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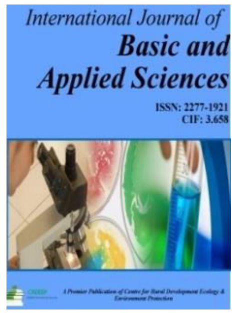

Full Length Research Paper

Finite Element Analysis of Steel Tubular Columns Filled With epoxy-sand mixture under Axial Compression

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ABSTRACT

This paper presents the behavior of square steel stub columns filled with epoxy-sand mix compressed under concentric axial loads. To predict the performance of such columns, a finite element analysis is conducted. A nonlinear finite element model (FEM) using the multi-purpose FE program ANSYS has been developed. The validity of the developed model was examined by comparing it with the experimental data founded in the current experiments. Herein, for the accurate modeling of the composite and hollow specimens, the identification of suitable material properties for both the epoxy-sand mix infill and steel tubes is crucial. A parametric study has been conducted over composite members under the effect of axial load. Axially loaded columns of different depth-to-thickness ratios have been investigated. Based on test results obtained, it is confirmed that the length of the tubes has a considerable effect on the bearing capacity and the failure mode. 3. Also, Sand and epoxy resin mix increase column strength signification and the epoxy-sand ratios have a significant effect on column strength.

Introduction

Concrete-filled steel tube columns are typical composite members consisting of outer steel tubes in filled with inner concrete. The outer steel tube confines the inner concrete, which increases the compressive strength and ductility of CFST columns. The inner concrete forms an ideal core to withstand the compressive loading, and it prevents local buckling of the outer steel tube, particularly in square CFST columns. Numerous tests have illustrated that Concrete-filled steel tube columns have both higher strength and ductility under compressive loading when compared with traditional steel reinforced concrete columns [1].

In current international practices, CFST columns have been widely applied as vertical load-bearing components in high-rise structures and bridges [2-5]. The axial load-carrying capacity of square CFST stub columns with large sectional aspect ratios is even lower than that of the combined core concrete and steel tube components owing to the effect of local buckling [6-11]. To improve the performance of square thin-walled CFST columns, it is necessary to take effective measures to avoid premature buckling of the outer steel tubes. Other researchers used pure polymers like epoxy as fill materials to fill steel tubes [12 and13]. From another side, some researchers used sand to fill steel tubes to improve the different buckling modes of steel tube column [14-17].

In this paper, the mixture between sand and epoxy materials has been used to fill the hollow steel section to enhance different buckling modes. Hollow steel columns filled with Sand and epoxy resin mix have given a range of advantages, including speed of construction, lightweight, high adhesion, low shrinkage, high tensile strength, and high ductility. It also has outstanding structural performance characteristics, including high stiffness and strength.

Experimental Program

Material Properties

The Properties of the Sand and epoxy resin mix used to fill the steel tubes presented in table 1. The stress-strain (F, ε) relationship for different epoxy-sand ratios 1:25, 1:50, 1:100, and 1:150 used in this paper shown in Figure 1. Steel properties represented in: steel yield strength (F_y) equal to 240 MPa, ultimate strength (F_u) equal to 360 MPa, and the modulus of elasticity of steel (E_s) equal to 21000 MPa, and the Poisson's ratio of steel (υ_s) equal to 0.3.

Table. 1 Results of Epoxy-Sand Ratios Cubes Test

Epoxy-Sand Ratio	Average Crushing Load (KN)	Average Compressive Strength (F_{cu}) (MPa)
1:25	230	8.9
1:50	95	3.7
1:100	35	1.4
1:150	11	0.5

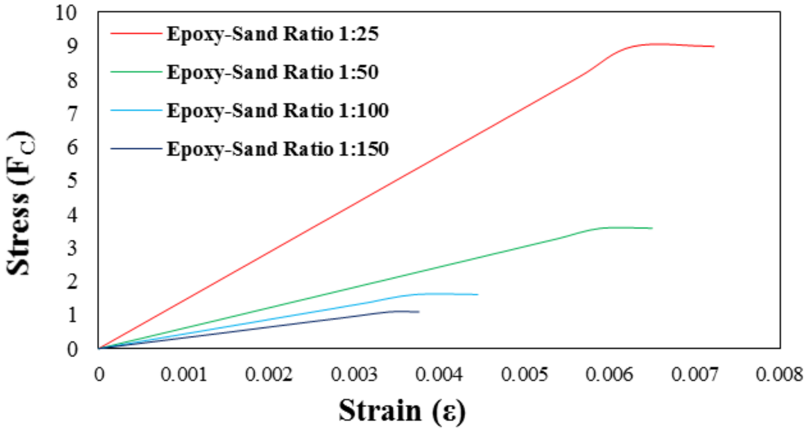

Fig 1. Stress-Strain Relationship of Epoxy-Sand Ratio

Experimental Results

A total of 8 square specimens of hollow and composite columns (steel tube column filled with sand and epoxy resin mix) have been constructed and tested under concentric axial compressive loads. The first group consists of 4 control specimens of hollow steel columns. The second group has 4 specimens of composite columns. The parameter considered in this study is the height-to-width ratio of columns (h/b = 4, 8, 12, and 16), epoxy to sand ratio considered 1:100 as shown in Table 2.

Table 2.Geometric, material properties and results of present research

Specimens	b/t	h/b	Epoxy-sand ratio	P_U (kN)
H 500	80	4	--	**118**
H 1000	80	8	--	**98**
H 1500	80	12	--	**85**
H 2000	80	16	--	**75**
C 500	80	4	1:100	**175**
C 1000	80	8	1:100	**160**
C 1500	80	12	1:100	**142**
C 2000	80	16	1:100	**130**

Where the letter "C" is the composite column or "H" is the hollow steel column. Numbers following the letter are representing column height.

The Finite Element Model

Elements and Mesh

The filling material (sand and epoxy resin mix) section is modeled by using SOLID65 element. This element is defined by 8 nodes having three translation degrees of freedom at each node in the X, Y, and Z directions. Steel sections are modeled using SHELL181 element which is suitable for simulating thin to moderately-thick plates. This element is a four-nodded element with six degrees of freedom at each node: translations in the X, Y, and Z directions, and rotations about the X, Y, and Z axes. Inelastic material and geometric nonlinear behavior are adopted for this element. Von Misses yield criteria is used to define the yield surface. Steel end plates are also modeled usingSHELL181 element. Contact elements (Contact 178) are used for the interface between the filling material and the steel components. This element has two faces: when a face sin contact, compressive forces develop between the two materials resulting-in frictional forces. To simulate the bond between the steel tube and the filling material, a surface based interaction with a contact element model (Contact178) in the normal direction to the surface is used. The surfaces can separate and slide relative to each other, and transmit contact pressure and shear stresses between the filling material and the steel section.

Boundary Condition and Load Application

The top surface of the column is prevented from displacement in the X and Z directions but it is allowed to move Y direction. On the other hand, the bottom surface of the column is prevented from displacement in the X, Y and Z directions at the point that is opposite to the point of load application at the top of column, as shown in Figure 2. The compressive load is applied through a rigid steel cap to the top surface in the direction of the Y to evenly distributed spread the load over the cross-section. The load is applied in increments using the modified RIKS method with arc-length control available in ANSYS.

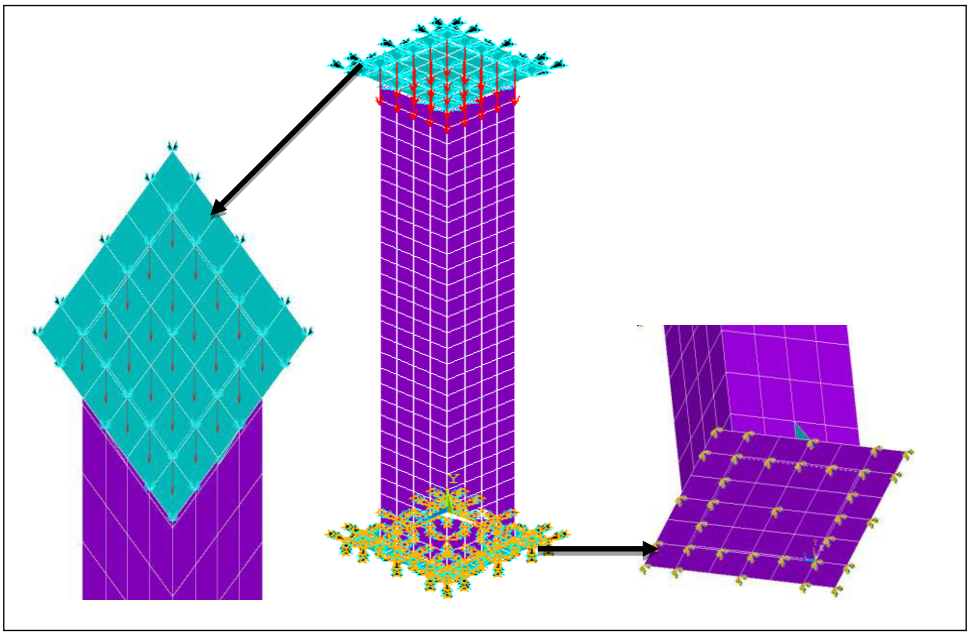

Fig 2. Finite element model (Boundary condition and load application)

Steel Properties
In the present research, an elastic-plastic model with the Misses plasticity and isotropic hardening plasticity is used to describe the behavior of the steel material. The material behavior provided by ANSYSusing plastic option allows nonlinear stress-strain behavior to be defined. Strain-hardening stress-strain curve is used to describe the behavior of the steel for modeling the steel tube and the end plates. The main parameters for the curve are steel yield strength, F_y, steel ultimate strength, F_u, modulus of elasticity of steel, E_s, which is taken equal to 210000 MPa, and Poisson's ratio, υ_s, which is taken equal to 0.3.A mathematical equation for the stress-strain (σ-ε) relationship of steel in a composite column is used as shown in Figure 3.

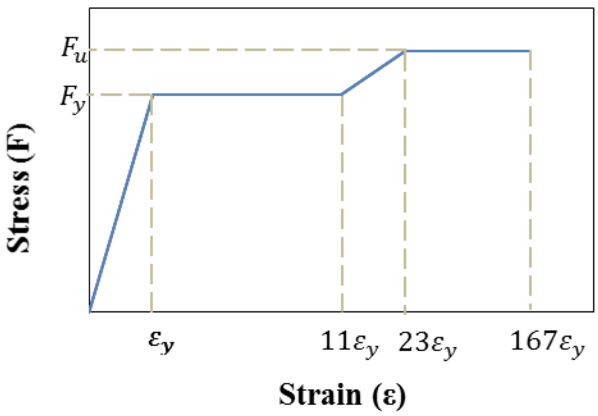

Fig 3. Stress-strain relationship of steel

Verification of FEM Using Current Experimental Results.
In order to verify the finite element model, a comparison is made between the current experimental results and the results of the finite element. The results obtained from the analysis of finite element analysis are verified against the present experimental results of all eight specimens.

The ultimate loads obtained after failure were investigated from the tests, P_u, the finite element analysis, P_{FEM}, and the deformed modes. A comparison between P_u and P_{FEM} is shown in Table 3.

Figure 4 shows a comparison between the results of the Experimental and the FEM. For most specimens, the good agreement achieved between both results can be seen. The ratio between FEM load and experimental load shows an average value of 1.08. A maximum difference of 17% is determined between experimental and FEM results for specimen H 1500.

A comparison between failure modes for hollow steel specimen and hollow steel filled with sand and epoxy resin mix observed experimentally and those recorded in the numerical analysis are shown in Figures 5 and 6.

Table 3. Comparison between FEM results and experimental results of present research

Specimens	P_U **(kN)**	P_{FEM} **(kN)**	$\frac{P_U}{P_{FEM}}$
H 500	118	130	**1.10**
H 1000	98	110	**1.12**
H 1500	85	100	**1.17**
H 2000	75	80	**1.07**
C 500	175	175	**1.00**
C 1000	160	165	**1.03**
C 1500	142	145	**1.02**
C 2000	130	130	**1.11**

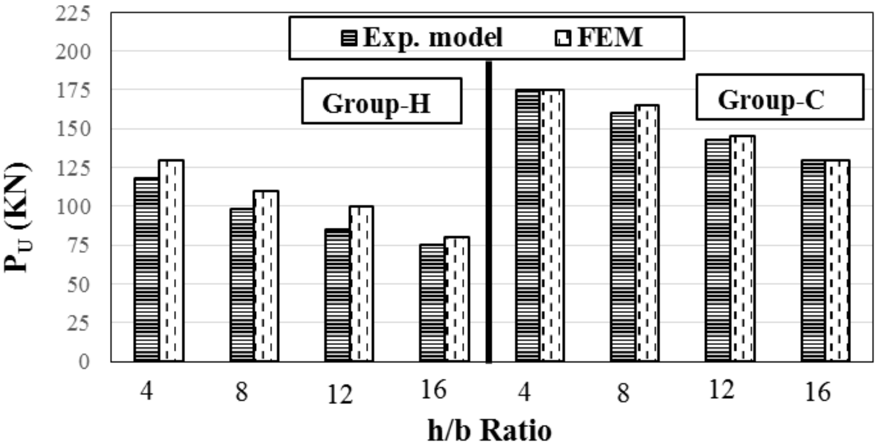

Fig 4. Comparison between experimental and FEM results of present research for h/b ratios

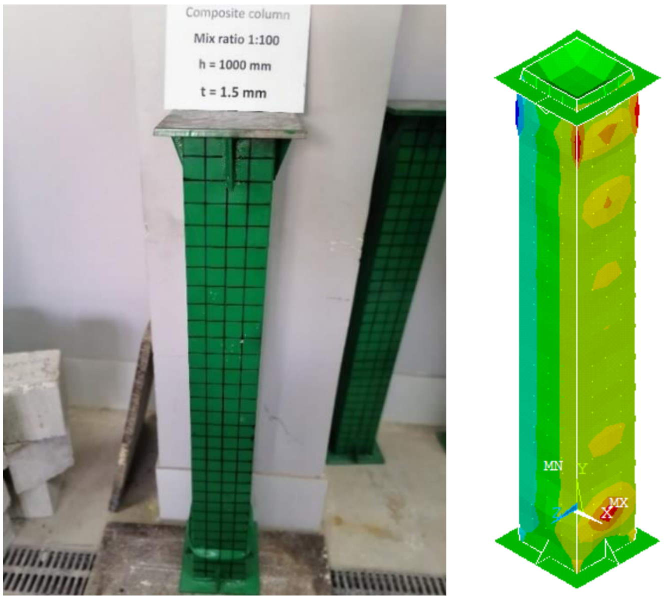

Fig 5. ***Comparison between experimental and FEM failure for specimen C 1000***

Effect of Height to Width (h/b) Ratios on Column Strength.

The effect of adding epoxy-sand filling on square hollow steel columns with different h/b ratios (5, 10, 15, and 20) is studied. The results of all specimens are tabulated in Table 4 for epoxy-sand ratios1:25, 1:50, 1:100, and 1:150. The table contains the ultimate load resulting from the finite element analysis PFEM.

Figure 7shows the relationship between P_C/P_H (composite column ultimate load / hollow steel column ultimate load) and different h/b ratios for epoxy-sand ratios1:25, 1:50, 1:100, and 1:150. The results show that specimens with epoxy-sand ratio 1:25 gained increasement in strength by 121%, 129%, 138%, and 151% for h/b ratios 5, 10, 15, and 20 respectively compared to hollow steel specimens. Specimens with epoxy-sand ratio 1:150 gained increasement in strength by 26%, 29%, 33%, and 45% for h/b ratios 5, 10, 15, and 20 respectively compared to hollow steel specimens. Also, the epoxy-sand ratios have a significant effect on column strength. It noted that specimens with higher h/b have gained strength more than specimens with low h/b. That's because the failure of specimens with high h/b is controlled by global buckling. Presence of sand-epoxy resin core results in the delay of global buckling occurrence.

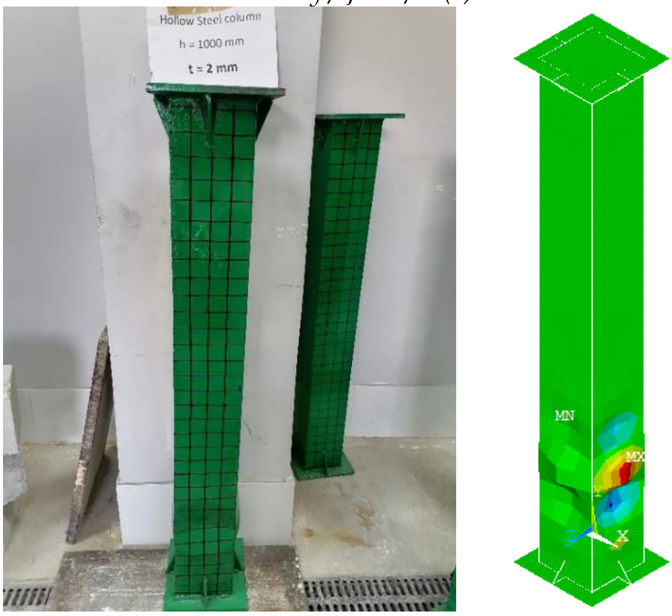

Fig 6. Comparison between experimental and FEM failure for specimen H 1000

Table 4. Results of FEM for h/b ratios

Specimen	$\frac{h}{b}$	P_{FEC} *(kN)*	P_{FEH} *(kN)*	$\frac{P_C}{P_H}$
[b200-t2-**h1000**-F_y240- **mix 1:25**]	5	520	235	**2.21**
[b200-t2-**h2000**-F_y240- **mix 1:25**]	10	481	210	**2.29**
[b200-t2-**h3000**-F_y240- **mix 1:25**]	15	429	180	**2.38**
[b200-t2-**h4000**-F_y240- **mix 1:25**]	20	364	145	**2.51**
[b200-t2-**h1000**-F_y240- **mix 1:50**]	5	370	235	**1.57**
[b200-t2-**h2000**-F_y240- **mix 1:50**]	10	340	210	**1.62**
[b200-t2-**h3000**-F_y240- **mix 1:50**]	15	305	180	**1.69**
[b200-t2-**h4000**-F_y240- **mix 1:50**]	20	260	145	**1.79**
[b200-t2-**h1000**-F_y240- **mix 1:100**]	5	335	235	**1.43**
[b200-t2-**h2000**-F_y240- **mix 1:100**]	10	307	210	**1.46**
[b200-t2-**h3000**-F_y240- **mix 1:100**]	15	277	180	**1.54**
[b200-t2-**h4000**-F_y240- **mix 1:100**]	20	238	145	**1.64**
[b200-t2-**h1000**-F_y240- **mix 1:150**]	5	295	235	**1.26**
[b200-t2-**h2000**-F_y240- **mix 1:150**]	10	270	210	**1.29**
[b200-t2-**h3000**-F_y240- **mix 1:150**]	15	240	180	**1.33**
[b200-t2-**h4000**-F_y240- **mix 1:150**]	20	210	145	**1.45**

[Width of column-thickness of steel-height of column-steel yield stress-epoxy-sand ratio]

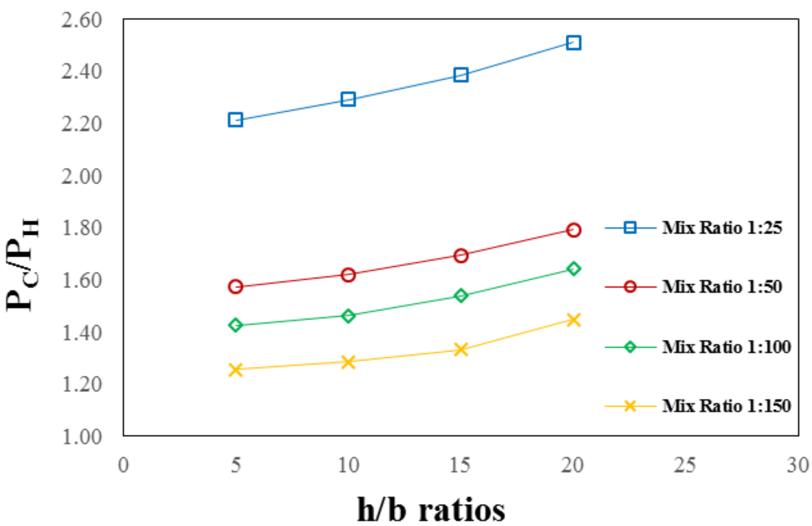

Fig 7. Relationship between h/b ratio and P_C/P_H with different epoxy-sand ratios

Lateral Deformation and Axial Shortening

Figure 8shows that there is one wave of local buckling initiated outwards at a quarter of the total column height with maximum lateral deformation of 1.4 mm. At these locations, the steel and epoxy-sand core are separated, while at the rest of the specimen the steel is still in contact with the epoxy-sand core. The steel plates are locally buckled outward on the four sides of the square steel tube, and no sign of inward buckling occurs. This is different from the buckling of the hollow steel tube where the local buckling waves have lengths equal to the full plate width. The tube sides have outward deformation on one side and inward deformation in the adjacent one. This is the reason why the local buckling of the thin-walled steel tube of composite columns initiates at a higher load than the same section of the hollow tube.

Figure 9shows that the maximum vertical deflection for the composite column is 2.3 mm. All nodes of the top endplate have the same vertical deformation. Although the endplate thickness of 10 mm is not rigid enough, yet it does not bend in the middle due to the applied load as a result of the restraint provided by the epoxy-sand core. For the rest of the column, the vertical deformation is distributed gradually along with the column height, and the shortening of the steel tube and the epoxy-sand core are distributed similarly. No significant differential axial shortening occurred between the epoxy-sand core and the steel tube, and the shortening distribution of the two elements is within the same rate.

From the results of lateral deformation and shortening of specimens of FEM, it can be concluded that outward local buckling is found in the four sides of composite columns, while inward as well as outward local buckling is found in the hollow sections. The vertical deformation is distributed gradually along with the column height in the presence of epoxy-sand mix. It is clear that, Adding epoxy-sand core increasing axial stiffness of specimens.

Fig 8. Lateral deformation of specimen [b200-t2-h1000-F_y240-ratio1:100]

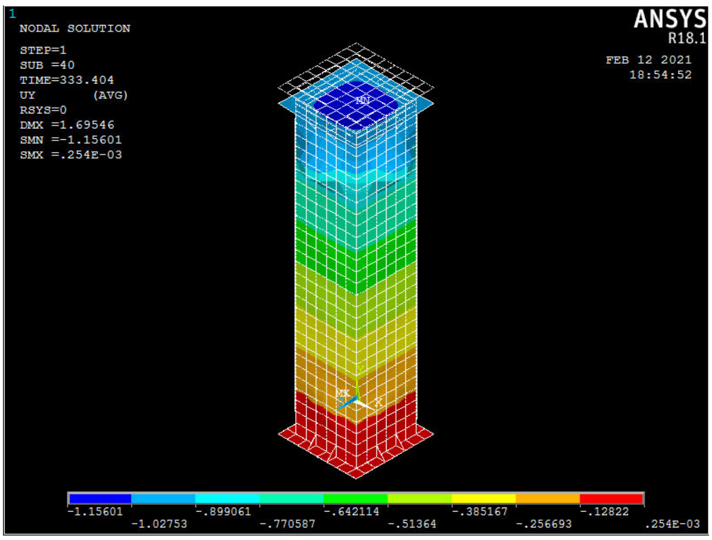

Fig 9. Shortening of specimen [b200-t2-h1000-F_y240-ratio1:100]

Conclusions

A nonlinear finite element analysis model has been developed for investigating the behavior and design of composite columns under concentric loads. The effect of steel tube width-to-thickness ratio, steel yield strength, the compressive strength of filler material (sand and epoxy resin mix), and the effect of steel tube height-to-width ratio on column strength were investigated using the FEM and presented in this paper. The developed FEM has been verified by the present experimental results. The following conclusions are deducted:

1. The results obtained from the developed model exhibits good correlation with the available experimental results.
2. Sand and epoxy resin mix filled hollow steel columns have given a range of advantages, including speed of construction, lightweight, high adhesion, low shrinkage, high tensile strength, high ductility.
3. Sand and epoxy resin mix increases column strength signification. Also, the epoxy-sand ratios have a significant effect on column strength.
4. The specimens with higher h/b have gained strength more than specimens with low h/b. That's because the failure of specimens with high h/b is controlled by global buckling. Presence of sand-epoxy resin core results in the delay of global buckling occurrence.
5. From the results of lateral deformation and shortening of specimens of FEM, it can be concluded that outward local buckling is found in the four sides of composite columns, while inward as well as outward local buckling is found in the hollow sections. The vertical deformation is distributed gradually along with the column height in the presence of epoxy-sand core. Adding epoxy-sand core increasing axial stiffness of specimens.

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