Performance of Hollow Reinforced Concrete Beam in Structural Member

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ABSTRACT

Recently, the problem faced by the construction industry is a significant shortage of raw materials of concrete. Thus, the main idea of this research is to replace the use of concrete at the middle area of neutral axis of beam with voided system by incorporating PVC pipe. This research aims to reduce the concrete usage; structure's self-weight without neglecting its strength performance. The experimental work consists of casting and testing the 1200 x 160 x 160 mm beams with (Ø40 mm, Ø50 mm, and Ø100 mm) and without void at the neutral axis. The test results indicated that the strength performance of all RC beams with voided section is stronger than the ordinary RC beam where the V50 RC beam is able to withstand loads up to 38.25 kN and has a strength increment of 49.2% compared to the ordinary RC beam. By this material optimization, the reduction of concrete usage and self-weight of the V100 RC beam recorded a reduction of up to 35.14% but in terms of its strength is relatively low compared to the V40 RC beam and V50 RC beam. This findings show a positive result in reducing the dead load without affecting the strength of the structure. Besides aiming to the reduction of concrete usage and structure's self-weight, the idea of this research could be used and implemented in producing a lightweight structure with easy handling and installing, and at the same time focusing to meet the IBS system.

Keywords: *concrete, flexural strength, lightweight structure, neutral axis, voided RC beam.*

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Introduction

The construction industry is one of the industries that contribute to the development of a country. However, the rapid construction development has increased the demand of concrete as the most common construction materials in building constructions. Thus, the reduction of these natural resources availability resulting in increasing the concrete price. Cement is the raw material that shows the most significant increase of prices when it showed an increase of 9.75% in 2011, 3.13% in early 2012 and 5.58% in the third quarter of 2012 [1].

Moreover, the concrete industry is one of the primary producers of carbon dioxide (CO_2), creating up to 5% of worldwide man-made emissions of this gas, of which 50% and 40% is from the chemical process and burning fuel respectively. Hence it should be used as efficiently as possible. If not, the concrete production will affect to the environment condition and can cause global warming by trapping the sun's radiant energy in atmosphere [2].

In Malaysia, the use of lightweight concrete is not very common; this may due to large amount of raw materials still available in the market but in future, the availability of raw materials cannot be guaranteed. In fact, sustainability is essential concern to satisfy the demands of the present generation without compromising the ability the future generations to meet their needs [3]. For example, if the world runs out of limestone, as it is predicted to happen in some places, then the Portland cement cannot be produce, therefore, concrete also cannot be produce. Designing for sustainability which takes into account the design for short-term and long-term consequences of the society impact, so, new generation of admixture or additives are needed to improve the durability of concrete structure.

On the other hand, RC beams is a load-bearing unit that can be used to carry both horizontal and vertical loads which undergoes a variable horizontal loading over time according to the use of the building. Thus, inaccurate in limit state design which the load applied exceeds its ultimate, serviceability and other limit states will encounter damage to the structure of the beam. If an element is exposed to this condition for a long period of time, the creep and fatigue in RC beam will occurs. In most cases for high-rise buildings, the beam structure is affected due to the higher unit weight of concrete. For examples, the New World Hotel, Singapore and Highland Tower, Malaysia are the buildings that have failed during their lifetimes.

In recent years, the ideas to make concrete lighter is by changing the proportion of the concrete mix in order to improvise the concrete structural performance such as by using natural fibre, waste materials and construction waste. Also, lightweight concrete can be prepared either by omitting the finer

sizes of the aggregate or even replacing them by hollow, cellular or voided materials [4]. So, it will reduce the usage of natural-sourced material in concrete and reduce the weight of the structural member by replacing the material in the mixture.

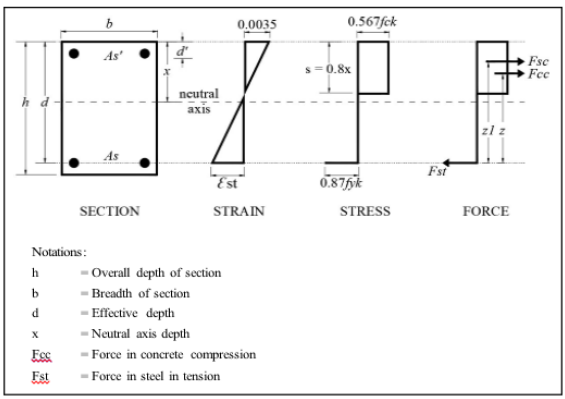


Figure 1: Doubly reinforced section with rectangular stress block [6].

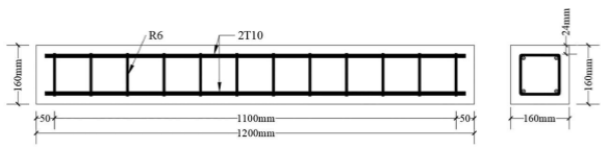
On top of that, various theories have been developed to reduce the self-weight of the structural elements for a given load-carrying capacity. In facts, the dead load can be reduce by the structural material optimization which contribute to the seismic affect in high-rise structures and very good at the vibration dampers, as well as good in heat insulation [5]. As shown in Figure 1, the rectangular stress block illustrates the stress-strain distribution in the section [6]. In RC beam, the stresses on the beams are maximum at the top and bottom area while minimum stresses at the neutral axis. So, the stress acting on the concrete near the neutral axis is not much contribute to the structure. Efficient use of concrete materials can be done by replacing the concrete in and near the neutral axis [7]. An alternate method of replacing the neutral axis zone with inert weightless substances will not greatly affect the strength and stress characteristics of the beam and also it will not affect the geometry and shape [8]. Hence, this research will focus on the technique of creating air voids inside the structural member for reducing its concrete amount by using of PVC pipe as continuous horizontal voided at neutral axis.

In this study, PVC pipe was placed at the middle of structure which classified as ineffective region. By this method, the reduction weight of the beam and efficient use the concrete materials can be done by placing a PVC pipe instead, hence making the beam hollow at the neutral axis to form the voided RC beam system. This is an alternative to reduce the use of concrete and the flexural behaviour of RC beam with hollow core is similar to that of

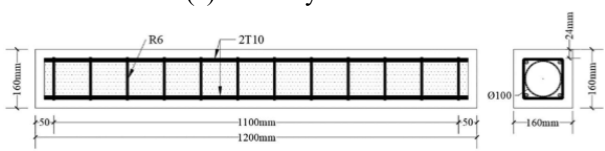
the conventional RC beam [9]. The beam structure was choosing due to the testing apparatus availability of the study. Therefore, flexural test is generally used to determine the flexural strength of material as it facilitates the preparation and testing of specimens and it is also described as actual practice at construction sites where load is imposed on the structure itself.

Data and Methods

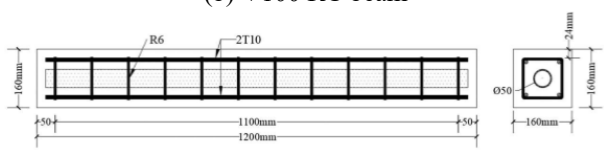
In this part, the preparation of experimental program, test setup and instrumentations is carried out. The preparation of these experiments includes beam specimens with various diameters of voided and without voided with beam dimension of 1200 mm x 160 mm x 160 mm as shown in Figure 2. All reinforced concrete beams designed as under reinforced section according to BS EN 1992-1-1:2004.



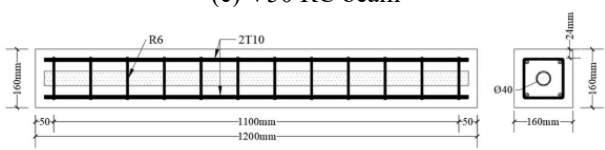
(a) Ordinary RC beam



(b) V100 RC beam



(c) V50 RC beam



(d) V40 RC beam

Figure 2: The illustration of RC beam specimens.

The flexural test was carried out in accordance with BS EN 12390-5:2009, testing concrete of method for determination of flexural strength. A flexural testing machine that provides two steel rollers with 38 mm diameter on which the beam specimen will be supported while length from the ends beam to the first steel roller is 100 mm. The load then divided equally between two loading rollers and it is mounted properly where the load applied axially (Figure 3).

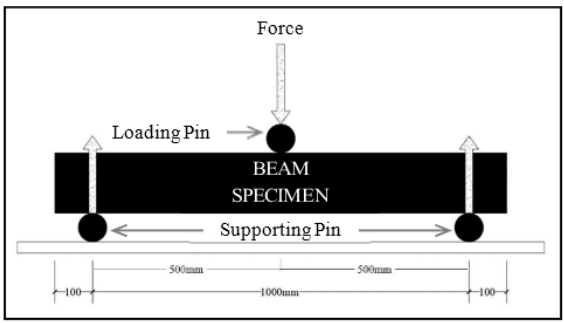


Figure 3: Schematic 3-point loading flexural test setup.

Results

Comparison of Flexural Test for Ordinary RC Beam and Voided RC Beam with Various Diameters

After few tests conducted on the beam specimens, Figure 4 shows the flexural strength of reinforced concrete (RC) beam with voided Ø100 mm, Ø50 mm and Ø40 mm, respectively. The load-displacement distributions were plotted for the initial and final strength.

The results compared the load-displacement relationship of RC beams with embedded PVC pipes and the ordinary RC beam at different load stages. It is clearly shown that voided RC beam that embedded PVC pipes have a better performance and able to withstand the load up to 34.25 kN, 38.25 kN and 32.50 kN for V40 RC beam, V50 RC beam and V100 RC beam respectively. Meanwhile, the ordinary RC beam just withstand the maximum load is 15.35 kN only (Table 1).

Replacing the concrete by PVC pipe at neutral axis exhibits significant changes in the load carrying capacity of the RC beam in term of strength. Varghese and Joy [9] also found that presence of void PVC pipe instead of concrete in the center region of the RC beam caused an increase 21% in strength of voided RC beam due to at the neutral axis is not fully utilized.

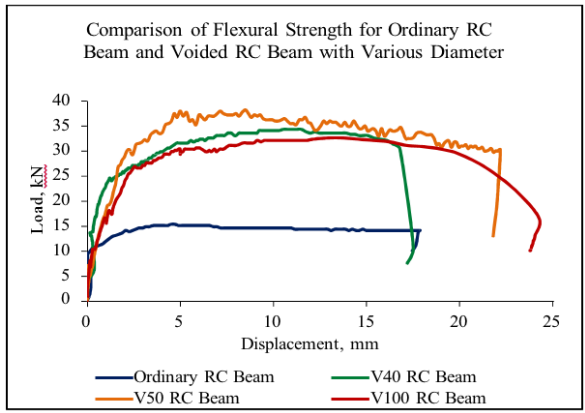


Figure 4: Comparison of flexural strength between ordinary RC beam and voided RC beam with various diameters

Table 1: Summary of load-displacement for RC beam

Type of RC Beam	Ordinary	V100	V50	V40
Maximum Load (kN)	15.35	32.50	38.25	34.25
Displacement (mm)	17.47	23.76	21.79	17.21

Based on the observation, the reason for all voided RC beams able to achieve more strength and durable than the ordinary RC beam, it is most probably due to the positive side shows that the concrete prepared with inserted by PVC pipe at the centre of RC beam was lighter (lower density), more ductile (and reduced modulus of elasticity), had lower drying shrinkage and higher resistance to chloride ion penetration. Although, greater the diameter void of PVC pipe, greater the reading of displacement. As according to Gasham [10] which concluded that when the diameter of PVC pipe exceeded two-third of the RC beam width, the influence of PVC pipe on the recorded displacement was relatively large especially for PVC pipe installed at the centre of RC beam. The result can be improved by taken into account the ratio of cover and bar diameter as suggested by Hamidun and Yoshimi [11].

In facts, small tubular void of PVC pipe can make RC beam more strength but more deformable than counter RC beam has big size tubular void of PVC pipe. While, similarity in structural behaviour between voided RC beam and ordinary RC beam tested specimens is clear even when the values are different. So, the present experimental results are compatible with the previous cited works.

Influence of Void Area to the Concrete Strength

A graph of maximum load for each reinforced concrete (RC) beam specimen with different void sizes were plotted as shown in Figure 5. It is clearly seen that the maximum load increased rapidly from 15.35 kN (ordinary beam) to 38.25 kN for the V50 and then dropped to 32.50 kN for the V100.

This result shows that the concrete strength of the RC beam specimens are affected by changes of different diameter sizes of PVC pipe. Since, the V50 RC beam has about 11% and 15% strength higher than V40 RC beam and V100 RC beam respectively, the effect of longitudinal void with medium size is better than the distributed to small or big size voids. It is because of the optimal void diameter was derived. To derive the optimal void diameter, three aspects of criteria which were safety, strength and deflection were considered [12].

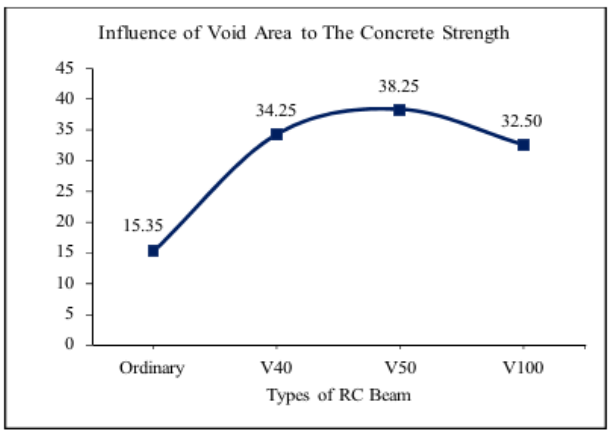


Figure 5: Influence of void area to the concrete strength.

Reduction of Concrete Usage in Reinforced Concrete Beam

Table 2 shows the results obtained from the calculation concrete saving between ordinary RC beam and voided RC beam with various diameter of PVC pipes. For comparison of all types of RC beams, the biggest reduction is from V100 with reduction of 35.14% than ordinary RC beam from the volume of concrete.

Varghese and Joy [13] stated a main component in the total cost of the product varying from 25 to 70% for the construction material cost. Thus, in order to control the cost, it is necessary to pay more attention for controlling material cost especially through abnormal losses. It should be made sure that the right quantities of materials are consumed with less wastage. These issues can be minimized by avoiding concrete in the neutral axis without bearing significant strength.

Table 2: Reduction of concrete usage in RC beam

Total of RC beam	Total concrete remaining (m^3)	Reduction of concrete usage (%)
Ordinary RC Beam	0	0
Voided RC Beam (V40)	0.028703	6.6
Voided RC Beam (V50)	0.027759	9.6
Voided RC Beam (V100)	0.019926	35.1

Reduction of Self-weight in Reinforced Concrete Beam

The self-weight comparison of ordinary RC beam and voided RC beam is given in Table 3. When comparing all self-weight of voided RC beam, the biggest reduction is from V100 specimen with 33.55% self-weight reduction than the ordinary RC beam. Meanwhile, there is 10.5% and 6.2% reduction from V50 and V40 specimen, respectively.

From these results, it is clear that when assumed the smaller the diameter of the PVC pipe is used, the self-weight reduction is also small and vice versa. Joy and Rajeev stated the volume of concrete is reduced then the self-weight of the beam can be reduced also. This can be done by avoiding concrete being placed at the neutral axis.

Table 3: Self-Weight Reduction in RC Beam

Total of RC beam	Difference in weight of concrete (m^3)	Weight of concrete reduction (%)
Ordinary RC Beam	0	0
Voided RC Beam (V40)	4.70	6.2
Voided RC Beam (V50)	7.95	10.5
Voided RC Beam (V100)	25.35	33.6

Comparison of all Factors: Total Reduction for Concrete Usage, Self-weight and Strength Increment in RC Beam

Based on the Figure 6, there are percentage of concrete usage, self-weight reduction and strength increment for four (4) reinforced concrete (RC) beam. The results show that the wider width of void diameter in the RC beam, the greater reduction of concrete volume and self-weight and vice versa. While, strength increment for all voided RC beam compared to ordinary RC beam is higher percentage of strength.

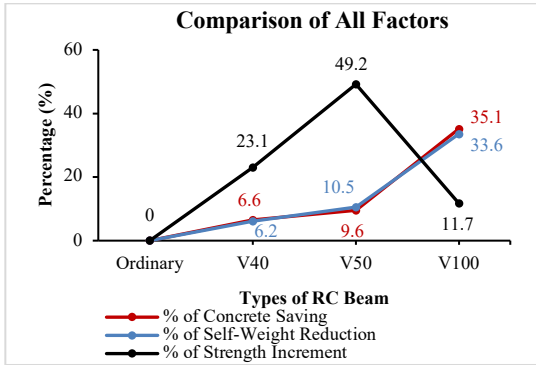


Figure 6: Total reduction of concrete usage, self-weight in RC beam and strength increment to RC beam.

In fact, when compared to all factors such as concrete reduction, self-weight and strength, V50 RC beam is the best. The V50 RC beam has a strength increment of 49.2% as well as the reduction of concrete usage and its self-weight of 9.6% and 10.5% respectively. Although, the V100 RC beam has the highest reduction in concrete usage and self-weight but in terms of its strength is relatively low compared to the V40 RC beam and V50 RC beam. Moreover, the performance of this voided structure could be predict by using the method proposed by Hamidun et al. [13] in predicting the structural strength and service life of structure by taken into account the chemical and mechanical damage.

Conclusion

In this research, the flexural strength behavior of the ordinary and voided RC beam with various diameters of PVC pipes was studied. It is clearly shown that voided RC beam that embedded PVC pipes have a better performance and able to withstand the load up to 34.25 kN, 38.25 kN and 32.50 kN for V40 RC beam, V50 RC beam and V100 RC beam respectively. Meanwhile, the ordinary RC beam just withstand the maximum load is 15.35 kN only. By replacing the concrete by PVC pipe at neutral axis, it exhibits significant changes in the load carrying capacity of the RC beam, in term of strength.

From the other side, the voided RC beam contributed to the reduction of concrete usage and the total self-weight. From all the specimen, voided RC beam V50 shows an optimum performance with a highest strength increment up to 49.2% with 10.5% self-weight reduction which save 9.6% of concrete usage.

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