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THE EFFECT OF SHOT PEENING AND CORROSION ON THE CRITICAL BUCKLING LOAD OF THE 304 STAINLESS STEEL COLUMNS

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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COMMITTEE DECISION

We certify that we have read the thesis/ dissertation titled (**the effect of shot peening and corrosion on the critical buckling load of the 304 stainless steel columns)** and we have examined the student (***Amjad Modher Bader*)** in its content and what is related with it, and in our opinion it is adequate as a thesis for the **Degree of Master of Science in Mechanical Engineering.**

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Date: / / 2022

Dedication

To My Family and wife

To My Friends with Love and Respect

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At the beginning, I express my gratitude to **Al-Mighty Allah** who gave me the will and patience to fulfill this work, Secondly I would like deeply to thank, beloved **MUHAMMAD** (peace be upon him and his family). And I submit the highest thankfulness, regards and respects to all those who ignited a candle to my work, and to all those who stand behind platforms to give knowledge to illuminate my way, and I extend to them all respect and regards.

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ABSTRACT

Machine part exposed to an axial compressive load is called strut, but a vertical strut is known as a column. The machine members that must be investigated for column action include connecting rods, piston rods, screw jack, etc. If a column is exposed to a compressive load and this load being slowly augmented, a stage will attain if the column will be exposed to an ultimate load. After that, the column will collapse via crushing and the load will be recognized as a (crushing load). When the column is short or intermediate, the column fails sometimes in bending, and when the column is long, it fails in buckling. The value of buckling load is low for long columns and is relatively high for intermediate columns.

The present investigation focuses on testing and evaluation of columns (samples) using (304) stainless steel used in many engineering industries and will choose 24 samples (12 dry samples and 12 samples submerged in sea water for 90 day) with and without shot peening (SP). The buckling behavior of axial compressive load has been studied experimentally and theoretically using Euler and Rankin theories and Solidworks program. For evaluating the dangerous failure, a laser electrical devise was used, and in the case of bending reaching to 1% of specimen length, the specimen reached the failure.

The results obtained from this study indicated that the column, whose slenderness ratio (SR) is higher than 120, is referred to long column, and the Euler theory can be successfully used. But, when (SR) is lower than 120, the column is known as an intermediate column, and the Rankine theory can be successfully used. The mechanical properties evinced a reduction due to wear modes and reasonable improvement when using

shot peening. The results obtained empirically without any treatment for the two conditions; without shot peening (WSP) and with shot peening (SP) that have been compared with the theoretical equations of Euler as well as Rankin. Such theories manifested an overestimation of the critical buckling loads. The factor of safety of 3 and 2.5 respectively made the experimental and theoretical results in good agreement. The mechanical properties of 304 stainless steel were increased after 15 min of quenching by using shoot peening by (2.08 and 5.9) for Ultimate Stress and Yield Stress, respectively, including increasing the critical torsion load by (24-30%) for long columns and (2-6%) for medium columns.

The effect of corrosion on the mechanical properties of the samples was studied, and its influence was noted by a decrease in the values of Ultimate Stress and Yield Stress by 2.08 and 5.9, respectively and for unhardened samples by 8.39 and 8.5, respectively. The size of corrosion was also calculated using the weight loss method and Tafel method. The effect of tempering on the corrosion volume was observed, with an improvement rate of 90.14%.

TABLE OF CONTENTS

List of Tables

List of Figures

Nomenclature

Nomenclature	Definition	Units
A	Cross – sectional area	m^2
a	Rankine's constant	
C_c	Column's constant	
CR	Corrosion rate	(mpy)
D	Diameter of column	mm
d	Diameter of hydraulic pump delivery rod	mm
E	Modulus of elasticity	N/m^2
F_{comp}	Applied compression load on column	N
DF	Deviation Factor	
G	Modulus of rigidity	N/m^2
I	Moment of inertia of cross section	m^4
I%	Improvement percentage in strength	
K	End condition coefficient	
L	Length of column	m
L_e	Effective length of column	m
n	Hardness index	
N_f	Number of cycle of failure	cycle
P_{cr}	Critical buckling force	N
P_R	Rankine load	N
P_C	Ultimate crushing load for column	N
r	Radius of gyration	m
r_{min}	Smallest radius of gyration	m
S.R.	Slenderness Ratio	m/m
ASM	American Society for Metals	
FEM	Finite Element Modeling	
ASTM	American Society for Testing and Materials	
WC	Water Corrosion	
SP	Shot peening	
RT	Room temperature	C^0
YS	Yield strength	MPa
UTS	Ultimate tensile strength	MPa

Greek Symbols

Symbols	Definition	Unit

$\sigma_{comp.}$	Compression Stress	N/m^2
σ_{cr}	Critical Buckling Stress	N/m^2
σ_u	Ultimate Stress	MPa
σ_y	Yield Stress	MPa
δ_{in}	Initial Deflection of Column	m
δ_{cr}	Critical Deflection of Column	m

CHAPTER 1
INTRODUCTION

1.1 Introduction

Structural stability calculations have traditionally been a crucial engineering field. Since Leonard Euler determined the critical buckling load (p_{cr}) for a singly-supported column in 1744 A.D. The (p_{cr}) computation of a structure has been a topic of study. Buckling is a phenomenon that occurs when a structure abruptly switches from one state of equilibrium to another. The structure's buckling loads computation is crucial due to the risk of structure failing suddenly when the (p_{cr}) being achieved, If a roof or other similar structures loses complete stability, this could put people in danger [1].

Failures because of the instability phenomena can occur suddenly and may cause the whole structure to breakdown. It's therefore in the engineer's interest to have good knowledge about this phenomenon. Column buckling is one of the most common examples of instability phenomena [2].

Structural failure due to buckling is still of interest to researchers. Study the buckling behavior of the columns is an important step to understanding and evaluating the reliability of the structures that have more complex designs [3].
Stability is a main issue of solid mechanics which should be controlled and achieved to secure the safety of structures against collapse. Its solution determines the ultimate load at which structures fail or deflect excessively.
The theory of stability is of fundamental significance for mechanical engineering, aerospace engineering, nuclear engineering, structural engineering and other engineering applications. It has an important role in many problems of space structures, geophysics, geotechnical structures, and materials science [4].
The (p_{cr}) is the maximum vertical frame loading permissible. The frame arrangement, the horizontal beams and columns cross-sections, and the arrangement, as well as the connections stiffness among them, all

contribute to this stress. Vertical loading is technically challenging to execute in existing non-destructive techniques of measuring the side sway frames critical load, which is especially important during full-size tests [5].

Structures can fail for a variety of reasons, including if the whole structure or members reach the yield or the ultimate strength, exceeds the peak deflection, or if the members fracture or collapse. Buckling is a broad word referring to a situation in which a structural element in compression deviates from the behavior of elastic shortening within the original geometry and endures substantial deformations involving a change in member shape for a relatively minor increase in load [6].

Buckling phenomenon can be described as bending of structural members under axial compressive load. Columns are slender members that support the axial compressive load. If the compressive load excessive, a column may fail due to the instability of the structure called buckling. Hence, the problem of the buckling of the columns is a very important issue. Underestimation of this effect may lead to disastrous results or unjustified factors of safety [7].

The current study will verify the miniature mechanical testing for stainless steel type 304 which is used in all commercial, industrial and domestic fields because of its good heat resisting properties and corrosion. Some applications include tanks and containers for a large variety of liquids and solids process equipment used in mines, cryogenic, chemical, food, dairy and pharmaceutical industries and drilling operations [8].

The adjective ‘stainless' denotes the absence of staining, rusting, or corroding in habitats The word ‘steel' denotes that iron constitutes the majority of the material, but the adjective ‘stainless' denotes the absence of staining, rusting, or corroding in settings [9].

Corrosion is a material degradation as a consequence of its reaction with its surroundings. Degradation refers to a material's physical qualities deteriorating. This can have a detrimental impact on the material due to the loss of cross-sectional area, and it can also cause the metal to corrode due to hydrogen embrittlement. Because it is generally recognized that seawater is an aggressive corrosive environment, corrosion is prevalent in offshore and marine constructions [10].

Many structural elements are subjected to a variety of corrosive environments in addition to stresses and temperatures. These characteristics frequently occur in unfavorable combinations, lowering the structure's load carrying capacity and service life. Neglecting

corrosive environments in the analysis might result in the system shutting down prematurely and unexpectedly, causing significant environmental and economic damage [11].
If the column is exposed to a dynamic axial load, it transits from one steadiness condition to another. The critical load is the greatest load that a column is able to bear prior to approaching unbalanced steadiness. Any additional increment in the load may cause a disastrous collapse. The critical load of the columns occurs inside the column's flexible border [12].

1.2 Treatments of Surface

Peening is commonly employed in manufacturing for reducing or eliminating the fatigue or the stress corrosion, with numerous fresh methods that are tested for competing with existing methods [13].
They're compared in terms of the cost of technique, the simplicity usage, the finish of surface, the plastic work levels, the concentration of the compressive remaining stress presented in material, and the depth of the compressive remaining stress presented in material. The highly famous peening methods utilized today in industry are the shot peening as well as the laser shock peening, the two of which have benefits and drawbacks.
Due to its low cost, shot peening is the most commonly used method; however, laser peening outperforms SP in terms of finish of surface, surface compressive remaining stress intensity, and compressive remaining stress depth [14].
There're various innovative peening procedures that may be viable with existing methods. At such point in the current peening procedures evolution, it appears that a comparison of the present and fresh approaches has to be done. Ultrasonic impact treatment is one peening technology that has been investigated; nevertheless, there're few outcomes upon the Austenitic Stainless Steel (304), which being a famous engineering stainless steel utilized in the industry [15].
Shot peening is a typical mechanical surface treatment used to improve the fatigue characteristics and corrosion resistance of metallic components by introducing severe plastic deformation and compressive residual stresses into the near surface area, shot peening, in general, causes changes in the refinement of grain as well as the roughness upon the metallic materials surface [16].

Surface roughness, as a critical surface property, is extremely significant in practical applications. Several researches have been published that demonstrate the importance of roughness [17].
However, there is currently a scarcity of data on the corrosion aspects of shot peening. The literature on corrosion resistance after shot peening is contradictory, with no obvious trend, shot peening-induced surface nano crystallization increased corrosion resistance [18].
When compared to untreated materials, shot peening increased surface roughness and decreased corrosion resistance [19].

1.3 Corrosion

Corrosion is the destructive attack of a metal on its surroundings caused by a chemical or electrochemical process. Physical deterioration is referred to as erosion, galling, or wear rather than corrosion. In certain cases, chemical assault is accompanied with physical degeneration, as indicated by the terms:
Corrosion can be defined as erosion, corrosive wear, or fretting corrosion. Nonmetals are not included in this corrosion definition. Plastics can expand or crack, wood can split or rot, granite can erode, and Portland cement can leak away.
"Rusting" refers to the corrosion of iron or iron-base alloys that results in the development of corrosion products mostly composed of hydrous ferric oxides. As a result, nonferrous metals corrode but do not rust [20].
"Corrosion is an irreversible interfacial interaction of a substance (metal, ceramic, and polymer) with its environment that results in the consumption or dissolution of a component of the environment into the material." Corrosion frequently, but not always, has a negative impact on the material under consideration's use. The word corrosion excludes just physical or mechanical processes like as melting and evaporation, abrasion, or mechanical fracture." With a better understanding of the involvement of diverse microorganisms found in soil and water bodies, the definition of corrosion must be expanded to include microbially-influenced elements. Corrosion may be classed into two types: Chemical and electrochemical. Temperatures are both high and low. There're two types of corrosion, wet corrosion and dry corrosion [21].
Environmental factors such as the presence of oxygen and other oxidizers, variations in flow rates (velocity), temperature, reactant

concentrations, and pH would all have an impact on the rates of anodic and cathodic reactions [22].
Despite the fact that the basic process of corrosion requires the formation or presence of corrosion cells, there are various types or forms of corrosion that can occur.

The most important types are

- Uniform corrosion.
- Galvanic corrosion, concentration cells, water line attack
- Pitting.
- Dezincification, Dealloying (selective leaching)
- Atmospheric corrosion.
- Erosion corrosion
- Fretting
- Crevice corrosion; cavitation
- Stress corrosion, intergranular and transgranular corrosion, hydrogen cracking and embrittlement
- Corrosion fatigue [23].

1.4 Research Problem

Buckling is one of the important topics studied by many researchers. This topic is related to many mechanical parts and structural compositions and to the various forms dealt with by the subject. Also, most structures are subject to corrosion when part of them is immersed in sea water, which negatively affects the columns and reduces their resistance to critical loads and increases the possibility of buckling and collapsing structures. Therefore, it was necessary to study the critical loads of long and intermediate columns without corrosion in oil field, as well as to study the effect of corrosion on these columns when it is immersed in the seawater for a period of time in Ports and commercial docks field.
With a choice of suitable formula to be more compatible with the experimental results and are approved in the future for engineers and researchers in petroleum filed.

1.5 Thesis Objectives

The purpose of this study is to investigate the lateral buckling of columns under dynamic loading. To accomplish these goals, the following measures were taken:-

1. Utilizing a test rig capable of imposing dynamic loads (compression, torsion) as well as carrying out applied tests for an perfect column beneath the dynamic loads.
2. Examining the corrosion (WC 90 days) effect on the buckling behavior of 304 stainless steel specimens.
3. Examining the influence of surface treatments (SP) on the buckling behavior of 304 stainless steel specimens.
4. Theoretically, estimating the critical load of the columns using (Euler, and Rankine) calculations.
5. Calculate the buckling load numerically using (SOLIDWORKS 2018).
6. Comparison of experimental findings achieved with Euler, Rankine, and SOLIDWORKS (software2018) formulas, with a declaration of which formula is highly satisfactory in terms of the applied outcomes.

1.6 Thesis Layout

- **Chapter one** contains an introduction to the present thesis as well as the main rationale for such research, as well as the work's aim and objective.
- **Chapter two** is devoted to a review of the published literature on column buckling resistance. Based on the findings in the literature, a proposal for a changed design strategy is offered.
- **Chapter three** presents the theoretical considerations of the phenomenon of buckling beneath an axial compression load. Also, buckling theories (Euler, Rankine) are introduced.
- **Chapter four** illustrates the experimental work concerning the columns buckling with the rest period and without the rest period properties involved in the present work. The layout of the specimens' test set-up, the measured quantities, and further being clarified.
- **Chapter five** comprises the experimental and theoretical outcomes and their debate.
- **Chapter six** involves with the conclusions as well as certain recommendations for the upcoming works.