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Interaction of axial, shear and bending loads in buckling behavior of pierced and non-pierced long steel plates

A. Yazdi [1], M. Alembagheri [2*]

[1] Department of Civil Engineering, Amirkabir University of Technology, Tehran, Iran

[2] Department of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran

ABSTRACT: Nowadays, there is a spread use of plates for various purposes because of their good performance and economic advantages. Hence, it seems that it is necessary to investigation the plate behavior. In this study buckling behavior of long plates under the combination of bending, shear and axial loads are studied using the finite element method. The effect of boundary conditions of the long plate under the combination of loads is considered. The effects of adding holes to the long plates are also considered. The holes have various radii with a unique array. The behavior of load intersection in non-pierced and pierced plates is compared. The loading consists of bending, axial and shear which all of them are in-plane and are applied to the plates' edges. For this purpose, more than 1000 models were created. For the investigation, two of the loads are applied to the plate and the load bearing capacity of the third load is calculated. Results showed that long plates under axial load have less sensitivity to holes in comparison with the shear and the bending loads. The holes with diameters equal to or less than 0.06 of plate's width can hardly influence the buckling behavior.

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1. INTRODUCTION

Steel materials have widespread uses and commonly used in steel structures and construction of buildings such as offshore and onshore structures. So there is a widespread demand to evaluate and investigate steel plate behaviors. Various parameters may affect on the mechanical performance of steel plates under the combination of loads such as boundary conditions, the interaction of loads on plate edges and thickness of steel plates. For this purpose current research concentrates on investigation of long steel plates under interaction of in-plane loads.

Over the last decades, extensive research studies were carried out to find out the performance of steel plates. Recently Rossow et al. investigated stiffened plates by using FEM analysis [1]. In another evaluation in 2013 behavior of plate girders' web under the combination of loads was evaluated [2]. Loads consisted of in-plane axial, shear and bending loads. Results showed the effect of the greater load on plate behavior is significant. In a research, plates with various boundary conditions, aspect ratio, thickness and ratio of loads was investigated [3]. Results showed aspect ratio of plates can determine to happen of plastic or elastic buckling of the plate. In another research buckling behavior of plates was carried out [4]. This investigation concentrates on shape modes and buckling loads. Also, a rectangular steel plate under the combination of axial and shear load was investigated [5]. In this research 3D, finite element method used. Another investigation was concentrated on rectangular and square plates with simple support edges investigated. Plates contain a hole with diameters of 0.1 and 0.7 of plate width. Results showed the result of small holes are more accurate than plates with bigger holes [6]. In a similar experimental investigation on square plates, it was proved that there is a good agreement between numerical and analytical methods [7]. Plastic buckling of pierced steel plate by using the Rayleigh-Ritz method was evaluated [8] and the investigation of plates under the combination of loads with anisotropic materials was carried out. Results consist of buckling mode and effect of anisotropic materials on buckling loads [9].

*Corresponding author's email: alembagheri@modares.ac.ir

In the current research, initially critical load bearing capacity of plates under each of shear, in-plane bending and axial load were investigated which is consisted of two boundary conditions (clamp and simple support on longitudinal edges). In the second step, buckling mode and the critical load of plates under the combination of loads were carried out. Finally, the effect of removing materials by adding holes to the plate was investigated. Holes are of varying diameters. For this purpose, Finite element method was carried out by use of ABAQUS software.

2. METHODOLOGY

For the present investigation, finite element method was carried out. In the finite element modeling, shell elements

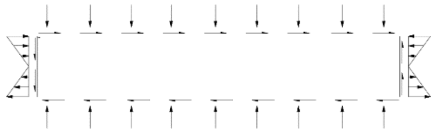

Fig. 1. Load combinations were applied to the plate

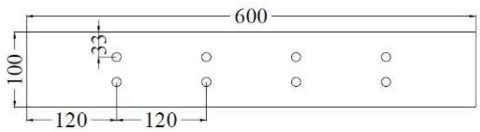

Fig. 2. A Typical pierced plate

Table 1. Steel material properties

υ	E(Mpa)
0.3	210000

were used to model Steel. For longitudinal edges clamp or simple support were considered and short edges were simple supports. All of the edges were constrained for out of plane degrees of freedom. Length and width of plates are 600 cm and 100 cm with Thickness of 1 cm. It was assumed that there is no out of plane loads and all of the loads are in-plane of steel plates. In-plane bending was considered on the short edge of plates and axial loads were applied perpendicularly to the longitudinal edges as shown in Figure 1. For investigation of loads interaction, at the first analysis, two loads were applied to the plate in static analysis and finally the third load calculated by use of buckle analysis. Also, elastic behavior for steel materials was considered as shown in Table 1.

In pierced plates, a uniform array for holes was considered which is consist of 8 holes as shown in Figure 2. The holes diameters are 0.06, 0.12, 0.18, and 0.24 of plate width. In finite element analysis, fine mesh was used to accurate calculated results. The meshes are as fine as the results do not change more than 5% by using finer meshes.

3. RESULTS AND DISCUSSION

3.1. Verification study

For verification study similar plate with steel materials was considered and interaction of loads was investigated and results were compared with results which were obtained from the analytical method by Gerard [10] and also, another verification was carried out by using theoretical equations and comparing the analytical results and numerical results. Equations 1 and 2 calculate the critical buckling load of steel plates under pure axial and pure shear load respectively [2]. The results are in good agreement with theoretical ones.

$$\boldsymbol{\sigma_{cr} = K_{axial} \times \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2} \quad \textbf{(1)}$$

$$\boldsymbol{\tau_{cr} = K_{shear} \times \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2} \quad \textbf{(2)}$$

The parameters in Equations 1 and 2 are defined as follow:

$$K_{axial} = \left(\frac{\varphi^2}{M^2} + \frac{M^2}{\varphi^2} + 2\right) \quad (3)$$

$$\boldsymbol{K_{shear} = 5.34 + \frac{4}{\varphi^2}} \quad (4)$$

Plate length to width aspect ratio is φ and the number of half waves in the longitudinal direction of the plate is M.

3.2. Unpierced steel plate

The results show plates with longitudinal clamp support and simple support. Plate with clamp longitudinal support shows increases in load bearing capacities significantly in comparison with the plate with simple support. Appling of pure axial load hardly decreases load bearing capacity but applying the combination of two loads decrease load bearing capacity especially critical bending load. Results are represented as a critical load under the combination of other two loads.

3.3. Pierced steel plates

Results are based on the investigation of holes' diameters effect on load bearing capacity. Holes with diameters equal to 0.06 of plate width can hardly effect on load bearing capacity. Results show bending load is more sensitive to holes in comparison with other loads. Holes with the ratio of diameters to plate width equal to 0.12 decrease load bearing capacity 6% and 11% for shear and axial load respectively and holes with the ratio of 0.18 decrease bending capacity at least 40% in comparison with non-pierced plates. Holes interrupt tension fields in plates under shear load that leads to a decrease in shear load capacity.

Comparison of results show bending load is the most sensitive load to adding holes and axial load is less effective.

4. CONCLUSIONS

Based on the results it can be concluded as follow:

1. Effect of load interaction in plates with clamp long edges is more than simple support.
2. Load bearing capacity of plates with simple support significantly increases by using clamp support.
3. The negative impact of holes on bending capacity is more than the other 2 loads.
4. Applying one the loads equal or more than 60% of critical load can decrease other loads capacity significantly.
5. Holes with the ratio (hole diameter to plate width) of 0.18 or greater values can lead to instability of the plate under lower loads.

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