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Structural Analysis of Partial Composite Columns

التحليل الانشائي للأعمدة المركبة جزئيا

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خلاصة

لقد تم استخدام القطاعات المركبة (الخرسانة المسلحة مع قطاعات الحديد) بشكل واسع نتيجة للميزات العديدة لهذا النظام. وتكمن الفكرة الاساسية في هذه التقنية في زيادة وتحسين مقاومة القطاع الحديدى وذلك لتواجد بعض نقاط الضعف مثل الإنحناء الموضعى أو الكلى للقطاع وذلك باستخدام الخرسانة المسلحة والتى تساعد على منع أو تقليل هذه النقاط. كما أن بعض أنظمة الدفاع المدنى تشترط تغليف الحديد إلى ارتفاع معين فى المصانع بطبقة من الخرسانة المسلحة وذلك للحماية من تأثير إرتفاع درجات الحرارة أثناء اى حريق على الحديد حيث أنها تقلل من الإجهادات التى يستطيع أن يتحملها بشك ملحوظ. إلا أنه لا يتم عادة حساب هذا الجزء من الخرسانة أثناء التصميم طبقا للأكواد العالمية. ولذلك تمت دراسة تأثير اضافة الخرسانة فى الجزء الأسفل من الأعمدة ومدي تأثيرها علي تحسين السلوك الانشائي للقطاع، وذلك بهدف عمل التوصيات اللازمة وأخذها في الاعتبار أثناء التصميم الانشائي.

ABSTRACT

Composite section has been used for many advantages than using steel or reinforced concrete alone. The main advantages of composite sections are enhancing the capacity of section, prevent local buckling, reduce the general buckling, achieve greater stiffness, resist fire, ... etc. Composite sections have been widely used in high towers and skyscrapers. For the factories and industrial buildings, steel structures only may be used. Civil defense regulations require using high cost special paintings for fire resistance, or the other solution is to cover the lower part with a thick layer of reinforced concrete. We can treat this part of the column as a composite section. This will result in what we can name a partial composite column. Most of the current design codes don't mention the behavior of this system (partial composite column) due to the lack of both experimental data and practical experience. Therefore this paper studies the behavior and the critical buckling load of such systems using Sap 2000 v11.04 finite element modeling software.

Keywords: Steel, Composite Sections, Critical Buckling Load, Finite Element.

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INTRODUCTION

The designers know that using of the composite steel-concrete structures is exploited of the advantages of the two materials [1]. The design of composite structures requires good understanding of the behavior of composite structures and the mechanism of their collapse [2]. The major design concern for steel, composite section and any thin-walled columns is local and global (Euler) buckling [3]. Upon Euler's new concept studies were conducted to determine buckling load and then the buckling length factor (K-factor) for both individual columns and frames. Livesley and Chandler (1956) focused on the effect of axial load on the member's stiffness and suggested Stability Functions (s , c) which could be used in the slope deflection method instead of well known rotational and transitional stiffness values[3]. Egyptian Code of Practice for Steel Construction (2001) [4], AISC (2005), both relied on the equation and charts of Euler.

Another study has been worked by Bahaa Machaly, [5] who studied the buckling load of the one column composed of two parts. Each part has different inertia and length. Eight charts and equations have been suggested to the relation between the different properties and the buckling factors of the two parts. The result of this research is "the deformed shape of both the upper and the lower portions at the critical load is a part of a sine wave".

In this paper, the behavior of the partial composite column using the finite element method has been examined.

Problem Statement

For decades the use of composite columns has been studied and international codes has applied empirical equations to determine the allowable loads on the columns by taking the sum of the capacity of both the reinforced concrete and the steel parts[6]. This could be applied if we have the same cross section for the whole column as it will have the same behavior all over its length. Most of the current design codes don't mention the behavior of partial composite column due to the lack of information on their behavior or experimental data or practical experience.

A 3D finite element analysis using sap 2000 v11.04 package has been developed to study the behavior of the partial composite columns in order to see the critical buckling load for the various composite column to shed light on these cases.

Objective

The main objective of this research is to study the behavior of partial composite columns under a constant vertical load equal 100 ton. The variables considered are:

1- Length of composite and steel section.
2- Area of composite section.

Finite Element Model

Finite element modeling provides the engineer with a powerful tool that consistently predicts the physical behavior of a particular structural member without having to conduct numerous Laboratory tests [7]. A linear analysis technique using SAP 2000 v.11.04 is developed in order to study the partial composite column. The concrete and steel portions are modeled using solid element "8 nodded-thick elements" as shown in figure (1). The upper end of the column is loaded by a vertical load of 100 ton. In most situations, only one buckling mode is considered at any given time. This is called isolated-mode analysis, and is the easiest to perform. However, the experimental results of Barbero and Tomblin (1994) have shown that two or more buckling modes can act coincidentally at certain lengths for thin columns [3]. Therefore, finite element procedures that can predict the buckling behavior of intermediate length columns are needed.

Input Data

Figure (2) illustrates the geometry of the studied column which consists of two parts, the lower part is the composite section and the upper part is the steel section only. This column is fixed at the base and free at the upper end and loaded by 100 ton vertical load at the upper end. The properties to be studied in the different cases are illustrated in the following table.

Table (1): Properties for the different cases:

case	A_{Rc}=0.1512				
L conc	4	4	4	4	4
L_{st}	0	1	2	3	4
T conc	0.36	0.36	0.36	0.36	0.36
B conc	0.42	0.42	0.42	0.42	0.42
t_f steel	0.02	0.02	0.02	0.02	0.02
t_w steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	7.303	4.96	3.31	2.21	1.54
A_{TOTAL}	0.1512	0.1512	0.1512	0.1512	0.1512
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.1362	0.1362	0.1362	0.1362	0.1362
A_{cm}	0.2862	0.2862	0.2862	0.2862	0.2862

case	A_{Rc}=0.2288				
L conc	4	5	6	7	8
L_{st}	0	0	0	0	0
T conc	0.52	0.52	0.52	0.52	0.52
B conc	0.44	0.44	0.44	0.44	0.44
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	11.4	6.2094	3.85	2.5789	1.81
A_{TOTAL}	0.2288	0.2288	0.2288	0.2288	0.2288
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.2138	0.2138	0.2138	0.2138	0.2138
A_{cm}	0.3638	0.3638	0.3638	0.3638	0.3638

case	A_{Rc}=0.192				
L conc	4	4	4	4	4
L_{st}	0	1	2	3	4
T conc	0.48	0.48	0.48	0.48	0.48
B conc	0.4	0.4	0.4	0.4	0.4
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	9.154	6.25	4.044	2.593	1.74
A_{TOTAL}	0.192	0.192	0.192	0.192	0.192
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.177	0.177	0.177	0.177	0.177
A_{cm}	0.327	0.327	0.327	0.327	0.327

case	A_{Rc}=0.1512				
L conc	4	5	6	7	8
L_{st}	0	0	0	0	0
T conc	0.42	0.42	0.42	0.42	0.42
B conc	0.36	0.36	0.36	0.36	0.36
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	4.25	4.1282	2.6229	1.789	1.282
A_{TOTAL}	0.1512	0.1512	0.1512	0.1512	0.1512
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.1362	0.1362	0.1362	0.1362	0.1362
A_{cm}	0.2862	0.2862	0.2862	0.2862	0.2862

case	A_{Rc}=0.2288				
L conc	4	4	4	4	4
L_{st}	0	1	2	3	4
T conc	0.52	0.52	0.52	0.52	0.52
B conc	0.44	0.44	0.44	0.44	0.44
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	11.4	7.81	4.84	2.959	1.926
A_{TOTAL}	0.2288	0.2288	0.2288	0.2288	0.2288
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.2138	0.2138	0.2138	0.2138	0.2138
A_{cm}	0.3638	0.3638	0.3638	0.3638	0.3638

case	A_{Rc}=0.2288				
L conc	4	5	6	7	8
L_{st}	0	0	0	0	0
T conc	0.36	0.44	0.44	0.44	0.44
B conc	0.42	0.52	0.52	0.52	0.52
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	5.37	5.253	3.258	2.182	1.534
A_{TOTAL}	0.1512	0.2288	0.2288	0.2288	0.2288
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{Rc}	0.1512	0.2288	0.2288	0.2288	0.2288
A_{cm}	0.3012	0.3788	0.3788	0.3788	0.3788

case	A_{st}=0.015 (steel only)				
L conc	0	0	0	0	0
L_{st}	4	5	6	7	8
T conc	0	0	0	0	0
B conc	0	0	0	0	0
tf steel	0.02	0.02	0.02	0.02	0.02
tw steel	0.01	0.01	0.01	0.01	0.01
b steel	0.3	0.3	0.3	0.3	0.3
h steel	0.34	0.34	0.34	0.34	0.34
factor	2.82	1.81	1.255	0.922	0.705
A_{st}	0.015	0.015	0.015	0.015	0.015
A_{cm}	0.15	0.15	0.15	0.15	0.15

Where :

L_{Rc} the length of composite part

L_{st} the length of free steel part

Tconc, Bconc the dimensions of composite section

t_f, t_w, b, h the properties of steel section

A_{total} the virtual area of composite section i.e. $(n*A_{st} + A_{Rc})$

A_{st} the area of steel

A_{Rc} the area of concrete part only

Acm the area of composite section

The young's modulus has been taken 2.5E6 t/m^2, 2.0E7 t/m^2 for Concrete and steel respectively.

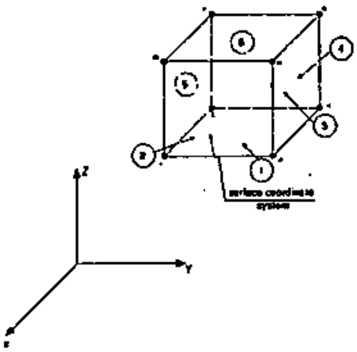

Figure (1): Solid structural element

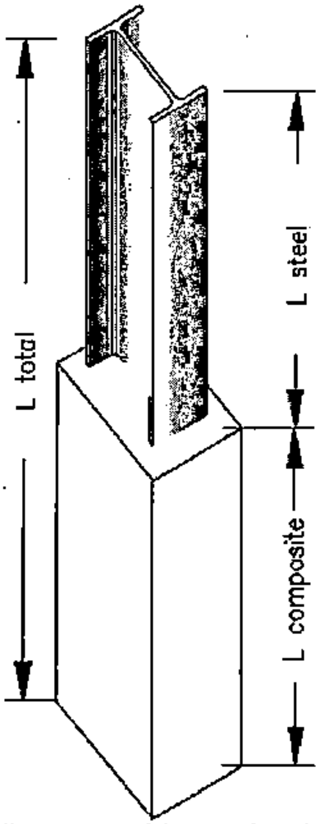

Figure (2): partial composite column

Analysis and Discussion

The critical buckling loads of the given models have been studied for the fixed-free partial composite column. The followings charts illustrates the relation between the critical buckling load of the different models with respect to the main properties of the model such as the area of the concrete section, the area of the steel section, the slenderness of the steel part only, the slenderness of the composite part only and the average slenderness ratio of the both steel and composite section. The various parameters have been studied in order to understand the behavior of such elements and the equations of the various cases have been demonstrated in order to reach a general approximate equation that could join the critical buckling load with some properties of the partial composite column. The average slenderness ratio has been assumed to be the division of the total length of the column by the average radius of gyration of the steel and composite sections.

(i.e. $i_{ax} = [i_{xst} + i_{xcm}]/2$). Where,

i_{xs} is the slenderness ratio of the steel part .

i_{xcm} is the slenderness ratio of the composite part.

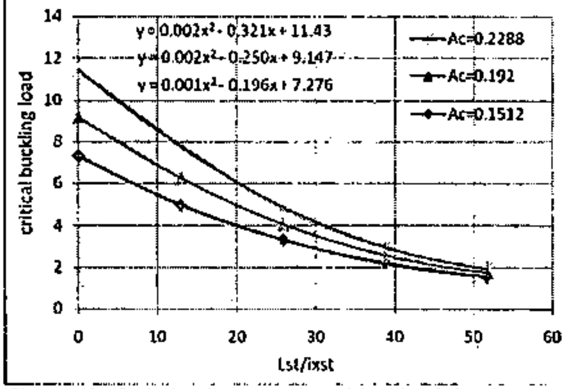

Figure (3): Relation between the critical buckling load and the slenderness of the steel section only

The effect of variation of slenderness ratio of the upper steel part of the partial composite column is illustrated in figure (3) for different areas of concrete. It can be noted that increasing the slenderness of the upper steel section leads to a reduction in the critical buckling load. On the other hand, it can be seen that increasing the area of concrete leads to improving the behavior of the columns by increasing the critical load. It could be noticed from the upper curves that the optimum slenderness ratios of the steel columns is on the range of twenty.

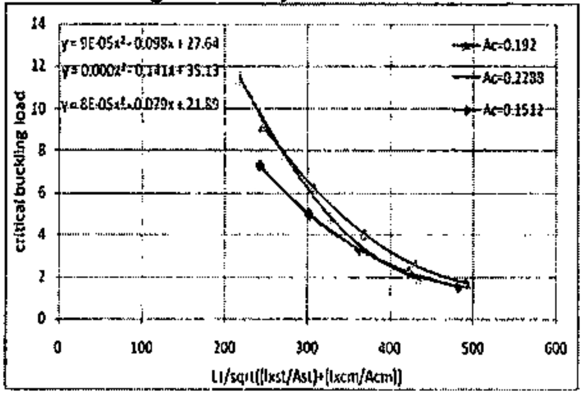

Figure (4): Relation between critical buckling load and the resultant slenderness of the steel & composite sections

Figure (4) demonstrates the effect of variation of resultant slenderness ratio of the steel part and the composite part for different areas of concrete. The resultant slenderness ratio has been suggested as the division of the total length by the square root of the summation of the squares of the radius of gyration of the steel part and the composite part. It can be noted that increasing the resultant slenderness of the partial composite column leads to a reduction decreasing in critical buckling load. On the other hand, it can be seen that increasing the area of concrete leads to improving the behavior of the columns by increasing the critical load. It could be seen that the equations in this trial has converged faster than the equations in figure (3).

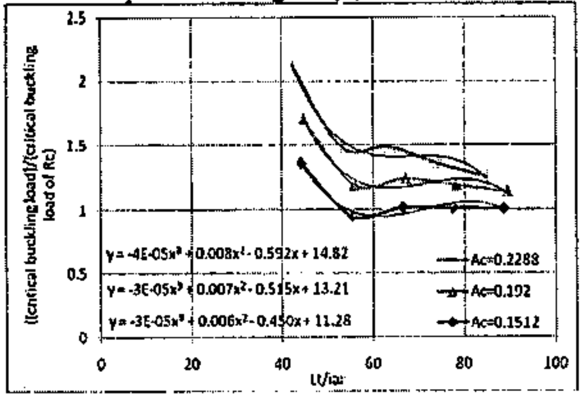

Figure (5): Relation between critical buckling load of a concrete column with the same length has been taken as a reference and the average slenderness of the steel & composite sections

Figure (5) shows the relation between the critical buckling load divided by the critical buckling load of a reinforced concrete column with the same length as a reference and the average slenderness ratio of the whole column for different areas of concrete. The resultant slenderness ratio has been suggested as the division of the total length by the average radius of gyration of the steel part and the composite part. It can be noted that increasing the resultant slenderness of the partial composite column leads to a random relation with the factored critical buckling load. Nevertheless increasing the resultant slenderness ratio tends to reduce the buckling in all cases. On the other hand, it can be seen that increasing the area of concrete leads to enhancement of the factored critical buckling load of the columns.

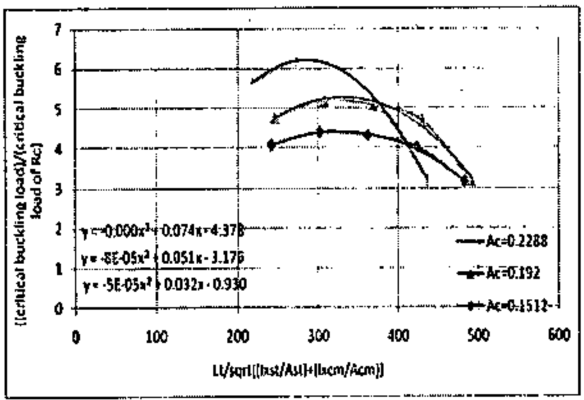

Figure (6): Relation between critical buckling load of a partial composite column with the reference concrete column with same length and the average slenderness of the steel & composite sections

Figure (6) shows the relation between the critical buckling load divided by the critical buckling load of a reinforced concrete column with the same length as a reference and the resultant slenderness ratio of the steel part and the composite part for different areas of concrete. It can be noted that increasing the resultant slenderness of the partial composite column leads to a random relation with the factored critical buckling load as it tends to be increased till a certain limit then it starts to be decreased again. On the other hand, it can be seen that increasing the area of concrete leads to enhancement of the factored critical buckling load of the columns except for the higher slenderness ratios.

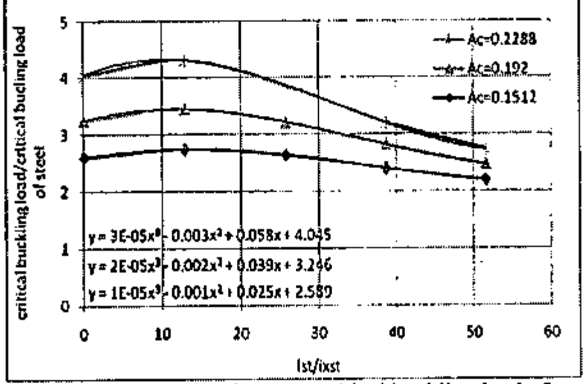

Figure (7): Relation between critical buckling load of a partial composite column with the reference steel column with same length and slenderness of the steel sections

Figure (7) shows the change of the critical buckling load divided by the critical buckling load of a steel column of the same length as a reference with the slenderness ratio of the steel part for different areas of concrete. It can be noticed that increasing the steel slenderness ratio leads to the increase of the factored critical buckling load until it gets the peak of the curve in the range of fifteen and then it tends to decrease. On the other hand, it can be seen that increasing the area of concrete leads to improving the behavior of the columns by increasing the critical load.

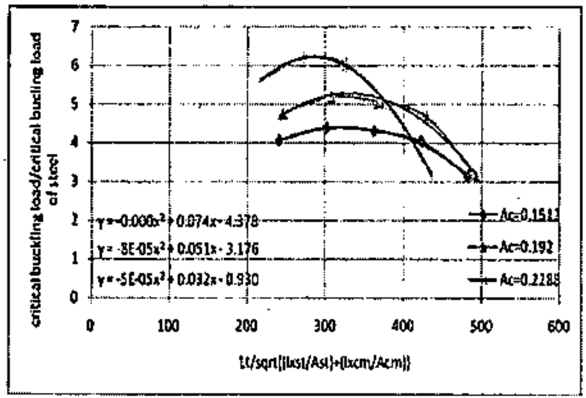

Figure (8): Relation between critical buckling load of a partial composite column with the reference steel column with same length and resultant slenderness of the steel & composite sections

Figure (8) shows the relation between the critical buckling load divided by the critical buckling load of a steel column with the same length as a reference and the resultant slenderness ratio of the steel part and the composite part for different areas of concrete. It can be seen that increasing the resultant slenderness of the partial composite column leads to a random relation with the factored critical buckling load as it tends to be increased till a certain limit then it starts to be decreased again. On the other hand, it can be seen that increasing the area of concrete leads to enhancement of the factored critical buckling load of the columns except for the higher slenderness ratios.

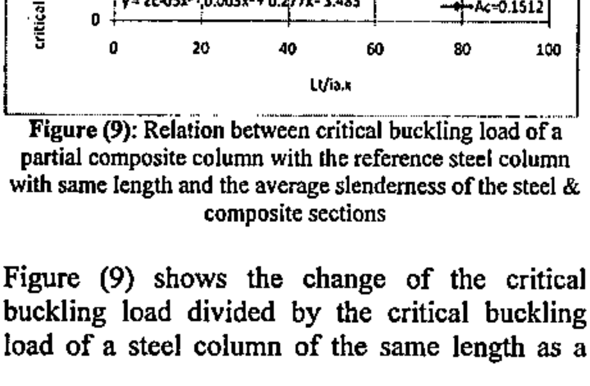

Figure (9): Relation between critical buckling load of a partial composite column with the reference steel column with same length and the average slenderness of the steel & composite sections

Figure (9) shows the change of the critical buckling load divided by the critical buckling load of a steel column of the same length as a reference with the average slenderness ratio of the steel part and the composite part for different areas of concrete. It can be noticed that increasing the steel slenderness ratio leads to the increase of the factored critical buckling load until it gets the peak of the curve in the range of fifty and then it tends to decrease. On the other hand, it can be seen that increasing the area of concrete leads to improving the behavior of the columns by increasing the critical load.

Figures (10, 11& 12) study the concept of the partial composite column. A change in the lower length of the column has been made to see the effect of the composite part on the critical buckling load of the whole column. The three figures are for different areas of the concrete section of (0.2288, 0.1920 & 0.1512) sq.m respectively. The critical buckling load of a steel or reinforced concrete section only with the same length has been illustrated in order to clarify the effect of the partial composite section. It could be seen from the figures that the best solution has not been to cover the whole column length with the reinforced concrete. It could be noticed that the best solution is to cover about 75 % of the total length. The enhancement in the critical buckling load of the column ranges from double to triple that one of the steel column alone. It could be seen also that when the area of the concrete column increases more than a certain limit, and consequently the percentage of the steel section is minimized, the critical buckling load of the composite section tends to be less than that of the concrete section as shown in figure (10).

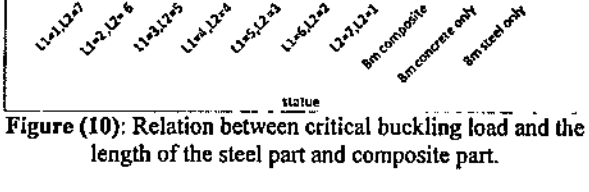

Figure (10): Relation between critical buckling load and the length of the steel part and composite part.

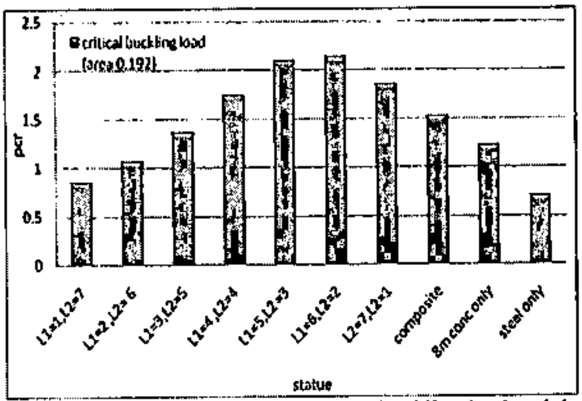

Figure (12): Relation between critical buckling load and the length of the steel part and composite part.

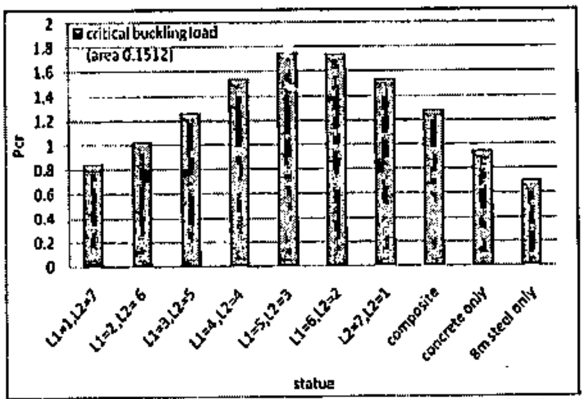

Figure (11): Relation between the critical buckling load and the length of the steel part and composite part.

Conclusion and recommendations:

- The recommended slenderness ratio of the steel part of the partial composite columns is about fifteen.
- The recommended average slenderness ratio of the whole partial composite column is about twenty.
- In case of partial composite section, it is better to increase the length of composite to 75% of total length to enhance the composite section behavior.
- It is recommended to study the effect of critical buckling load in other cases of end conditions such as the case of fixed - hinged.

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