The Use of Voided Reinforced Concrete in Structural Member

Hamidun Mohd Noh, Norlailatul Izzatil Azwani Mohamad, Nur'ain Idris, NurazuwaMd Noor, Narimah Kasim, Norliana Sarpin, Rozlin Zainal

Abstract: ***Concrete is widely used as one of the important construction materials. Recently, the problems faced by the construction industry is a significant shortage of raw materials. Thus, various methods are being adopted to reduce the use of concrete. In case of simply supported RC beams, the transition from compression to tension zone at the middle area of neutral axis in stress distribution of a beam was identified as the ineffective region. So, the use of concrete in this ineffective region was replaced by the voided system to the beam by incorporating PVC pipe in order to reduce the weight of the structure. Therefore, the research objectives in this study are to investigate the flexural strength of voided reinforced concrete (RC) beam with various diameters, to determine the total reduction of concrete usage, self-weight, and strength increment of voided RC beam, and to compare the structural strength performance between voided and ordinary of RC beam. The experimental work consists of casting and testing the 1200 x 160 x 160 mm beams with (Ø40mm, Ø50mm, and Ø100mm) and without void at the neutral axis. In order to investigate the flexural strength of the beams, the 3-point loading test has been carried out and the flexural strength between voided and ordinary RC beams were compared. 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 38.25kN 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 study has shown that the replacement of concrete in RC beam with PVC pipe shows 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.***

Revised Manuscript Received on May 22, 2019.

Hamidun Mohd Noh, Faculty of Technology Management and Business, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

Norlailatul Izzatil Azwani Mohamad, Faculty of Technology Management and Business, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

Nur'ain Idris, Centre for Diploma Studies, UniversitiTun Hussein Onn Malaysia, HabPendidikanTinggiPagoh, KM 1, JalanPanchor, 84600, Pagoh, Muar, Johor, Malaysia

NurazuwaMd Noor, Faculty of Civil and Environmental Engineering, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

Narimah Kasim, Faculty of Technology Management and Business, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

Norliana Sarpin, Faculty of Technology Management and Business, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

Rozlin Zainal, Faculty of Technology Management and Business, UniversitiTun Hussein Onn Malaysia, 86400, Parit Raja, BatuPahat, Johor, Malaysia

I. INTRODUCTION

The construction industry is one of the industries that contributes 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'sradiant 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 run 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 take 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 fiber, 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.

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 illustrate 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 neutralaxis.

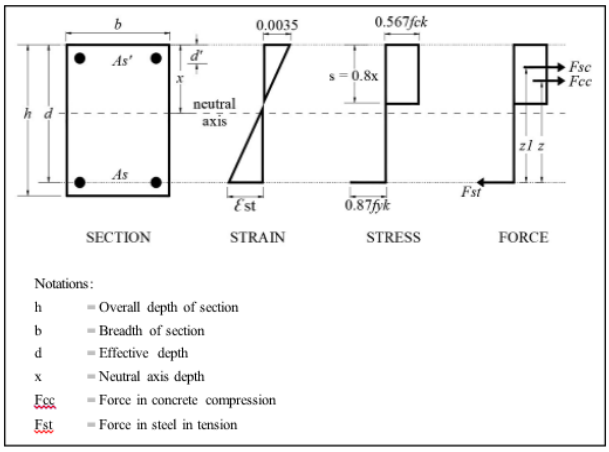
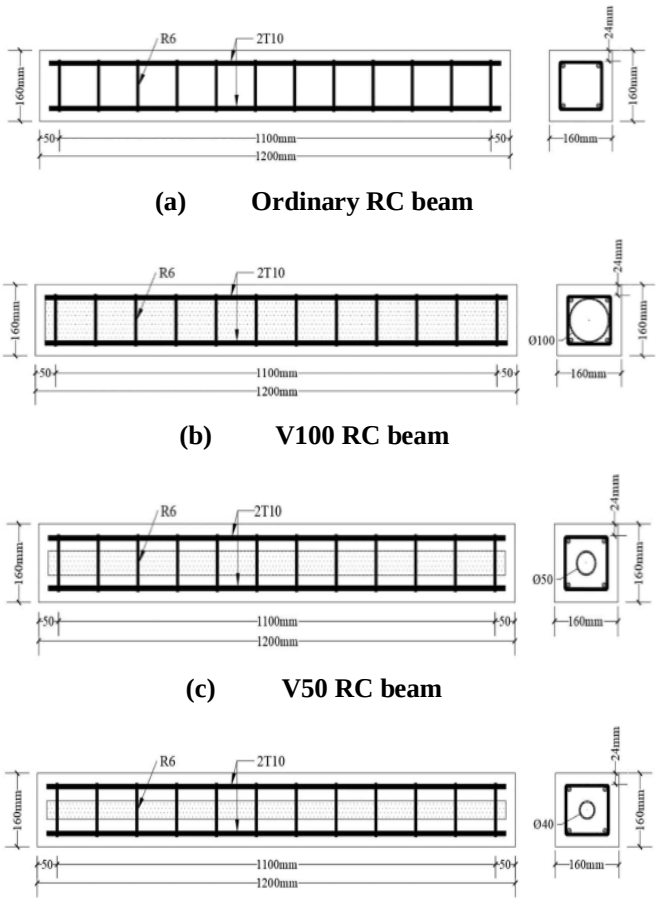


Fig. 1 Doubly reinforced section with rectangular stress block (Yassin& Abdullah, 2012)

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 behavior 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.

II. 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 voidedwith beam dimension of 1200mm x 160mm x 160mm 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

Fig. 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 38mm diameter on which the beam specimen will be supported while length from the ends beam to the first steel roller is 100mm. The load then divided equally between two loading rollers and it is mounted properly where the load applied axially (Figure 3).

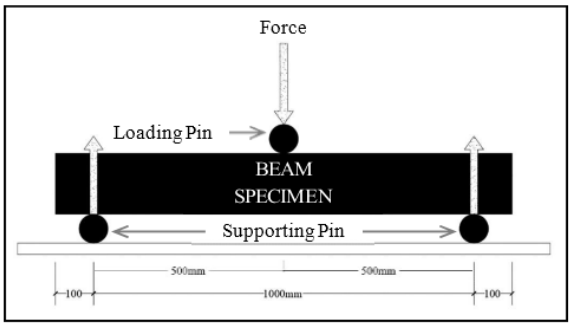


Fig. 3 Schematic 3-Point Loading Flexural Test Setup

III. RESULTS

After few tests conducted on the beam specimens, Figure 4 shows the flexural strength of reinforced concrete (RC) beam with voided Ø100mm, Ø50mm and Ø40mm, respectively. The load- displacement distribution were plotted for the initial and final strength.

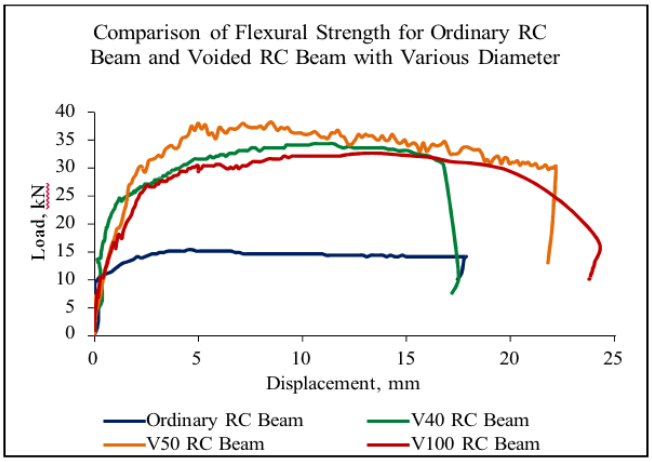


Fig. 4 Comparison of Flexural Strength between Ordinary RC Beam and Voided RC Beam with Various Diameter

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 showing that voided RC beam that embedded PVC pipes have a better performance and able to withstand the load up to 34.25kN, 38.25kN and 32.50kN for V40 RC beam, V50 RC beam and V100 RC beam respectively. Meanwhile, the ordinary RC beam just withstand the maximum load is 15.35kN only.

Replacing the concrete by PVC pipe at neutral axis exhibit significant changes in the load carrying capacity of the RC beam in term of strength. [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 fullyutilized.

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 center 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, while greater the diameter void of PVC pipe, greater the reading of displacement. As according to [10], he also 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 center of RC beam.

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 behavior 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.

Table. 2 Summary of Load-Displacement for RC Beam

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

A graph of maximum load for each reinforced concrete (RC) beam specimen is plotted as shown in Figure 5. It is clearly seen that the maximum load increased rapidly from 15.35kN (ordinary beam)to 38.25kN for the V50 and then dropped to 32.50kN 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, then 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 (3) aspects of criteria which were safety, strength and deflection were considered [11].

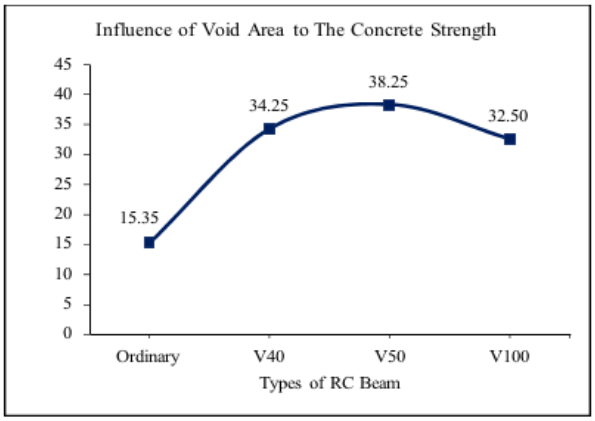


Fig. 5 Influence of Void Area to the Concrete Strength

IV. DISCUSSION AND CONCLUSION

Flexural strength behavior of the ordinary reinforced concrete (RC) beam and voided RC beam with various diameter of PVC pipe were 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 34.25kN, 38.25kN and 32.50kN for V40 RC beam, V50 RC beam and V100 RC beam respectively. Meanwhile, the ordinary RC beam just withstand the maximum load is 15.35kN only. Replacing the concrete by PVC pipe at neutral axis exhibit significant changes in the load carrying capacity of the RC beam, in term of strength.

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Appreciation to MOHE and ORICC, UniversitiTun Hussein Onn Malaysia for supporting this research (vot:H245). Appreciation also to Construction Management and Innovation (CMI) focus group, Faculty of Technology Management and Business.

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