Effect of Rest Period on the Buckling of the 304 Stainless Steel under Increasing Loading

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Abstract-Buckling plays a very important role in the design of slender columns. When the members are long, the loading, which is lower than yielding, may be large enough to cause the member to deflect laterally. It is well established that the mechanical surface treatments, e.g. shot peening, plasma peening and laser peening are effective method to enhance the resistance of metallic material. In this work, the main aim is to estimate the optimum improvement of dynamic behavior of medium carbon steel alloy due to shot peening experimentally. The behavior of rotating arcular column buckling of steel alloy under compression loading showed significant improvement due to shot peening time (SPT) at 25 mints. Which gave higher resistance against buckling and increasing the buckling time, after that the improvement tends to be reduced?

Keywords: *Increasing buckling loads, Rest periods, 304 stainless steel*

المستخلص–الانبعاج الجانبي يلعب دوراً شديد الأهمية في تصميم الاعمدة عندما تكون هذه الأعمدة (الاجزاء) طويلة. الحمل المسلط عليها حتى لو كان أقل من الخضوع ربما يكون كافياً لعمل الانحراف الجانبي حيث تم التوصل الى أن المعالجات السطحية الميكانيكية ومثال ذلك التصليد بالقذف ، التصليد بالبلازما ، التصليد بالليزر هي طرق فعالة لزيادة المقاومة للمواد المعدنية في هذا العمل. الهدف الرئيسي هو لتقييم أفضل تحسن لسلوك سبيكة الفولاذ متوسط الكاربون تحت الانبعاج الديناميكي عملياً . تم استخدام جهاز فحص الاعمدة الدوارة دائرية المقطع لتقييم تصدف الانبعاج الجانبي لسبيكة الفولاذ تحت الحمل الضغطي. تحسن ملموس تم تأشيره لحالة الانبعاج الجانبي عند التحميل الداينميكي الضغطي عند زمن تصليد القذف ومقداره (25) دقيقة والذي اعطى تحسن عالي في المقاومة ضد الانبعاج الجانبي وعمل على زيادة زمن الانبعاج وبعده بدأ التحسن يميل الى النقصان.

INTRODUCTION

Columns are generally classified according to the type of stresses developed within the column at the time of failure long slender columns will become unstable when the compressive stress remains elastic. The failure that occurs is referred to elastic instability. Intermediate columns fail due to inelastic instability, meaning that the compressive stress as a failure is greater than the materials proportional limit. And, short columns sometimes called posts; do not become unstable rather the material simply yields or fractures [1].

In this study, it can be used with and without rest period process to improve the success of columns critical force. Rest period is the most important aspect of recovery and regeneration. The effect of rest period on the buckling behavior under different loadings and different time of rest period is often expressed experimentally, numerically and theoretically [2].

Alalkawi and abed al Aziz[3] examined the Euler and Johnson theories using experimental dynamic buckling tests on 1020 Hot rolled and 5052 aluminum alloys. They conclude that the above theories can be used to estimate the dynamic critical buckling load with design factor of 3 or more.

Alinia and Dibaie[4] studied and investigated the material and geometric nonlinear behavior of slender webs in I-column girders having stocky flanges under the action of combined lateral and axial loads. Interaction curves corresponding to the application of compressive and shear loads at buckling and ultimate stages for both column and web plates sections are plotted. In addition, the effects of flange and web slenderness rations on the behavior of columns are studied. The results showed that the effect of compressive loads on decreasing shear buckling and ultimate capacities of slender web plates is more than the effect of shear on the relative axial capacities. In the case of dominate compressive load, the increase of shear force does not reduce the ultimate axial capacity of web plates.

Boris and Elia[5] studied the critical sway of buckling load in the upper limit of the allowed vertical frame loading. This load is defined by the frame configuration, cross-sections of the columns and horizontal beams as well as configuration and stiffness of the connections between them. Also deals with a new non-destructive method for experimental for determining the critical sway buckling load of frames. For ensuring mobility of the frame in the sway mode the vertical loading is carried out by the flexible traction element mounted between the frame beam and fixed base through the loading device. The critical vertical load of the 'frame traction element' combined system is higher than of single frame. This fact allows loading the system with load that corresponds to critical load of a frame without loss of system stability.

Alalkawi et.al.[6]Presented buckling model for describing the critical dynamic load of long and intermediate columns based on mechanical properties and number of cycles to failure. They found that the application of the above model on 304 stainless doesnot need to consider the factor of safety. The model predications observed that safe compared to experimental results.

This study attempts to determine the tool to the amount of critical buckling load and increase the safe life of columns under different types of working condition. However, as there is an interest to observe the effects of investigating the rest period on the buckling load, so this work will examines the effect of rest period on the dynamic buckling loads and the number of cycle to cause failure of columns when subject to compression. The effect of rest period is often expressed experimentally, numerically and theoretically.

EULER and JOHNSON FORMULAS

According to Euler's theory, the crippling or buckling load under various end conditions is represented by general equation:-

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} = \frac{\pi^2 EAr^2}{L_e^2} \quad (1)$$

$$I = Ar^2$$

$$P_{cr} = \frac{\pi^2 EA}{(\frac{L}{r})^2} \quad (2)$$

The value of actual slenderness (S.R. "Le/r"), which determines whether the column is intermediate or long, is found by equating the transition slenderness ratio formula[7] (column constant formula) which is:

$$C_c = \sqrt{\frac{2\pi^2 E}{\sigma_y}} \quad (3)$$

If the actual effective slenderness ratio S.R. is greater than C_c, then the column is long, and the Euler formula should be used to analyze the column. If the actual effective slenderness ratio S.R. is less than C_c, then the column is intermediate. In these cases, Johnson formula should be used [8].

$$P_{cr} = A\sigma_y \left[1 - \frac{\sigma_y \left(\frac{L_e}{r}\right)^2}{4\pi^2 E}\right] \quad (4)$$

HONG THEORETICAL MODEL

Hong Hao et.al. [9], personal a dimensionless theoretical model depend on several dimensionless parameters which include the most dynamic buckling properties. The model was presented in the following form:

$$\alpha_{CR} = 1 + \frac{17\pi^6 I^2 (4\sqrt{6} - \delta)}{\tau_c SR^{2(2\sqrt{3}+I\delta)}} \qquad (5)$$

Whereα_{cr} is the dimensionless theoretical dynamic buckling critical load parameter, a dimensionless value of α can be obtained experimentally and α_{exp}Is obtained experimental and its value equals to:

$$\alpha_{exp} = \frac{P_{exp}}{P_{cr}} \qquad (6)$$

$$\left\{\begin{matrix} \bar{\delta} = \frac{\delta_{initial}}{r} & r^2 = \frac{I}{A} & SR = \frac{L}{r} \\ \tau_0 = \frac{t_0}{\eta} & \eta = \frac{r^2}{s^2 c} & c^2 = \frac{E}{\rho} \\ I = \frac{sL}{r} & s^2 = r^2 k^2 & k^2 = \frac{P_E}{EI} \end{matrix}\right\} \qquad (7)$$

Where:

α_{CR}: the dimensionless theoretical dynamic buckling critical load.

α_{Exp}: The dimensionless experimental dynamic buckling critical load.

Pcr: Euler critical buckling load if the column is long and Johnson critical buckling load if the column is intermediate.

P_{Exp}: Experimental critical buckling load (form test rig).

$\delta_{Initial}$: The maximum initial lateral deflection of column.

$t_{\circ}$: radius of loading (sec).

C: stress wave velocity of column material (m/sec).

SR: slentems ratio of column.

P_E: Euler critical buckling load.

EXPERIMENTAL MATERIAL

The current study will verify the miniature mechanical testing for stainless steel type 304 that used in all commercial, industrial and domestic's fields because of its good heat resisting properties and corrosion. Some application include tanks and containers for a large variety of liquids and solids process equipment in the mining, cryogenic, chemical, good,dairy and pharmaceutical industries and drilling operations. The material was received as a rod of 3m in length and 10mm in diameter. All the material was received from a State Company Mechanical Industries AL-Ascandarya and tested to determine its chemical composition of the steel alloy. Results are listed in Table (1), while the mechanical properties showed in Table (2), were obtained by using the test machine WDW-200E in University of Technology-Material, Engineering Department under room temperature (25°c).

TABLE 1: CHEMICAL COMPOSITION OF 304 STAINLESS STEEL (WT %)

304 stainless steel	C% Carbon	Mn% Manganese	P% Phosphorus	S% Sulfur	Si% Silicon	Cr% Chromium	Ni% Nickel	N% Nitrogen	Fe% Iron
Standard ASTM A240 [10]	0.08 max	2.00. max	0.045. max	0.030 Max	0.75 max	18.0- max	8.0- Max	0.10 max	Balance
Experimental	0.026	1.72	0.016	0.021	0.66	18.9	9.6	0.07	Balance

TABLE 2: MECHANICAL PROPERTIES OF THE 304 STAINLESS STEEL

304 stainless Steel	δu (Mpa)	δy(Mpa) 0.2%proof stress	E (Gpa)	G (Gpa)	μ Poi-ratio	ε % Elongation
Standard ATM A370[10]	621	290	193-200	74-77	0.30	55
Experimental	630	300	200	77	0.31	52

where: δu: Ultimate Strength (Mpa), δy: Yield Strength (Mpa), E: Modulus of Elasticity (Gpa), G: Modulus of Rigidity (Gpa), μ: poisions ratio, ε: Elongation Perecentage

BUCKLINGSPECIMEN PREPARTION

Buckling columns with different length and slenderness ratio(S.R.=Le/r) were chosen for the present test program. It was designed to useDifferent slenderness ratio (S.R.) to different.

Between Intermediate and long buckling columns behavior. The buckling test specimens are shown in Figure 1 and Table 3, respectively.

And the existence of different specimen's length to radius ratios are shown in the Table 4 to get different slenderness ratios (Le/r) to simulatethe long and intermediate buckling sample behavior.

Figure1: Buckling specimen for long and intermediate columns.

TABLE 3: BUCKLING SPECIMEN FOR DIFFERENT LENGTH

No.	Lt(mm)	Le(mm)	D(mm)	A(mm^2)	I(mm^4)	Type of column
1	400	320	10	78.539	490.87	Intermediate
2	380	300	10	78.539	490.87	Intermediate
3	360	280	10	78.539	490.87	Intermediate
4	340	260	10	78.539	490.87	Intermediate
5	500	420	10	78.539	490.87	long
6	480	400	10	78.539	490.87	long
7	460	380	10	78.539	490.87	long
8	440	360	10	78.539	490.87	long

where: Lt: Total Length (mm), , Le: Effective Length (mm) , D: Diameter of Colum (mm) , A: Cross-Sectional Area (mm^2), I: Second moment of Area (mm^4)

TABLE 4: SLENDERNESS RATIOS FOR BUCKLING SPECIMENS

Item	L t (mm)	L (mm)	S.	Type of column
1	500	420	117.6	Long
2	480	400	112	Long
3	460	380	106.4	Long
4	440	360	100.8	Long
5	400	320	89.6	Intermediate
6	380	300	84	Intermediate
7	360	280	78.4	Intermediate
8	340	260	72.8	Intermediate

DYNAMIC BUCKLING TEST RIG:

The buckling test – rig machine as shown in Figure 2 used in this work. The Test–Rig machine contests of the following parts:

- Torsion system
- Compression system.

5rThese systems operate with high speed is (34RPM) and low speed of (17RPM). The counter which measures the number of turn with 9999.9 digits, a digital dial gauge indicator

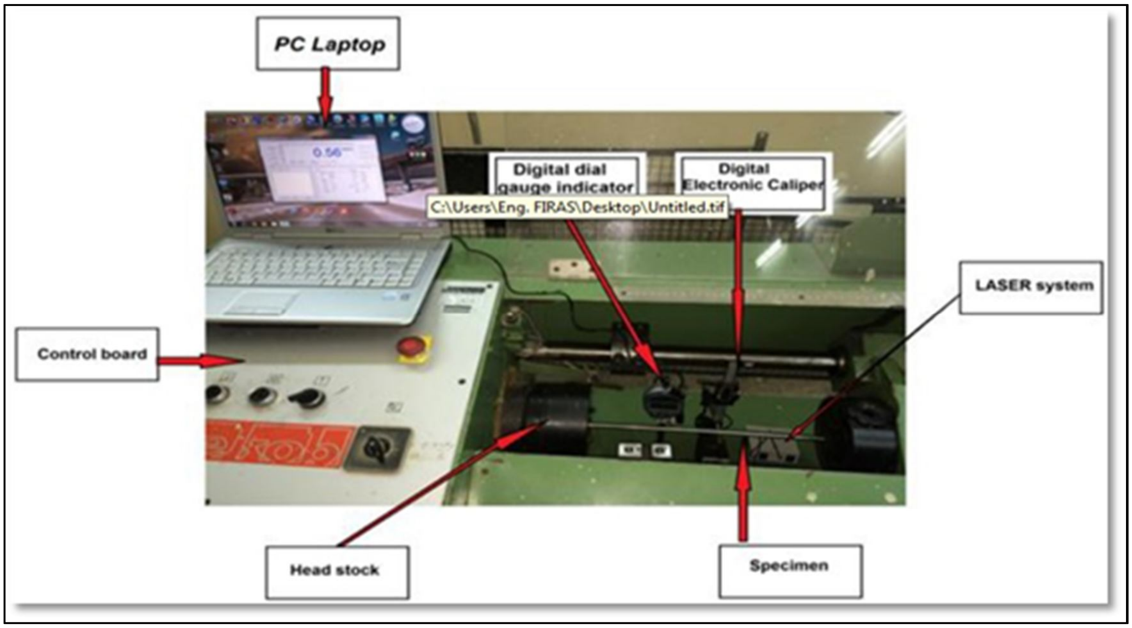

Figure2:The test rig for dynamic buckling rests with control panel

is used to measure the deflection of the specimen.

Failure definition

Under the controlled load, failure may be defined as the instance when the specimen deformed laterally to about (1%) of specimen effective length, i.e. the total laterally deflection (and final equal 1% of the effective length) [8].

Rest Period Effect

It was found that fatigue life of specimens increases with stress relief and with rest period[11]. Also it was found that the rest period might increase the resistance of material of steel at room temperature. This is a probable result of strain ageing, which decreases the effect of progressive dislocation and delay crack initiation(deflection) mainly at earlier step of lateral deflection [12].

As seen in Table 5 rest period of 10 min increased the critical buckling loads and life (N_f) at failure. The rest period tends to release some internal stresses and improve in the mechanical properties of the material.Consequently, columns would sustain additional stresses and their lives will increase[13]. Figure 4 shows the comparison between the experimental results without rest period. It can be seen that the average difference percentage is about (13%).

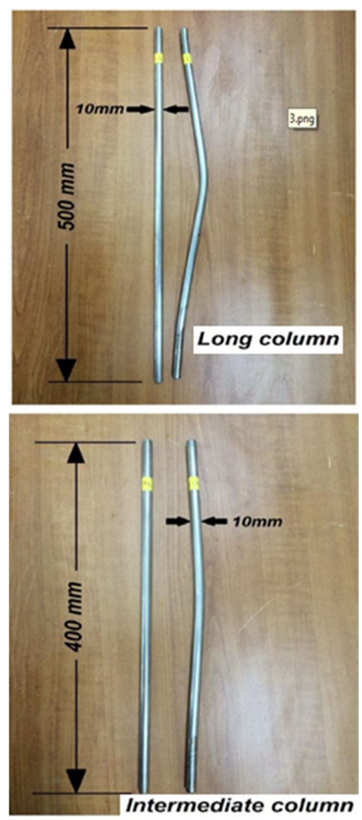

Figure 3:The specimen after and before buckling test.

TABLE 5: COMPARISON BETWEEN COLUMNS WITHOUT AND WITH RESTPERIOD(10 MIN. REST PERIOD)

Long columns					
No.	S.R.	P_{cr}(N) EXP.	P_{cr}(N) EXP.With rest period	$N_f$cycles EXP.	N_f Cycles EXP.With rest period
1	117.6	8478	8901.9	39.5	45.5
2	117.6	8407.4	9043.2	41.9	53.8
3	112	8124.8	9891	32.9	50
4	112	8831.3	9961.7	39.8	55.6
5	106.4	8689.9	11304	45.4	62.7
6	106.4	9184.5	11727.9	46.7	72.5
7	100.8	8901.9	11869.2	46.1	61.3
8	100.8	9537.8	120105	46.4	71.7
Intermediate Columns					
No.	S.R.	P_{cr}(N) EXP.	P_{cr}(N) EXP. With rest Period	$N_f$cycles EXP.	N_f cycles EXP. With rest period
1	89.6	11304	11445.3	61.6	70
2	89.6	11162.7	11727.9	61.5	80
3	84	12010.5	12858.3	58.8	80
4	84	12717	14836.5	68.8	88.7
5	78.4	12858.3	15189.8	64.1	96.8
6	78.4	13282.2	15472.4	59.4	85.9
7	72.8	14130	15754.9	88.6	102.3
8	72.8	14836.5	16108.2	75.6	104.2

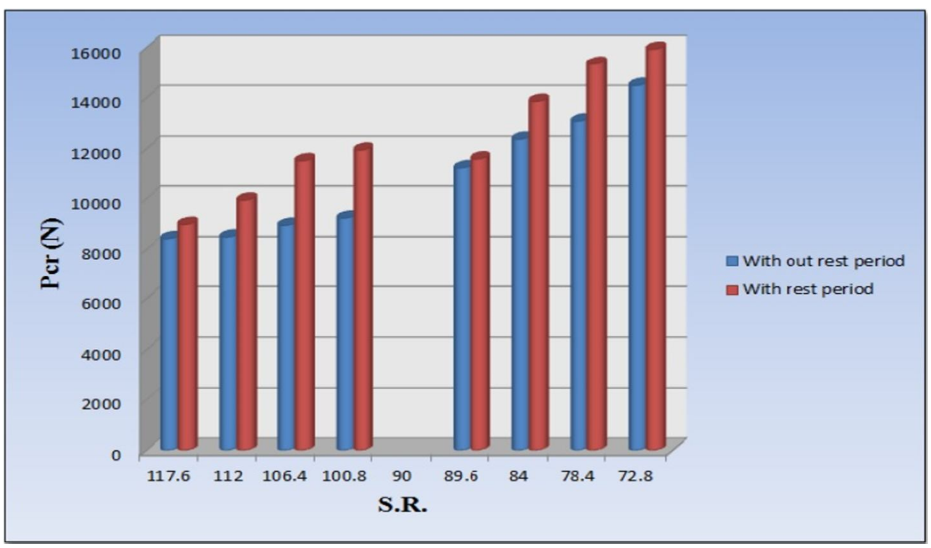

Figure (4):Comparison between the experimental results without rest period and with rest period.

ANSYS ANALYSES

Numerical model using ANSYS package were employed and compared with the experimental results. Table 6 shows the numerical results of critical buckling under dynamic increasing load without factor of safety (F.S). If a factor of safety of 4 may be takenthen below table gives the percentage discrepancy between the experimental and numerical results. The difference might be attributed to the fact that, due to the assumption made in the ANSYS package and Hong model, the difficulties to control the measurement in the experimental work and some error may occurs in reading the experimental data.

TABLE 6: NUMERICAL RESULTS OF CRITICAL BUCKLING UNDER DYNAMIC INCREASING LOAD WITH AND WITHOUT FACTOR OF SAFETY

Of 4P_{cr} Hong (N)	with S.F.P_{cr} ANSYS(N)	FactorP_{cr} Hong (N)	Without S.F. P_{cr}ANSYS(N)	P_{cr} Exp.(N)	Seq
2119	2809	8477	11237	8478	1_L
2102	2809	8406	11237	8407	2_L
2084	2809	8336	11237	8337	3_L
2098	2809	8392	11237	8393	4_L
2111	2809	8442	11237	8443	5_L
2031	3097	8125	12389	8125	6_L
2208	3097	8831	12389	8831	7_L
2173	3432	8690	13727	8690	8_l
2296	3432	9185	13727	9185	9-L
2226	3824	8902	15295	8902	10_L
2385	3824	9538	15295	9538	11_L
2225	2809	8901	11237	8902	12-L
2261	2809	9042	11237	9043	13_L
2473	3097	9890	12398	9891	14-L
2490	3097	9961	12389	9962	15_L
2826	3432	11303	13727	11304	16_L
2932	3432	11727	13727	11728	17_L
2968	3824	11869	15295	11870	18_L
3003	3824	12010	15295	12011	19_L
305502826	3824	12221	15295	12222	20_L
2791	4840	11304	19358	11304	1-M
2808	4840	11163	19358	11163	2_M
2800	4840	11233	19358	112233	3_M
2822	4840	11198	19358	11198	4_M
3003	4840	11289	19358	11290	5_M
3003	5506	12011	22025	12011	6_M
3179	5506	12011	22025	12717	7_M
3215	6321	12717	25283	12858	8_M
3321	6321	12858	2583	13282	9_M
3533	7331	13283	29323	14130	10_M
3709	7331	14130	29323	14837	11-M
2861	4840	14837	19358	11445	12_M
2932	4840	11445	19358	11728	13_M
3215	5506	11728	22025	12858	14_M
3709	5506	12858	22025	14837	15_M
3798	6321	14837	25283	15190	16_M
3868	6321	15190	25283	15472	17_M
3939	7331	15472	29323	15755	18-M
4027	7331	15755	29323	16108	19_M
3992	7331	15967	29323	15967	20_M
Where: L = longcolumn and M = Intermediate column					

CONCLUSION

1. Euler and Johnson formulas give over estimation for critical buckling compared to the experimental results. While if taking a factor of safety about (4) gave satisfactory prediction.
2. Rest period play an important factor for increasing the critical buckling load compared with columns tested without rest period.
3. The ANSYS program used in calculating stresses showed good agreement in comparison with the analytical and experimental results, with (4) safety factor.

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