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Comparison on Behaviour of Reinforced Concrete Column using GFRP and Steel Slag Materials

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Abstract: In order to make environment sustainable, the use of waste material in place of natural resources is one of the best alternatives. The utilization of industrial waste in concrete as partial replacement of coarse aggregates by steel slag on different proportions (0%, 10%, 20%......60%) studies are conducted on concrete mixes of M25 Grade. A large number of reinforced concrete (RC) structures that have been damaged due to corrosion of steel reinforcements are rehabilitated with fiber-reinforced polymer (FRP) composites. GFRP (Glass Fibre Reinforced polymer) sheet is used to cover the reinforcement in the column to attain more strength. The objective of the program is to investigate the comparison on behavior of the FRP sheet wrapped steel encased concrete columns, steel slag reinforced concrete column and conventional concrete column under concentric loading and also evaluate the progression of corrosion of steel in concrete after it has been treated with surface bonded FRP immersed in salt water.

The experimental program was conducted on cubes, cylinders and column of Rectangular section of size 150mm x 150mm and height 400mm based on the height and cross section. The study on workability, setting time, density, compressive strength, ductility and buckling behaviour of column are performed and compared with the conventional column. The concrete cubes were tested for compressive strength at 7, 14, 28 days is obtained at room temperature. The diameter of the FRP sheet was 2 mm make the diameter to be 8 mm. The first group had two columns of Conventional concrete column, and the remaining three groups were reinforced with FRP sheet wrapped steel encased concrete columns and steel slag reinforced concrete column respectively. Test results indicated that FRP wrapped specimens had prolonged test life, decreased reinforcement mass loss, and reduced concrete chloride content .The performance of wrapped specimens was superior to that of control samples. It was concluded that GFRP wraps were able to confine concrete, slowing deterioration from cracking and spalling and inhibiting the passage of salt water.

Keywords: Glass fiber mat, Industrial waste steel slag, M25 mix and Composite columns

I. INTRODUCTION

Column is compression element which locomotes loads from the upper level to the bottom level and then to the foundations which transfer loads to the soil, columns are the most important structural elements in the construction, the collapse of the structures is due to a partial or total failure of columns because lateral loads or vertical loads, they are several types and are classified according to the materials manufactured from them (stone, timber, brick, concrete, steel). Concrete structures in an aggressive environment, such as coastal areas, marine environments and regions where de-icing salts are used, are specifically prone to premature deterioration. The ingress of chlorides present in seawater, salt spray, and de-icing compounds into concrete promotes reinforcement corrosion and subsequent deterioration of the entire concrete member. As reinforcement corrosion intensifies, not only the expansive products of corrosion cause failures in the concrete surrounding the reinforcement frequently evidenced by cracking and spalling of the concrete, but may also lead to a loss in the structural integrity of the reinforcing steel. When bridges and structures are built in coastal areas, corrosion related problems are especially evident. Overall, developing innovative ways to prevent corrosion from taking place and implementing long-term solutions to repair chloride contaminated concrete are necessary endeavours. A recent solution for repairing damages due to corrosion in reinforced concrete is to use fiber reinforced plastic (FRP) composite wrap. Several works have focused on the use of FRP composites for repairing and strengthening of structures, however, information about the corrosion performance of systems using these advanced materials is still lacking. Little is known about the long-term performance of FRP composites in corrosion prevention. This research is directed towards this endeavor.

Repair, rehabilitation and strengthening of existing structures have become a major part of construction activity in the World. Although many traditional methods can be adopted, the application of fiber reinforced plastic (FRP) sheets, impregnated with epoxy resin, to reinforced concrete structures for strengthening purposes has received considerable attention due to its high-strength, light weight, applicability, and resistance against corrosion. FRP products may achieve the same or better reinforcement object of commonly use metallic products such as steel reinforcement bar pre stressing tendons and bonded plates. The glass fibre is usually flattened into sheets randomly arranged or woven into a fabric. According to the use of fibre glass, the glass fibres can be made with different type of glass (A-glass, C-glass, E-glass, AE-glass and S2-glass) fibre glass is light weight, strong and less brittle. Although not as rigid as carbon fibre, it is much cheaper and significantly less brittle when is in composites. Glass fibres are used as a reinforcement agent for many polymer products to form a very strong and relatively light weight fibre reinforced polymer(FRP) composite material called glass reinforced plastic(GRP), also popularly known as fibre glass. This material contains little or no gas or air, is denser, and is a much poorer thermal insulator then its glass wool. Use of externally bonded FRP composite for strengthening can be a cost effective alternative for upgrading the performance of existing RC columns. Even though a lot of research has been directed towards circular columns, relatively less work has been performed on square and rectangular columns, to examine the effects of FRP confinement on the structural performance.

Therefore, an attempt has been made to upgrade the performance of square RC columns by confining reinforcement with GFRP wraps in the present investigation. GFRP strengthened RC column performed better than steel reinforced concrete column. The reinforced concrete columns were subjected to concentric loading, and the failure modes were reported as concrete crushing or compressive or tensile rupture of the FRP reinforcement. In addition, the ductile failures of columns were primarily influenced by the compressive strength of the FRP rebars.

Steel slag, a by-product of steel making is produced during the separation of the molten steel from impurities in steel making furnaces. The slag occurs as the molten liquid melt. There are many grades of steel that can be produced and the properties of the steel slag can be change significantly with each grades of steel can be classified as high, medium and low depending on the carbon content Approximately 160 kg of steel slag is generated per ton of steel produced. Common chemical compounds in steel slag are SiO_2, CaO, Fe_2O_3, Al_2O_3, and MnO. Major mineral components of steel slag are C_3S, C_2S, C_4AF, RO phase, and free-CaO. Many studies have shown that steel slag can be applied in ceramics, road pavement materials, and other materials. Studies have shown that concrete that contains steel slag powder performs better in terms of workability than plain cement concrete does. This non-metallic slag material can either be crushed or screened for aggregate use (steel slag aggregates) or sintered and recycled as flux material in the iron and steel furnaces.

The idea of utilization of industrial waste, including (slag) material extends to a long time ago, leaving this waste without handling leads to damage to the eloquent environment. Steel slag has been used in the construction industry as a partial substitute of either coarse aggregate or fine aggregate. This slag is currently being used in road construction work and use as the percentage of coarse aggregate and high density concrete production to use in radiation shielding purpose, so researchers began to study the steel slag properties and its impact on the concrete properties.

II. OBJECTIVES

A. The main objective of our project work is to prepare a high strength concrete by using GFRP fibre wrapped steel and industrial waste steel slag.
B. To use industrial wastes most effectively to reduce the pollution.
C. To study the Concrete mix proportions and its workability.
D. To develop concrete as economically feasible.
E. To achieve the desired durability of the Concrete mix in the given environment surrounding and conditions.
F. To find out possible utilization of waste materials in construction industry that in turn considerably minimize the usage of coarse aggregate and ultimately reduce construction cost.
G. To explore possibilities of improving mechanical properties of concrete using steel slag instead of coarse aggregate partially.
H. To obtain the Compressive strength, Tensile strength of cubes and cylinder by using GFRP and Industrial steel slag in the Concrete mix.
I. To find the Ultimate load carrying capacity of column using steel reinforcement wrapped by GFRP fibre mat and finally compared with conventional concrete column in various conditions such as ordinary water and sea water.
J. Comparing the properties with normal concrete by casting various cubes and cylinders to the conventional concrete.

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III. MATERIALS USED AND THEIR PROPERTIES

The most common ingredients used in this mix design project are,

1) Cement
2) Fine aggregative
3) Coarse aggregate
4) Steel slag
5) Glass fibre sheet (GFRP mat)
6) Water

A. Cement

The cement is the binding material which helps to provide bond between the reinforcement and other ingredients of concrete mix. The ordinary Portland cement (OPC) 53 grade cement is used. The following test has been carried out as per IS 456-2000. They are consistency test, setting test, soundness test.

Table 3.1 Physical properties of Cement

Grade	OPC 53
Color	Grey
Initial setting time	60 mins
Final setting time	600 mins
Specific gravity	3.75
Standard consistency	26%

Fig 3.1 Cement OPC 53 grade

B. Fine Aggregate

Fine aggregate are the structure filler that occupies most of the volume of concrete mix formulas. The purpose of fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent. Aggregate is the granular material used to produce concrete or mortar passes through 4.75 mm sieve. River sand has a density of 1460 kg/m^3.

Table 3.2 Physical properties of Fine Aggregate

Density	2.5 g/cc
Zone	III
Specific gravity	2.65
Type	River sand

Fig 3.2 Fine Aggregate

C. Coarse Aggregate

When the size of aggregate is grater then 4.75mm during the sieve analysis it is called coarse aggregate. This aggregate fills the concrete of about 60-80% in the mix. There create a bonding between the materials when it is mixed with cement. Coarse aggregate has a density of 1.684 kg/cm2 and 20 mm size aggregate are used.

Table 3.4 Physical properties of Coarse Aggregate

Size	20 mm
Zone	I
Specific gravity	2.82
Fineness modulus	8.26
Density	1.684 kg/cm^2
Water absorption	0.5%

Fig 3.3 Coarse Aggregate

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D. Steel Slag
Steel slag aggregate are highly angular in shape and have rough surface texture. They have high bulk specific gravity and moderate water absorption (less than 3%)

Table 3.4 Physical properties of Steel slag

Specific gravity	3.4
Unit weight	1850 kg/cm^3
Absorption	Up to 3%


Fig 3.4 Industrial waste steel slag

E. Glass Fiber Sheet
Glass fibre reinforced polymer sheet or glass fibre reinforced plastic. Which are strongest and most resistive to the deformation force when the polymers fibre are parallel to the force. Specifying the orientation of reinforcing fibres can increase the strength and resistance to deformation of polymer. GFRP sheet of 2 mm thickness is used has wrapping material in the reinforcement.

Table 3.5 Physical properties of Fine Aggregate

Maximum thickness	2 mm
Density of Sheet	2.58 g/cm^3
Tensile strength	3445 Mpa
Compressive strength	1080 Mpa


Fig 3.5 Glass fiber mat

F. Water
Water should be considered as an important material for construction, where it is mainly used with cement for making mortar, concrete and also used for curing. It actively participates in the chemical reaction with cement and helps to form the strength in cement gel. Hence, the quantity and quality of water required should be overlooked. Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. The quantity and quality of water are required to be watched very carefully so that it can form the strength giving cement gel. Because if we exceed the water quantity level means then automatically the strength of the concrete get and likewise if the water quantity level is decreased means then also the strength of concrete is decreased. Portable water available in the laboratory was used for making concrete.

G. Sea Water
Sea water is the water which is obtained from the sea which having a salinity rate of 3.5%. In this experimental study the Concrete specimens are subjected to curing process in both Normal water as well as the Sea water and to compare and study the strength of each Concrete specimens.

IV. EXPERIMENTAL INVESTIGATION

A. Mix Proportion
The minimum strength and durability can be determined only with the help of the Concrete mix design. It is a process by which various raw materials of Concrete are determined. The Concrete mix was designed as per the IS 10262:2009. The Concrete mix design is required to determine the minimum compressive strength required from structural consideration. The surface water and percent water absorption of aggregates shall be determined according to IS 2386. The type of mix used in this experimental study is Design mix. The mix adopted for the study is given in the table 4.1.

Table 4.1 Mix Proportion

Cement	Fine Aggregate	Coarse Aggregate	Water
1	1.54	2.78	0.45

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B. Details of Specimen Preparation

Table 4.2 Specimen Preparation Details

MIX ID	MATERIAL DESCRIPTION
CC	CONVENTIONAL CONCRETE
CSS	RCC CONCRETE COLUMN USING STEEL SLAG
CSGN	COLUMN USING STEEL SLAG AND GFRP WRAPPED REINFORCED CONCRETE (NORMAL WATER)
CSGS	COLUMN USING STEEL SLAG AND GFRP WRAPPED REINFORCED CONCRETE (SEA WATER)

C. Casting of Specimens

When the concrete mix is done, the mould is cleaned with cloth and grease or oil is applied. The concrete is filled into the mould with three layers and each layer is tampered using tampering rod up to 25 times of compaction.

1) *Cube:* The size of the mould used 150 mm X 150 mm X 150 mm. The cube moulds are cleaned with the help of using waste oil along its surface. After cleaning the moulds the concrete was poured into the mould and compacted with the help of using a standard tampering rod having a length of 600 mm. This concrete cubes are casted in order to determine the compression strength of the concrete.
2) *Cylinder:* The size of the mould used 150 mm X300 mm. The cube moulds are cleaned with the help of using waste oil along its surface. After cleaning the moulds the concrete was poured into the mould and compacted with the help of using a standard tampering rod having a length of 600 mm. This concrete cubes are casted in order to determine the Tensile strength of the concrete.
3) *Column:* The size of the mould used 150 mm X150 mm X400 mm. The columns are casted with various combinations they are CC, CSS, CSGN and CSGS cured in normal water and sea water.

Table 4.1 Specimen Details

SPECIMEN DESCRIPTION	NO OF SPECIMENS			
	7 DAYS	14 DAYS	28 DAYS	TOTAL
CUBE	18	18	18	54
CYLINDER	18	18	18	54
COLUMN	-	-	12	12

Fig 4.1 Mixing of Concrete ingredients and Casting of specimen

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Volume 8 Issue VIII Aug 2020- Available at www.ijraset.com

D. Curing of Specimens

After casting the Concrete specimens they are demoulded after 24 hours and then these demoulded specimens are subjected to Curing process in the Curing tank for 7, 14 and 28 days on Normal water and also in sea water and then subjected for testing the Cured Concrete specimens in order to achieve their strength properly.

Fig 4.2 During Curing of specimen

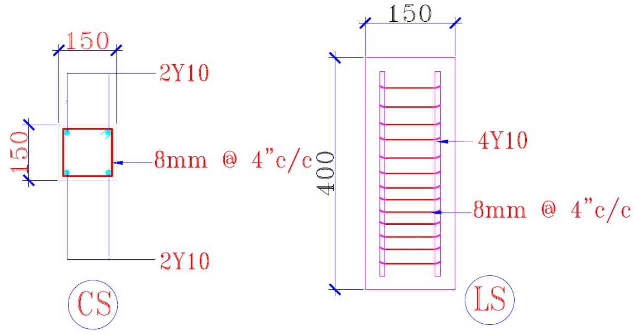

Fig 4.3 Reinforcement Detailing of RCC Column

E. Reinforcment Details

Here Fe 415 HYSD, 8 mm diameter, high yield strength, and hot rolled deformed bars having characteristic strength of 415 N/mm^2 were used. Three samples of bars were placed in the universal testing machine one after another and tested for their tensile strength. It was found that the bars had average yield strength of 390 N/mm^2. The Cross sectional details and longitudinal details of R.C.C Column are shown in figure 4.3.

F. Preparation of CSGN & CSGS Concrete Column

The column size of 400 mm long, 150 mm wide and 150mm thick reinforced with 4 numbers of 10mm diameter bar and stirrups are 8mm dia rod spacing at 100 mm c/c casted with M25 concrete is taken as Control Column. Control Column is cured for 28 days and tested under Compression testing machine (CTM) under concentric loading. Then CSGN column of size same as the control column has been taken by partial replacement of coarse aggregate by steel slag as optimum percentage and steel reinforcement wrapped with GFRP mat using bonding agent epoxy resin and hardener is taken as correct proportions in the column with same reinforcement. Processing of specimen's reinforcement cages were done as shown in figure and put inside steel forms, then concrete was casted while compacted in successive layers.


Fig 4.4 Preparation of CSGN & CSGS Concrete Column

G. Experimental Setup

All the columns were tested under axial in Universal testing machine (UTM) having a capacity of 2000 kN. The column member was placed on the supports, and care was taken to ensure that its center line was exactly in line with the axis of the machine. The columns were instrumented to measure nature of the failure, axial deformation, and ultimate load. The load was applied to the columns using an electronic jack and they were tested to failure.

The following are the test performed to determine the test results

1) Compressive test for cubes
2) Split – Tensile strength test for cylinder
3) Ultimate load carrying capacity (P_u) of column

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Volume 8 Issue VIII Aug 2020- Available at www.ijraset.com

Fig 4.5 Preparation of CSGN & CSGS Concrete Column

V. RESULTS AND DISCUSSION

A. General

The Tests which are conducted in this research are Compressive test and Split tensile test of the casted Concrete specimens. These tests are done in order to determine the Ultimate load carrying capacity of the Concrete column.

B. Slump Value

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a cone having the internal dimension as 20 cm bottom dia, 10 cm top dia and 30 cm height. It is the fall in vertical height of a freshly laid concrete with respect to the standard slump cone height. The Slump cone test is conducted in order to achieve the workability of the Concrete mix. The values are shown in the table 5.1.

Table 5.1 Slump cone test

S.No	Casting Trial	W/C Ratio	Slump value
1.	Conventional	0.45	100mm
2	CSS	0.45	95 mm

C. Test on Hardened Concrete

The main purpose of the hardened Concrete test is to ensure that the Concrete used at site has developed the required strength. The hardened Concrete test plays a vital role in controlling the quality of Cement Concrete works by conducting the Compressive test, Split tensile test on Concrete Cubes as well as Concrete cylinders for 7, 14 and 28 days in order to determine the Ultimate strength of Casted different Concrete Column specimens.

1) *Compressive Strength:* In this experimental investigation totally 54 cubes of 150 mm x 150 mm x 150 mm size were casted and after curing period of 7, 14 and 28 days, the cubes were tested in compression test machine. The concrete shall be filled into the mould in layers approximately 5 cm deep. It would be distributed evenly and compacted either by vibration or by hand tamping. After the top layer has been compacted, the surface of concrete shall be finished level with the top of the mould using a trowel; and covered with a glass plate to prevent evaporation. The cube test was conducted as per IS 516: 1959. The compressive strengths values for the CC and CSS specimens with various percentage of slag by replacement of coarse aggregate are shown in Chart 5.1. From Compressive strength result, when comparing CC with CSS concrete cubes we came to know that the Optimum percentage of replacement of coarse aggregates by steel slag is 40% and Compressive Strength of CSS specimen is 2 times more than that of Conventional Concrete.

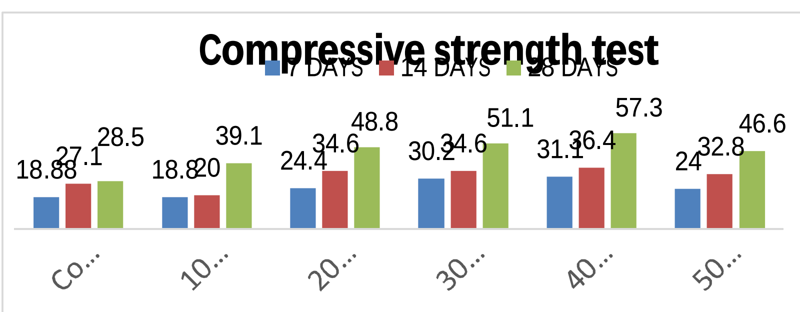

Chart 5.1 Comparison on Compressive strength of Concrete

Fig 5.1 During Testing of Compressive strength of Cubes

2) *Tensile Strength:* In this experimental investigation totally 54 cylinders of size 150 mm diameter and 300 mm length were casted. And after curing period of 7, 14 and 28 days, the cylinders were kept horizontal tested under Compression testing machine and the Split tensile test was performed. The split test was conducted as per IS 516: 1959. The split tensile strengths values for the CC and CSS specimens with various percentage of steel slag by replacement of coarse aggregates.

$$\text{Tensile strength} = 2p/\pi DL\ (N/mm^2)$$

where, P = Load, D = depth, L = length

The test results shown that Optimum value of Slag Concrete is 30% and Split Tensile Strength of CSS Specimen is 1.12 times more than that of Conventional Concrete are shown graphically in Chart 5.2.

Chart 5.2 Tensile strength of Concrete

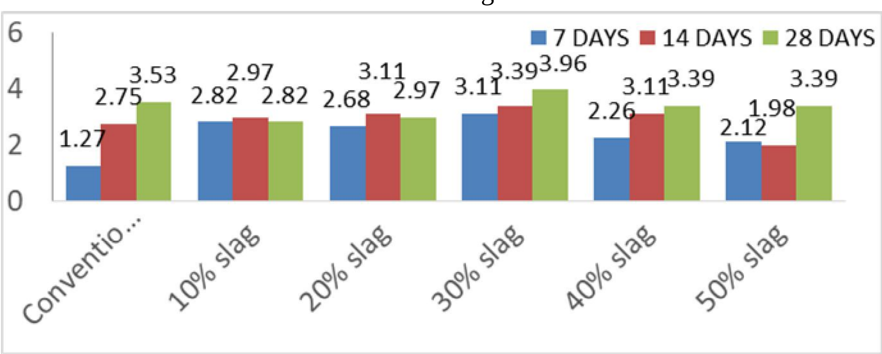

Fig 5.2 During Testing of Splitting tensile strength of cylinder

3) *Ultimate Load Carrying Capacity Of Column:* To investigate their structural performance and behavior, the concrete column specimens were tested under axial load based on the design mix which we have adopted. This section presents the test results of steel RC columns and GFRP RC columns. All specimens were tested until they failed and reached their maximum carrying capacity, and the machine recorded the data. Totally 4 types of Concrete Columns are casted in order to compare the Ultimate tensile strength of columns test results. The 4 types of Concrete Column design are CC, CSS, CSGN and CSGS.

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a) *Conventional Concrete Column (CC)*
b) *Column using Steel Slag (CSS):* In this column concrete mix consists of replacement of coarse aggregate by steel slag as optimum percentage (40%).
c) *Column using Steel Slag and GFRP (Normal water) (CSGN):* The mix is prepared and casted by CSS Column procedure and Glass fibre mat (GFRP) is wrapped to the reinforcement of the columns using bonding agent epoxy resin and hardener is taken as correct proportions and cured in normal water
d) *Column using Steel Slag and GFRP (Sea water) (CSGS):* The same procedure followed by CSGN mix except that it will be cured in sea water

IS CODE

According to IS code an ultimate strength will calculated by using the following equation,

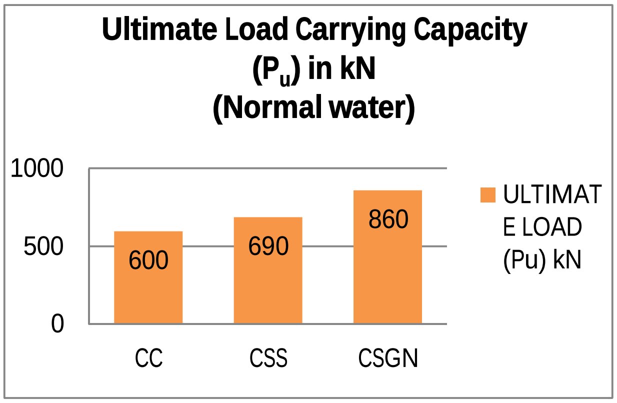
$$P_u = 0.4f_{ck}A_c + 0.67f_yA_{sc}$$

Where,
A_{sc}, Area of reinforced section = $PA_g/100$.
A_c, Area of concrete = A_g (1-P/100).
f_{ck}, Compressive stress of concrete in N/mm^2
f_y, yield stress of concrete in N/mm^2

The Structural behaviour of all the four different combinations of RCC columns of M25 grade concrete was calculated and the test results are compared and graphically shown in Chart 5.3.

Fig 5.3 During Testing and failure pattern of Ultimate load carrying capacity of Columns

Chart 5.3 Comparison of Ultimate load carrying capacity of Column cured in Normal water



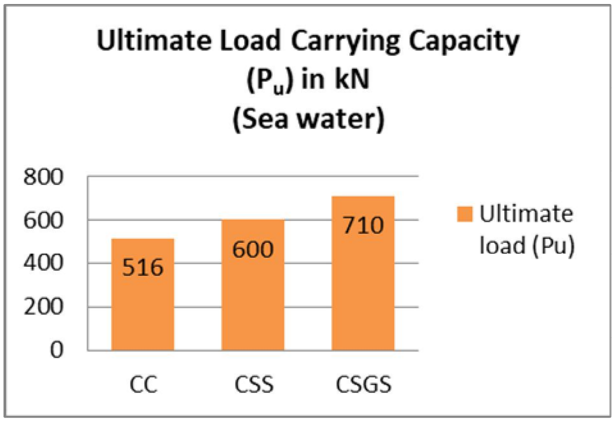


Table 5.2 Comparison on Ultimate load carrying capacity of Column cured in Normal water & Sea water (kN)

Specimen Mix ID	Ultimate Load P_u (kN)	
	NW	SW
CC	600	516
CSS	690	600
CSGN	860	688

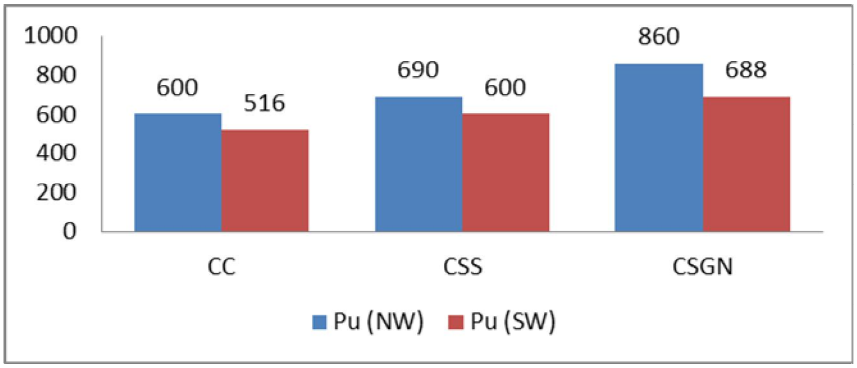


Chart 8: Comparison on Ultimate load carrying capacity of columns (Normal Water & Sea Water)

VI. CONCLUSION

From the experimental work conducted in this study, the following conclusions are made:

A. By providing internal confinement with FRP-composite the strength of a concrete column can increase considerably.
B. Providing steel slag to the concrete specimen will increase the Ultimate load.
C. It should be noted that specimen CSGN when loaded concentrically will give max load and smaller cracks compared to other specimens.
D. Compressive strength of Concrete is increased by 2 times for CSS specimen at 40% of replacement of coarse aggregate by steel slag when compared to Conventional Concrete (CC)
E. Splitting Tensile strength of Concrete is increased by 1.12 times for CSS specimen at 30% of replacement of coarse aggregate by steel slag when compared to Conventional Concrete (CC)
F. The ultimate load carrying capacity of column is increased by 1.16 times for CSS specimen and 1.43 times for CSGN specimen when compared to Conventional Concrete (CC) cured in normal water.
G. The ultimate load carrying capacity of column is increased by 1.15 times for CSS specimen and 1.37 times for CSGN specimen when compared to Conventional Concrete (CC) cured in sea water.
H. When the Concrete is casted and cured in Sea water, it has been observed that Ultimate load carrying capacity of Concrete column decreased by 14% when compared with Concrete cured under normal water
I. But Ultimate load carrying capacity values could reflect that not so much changes in the strength and reinforcement is not corroded due to GFRP mat wrapped reinforcement and steel slag composites
J. These composite techniques should be adopted in seashore and underwater construction with confidence due to durability and relative performance of composites.
K. While testing a Ultimate load carrying capacity, conventional concrete specimen's shows a typical cracking pattern, but CSS, CSGN and CSGS column showed reduced crack. This shows the ductile behavior due to the presence of GFRP Composites and steel slag.

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