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Analytical and Experimental Study of Flexural Behaviour of Slag Sand Reinforced Concrete Beams with Various Duct Openings

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Abstract: ***The provision of transverse openings in floor beams to facilitate the passage of utility pipes and service ducts results not only in a more systematic layout of pipes and ducts.it also translates into substantial economic savings, in the construction of a multi-storey building. Along with opening, the partial replacement of steel slag sand with crushed stone is done which further reduces the cost of the beams. In order to obtain the optimum level of replacement, steel slag sand is varied from 0-100% and tested under compressive strength for maximum strength. With help of ANSYS software, various shapes of openings, keeping equivalent area of cross section such as circular, rounded rectangular and rounded square, provided at critical zone are modelled and analysed in order to obtain the optimum shape of the openings in beams. To reduce stress concentration at corners of the openings, Special reinforcements are provided as per ACI specification. With that optimum shape experimental work is carried out. Where 8 beam were casted of size 2000*450*230mm and tested under loading frame with two pint loading and simply supported condition. The results obtained such as deflection, initial cracks, and ultimate failure load were compared with the beams without openings, with openings using steel slag sand and without using steel slag sand. Also comparison of analytical results with that of experimental results was carried out.***

Key words: Compressive Strength, ANSYS, Openings.

I. INTRODUCTION

A. General

In the present scenario, we know that the second widely utilized material is cement next to water, hence it has a very adverse impact on the present environment. Engineers and scientists are trying all the possible alternatives for replacement of building material, which are eco-friendly and emphasizing on the use of reprocessed and reutilized metallurgical waste, such that accumulation of industrial waste like iron and steel slag can be minimized and put into practice to produce concrete by making use of it efficiently to its full extent. Slag sand is solid waste disposed in huge amount by iron and steel industry across the world.

It possess similar property as that of river sand, hence can be used as replacement for fine aggregate or coarse aggregate depending on the application of the concrete. Steel slag sand can also be used with cement as active admixture to order to enhance the concrete properties. These supplementary cementitious materials greatly reduce the impact on natural resources along with decrease of CO2 emissions. Due to fast economic growth there is an urgent need to pay attention towards alternatives and research work needs to be carried out towards it. In the current study, the usefulness of slag sand is studied in reinforced concrete beams with different duct opening. Experimental and analytical work is carried out to understand the behaviour of the RC beams. For the conveyance of pipes and ducts for various purposes such as air conditioner, sewage pipe and water supply system etc. are passed through the transverse opening in the floor beams. When such type of design is adopted, it reduces the height of the structures and it tends to a most economical design. Whenever an opening is provided in beams, it possess problems pertaining to stress concentration at the corners of the opening, deformation and excessive deflection under service load, hence a special consideration on design of the beam around the opening. According to ACI code is carried out, in order to counteract the negative effects of the premature failure of the beams due to Vierendeel Truss Action. When diagonal reinforcements are provided it improves the load carrying capacity of the beam. The aim of this study is to investigate the behaviour of steel slag sand reinforced concrete beams with various shapes of duct openings.

B. Steel Slag Sand

The slag sand is a secondary product obtained from steel and iron manufacturing industry by Basic Oxygen Furnace (BOF) & Electrical Arc Furnace (EAF). Nearly 110-180kg of steel slag is produced from every 1 ton of steel produced. The components of steel slag include MgO, SiO_2, CaO, Al_2O_3 & Fe.

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C. Openings

Transverse openings in beam may be classified based on the shape and size of the openings. Openings that are of square, rectangular and circular shape may be considered as small openings, depending on the depth or diameter of the opening which should be proportional to the depth of beam size, which is usually less than 40% of beam depth. In this case there may be beam action which exists and beam with small opening behaves same as that of solid beam. If the openings size is more than 40% of the depth of the beam, it is taken as large openings.

D. Significance of Present Study

It is due to economical and growing trend towards the use of more systematically and advanced approach to building design that structural engineers are often used to provide transverse openings in beams. For low-rise buildings the saving in cost may not be predominant compared to high-rise buildings where any savings in wall height multiplied by number of stories will reduce the consumption of concrete and increase profit, the length of service pipes, computer network cables, water supply pipes which reduces inversely increasing effective use of waste materials(Steel Slag Sand) and minimizing cost of construction, by providing opening in beam we will not only reduce length of service pipes, height of floor but we will also reduce the overall service ducts. Weight of building which will lead to more effective earthquake design and also lesser load on foundation. Many designers permit the embedment of small pipes by providing few additional reinforcement around periphery of opening. But when large openings are provided, particularly in RCC and pre-stressed concrete members, they show a general reluctance to deal with them due of lack of technical details not readily available. There is also a lack of particular guidelines in building codes which are being practiced namely (ACI, 1995 & BS 8110-97), but they contains detailed treatment for slabs with opening. Therefore structural engineers are frequently based on intuition which may lead to improper design and disastrous consequences. There has been at least one event in which the building has failed due to provision of large opening in beams, which is described by Merchant(1967). Hence it is essential to understand the behaviour of beam with opening in order to use it in practice for construction of building and also give more prominence for stress locations of beams during the designing stage only.

II. MATERIALS AND METHODOLOGY

A. Materials

Slag Sand was collected from Emerald factory Kannur, different sizes 2mm slag sand, processed rough slag sand, plastering fine slag sand was available. Steel slag sand of processed rough slag was best and used for the current exploration. 40% replacement of processed slag sand was done for this exploration. Coarse aggregate of 20mm & 12.5mm sizes were utilised in ratio of 60:40. The most favourable ratio of fine aggregate to coarse aggregate was made a trial. Ratio and best fixed ratio was 42:58 is fixed to keep up density- IS 383:1970.

Dalmia Cement OPC 53 grade was adopted for the experiment - IS 12269:2013. Concrete mix of 340kg/m3 was taken corresponding to grade of M30- IS2156:2000. Admixture dosage was taken as 0.25 to 0.4% by mass of cement content as per codal provision.

Fe 500 Steel for normal reinforcement confirming to IS 1786.

B. Methodology for Analytical Investigation

In the numerical method of analysis, beam with different shapes of duct openings and without any openings model was developed using three dimensional non-linear FE model using macro concept with the help of ANSYS 14.5.The concrete was modelled considering the replacement of steel slag sand adopting SOLID65, which is eight node element.Solid65 element is provisioned with simulating the cracking and crushing behaviour of brittle materials in all the three orthogonal direction. The steel reinforcement is modelled discreetly using LINK180, a 3D solid element and which consists two nodes three degree of freedom at each node. The link180 element is provisioned for simulating compressive and tensile stress in the reinforcement. The modulus of elasticity, stress-train characteristic etc. are concrete with replacement are taken from earlier research works. The ultimate failure compressive stress and crack pattern predicted by FE model is compared with experimental results.

C. Beam Specimens

For the present experimental study, two types of reinforced concrete beam specimens have been considered one with different shapes of openings in beam with replacements and another one is nominal conventional beam without openings. Initially the three different shapes of duct openings i.e. Circular, Rounded Rectangular and Rounded square openings are modelled and analysed in ANSYS to get the optimum shape of the openings and then that shape of opening is experimentally validated.

The following specifications have been adopted for this study:-

a) For carrying out the experimental study the specifications of beam specimen of 2000 mm length with cross section of 230 mm × 450 mm is considered.

b) A conventional RC beam using M30 Grade concrete and steel Fe 500 have been casted. The longitudinal reinforcement of 3#16 mm and anchor bars of 2#10mm with #8mm stirrups @ 300 mm c/c spacing has been considered. The design details of specimen as per IS 456-2000 have been explained separately.

c) A RC beam with different shapes of opening using M30 Grade concrete and steel Fe 500 have been casted. The longitudinal reinforcement of 3#16 mm and anchor bars of 2#10mm with #8mm stirrups @ 300 mm c/c spacing has been considered, also a special reinforcement around opening of 8mm diameter is considered.

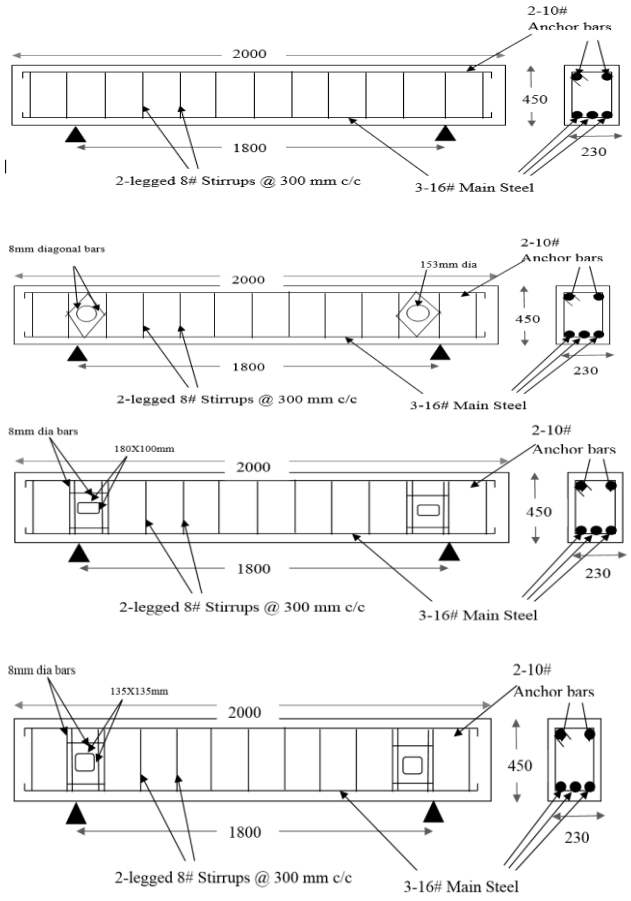

Fig.1: Reinforcement Details of Conventional RC beam, Circular, Rounded Rectangular and Rounded square Openings

D. Analytical Investigation on Beams

In order to get accurate results from numerical analysis,solid65 element is conidered and rectangular mesh is preffered other types of meshes.the beam beam element is primarily modeled by considerering volumes.the reinforcements are modelled using nodes created by mesh of the concrete volume.merge item command is used to merge separate elements that have similar location,these elements are then merged into single elements.in order to get the model,which behaves the same way as the experimental beam.boundary conditions are needed to get a unique solution and hence it is applied at the supports and loadings.

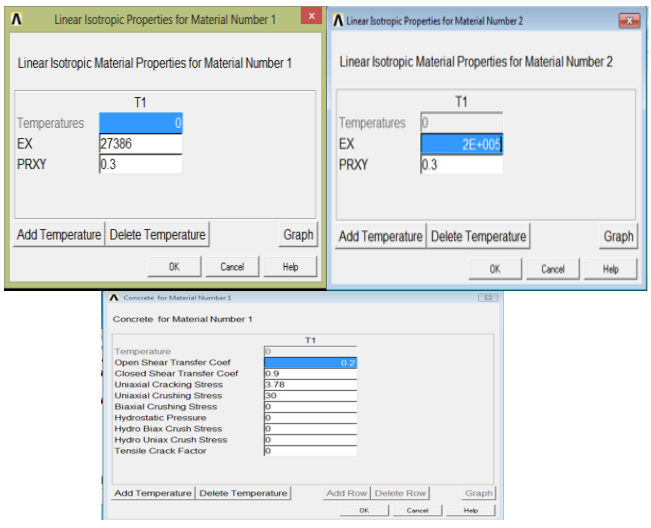

Fig.2: Material Property given to SOLID65, Reinforcement and Concrete Beam

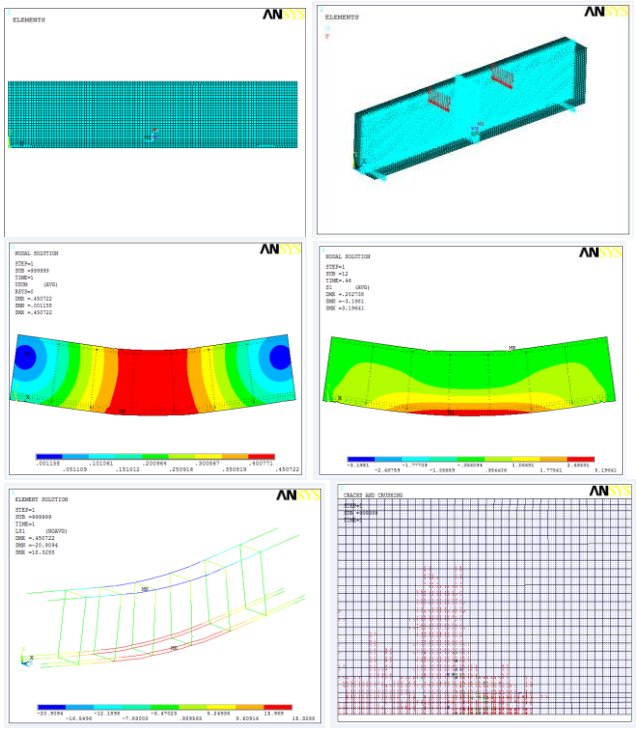

Fig.3: Modelling, Meshing, Deflection, Stress and Cracks of Conventional Beam

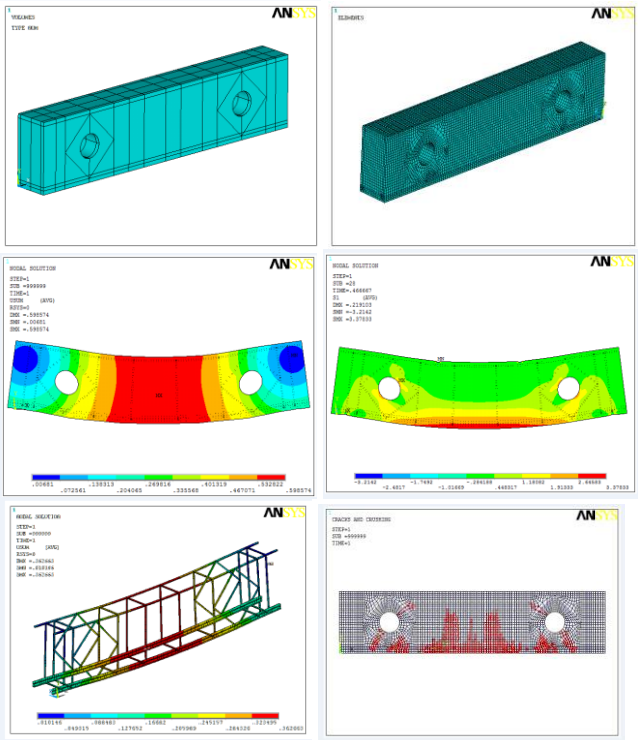

Fig4: Modelling, Meshing, Deflection, Stress and Cracks of Circular Opening with Steel Slag sand

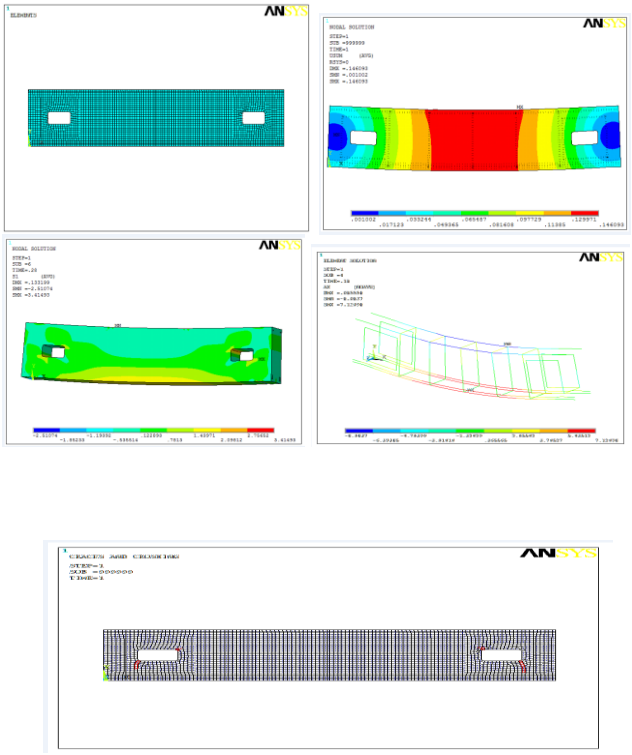

Fig.5: Modelling, Meshing, Deflection, Stress and Cracks of Rounded Rectangular Opening with Steel Slag Sand

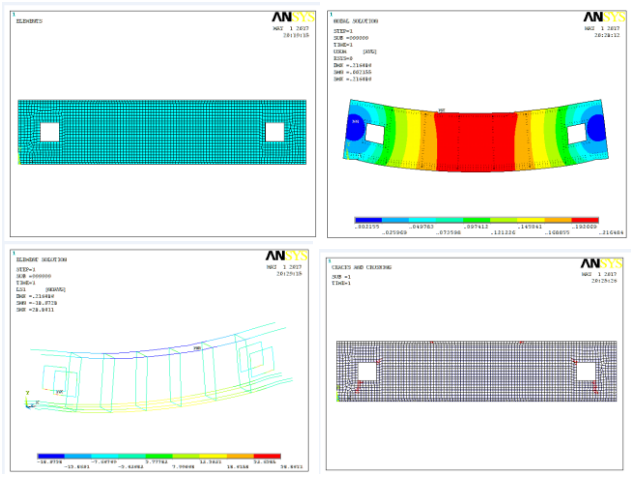

Fig.6: Modelling, Meshing, Deflection, Stress and Cracks of Rounded Square Opening with Steel Slag Sand

III. RESULTS AND DISCUSSIONS

From the test conducted on cubes for 28days strength, it is seen that at 50% replacement of Steel slag sand with crushed stone sand, the compressive strength starts decreasing, 40% replacement of steel slag gives the maximum compressive strength of 39.20N/mm^2.partial replacement of steel slag with 40% has performed better compared to full replacement with crushed stone stand.

After optimizing the appropriate percentage of steel slag as fine aggregate in concrete i.e. 40%, primarily through compressive strength test. The beams of dimension 2000*450*230 are casted and tested in order to study the flexural behaviour of the reinforced concrete beam with various duct openings, under two point loading and simply supported condition in loading frame of capacity 100T.M30 grade concrete is used for the study and special reinforcement around opening is provided. For the experimental work steel slag sand with 40% replacement with crushed stone sand with

Sl. No.	Percentage of Steel Slag variation	Weight of specimen (Kg)	Compressive Strength at 28days (N/mm^2)
1	0%	8.17	38.20
2	10%	8.09	38.50
3	20%	8.07	38.74
4	30%	8.05	38.90
5	40%	8.03	39.20
6	50%	8.04	38.8
7	60%	8.02	38.30
8	70%	8.01	38.10
9	80%	8.00	37.90
10	90%	8.01	37.47
11	100%	8.01	37.25

circular opening on both sides of the beam is casted, twin circular openings with 100% crushed stone sand is casted and beam without opening using 100% crushed stone sand and also with 40% replacement of steel slag sand is casted.

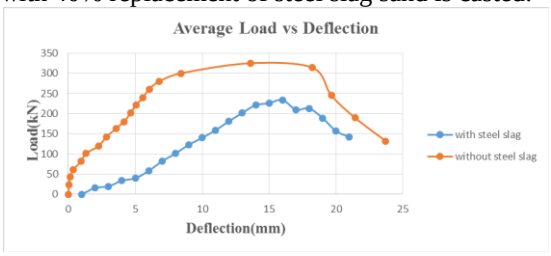

Fig.7: Load vs Deflection Curve for Conventional Beam

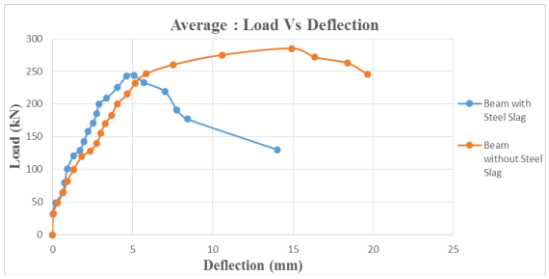

Fig.8: Load vs Deflection Curve for Beams With Circular Openings

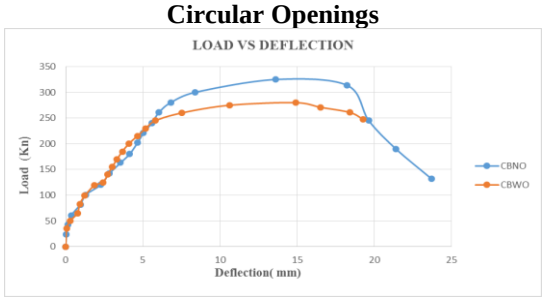

Fig.9: Load Deflection Behaviour of Conventional Beam With and Without Openings

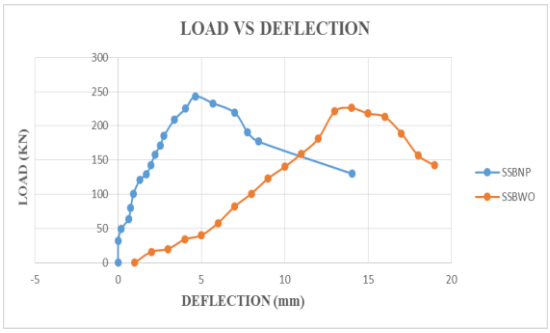

Fig.10: Load Deflection Behaviour of Steel Slag Reinforced Beam With and Without Openings

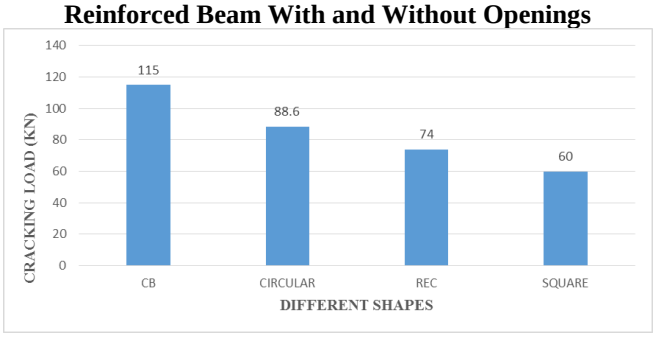

Fig.11: Effect of Different Shapes of Openings having Equivalent Area on the Initial Cracking Load using ANSYS

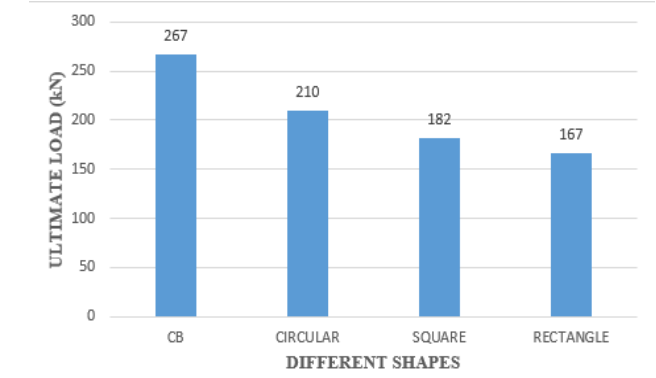

Fig.12: Effect of Different Shapes of Openings having Equivalent Area on the Ultimate Load Carrying Capacity using ANSYS

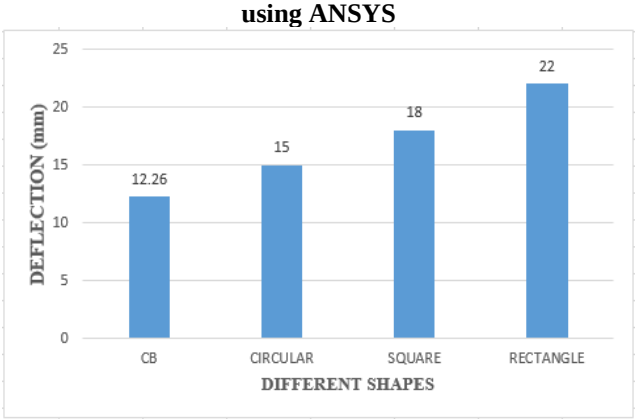

Fig.13: Effect of Different Shapes of Openings having Equivalent Area on Deflection using ANSYS.

The reinforced concrete beam casted using steel slag sand is a stable and eco-friendly material, which has very similar property as that of natural river sand, whose performance were evaluated by conducting experiments on it, the steel slag sand which is available in abundance can be used as a partial replacement of fine aggregate.

The density of Steel slag is comparatively low, which provides added advantage on cost of the material. When such replacement materials are used for constructing beams with openings which are provided at time of casting of beams, also significantly reduces the cost of construction, in a high rise buildings, where a small reduction of cost of any element reduces the overall cost of the building to a significant amount. Providing openings at the time casting not only reduces the amount of concrete, but significantly increased ultimate load carry capacity is obtained when compared to post openings. Providing optimum or best shape is equally important to get increased load carrying capacity for passage of duct or provision for any other services.

Now a day's deforestation is the major threat to the environment. Global warming is the first affect caused by deforestation. Hence, every action took which decreases deforestation will decrease the chances of threat to the environment. Decline in resource of natural available river sand have led to numerous problems and using them for construction purposes have become intricate. Cause behind difficulty is unavailability of natural sand in river beds, reasons in huge range constructing structures

A proper measure should be taken to accelerate the use of steel slag sand as a building material in construction by the government and also it is very important to generate the awareness regarding importance of steel slag sand as fine aggregate.

IV. CONCLUSIONS

With 40% replacement of steel slag with crushed stone sand gives maximum compressive strength. Beams with special reinforcement around the opening helps in controlling early crack formation. Beam without any openings has maximum load carrying capacity. Circular opening is the best shape of opening that showed least reduction in ultimate load carrying capacity. Deflection is marginally reduced with the use of steel slag sand. From the experiment it is concluded that steel slag has the ability to perform same as that of crushed stone sand, hence steel slag sand needs to be encouraged in using as building material.

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