Effect of Shot Peening on Dynamic Buckling Critical Load Parameter Produced for Carbon Steel Columns

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Abstract

This paper has investigated the comparison of column buckling behavior between experimental results of medium carbon steel CK35 and Hong model. These columns are tested under dynamic buckling with and without shot peening. This comparison showed a good correlation and conservative for the columns. The maximum difference in percentage was about 10%. The above comparison involved initial imperfection, load duration and slenderness ratio of columns. The results indicated that the Hong model was capable of predict the dynamic buckling behavior of Ck35 columns.

Keywords: Column dynamic buckling, dynamic shot peening buckling model, Critical load parameter, CK35 carbon steel alloys.

الخلاصة

في هذا البحث، تم مقارنة سلوك الانبعاج الديناميكي للأعمدة بين النتائج العملية للأعمدة المصنوعة من سبيكة (CK35) وموديل هونغ. والتي اختبرت تحت تأثير الحمل الديناميكي مع وبدون القذف بالكريات. هذه المقارنة بينت توافق جيد وتطابق للأعمدة. النسبة المئوية للفرق بين هذه المقارنة كانت لاتتجاوز ١٠%. تضمنت المقارنة التشوه الابتدائي، زمن التحميل ونسبة النحافة للاعمده. أشارت النتائج إلى إن موديل هونغ كان صالح على إعطاء السلوك الديناميكي للانبعاج للعمدة المصنوعة من سبيكة CK35.

الكلمات ألمرشدة: انبعاج العمود الديناميكي، انبعاج السفع بالكريات الديناميكي للنموذج ،معامل الحمل الحرج، سبيكة كاربون الفولاذ CK35.

الكلمات المفتاحية : عمود التواء دينامية، النار ديناميكية الرصاص Peening نموذج التواء، معلمة الحمل الحرج، CK35 سبائك الفولاذ الكربوني

Nomenclature	Definition	Units
c	stress wave velocity of column material	m/sec
P_E	Euler critical buckling load	N
L	Length of specimen	mm
N_f	Number of cycle to failure	cycle
r	radius of gyration of column	mm
SR	slenderness ratio of column	
SPT	Shot peening time	min
$t_\circ$	time of loading	sec
$\delta_{initial}$	the maximum initial lateral deflection of column	mm
α_{cr}	dimensionless theoretical dynamic buckling critical load parameter	
$\alpha_{Exp.}$	dimensionless experimental dynamic buckling critical load parameter	

Introduction

The analysis of the dynamic behavior of beam-column systems is of great importance in structural and engineering design. If a structural component is subjected to a dynamic loading, the dynamic buckling problem can be observed. The dynamic stability depends on the applied force and the geometry of the structure (Artem and Aydin, 2010).

Stability represents one of the main problems in solid mechanics, and must be controlled to ensure the safety of structures against collapse. It has a crucial importance, especially for structural, aerospace, mechanical, nuclear, offshore and ocean engineering (Bazant, 2000).In classical stability analysis, an elastic column is said to be stable if for any arbitrarily small displacement from its equilibrium position the column either returns to its original undisturbed position or acquires an adjoined stable position when left to itself (Aristizabal-Ochoa, 2004).

Buckling is one of the fundamental forms of instability of column structures. Buckling of a column is defined as the change of its equilibrium state from one configuration to another at a critical compressive load (Timoshenko, and Gere, 1961).

Columns and compression members may contain various imperfections. For example, columns may be subjected to unintended small lateral loads, they may be initially curved rather than perfectly straight, the axial load may be slightly eccentric, or disturbing moments and shear forces may be applied at column ends. Unlike beams subjected to transverse loads and small axial forces, columns are quite sensitive to imperfections (Arif and Kisa, 2005).

(Karagiozova *et al.*,1995) studied the dynamic buckling phenomenon of a "spring-rigid-bar" model subjected to a rectangular pulse load and two triangular shape loads. According to the responses of the model,dynamic buckling characteristics were discussed. The effects of load duration, initial imperfection, axial inertia and hardening ratio of material on the dynamic buckling behavior of the model were also investigated. (Boyle *et al.*,2003)designed and synthesized a complaint constant force robot arm that provides a constant output over a range of large deflections incorporating flexible beams.They derived and synthesized a dynamic model, considering the large deflections of the flexible beams using pseudo-rigid body model simplification of the mechanism.

In the present work, buckling behavior of CK35 steel alloy column is evaluated using two methods, experimental and (Hong Hao *et al.*, 2000) model. It was found that the Hong model is in well agreement with the peening and unpeened experimental results, while there is some difference between them, this was due to the assumptions of the (Hong Hao *et al.*, 2000) model and the approximation in the experimental work.

Hong model:

To provide a simple and effective method to estimate the critical load parameter and to examine the influence of imperfection and load duration on the dynamic buckling properties of column, a study can be done about the dimensionless dynamic buckling load parameter of column with regard to the initial deflection of column. (Hong Hao *et al.*, 2000) proposed a non-dimensionless model based on a number of dimensionless parameters which includes the most the dynamic buckling behavior.
The model may be written in the form

$$\alpha_{cr} = 1 + \frac{17\pi^6 l^2 \left(4\sqrt{6} - \bar{\delta}\right)}{\tau_0{}^* SR^2 \left(2\sqrt{3} + l\bar{\delta}\right)} \qquad (1)$$

Where α_{cr} is the dimensionless theoretical dynamic buckling critical load parameter, a non dimensionless value of α can be obtained experimentally and may be denoted as $\alpha_{Exp.}$ which is equal to:

$$\alpha_{Exp.} = \frac{P_{exp.}}{P_{cr.}} \tag{2}$$

In which

$P_{cr.}$: Euler critical buckling load if the column is long and Johnson critical buckling load if the column is intermediate (N).

$P_{exp.}$: Experimental critical buckling load (from test rig) (N).

Where the dimensionless parameters are

$$\left\{\begin{matrix} \bar{\delta} = \frac{\delta_{initial}}{r} & r^2 = \frac{I}{A} & SR = \frac{L}{r} \\ \tau_0 = \frac{t_0}{\eta} & \eta = \frac{r}{s^2 c} & c^2 = \frac{E}{\rho} \\ l = \frac{sL}{r} & s^2 = r^2 k^2 & k^2 = \frac{P_E}{EI} \end{matrix}\right\} \tag{3}$$

When no initial lateral deflection ($\bar{\delta}$ =0), eq. (1) becomes

$$\alpha_{cr} = 1 + \frac{34\sqrt{2}\pi^6 l^2}{\tau_0{}^* SR^2} \tag{4}$$

It should be noted that the effect of damping is not considered in this model. More details about derivations of equation (1) can be seen in (Hong Hao *et al.*, 2000).

Experimental work:

The material used was CK35 carbon steel alloy which is widely applied in industry materials.The chemical composition of the above material alloy is given elsewhere (Al-alkawi *et al.*, 2014).While all specimens manufacturing process was done in the General Company for Mechanical Industries in Al-Eskandria using CNC machine according to (AL-Jubori, 2005).

On the other hand, the details of buckling test rig and shot peening device were described in (Al-alkawi *et al.*, 2014).

Results and Discussions:

Application of Hong model to experimental dynamic buckling data without shot peening:

The Hong model explained before, equation (1) is now adopted to experimental dynamic buckling data without shot peening. The results of six specimens with the diameter (D=9 mm) are given in table (1).

Table (1): Theoretical and experimental dynamic buckling load parameters of carbon steel (CK 35) columns without shot peening.

No.	L (mm)	$\delta_{initial}$ (mm)	N_f (cycle)	P_{exp} (N)	$P_{cr.}$ (N)	α_{cr} Hong	$\alpha_{Exp.}$	*Error%*	*Type of column*
1	500	0.33	1.8	4946	5319.34	1.0028	0.93	7.83	Long
2	370	0.3	2.5	8831	9713.91	1.002	0.91	10.11	=
3	330	0.3	2	11304	12211.52	1.0025	0.93	7.79	=
4	310	0.21	2.2	13424	13749.33	1.0024	0.98	2.27	Intermediate
5	270	0.3	2.7	16250	16572.48	1.0019	0.981	2.13	=
6	250	0.17	2.6	19076	17838.47	1.0021	1.06	-5.46	=

It seems from the above table that the predicted α_{cr} obtained by Hong model showed good agreement with the experimental $\alpha_{Exp.}$.

The maximum difference percentage is about 10% and it may be to the assumptions made in Hong model.

From table (1), it can be seen that Hong *et. al*. model was acceptable to determine the dynamic buckling critical load parameter without shot peening treatment for column.

Application of Hong model to experimental dynamic buckling data with shot peening:

To determine the suitability of Hong model for the different shot peening specimens, an attempt is made to apply Hong model to the shot peening dynamic buckling column. Table (2) gives the comparison between Hong model predictions and experimental data.

Table (2): Application of Hong model to experimental results with shot peening treatment.

No.	L (mm)	SPT (min)	$\delta_{initial}$ (mm)	N_f (cycle)	P_{exp} (N)	$P_{cr.}$ (N)	α_{cr} Hong	$\alpha_{Exp.}$	*Error%*	*Type of column*
1	500	15	0.2	1.9	5230	5449.04	1.0027	0.96	4.45	Long
2	500	25	0.3	2.2	5440	5604.7	1.0022	0.97	3.32	=
3	500	30	0.45	2	5300	5397.14	1.0024	0.98	2.28	=
4	370	15	0.27	2.5	9538	9950.83	1.002	0.96	4.37	=
5	370	25	0.24	2.9	10032	10235.14	1.0017	0.98	2.21	=
6	370	30	0.3	2	9185	9856.1	1.0025	0.93	7.79	=
7	330	15	0.3	2.3	12434	12509.27	1.0022	0.994	0.83	=
8	330	25	0.24	2.5	12717	12866.67	1.002	0.99	1.21	=
9	330	30	0.22	2.3	12293	12390.13	1.0023	0.992	1.03	=
10	310	15	0.15	2.3	14130	14113.87	1.0023	1.0011	0.12	Intermediate
11	310	25	0.2	2.6	14483	14563.12	1.002	0.995	0.7	=
12	310	30	0.23	2	14342	14041.34	1.0026	1.021	-1.8	=
13	270	15	0.27	2.8	17309	17094	1.0018	1.012	-1.01	=
14	270	25	0.26	3.3	18369	17834.69	1.0015	1.03	-2.77	=
15	270	30	0.31	3	17804	17392	1.0017	1.023	-2.1	=
16	250	15	0.14	3.4	19782	18431.44	1.0016	1.07	-6.4	=
17	250	25	0.18	3.5	20277	19301.85	1.0015	1.05	-4.6	=
18	250	30	0.21	3.1	19429	18895.76	1.0017	1.03	-2.8	=

Hong model prediction overestimates the column parameter for some specimens and underestimates in some cases. The maximum percentage difference is about 7.79%.

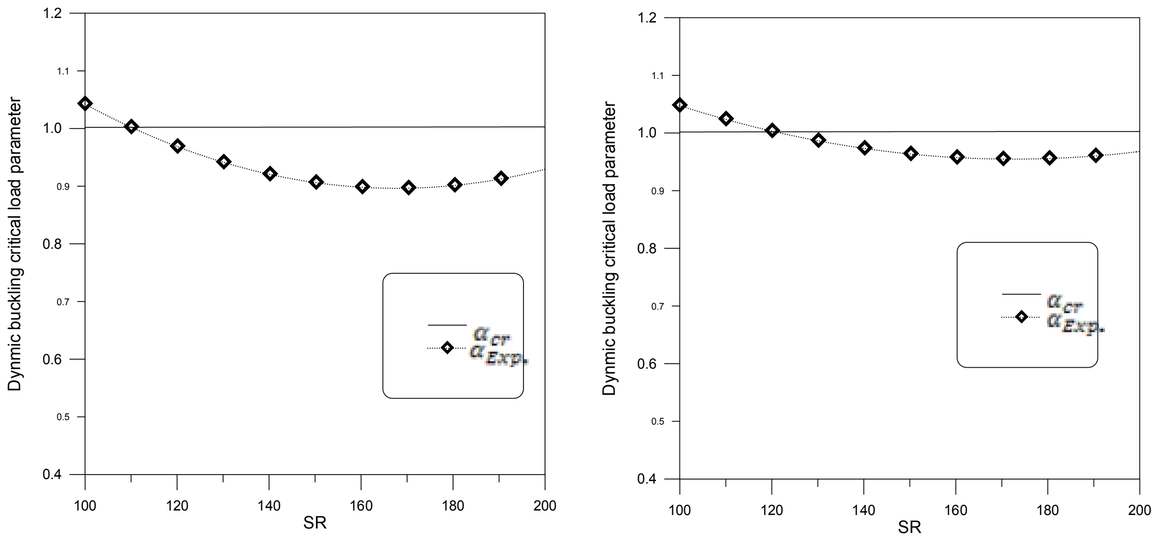
The predictions of Hong model give good correlation with the experimental results.

The error between the theoretical and the experimental results for tables (1) & (2) might be attributed to the facts that: theoretical load is not exactly the same as the actual load, and small loading eccentricity is inevitable for each column in the test, but no loading eccentricity is considered in the theoretical study.

Comparison between theoretical and experimental critical load parameters

Figure (1) shows the comparison between Hong model (α_{cr}) and experimental model ($\alpha_{Exp.}$) without and with shot peening.

It can be seen that the theoretical results obtained in the present study agree well with the experimental results.



(a)without shot peening. (b)with shot peening.

Fig. (1): Comparison between theoretical and experimental critical load parameters.

Effect the parameters of column on the Hong model:

To investigate the effect of initial deflection of column on its dynamic buckling critical load parameter, Fig. (2) shows the variation of dimensionless critical buckling load versus initial deflection of column with $\tau_0 =$ 5, 10 and 20 respectively, when slenderness ratio was constant (SR=125). It is obvious; from the figure; that the critical buckling load of column is very sensitive to its initial deflection, especially when the loading duration is short and initial imperfection is small. In the cases when the initial deflection is small, the effect of initial deflection on the dynamic buckling behaviors of column is so significant. The critical buckling load of column decreases rapidly as the initial deflection increases. When initial deflection increased,the relationship between α_{cr} and $\bar{\delta}$ is basically linear, and the effect of imperfection is not very pronounced. Moreover, it can also be found from the figure that the shot peening duration will influence the sensitiveness of imperfection. When the shot peening duration is large, the effect of column imperfection on its buckling load is less significant. When the load duration is small, the column buckling load increases sharply as the imperfection decreases. These observations indicate that the loading duration strongly affects either the dynamic buckling load or the sensitiveness of the column imperfection.

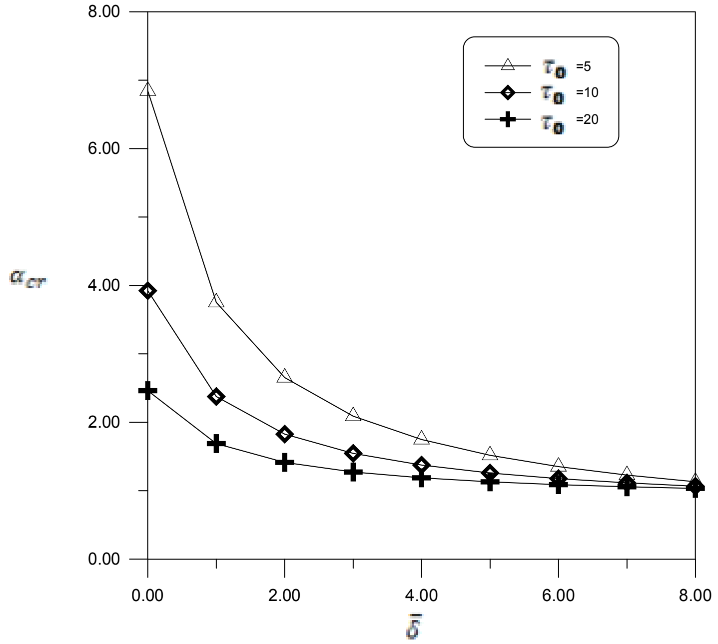


Fig. (2): Effect of initial deflection of column on α_{cr}.

Fig. (3) shows the variation of dynamic buckling critical load parameter α_{cr} with respect to slenderness ratio (SR) for columns with initial deflection $\bar{\delta}$ =0:1, 0.6 and 1.2 respectively, when loading time was constant (τ_0 =10). It can be seen from the figure that, as expected, the smaller the slenderness ratio of a column, the higher critical load parameter.

The critical load parameter decreases exponentially with the increase of (SR). When (SR) is large, its effect on the column dynamic buckling critical load parameter is less pronounced, especially when the imperfection of column is large.This observation indicates that, for columns with small slenderness ratios, reducing slenderness ratio is very effective in preventing the dynamic buckling of columns.

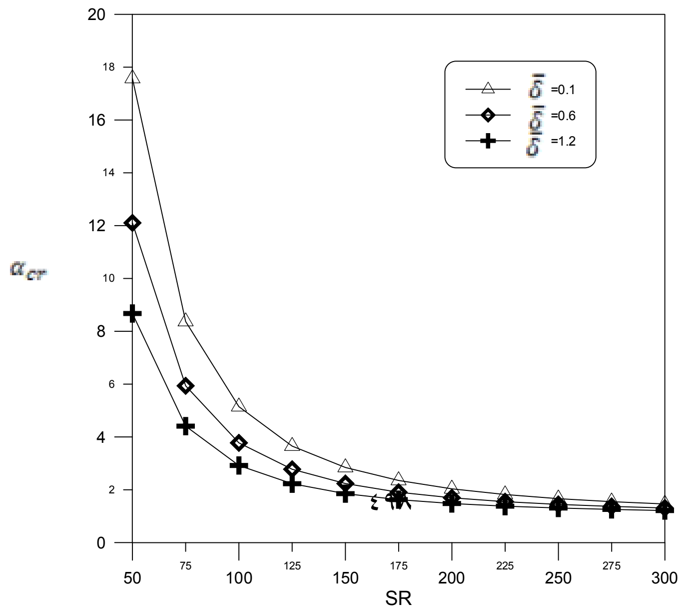


Fig. (3): Relationship between α_{cr} and SR.

To inspect the influence of shot peening duration on the dynamic buckling properties of columns, Fig.(4) displays the critical load parameter α_{cr} with the loading duration τ_0 for columns with different slenderness ratios and constant initial deflection of column ($\bar{\delta}$=0.6). It can be found that the critical load parameter α_{cr} increases significantly as τ_0 decreases.

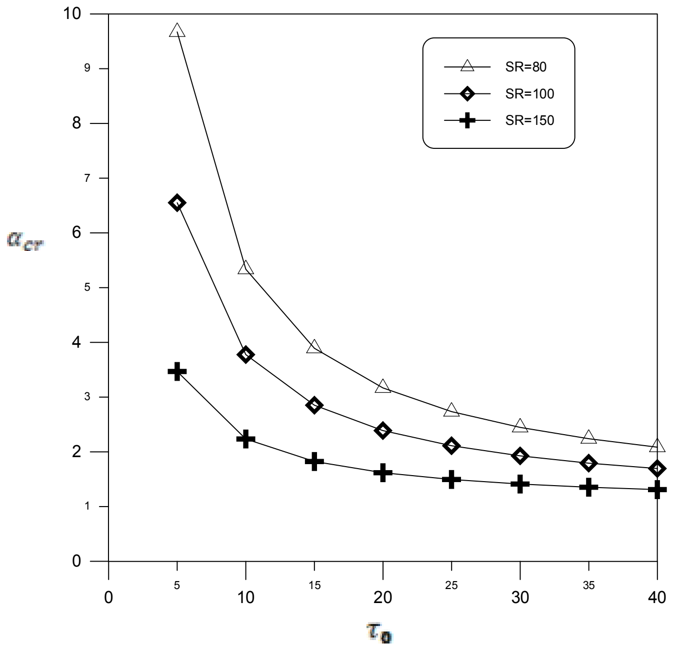


Fig. (4): Critical load parameter versus load duration.

Conclusions

1. A good agreement is obtained between the experimental results and Hong model.
2. The initial imperfection, load duration and slenderness ratio of column affect the dynamic buckling properties of columns.
3. The smaller the initial imperfection of column, the higher the dynamic buckling critical load.
4. For columns with prescribed imperfection and load duration, the dynamic buckling critical load will increase rapidly as the slenderness ratio of column decreases. Thus, reducing slenderness ratio is very effective in preventing dynamic buckling of columns.

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