MID-SPAN HOLLOW FOAM CONCRETE BEAM

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ABSTRACT

In the design of elevated precast concrete slab, hollow section is often adopted in order to reduce the selfweight of precast slab. With that idea, this project proposed hollow beams made of foam concrete and the investigate the performance of beams in terms of deflection, cracking, and strain. An experimental program including a solid foam concrete beam and 4 hollow foam concrete beams with different area of hole were tested under monotonic four point loading until ultimate physical failure. The dimension of beam is 0.15 x 0.2 x 3.0 m. The beam was simply supported during test with use the roller support. The results of performance for a solid beam and the hollow beams were compared in term of deflection, cracking, and strain. The strain gauge and linear variable displacement transducer (LVDT) were used to determine the strain and deflection of beam, respectively. From this experiment, the result show that the shear failure were occurred on the foam concrete beam. Therefore, the shear reinforcement or link need to be rectified. The hollow beam able to withstand until to the design load but will produce more deflection compare to a solid beam. However, the deflection of the hollow beam is expected to be in the limit stated in code of practice.

ABSTRAK

Dalam mereka bentuk slab pratuang yang tinggi, jenis berlubang sering digunakan untuk mengurangkan berat sendiri slab. Dengan idea tersebut, projek ini mencadangkan mereka rasuk berlubang yang diperbuat daripada konkrit buih dan menyiasat prestasi rasuk tersebut dari segi pesongan, retakan, kekuatan lenturan, kekuatan ricih, dan terikan. Satu eksperimen dilakukan yang mengandungi rasuk solid konkrit buih dan 4 rasuk berlubang konkrit buih dengan luas lubang yang berbeza akan dilakukan ujian monotonik muatan empat titik sehingga kegagalan fizikal akhir. Ukuran rasuk ini ialah 0.15 x 0.2 x 3.0 m. Rasuk ini merupakan rasuk sokong mudah yang menggunakan sokong roda semasa melakukan ujian. Keputusan prestasi rasuk solid dan rasuk berlubang akan dibandingkan dari segi pesongan, retakan, kekuatan lenturan, kekuatan ricih, dan terikan. Tolok terikan dan transduser sesaran (LVDT) adalah satu alat untuk mengukur terikan dan pesongan rasuk. Daripada eksperimen ini, keputusan menunjukkan yang kegagalan ricih berlaku ke atas rasuk konkrit buih. Jadi, tetulang ricih atau link perlu diperbetulkan. Rasuk berlubang dapat menahan sehingga ke muatan rekaan tetapi akan menghasilkan lebih pesongan berbanding rasuk solid. Bagaimanapun, pesongan untuk rasuk berlubang adalah dijangka berada dalam had yang dinyatakan dalam kod amalan.

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LIST OF ABBREVIATIONS

PVC	Polyvinyl chloride
LVDT	Linear Variable Displacement Transducer
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is one of the materials usually used for the construction like road construction, bridges construction, building construction and so on. It is the most durable, fire resistant, and corrosive environment construction material that easily found. Concrete made from a mixture of materials that are easily found. Which are cement, water, fine aggregate, and coarse aggregate. Reaction of hydration between cement and water to create a hardening concrete that bind aggregate with strength of the resulting concrete obtained from the use of the water-to-cement ratio. Concrete is good in the compressive strength while weakness in the tension strength. Therefore, plain concrete is not suitable for application of building structures because low tensile capacity. Reinforced concrete combines concrete with steel reinforcements and with this combination provides a strong durable building material that could cater for both compressive and tensile stress.

Beam is the one of flexural member that carrying laterals load that consist of permanent load and variable load. When the load applied to the beam, the compressive strength will occur at the top of the beam and the strength of the tension will occur at the bottom of the beam. Compressive stress catered by concrete which is strong in compression tensile stress catered by steel reinforcements which is strong in tension. Thus, concrete that the main materials for making beam compare to steel is not being used in the tensile zone but needed in the compression zone. So, the concrete can be removed but not all of which are below the neutral axis in the tension zone, with make half a hole along in the beam thereby can to reduce the self-weight of the beam.

1.2 STATEMENT OF PROBLEM

Precast concrete beam is concrete beams are often used for construction that require a short construction period. This is because the precast concrete beams are construction products produced by casting concrete in a reusable mold which is then cured in a controlled environment, transported to the construction site and lifted into place. So, the project construction period such as the construction of the bridge can be reduced by ordering the precast concrete beams from the factory and transport to the site. But, by using normal concrete for precast concrete beams with density range in between 2400 kg/m^3 to 2500 kg/m^3 is very difficult to do construction work, especially to do lifting work at the high level because that beams is very heavy to lift up. This lifting works require the use of heavy machinery to lift up the heavy beams at the high level. The use of heavy machinery need a high cost and can increase the cost of the project. Foam concrete is a best way to reduce the weight of the beam because the foam concrete is one of the lightweight concrete. The density of foam concrete less than compare to normal concrete in the range of 1600 kg/m^3 to 1800 kg/m^3 which can reduce the self weight of the beam.

To make the precast concrete beams to be more light, a hole is proposed half of the length of beam. Based on the theory, the strenght of beam is not reduced by removal of some concrete below the neutral axis of the beam. This case because a concrete response is great to withstand compressive stress occurs at the top of the beam compared with tensile stress occurs at the bottom of the beam which is held by a steel reinforcement. However, reduction in cross-sectional area of the beam can affect inversely proportional to the deflection of the beam. Thus will resulting the deflection to be higher for a hollow beam compare to a solid beam. Other than that, the failure of the beam could occur than the solid beam in terms of bending strenght, shear strenght and cracking.

1.3 OBJECTIVE OF STUDY

The objectives of this study are:

i. To investigate the performance of circular mid-span hollow foam concrete beam under four point bending test in term of deflection, strain of concrete and reinforcement bar and cracking.
ii. To determine the types of failure and plot the crack pattern of the beam under bending.

1.4 SCOPE OF STUDY

The foam concrete needed to pour into a formwork to create the hollow beam should be tested first so that concrete is getting a real strength when doing this experiment. Concrete tests are slump test and cube test. The experimental setup performed based on the four point bending test and the type of beam used for this test is simply supported beam which is supported by two support rollers at both ends of the beam. The experiment was conducted to investigate the performance of the hollow beam after the loading applied to this beam in linearly proportional. An experimental program including a solid foam concrete beam and 4 hollow foam concrete beams with different area of hole will be test under monotonic four point loading until ultimate physical failure. The dimension of beam is 0.15 x 0.2 x 3.0 m. The 4 foam concrete beam sample was prepared according to the difference of the hole diameter which is 25mm, 32mm, 50mm, and 80mm. Figure 1.1 show the set up the experimental for this research.

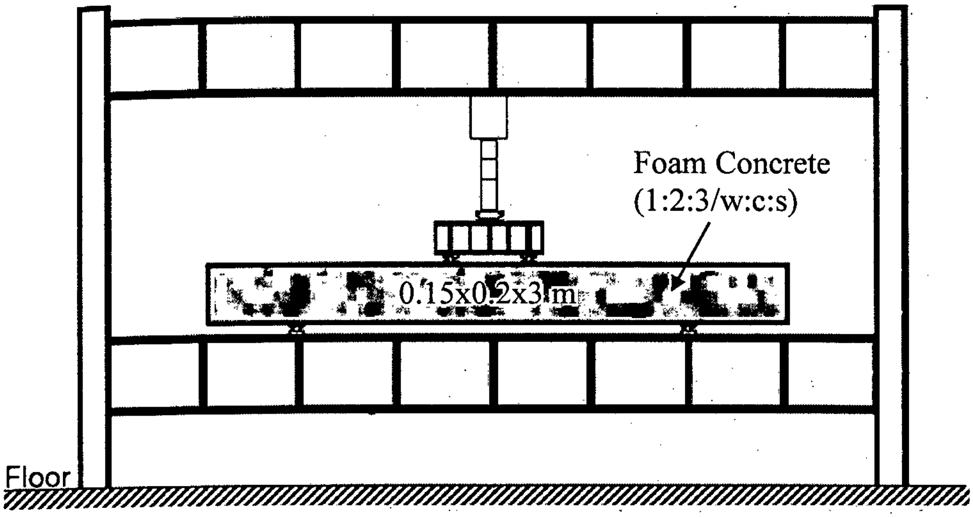


Figure 1.1: Experimental Set Up

1.5 RESEARCH SIGNIFICANT

The precast concrete beam is to be used as permanent formwork placed between arches and put the slab on that beams. If the precast concrete beams with 0.15 m x 0.2 m x 3.0 m measurement using normal concrete, the beam is very difficult lifted using a manpower that have weight in the range of 216 kg to 225 kg. Using foam concrete and make half a hole in the beam, the beam can be reduced weight in the range of 135 kg - 161 kg that can be lifted by the manpower at least two people.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A literature review is an account of what has been published on a topic by accredited scholars and researchers. In this study, we are discussing about the foam concrete which is the lightweight concrete and the behaviour of beam under the bending. The purpose of literature review is to convey the knowledge and ideas have been established this topic.

2.2 FOAM CONCRETE

Foamed concrete is a material with a lot of practical aspects, a low weight and good thermal conductibility. Due to these good properties, foamed concrete has been used so far mainly as a filling material. It is a lightweight concrete manufactured from cement, sand or flyash, water and a performed foam. Its dry density rnages from 300 to 1600 kg/m^3 with 28 days strength normally ranging from 0.2 to 10 N/mm^2 or more.

In general, foamed conretes with densities below 600 kg/m^3 consists of cement, foam and water, with the possible addition of fly ash or limestone dust (H.Pielert, 2006). Higher densities are achieved by adding sand. At higher densities (above 1500 kg/m^3) there is higher filler loading and a medium concreting sand may be used. As the density is reduced the amount of filler should also be reduced and at densities below abou 600 kg/m^3 filler may be completely eliminated.

The preformed foam can be divided into two category, which is wet foam and dry foam. Wet foam has a large loose bubble structure and although stable, is not recommended for the production of foamed concretes with densities below 1000 kg/m^3. It involves spraying a solution of the agent and water over a fine mesh, leading to a foam with bubbles sized between 2-5 mm. Dry foam is extremely stable, a characteristic that becomes increasingly important as the density of the foamed concrete reduces. It is produced by forcing a solution of foaming agent and water through restrictions whilst forcing compressed air into the mixing chamber. The resulting bubble size is smaller than wet foam at less than 1 mm in diameter and of an even size. For other aggregates and materials like coarse normal weight aggregates cannot be used in foamed concrete as they would sink in tke lightweight foam.

2.2.1. Production of Foamed Concrete

There are two main methods of producing foamed concrete, namely the inline and pre-foam methods (Roosen 2004). Inline is the base mix is put into a unit where it is blended with the foam. The mixing process is more controlled and greater quantities can be more easily produced. According to Kew (2009), it can be split into two processes:

i. Inline system (wet method)

   The base materials are the same as those used in the pre-foam system but are generally wetter. The base materials and the foam are fed through a series of static inline mixers where the two are mixed together. The foam and the base materials are blended together and checked with a continual on-board density monitor. The output volume is not governed by the size of the ready-mixed concrete truck, but by the density of the foamed concrete-one 8 m^3 delivery of base material can produce 35 m^3 of a 500 kg/m^3 foamed concrete.

ii. Inline system (dry method)

   This method is widespread in Europe and is also used in the UK. Dry materials are loaded into on-board mixers. The base mix is then pumped into a mixing chamber where the foam is then added in the same way as the wet inline system. They require large amounts of water at site for mixing. One delivery of cemnt blend can produce up to 130 m^3 of foamed concrete.

Pre-foam method the base materials are delivered to site in a ready-mixed concrete truck. The pre-formed foam is then injected directly into the back of the truck whilst the mixer is rotating. This method has the advantage that relatively small quantities can be ordered, for trench fill, for example, however, it does rely on the mixing action of the concrete truck. Densities in the range of 300-1200 kg/m^3 can be achieved. These systems are typically foamed air in the range 20 to 60% air. As this normally takes place in a ready-mix truck, the volume of base mortar or concrete mixed in the drum must be reduced to allow for the final volume of foamed concrete. The amount of stable air and hence density under and over yield must be allowed for when estimating deliveries.

Once the foam is formed it is added to the sand cement mortar that normally has a water cemnt ratio of 0.4 to 0.6. Too wet a mortar leads to an unstable foam, too dry and the pre-foam may not be able to blend with the mortar.

2.2.2. Fresh Properties

The foam has a string plasticising effect and foamed concrete is normally of high workability woth slumps ranging from 150mm to collapse. For most applications of foamed concrete this is an ad vantage and it can be difficult to make a low slump if this is what is required (Mier 2004). Foamed concrete is quite thixotropic and it can be quite difficult to restart the flow once the concrete has been static for several minutes (although this is not always the case).

As slump is normally high, the slump test is not ideal but can be used to indicate whether the foamed concrete workability is too low. The consistence of foamed concrete can be quantified by the slump flow test to BS EN 12350-5:2000 *Testing fresh concrete Part 5 Flow table test,* (BSI, 2000d) but without jolting the table.

2.3. BEHAVIOUR OF REINFORCED CONCRETE BEAM

2.3.1. Deflection

There is an important relation between applied load and stress (flexural and shear) and the amount of deformation or deflection that a beam can exhibit. In design of beam, it is important to limit the deflection for specific load. Thus, in these situation, it is not enough only to design for the strength (flexural normal and shearing stresses), but also for excessive deflection of beams. Failure to control beam deflection is frequently reflected by the development of crack in plastered walls and ceiling.

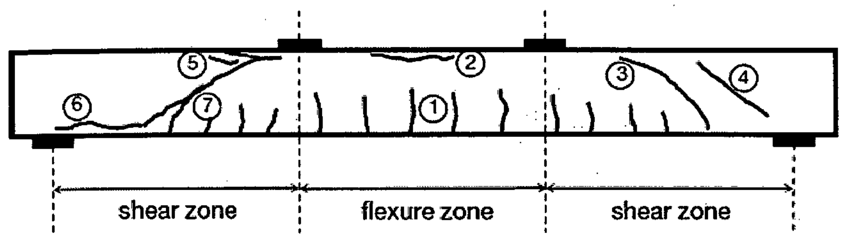
When a flexural member subjected to a bending moment, the distinctly different stress configuration member at a various cross sections will apply along the span. In addition, a tension and compression zone will occur which is divided by neutral axis. When a greater moment applies to the flexural member, the concrete fails at the outer fibers of the tension and minute cracks are formed at random intervals.

At places of still greater moment the tensile failure in the concrete is more extensive, cracking extends closer to neutral axis and cracks widen. However the concrete between cracks still carries some tension. Owing to this fact, the tensile stress in the steel between the cracks is less than that at the cracks.

2.3.2. Cracking

Beams subjected to flexure-shear loading develop structural cracks that can be classified into six types depending on the cracking mechanism. These cracks in order of formation through the loading history are: flexure tension cracks, flexure-shear cracks, diagonal tension shear cracks, dowel cracks, shear compression cracks, and flexural compression cracks. The last four types of cracks appear at loads well beyond service while the final two cracks are symptomatic of ultimate physical failure.

The cracking pattern meanwhile is influenced by the loading configuration used, which in the case of this experimental program, was a four point loading. As such, only flexure compression and flexure tension cracks occur in the flexural zone. The other five of the six types, flexure compression being the exception, may occur within the shear zone.



1. flexure tension cracks 2. flexure compression cracks 3. flexure – shear cracks 4. diagonal tension cracks 5. shear compression cracks 6. dowel cracks 7. diagonal tension crack from flexure – shear crack

Figure 2.1: Type of crack.

Source : Kum Yung Juan 2011

i. Flexure tension cracks

Flexural tension cracks begin from the extreme flexural tension fiber at the soffit of the beam, propagating vertically upward as the load increases. They first appear in the flexural zone where the greatest bending moment for a given load occurs. Comparatively shorter cracks then gradually develop in the shear zone as the load increases. Flexure tension cracks occur first as the flexural tensile stresses increase such that they exceed the concrete tensile capacity before the principle tensile stresses of combined shear and normal stresses at mid depth exceed.

ii. Flexure-shear cracks

Within the shear zone, the combination of flexure and shearing action leads to the formation of flexure-shear cracks. This crack is identified by a curved profile starting out as a vertically oriented flexure crack from the extreme flexure tension fiber which then gradually curves and continues propagating toward the load application point at the top of the beam. The curved trajectory of the flexure-shear crack is close to the interaction of flexure and shear stresses of a homogenous uncracked elastic beam that vary along the length and the height of the member as given by Mohr's circle of stresses. Cracking occurs along the principle tension plane since concrete is much weaker in tension than compression.

iii. Diagonal tension cracks

In members where the concrete is weak or where the section is heavily reinforced, stresses within the section may increase sufficiently such that diagonal tension shear cracks precipitate. These cracks appear suddenly and without warning, simultaneously extending from the neutral axis towards the loading point and the support in a straight line. Onset of these diagonal cracks indicate that the shear flow has been interrupted by the flexure cracks and beam action gives way to tied arch action.

iv. Dowel crack

As flexure-shear cracking and diagonal tension shear cracks become more severe, dowel cracks may form as shearing is redistributed to a dowel mechanism. This type of crack is characterized by a horizontal crack running parallel to the longitudinal bar at a similar level as the bar splits the concrete cover.

Dowel cracking was frequently observed close to or at failure of beams. These dowel cracks only develop in beams loaded at large shear span-to-depth ratios and appear at the instance of ultimate physical failure. Overwhelmingly, dowel cracks form after the inclined flexure shear stress develop into diagonal tension cracks.

v. Shear compression crack and flexure compression crack

A fourth type of crack that was observed is the shear compression crack. This type of crack occurs in the region where the interaction of flexural and shear stresses cause maximum principle compression. Local crushing of the concrete occurs which is frequently accompanied by spalling of the concrete cover. From the loading configuration used in this test, shear compression cracks occur near the load application point in the shear zone. The confined section is able to continue carrying load even after the unconfined concrete cover has spalled indicating that the section has considerable residual strength after failure. Finally, if the bending moment increases such that the compression capacity of the concrete is exhausted, the material will crush leading to flexure compression cracks at the ultimate load.

2.3.3 Failure of beam subjected to four points loading

In current British design practice, BS 8110 refers to this nominal shear as the design shear stress. For a rectangular beam, the failure mode is strongly dependent on the shear span / depth ratio, a_v / d :

a) $a_v/d > 6$: Beams with such a high a_v/d ratio usually fail in bending.

b) $2.5 < a_v/d < 6$: Beams with a_v/d lower than about 6 tend to fail in shear. With reference to Figure 2.2 (a), as the force V is increased, the flexure crack a-b, the nearest support would spread to the point of loading, gradually become inclined cracks, known as flexural shear cracks but are often referred to as diagonal cracks (Figure 2.3: crack a-b-c). The failure usually occurs in one of two modes with a further increase in V. If the ratio of a_v / d is relatively high, the diagonal crack quickly extended to point e, resulting in the collapse of splitting the beam into two parts. This failure mode is often called diagonal tension failure mode of such failure, the ultimate load is significantly the same as the diagonal crack formation. If the a_v/d ratio is relatively low, the diagonal crack tends to stop somewhere at j (Figure 2.3) a number of random cracks may develop in the concrete around the longitudinal tension reinforcement. As V is further increased, the diagonal crack widens and spread along the level of the tension reinforcement (Figure 2.3 : crack g-h). The increased shear force presses down the longitudinal steel and causes the collapse of the bond between the concrete and the steel, usually leading to the splitting of the concrete along g – h. If the longitudinal reinforcement is not hooked at the end, the destruction of bond and the concrete splitting will cause immediate collapse. If hooks are provided, the beam become like a two-hinge arch until the increasing force in the longitudinal reinforcement destroys the concrete surrounding the hooks, then collapse occurs. This failure mode is often called shear tension failure or shear bond failure. The ultimate load is not much higher than the diagonal cracking load.

c) $1 < a_v/d < 2.5$: For a_v/d lower than about 2.5 but greater than 1, the diagonal crack often forms independently and not as a development of a flexural crack (Figure 2.4). The beam usually remains stable after such cracking. Further increase in the force V will cause the diagonal crack to break into the concrete compression zone at the loading point, until crushing failure of the concrete occurs there, sometimes explosively (Figure 2.4:shaded portion). This failure mode is usually called shear compression failure for this mode, the ultimate load is sometimes more than twice that at diagonal cracking.

d) $a_v/d < 1$: The behaviour of beams with such low a_v/d ratio approaches that of deep beams. The diagonal crack forms approximately along a line joining the loading and support points (Figure 2.5). It forms mainly as a result of the splitting action of the compression force that is transmitted directly from the loading point to the support it initiates frequently at about d/3 above the bottom face of the beam. As the force V is increased, the diagonal crack would propagate simultaneously towards the loading and support points. When the crack has penetrated sufficiently deeply into the concrete zone at the loading point, or, more frequently, at the support point, crushing failure of the concrete occurs. For a deep beam failure mode, the ultimate load is often several times that at diagonal cracking.

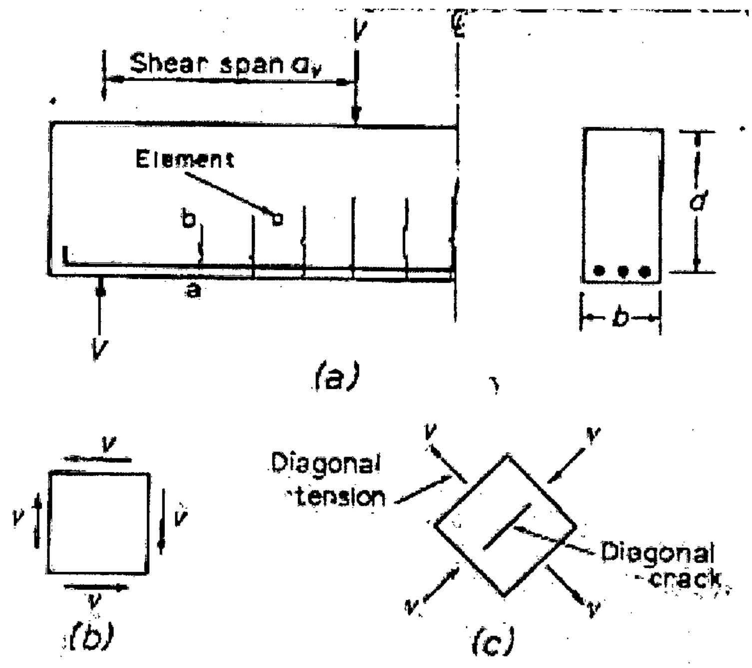


Figure 2.2 (a – c): Concept of shear and diagonal tension

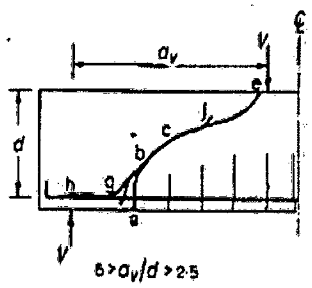


Figure 2.3: Flexure-shear crack

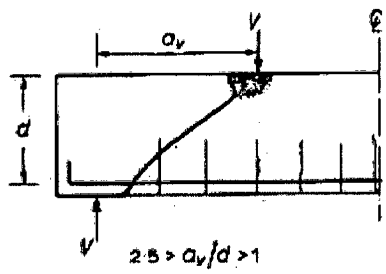


Figure 2.4: Shear-compression failure

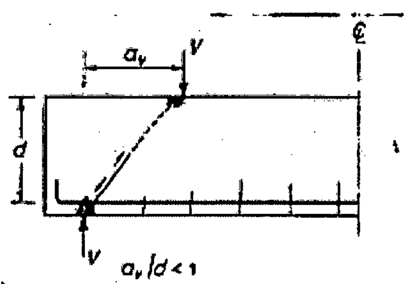


Figure 2.5: Shear failure

Source : Amir Yusuff 2005