Experimental Investigation of the Effect of Filled Steel Tubular with Various Sand Grains Diameters on the Buckling Behavior

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Abstract: *An experimental study of the sand filled steel tubular (SFST) column structure was considered in this paper to enhance the composite structures of the seismic steel design to study the effect of using different sand grains of (0.15, 0.3, 0.6, 1.18 and 2.36 mm). Twelve specimens filled-steel tubular Type-316 with different outer diameters of (13, 17 and 19 mm) with constant thickness of (1.0 mm) and different lengths of (15, 20, 25 and 30 cm) are considered. Experiments were carried out for two different cases: Hollow and compacted sand in order to know the behavior and buckling load of above columns and tests were conducted under monotonic loading. Major conclusion from this study are: the maximum load carrying capacity found in tubes with sand grain give an increasing by (0.8, 7.8, 8.5, 8.7, 6.2 and 25.4 %) if test steel tubular filled by sand grain size of (0.15, 0.3, 0.6, 1.18 and 2.36* *mm) respectively as compared with the hollow empty specimen at the same displacement and at specimen diameter of (13 mm) and length of (15 cm). Also, observed that the using steel tubular with sand will delayed the buckling process as compared with the hollow empty steel tubular. Finally, the buckling behaviors of the present study were compared with the previous study and give a good agreement for the load-displacement curve for the all specimens studied.*

Keywords: Axial buckling, Steel tubular, Sand grain.

1. Introduction

Local buckling is more likely to occur for thin-walled tubes, and thus has adverse effects on strength and ductility for the composite columns. In order to improve their overall performance, one of the most effective stiffening measures is to provide longitudinal stiffeners for the steel tubes. One method of increasing the ductility and capacity of tubular elements is filling them with another material. One of the classical materials such as: 1) Compacted Sand, 2) Uncompact Sand, 3) Dry Cement, 4) Dry Sand or concrete. The pipe-piles include concrete reinforced encased in tubes of steel. These tubes are used as a casing of permanent which simple construction. One of confined steel methods is concrete, increasing compressive strength, and concrete core prevents steel tube from buckling inward. Steel tubes filled by concrete are employed with different structures including high rise, bridges, power plants and buildings. They are especially used in structures where large moments and displacements must be resisted, such as in high seismic regions [1]. There are large numbers of researches on the behavior of concrete-filled columns and columns beam such as researches done by [2], [3], [4] and [5] which show that there is a substantial increase in the axial strength, moment of inertia and the corresponding peak curvature of the hollow sections when they are filled with concrete.

[6] tested twelve large scale Reinforced Concrete Filled Steel Tubes (RCFSTs), seven of which are reported here focusing on the effect of varying D/t ratio. The pipe-piles were subjected to reversed cyclic four-point bending with a constant moment region centered in the pile. [7] studied five Concrete Filled Steel Tubes (CFSTs) subjected to a reversed cyclic and constant load axial load. All specimens had D/t ratios of 73 and 1078 inches in diameter. Their results showed that the energy dissipation increased with increasing steel shell as compared with conventional columns of reinforced concrete. Many of studies presented to examine the loading conditions, loading history, D/t impact. However, due to their size, in many cases as small as 1.7" in diameter, they are not discussed further here [8]. [9] studied the RCFSTs behavior. They used D/t ratio as a primary variable with range 34 to 214. The specimens had an outer diameter in range of 10.63" to 17.7" and 142" long. And using two cycles set reversed cyclic loading to the piles until the steel pipe is rupture or until reached the equipment limitations.

[10] investigated the Concrete Filled Steel Tubular (CFT) column. The new type of Concrete Filled Steel Tubular (CFT) column, named as Confined Concrete Filled Steel Tubular (CCFT), is employed to provide an ideal choice for tall buildings in seismic regions structural design and to overcome many conventional CFT column disadvantages. **[11]** employed three different section sizes of steel and composite members were subjected to monotonic and cyclic axial displacements in the inelastic range for filled and hollow specimens. The normalized slenderness for cyclic test specimens varied from 0.4 to 3.2, to cover the possible practical range, and both elastic and inelastic buckling was observed. The mode of failure affect by presence of the concrete infill.

[12] used steel tube filled by steel foams with high (strength/weight ratio) to modify the steel tubes response. Steel tubes with large second moment of inertia have an efficient shape in term of light weight. These members have a problem of having thin walls lead to low buckling resistance. They are using the linear eigenvalue and plastic collapse Finite Element Method (FEM) analysis on steel foam filled tube under pure compression. They show that the the ability of energy absorption and maximum strength of the steel tubes were improved significantly by using steel foam. **[13]** presented a monotonic behavior of circular steel stiffened composite column under compression. They considered fifty four specimens of variable thickness and variable diameter with piercing and also 54 specimens of thickness, and variable diameter without piercing. As show above there are many studies on the buckling behavior in the case of concrete filled steel but few works on the steel pipes filled by sand. Thus, this paper give a comparison between the cases of steel pipes with and without sand grains to study the effect of the presence the sand grains on the (1) Tube local buckling of the tube wall; (2) Failure described by plastic deformation or tube material fracture; (3) Hysteretic damping; and (4) Maximum load. These goals were accomplished through an extensive experimental works presented in the present work.

2. Experimental Procedure

To examine the circular steel tubular behavior, twelve specimens with 1.0 mm wall thickness with different outer diameter of (13, 17, 19 mm) and different length of (15, 20, 25, 30 cm) and five nominal grain sand size (very fine 0.15, fine 0.3, medium 0.6, coarse 1.18, very coarse 2.36 mm) as shown in Figure 1. The steel tube with 300 mm in length in order to ensure that the specimens behaved as stub columns with little column slenderness effect and to reduce the effects of the specimens ends. Testing of empty and composite columns was carried out using a 300 kN capacity Toni-PACT testing machine and the experimental set up is shown in Figures 2 and 3. The specimens both ends were capped with rigid steel plate and milled flat in order to ensure that the applied load distributed uniformly over both the steel section and filled for the columns of composite loaded. The experimental testes includes varied the load by 10 kN intervals on the specimens at the beginning of the test (i.e. in the elastic region) and using 1kN intervals loading rate after the yield exist in the column. In this experimental work was used the linear variable differential transducer (LVDT) to record the horizontal deformation. The processes of change loading rate were operated manually and the readings were recorded as the both strain and load. After the load immediately drops due to the local buckling, the test continued until excessive deformation of the column was observed. After the test, the specimens were removed, carefully examined and photographed.

Figure 1: Grain sand size employed in this work.

Figure 2: General scheme of the test rig.

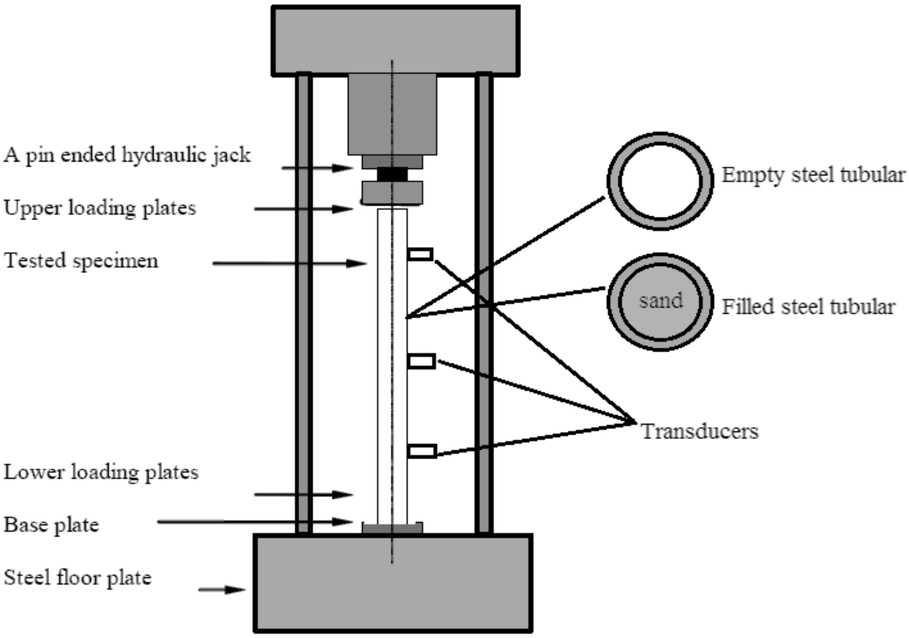


Figure 3: General view of the test rig and the data acquisition system.

3. Buckling Theory

Euler's formula for composite column Euro code 4 (1994) is considered to provide the most logical approach for the design of composite columns. Euler's critical buckling load for concentrically loaded composite columns is given by Euro code 4 **[14]**.

$$P_{cr} = \frac{\pi^2 (EI)_e}{(L_{eff})^2} \qquad (1)$$

Where,

$$(EI)_e = E_s I_s + 0.8 E_{sa} I_{sa} \qquad (2)$$

Following properties are used in this study for modeling steel column:

Steel: Young's Modulus, E_s=200 Gpa Poison's ratio, ν_s=0.3 Density, ρ_s=7800 kg/m^3 [14].

Sand: Young's Modulus, E_{sa}=0.03 Gpa Poison's ratio, ν_{sa}=0.1 Density, ρ_{sa}= 1.75 kg/m^3 [15].

Slender quantified by the radius of gyration is a geometric concept of a two-dimensional area. The r represented the radius of gyration; it explains the distributed of area of a cross-section around its centroidal axis. The area will have a greater value of r and a greater resistance to buckling, if it is concentrated far from the centroidal axis **[1]**.

Using R to demonstrate the circle radius to get:

$$r = R / 2 \qquad (3)$$

The second geometric concept is the long which represented by the non-dimensional "slenderness ratio" L / r. it can be define the slenderness ratio as the long as following **[1]**.

$$\frac{L}{r} > \left(\frac{\pi}{k}\right)\left(\frac{2E}{\sigma_y}\right)^{1/2} \qquad (4)$$

The constant k depends on the column two ends restraints; in this study it chosen by 4 for fixed ends. A long typically in range of (L/r) > 120. The above equation is the intermediate (empirical) columns and dividing point between long (Euler) columns. The stress of critical compressive that will cause buckling always decreases as the (L/r) increases. The force of critical buckling is [14].

$$F_{Euler} = \frac{k\pi^2 EI}{L^2} = \frac{k\pi^2 EA}{(L/r)^2} \tag{5}$$

So the stress of critical Euler buckling [14]:

$$\sigma_{Euler} = \frac{F_{Euler}}{A} = \frac{k\pi^2 EA}{(L/r)^2} \tag{6}$$

The calculation of moment of inertia of circular confinement:

$$I = \frac{\pi^2 (D_o - D_i)^4}{64} \tag{7}$$

Calculation of buckling load for hollow column:

$$F_{cr} = \frac{\pi^2 EI}{(L)^2} \tag{8}$$

The result of the above calculation for steel hollow column is presented in Table.1.

Table 1: Data of the steel hollow column

L mm	D_o mm	D_i mm	A mm^2	I mm^4	F_{cr} N	Slenderness Ratio	$(\pi/k)(2E/\sigma y)^{0.5}$
0.15	0.013	0.012	0.00002	9.47547E-10	8.719604	23.07692308	326.8215619
0.15	0.017	0.016	0.0000264	3.0158E-09	27.75225	17.64705882	373.7347544
0.15	0.019	0.018	0.0000296	4.84155E-09	44.55333	15.78947368	395.1080021
0.2	0.013	0.012	0.00002	9.47547E-10	4.904777	30.76923077	283.0357751
0.2	0.017	0.016	0.0000264	3.0158E-09	15.61064	23.52941176	323.6637916
0.2	0.019	0.018	0.0000296	4.84155E-09	25.06125	21.05263158	342.1735671
0.25	0.013	0.012	0.00002	9.47547E-10	3.139058	38.46153846	253.1548933
0.25	0.017	0.016	0.0000264	3.0158E-09	9.990809	29.41176471	289.493696
0.25	0.019	0.018	0.0000296	4.84155E-09	16.0392	26.31578947	306.0493424
0.3	0.013	0.012	0.00002	9.47547E-10	2.179901	46.15384615	231.0977427
0.3	0.017	0.016	0.0000264	3.0158E-09	6.938062	35.29411765	264.2703792
0.3	0.019	0.018	0.0000296	4.84155E-09	11.13833	31.57894737	279.3835476

4. Results and Discussion

The compressive response of circular hollow section (CHS) columns has been examined in this study. A total of forty flexural buckling experiments were performed about twelve about the major axis. The compression tests were performed on short steel tubular of length of (15, 20, 25, 30 cm) and outer diameter of (13, 17, 19 mm) with thickness of (1.0 mm) specimens for two cases of empty and filled with grain sand of five ranges of sand grains (very fine 0.15, fine 0.3, medium 0.6, coarse 1.18, very coarse 2.36 mm). The experimental buckling results according to the visual observations and due to the experimental failure loads presented in the **Figure 4**

Figure 4: Range of tested column lengths

Figure 5 and 6 illustrated the data collection from the compression tests for the all specimens employed in this study in the case of the empty tubular. As show from the results that all specimens give the same profile in the relation of the increasing the load with the displacement and show that the increasing the load from 0 to 3 kN the specimen appeared an elastic behavior. There is no any change in the shape of the specimen and if we remove the load the specimen will return to the original shape. This is a straight relation between the load and the displacement and between stress and strain of the specimens. However, we can see that the maximum load and maximum displacement would differ from a specimen to another, it dependent on the length and diameter. For example the tubular with outer diameter D_o=17 mm give a maximum load by 38.8 kN as compared with tubular with diameter D_o=13 mm give a maximum load by 32.3 kN tubular with diameter

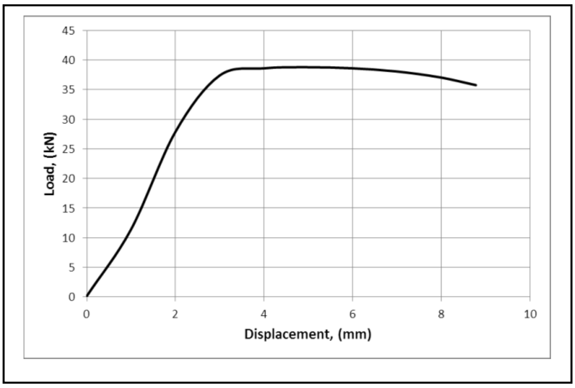
D_o=17 mm at the same length of the tubular of (15 mm). Figure 7 and 8 summarized the effect of the tubular diameters and lengths on the load-displacement curves of the compression tests, the results show that the maximum load will increasing with increased the diameter of the specimen, but the maximum load will decreasing with increased the length of the specimen. And these results will give validity to the present work as compared with Table.1. The results showed that the very similar responses for other specimens.

To study the effect of the steel tubular filled with grain sand, the load-displacement curves are plotted in the Figure 9. The results showed that the tube buckling capacity increasing with using the infill steel tubular, but more so the capacity of post-buckling of the tube. However, the both composite steel tubular maximum compressive resistance was increased by 15% by using the sand filling the steel tubes in the case of D_{sand}=0.15 mm and by 22% in the case of D_{sand}=1.18 mm thus the buckling maximum load increased with increasing the sand grain size from 0.16 to 2.36 mm proportionality. The steel tubes models that filled with lightweight sand grains appeared an ultimate axial capacity and significantly development the steel sections strength. The load carrying capacity of the column was increased in the view of the fact that the sand grains core, in addition to its own strength contribution, also helped prevent the local buckling effects of the steel tube. This increased strength contribution of tube portion over the hollow section. The effect of using sand grains filled in the steel tubular on the stress-strain curves are presented in the Figure 10, the figure shows that the maximum stress increased with using grain sand and with increased the grain size. For example the maximum stress increased by 13% if when using 0.15 mm sand size and by 20% when using 0.3 mm at strain of (5.974 m/m). And when increased the diameter to D_o=17 mm the load-displacement curves and are plotted in the Figure 11 and 12.

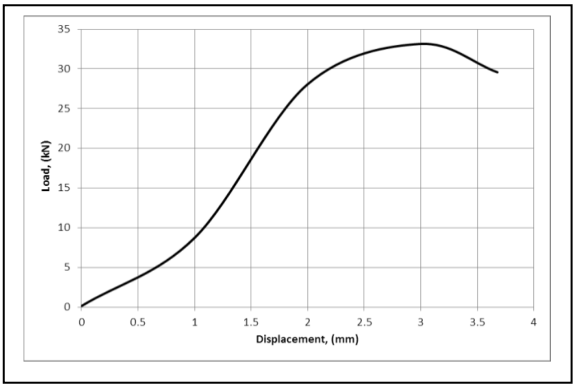
And when increased the diameter to D_o=19 mm the load-displacement curves and are plotted in the Figure 13 and 14. The load resistance of the column continues to increase due to the enhanced strength of the confined sand grains (and possible strain hardening of the steel tube) until failure processes occur. The effect of sand grain on the stress and strain of the steel tubular was plotted in Figure 15 and 16. The figures show that the stress increased with increased the tubular diameter and with increasing the grain size of the sand. Due to the lack of information regarding where there is no previous data recorded on the case of steel tubes filled with lightweight grain sand, we made a compression of the behavior of the buckling phenomena between Figure 16 and Figure 17 [16], show that a good agreements in the buckling curve profile.

a) L=15 cm, D=13 mm, P_{max}=32.3 kN

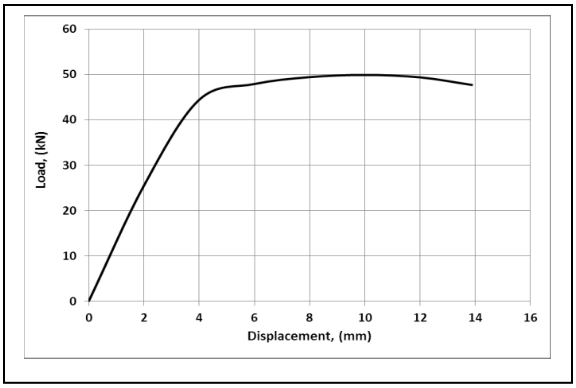
d) L=20 cm, D=13 mm, P_{max}=28.1 kN



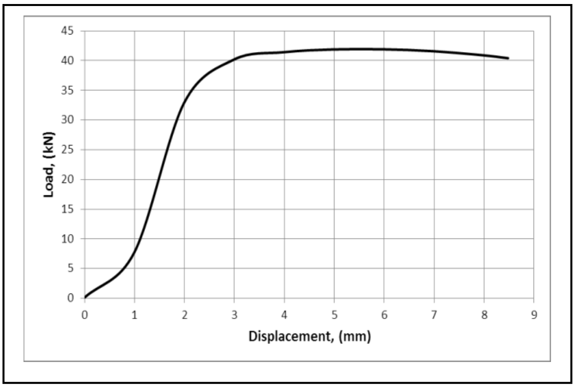
b) L=15 cm, D=17 mm, P_{max}=38.8 kN



e) L=20 cm, D=15 mm, P_{max}=33.2 kN



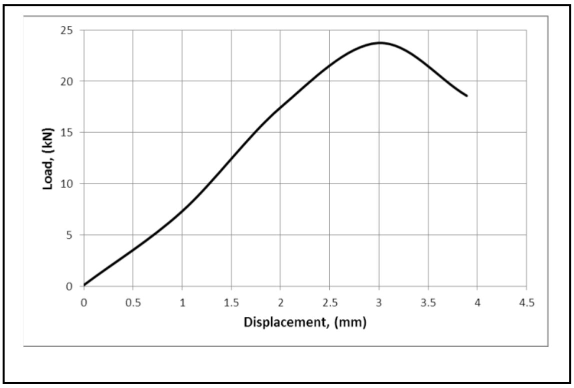
c) L=15 cm, D=19 mm, P_{max}=49.9 kN



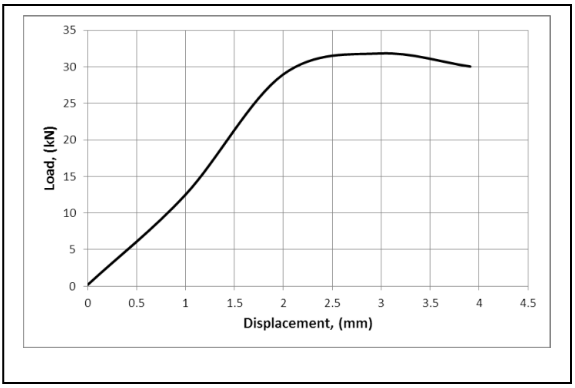
f) L=20 cm, D=17 mm, P_{max}=41.9 kN

Figure 5: Compression load-displacement curves and maximum load for empty steel tubular for lengths of L_{pipe}= 15 and 20 cm.

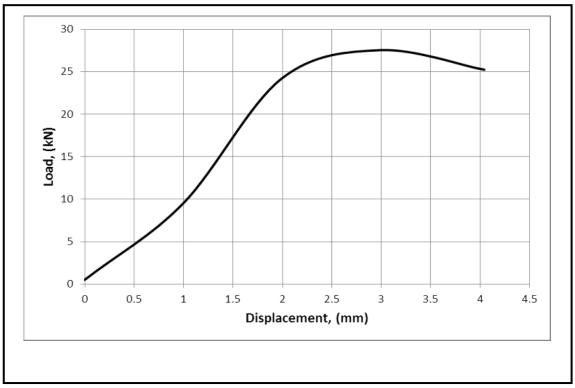
a) L=25 cm, D=13 mm, P_{max}=26.5 kN



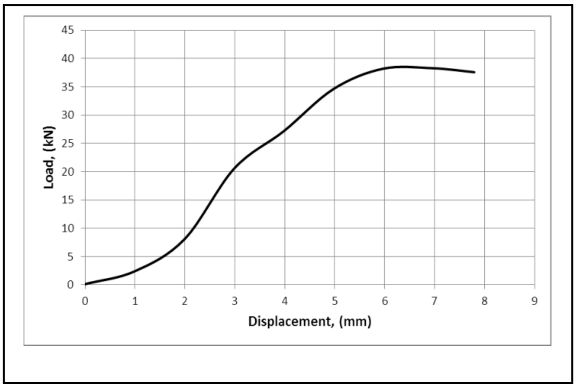
d) L=30 cm, D=13 mm, P_{max}=23.7 kN



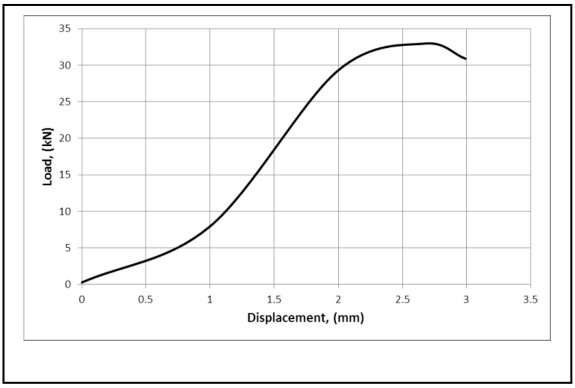
b) L=25 cm, D=17 mm, P_{max}=31.8 kN



e) L=30 cm, D=17 mm, P_{max}=27.5 kN



c) L=25 cm, D=19 mm, P_{max}=38.2 kN



f) L=30 cm, D=19 mm, P_{max}=32.9 kN

Figure 6: Compression load-displacement curves and maximum load for hollow empty steel tubular for lengths of L_{pipe} =25 and 30 cm.

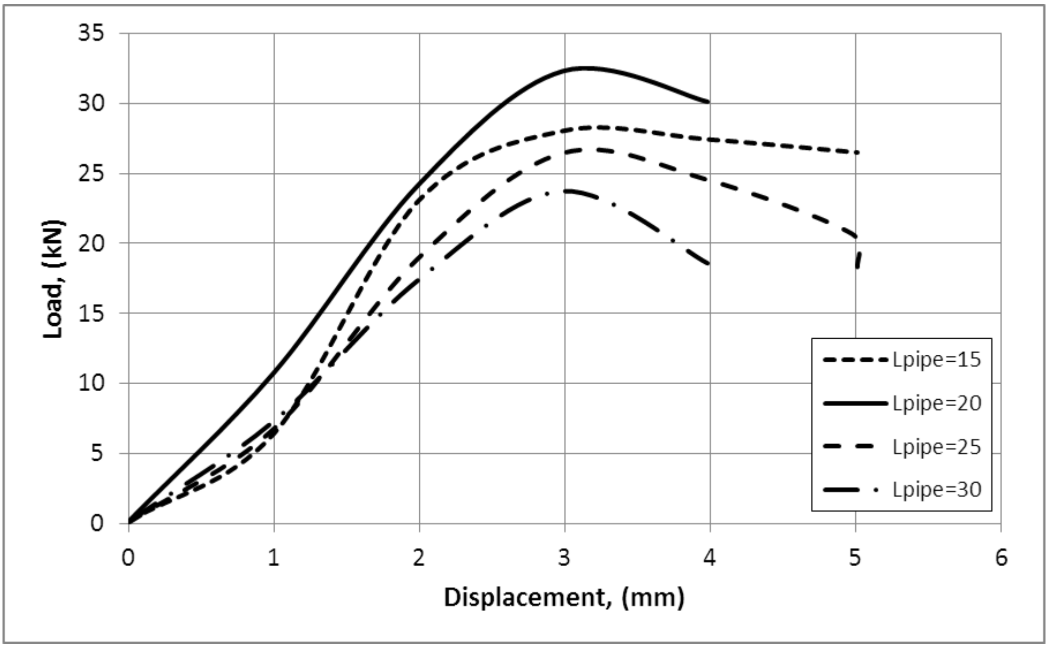


Figure 7: Compression load-displacement curves and maximum load for hollow empty steel tubular for diameter D_{pipe}=13 mm.

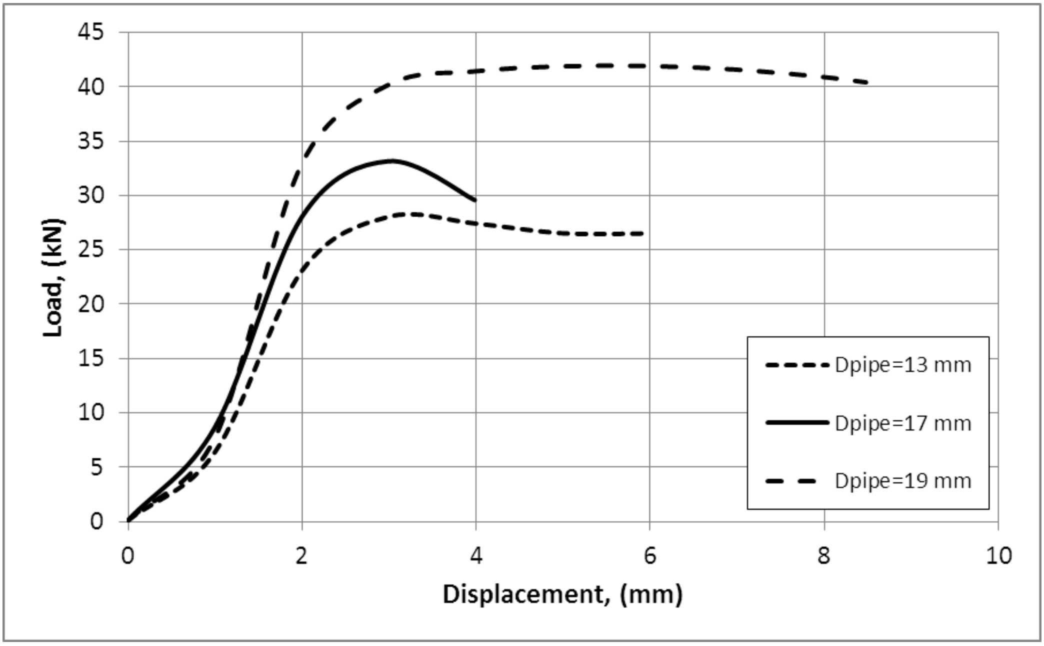


Figure 8: Compression load-displacement curves and maximum load for hollow empty steel tubular for diameter L_{pipe}=20 cm.

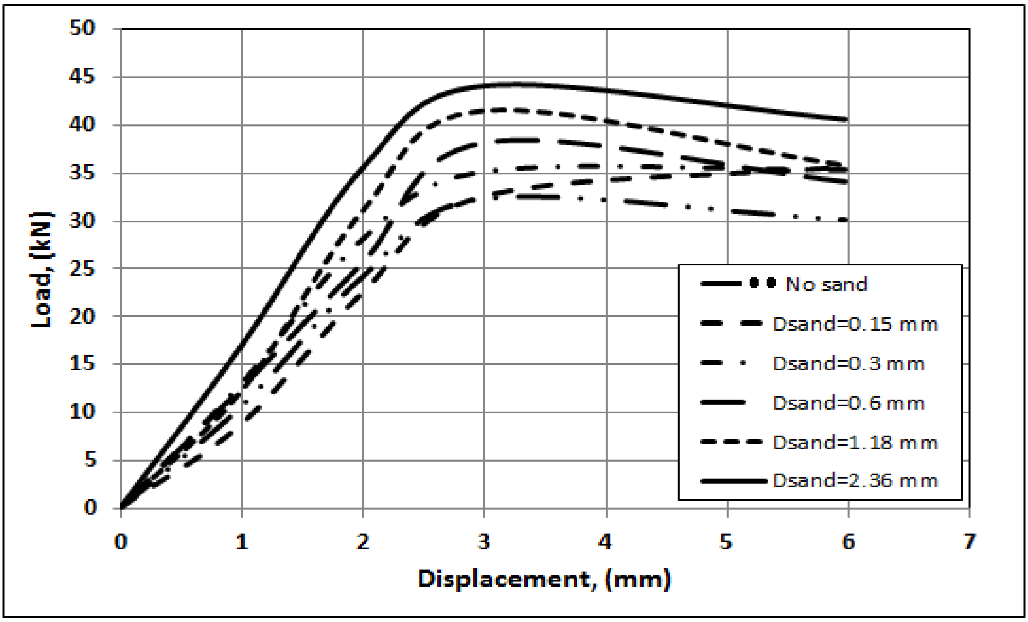


Figure 9: Effect of grains sand on the compression load-displacement curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=13 mm.

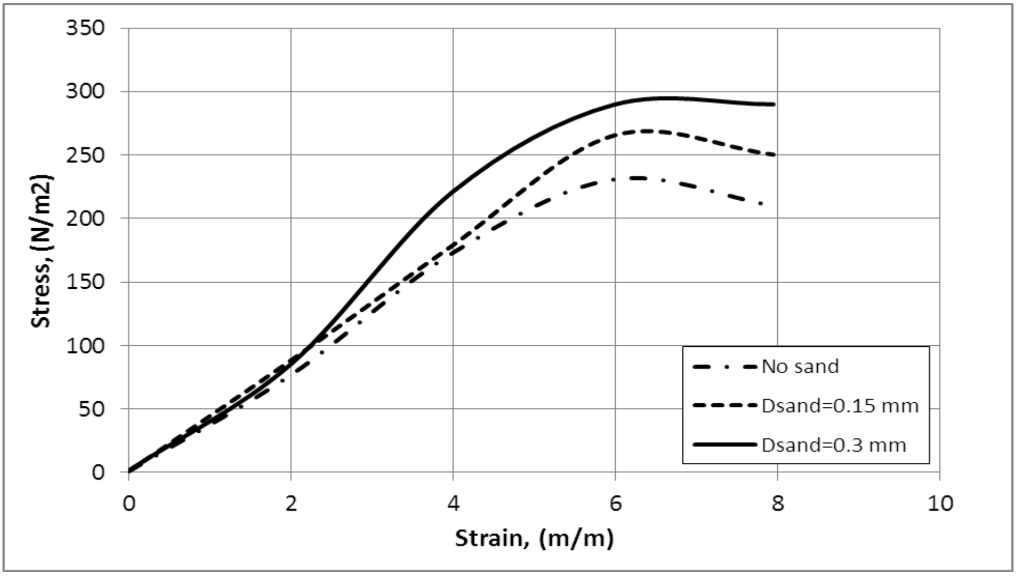


Figure 10: Effect of grains sand on the compression stress-strain curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=13mm.

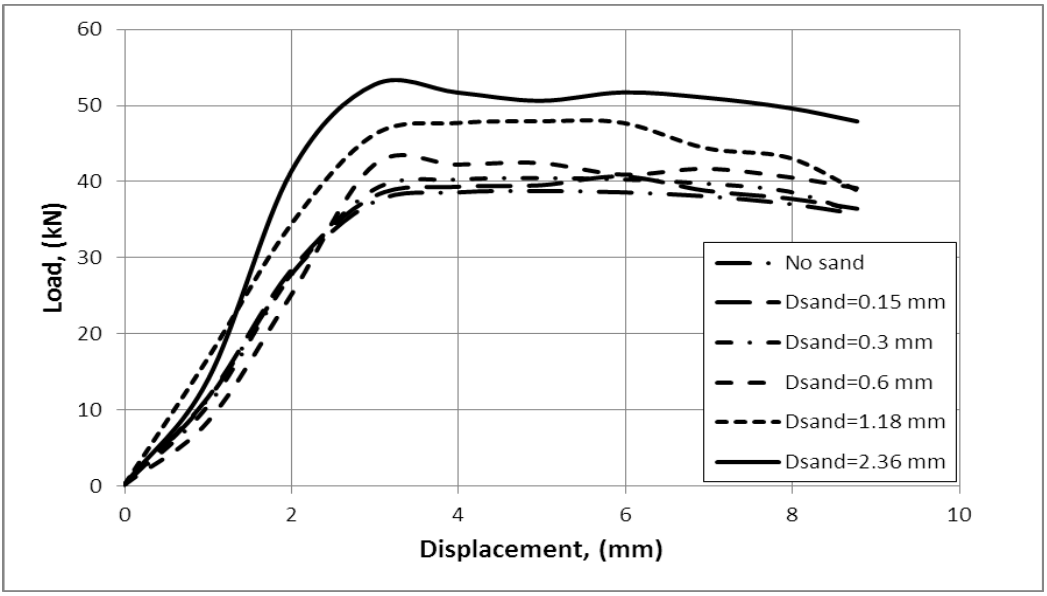


Figure 11: Effect of grains sand on the compression load-displacement curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=17 mm.

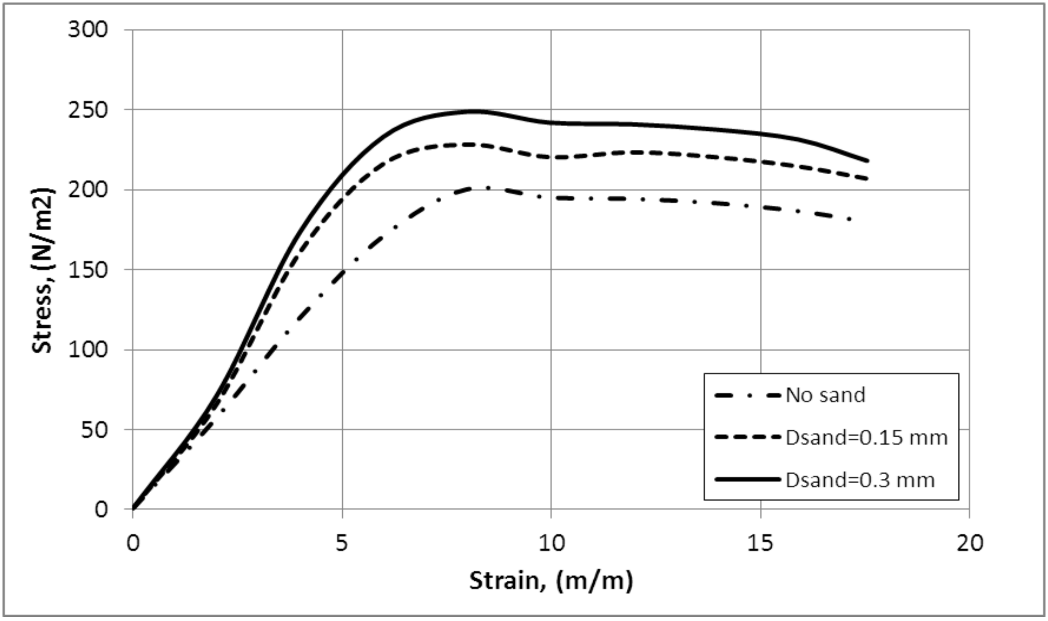


Figure 12: Effect of grains sand on the compression stress-strain curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=17 mm.

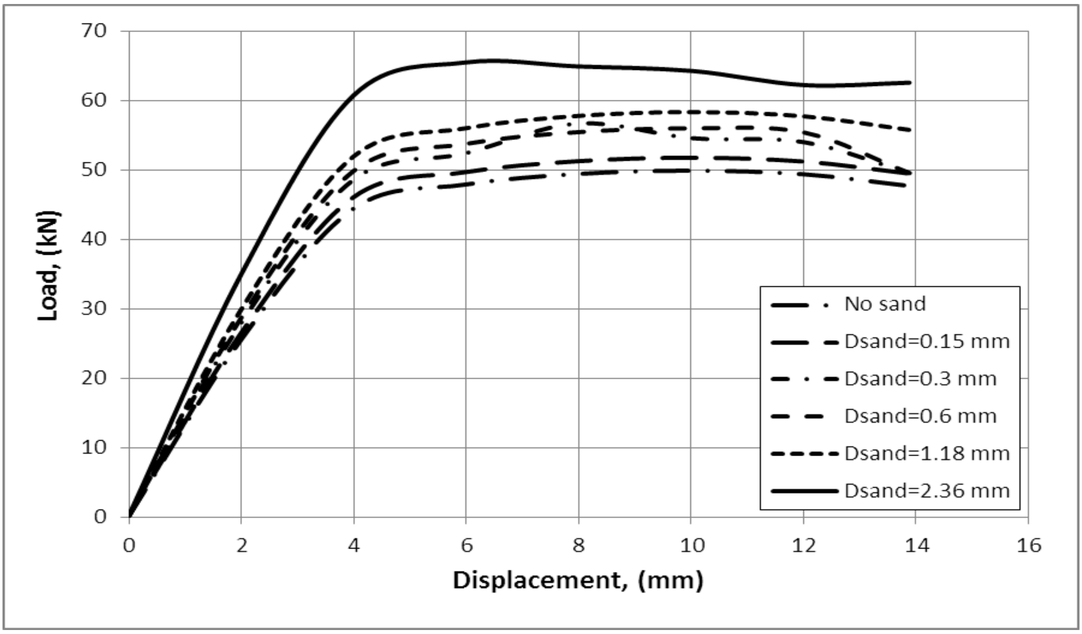


Figure 13: Effect of grains sand on the compression load-displacement curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=19 mm.

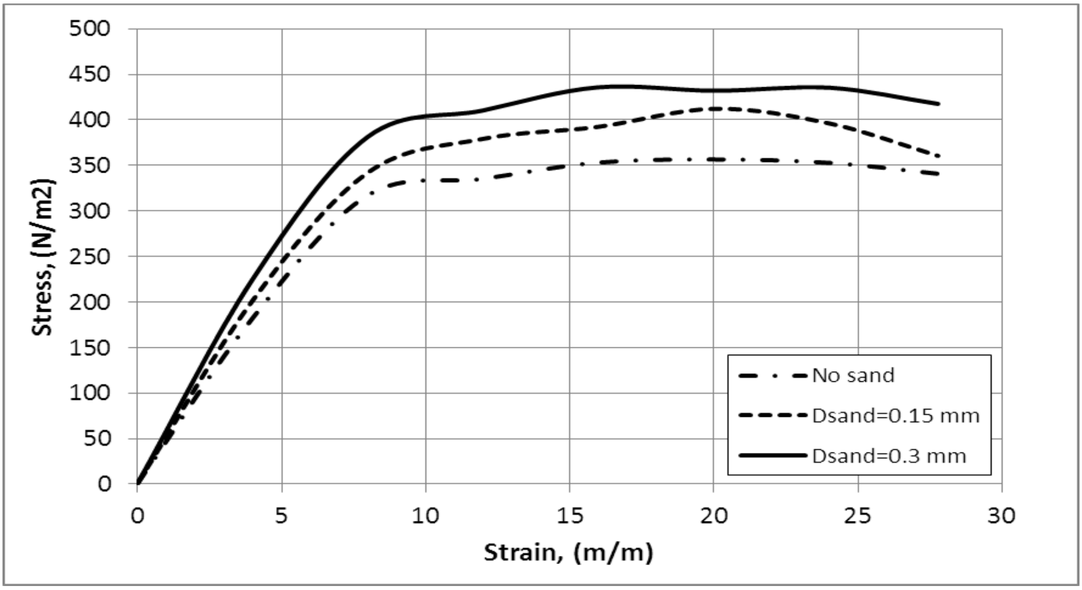


Figure 14: Effect of grains sand on the compression stress-strain curves and maximum load for steel tubular for diameter for L_{pipe}=15 cm, D_{pipe}=19mm.

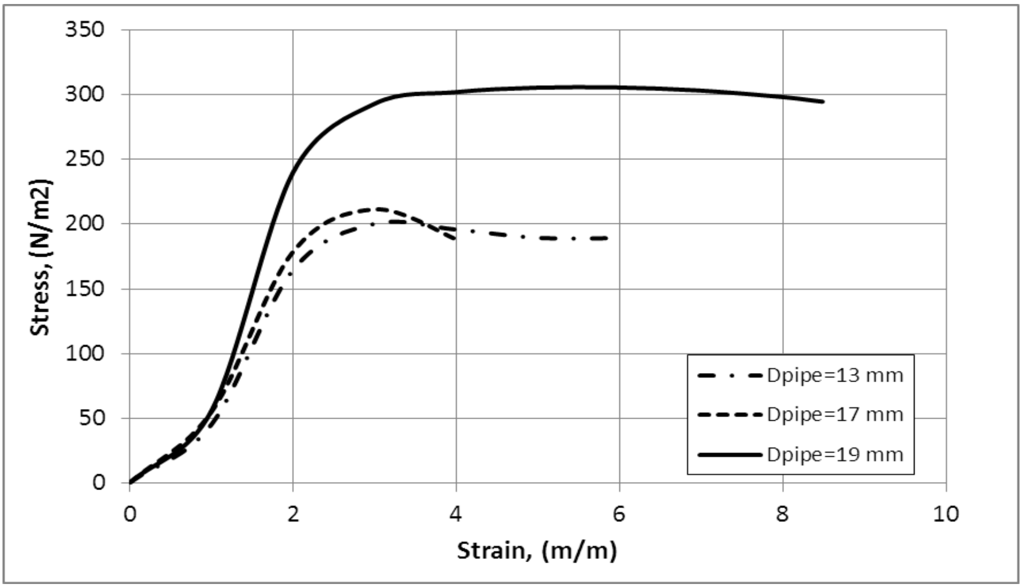


Figure 15: Effect of grains sand on the compression stress-strain curves and maximum load for empty steel tubular for diameter for L_{pipe}=20 cm.

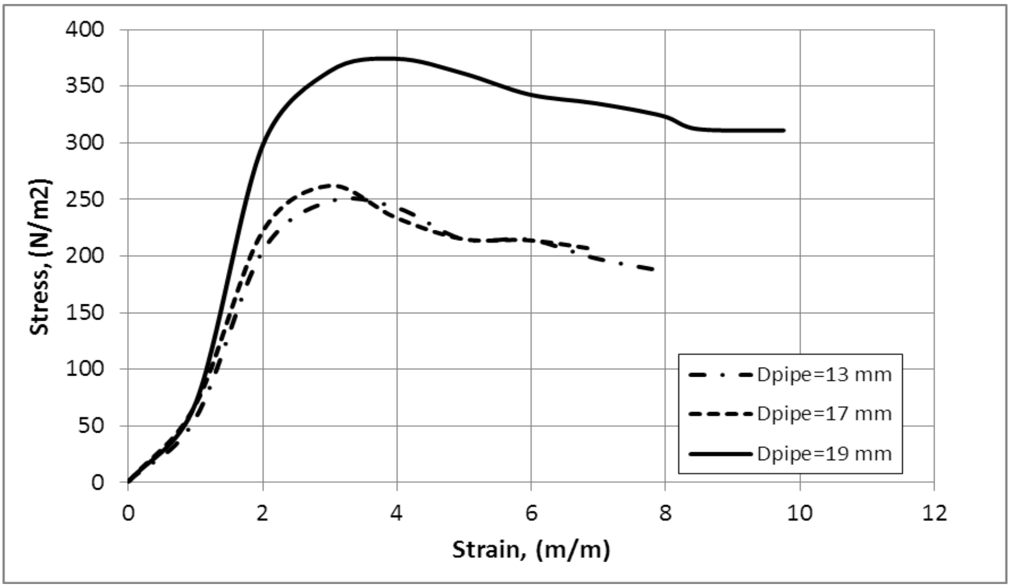


Figure 16: Effect of grains sand on the compression stress-strain curves and maximum load for empty steel tubular for diameter for L_{pipe}=20 cm, D_{sand}=0.3 mm

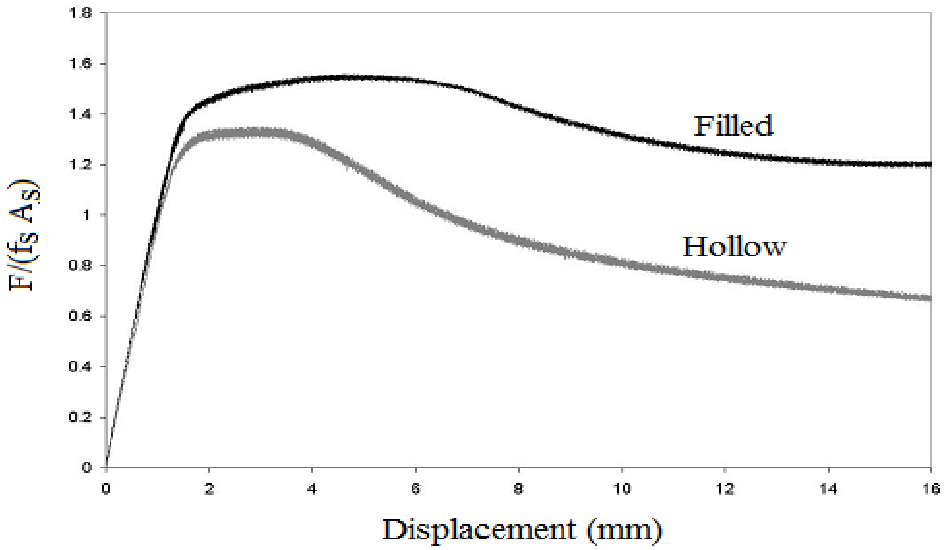


Figure 17: Monotonic compression load-displacement curves [16].

5. Conclusions

The twelve specimens models of steel tubes were filled with lightweight grain sand with deferent size were appeared an acceptable strength under a constant subjected load as compared to theory design calculations. The experimental and theoretical calculations can be showed that:

1. The load–strain carves behavior for lightweight grain sand steel tubular columns and normal steel tubular columns were appeared very coincident.
2. The presence of the grain sand in the steel tubular perform a highest values for the maximum buckling load and delayed the buckling occurring for all tested cases.
3. The employed column steel specimens that filled with sand grains was significantly developed the strength of steel sections and also enhanced the ultimate axial capacity and.
4. Finally, the sand grains helped to prevent the effects of the steel tube local buckling and lead to increase the contribution strength of the steel tube portion over the hollow section.

Nomenclatures

$(EI)_e$	effective elastic flexural stiffness, pa.m^4
D_i	internal diameter, m
D_o	outer diameter, m
D_{pipe}	steel tubular diameter, m
D_{sand}	gran sand diameter, m
E_s	elastic modulus of steel, pa
E_{sa}	elastic modulus of sand, pa
F_{cr}	Euler's critical buckling load
I	second moment of area of the column cross section, m^4
I_s	second moment of area of steel, m^4
I_{sa}	second moment of area of sand, m^4
L_{pipe}	steel tubular length, m
P_{max}	maximum buckling load, kN
σ_y	yield axial stress, N/m^2
k	constant
L	length of the columns

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استقصاء عملي لتأثير استخدام انابيب مملوءة بالرمل مع اقطار مختلفة على سلوك الانبعاج

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المستخلص

هذه الورقة البحثية تدخل الى استقصاء جدوى استخدام واختبار انابيب مملوءة بحبيبات الرمل مختلفة المقاسات من اجل تحسين الحمل التصميمي لانابيب الفولاذ المجوفة والانابيب المركبة حيث تم دراسة استخدام خمس مقاسات من حبيبات الرمل هي: (0.15، 0.3، 0.6، 1.18، 2.36) ملم. وايضا تم اختبار اثناعشر انبوب من الفولاذ نوع 316 مع اقطار مختلفة (13, 17, 19) ملم وبسمك محدد هو (1.0 mm) اما الاطوال فقد اخذت كما يلي (15, 20, 25, 30) سم. التجارب اجريت على حالتين هما : انبوب مجوف فارغ واخر مجوف مملوء بحيبات الرمل من اجل معرفة سلوك المنحني وحمل الانبعاج للاعمدة السابقة والاختبارات اجريت تحت تاثير حمل تراتبي. كانت اهم الاستنتاجات من الدراسة الحالية: هو ان اعظم سعة حمل للعينات وجدت مع استخدام حبيات رملية تزداد بمقدار(0.8، 7.8، 8.5، 8.7، 6.2، 25.4 %) عند استخدام حبيبات بحجم (0.15، 0.3، 0.6، 1.18، 2.36) ملم على التوالي عند نفس االازاحة وعند القطر 13 ملم وبطول 15 سم مقارنة مع الانبوب المجوف الفارغ. وايضا تم ملاحظة ان استخدام الحبيبات الرملية يؤدي الى تاخر عملية الانبعاج بكثير مقارنة مع العينات التي لم تملىء بالحبيبات الرملية عند نفس القياسات. واخيرا فقد تم مقارنة السلوك المتحصل من

الدراسة الحالية مع نتائج سابقة وتم الحصول على تطابق في السلوك لمنحني الحمل – الازاحة لجميع الحالات المدروسة.

الكلمات الرئيسية: الانبعاج المحوري، انابيب فولاذ، حبيبات رملية.