UNIVERSITI PUTRA MALAYSIA

FLEXURAL AND SHEAR BEHAVIOUR OF LIGHTWEIGHT EXPANDED POLYSTYRENE PRECAST CONCRETE HALF-SLAB

SANUSI SAHEED

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By

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Thesis submitted to the school of graduate studies, Universiti Putra Malaysia, in the fulfilment of the Requirement for the degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair: Farah Nora Aznieta Abd Aziz, PhD

Faculty: Engineering

Industrial Building System (IBS) design is a building system in which structural components are manufactured in a factory, or off site, transported, and coupled into a structure with less additional site works (CIDB, 2001). However, the main problems with precast components are its heavy weight and water leakage at the joint between the precast slabs. Hence, this research aims at producing a lightweight precast slab that could overcome the second problem as well.

Lightweight aggregate concrete is made from three main resources, namely natural aggregates (pumice, scoria, vermiculite, etc.), manufactured aggregates (e.g. Expended clay, expanded silt, Expanded polystyrene (EPS) etc.) and aggregates from industrial by-products (Delayed et al 2006). These lightweight aggregates have many advantages among which are low densities, reduced thermal conductivity, easy handling and high energy absorption. However, the easiest to purchase and practical to use is the EPS beads. EPS beads in concrete have shown sufficient early age strength but reduced the strength of concrete at 28 days. Hence, to address this, Ilangovana (2008) have recommended quarry dust as replacement to fine aggregate by about 20% to improve the compressive strength of EPS concrete. Based on these previous works, the first objective of this research is to determine the optimum mix design of lightweight concrete using quarry dust and Expanded Polystyrene (EPS) based on the targeted compressive strength of 35 MPa, which is sufficient for structural application. An experimental study was conducted to develop the lightweight concrete by partial replacement of sand and coarse aggregates using quarry dust and Expanded Polystyrene (EPS). Sand replacements used were 7.5%, 15% and 22.5%, while coarse aggregate was replaced by EPS beads at 15%, 22.5% and 30% by volume of the mix. A total of 256 trial mixes were made and their mechanical behaviour in terms of compressive strength test, split tensile strength test, Ultra Pulse Velocity test (UPV) and unit weight test were measured, from which the optimum mixture for grade 35 concrete was chosen and used to produce lightweight EPS slabs.

There are numerous types of precast slab includes hollow core, half slab, double tee and metal deck. However, to prevent leakage between the slabs and improve

connectivity between panels, Ng et al (2011) suggested a C-channel half slab because apart from mentioned advantages, it also does not require propping and therefore less formwork is needed. Therefore, using the optimum lightweight EPS concrete, precast C-channel half slabs were produced and subjected to flexural and shear tests as these two behaviours are the dominant contribution during the lifespan of the slab. Normal weight concrete slabs were also produced as control specimens. In total, 10 precast concrete C-channel half slabs of 1 m width by 3.5 m, 4.5 m and 6.0 m span were prepared. Five slabs were made of normal weight concrete and another five of lightweight EPS concrete. On the other hand, 4 numbers of precast slabs both lightweight and normal weight concrete of 200 mm and 250mm thickness were produced and subjected to direct shear load test at span of two times the depth of the slab. During the tests, the ultimate load, deflection behaviour, ductility, reinforcement strain, shear capacity and failure patterns were observed and analysed.

Based on the compressive strength of a few trial mixes, the optimum mix of lightweight EPS concrete of compressive strength 35 MPa was achieved by the replacement of 30% EPS and 15% quarry dust in the concrete. This produces lightweight concrete with a density of 1980 kg/m^3, which is 17% lighter than normal concrete. This lighter concrete will significantly reduce the total self-weight of the structures and subsequently will reduce the size of foundation required and reduce the overall cost of the structure.

The flexural and shear of EPS lightweight half slab showed a comparative capacity as compared to normal weight slab. The ultimate bending moment capacity for lightweight precast C-channel slabs has approximately the same capacity as normal weight precast C-channel for a slab span of 3.5 m, 4.5 m and 6 m respectively. These show that reduction in the dead load due to the EPS lightweight concrete matrix has not reduced its ability in carrying loads regardless of the span of the slab. In terms of the ductility, precast lightweight C-channel slab achieved ductility ratio of 2.9 - 3.1 higher than the normal concrete of 2.2 -2.6. This explained why the lightweight precast channel slabs give more cracks signs before failure and this will provide a safer structure to the user. On the other hand, the ultimate shear capacity for lightweight precast C-channel slabs with lightweight concrete topping with 200 mm and 250 mm depths show a reduction of shear capacity by 6 % and 12% respectively as compared to the experimental capacity of normal concrete C-channel precast slab. However, when compared to the theoretical calculation, experimental shear capacity of lightweight precast C-channel slab for 200 mm and 250 mm depths is 26% and 32% higher than the calculated value. This shows that the shear capacity of lightweight precast slab is sufficient and can be predicted by the theoretical shear calculation for normal concrete. In conclusion, it can be stated that the precast EPS lightweight precast C-channel half slab can be estimated using a similar theoretical calculation for normal concrete. Also, as the self-weight of the slab is reduced, the foundation size can be reduced too, which directly will also contribute in a cost saving of the whole structure. Therefore the lightweight precast C-channels half slab could be used as a flooring system in single and double story housing construction.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebaggi memenuhi sy keperluan untuk ijazah Master Sains

KELAKUAAN LENTURAN DAN RICIH BAGI PAPAK SEPARA KONKRIT PRATUANG POLISTREN RINGAN TERKEMBANG PRATUANG

Oleh

SANUSI SAHEED

July 2014

Pengerusi: Farah Nora Aznieta Abdul Aziz, Phd

Fakulti: Kejuruteraan

Rekabentuk sistem perindustrian Pembinaan bangunan (IBS) adalah sistem pembinaan bangunan di mana pembentukan komponen dihasilkan di kilang, atau diluar kawasan pembinaan, dipindahkan dan di pasang pada struktur di mana ia akan pengurangan pekerja di tapak (CIDB, 2001). Walaubagaimanapun, masalah utama yang dihadapi dengan menggunakan komponen pratuang adalah; berat yang berlebihan dan kebocoran pada bahagian penyambung diantara papak pratuang ringan. Oleh itu, kajian ini bertujuan untuk menghasilkan papak pratuang separa ringan yang juga mampu menyelesaikan masalah kebocoran tersebut.

Konkrit agregat ringan ini diperbuat daripada tiga sumber utama yang dikelaskan sebagai agregat semulajadi (*pumice*, *scoria*, *vermiculite*, dll.), agregat dari kilang (contohnya; pengembangan tanah liat, pengembangan kelodak dan pengembangan polistrine (EPS) sebagainya) dan agregat daripada industri mengikut jenis produk (Delayed et al 2006). Agregat ringan ini mempunyai banyak kelebihan diantaranya kepadatan rendah, pengurangan kekonduksian terma, pengendalian yang mudah dan penyerapan tenaga yang tinggi. Walaubagaimanapun, bahan yang paling mudah dibeli dan praktikal digunakan ialah manik EPS. Konkrit yang mengandungi manik EPS telah menunjukkan kekuatan yang mencukupi pada tahap awal pengembangan tetapi ia mengurang kekuatan konkrit pada hari ke28 hari. Oleh itu, untuk menghuraikan kenyataan ini, Ilangovana (2008) telah mencadangkan penggunaan habuk kuari sebagai pengganti kepada agregat halus sebanyak 20% bagi meningkatkan keupayaan mampatan konkrit EPS. Berdasarkan kepada kajian-kajian awal ini, objektif utama adalah bagi menentukan rekabentuk optimum campuran konkrit ringan menggunakan habuk kuari dan polistrine mengembang (EPS) berdasarkan kepada kekuatan mampatan sasaran 35MPa, di mana ia mencukupi bagi pengaplikasian untuk sesebuah struktur. Satu kajian eksperimen telah dijalankan bagi membangunkan konkrit ringan daripada penggantian separuh pasir dan agregat kasar menggunakan habuk kuari serta polistrine mengembang (EPS). Pasir gantian yang digunakan ialah 7.5%, 15% dan 22.5%, manakala agregat kasar telah digantikan dengan manik EPS pada tahap 15%, 22.5% dan 30%, mengikut jumlah isipadu

campuran yang digunakan. Sebanyak 256 percubaan campuran telah dibuat dan tingkah laku mekanikal dari sudut kajian kekuatan komprehensif, pengasingkan ujian kekuatan tegangan, Ujian halaju denyutan ultra (UPV) dan ujian penilaian berat telah diukur, daripada ukuran optimum campuran bagi penggredan, 35 konkrit dipilih dan digunakan untuk menghasilkan papak ringan EPS.

Terdapat pelbagai jenis papak pratuang termasuklah *hollow core*, separa papak, *double tee* dan geladak logam. Walaubagaimanapun, bagi mengelakkan kebocoran antara papak dan meningkatkan daya penyambungan antara panel, Ng et al (2011) mencadangkan sebuah C-channel separa papak kerana selain dari kelebihan yang dinyatakan, ia juga tidak memerlukan ampuan serta menjadikan acuan yang diperlukan dapat dikurangkan. Oleh yang demikian, dengan menggunakan konkrit EPS ringan secara optimum, papak pratuang separa C-channel telah dihasilkan dan tertakluk kepada ujian lenturan dan tahap kericihan yang mana tingkahlaku keduanya adalah dominan sepanjang jangka hayat papak. Papak konkrit dengan jumlah berat normal juga dihasilkan sebagai spesimen kawalan. Secara keseluruhannya, 10 konkrit pratuang C-channel separa papak berkelebaran 1 m dengan panjang 3.5m, 4.5m dan 6.0m telah disediakan. Lima dari papak-papak tersebut dihasilkan melalui kaedah konkrit isipadu normal manakala lima selebihnya adalah dari konkrit EPS ringan. Dari sudut lain pula, 4 papak pratuang dengan dua daripadanya ialah papak konkrit ringan dan papak konkrit normal berketebalan 200mm dan 250mm dihasilkan bagi menguji tahap kericihan pada jarak dua kali ganda kedalaman papak. Semasa ujian, beban muktamad, pesongan tingkah laku, kemuluran, tarikan tetulang, keupayaan ricih dan corak kegagalan dapat diperhatikan dan dianalisis.

Berdasarkan kepada kekuatan komprehensif terhadap beberapa percubaan campuran, campuran optimum bagi konkrit EPS ringan bagi kekuatan komprehensif 35MPa telah dicapai dengan penggantian 30% EPS dan 15% serbuk kuari kedalam konkrit. ini mengha silkan konkrit ringan dengan kepadatan 1980 kg/m^3, di mana 17% lebih ringan dari konkrit yang normal. Konkrit ringan ini mengurangkan jumlah berat persendirian sesuatu struktur secara signifikan seterusnya akan mengurangkan saiz asas yang diperlukan serta mengurangkan kos keseluruhan struktur.

Dalam lenturan dan ricih papak separuh ringan EPS menunjukkan perbandingan kapasiti diantara papak yang mempunyai berat normal bagi ketiga-tiga papall. Lenturan muktamad yang diperoleh daripada papak pratuang C-channel ringan hampir menyamai jumlah kapasiti papak C-channel dengan berat normal 3.5m, 4.5m dan 6m setiapnya. Ini menunjukkan bahawa pengurangan beban kekal disebabkan konkrit EPS ringan tidak mengurangkan keupayaan membawa beban papak tanpa mengira panjang papall. Dari sudut kemuluran pula, papak pratuang C-channel dapat mencapai tahap kemuluran 2.9 – 3.1 lebih tinggi daripada konkrit dari normal konkrit yang mana tahap kemuluran hanya bernisbah diantara 2.2 – 2.6. Ini menerangkan bahawa papak pratuang ringan memberi tanda awal keretakan sebelum berlaku kegagalan dan ini akan memberikan satu bentuk struktur yang selamat kepada pengguna.Di samping itu, keupayaan utama ricihan papak pratuang C-channel dengan salutan konkrit ringan berkedalaman 200mm dan 250mm menunjukkan pengurangan ricihan sebanyak 6% dan 12% keseluruhannya jika dibandingkan dengan kajian keatas papak konkrit C-channel berkapasiti normal. Walaubagaimanapun, apabila dibandingkan dengan teori pengiraan, kajian keatas kapasiti ricihan papak pratuang C-channel bagi 200 mm dan 250 mm, kedalamannya ialah 26% dan 32% lebih tinggi dari nilai yang dikira melalui te pengiraan. Ini menunjukkan kapasiti ricihan papak pratuang ringan adalah mencukupi dan teori dijangka dengan menggunakan teori pengiraan ricihan untuk konkrit normal. Kesimpulannya, boleh dinyatakan bahawa papak pratuang EPS ringan C-channel separa papak boleh boleh dianggar menggunakan pengiraan teori sama seperti konkrit biasa. Tambahan pula, oleh kerana berat papak telah berkurangan, saiz asas juga dapat dikurangkan di mana secara lansungnya akan menyumbang kepada penjimatan kos struktur keseluruhan. Oleh yang demikian, papak separa pratuang ringan C-channel boleh digunakan sebagai tapak asas dalam pembinaan rumah satu atau dua tingkat.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Masters of Science. The members of the Supervisory Committee were as follows:

Farah Nora Aznieta Abdul Aziz, PhD
Senior Lecturer
Faculty of Engineering
University Putra Malaysia
(Chairman)

Nor Azizi Safiee, PhD
Senior Lecturer
Faculty of Engineering University Putra Malaysia
(Member)

Izian Abd. Karim , PhD
Senior Lecturer
Faculty of Engineering University Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

Declaration by the student

I hereby confirm that:

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- The research conducted and the writing of this thesis was under our supervision;
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Signature: ______________________

Name of member of Supervisory committee: ______________________

Signature: ______________________

Name of member of Supervisory committee: ______________________

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LIST OF ABBREVIATIONS

CIDB	Construction industry development board
CS	Compressive Strength
CS	Coconut Shell
EPS	Expanded Polystyrene
EPSC	Expanded Polystyrene concrete
FIB	fédération internationale du béton
FRC	Ferber reinforced concrete
IBS	Industrial Building System
LWAC	lightweight Aggregate Concrete
LWC	lightweight concrete
LVDT	linear variable differential transformer
LWA	lightweight Aggregate
PFA	Pulverised fuel ash
NC	Normal Concrete
OPS	oil Palm Shell
UPV	Ultra Pulse Velocity
UEPS	un-expanded polystyrene
E0qd0	Expanded polystyrene 0% quarry dust 0%
E0qd7.5	Expanded polystyrene 0% quarry dust 7.5%
E0qd15	Expanded polystyrene 0% quarry dust 15%
E0qd22.5	Expanded polystyrene 0% quarry dust 22.5%
E15qd0	Expanded polystyrene 15% quarry dust 0%
E15qd7.5	Expanded polystyrene 15% quarry dust 7.5%
E15qd15	Expanded polystyrene 15% quarry dust 15%
E15qd22.5	Expanded polystyrene 15% quarry dust 22.5%
E22.5qd0	Expanded polystyrene 22.5% quarry dust 0%
E22.5qd7.5	Expanded polystyrene 22.5% quarry dust 7.5%
E22.5qd15	Expanded polystyrene 22.5% quarry dust 15%
E22.5qd22.5	Expanded polystyrene 22.5% quarry dust 22.5%
E30qd0	Expanded polystyrene 30% quarry dust 0%
E30qd7.5	Expanded polystyrene30% quarry dust 7.5%
E30qd15	Expanded polystyrene 30% quarry dust 15%
E30qd22.5	Expanded polystyrene 30% quarry dust 22.5%
NC-3.5	normal concrete 3.5 m
EPSC-3.5	Expanded Polystyrene concrete 3.5 m
NC-4.5	normal concrete 4.5 m
EPSC-4.5	Expanded Polystyrene concrete 4.5 m
NC-6	normal concrete 6 m
EPSC-6	Expanded Polystyrene concrete 6 m
NC200A	normal concrete 200 mm side A
NC200B	normal concrete 200 mm side B
EPSC200A	Expanded Polystyrene concrete 200 mm side A
EPSC200B	Expanded Polystyrene concrete 200 mm side B
NC250A	normal concrete 250 mm side A
NC250B	normal concrete 250 mm side B
EPSC250A	Expanded Polystyrene concrete 200 mm side A
EPSC250B	Expanded Polystyrene concrete 200 mm side **B**

CHAPTER 1

INTRODUCTION

1.1 Background

According to the definition by the Construction Industry Development Board (CIDB) Malaysia, Industrial Building System (IBS) design is the building system in which structural components are manufactured in a factory, or off site, transported, and coupled into a structure with fewer additional site works (CIDB, 2001). The main IBS structural components are wall panels, slab panels, beams and columns. These are also called pre-fabricated or precast structural components and are installed on site piece by piece with minimum use of cast in-situ concrete (Elliott, 2002).

There are many types of precast slab which include: hollow core, half slab, double tee and metal deck as shown in Figure 1.1. However, implementation of metal deck type may face challenges with corrosion in a country like Malaysia due to its humid climate. Hollow core, double tee and block and beams systems however are basically pre-stressed and meant for long spans, which therefore make it expensive and impractical for urban and rural housing with a very light load. The basic features of available precast slabs are tabulated in Table 1.1 as a summary from various literatures such as Elliott (2002), Ibrahim, Kim, and Copeland (2008) and CIDB (2001).

Apart from types of precast slab, the type of concrete used is also another main contribution to the cost of buildings, particularly single and double story houses. A heavy slab, i.e. structural element will require a larger size of the foundation and consequently increased the cost of the house. According to Lo and Cui (2004), weight of lightweight concrete is typically 16 % to 35% lighter than normal concrete but its strengths are compared to normal weight concrete. Hence, using lightweight concrete is an option to have better design flexibility, substantial cost savings, lesser dead load, improved cyclic structural response, allow longer spans, allow thinner sections and smaller size structural members.

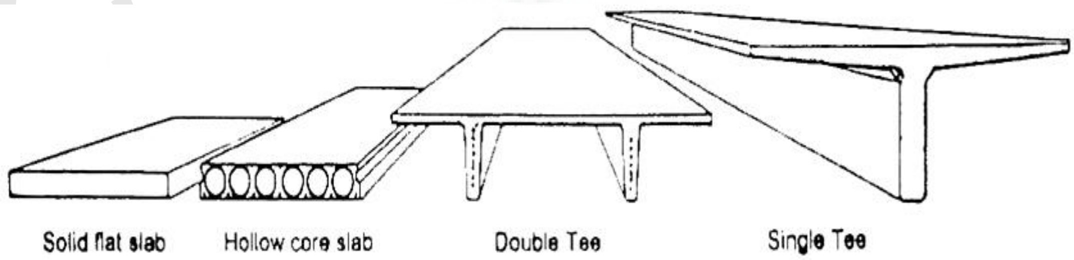

Figure 1.1: precast slab panel (www.eu.lib.kmutt.ac.th)

Table 1.1: Types of precast slab with basic features

Description	Types of precast floor panels				
	Hollow core slab	Double tee	Beam and block	Half slab	C channel
Panel width (m)	0.6 - 1.2	2.4	0.3 - 0.57	2.4	1.0
Panel span (m)	3 - 15	5 – 18	3 - 7	2 – 11	3 - 8
Panel thickness (mm)	150 – 400	50 + span or rib	150 - 350	50 - 75	50 + rib
Type of fabrication	Prestressed concrete	Prestressed concrete	Prestressed concrete	Reinforced concrete	Precast concrete
Grade of concrete (MPa)	35	50	35	30 and above	25 - 35
Type of steel used	Prestressing strand	Prestressing strand	Prestressing strand	Plain and deformed bars	Plain and deformed bars
Topping concrete and thickness (mm)	Yes 50 - 75	Yes 60 -200	Yes	Yes 65 – 325 depending on span and design load	50
Temporary propping	No	No	No	Yes	No
Immediate working space	Yes	Yes	No	No	Yes
Fast erection	No	No	No	No	Yes
Site labour	High	High	High	High	less
Jacking system required	Yes	Yes	Yes	No	No

Lightweight concrete is produced by using lightweight aggregates that can be classified into syntactic aggregate and natural aggregate from a volcanic eruption. Natural lightweight aggregate from a volcanic eruption is too expensive and not available locally. Other natural lightweight aggregate like oil palm shale (OPS) which is available in Malaysia, have high water absorption. Syntactic lightweight aggregate produced from environmental waste, like fly ash and expanded polystyrene (EPS) could be explored Lo TY, Cui HZ (2004). In this research, EPS lightweight aggregate is introduced as it is a waste material and cheaper than other synthetic aggregates. EPS artificial lightweight aggregate is made from styrene monomer that produces Expanded Polystyrene. As the styrene monomer is made from a plant like Oriental sweet gum, natural gas, low level styrene occurs naturally in fruits, vegetables, nuts and meat (http://www.plasticseurope.org). Expanded Polystyrene (EPS) beads are an example of environmental waste that is often used as the basis for packaging materials and leads to a large amount of non-biodegradable waste. By employing heat treatment method, this material can be modified and be used as a lightweight aggregate for concrete. This therefore results in, reduction in environmental load, waste management cost, reduction of production cost as well as augmenting the quality of concrete.

Since 2006, Malaysia have produced 60.0 million tonnes of granite giving approximately 20% of quarry dust from the quarry activities which is approximately 12.0 million tonnes of quarry dust left unutilised. Hence, a great potential to be used as replacement sand in concrete (www.aggbusiness.com). Quarry dust is also introduced to partially replace river sand as to make lightweight concrete more environmentally friendly and also help to improve the compressive strength. This is because quarry dust is a by-product of crushed rock which can also be referred to as environmental waste (Ukpata, J. and Ephraim, M. 2006), while less use of river sand can lessen environmental problems.

1.2 Problem Statement

Most studies that were carried out on the lightweight aggregate concrete are made from natural aggregates (Pumice, scoria, vermiculite, etc.), manufactured aggregates (e.g. Expanded clay, expanded silt, etc.) and aggregates from industrial by-products (Delayed et al 2006). These lightweight aggregates have advantages among which are low densities, reduced thermal conductivity, easy handling and high energy absorption. On top of that, EPS has the advantage of improving early age strength of concrete, but not the ultimate strength, therefore Ilangovana (2008) recommended use of quarry dust as replacement of fine aggregate by about 20% to improve the ultimate strength of concrete with EPS. Furthermore, Sadrmomtazi et al (2012) also reported that lightweight concrete using EPS as aggregate can achieve a compressive strength of 17-35 MPa, which is sufficient strength for structural application such as lightweight slab, deck and precast flooring system.

The precast flooring system without concrete topping are popular in the industry, however, this will cause water leakage at the joint between the precast slabs particularly in a residential building (Ng et. al. 2011). Hence, the precast half slab with concrete topping is studied as a potential practical solution, particularly for a single and double storey building. The shear key connection between slabs is introduced and the slab is named as precast C-channel half slab with 50 mm thick concrete topping. Introductions of shear key and concrete topping are to prevent leakage between the slabs and improve connectivity between panels. Also, the C-channel slab is chosen because no propping is required and therefore less formwork's and props needed. (Ng et al 2011).

According to Kurian (2007), two important properties of slab that need to be studied are flexural and shear. The flexural capacity of EPS lightweight precast C-channel half slab must be determined to ensure its carrying capacity and performance. While its shear capacity and behaviour should be investigated to ensure no debonding between layers may happen. In view of the aforementioned, this research is aimed to produce a structural lightweight precast C-channel half slab using coarse aggregate with sand and partially replacing them with EPS and quarry dust, respectively. Then its capacities when subjected to bending and shear will be identified. These two behaviours of lightweight precast C-channel half slab will be compared to normal weight C-channel half slab to determine its performance and behaviour.

1.3 Objectives

In order to achieve the aim of this research as stated above, the following objectives are:

- To determine the optimum mix design of lightweight concrete using quarry dust and Expanded Polystyrene (EPS) based on the targeted compressive strength of 35 MPa and density in range of 1900-2000 kg/m3.

- To assess the flexural behaviour of a lightweight and normal weight precast C-channel half slab of three different slab spans.

- To evaluate the shear behaviour of a lightweight and normal weight precast C-channel half slab with two different slab thicknesses.

1.4 Scope and Limitation

The scope of this research is divided into two parts. The first is on the development of lightweight concrete with partially replacement of sand and coarse aggregates; and the second parts is the flexural and shear tests of C-channel lightweight concrete precast half slab. The first part is an experimental study on the effect of quarry dust and expanded polystyrene (EPS) in producing lightweight concrete with compressive strength of 35 MPa. The EPS replacements are limited to 15%, 22.5% and 30% by volume of coarse aggregate while the quarry dust replacements are limited to 7.5%, 15% and 22.5% by weight of sand. The properties of the mixes are tested in terms of density, compressive strength, splitting tensile strength, and Ultrasonic Pulse Velocity (UPV) test.

The second part covers experimental test on precast C-channel half slab made of lightweight EPS concrete and also normal weight concrete. In both concrete types, minimum concrete strength used is 35 MPa. The study is limited to flexural on precast lightweight and normal weight C-channel half slab of 3.5 m, 4.5 m and 6.0 m span. The slab is designed in accordance to British standard (BS8110, 1985) and is subject to flexure test with simply supported support. On the other hand, the shear test was conducted on two different thicknesses of slab 200 mm and 250 mm. The test was carried out by applying a point load at a=2d and the slab is supported by a roller at its ends.

1.5 Significance

Increasing waste materials around the world, particularly quarry dust and expanded polystyrene (EPS) require more research on utilizing them. Hence this research utilizes quarry dust and EPS to partially replace river sand and aggregates in producing lightweight concrete. The optimum lightweight concrete mix design will then be used to produce precast C-channel slab.

Increase in the search for better and lighter flooring system among researchers around the world most especially in half slab. Hence this research utilizes lightweight EPS concrete to produce precast C-channel half slab and then subject it to flexural and shear loading to understand its structural behaviour when use as a flooring system in light construction. The success of this study will give an alternative material for half slab which is lighter, greener and economical.

1.6 Thesis Outline

This thesis consists of five chapters that present the study of lightweight concrete made with an addition of quarry dust and EPS and its behaviour as precast C channel half slab concrete subjected to flexural and shear test. The introduction, background and objectives of the work are explained in this chapter. The discussion of previous research work follows in Chapter 2, the methodology and experimental decision are made and the details of research methodology are explained in Chapter 3. Chapter 4 discusses the experimental results and lastly the conclusions and recommendations for further investigation are presented in Chapter 5.

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