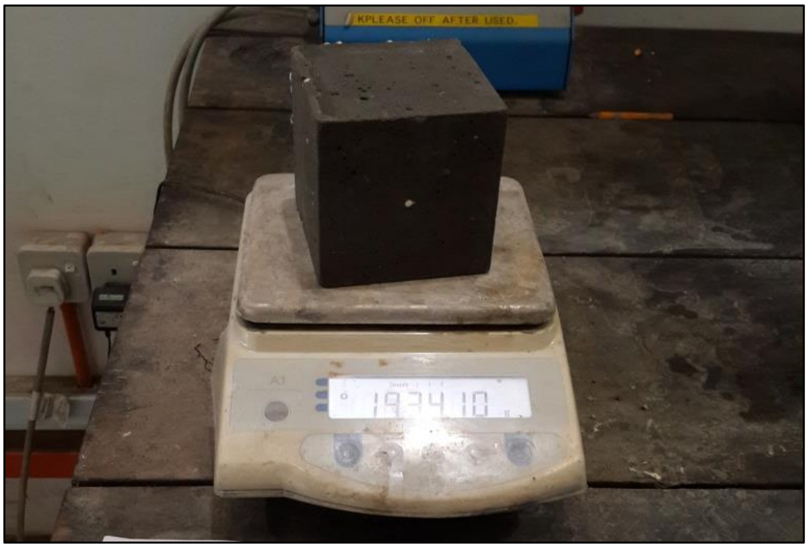

Figure 3.19 : Weigh the harden concrete.

3.6 Milestone

Activities	Completed Duration
Project title and scope of project	Sept 2^{nd} – 4^{th} week
Find problem statement	Oct 4^{th} – Dec 3^{rd} week
Determine research methodology	Nov 3^{rd} – 4^{th} week
Present the proposal	Dec 4^{th} week
Submit proposal	Jan 2^{nd} week
Identify and design arch pan	Jan 3^{rd} –March 2^{nd} week
Prepare arch pan mold	Feb 4^{th} week
Casting concrete	Feb 3^{rd} – 4^{th} week
Laboratory test for 28 days	Feb 4^{th} – April 3^{rd} week
Present the research	June 1^{st} week

Table 4.1: Compressive strength of concrete trial mix and slab.

Day		3		7		28	
Type	Sample	Compressive strength (N/mm^2)	Average (N/mm^2)	Compressive Strength (N/mm^2)	Average (N/mm^2)	Compressive Strength (N/mm^2)	Average (N/mm^2)
Trial Mix	1	4.55	5.34	10.63	11.15	15.93	15.29
	2	5.97		9.05		14.77	
	3	5.5		13.77		15.21	
Slab	1	7.10	6.10	8.82	11.39	14.83	15.99
	2	6.5		13.83		15.6	
	3	4.71		11.51		17.54	

From the results, the quality of concrete used for arch slab almost meet the required characteristic strength, which is $20N/mm^2$; thus validates its adequacy, prior to testing of specimens.

4.3 Flexural Test

Table 4.2: Load capacity and displacement of arch tiles for 50mm arch rise.

Rise of arch = 50mm					
Sample 1		Sample 2		Sample 3	
Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)
0.2	0.254	0.2	0.046	0.2	0.520
0.4	0.566	0.4	0.154	0.4	0.718
0.6	0.814	0.6	0.316	0.6	0.966
0.8	1.074	0.8	0.522	0.8	1.230
1.0	1.262	1.0	0.676	1.0	1.434
1.2	1.432	1.2	0.766	1.2	1.558
1.4	1.550	1.4	0.844	1.4	1.652
1.6	1.670	1.6	0.924	1.6	1.770
1.8	1.790	1.8	1.028	1.8	1.934
2.0	1.926	2.0	1.108	2.0	2.066
2.2	2.040	2.2	1.208	2.2	2.164
2.4	2.176	2.4	1.312	2.4	2.258
2.6	2.274	2.6	1.406	2.6	2.336
2.8	2.360	2.8	1.488	2.8	2.406
3.0	**2.590**	3.0	1.566	3.0	2.470
2.8	2.672	3.2	1.660	3.2	2.532
2.6	2.702	**3.4**	**1.766**	3.4	2.592

2.2	2.702	3.0	1.828	3.6	2.648
		2.8	1.833	**3.8**	**2.708**
		2.6	1.830	3.6	2.750
				3.4	2.754
				3.2	2.778
				3.0	2.814
				2.8	2.818
				2.6	2.818
				2.4	2.820
				2.2	2.824
				2.0	2.832
				1.8	2.840
				1.6	2.846
				1.4	2.854
				1.3	2.866
Average Load = (3.0 + 3.4 + 3.8)/3 = 3.4 kN					
Average Displacement = (2.590 + 1.755 + 2.708)/3 = 2.355 mm					

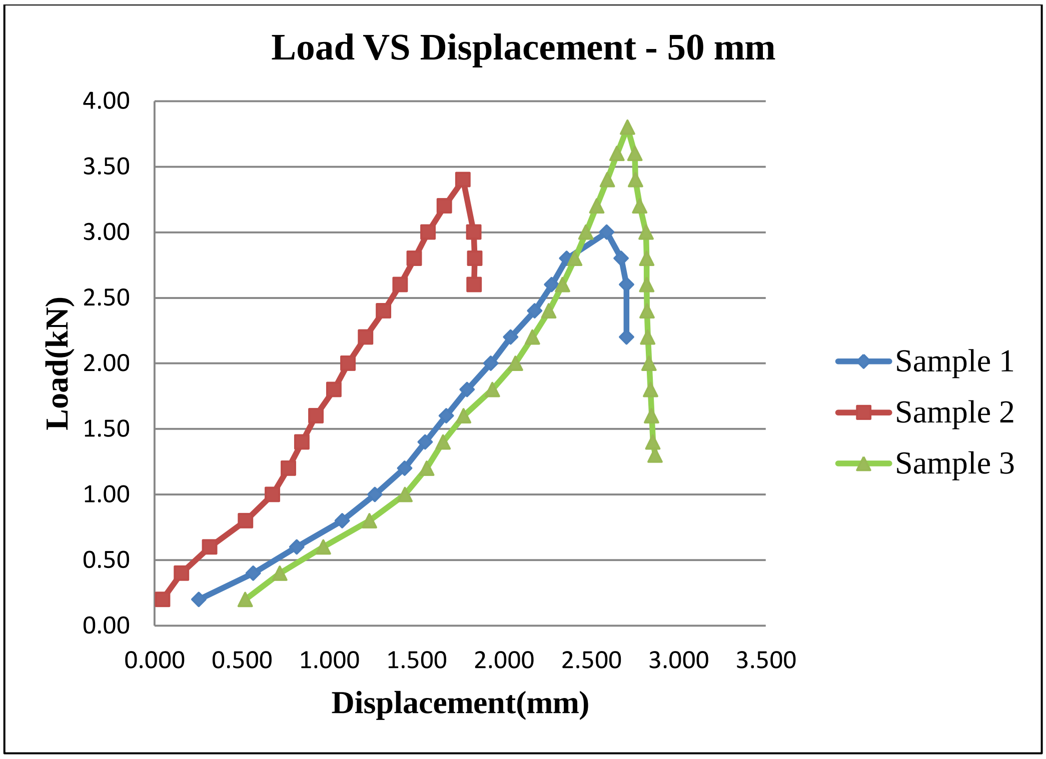

Figure 4.1: Graph Load vs. Displacement 50 mm arch rise.

From Figure 4.1 and Table 4.2, we can observe the load bearing capacity of each sample. In general, load and displacement increases almost correspondingly until a point where the structure fails. From the observation, for 50mm arch rise; sample 3 possesses higher load bearing capacity compared to sample 1 and 2, measuring 3.8 kN. The sudden drop from the graph for both samples indicate that the structure fail under maximum load.

Table 4.3: Load capacity and displacement of arch tiles for 75mm arch rise.

Rise of arch = 75mm					
Sample 1		Sample 2		Sample 3	
Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)	Load (kN)	Displacement (mm)
0.2	0.266	0.2	0.152	0.2	0.398
0.4	0.632	0.4	0.414	0.4	0.724
0.6	1.008	0.6	0.780	0.6	1.078
0.8	1.418	0.8	1.084	0.8	1.442
1.0	1.752	1.0	1.358	1.0	1.738
1.2	2.038	1.2	1.602	1.2	1.996
1.4	2.278	1.4	1.778	1.4	2.198
1.6	2.548	1.6	1.976	1.6	2.366
1.8	2.802	1.8	2.202	1.8	2.540
2.0	**3.018**	**2.0**	**2.398**	2.0	2.690
1.8	3.042	1.8	2.428	2.2	2.862
1.4	3.046	1.4	2.438	**2.4**	**3.038**
				2.2	3.124
				1.4	3.124
Average Load = (2.0 + 2.0 + 2.4)/3 = 2.133 kN					
Average Displacement = (3.018 + 2.398 + 3.038)/3 = 2.818 mm					

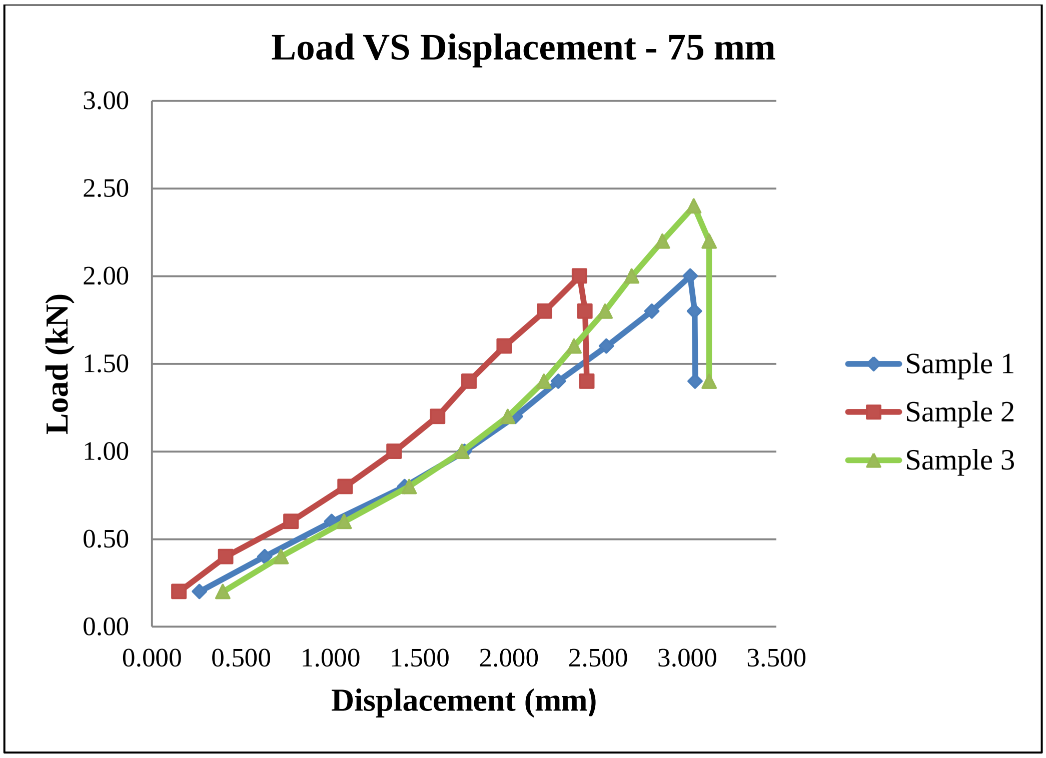

Figure 4.2 : Graph Load vs Displacement 75mm arch rise.

For 75mm arch rise; result was shows in Figure 4.2 and Table 4.3. From the observation, sample 3 has higher load bearing capacity compared to sample 1 and 2, measuring 2.4 kN; while the load bearing capacity of sample 1 and 2 have the same value with 2.0 kN. The sudden drop from the graph for all samples indicate that the structure fail under maximum load.

4.4 Density

The main purpose of this research is to identify the performance of EPS lightweight concrete in term of density and compressive strength. The density results are presented in Table 4.3 and Figure 4.2. The increment of voids throughout the sample caused by the EPS in the mixture will lower the density. As a result, density of fresh concrete with EPS got the lowest value compare then hardens concrete and fresh concrete without EPS. And different result between the density before and after adding the EPS is about 68 kg/m^3.

Table 4.4 : Density of concrete.

Sample	Density of harden Concrete (kg/m^3)	Average density of harden concrete (kg/m^3)	Density of fresh concrete without EPS (kg/m^3)	Density of fresh concrete with EPS (kg/m^3)
1	1889.54	1815.58	1856	1788
2	1877.26			
3	1766.67			
4	1750.60			
5	1779.58			
6	1910.27			
7	1784.55			
8	1824.78			
9	1756.98			

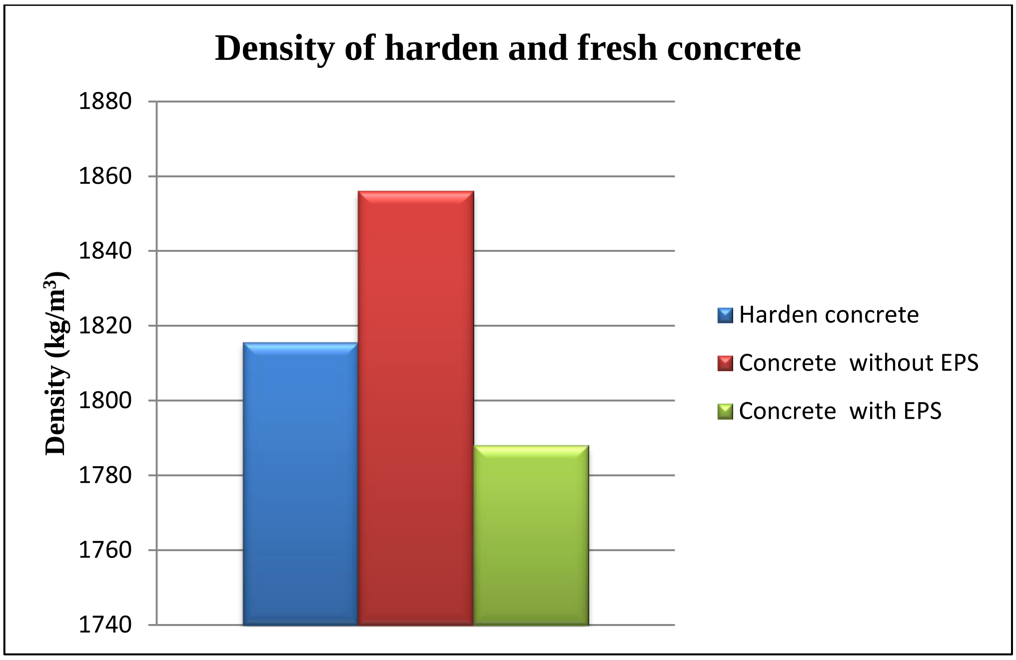

Figure 4.3 : Different density of harden and fresh concrete.

The required density of lightweight concrete must less than normal concrete which is less than 2400 kg/m^3. Therefore, since the density of the fresh concrete with EPS is 1788 kg/m^3, so it is acceptable to be produced as arch tiles permanent formwork for upper floor slab structure.

4.5 Discussion

Theoretically (see design calculation in Appendix A and B), arch tile of 50mm arch rise transfers higher horizontal thrust compared to arch tile of 75mm arch rise. This difference indicates that arch tile of 50mm arch rise is able to withstand greater load compared to arch tile with 75mm arch rise, because of its geometry. However, from the observation, we can hardly distinguish which of this arch tile is stronger. Besides that, the development of the graph pattern for each sample is not consistent, thus explains the indifferences of the load bearing capacity.

5.2 Recommendation

The result of this study can be improved by refer to recommendations as below:

1. Maintain to use various sizes of EPS but to get more value of compressive strength, suggest decreasing the EPS's size. In this study, size of EPS was used is 1.5mm to 5.0mm.

2. This study was only conducted for compressive strength test and flexural test. In order to get more information on lightweight polystyrene concrete, others testing should be carry out such as water absorption, etc.

3. To increase the strength of the arch tile, adding the reinforcements is much better.

4. Other than ellipse, the shape of arch can be change as semicircular or parabolic shape

5. For the saving cost purpose, suggest increasing the length of the slab.

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Nowadays in Malaysia, many contractors and developers are still struggling to catch up with the current pace of development, especially in meeting country's demand, as conventional construction methods still work. Although traditional practice, this conventional method has several disadvantages such as high skill labor and material costs, and especially, a tendency not to change production of construction waste. Therefore, to overcome these weaknesses, permanent formwork using lightweight concrete is chosen as an alternative solution. Briefly, the new technology existence in construction to overcome this problem is permanent formwork using lightweight concrete which is more useful than conventional methods in terms of effectiveness of the functions, lighter, safety features and productivity.

In conjunction, this research presents the design of a lightweight concrete arch slab to investigate the adequacy of the dish as a fixed reference for the floor slab above. In addition, two sets of arch slabs will be prepared with different density and dimension to propose to investigate the behavior under load application. Following this investigation, made significant experimental procedure of the properties of materials and preparation, to test established. From the results and discussion, as conclusion that the design of the lightweight concrete arch slab function adequately as a fixed reference for the floor slab above while arch slab that has a higher arch increases under constant and thickness measured period, stronger than the arch of the increase is lower.

CHAPTER 2

LITERATURE REVIEW

2.1 General

2.1.1 Permanent Formwork

Formwork is the term given to either temporary or permanent molds into which concrete or similar materials are poured. The formwork is built on site out of steel, timber or plywood. It is easy to produce but time-consuming for larger structures and the plywood facing has a relatively short lifespan. It is the flexible type of formwork, so even where other systems are in use, complicated sections may use it. Permanent formwork provides a practical and economical way of supporting freshly poured in-situ concrete in composite upper floor.

In this research, the type of formwork being use is a permanent one specifically for slab construction. A permanent formwork is a formwork that stays in place for the life of the element it is supporting and becomes a part of the permanent structure of the building. It does not only act as a temporary support to control the shape of the fluid concrete, but it also helps to strengthen the finished concrete structure

Industrialized Building System (IBS) or semi-precast system known in Malaysia as a ‘half slab’ is another development in floor slab construction. The technique employs a reinforced precast floor panel that serves as permanent formwork for the composite with cast in-situ concrete. Steel lattice trusses projecting from the top of the

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This research methodology chapter are explains clearly about the study methods for producing lightweight concrete arch slab by using polystyrene beads as an extenuating agent. The main objective of this study is to determine the density and compressive strength of lightweight concrete to be used as arch slab by using polystyrene beads. The tests will be conducted is to find compressive strength and the displacement of the arch slab. All the procedures are prepared accordingly, to assure the research objectives are applicable, and to secure proper sequence and smooth running of the entire flow, from start until end. Six samples will provided, which three of them are 50mm and the rest is 75mm.

3.2 Arch Slab Design and Properties

In this research, the rise of arch or arch height is the varying parameter, while the span length and thickness are fixed. The arch slabs are designed as shown in Figure 3.1 and 3.2. The design is made by using the ellipsoid arch formula.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the result and discussion will be focused on the performance of EPS in the lightweight concrete. All the tests method involved were described in the previous chapter. The results presented comprehensively through tables, graphs and bar chart, with essential analysis and discussion. All the results obtained from the density, compressive strength, and flexural test for two different height of arch slab. The main objective in assessing the results is to compare the measured performance with the basis of the manual calculations. In the end, these results and discussions will draw necessary conclusion and suggest relevant recommendations.

4.2 Compressive Strength Test

Compressive Strength Test, trial and error method was used in determining the most suitable mixture in preparing research samples. A trial mix have been prepared during the research and from the results, the mixture with the compressive strength with the density will be used for further investigation.

After 3, 7 and 28 days of curing the concrete cubes, the result of the compressive strength of concrete is obtained, as shown in Table 4.1. There were three samples for each test and the results would be taken as the average of these three. The percentage of EPS applied is fixed for all mixtures and the difference in the results would occur because of the error or precaution.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Based from the study, the result and analysis can be concluding that all the objectives were achieved. Hence, the results and discussion can be summarized as follow:

1. Polystyrene concrete can be classified as lightweight concrete according to American Concrete Institute (ACI). It is because the density of polystyrene concrete is in the range set by ACI which is 300 to 1850 kg/m3.

2. The workability characteristics of the mixes are very different from the normal concrete. Compaction by vibration was not effective owing to the lightweight nature of the mixes. The mixes were cohesive that the cement slurry coating the beads was very effective in holding the mix together.

3. EPS contribute to low weight and low density; it also contributes to the low strength of the specimens. EPS do not contribute to the strength of the material. The strength obtained in the mixes with EPS is very low, due to the bead’s weakness in compression. This is also because EPS do not react chemically with the mix to contribute strength.

4. The arch rise of an arch tile affects its behavior under load application. Comprehensively, under a fixed measurable span length, and thickness; an arch structure with lower arch rise dimension possesses higher load bearing capacity.

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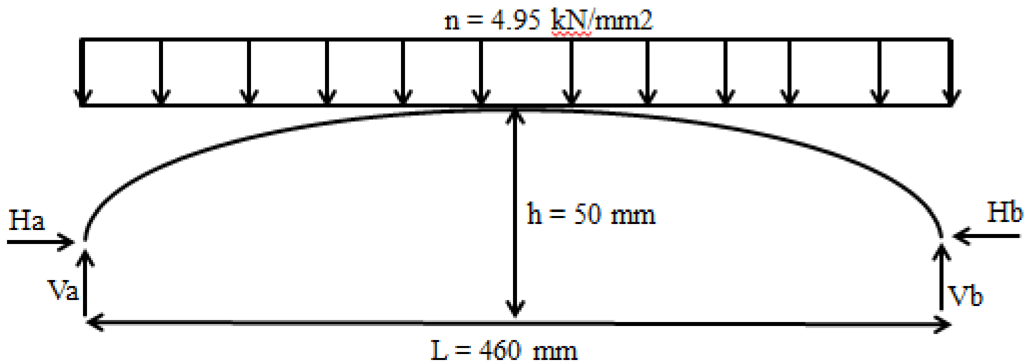
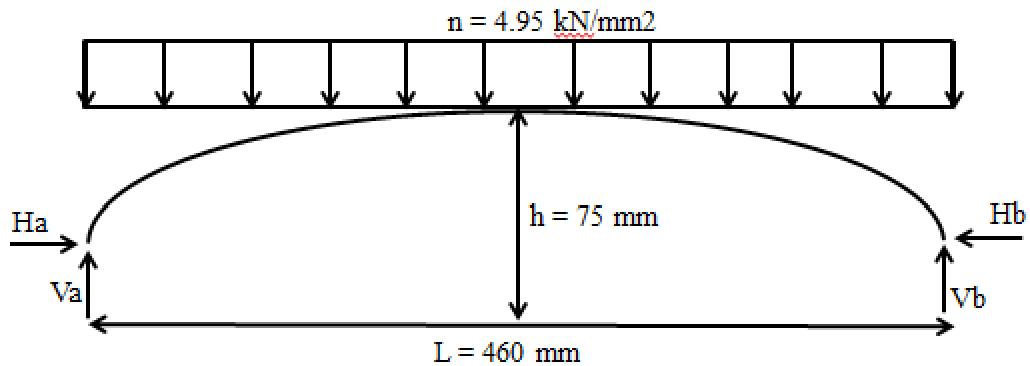
Appendix A

DESIGN CALCULATION FOR ARCH RISE 50mm

$\sum Ma = 0$, $V_a - 4.95(0.46)(0.23) = 0$ $V_a = 1.14$ kN, $\sum Fy = 0$, $V_b - 4.95(0.46) + 1.14 = 0$ $V_b = 1.14$ kN, $M_a = M_b = 1.14x$
$y = \frac{4hx\,(L - x)}{L^2}$ $y = \frac{4(0.05)x\,(0.46 - x)}{0.46^2}$

$y = 0.95x\,(0.46 - x)$
$M_y = (1.14x)\,[0.95x\,(0.46 - x)]$ $= 1.083\,x^2\,(0.46 - x)$
$\int_0^L My\,dx = 2 \text{ X } \int_0^{0.23} 1.083\,x^2\,(0.46 - x)\,dx$ $= 0.0013 \text{ kN/m}^3$
$\int_0^L y^2\,dx = \frac{8\,h^2 L}{15}$ $= \frac{8(0.05)^2(0.46)}{15}$ $= 0.00061\text{m}^3$
$H = \frac{\int_0^L My\,dx}{\int_0^L y^2\,dx} = \frac{0.0013}{0.00061} = 2.13 \text{ kN}$ $H_a = H_b = 2.13 \text{ kN}$

Appendix B

DESIGN CALCULATION FOR ARCH RISE 75mm

$\sum Ma = 0$, V_a – 4.95(0.46)(0.23) = 0 V_a = 1.14 kN, $\sum Fy = 0$, V_b – 4.95(0.46) + 1.14 = 0 V_b = 1.14 kN, $M_a = M_b$ = 1.14x
$y = \frac{4hx\,(L - x)}{L^2}$ $y = \frac{4(0.075)x\,(0.46 - x)}{0.46^2}$

$y = 1.42x\,(0.46 - x)$
$M_y = (1.14x)\,[1.42x\,(0.46 - x)]$ $= 1.62\,x^2\,(0.46 - x)$
$\int_0^L My\,dx = 2 \text{ X} \int_0^{0.23} 1.62\;x^2\,(0.46 - x)\,dx$ $= 0.0038 \text{ kN/m}^3$
$\int_0^L y^2\,dx = \frac{8\,h^2 L}{15}$ $= \frac{8(0.05)^2(0.46)}{15}$ $= 0.0014\text{m}^3$
$H = \frac{\int_0^L My\,dx}{\int_0^L y^2\,dx} = \frac{0.0038}{0.0014} = 2.70 \text{ kN}$ $H_a = H_b = 2.70 \text{ kN}$

Appendix C

CALCULATION DENSITY OF HARDEN CONCRETE
Procedures: 1. Weigh sample using weighing scale. 2. Get the average weight of those 9 cube samples. 3. Calculate the density using the formula given below.
$$\text{Density} = \frac{\text{Average Weight of Samples (kg)}}{\text{Volume of Sample (m}^3\text{)}}$$ $$\text{Density} = \frac{0.181558\ \text{kg}}{0.001\ \text{m}^3}$$ $$\text{Density} = 1815.58\ \text{kg/m}^3$$