Experimental Investigations on Modified Structural Beams for the Disposal of E-Waste

Neeraj J., Dr. C. Justine Jose

Abstract - New electronics products are invented every day as a result of the growth of the nation. This leads the older becomes out dated and becomes waste. They mainly include E-wastes and plastic wastes. These wastes contaminate the water body and affect the human health. Due to the lack of availability of land and the risks in the methods of disposal, the ways available for disposal cannot meet the actual requirement. Their disposal problem can be properly solved by introducing and utilizing them suitably in the construction industry. This will help to dispose wastes as well as to minimize the materials for construction. This paper deals with the utilization of defective or waste plastic bottles and e-wastes in structural members. Since the concrete in the tension zone is not efficient to take the load, this concrete is replaced with the plastic bottles and thus to create a void region. These bottles may or may not be filled with E-waste. Since the effect of voided beam is mainly studied in this paper, the bottle was kept empty. The beams casted include a pair of conventional beam as a control specimen, a pair of voided beam without spacing and a pair of voided beam with an arbitrary spacing. The flexural behaviour of all the beams was studied. The performance of voided beams is comparable with conventional beams. So they are possible to use in the site. The voided beam saved 7% of the cost of construction and 6.9% of the concrete material. The self-weight of the beam is also reduced by 6.9% of the conventional beam. In order to generalize the result, beams of span from 3 m to 10 m were modelled in ANSYS. From the generalized result it can be suggested that up to 20 % of void can be provided to any beams with the required factor of safety. This space can be utilized for the disposal of E-waste.

Index Terms -ANSYS, construction industry, conventional beam, E-waste disposal, generalization, plastic bottles, voided beam.

1 Introduction

THE wide range of application of plastic displaced many of the traditional materials such as wood, glass, metal pipes, etc. But their excess usage leads to the creation of plastic wastes. The growth of the electronics and information technology lead to the invention and updating of novel products which results the older becomes out dated and waste. These wastes are collectively known as E-wastes. It consists of highly toxic substances and heavy metals like lead, mercury, arsenic, beryllium, cadmium and chromium; the inhalation of them is equivalent to that of toxic fumes. The presence of both plastic waste and E-waste in the sea adversely affects the marine food chain and cause serious environmental problems such as global warming. They also adversely affect human through the marine food chain lead to the increase in cancer, immune disorders and birth defects. Their presence in soil reduces the rate of rain water percolation resulting in lowering the water table, contaminates the water body and deteriorates the soil fertility.

Both the plastic waste and E-waste generation has a fearful growth in India. More than 15000 tonnes of plastic waste are generated in India every day. Studies say that about 18.5 lakh tonnes of electronic waste generated every year in the country. The lack of availability of land to dispose E-waste and plastic waste is a serious problem. The available methods for disposal cannot meet the actual requirement. Therefore, incineration, land filling and disposal in sea is commonly used methods to dispose waste. But they have their own draw backs. Another possibility is recycling. But about 30-40% of plastic wastes and less than 12.5% of E-waste can only be recycled.

1.1 Construction Industry

The lacks of availability of resources is a serious problem faced by the industry. The only way to overcome this issue is the replacement of various materials of concrete. The replacement of them has two reasons and the second reason is the disposal of problem of some materials. In this point of view, can plastic waste be incorporated into concrete? Yes, many researchers had partially replaced coarse aggregate, fine aggregate and cement by plastic and E-waste in crushed or powdered form.

Significant research works have been done by many researchers in the construction field by introducing plastic and E-wastes. The replacement of coarse aggregate by 30% of plastic waste aggregate gives good workability as well as characteristic compressive than conventional concrete mix (Anju Ramesan et. al. 2015). But the replacement of fine aggregate by grinded plastic reduces the strength of concrete, but the failure mode of concrete changing from brittle failure to ductile failure (Manhal Jibrael A. et.al. 2016). The replacement coarse aggregate by 5% of non-metallic E-waste gives comparable results with conventional concrete mix (Praveen Manatkar A. et. al. 2015).

From the assumptions in the analysis of design of beams the tensile strength of concrete is ignored. So the concrete below the neutral axis of the beam is in effective and this acts only as a strain transferring medium. So the concrete in

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this portion can be replaced. The thickness of the slab is increased in order to avoid larger deflection. But the uniform thickness is not required throughout the section. As a result of this slab uses more concrete than the required. This extra concrete can also be replaced.

The use of recycled plastic waste elliptical bubbles in slabs improved the flexural capacity, stiffness and shear capacity by 70% when compared to solid slab of the same amount of concrete and same amount of reinforcement (Arati Shetkar et. al. 2015). The variation of different grades of concrete is possible in beams. Beams can be made with low grade concrete in the tension zone (Kandekar S. B. et. al. 2013). The flexural behaviour of reinforced beams with hollow core was similar to that of conventional reinforced beams. The optimum depth of hollow core is just below the neutral axis of the beam (Nibin Varghese et. al. 2016).

1.2 Overview of the Project

This project deals with the incorporation of waste or defective bottles of packaged drinks such as soda, Pepsi, etc. below the neutral axis of the beam as shown in Fig. 1. Since the recycled products of theses bottles are dangerous, they can be used with concrete and thereby get a good solution for their disposal. These bottles may or may not be filled with E-waste which will help the effective disposal of E-waste.

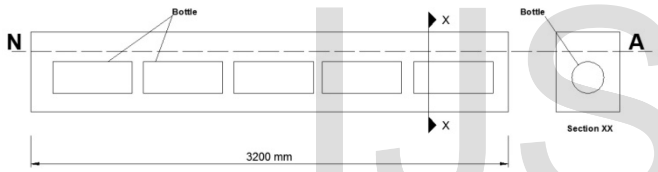

Fig. 1. Proposed model of the beam

1.3 Advantages and Applications

- The E-waste and plastic waste can be disposed in a proper and safer way.
- Reduction in the exploitation of natural resources for manufacturing of cement, fine aggregate and coarse aggregate.
- Reduction in emission of CO_2 to the environment during the manufacturing of cement.
- Reduction in overall cost for construction.
- Reduction in the self-weight of the beams and thereby the foundations can be designed for smaller loads.

1.4 Objectives

- To dispose plastic waste and E-waste in a proper and safer way.
- To determine the optimum volume of E-wastes and plastic wastes that can be properly used in the structural members by maintaining the strength and aesthetic view.
- To find out the positions where they can be properly used.

2 Material Used And Mix Design

The materials used consists of OPC 53 grade cement, M sand, 12 mm sized coarse aggregate, class F fly ash and Master Glenium SKY 8233 superplasticizer. Since the compaction of concrete is not possible because of the presence of bottles, self-compacting concrete is used for the project work. The proportion of concrete mix is shown below.

Cement	: 362.87 kg
Fly ash	: 178.73 kg
FA	: 928.96 kg
CA	: 702.59 kg
Water	: 180.53 kg
Admixture	: 5.958 kg

3 Design And Construction Of Beams

The experimental program consists of designing, casting and testing of six beams of size 150 mm x 200 x 3200 mm. But the effective span is taken as 3000 mm. Of the six beams two were conventional beams and the rest are voided beams. The voided beams are made with plastic bottles placed below the neutral axis with and without spacing.

3.1 Design of Beams

The beam is designed as under reinforced section as per IS 456:2000 with minimum reinforcements in order to study and compare the behaviour of conventional beam and voided beam under flexure and cracking. Both the conventional beam and voided beam were designed in the same manner and a bottle is placed below the neutral axis in the case of voided beam. The design details of conventional and voided beam are as shown in Fig. 2 and Fig. 4 respectively. The design load of the beams for two-point load are 8.784 kN with a design deflection of 12 mm.

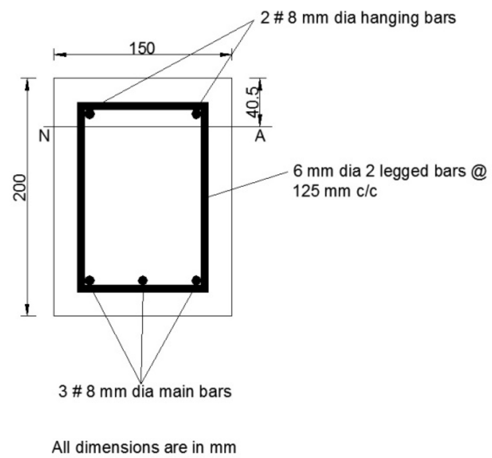

Fig. 2. Design details of conventional beam

3.2 Determination of Optimum Position for Bottles

The optimum position of bottle was determined by conducting a series of analytical study on beams with holes by using ANSYS 15 by varying the dimension of hole, span of the beam and cross section of the beam. From the study it was clear that the optimum position for bottle placement is at or near to the geometrical centre of the beam cross section irrespective of its length and cross section and the size or diameter of the hole or bottle. At this position the beam shows least deflection for any loads. It is shown in Fig. 3. So the bottle was placed below the neutral axis and near to the geometrical centre of the cross section of the beam and away from the supports in order to avoid shear failure. Since the concrete below the neutral axis of the beam acts as a strain transferring medium from the compression zone to the tensile reinforcements, the bottles were placed away from any of the reinforcement. The design details of voided beam are shown in Fig. 4.

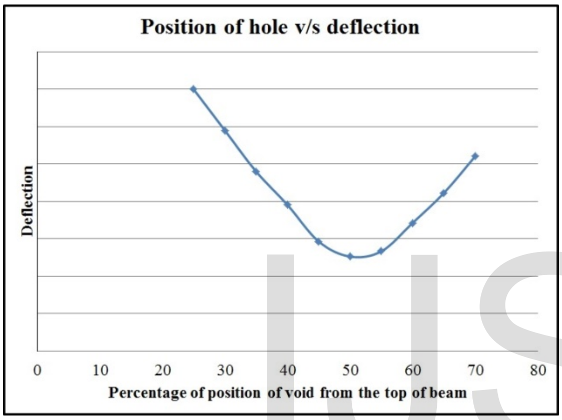

Fig. 3. Position of hole v/s deflection of beams

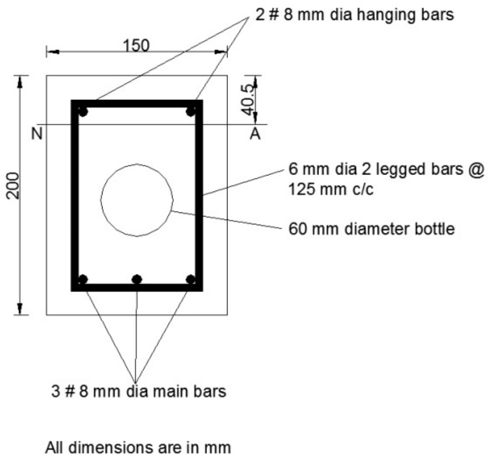

Fig. 4. Design details of voided beam

3.3 Casting of Beams

The first process of any construction work is the preparation of reinforcement cages. Fig. 5 shows the reinforcement cage for conventional beam. A pair of voided beam was casted without any spacing between bottles. The other pair of voided beam was casted with an arbitral chosen spacing of 5 cm. The Fig. 6 and Fig. 7 show the placement of bottles in the voided beam without and with spacing respectively. The conventional beams are designated as CB-1 and CB-2; voided beams without spacing are designated as VBWOS-1 and VBWOS-2; and voided beams with spacing are designated as VBWS-1 and VBWS-2.

Fig. 5. Reinforcement cage for conventional beam

Fig. 6. Reinforcement cage for voided beam without spacing

Fig. 7. Reinforcement cages for voided beam with spacing

4 Tests on Beam

The beams were cured for 35 days and tested. The cubes were also tested along with the beams. Two beams were tested per day in the casting order.

4.1 Experimental Set Up

The experimental set up consists of a loading frame of 100 ton capacity. The loading was done though a hydraulic jack, of 20 ton capacity, with the help of a hydraulic pump of 100 ton capacity. A load cell of 40 ton capacity was used to measure the applied load. It is attached to the bottom of hydraulic jack. The magnitude of the applied load can be seen from the digital indicator. It expresses the load in tons with a least count of 0.01 ton. The deflections at the mid-span were measured through two linear variable differential transducers (LVDT) of 60 mm capacity connected at the mid-span and the average values were selected. The LVDTs were connected to digital indicator to read the deflection. It reads the deflection in mm with a least count of 0.01 mm. The load and deflection measuring set up is shown in Fig 8.

Fig. 8. Loading and deflection measuring set up

4.2 Loading Protocol

Two-point loading was performed in order to study the pure flexural behaviour of the beam. The load controlled loading was provided. The load was applied initially as an increment of about 0.05 to 0.15 ton until yielding started. The deflections were also measured and cracks were marked after each step of loading. Loading is continued until the beam touched the bottom or at any point after yielding.

5 Test Results and Discussions

5.1 Ultimate Load Carrying Capacity

Ultimate load carrying capacity of beam is taken as the maximum load withstand by the beam during the period of loading. The load carrying capacity is considered for two-point loading. VBWOS-2 showed slightly more load carrying capacity than CB and VBWS. VBWOS-2 is taken this load when the deflection reached 72.2 mm whereas CB-1 is taken the load at a deflection of 100.45 mm. This indicates the load carrying capacity of voided beam is same as that of conventional beam. The ultimate load carrying capacity of beams is shown in Table 1.

TABLE 1
Ultimate Load Carrying Capacity of Beams

Beam specimen	Ultimate load carrying capacity (kN)
CB-1	15.058
CB-2	14.715
VBWOS-1	13.391
VBWOS-2	15.156
VBWS-1	14.519
VBWS-2	11.429

5.2 Force - Deflection Relationship

The load deflection curve is found to be a linear staring with very small deflections for all the beams. The curve changed its path after 10 to 15 kN load except that of VBWS-2. This may be due to the low compressive strength of the mix. The yielding of all beams except VBWS-1 started at about 23.5 kN. All the beams were showed a ductile behaviour after yielding. The load carrying capacity of VBWOS-1 suddenly decreased after a load of 25.58 kN with a bottle crushing sound. The load deformation curves of various beams are as shown in Fig. 9.

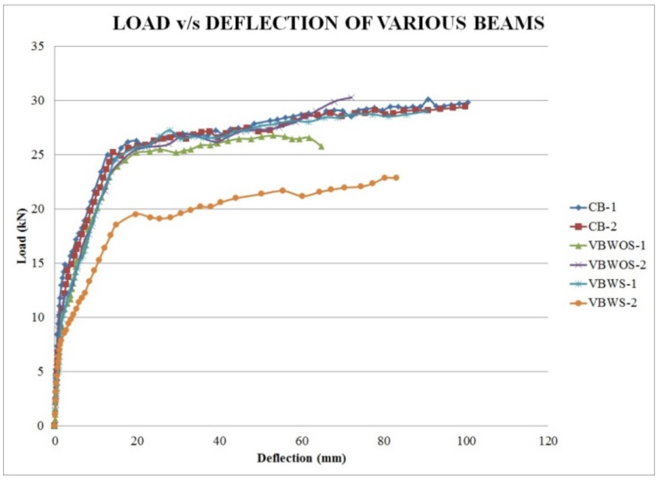

Fig. 9. Load v/s deflection curve for all beams

5.3 Crack Pattern

The first crack formed in various beams is shown in Table 2. All the cracks were formed are of flexural cracks. No shear crack is found in any of the beams. This is due to the shear reinforcement provided. The flexural cracks were formed between the load points at initial stages of loading. When yielding started, the flexural cracks are found beyond the load points. New cracks came after the existing crack widened or propagated. The crack widths of up to 5 mm were observed during the testing period in any of the beams. In CB-1 a crack was formed at bottom of the beam at a load of 18.25 kN and the crack crossed the neutral axis when the load reached 26.88 kN. In CB-2, bottom crack was developed at 25.8 kN load and the crack crosses the neutral axis at 26.29 kN load. In VBWOS-1, a crack was formed at bottom at a load of 12.07 kN. But the crack crosses the neutral axis at 24.94 kN load. In VBWOS-2, the crack formed at the bottom was at a load of 25.8 kN. In VBWS-1, a crack was found at the bottom of the beam at a load of 18.74 kN and crack crosses the neutral axis at 27.27 kN load. In VBWS-2, the bottom crack formed at 16.38 kN load and crack crossed the neutral axis at 19.52 kN load. Fig. 10-15 shows the crack formed in various beams.

TABLE 2
Formation of First Crack In Various Beams

Specimen	Load at first crack formed (kN)	Mid span deflection when first crack formed

		(mm)
CB-1	7.64	2.55
CB-2	6.27	2.425
VBWOS-1	5.58	2.4
VBWOS-2	5.34	1.225
VBWS-1	5.34	2.2
VBWS-2	4.11	1.6

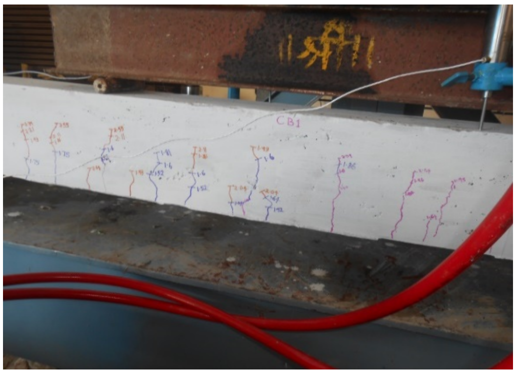
Fig. 10. Crack formed in CB-1


Fig. 11. Crack formed in CB-2


Fig. 12. Crack formed in VBWOS-1


Fig. 13. Crack formed in VBWOS-2

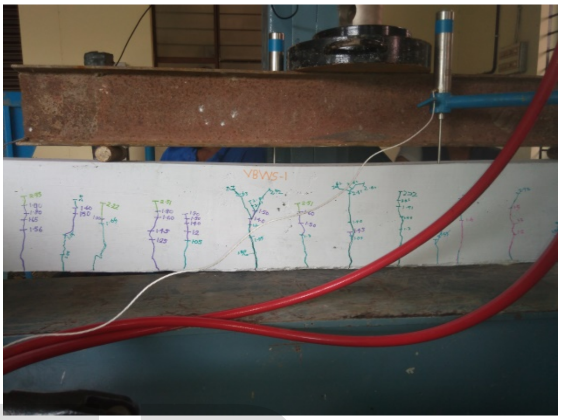
Fig. 14. Crack formed in VBWS-1

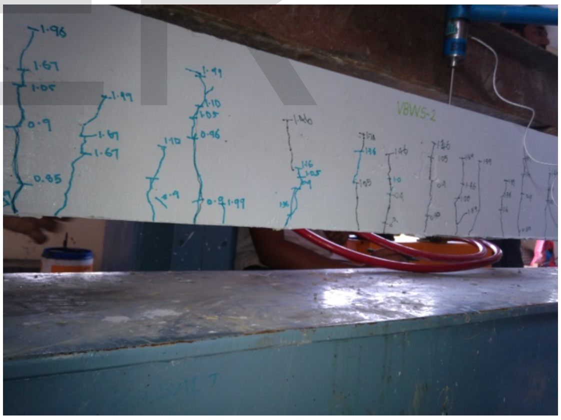
Fig. 15. Crack formed in VBWS-2

5.4 Failure Mode

The beams cannot be loaded up to failure. Therefore, failure mode can be stated based on crack, deflection or load. No beams were failed by sudden cracking. Spalling out of pieces from the faces of some beams could be found and these mays be also stated as a failure mode. In CB-2 a piece of concrete of 0.5 cm thickness was spalled out at tension zone near to load point. In VBWOS-1, the compression face was crushed and the load decreased continuously with continuous sounds of bottle crushing. The concrete was also spalled out from this specimen. Top crushing was also found in VBWOS-2. The reasons for this may be due to the low compressive stress of the mix. The bottle crushing sound was heard in both VBWS-1 and VBWS-2, but no spalling out of specimen was observed. The failure based on deflection can be defined by the load at which deflection equals design deflection (12 mm). The failure based on crack can be defined by the load at which first crack formed. The failure based on load can be defined as the load at which yielding started. The failure based on deflection is shown in Table 3 and failure based on load is shown in Table 4.

TABLE 3
FAILURE BASED ON DEFLECTION

Specimen	**Load at failure (kN)** (failure load = load at which deflection = 12 mm)
CB-1	11.91
CB-2	11.62
VBWOS-1	10.74
VBWOS-2	10.74
VBWS-1	11.08
VBWS-2	8.38

TABLE 4
FAILURE BASE ON LOAD

Specimen	**Load at failure (kN)** (Failure load = load at which yielding started)
CB-1	12.7
CB-2	12.8
VBWOS-1	11.67
VBWOS-2	12.35
VBWS-1	12.5
VBWS-2	9.46

5.5 Overall Evaluation

The load deflection behaviour of voided beam was evaluated by comparing the load deflection behaviour, crack pattern, ultimate load carrying capacity and failure pattern. The load displacement curves of conventional beam as well as voided beam are almost similar. The ultimate load carrying capacity of voided beam was slightly more than that of conventional beam. The load taken by the voided beam at failure based on loading and failure based on deflection was less than that of conventional beam. But these loads are greater than the design load of the beam. The ductile behaviour of voided beams was also same as that of conventional beams. Thus from these findings it can be concluded that voided beam without spacing can be used in places of conventional beams.

5.6 Cost or Material Saving v/s Performance

The performance of voided beam was same as that of conventional beam. The placing of bottle saved a volume of 0.0066 m^3 of concrete which costs about Rs. 40. This void reduces the self-weight of the beam by 16 kg. This material saving, cost saving and weight reduction may be small for this beam, but in a large construction project, this amount of material saving, cost saving and reduction in self-weight has high value. The void volume can be utilized for disposing E-wastes of 0.0066 m^3. Generally speaking, the voided beam saved 7% of the cost of construction and 6.9% of the concrete or reduced 6.9% kg of self-weight of the structure. Thus the voided beam can be used in the site with the required factor of safety.

6 Analytical Study

The analytical study was conducted after validating the model and was done by modelling eight conventional beams as well as eight voided beams in ANSYS. They were designed as under reinforced sections with minimum reinforcement as per IS 456:2000. They were of effective length from 3 m to 10 m with proportional cross section. The design details of the beams are shown in Table 5. The beams of span less than 3 m were not studied here because they never give a good result or the beams of span from 3 m give better results.

TABLE 5
DESIGN DETAILS OF BEAMS

Effective Span (m)	**Cross section**	**Area of steel provided (mm^2)**	**Design Load (kN)**
3	120 x 180	100.53	7.93
4	154 x 230	100.53	8.27
5	187 x 280	100.53	8.43
6	220 x 330	150.8	12.62
7	254 x 380	201.06	16.83
8	287 x 430	201.06	16.98
9	320 x 480	251.33	21.23
10	354 x 530	301.59	25.49

The beams were modelled in ANSYS with the cross sections obtained from Table 5. They were modelled for both conventional and voided beams in the same way as that modelled for the validation purposes. In the actual experimental work, the percentage of void used was 9.42%. So this percentage of void was maintained for all the beams. The loading was done by providing a displacement at its centre which is equal to the permissible deflection of the beam as per IS 456:2000. The beams are then analysed in

ANSYS and the load carrying capacity of each beam was noted for this mid span deflection. It is shown in Table 6. The load carrying capacities of the beams was obtained from the support reactions. Then randomly a beam was selected and its void ratio or percentage of void was changed to different values. The beam of 7 m span was selected for this study. It was provided with void ratios from 0 to 35 % with an increment of 5%. They were analysed in the same manner as that done in the previous studies and the load carrying capacity was evaluated. The details of load carrying capacity are shown Table 7.

TABLE 6
COMPARISON OF LOAD CARRYING CAPACITY OF CB AND VBWOS

Effective Span (m)	**Deflection provided (mm)**	**Load obtained for CB (kN)**	**Load obtained for VBWOS (kN)** (% void = 9.42%)	**Percentage reduction in load carrying capacity for VBWOS from CB**
3	12	12.47	11.15	10.58
4	16	19.64	17.64	10.15
5	20	28.52	25.73	9.79
6	24	39.40	35.64	9.54
7	28	52.50	47.60	9.33
8	32	67.43	61.22	9.21
9	36	84.65	76.96	9.09
10	40	104.46	95.03	9.03

TABLE 7
LOAD CARRYING CAPACITY OF 7 M SPAN BEAM WITH DIFFERENT PERCENTAGE OF VOIDS

% void	**Load carrying capacity (kN)**	**Percentage reduction in load carrying capacity as compared to conventional beam**
0	52.50	0
5	48.22	8.14
10	47.51	9.49
15	46.63	11.18
20	45.56	13.21
25	44.34	15.54
30	42.98	18.13
35	41.54	20.87

6.1 STUDY RESULTS AND DISCUSSIONS

The analytical study on the beams of various cross sections was carried out and the results were obtained. The results tell that the load carrying capacity of the beams reduces with the void for all the eight beams. But these values are greater than the design load of the beam. But the percentage reduction in the load carrying capacity decreases with increase in the span. It is shown in Fig. 16. This indicates that the void can be properly provided for beams of large length and large cross sections. From the results of various percentages of void ratios, the load carrying capacity decreases with increase in percentage of void. But up to 20% of void, the percentage reduction in load carrying capacity is below 15%. This condition was also checked and ensured with a 10 m spanned beam which was provided with 20% of void and the reduction in load carrying capacity obtained was less than 15%. This percentage of reduction in load carrying can be acceptable with the required factor of safety. This percentage of void reduces 20% of the cost of construction.

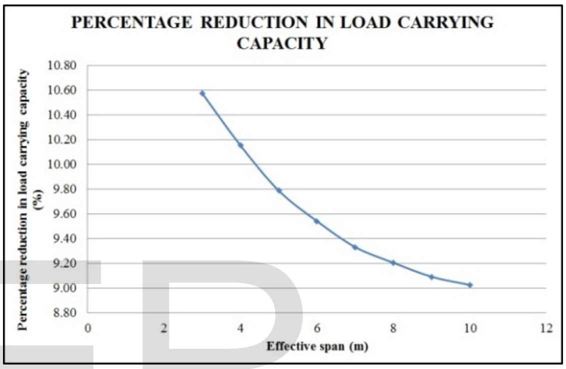

Fig. 16. Percentage reduction in load carrying capacity for various spans of beams

7. CONCLUSIONS

The conclusions obtained from the study are as follows.

- The E-waste and plastic waste causes serious problems to the humanity as well as other living things and to the environment. Their disposal is also a serious problem. They can be incorporated into construction industry for their suitable disposal.
- The E-waste and plastic wastes were used in the material level studies. Their application into the member level is not widely studied. It is a new area for research.
- The optimum position of void is the geometrical centre of the cross section of the beam irrespective of the length, load and cross section of the beam.
- The load carrying capacity and ultimate load carrying capacity of both the conventional beam and voided beam without spacing are almost same. The difference in it may be due to the variations in compressive strength of cubes.
- Flexural failure was found in all beams and no one was failed by shear.

- The deflection pattern, flexure and crack pattern were same for all the beams.
- No beam was failed by any of the failure criteria.
- From these it can be inferred that voided beam with or without spacing can be used for construction applications in order to save materials. But the voided beam without spacing is more effective because it can save more material. About 7% of the cost of work or 6.9% of the construction materials can be saved.
- From the analytical study, it can be inferred that up to 20 % of void can be provided in beams within the required factor of safety. Thus the optimum percentage of void that can be incorporated to beam is found. This space can be utilized for disposing E-waste.

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