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Comparative Studies on Strength Properties of RC Column With Basalt & Steel Reinforcement.

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Abstract : To investigate the strength properties of basalt rebar compared to steel rebar in columns under axial loading . The columns were reinforced with 4 no's of rebar , of 10 and 12mm diameters. They were tested under loading frame. The crack pattern was recorded and ultimate load carrying capacity was noted experimentally and analytically. The Ansys software was used to model the column and two end hinged support was provided. The failure was characterized by bond splitting and flexural type failure.

Keywords: Axially loaded short column, , Basalt rebar,Steel rebars.Deflection .

1.INTRODUCTION

Basalt is one of the most common rocks on the planet, and is the only ingredient needed to make basalt fiber. Basalt Rebar is an outstanding product for concrete reinforcement. It weighs 4 times less than steel rebar and its tensile strength is 3 times higher. Basalt rebars are manufactured from basalt fibers by pultrusion technology. Basalt rebar is that material which can be manufacture on large scale. Basalt rebars are non-toxic in nature, non –combustible and also do not explode when comes directly in contact with fire. When they come in direct contact with chemicals they will not form a product which is harmful and dangerous to environment.

Concrete structures made up of steel reinforced bars are normally used in construction industry. But steel reinforced structures are susceptible to corrosion attack which affects its durability and strength parameters. Non-corrosive Basalt bars as reinforcement of concrete structures is an alternative solution to this. Basalt bar is lighter than steel bar as its density is much lower. The main advantage of basalt bar is that it is naturally resistant to chemical attack such as alkali, rust and acids. Basalt rocks are volcanic igneous rocks which are located at a depth of hundreds of kilometers beneath the surface by the cooling of molten lava.

. Recently fiber reinforced polymer FRP has emerged as a new material to be used in structural engineering due to its attractive mechanical properties such as: high tensile strength, light weight, high resistance for corrosion, high fatigue endurance, low thermal coefficient, short period of installation, easy application and low cost for maintenance during the course of time of the structure.

In addition to good mechanical properties, basalt rebars have a high chemical and thermal stability, insulating, electrical and sound properties. Basalt thermal insulation is three times better than the asbestos. Due to good insulating properties, basalt is successfully used for fire protection. Furthermore, basalt rebars have 10 times better electrical characteristics. Basalt rebars are also significantly better chemically resistant, particularly in a strongly alkaline environment. Service life of concrete slabs with steel reinforcement for use in bridges, expected to be 25 years. However, the service life of panels with Basalt reinforcement is usually expected to be at least 75 years (i.e. the period of use of the bridge).

2.FINITE ELEMENT MODELLING

Element Property

Three types of Elements were utilized to model the geometry of the Beam namely:

1) Solid185
2) Solid65
3) Link180

Solid185 Element:

SOLID185 is utilized for 3-D modelling of solid and steel structures. It's described by eight nodes 2 having three DOF at every node: x, y, and z translations at the nodes. The Impactors & the Supports were modelled using this element. This element is utilized specifically to distribute the load to `prevent stress concentrations that would affect the convergence. To be able to accomplish this rigid surface a high young's modulus was input matching that of steel.

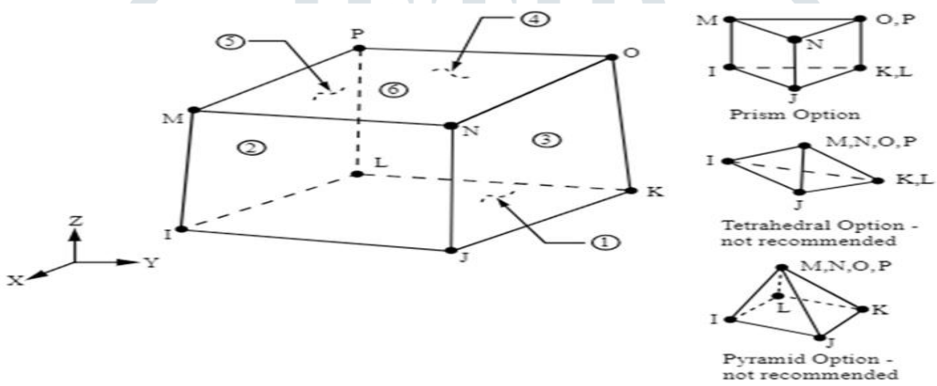

Fig 1.0: Homogenous Structural Solid Element

Solid65 Element:

Concrete is quasi-brittle material that exhibits different behaviour in compression and tension. ANSYS provides an element known as a SOLID65 that can be utilized to model concrete. This solid can crack in tension and crush in compression. Solid65 is a 3D 20-node solid element. It has eight nodes on the corners and twelve additional nodes on the edges, enabling more precise representation of complex geometry. It is designed to handle the nonlinear actions of concrete, including its ability to withstand compressive and tensile loads.

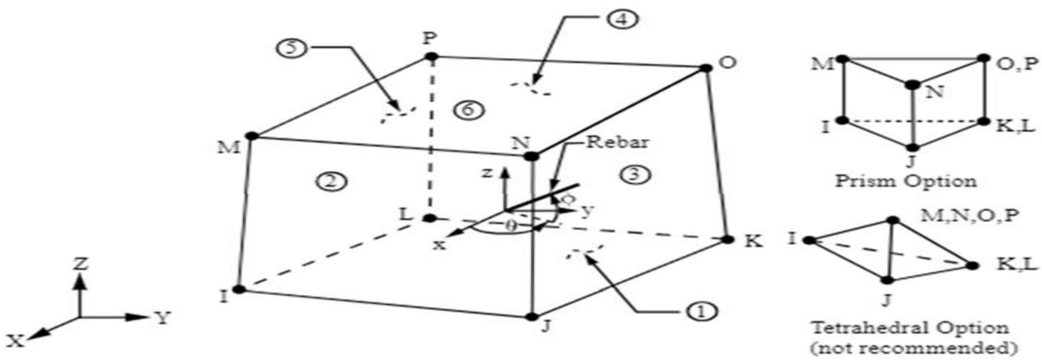

Fig 2.0: Solid65 Geometry

Link180 Element:

LINK180 is a 3-D spar element. It is a single-axis tension-compression element with three DOF at every node: x, y, and z translations at the nodes. The reinforcements were modeled using this element.

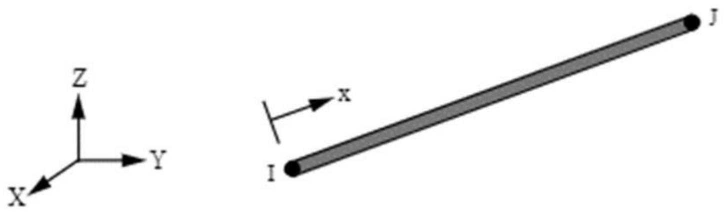

Fig 3.0: Link180 Geometry

Material property

Impactors and Supports were modeled with Structural Steel Properties.

Table 1.0: Properties of Impactor and Support

Component	Element-Type	Material-No	Material-properties	
Impactor and Support	Solid185	5	Linear-Isotropic	
			Ex (MPa)	200000
			Poisson's Ratio	0.3

Beam element were modeled with M20 grade of concrete

Table 2.0: Properties of Concrete.

Component	Element-Type	Material-No	Material-properties	
Concrete	Solid65	1	Linear-Isotropic	
			Ex (MPa)	20000
			Poisson's Ratio	0.2
			Multilinear properties	
			Stress	Strain
			0	0
			5	0.00019
			17.40	0.0008
			23.39	0.0013
			20	0.00017

Concrete crushing and cracking behaviour are modelled utilizing the following data

TBDATA inputs are necessary to reflect the concrete cracking and crushing criteria, if constants 1-4 are input, then 5-8 will be set to default. Range of shear transfer coefficients from0 to 1, with 0 denoting a smooth crack and 1 denoting a rough crack. Values for the coefficient of open crack shear transfer are suggested by several studies to range from 0.2 to 0.9. Stress at uniaxial tensile fracture was taken as 25, Uniaxial crushing stress was taken as 2.5 and the othervalues were set to default.

The reinforcement element was modelled with the link180 element with the following property, these elements are capable of handling nonlinear behaviour relatively well, which can be created with a bilinear isotropic definition. Although the BFRP rebar does not yield, bilinear behaviour was utilized in case there were convergence issues near failure.

Table 3.0: Properties of Reinforcement

Component	Element Type	Material No	Material properties	
Steel Rebar (fe500)	Link180	2	Linear isotropic properties	
			Ex (MPa)	200000
			Poisson's ratio	0.3
			Bilinear isotropic properties	
			Yield Strength	500
			TangentModulus	20
Steel Rebar (fe250)	Link180	3	Linear isotropic properties	
			Ex (MPa)	200000
			Poisson's ratio	0.3
			Bilinear isotropic properties	
			Yield Strength	250
			TangentModulus	20
Basalt Rebar	Link180	4	Linear isotropic properties	
			Ex (MPa)	59500
			Poisson's ratio	0.258
			Bilinear isotropic properties	
			Yield Strength	500, 400
			TangentModulus	20

Geometric modellingCreating Solids

First the key points were created in the active workspace to model the beam element, and the volume was created using with those key points and at this point the volume was meshed with respective concrete element and material type with mesh size of 25mm.

The impactors and support element were modelled with the same process as that of the beam element.

Creating lines

Line elements were also created using key points method, were in the key-points were created at the coinciding nodes of the solid element and with the line command the lines were created and the lines were meshed with the characteristics of steel and basalt rebar with mesh size of 25mm.

Boundary Conditions, Contact Surfaces and Applying Loads

The model requires satisfactory boundary conditions to be able to solve the problem. Firstly, the supports and impactor were connected to the concrete surface using the CEINTF command. This contact surface was assigned a tolerance interval of 0.01. To connect the reinforcement to the concrete components NUMMRG command was applied to every the LINK180 and SOLID65 elements. This command merges all coincident nodes.

A simply-supported condition was applied and 200KN load was used at the impactors. To load the impactor with 200KN the value was divided by the amount of nodes along the z-axis of the support.

Behavior of Column under Axial Load [Experimental]

Four columns were casted and tested under axial load. The constant axial load was transferred to the column by means of a steel axial loading frame, which was positioned on top of the column The specimens tested are shown in the below figure.

Fig 4.0: Column model

The reading is recorded by digital data acquisition servo controlled machine. The specimens are attached with two LVDT's both one in x-direction and one in y-direction, through which the deflections were recorded in both the directions. The strain gauges are attached to monitor the strains in the specimen. The strains are attached along the same location as the LVDT's are placed over he specimen. The column is held straight with the help of ropes from lateral direction .The column was preloaded by the loading frame in order to attain the fixity of the column in the vertically erect position. The verticality was checked by the plumb bob and other equipment's in order to attain exact 90^{o} along all the directions. The column was placed at swage blocks in the bottom. The kind of support was assumed to be hinged as no other support was given at the bottom to the column. In order to attain full load transfer to the column from the bottom the foundation was redesigned by proper excavation and reinforcing bars were used to create a new isolated footing with sufficient capacity to carry the load from the top by the loading frame, and also swage blocks could also return back some load to the column specimen from the bottom because of metallic nature and property within it.

Testing:

The testing was carried out by the loading frame. The load was given to the column at an incremental loads at the controlled way, the loading was set in manual mode in the data acquisition machine. The formation of cracks were closely watched and recorded. The cracks formed during loading were recorded and the reading was also recorded by the data acquisition machine simultaneously. The loading was continued until the formation of major cracks at the bottom and top of the column. Once the column starts cracking beyond its safety limits, the loading was stopped due to the safety standards. Once the loading is stopped the column was unloaded and the column was removed with the help of crane.

Below are the specimen details with figures and result tables composing of the load taken up by the specimen and also the deflection results. The deflections are the maximum values irrespective of the axis. All the specimen failed due to The bond between the reinforcement and concrete was lost. Slipping of the reinforcements of dowels and column re-bars were observed.

There are four specimens, each specimen details is mentioned below starting with basalt rebar specimen and then followed by the steel rebar specimen.

Table 4.0: Specimen Details

Series	Column	Effective length	column size mm	reinforcement details
RC column specimens with conventional rebar	10S1	1500	1500X150X230	4#10, 2LVS-6mm stirrups @150mm c/c
	10S2	1500	1500X150X230	4#10, 2LVS-6mm stirrups @150mm c/c
RC column specimens with conventional rebar	12S1	1500	1500X150X230	4#12, 2LVS-6mm stirrups @150mm c/c
	12S2	1500	1500X150X230	4#12, 2LVS-6mm stirrups @150mm c/c
RC column specimens with Basalt rebar	10B1	1500	1500X150X230	4#10, 2LVS-6mm stirrups @150mm c/c
	10B2	1500	1500X150X230	4#10,2LVS-6mm stirrups @150mm c/c

RC column specimens with Basalt rebar	12B1	1500	1500X150X230	4#12, 2LVS-6mm stirrups @150mm c/c
	12B2	1500	1500X150X230	4#12, 2LVS-6mm stirrups @150mm c/c

Column with 10mm steel as longitudinal rebar's. SPECIMEN 1

Fig 5.0: Column with 10mm steel as longitudinal rebar's. SPECIMEN 1

The column above is reinforced with 4 numbers of steel rebar's, the column failed under crushing of concrete. The bond between concrete and steel rebar has behaved adequately in order to offer proper bond coefficient.

Fig 6.0: Column with 10mm steel as longitudinal rebar's. SPECIMEN 2

Table 5.0:

Sl.No.	Specimen details	Load in KN	Mean Load In KN	Deflection in mm		Mean deflection in mm
				X-DIR	Y-DIR	Along X-direction
1	10S1	380	**386**	2.64	0.57	3.33 mm
2	10S2	392		3.95	1.27	
3	12S1	424	**425**	8.12	2.12	10.00
4	12S2	427		11.89	3.29	
5	10B1	404	**405**	8.23	2.33	9.08
6	10B2	406		9.94	1.64	
7	12B1	431	**435**	15.02	6.96	15.2
8	12B2	438		15.20	7.04	

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Sl.No.	Specimen details	Mean Load In KN	Mean deflection in mm Along X-direction
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5	10B	**405**	9.08
7	12B	**435**	15.2

Observations

- The columns with steel rebar carried lesser axial load compared to the column specimens with basalt rebar. Since the compressive strength of basalt rebar is comparatively more, this has resulted in higher compressive load carrying capacity of the columns with basalt rebar.
- The load carrying capacity of the basalt columns or steel columns found to increase with increase in the bar diameter.
- The deformations observed in the columns with steel rebar are lesser than columns with basalt rebar. Also the deformations are increasing with the increase in the diameter of the rebar size both in steel rebar and basalt rebar.
- The basalt rebar has the tendency of rebounding nature because of which the displacements of basalt rebar specimens found to be higher than steel rebars. This also pertains to the ductility nature of basalt rebar compared to the steel rebar.

Conclusions

- By the observation it is clear that load carrying capacity of the basalt rebar specimen is more compared to the Steel rebar specimen. For the 10mm steel it is found that basalt rebar specimen carried 5% more load than steel rebar specimen. For 12mm diameter basalt bar carried 2.5% more load than steel rebar specimen. Though the increase in load carrying capacity is considerable low, but it is still considered because, the basalt rebar being of lower yield stress still offering more load carrying capacity than steel rebar.
- Bond Splitting Failure was observed in case of columns reinforced with steel rebar, as failure was observed with no yielding in the steel rebars as the major stress concentration was on the concrete.
- Flexural type of failure was observed in the basalt reinforced columns as we found the rebars were getting yielded under the ultimate loading. The failure nature of columns reinforced with the basalt rebar was in the form of debonding nature.

Behavior of Column under Axial Load [Analytical]

To simulate the interaction between the reinforcement and the concrete, the ABAQUS built-in constraint "embedment" was used. This constraint restricts the nodes of the reinforcement to the corresponding degrees of freedom of the host domain, rigid plates were added to the model to ensure the uniformity of the load applied on the top and bottom surfaces. Moreover, normal and tangential surface-to-surface contact defined the interaction between the rigid plates and concrete surfaces using the penalty contact approach. Boundary conditions and displacement were assigned on the plates through reference points defined on the center of each rigid plate. A mesh sensitivity analysis was also conducted to select the appropriate mesh size that provide results accuracy with less computational cost. The model with a mesh size of 20 mm was considered throughout the analysis.

Parametric Analysis: Performance of the GFRP- and BFRP-RC Columns

A parametric study was conducted to further investigate the response of the GFRP and BFRP bars in RC columns by considering different type of rebars and reinforcement ratios, the effect of changing these parameters on the overall behavior of the RC columns is also presented and discussed.

3.0RESULTS AND DISCUSSIONS

Column Results

Table 7.0: Column Results

Sl no	Specimen details	Load in KN	Mean Load in KN	Deflection in mm		Mean deflection in mm
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7	12B1	431	**435**	15.02	6.96	15.2
8	12B2	438		15.20	7.04	

Table 8.0: Column Consolidated

Sl no	Specimen details	Mean Load In KN	Mean deflection in mm Along X-direction
1	10S	**386**	3.33
3	12S	**425**	10.00
5	10B	**405**	9.08
7	12B	**435**	15.2

Discussions:

- The columns with steel rebar carried lesser axial load compared to the column specimens with basalt rebar. Since the compressive strength of basalt rebar is comparatively more, this has resulted in higher compressive load carrying capacity of the columns with basalt rebar.
- The load carrying capacity of the basalt columns or steel columns found to increase with increase in the bar diameter.

- The deformations observed in the columns with steel rebar are lesser than columns with basalt rebar. Also the deformations are increasing with the increase in the diameter of the rebar size both in steel rebar and basalt rebar.
- The basalt rebar has the tendency of rebounding nature because of which the displacements of basalt rebar specimens found to be higher than steel rebars. This also pertains to the ductility nature of basalt rebar compared to the steel rebar.

Results of Study of Columns [Analytical]

The analysis of the column was carried out by considering the column has hinged from bottom support and free from the top. The loading was applied at the top of the column. The reinforcement details and the material properties was applied similar to the values that were considered for the specimens which were tested experimentally. The following load taken and deflection are recorded and values are given below.

Load Deflection Values

Table 9.0: Basalt 10mm

Basalt 10mm	
Load In kN	Deflection in mm
0	0
45	0.87
90	1.74
135	2.61
180	3.48
225	4.35
270	5.22
315	6.09
360	6.96
405	7.83

Table 10.0: Basalt 12mm

Basalt 12mm	
Load in kN	Deflection in mm
0	0.00
48.3	1.34
96.7	2.73
145.0	4.12
193.3	5.51
241.7	6.90
290.0	8.29
338.3	9.68
386.7	11.07
435.0	12.46

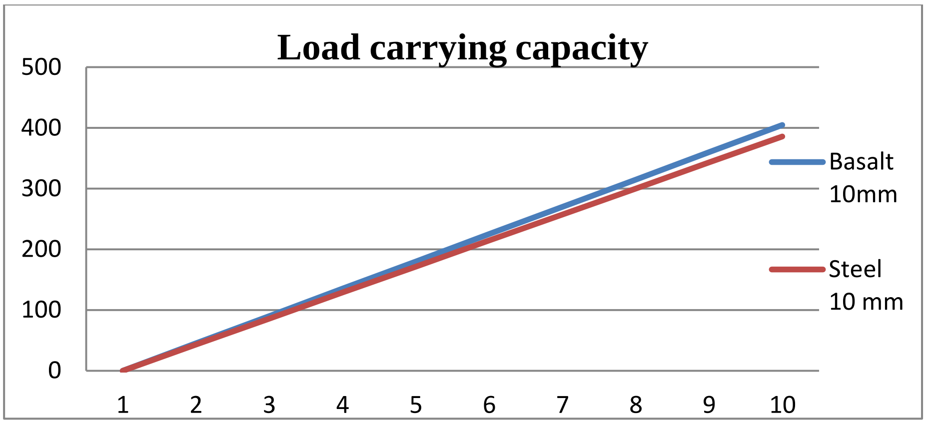
Table 11.0 : Steel 10mm

Steel 10mm	
Load	Deflection
0	0
42.9	0.34
85.8	0.68
128.7	1.02
171.6	1.36
214.5	1.7
257.3	2.04
300.2	2.38
343.1	2.72
386.0	3.06

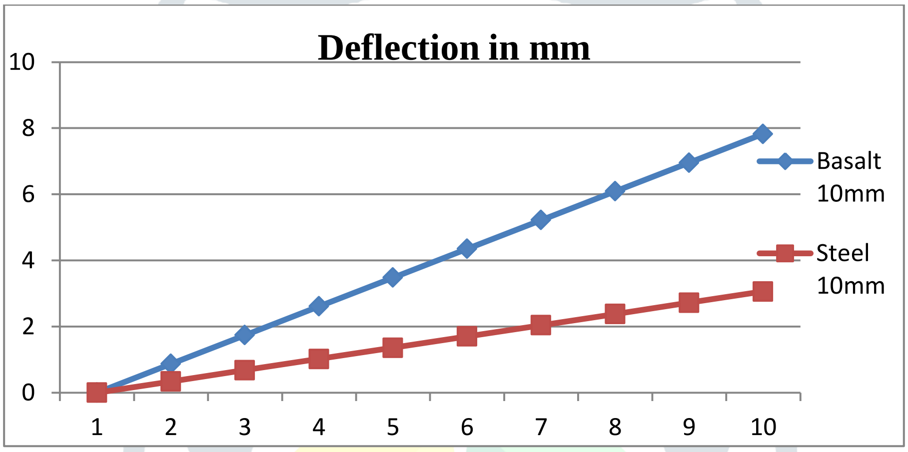
Table 12.0: Steel 12mm

Steel 12mm	
Load in kN	Deflection in mm
0	0
47.2	0.69
94.5	1.38
141.7	2.07
188.9	2.76
236.1	3.45
283.4	4.14
330.6	4.83
377.8	5.52
425.1	6.21

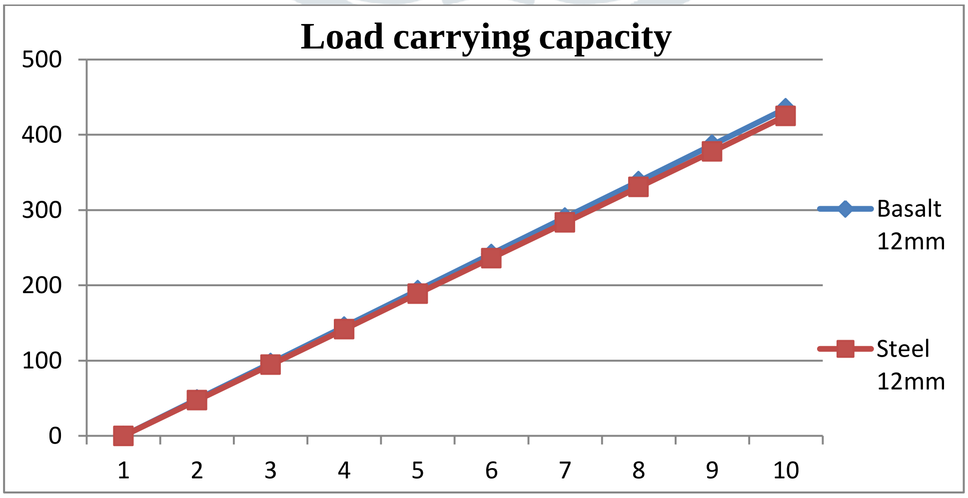
The graphical representation of the load carrying capacity and deflection is as given below:



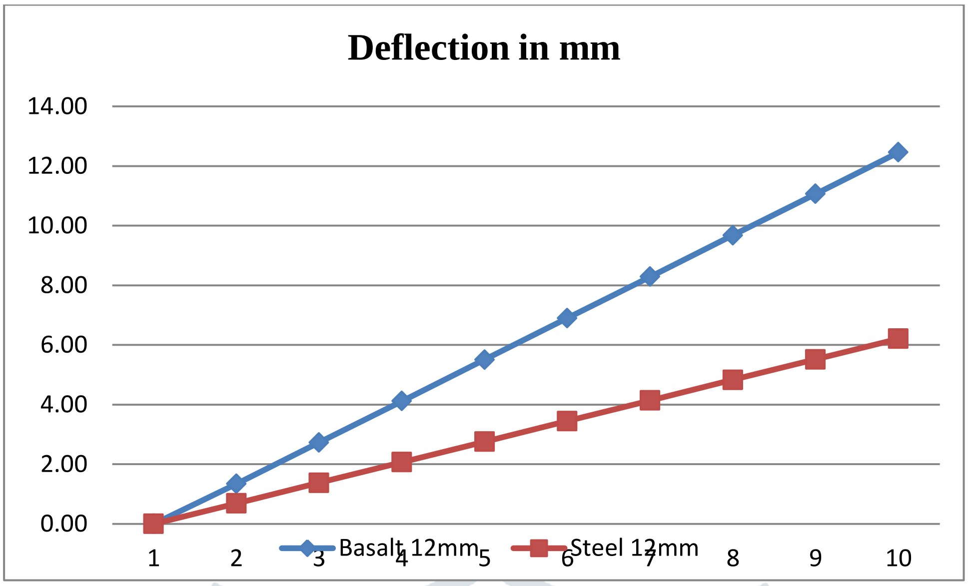
Graph 1.0: Load Carrying Capacity 10mm



Graph 2.0: Deflection in mm



Graph 3.0: Load Carrying capacity 12mm



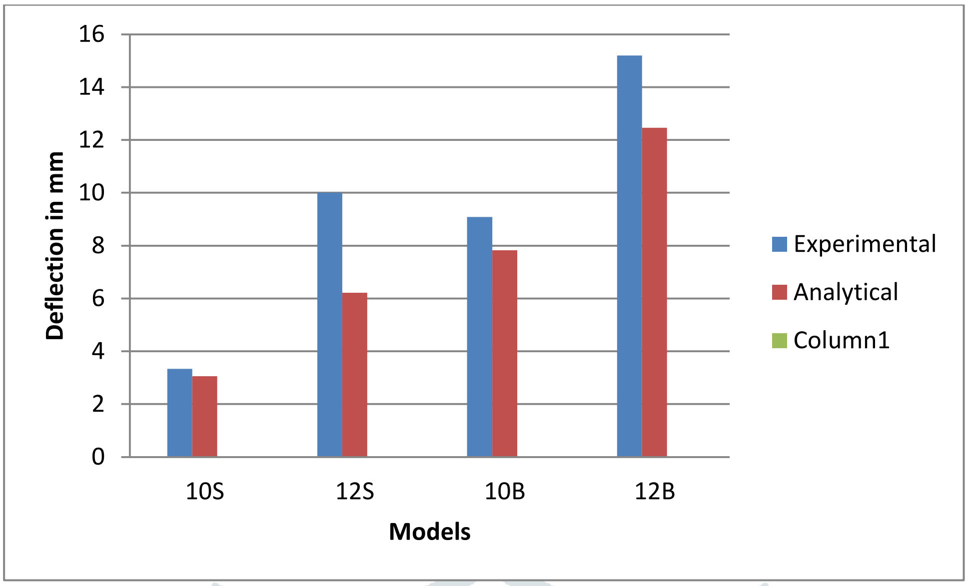
Graph 4.0: Deflection in mm

Table 13.0: Experimental values of Column Specimens

Experimental values of Column Specimens.			
Sl no	**Specimen details**	**Mean Load In KN**	**Mean deflection in mm** Along X-direction
1	10S	**386**	3.33
3	12S	**425**	10.00
5	10B	**405**	9.08
7	12B	**435**	15.2

Table 14.0: Analytical values of Column Specimens

Analytical values of Column Specimens.			
Sl no	**Specimen details**	**Mean Load In KN**	**Mean deflection in mm** Along X-direction
1	10S	**386**	3.06
3	12S	**425**	6.21
5	10B	**405**	7.83
7	12B	**435**	12.46



Graph 5.0: Comparison between EXP and ANL

4. CONCLUSION

1 By the observation it is clear that load carrying capacity of the basalt rebar specimen is more compared to the Steel rebar specimen. For the 10mm steel it is found that basalt rebar specimen carried 5% more load than steel rebar specimen. For 12mm diameter basalt bar carried 2.5% more load than steel rebar specimen. Though the increase in load carrying capacity is considerable low, but it is still considered because, the basalt rebar being of lower yield stress still offering more load carrying capacity than steel rebar.

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4 The experimental and analytical values found to be similar and it validates the values obtained experimentally .

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