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Effect of Corrosion Time on Critical Buckling Load of AISI 304 Columns

Hussain J. Al-alkawi
Electromechanical Eng. Dept, University of Technology, Baghdad, Iraq.
Alalkawi2012@yahoo.com

Samih K. Al-najjar
State Company for Automobile Industries and Equipment, Babylon, Iraq.
samihkhtan@yahoo.com

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Abstract- *In this work Corrosion buckling interaction behavior of AISI 304 stainless steel circular columns was investigated. Long and intermediate columns diameter of (6 mm) are tested in as received and corroded condition. Corroded columns are tested after embedded it in soil for different times. Rotating buckling machine test was used to evaluate the critical buckling load (pcr) under dynamic compression loads. By using Perry Robertson formula, experimental work results are compared. The results showed that increasing in corrosion time (embedding time), the reduction in critical buckling load increases also. Maximum reduction of buckling load value are (2.28%, 1.37%) for long and intermediate column respectively as compared with as received condition.*

Keywords- *Buckling load, stainless steel, Corrosion and AISI 304.*

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1. Introduction

A column is a structural member that carries an axial compressive load and that tends to fail by elastic instability, or buckling [1]. The columns are divided into three sections: long, intermediate and short length columns. The objective of column analysis method is to predict the load or stress level at which a column would become unstable and buckle [2,3]. Corrosion can be defined as the degradation of a material due to a reaction with its environment. Degradation implies deterioration of physical properties of the material [4]. Specific alloy systems are susceptible to specific form of attack, for example, mild steels are susceptible to general corrosion and stainless steels (like any metals with an oxide layer such as aluminum) are susceptible to pitting, crevice corrosion, and stress corrosion cracking. Oszvald [5] carried out the Compressive buckling tests on corroded steel angle members. Using solid and shell finite elements, the finite element models are advanced to follow the material reduction in the compression members. The ratio of the maximum buckling force of the corroded and non-corroded members is determined concerning the connection types and the corrosion parameters. The suggested method to analyze a corroded member is easily applicable in the practice. The evaluation method suggests refurbishment or total replacement of the members taking into account the result. Kashani et al. [6] presented a numerical model that enables simulation of the nonlinear flexural response of corroded reinforced concrete (RC) components. A new phenomenological uniaxial material model for corroded reinforcing steel column is used. This model accounts for the impact of corrosion on buckling strength, post-buckling behavior and low-cycle fatigue degradation of vertical reinforcement under cyclic loading. The basic material sample is established through comparison of simulated and observed response for uncorroded RC columns. Kim et al. [7] completed experimental analyses and based on the test results numerical analyses on the locally corroded web of the girder were executed. As a result, an equation was derived to calculate the shear buckling strength ratio (RS_f) of the corroded and non-corroded members.

$$RS_f = 0.7368 + \frac{0.2859}{1+e^{-\left(\frac{Cv-8.8318}{-3.4666}\right)}} \qquad (1)$$

Mark M. Fridman [8] proposed the optimal design of compressed columns with a circular cross section under axial compressive forces and exposed to a corrosive environment. The main constraint is the buckling of a loaded column at the final time of its operation. . Analytical and numerical results are derived for optimal variation of the cross-sectional area of the bar along its axis. This work involves the corrosion buckling interaction behavior of 304 stainless steel with different corroded time. Comparison between the corroded columns with as received columns is achieved. The Perry-Robertson formula is used to evaluate the experimental results.

2-Theory

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

I. Perry-Robertson Formula [9].

Buckling load p

$$= A\left[\frac{\sigma_c+(\eta+1)\sigma_e}{2} - \sqrt{\left(\frac{\sigma_c+(\eta+1)\sigma_e}{2}\right)^2 - \sigma_c\sigma_e}\right] \quad (2)$$

Where

$$\eta = 0.3\left(\frac{L_e}{100r}\right)^2 \quad (3)$$

L_e= actual length of pinned end strut.
= 2.0 x actual length of strut with one end fixed, One end free.
r = radius of gyration.

σ_e= Euler buckling stress= $\frac{\pi^2 E}{(L_e/r^2)}$ (4)

σ_c=Yield stress in compression.

II. Euler and Johnson Formula

Theoretical critical buckling load (P_{cr}) can be obtained by using Euler's theory, which is used for represent long columns.

$$P_{cr} = \frac{\pi^2 EI}{(L_e)^2} \quad (5)$$

I=Ar^2 (6)

For intermediate columns Johnson formula can be applied to show the behavior of critical buckling load [10]:

$$P_{cr} = A\sigma_y\left[1 - \frac{\sigma_y(S.R)^2}{4\pi^2 E}\right] \quad (7)$$

Slenderness ratio (S.R =Le/r) was used to determine columns lengths long or intermediate. By using column constant formula (C_c) [10]. If the (S.R) is greater than (C_c) then the column is long and vice versa.

$$C_c = \sqrt{\frac{2\pi^2 E}{\sigma_y}} \quad (8)$$

3-Experimental Work

I. Material Used and Buckling Specimen

In this work AISI 304 stainless steel was used as long and intermediate columns of Ø=6 mm diameter. This alloy have widely used in industrial such as tanks and containers for a large variety of liquid and solids process. Table 1 shows the detail of the chemical composition of AISI 304 tested in state company for inspection and engineering rehabilitation. Table 2 illustrated average of three specimens mechanical properties of alloy according to ASTM E8 which is tested in university of technology at room temperature 25 ^{o}c .

The buckling specimen parameters are shown in Table 3 with both long and intermediate columns.

Table 1: Chemical compositions (wt. %) of AISI 304 stainless steel.

Alloy	C	Si	Cr	Ni	Mn	N	P	S	Fe
Experimental	0.02	0.66	18.9	9.6	1.72	0.07	0.01	0.02	**Bal.**
Standard ASM [11]	0.08	0.75 max.	18-20	8-12	2 max.	0.1 max.	0.04 max.	0.021	**Bal.**

Table 2: Mechanical properties of AISI 304 stainless steel.

Alloy	**σu (MPa)**	**σy (MPa)**	**E (GPa)**	**G (GPa)**	**Elongation %**
Experimental	631	300	200	77	**52**
Standard [11]	621	290	193-200	74-77	**55**

Table 3: Specimen parameters of AISI 304 stainless steel.

No.	L_t (mm)	$L_{eff.}$ (mm)	D (mm)	A (mm^2)	I (mm^4)	S.R	C_c	Type of column
1	400	280	6	28.2	63.45	186.6	114.7	long
2	200	140	6	28.2	63.45	93.3	114.7	Intermediate

II. Dynamic Buckling Test Machine

AISI 304 stainless steel columns with and without corrosion were tested by rotary dynamic buckling machine, which is capable to buckle the columns by, apply compression load. Column ends support of fixed-pinned and the machine operates with high speed (34 r.p.m) and low speed (17 r.p.m). In this study, the speed of (17 r.p.m) was used in all experiments. When the motor starts, the recording digits, which refer to the number of cycles during test. The compression system includes a manual hydraulic pump. A screwed shaft is used to carry the pressure from the hydraulic pump to the jaw, which supports the specimen. Ref. [12] indicates more information about buckling test machine, who studied the buckling behavior of solid and hollow CK35 and CK45 alloy steel columns under combined dynamic loading.

III. Specimens Test Environment

In this study, two types of testing groups were used. Group (1) as received (without corrosion). Group (2) corroded specimens, the specimens were embedded in soil for (30, 60, 90) days and then applying buckling test after removing the specimens from soil. The soil was used in this study is selected from house garden and its type is clayed soil and has water content 17%, void ratio is 0.8% and its temperature is 30 °c.

IV. Failure of buckling specimen

The value of critical buckling load (P_{cr}) was reached when the maximum deflection of the specimen reached the critical value (δ_{cr}) which is equal to (1%) of specimen length Plus initial deflection (δ_{in}) [1]. For more accuracy, the deflection of column is measured using a dial gage in the middle of specimen and a laser cell circuit tool with alarm sound fixed on digital vernier with accuracy 0.01mm. Figure 1 shows the test rig with buckling specimen.

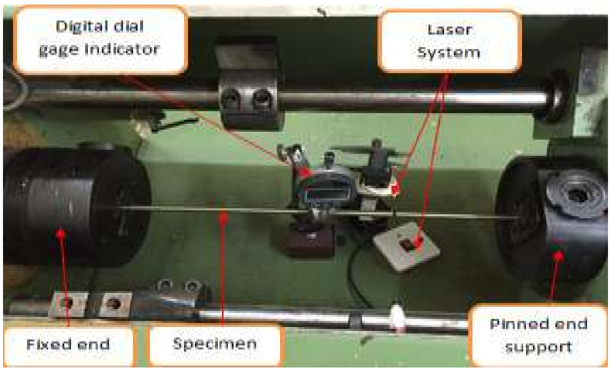

Figure1: Test rig of dynamic buckling machine.

4. Results and Discussion

I. Tensile test results

Table 4 shows results of tensile test for dry and corrosion state of AISI 304 column specimens with average of three readings. From Table 4 it can see that the corrosion reduces the strength of the substance and affects the surface quality of a structure, because of corrosion weakens the surface and lessening its hardness. This finding agreed with conclusion of Ref. [٥].

II. Buckling Test Results

All the columns were stable up to the yield stress of material and instability began after yielding then followed by buckling loading and softening behavior .The column specimen, which fails by cracking, is inhibited in the case of compression, since cracks will be closed up rather than opened by applied loading. Corrosion causes unsymmetrical cross section along the length of column because of random corrosion, therefore a corroded column yields and buckling load is reduced compared with uncorroded column. In dynamic buckling, the maximum load, sometimes called the critical load, causes the column to be in a sta te of unstable equilibrium. Table 5 presents the empirical results of dynamic buckling test of AISI 304 column specimens without corrosion effect (as received). Table 6 illustrated the experimental results of buckling test of corroded columns (group2). It can be showed from Table 6, that with rising in corrosion time the lowering in critical buckling load increases also, irrespective on type of columns (long or intermediate). The buckling period (cycle) of corroded column specimens lowered compared with that of as-received specimens. The reason of this finding is that the obstruction of columns corroded surfaces to endure the buckling load. It appear that the corrosion condition at 90 days gives a maximum decreasing of dynamic buckling resistance for the specimen of (group2) in both types of columns compared with non-corroded columns specimens (group1) this is due to the effect of low-cycle fatigue of columns at pitting locations. Comparison between Euler, Johnson and Perry-Robertson was made in order to predict the critical load values. The actual critical load (experimental) always is greater than the above formulas by safety factor. The Perry-Robertson formula prediction of critical loads for both long and intermediate columns showed safe estimation in case of corroded specimens. The range of safety factor takes from 1.33-1.57. While larger safety factors were obtained in case of Johnson and Euler formulas as shown in Table 7.

Table 4: Tensile test for dry and corrosion state of AISI 304.

AISI 304	σu (MPa)	σy (MPa)	E (GPa)	Elongation %
As received	631	300	200	52
30 days	622	295	198	54
60 days	618	291	192	56
90 days	612	287	188	58

Table 5: Experimental results of buckling test of AISI 304 column without corrosion.

Type of column	L total (mm)	Leff. (mm)	Pcr (N)	Pcr Average	δcr (mm)	Cycle (Nf)
Long	400	280	6382	6358	5.8	29
	400	280	6322		5.5	35
	400	280	6370		6.7	38
Intermediate	200	140	8817	8832.6	3	37
	200	140	8823		3.6	39
	200	140	8853		2.8	44

Table 6: Experimental results of buckling test of corroded columns.

30 days corrosion condition						
Type of column	L total (mm)	Leff. (mm)	Pcr (N)	Pcr Average	δcr (mm)	Cycle (Nf)
Long	400	280	6320	6355.3	5.6	29
	400	280	6380		6	33
	400	280	6366		5.9	35
Intermediate	200	140	8831	8831	3	32
	200	140	8835		2.7	37
	200	140	8832		3.4	42
60 days corrosion condition						
Long	400	280	6296	6299.6	5	32
	400	280	6300		5.3	30
	400	280	6303		6	32
Intermediate	200	140	8820	8825.3	3	31
	200	140	8827		2.6	33
	200	140	8829		3.1	34
90 days corrosion condition						
Long	400	280	6195	6212.6	5.2	29
	400	280	6200		5	25
	400	280	6243		5.4	32
Intermediate	200	140	8770	8710	3.1	32
	200	140	8764		3.3	30
	200	140	8755		2.2	31

Table 7: Comparison between Euler, Johnson and Perry-Robertson formulas with experimental critical load values.

Type of Column	Pcr. (N) Euler	Pcr. .(N) Johnson	Pcr. .(N) exp.	Pcr. .(N) Perry-Robertson	S.F Perry-Robertson	S.F Euler	S.F Johnson
As received							
Long	1601.5	------	6358	4125.6	1.54	3.97	----
Intermediate	-----	5674	8831	4521.9	1.95		1.55
30 days corrosion condition							
Long	1585.5	------	6355.3	4058.8	1.56	4	----
Intermediate	-----	5598	8832.6	6601.6	1.33	-----	1.57
60 days corrosion condition							
Long	1537.4	------	6299.6	4003	1.57	4.09	----
Intermediate	-----	5477.3	8825.3	6511.8	1.35	-----	1.61
90 days corrosion condition							
Long	1505.4	------	6212.6	3947.7	1.57	4.12	----
Intermediate	------	5380.6	8763	6422.2	1.36	----	1.62

5. Conclusions

In this work, the effect of corrosion periods (30, 60, 90) days on dynamic buckling load performance was investigated on AISI 304 stainless steel and the following conclusions can be drawn:

1- Reduction in critical dynamic buckling load increase with increase in corrosion time.

2- Maximum reduction was (2.28%) for long columns and (1.37%) for intermediate columns as compared with as received columns under dynamic compression loading and 90 days embedding time.

3- In as received condition Johnson formula gives better prediction to the experimental results as compared with Perry-Robertson formula.

4- For all corrosion times, Perry-Robertson formula showed good agreement in comparison with experimental results. While Euler and Johnson formulas give under estimation for critical buckling load.

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Nomenclature

Cv	The volume of the corroded web	m3
σ y	Yield stress	MPa
σ u	Ultimate stress	MPa
Leff.	Effective column length	mm
Lt	Total column length	mm
I	Moment of inertia	mm4
Cc	Column constant	
A	Cross section area	mm2
D	Diameter of column	mm
E	Modulus of elasticity	GPa
r	Radius of gyration	mm
AISI	American Iron &Steel Institute	
δ_{in}	Initial column deflection	mm
δcr.	Critical deflection	mm
P_{cr}	Critical buckling load	N
N_f	Number of machine cycle	Cycle
S.R.	Slenderness ratio	