CONCRETE RESEARCH LETTERS

www.crl.issres.net Vol. 1 (1) – March 2010

Comparison between Ribbed Slab Structure using Lightweight Foam Concrete and Solid Slab Structure using Normal Concrete

Rana Shabbar[C], Norizal Noordin, Eethar T. Dawood and Mohd Zailan Sulieman

Building Technology, Housing Building and planning School, University Science Malaysia, MALAYSIA

Selected paper from the Asia Pacific Structural Engineering Conference, APSEC 2009

Abstract

The aim of this study is to demonstrate that one-way ribbed slab with lightweight foam concrete can be used to reduce the dead load on slab concrete structure. This would allow the structural designer to reduce the size of column, footing and other load bearing elements. In addition, the scope of this study is to design one-way ribbed slab and two-way solid slab by using Esteem® software. The methodology employed in this study consists of two parts, the first part is the Lab tests for the density and compression strength while the second part is the analysis of the data made by using the ESTEEM® software. The result of this study shows that one-way ribbed slab with beam used in residential building is more preferable from the economical point of view since it is less expensive than the two-way solid slab with beam. Furthermore, one-way ribbed slab with L.W.F.C. is more efficient. As a conclusion, it seems that L.W.F.C. could be considered as an-alternative in place of other frequently used conventional cement due to its capability to reduce the weight of building. On the other hand, ESTEEM® software is considered as an efficient and accurate method of making the analysis and the optimization of building structure.

Keywords: Building structure; L.W.F.C.; Lightweight foam concrete; One way ribbed slab; Two way solid slab; ESTEEM® software

1. Introduction

Structure is a system formed from the interconnection structural members or the shape or form that prevents buildings from being collapsed. A structure supports the building by using a framed arrangement known as Structure [1]. There are two important steps for the construction of a building, (i) Structural Analysis and (ii) Structural Design.

Structural analysis is the force acting on different parts of the structure that can be determined through structural analysis. Movements and shear forces are considered as the most common forces which are calculated. Complicated formula and charts will be used in this calculation works and this requires the use of computer software as well as trained and experienced engineers. However, basic understanding of the concept of the design and structural analysis is significantly required. In order

[C] Corresponding Author: R.H. Shabbar
Email: ranashabbarr@yahoo.com Telephone: +60174106426

to ensure that the design is suitable and the calculation is also correct, a computer is used. The result produced by the computer will be very accurate but the error might be in the input parameters [1].

At this stage, suitable structural members are selected or designed. The reinforcement steel and member sizes (i.e. in the case of RC structures) are proposed and selected. A specific code of practice is considered as a base for the design works. In this case, the compliance with local requirements and the design will be standardized. The British code of practice is widely used in Malaysia while other codes such as from US, Japan, Germany and Australia are used by some other designers [1]. For the design structure, the following precautions should be taken into consideration, (i) The structure design is a general problem for all physical objects and (ii) An intelligent manner in making decisions cannot be achieved by building designers regarding the form and fabric of a building without some understanding of basic concepts of structures [2].

One of the structure elements is the slab which is a flexural member of uniform depth supporting the area loads over its surface. One of the most important examples for the early reinforced slab structure was Soo Line terminal in Chicago which was constructed in 1913. This Soo Line terminal was tested in terms of load of ten railway cars at 200.8 Kips (893,158N) each. One panel of the Schwin Bicycle Factory in Chicago was also loaded to 450psf (21,546 N/m^2) for the entire year. However, the rational analysis of slabs has lagged behind the practice of designing and construction. When the first rational analysis was published by Nichols in 1914, more than 1000flat slab buildings had already been built [3].

There are two significant types of slabs, solid slab and flat slab but the loads and span will determine largely the choice of slab type. Solid slab is of two categories, one-way slab and two-way slab [4]. The one-way slab is one of the simplest forms of solid slab. It is considered economical for small span only (up to 4.6 m) due to its low efficiency and weight. Sometimes and in special cases, the reduction of the weight can be achieved by using some forms of elements in order to create hollow voids in the slab [2].

On the other hand, the two-way slab is usually used for heavy loading and large spans [5]. The reinforcement in two-way slab should be designed in order to enable the slab to act in both directions. The ratio of long to short side of the floor panel would determine the load proportion taken by each set of reinforcement. However, there are three types of Two-way slab, (i) Two-way slab with Edge support (Edge supports may be bearing walls or monolithic beams), (ii) Two-way slab without beams (It could be called flat plate system or the flat slab. Only the column supports and slab can be of this type), (iii) Two-way Ribbed slab (waffle) (A ribbed slab gives considerable extra strength in one direction while a waffle slabs gives added strength in both directions). This is possible only in monolithically cast concrete [6] which is the two way grid of beams. In comparison to solid slab, the span limits of ribbed slabs are considerably longer. So, longer span and light to moderate live loads (generally less than 3 KN/m^2) can be used for this type of slab. It is considered more economical than the other types because it provides a ribbed slab is constructed by using removable forms, hollow block or permanent or removable void formers [6].

Lightweight concrete is a type of concrete which has an expanding agent to increase the volume of the mixture. This in turn gives some additional properties, such as lessening the dead weight. Furthermore, it is lighter than the conventional concrete with a dry density of 300 $kg.m^{-3}$ up to 1840 $Kg.m^{-3}$, 23% to 87 lighter [7]. Lightweight was introduced by the Romans during the second century, where the Pantheon is still being used until now (for about 18 centuries) and it is constructed from light weight concrete. Of course, the main advantage of light weight concrete is that it is economical over the use of other types of concrete [8]. Since the beginning of the nineteenth century, cellular concrete was first developed in Stockholm, Sweden. "Gas concrete" was known to be the original material and it was used as insulated building materials. In 1920, Dr. Axel Eriksson had succeeded in making aerated concrete, and factory production of reinforced lightweight roof slabs started in Sweden in 1929.After thirty years, foamed slab was used in Great Britain. It is an excellent aggregate but it is mostly used at blast furnaces and with all other aggregates. On the other hand, lightweight concrete was used in Great Britain. Later, this led to the development of lightweight concrete in many forms as cellular concrete, aerated concrete, autoclaved concrete, or foamed concrete. This technology spread quickly (after 1940) to different parts of the world, especially, the Soviet Union and Europe. This technology was applied for the production of economical large-size structural panel units. These were used in low-rise structures, and in site reconstruction. During the late 1950s, this technology was introduced to the US as foamed or cellular concrete. The applications were for wall units, floor, and roof. The low compression strength makes the use of this type of concrete restricted to fills and insulation only. After that, the development of cellular concrete continued in Sweden but with different lightweight concrete. However, In Europe, lightweight concrete was known as "Gasbetong" and in the United States it was known as "Cellular concrete". Nowadays, lightweight concrete is also used in Malaysia and is known as "Foamed concrete". The demand of lightweight concrete become stronger now, concrete has increased many folds in recent years because of its inherent economies and advantages over conventional concrete in a variety of structural applications. Numerous lightweight concrete (LWC) structures, ranging from low-rise bungalows to multistory buildings, bridges and flyovers to marine and offshore structures can now be found in many parts of the world [9]. Lightweight concretes are cementations conglomerates with a bulk density (ranging between 300 and 2000 kgm^{-3}) sensibly lower than that of an ordinary concrete (usually between 2200 and 2600 kgm^{-3}) [10].

There are many types of software that can be used for making the analysis and design, such as ESTEEM® and PROKON® etc. ESTEEM® software is selected because of its efficiency in producing accurate values and also easy to use. Moreover, there are many versions of ESTEEM® software but the one that is usually used is ESTEEMPLUS®, a version with 6 integrated total solution structures used for analyzing the structure. Some of the ESTEEM® applications are for the construction of Twin Tower Condominium and the Stadium [Esteem Innovation,11].

Statement of Problem is that the increment of dead load represents one of the most critical problems in the present research under which the sizes of foundations have to be increased and this leads to the addition of more materials making the building more expensive. Hence, an alternative lightweight concrete to reduce the dead loads is needed. As a result, the total cost would be reduced.

The objective of this study is to prove the use of Lightweight concrete is purposeful for the reducing of dead load on slab concrete structure, so that it would allow the structural designer to reduce the size of columns, footings and other load bearing. The hypothesis of the study is to design one way ribbed slab by using Esteem® software. Esteem® software v6 is to be used to make a comparison between one way ribbed slab with lightweight foam concrete and two way solid slabs with normal concrete in order to find out which one is more economical.

2. Materials

Cement (SIMEN SINGA BIIRU®) was purchased from CIMA GROUP OF COMPANIES Sdn. Bhd. (Perak, Malaysia). Sand (BOON TIN®) was purchased from Guan Seng building trading co. Foam (Noraite PA-I) was purchased from USAINS HOLDING. Sdn. Bhd. (Penang, Malaysia) and the water used was tap water.

3. Mix proportions

The cement was mixed with sand and water was mixed in the mixer for a few minutes. Then foam was added gradually until the required density (1680-1720 Kg/m^3) was obtained. The ratio of cement, sand and foam mixture was 1:1:0.45. For the compressive strength test, the casting was carried out by using steel molds, with the (Selangor, Malaysia) of 100 × 100 × 100 mm [12] and the molds were founded to be well sealed, free from rust and had smooth surfaces. These molds had molds to be brushed with oil to prevent from sticking to the moulds.

4. Test method

4.1. Flow test

ASTM C 1437, the Standard Test Method for the flow of Hydraulic-Cement Mortar [13, 14] was carried out to measure the workability of the mortar by using the flow table test, and the soil test Company (USA). The flow is repeated by using a fresh batch of mortar each time until the desired flow is achieved.

4.2. Density test

4.2.1. Mortar

The density of concrete according to the BS1881: Part 114:1983 [15] was measured to determine the density of hardened concrete by using a cup with a known volume (1 L) and weight (568.3g) which was filled with mortar. Then the weight of the mortar was measured by using the Top pan balance, the vibra shinko deashi (Japan). The density was controlled by adding foam to the mixture. The bulk density of the structural lightweight concretes (ranging between 1400 and 2000 kg/m^3) were discovered to be sensibly lower than that of an ordinary concrete (usually between 2200 and 2600 kg/m^3) [10].

4.2.2. Density for sample

The first density of the mortar was measured (fresh density) by using a cup with a known volume (1L) and weight (568.3g) which was filled with mortar. The second measurement was held 24hr after casting (wet density) while the third measurement was carried out after 28 days (dry density). The samples had to be submerged under water for 27 days and dried by using an oven [16] (Locasi E40-007, member 854 schwabach, W-Germany) before proceeding with the next measurement. The experiment was replicated in quadricate and then the average was taken.

4.3. Compression test

The compressive mechanical strength for structural lightweight concrete was >20MPa [10]. Axial compression testing is useful for the measurement of elastic and compressive fracture properties of brittle materials or low-ductility materials [17] the compressions of the dry samples were taken by using an automatic compression machine (ELE automatic compression machine, MS INSTUMENTS SON.BHO). This test was carried out only on day 28 [16, 18]. The measurement was carried out in quadricate and the average was then taken.

4.4. ESTEEM® Software

ESTEEMPLUS, a version with 6 integrated total solution structures was used for analyzing the structure [19]. The data was collected from the result of the density and compression tests for the concrete and were fed to the software. This software was designed according to British standard. It can analyze and calculate the volume of concrete, amount of steel and formwork, and produce the drawing of the sections and amounts of shears, moments and deflections. Furthermore, this software is able to calculate the raw cost and placement cost for the floor plan.

5. Results and discussion

5.1. Flow test

The flow of the mortar was discovered to be 200 mm which is considered acceptable.

5.2. Density and Compression Test

The result showed that the density of the sample after the mixing and before the foam was added was 2168.7 Kg/m^3 (normal concrete). The densities of samples after the foam added were then measured. After 24hr, the molds were opened and the density of the samples was measured. The average value of these samples was taken based on the result of this test. On 28th day, the samples were removed from the oven and the oven dry densities of the samples were taken. The average value of these samples was taken as the result of this test. The average value for each fresh density of sample after the addition of the foam, the wet density after 24hr, the dry density after drying in oven, and the compression strength after 28 days are shown in Table 1.

TABALE1: FRESH DENSITY OF SAMPLE AFTER THE ADDITION OF FOAM, THE WET DENSITY AFTER 24hr, THE DRY DENSITY AFTER DRYING IN OVEN, AND THE COMPRESSION STRENGHT AFTER 28 DAYS

Fresh density	Wet density	Dry density	Compression strength
1712Kg.m^{-3}	1671 Kg.m^{-3}	1650Kg.m^{-3}	20 MPa

5.3. ESTEEM® Software

5.3.1. The lab results

The result of the flow test within the acceptable range according to ASTM C 1437, the Standard Test Method for the Flow of Hydraulic-Cement Mortar for Flow Table Test [14], were noted. While the bulk density of the structural lightweight concrete was within acceptable range [10], additional to the result of compressive strength was discovered to be within the acceptable range of structural lightweight concretes [10].

5.3.2. The Analysis of One Way Ribbed Slab

The plan for the building which consisted of ribbed slab, beam, and column is shown in Figure 1, and the result of this analysis which was done by using the ESTEEM® software for one way ribbed slab which produced the result of the calculations of moments for ribbed slab, are listed in Table 2 which shows the maximum moments in the slab (FS11) whether at support short span, long span, support short span, or at support long span.

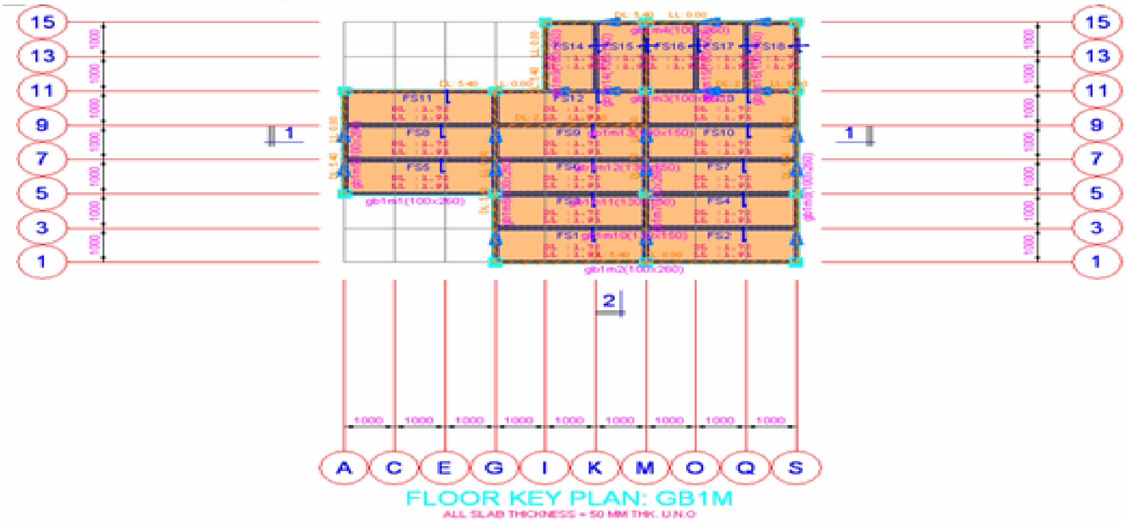

Figure 1. The Plan for Building which consists of Ribbed Slab, Beam, and Column

TABLE 2: RESULT OF THE CALCULATIONS OF MOMENTS FOR RIBBER SLAB

Slab mark	Mx[a] (KN.m^2)	My[b] (KN.m^2)	Msx[c] (KN.m^2)	Msy[d] (KN.m^2)
FS1	0.5	0.2	0.66	0.27
FS2	0.5	0.2	0.66	0.27
FS3	0.35	0.16	0.47	0.22
FS4	0.35	0.16	0.47	0.22
FS5	0.5	0.2	0.66	0.27
FS6	0.34	0.14	0.45	0.19
FS7	0.35	0.16	0.47	0.22
FS8	0.35	0.16	0.47	0.22
FS9	0.34	0.14	0.45	0.19
FS10	0.35	0.16	0.47	0.22
FS11	0.5	0.2	0.66	0.27
FS12	0.48	0.16	0.64	0.22
FS13	0.35	0.16	0.47	0.22
FS14	0.42	0.2	0.56	0.27
FS15	0.3	0.16	0.4	0.22
FS16	0.3	0.16	0.4	0.22
FS17	0.3	0.16	0.4	0.22
FS18	0.42	0.2	0.56	0.27

[a]: Short span moment
[b]: Long span moment
[c]: Support short span moment
[d]: Support long span moment
Note: Area =120 mm^2, and rebar =R6 mm

The result of the analysis which was done by using the ESTEEM® software and the calculations of the thickness of slab, volume, formwork, X-Direction bar, Y-Direction bar, and weight for ribbed slab are as listed in Table 3.

TABLE 3: RESULT OF THE CALCULATIONS OF SLAB THICKNESS, VOLUME, FORMWORK, X-DIRECTION BAR, Y-DIRECTION BAR AND WEIGHT FOR RIBBED SLAB

Slab mark	Volume M^3	Formwork M^2	X -Direction bar mm	Y -Direction bar mm	Weight Kg
FS1	0.127	2.54	14R6-75,3200	41R6-75,1200	20.9
FS2	0.128	2.553	14R6-75,3200	41R6-75,1200	20.9
FS3	0.125	2.497	14R6-75,3200	41R6-75,1200	20.9
FS4	0.125	2.51	14R6-75,3200	41R6-75,1200	20.9
FS5	0.128	2.553	14R6-75,3200	41R6-75,1200	20.9
FS6	0.125	2.497	14R6-75,3200	41R6-75,1200	20.9
FS7	0.125	2.51	14R6-75,3200	41R6-75,1200	20.9
FS8	0.125	2.51	14R6-75,3200	41R6-75,1200	20.9
FS9	0.125	2.497	14R6-75,3200	41R6-75,1200	20.9
FS10	0.125	2.51	14R6-75,3200	41R6-75,1200	20.9
FS11	0.128	2.553	14R6-75,3200	41R6-75,1200	20.9
FS12	0.127	2.54	14R6-75,3200	41R6-75,1200	20.9
FS13	0.128	2.553	14R6-75,3200	41R6-75,1200	20.9
FS14	0.086	1.71	27R6-75,1200	41R6-75,1200	14.1
FS15	0.084	1.681	27R6-75,1200	41R6-75,1200	14.1
FS16	0.084	1.681	27R6-75,1200	41R6-75,1200	14.1
FS17	0.086	1.71	27R6-75,1200	41R6-75,1200	14.1
FS18	0.086	1.71	27R6-75,1200	41R6-75,1200	14.1
Total	2.066	41.316			431.8

Note: Thickness = 50 mm

The section and the distribution of steel bars at the bottom and top of ribbed slab are shown in Figure 2.

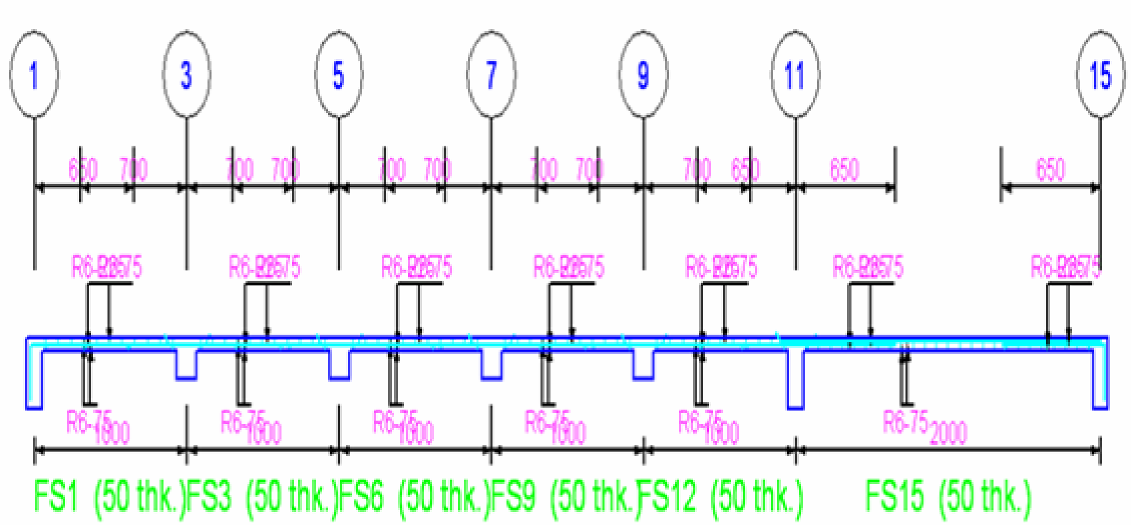

Figure 2. Section and Distribution of Steel Bars on top and at the bottom of Ribbed Slab

The material costs for the concrete (volume= 2.1m^3) and Formwork (area= 41.3 m^2) were RM310 and RM826 respectively while the total material cost for Bottom bar R6 with weight 341.8Kg was RM 376. The total was RM 1888. In addition to this, the result of the calculations of beam, depth, concrete volume, and formwork for beams are listed in Table 4.

TABLE 4: RESULT OF THE CALCULATIONS OF BEAM WIDTH, DEPTH, CONCRETE VOLUME AND FORMWORK FOR BEAMS

Beam name	Width m	Depth m	Concrete volume M^3	formwork	
				Bottom M^2	Side M^2
gb1m1	100	260	0.16575	0.6375	3.315
gb1m2	130	150	0.120217	0.8015	1.8495
gb1m3	100	260	0.08775	0.3375	1.755
gb1m4	130	150	0.124312	0.8288	1.9125
gb1m5	130	150	0.178425	1.1895	2.745
gb1m6	130	150	0.178425	1.1895	2.745
gb1m7	100	260	0.24375	0.9375	4.875
gb1m8	100	260	0.13975	0.5375	2.795
gb1m9	100	260	0.08775	0.3375	1.755
gb1m10	130	260	0.181675	0.6988	2.795
gb1m11	100	260	0.0598	0.23	1.196
gb1m12	100	150	0.03225	0.215	0.645
gb1m13	130	260	0.249275	0.9588	3.835
gb1m14	100	150	0.03225	0.215	0.645
gb1m15	100	150	0.03225	0.215	0.645
gb1m16	100	260	0.19175	0.7375	3.835

The distribution of steel bars for maximum moment in beam 13 (joist) after the calculation was done by using ESTEEM® software and the section for beam joist is shown in Figure 3.

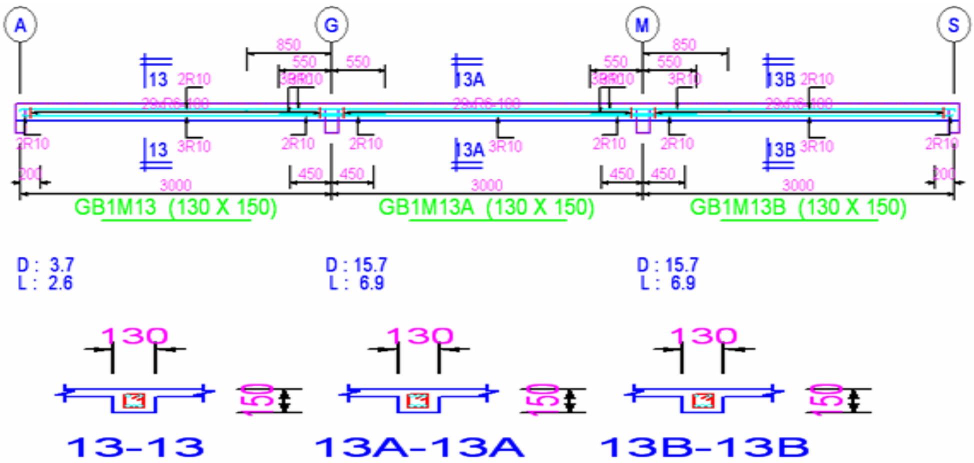

Figure 3. Section and Distribution of Steel bars for Maximum Moment in $Beam_{13}$ (joist)

The result of analysis, which was done by using ESTEEM® software showed the section and the distribution of steel bars for maximum moment in major beam13 is as shown in Figure 4.

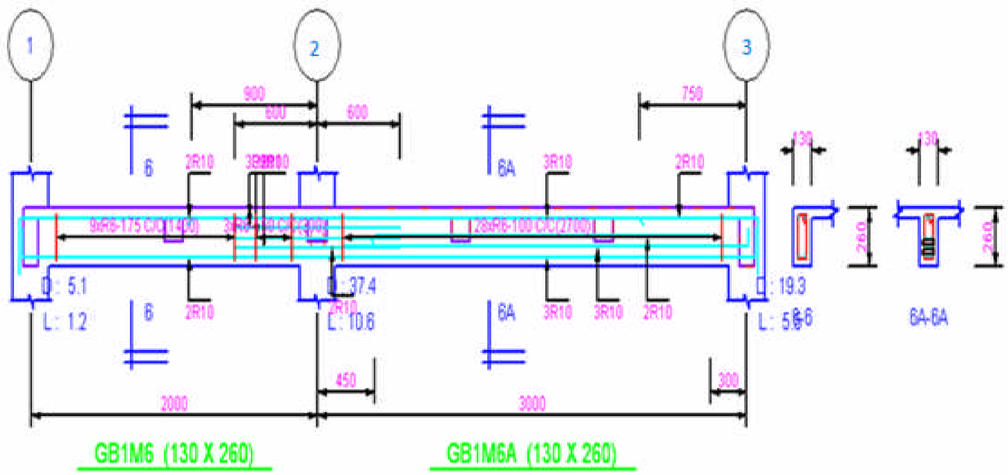

Figure 4. Section and Distribution of Steel Bars for Maximum Moment in Major $Beam_6$

The result of the calculations of major and joist beam top steel bars, bottom steel bars, and link bars are listed in Table 5.

From the above analysis, it can be seen that the software had calculated the total volume of concrete beam (for ribbed slab) which was 2.10538 m^3 and its cost was RM 315.8. This is considered as a raw cost. Furthermore, the total area of formwork for the bottom and the top of the plan were 10.067 m^2 and 31.063 m^2 respectively, and the total cost of formwork for the bottom and the top was RM 1028.3 which is also considered a raw cost while the weight of the main beam steel (R6 and R10) were 39.8 Kg and 247.8 Kg respectively. On the other hand, the raw cost of R6 and R10 was RM 34.8 and RM 272.6 respectively (the total cost was RM 316.3).The total raw cost for Beam link steel of Diameter 6 mm weighting 79.9 Kg was RM 87.8.

Furthermore, the total cost for the beam of ribbed slab was RM 1748.2. This is considered as a raw cost and the total cost for the building which consisted of ribbed slabs and beams was RM 3636.2.This is also considered a raw cost.

TABLE 5: RESULT OF MAJOR AND JOIST BEAMS TOP STEEL BARS, BOTTOM STEEL BARS AND LINKS BARS

Beam name	Steel			Steel			Link Bar	
	Top Bar			Bottom Bar				
	Bar mm	Length m	weight Kg	Bar mm	Length m	weight Kg	Length m	weight Kg
gb1m1	R6 R10	23.16 6.4	9.1	R10	12.85	8	22.8	5.1
gb1m2	R10	15.92	9.9	R10	17.18	10.7	27.4	6.1
gb1m3	R6	14.54	3.3	R10	6.85	4.3	10.7	2.4
gb1m4	R10	17.45	10.8	R10	17.45	10.8	26.4	5.9
gb1m5	R6 R10	4.11 22.84	15.1	R10	23.15	14.3	41.1	9.2
gb1m6	R6 R10	4.11 24.9	16.3	R10	25.58	15.8	41.1	9.2
gb1m7	R6 R10	30.82 12.8	14.8	R10	18.85	11.7	34.8	7.8
gb1m8	R6 R10	19.16 6.4	8.3	R6 R10	7.82 12.34	9.4	20.2	4.5
gb1m9	R6	14.54	3.3	R10	18.33	11.4	17.7	4
gb1m10	R10	23.69	14.7	R10	27.1	16.8	27.7	6.2
gb1m11	R6	9.73	2.2	R10	4.7	3	7	1.6
gb1m12	R6	4.2	1	R10	4.11	2.6	8.2	1.9
gb1m13	R10	29.28	18.1	R10	23.81	14.7	29.1	6.5
gb1m14	R6	4.2	1	R10	4.11	2.6	8.2	1.9
gb1m15	R6	4.2	1	R10	4.11	2.6	8.2	1.9
gb1m16	R6 R10	22.82 12.8	13	R6 R10	15.63 8.44	8.7	28.4	6.4

Note: Link rebar =R6 mm

5.4. The Analysis of Two Way Solid Slab

The plan for the building which consisted of solid slab, beam, and column is shown in Figure 5.

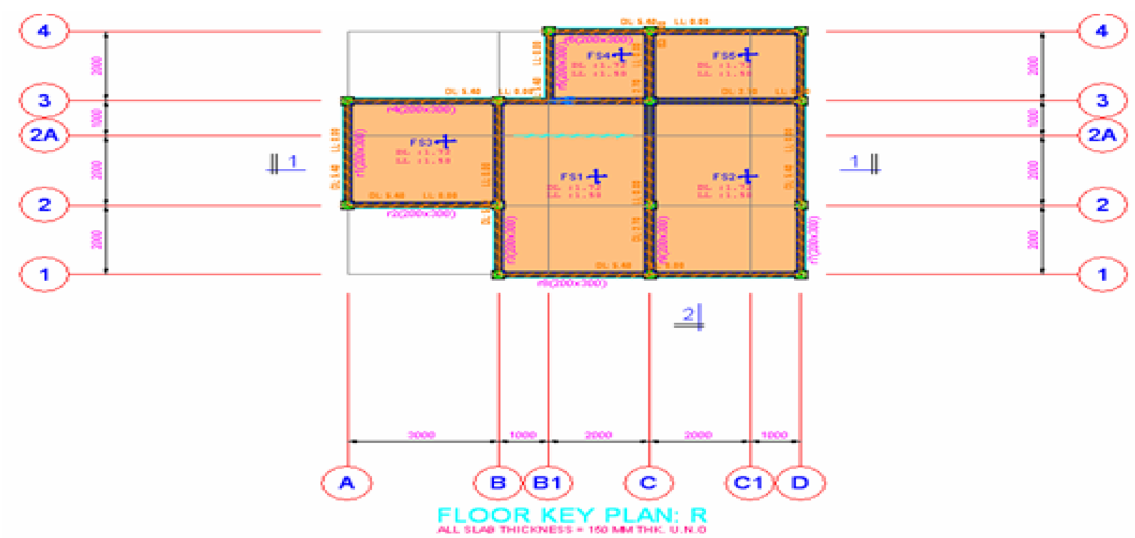

Figure 5. Building Plan which consists of Solid Slab, Beam, and Column

The result of this analysis, which was done by using the ESTEEM® software for two way solid slab, produced the result of the calculations of moments for solid slab and is listed in Table 6 which shows the maximum moments which are in slab (FS2) whether at support short span, long span, support short span, and support long span.

TABLE 6: RESULT OF THE CALCULATION OF MOMENTS FOR SOLID SLABS

Slab mark	Mx[a] $KN.m^2$	My[b] $KN.m^2$	Msx[c] $KN.m^2$	Msy[d] $KN.m^2$
FS1	4.77	3.03	0.18 -6.96 -3.44 -5.65	
FS2	5.59	3.01	7.46	4.02
FS3	3.76	3.86	0	5.14
FS4	1.4	1.34	1.87	1.79
FS5	2.3	1.34	3.07	1.79

[a]: Short span moment
[b]: Long span moment
[c]: Support short span moment
[d]: Support long span moment
Note: area =360 mm^2, and rebar =R10 mm^2

The result of the analysis, which was done by using ESTEEM® software, gave the calculations of the thickness of slab, volume, formwork, X-Direction bar, Y-Direction bar, and weight for solid slab as listed in Table 7. The section and the distribution of steel bars at the bottom and top of solid slab are shown in Figure 6.

TABLE 7: RESULT OF THE CALCULATIONS OF SLAB THICKNESS, VOLUME, FORMWORK, X-DIRECTION BAR, Y-DIRECTION BAR AND WEIGHT FOR SOLID SLAB

Slab mark	Volume M^3	Formwork M^2	x-Direction bar mm	y-Direction bar mm	Weight Kg
FS1	2.073	13.823	26R10-200,3200	16R10-200,5200	102.8
FS2	2.073	13.823	26R10-200,3200	16R10-200,5200	102.8
FS3	1.218	8.123	16R10-200,3200	16R10-200,3200	63.3
FS4	0.513	3.422	11R10-200,3200	11R10-75,2200	29.9
FS5	0.791	5.273	11R10-200,3200	16R10-200,2200	43.5
Total	6.669	44.463			342

Note: Thickness = 150 mm

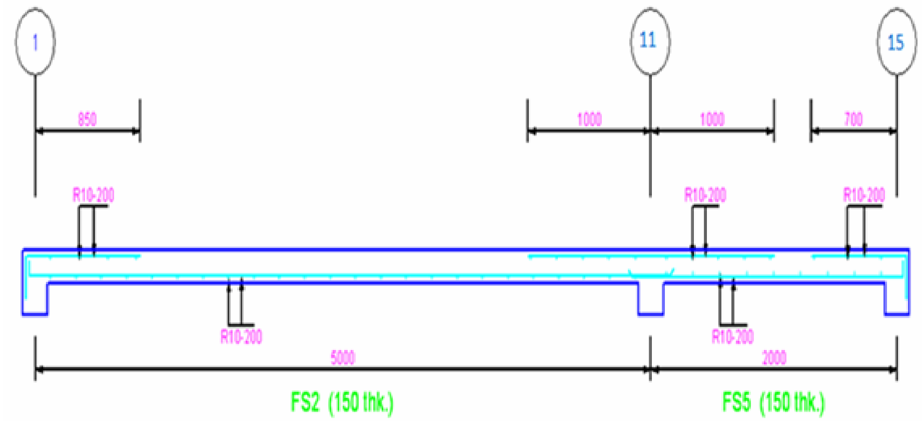

Figure 6. Shape of Section and Distribution of Steel Bars at the Top and Bottom of Solid Slab

The material cost for the concrete (volume= 6.7 m^3) and Formwork (area= 44.5 m^2) was RM1000 and RM889 respectively while the total material cost for the Bottom bar R6 weighting 342 Kg was RM 379. Finally, the total amounted to RM 2642. The result of the calculations, which was done by using the ESTEEM® software for the beam the width, depth, concrete volume, formwork, individual beam loadings, reactions and shears for the beams, are listed in Table 8.

TABLE 8: RESULT OF THE CALCULATIONS OF BEAM WIDTH, DEPTH, CONCRETE VOLUME AND FORMWORK FOR BEAMS

Beam name	Concrete volume M^3	Formwork	
		Bottom m^2	Side m^2
r1	0.3825	1.275	3.825
r 2	0.2025	0.675	2.025
r 3	0.5625	1.875	5.625
r 4	0.3225	1.075	3.225
r 5	0.2025	0.675	2.025
r 6	0.3225	1.075	3.225
r 7	0.141	0.47	1.41
r 8	0.4425	1.475	3.425
r 9	0.4425	1.475	4.425

Note: Width = 200 mm, Depth = 300mm

It shows the maximum concrete volume of beam (r 3). The result of the analysis, which was done by using the ESTEEM® software, illustrated the distribution of steel bars for the maximum moment in major $beam_3$ and the section for the beam as shown in Figure 7.

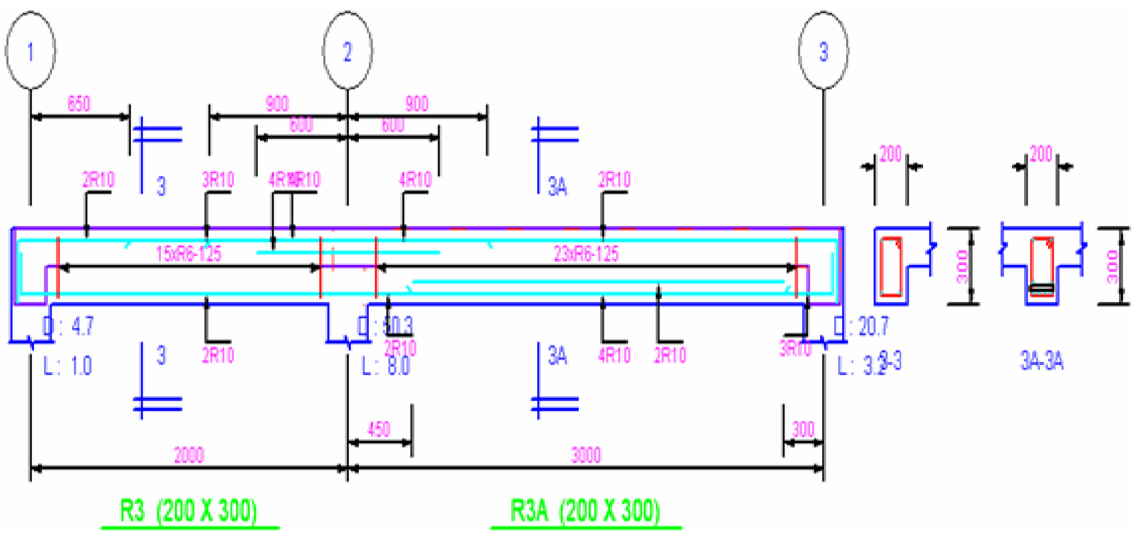

Figure 7. Distribution of Steel Bars for Maximum Moment in Major $Beam_3$ and Section for Beam

In addition to this, the result of the calculations of major and joist beam top steel bars, bottom steel bars, and link bars are listed in Table 9.

The software had calculated the total volume of the beam concrete (solid slab) as 3.021 m^3 and its cost was RM 453.1. This is considered as the raw cost. Furthermore, the total area of steel bar formwork for the bottom and side of the plan were 10.07 m^2 and 21.51 m^2 respectively, and the total cost of steel bar for the bottom and the side was RM 789.5. This is also considered a raw cost while the weight of the main beam steel R10 was 199Kg and for beam link R6 was 72.6Kg. Thus, the raw cost of R10 and R6 was RM 218.9 and RM 79.8 respectively (total cost was RM 298.7) while the total cost for the beam of (solid slab) was RM1541.3. This is considered as a raw cost. Furthermore, the total cost for the building which consisted of solid slabs and beams was RM 4183.3. This is also considered a raw cost. The comparison between ribbed slab and solid slab in concrete volume, formwork and bottom bar R6 clarifies that the quantities which were mentioned above for ribbed slab was less than that of the solid slab as shown in Figure 8.

TABLE 9: RESULT OF MAJOR AND JOIST BEAMS TOP STEEL BARS, BOTTOM STEEL BARS AND LINKS BARS

Beam name	Steel			Steel			Link	
	Top bar			Bottom bar				
	Bar mm	Length m	weight Kg	Bar mm	Length m	weight Kg	Length m	weight Kg
gb1m1	R10	19.16	11.9	R10	20.40	12.6	42.0	9.4
gb1m2	R10	7.36	4.6	R10	18.00	11.2	21.0	4.7
gb1m3	R10	32.08	19.9	R10	31.49	19.5	62.9	14.0
gb1m4	R10	14.86	9.2	R10	13.36	8.3	34.7	7.8
gb1m5	R10	7.36	4.6	R10	18.00	11.2	21.0	4.7
gb1m6	R10	19.96	12.4	R10	20.90	13.0	34.7	7.8
gb1m7	R10	5.18	3.2	R10	4.96	3.1	13.7	3.1
gb1m8	R10	28.08	17.4	R10	20.10	12.5	48.3	10.8
gb1m9	R10	23.48	14.5	R10	17.56	10.9	48.3	10.8

The software had calculated the total volume of the beam concrete (solid slab) as 3.021 m^3 and its cost was RM 453.1. This is considered as the raw cost. Furthermore, the total area of steel bar formwork for the bottom and side of the plan were 10.07 m^2 and 21.51 m^2 respectively, and the total cost of steel bar for the bottom and the side was RM 789.5. This is also considered a raw cost while the weight of the main beam steel R10 was 199Kg and for beam link R6 was 72.6Kg. Thus, the raw cost of R10 and R6 was RM 218.9 and RM 79.8 respectively (total cost was RM 298.7) while the total cost for the beam of (solid slab) was RM1541.3. This is considered as a raw cost. Furthermore, the total cost for the building which consisted of solid slabs and beams was RM 4183.3. This is also considered a raw cost. The comparison between ribbed slab and solid slab in concrete volume, formwork and bottom bar R6 clarifies that the quantities which were mentioned above for ribbed slab was less than that of the solid slab as shown in Figure 8.

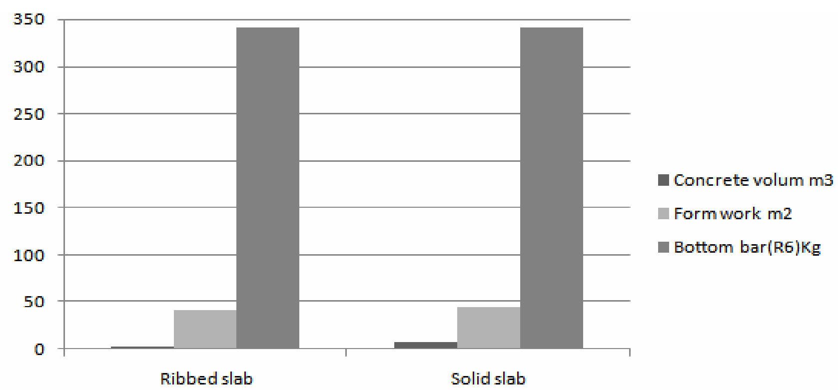

Figure 8. Comparison between Ribbed Slab and Solid Slab by Concrete Volume, Formwork and Bottom Bar R6

The comparison between the beams for ribbed slab and solid slab in concrete volume, form work, main beam steel bar R6 and R10 and beam link steel R6 clarifies that the quantities which were mentioned above for ribbed slab was more than that of the solid slab as shown in Figure 9.

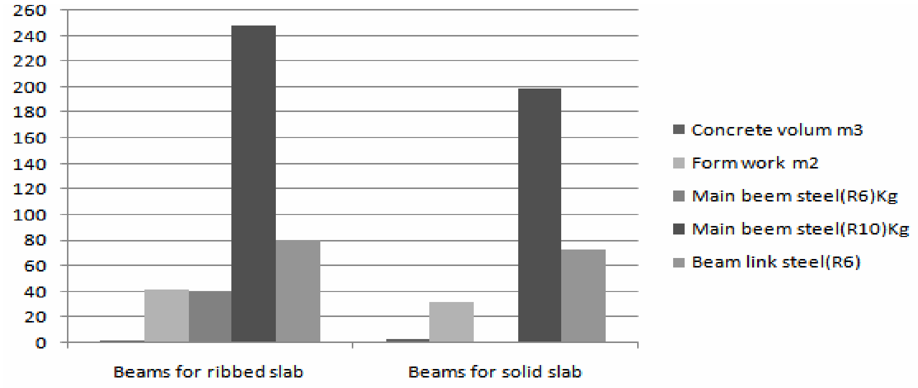

Figure 9. Comparison between Beams for Ribbed Slab and Solid Slab in Concrete Volume, Formwork, Main Beam Steel Bar R6 and R10 and Beam Link Steel R6

Finally, a comparison of the cost of one way ribbed slab and the beam with two way solid slab and beam is shown in Figure 10.

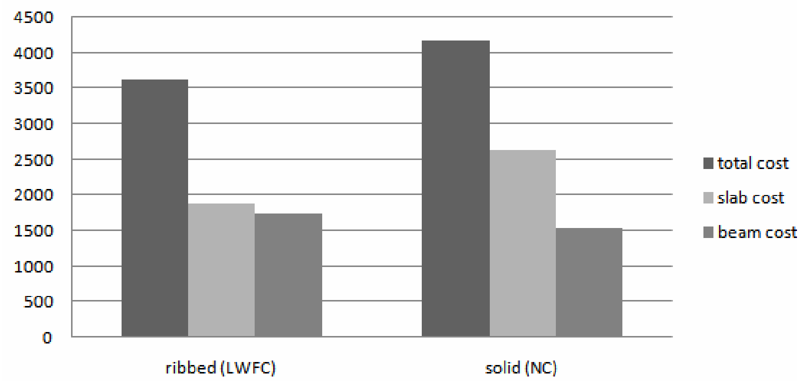

Figure 10. Cost Comparisons between One Way Ribbed Slab and Beam with Two Way Solid Slab and Beam. LEFC= Lightweight foam concrete; NC= Normal concrete

6. Discussion

Foam concrete is an economical material to be used as effective and efficient concrete for construction projects. It is known as lightweight concrete within the range of 300-1840 Kg/m^3 [20]. The result of the flow test reveals that the flow of mortar is acceptable. This means that the mortar has good workability. In addition the density of mortal was within the range for structural lightweight concrete [10,21]. Finally it is reliable for good compression strength to resist the loads.

The analysis was performed by using the ESTEEM® software regarding the cost of one way ribbed slab with beams method and two way solid slabs with beams method. The calculations revealed that the cost of concrete in ribbed slab was less than that in solid slab. This is because the ribbed slab requires less quantity of concrete compared to solid slab. Furthermore, the cost of formwork for ribbed slab is less than that at solid slab because the cost of installing the timber moulds was less. In addition, the dimensions of the moulds were smaller in ribbed slabs compared to that of solid slabs. Furthermore, the cost of the bottom bars R6 in ribbed slabs is not of difference than that in solid slab.

On the other hand, the cost of concrete beams for ribbed slab was also less than that of solid slab because the dimensions of the beam moulds were less compared to that of solid slab. The formwork for the bottom and the top of the plan were much more in ribbed slab compared to that of solid slab because the ribbed slab has more beams than the solid slab. Moreover, the cost of the main steel bars in ribbed slab was much more than that of solid slab because ribbed slab used a lot more quantity of steel bars of different diameters (R6, R10), while solid slab used only steel bars (R10). Finally, the beam links were not of much difference in ribbed slab compared to that of solid slab.

7. Conclusion

1. The result of the analysis, which was done by using the ESTEEM® software, shows that Foam concrete can be designed to meet the criteria of compressive strength of load bearing concrete and Foam concrete is a suitable solution in the construction of multi-storey buildings. Besides, foamed concrete has been identified as a suitable material to replace the normal concrete used for this purpose. At the same time, the density of foamed concrete can be designed and controlled according to the ratio of the mixture and the stability of the foam used. Furthermore, the construction cost of one-way ribbed slab with beams is more economical than that of the two- way solid slabs with beams. Furthermore The ESTTEM® software appears to be an efficient and accurate instrument that is reliable to be used in making the analysis and calculations.

2. The two-way solid slab with beams is not cost efficient in loading on buildings for low-cost residential building project. In other words, two-way solid slabs with beams might be more expensive than the one-way ribbed slab with beams with some quantities of steel bars used in the building. This main reason contributes to the above conclusion which is mainly due to the high cost of steel bars used in two-way solid slabs with beams compared to one-way ribbed slab with beams. Furthermore, the cost of the material of steel formwork in solid slab is more than that of the ribbed slab. Only for formwork steel in beams, the cost of the material for solid slab is slightly lower than that of the ribbed slab.

Acknowledgments

This work is a part of project and the authors would like to thank University Science Malaysia for their financial support. The authors would also like to acknowledge Mr. Khalid B. Ahmad, Mr. Idris B. Shaari, and Ms. Diana Bin Ishak for their technical support. Finally, the authors' gratitude also goes to the members of ESTTEM ® Company for their kind provision of the software.

REFERENCES

[1] Chandrasekar, S., Satyanarayana, K.G., and Raghavan, P.N., *Processing, Properties and Applications of Reactive Silica from Rice Husk — an Overview*. Journal of Materials Science, 2003. **38**:p. 3159.

[2] Maeda, N., Wada, I., Kawakami, M., Ueda, T., and Pushpalal, G.K.D. *Development of a New Furnace for the Production of Rice Husk Ash. The Seventh CANMET / ACI International Conference on Fly ash, Silica Fume, Slag and Natural Pozzolans in Concrete*. Vol. 2, 2001, Chennai, India.

[3] Muthadhi, A., Anitha, R., and Kothandaraman, S., *Rice Husk Ash — Properties and its Uses: A Review*. Department of Civil Engineering, Pondicherry Engineering College, Puducherry. I.

E (I) Journal, 2007.
[4] Mehta, P.K. *Rice husk ash—a unique supplementary cementing material*. In 1992 *Proceedings of the International Symposium on Advances in Concrete Technology, CANMET/ACI, Athens, Greece, pp. 407–430*.
[5] Mehta, P. K. Siliceous ashes and hydraulic cements prepared there from Belgium. Patent 802909 (1973), U.S. Patent 4105459 (1978).
[6] Pitt, N. Process for preparation of siliceous ashes. U.S. Patent 3959007 (1976).
[7] Yu, Q., Sawayama, K., Sugita, S., Shoya M., and Isojima, Y. *The reaction between rice husk ash and $Ca(OH)_2$ solution and the nature of its product*. Cem. Concr. Res., 1999. **29**(1):p. 37-43.
[8] Yamamoto, Y., and Lakho, S.M. *Production and utilization of rice husk ash as a substitute for cement*. In 1982 *Proceedings of the Japanese Society of Civil Engineers*, vol. 322, pp. 157-166.
[9] Boateng, A.A., and Skeete, D.A. *Incineration of rice hull for use as a supplementary cementing material*. *The Guyana experience*. Cem. Concr. Res. 1990. **20**: p.795–802.
[10] Singh, N.B., Sarvahi, R., Singh, S.P., and Shukla, A.K. *Hydration studies of RHA blended white portland cement*. Adv. Cem. Res., 1994. **6** (21): p.13– 18.
[11] Mahmud, H.B., Chia, B.S., and Hamid N.B.A.A. *Rice husk ash—an alternative material in producing high strength concrete*. A. Al-Manaseer, S. Nagataki, R.C. Joshi (Eds.), in 1997 *Proceedings of International Conference on Engineering Materials*, vol. II, CSCE/JSCE, Ottawa, Canada, pp. 275–284.
[12] Cisse, I.K. and Laquerbe, M. *Mechanical characterization of sandcretes with rice husk ash additions: study applied to Senegal*. Cem. Concr. Res., 2000. **30** (1): p.13– 18.
[13] Cook D.J., Pama, R.P., Damer, S.A. *Behaviour of concrete and cement paste containing RHA*. In *1976 Conference Proceedings on Hydraulic Cement Paste,* Cement and Concrete Association, London, pp. 268–282.
[14] Hwang, C.L., and Wu, D.S. *Properties of cement paste containing rice husk ash*. Am. Concr. Inst. SP-114, 1989, pp. 733– 765.
[15] Zhang, M.H., and Malhotra, V.M. *High-performance concrete incorporating rice husk ash as a supplementary cementing material*. ACI Mater. J., 1996. **93** (6): p. 629– 639.
[16] Bouzoubaa, N., and Fournier, B. *Concrete incorporating rice husk ash: compressive strength and chloride-ion durability*. Report MTL 2001-5 (TR), CANMET, pp.17.
[17] Mehta, P.K. *The chemistry and technology of cements made from rice-husk ash*. In *1979 Proceedings of UNIDO/ESCAP/RCTT Workshop on Rice-Husk Ash Cement*, Peshawar, Pakistan, Regional Centre for Technology Transfer, Bangalore, India, pp. 113– 122.
[18] Yeoh, A.K., Bidin, R., Chong, C.N., and Tay, C.Y. *The relationship between temperature and duration of burning of rice-husk in the development of amorphous rice-husk ash silica*. In *1979 Proceedings of UNIDO/ESCAP/RCTT, Follow-up Meeting on Rice-Husk Ash Cement*, Alor Setar, Malaysia.
[19] Chopra, S.K., Ahluwalia, S.C., and Laxmi S. *Technology and manufacture of rice-husk ash masonry (RHAM) cement*. In *1981 Proceedings of ESCAP/RCTT Workshop on Rice-Husk Ash Cement,* New Delhi, 1981.
[20] Hwang, C.L., and Wu D.S. *Properties of cement paste containing rice husk ash*. Am. Concr. Inst. SP-114, 1989, pp. 733–765.
[21] Ikpong A.A, Okpala D.C. *Strength characteristics of medium workability ordinary Portland cement-rice husk ash concrete*. Building and Environment, 1992. **27** (1): p. 105–111.
[22] Wada I., Kawano T., Mokotomaeda N. *Strength properties of concrete incorporating highly reactive rice-husk ash*. Transaction of Japan Concrete Institute, 1999. **21** (1): p. 57–62.
[23] Saraswathy, V., Song Ha-Won. *Corrosion performance of rice husk ash blended concrete*. Construction and Building Materials, 2007. **21** (8): p.1779–1784.
[24] ASTM C 1202. Standard Test Method for Electrical Indication of Concrete's Ability to Resist

Chloride Ion Penetration, ASTM C1202-97. Annual Book ASTM Stand. 04.02, 2001. p. 646–51.

[25] Tang, L. and Nilsson, L. O. *Rapid determination of the chloride diffusivity in concrete by applying an electrical field*. ACI Mater., 1992. **89**(1):p. 49–53.

[26] Tong L., and Gjorv, O. E. *Chloride diffusivity based on migration testing*. Cement Concrete Research, 2001. **31**:p.973–82.