Aksaray University
Journal of Science and Engineering
e-ISSN: 2587-1277

http://asujse.aksaray.edu.tr

Aksaray J. Sci. Eng.
Volume **6,** Issue **1,** pp. **71-78.**
doi: 10.29002/asujse.1097633
Available online at DergiPark AKADEMİK

Research Article

Eigenvalue Buckling Analysis of Beams with Different Width and Square Cutouts

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▪*Received Date:* Apr 02, 2022 ▪*Revised Date:* Jun 05, 2022 ▪*Accepted Date:* Jun 06, 2022 ▪*Published Online:* Jun 17, 2022

Abstract

In this study, effect of square cutout and beam widths on eigenvalue buckling analysis of beams is evaluated using finite element and Taguchi methods. ANSYS software is used to perform the finite element analyses and the analyses were conducted Taguchi L9 orthogonal array with three control factors. Each control factor has three levels. The first control factor is considered as position of square cutout whereas the second control factor was assumed as beam widths. The influence of levels of the beam widths and square cutouts on responses is determined using analysis of signal-to-noise ratio whereas variance analysis was operated to notice the effect of each control factor on the buckling behavior of the beams. According to results obtained from the study, the buckling value of the beams increase as the square cutout get closer to the free edge. Increase of the beam widths leads to an increase on buckling result of the beams. The effect of beam width on the buckling analysis is higher than square cutout.

Keywords

Beam, Cutout, Buckling, Finite element method

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1. INTRODUCTION

Buckling analysis of isotropic beams can be a research topic for solid structure mechanics. The isotropic beams with cutouts have been used in different areas such as automotive industry, shipbuilding, aviation, steel structure. The buckling behavior of isotropic beams and plates has attracted the attention of many scientists. In literature, there are many studies examining the buckling behavior of isotropic beams. The buckling behavior of plates including cutout under non-uniform in-plane forces was evaluated [1]. The buckling behavior of isotropic and orthotropic plates was analyzed [2]. The buckling analysis of thin isotropic plates under different boundary conditions was presented and the plates were made of circular cutouts [3]. The buckling behavior of plates which have rectangular shape according to various compressions was reported [4]. The buckling loads of plates which have tapered thickness was investigated and impact of plate thickness and aspect ratios were analyzed [5]. The buckling behavior of thin plates using differential quadrature method and the plates had rectangular geometry was evaluated [6]. The buckling analysis of plates under various boundary conditions was presented [7]. The nonlinear buckling analysis of isotropic and FG thin-walled beams was presented and finite element approach was used in study [8]. The critical buckling behavior of structures made of isotropic, functionally graded materials, and laminated composite under simply supported boundary conditions was analyzed [9]. The buckling characteristic of isotropic and orthotropic cylinders based on induced moments was evaluated [10]. Buckling behavior of carbon nanotubes was analyzed [11]. Buckling behavior of thin isotropic plates and columns was investigated depends on the comparative use of different methods [12]. The buckling behavior of microbeams designed using the functional grading method was investigated [13]. As can be seen from the researched literature review, there are many buckling analysis of plates and beams under different boundary conditions. In this study, influence of square cutout and beam widths on eigenvalue buckling analysis of beams was calculated using finite element and Taguchi methods.

2. MATERIALS AND METHODS

The beams were designed using Steel material. Elasticity module of the steel material was used as 200 GPa. Design of numerical analysis was conducted Taguchi L9 orthogonal array with three control factors including three levels. The first control factor was assumed as beam width with 20 mm, 25 mm, and 30 mm whereas the second control factor was considered as square cutout position with 50 mm, 100 mm, and 150 mm according to clamped ends. The control factors and their levels were showed in Table 1. Signal to Noise (S/N) ratio analysis was performed to see the effect of control factor at each level on critical buckling load of the beams in accordance with the first mode.

Table 1. Control factors and levels

Control Factors	Symbol	Unit	Levels		
			Level 1	Level 2	Level 3
Beam Width	A	mm	20	25	30
Cutout Position	B	mm	50	100	150

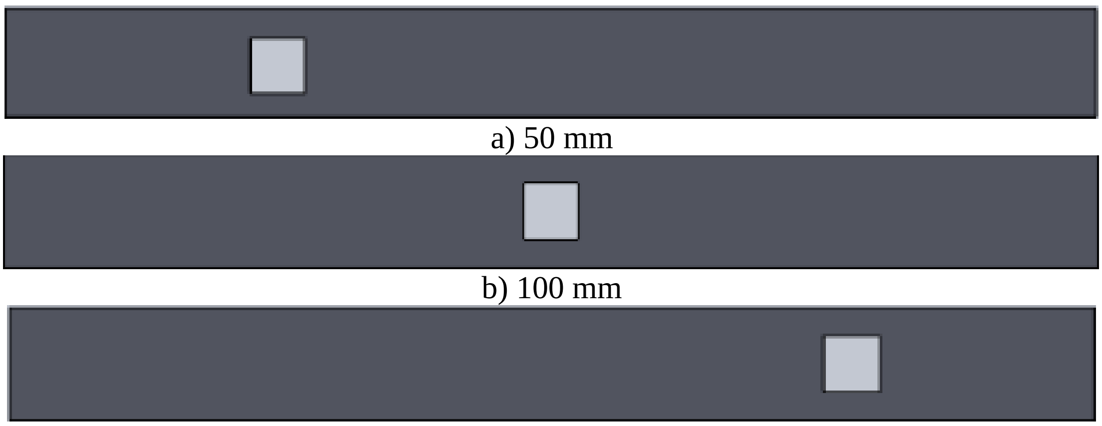
In analysis, "higher is better" quality characteristic to obtain the maximum buckling value of the beams was used and it was showed in Equation 1 [14].

$$(\mathrm{S/N})_{\mathrm{HB}} = -10.\log\left(\mathrm{n}^{-1}\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{y}_{\mathrm{i}}^{2})^{-1}\right) \quad (1)$$

where, n was used as the number of buckling analysis in a trial and y_i displays i^{th} data applied.

3. FINITE ELEMENT APPROACH

Finite element analysis was performed using ANSYS Workbench software. Mesh operations were carried out as linear based on element order. Element size was used as 0.5 mm. Numerical analysis for each beam was performed using eigenvalue buckling method. The beam length was assumed as 200 mm. Size of each square cutout was determined as 10mm x 10mm. Positions of cutouts in accordance with fixed end of beam were considered as 50mm, 100mm, and 150mm. The beams have fixed ends and free ends. 1 N force on free side of the beams was applied and the other end was assumed as fixed end. Cutout positions were demonstrated in Fig. 1.



a) 50 mm

b) 100 mm

c) 150 mm

Figure 1. Cutout positions on the beams

4. RESULTS AND DISCUSSION

This study deals with the investigate the effect of beam widths and square cutout position on the buckling behavior beams made of steel material. Test design for finite element calculations was conducted using L9 orthogonal array based on Taguchi Method. Nine analyses were carried out using ANSYS Workbench. Buckling analysis was performed as numerical approach and each result was converted S/N ratio. The results calculated for numerical and S/N ratio data were demonstrated in Table 2.

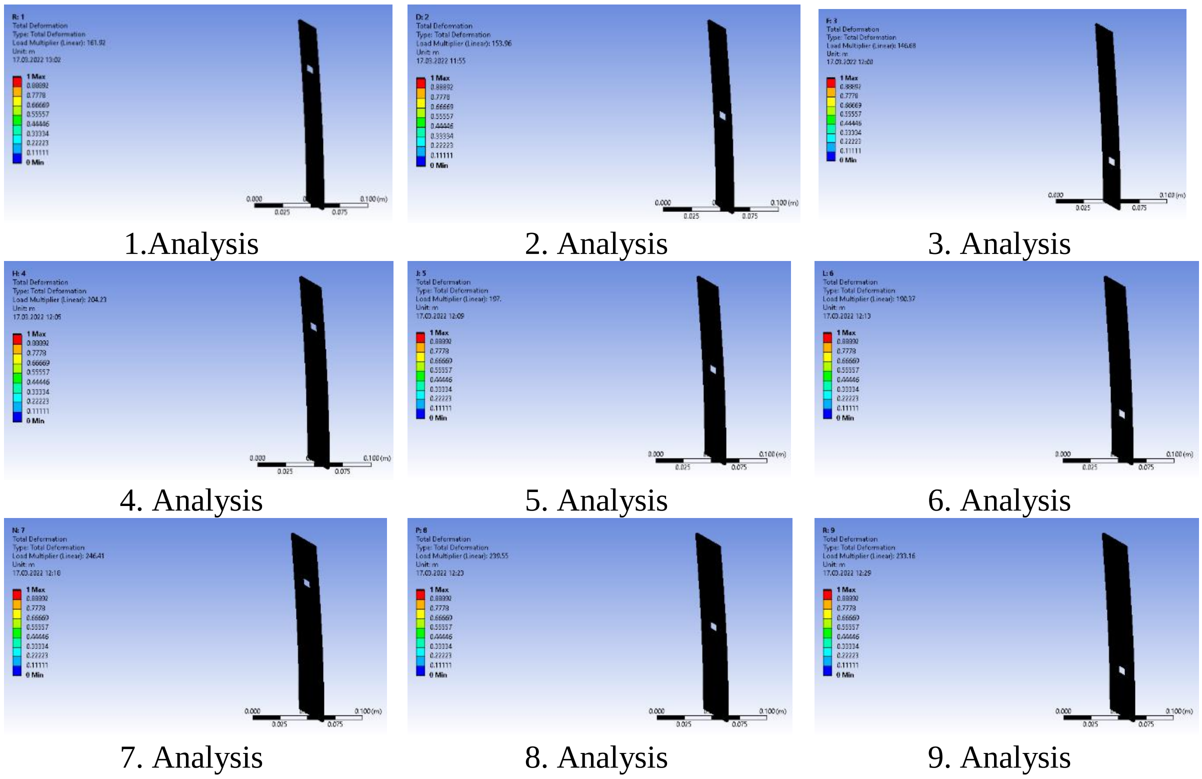


Figure 2. Numerical results

Table 2. Results for numerical and S/N ratio analyses

Analysis	Control Factors		Results	
	A	B	Buckling Load P (N)	S/N ratio η (dB)
1	A_1	B_1	161.92	44.1860
2	A_1	B_2	153.96	43.7482
3	A_1	B_3	146.68	43.3274
4	A_2	B_1	204.23	46.2024
5	A_2	B_2	197.00	45.8893
6	A_2	B_3	190.37	45.5920
7	A_3	B_1	246.41	47.8332
8	A_3	B_2	239.55	47.5879
9	A_3	B_3	233.16	47.3531
Overall Mean ($\overline{T_P}$)			197.03	-

According to Table 2, the overall mean for the buckling loads of the beams based on Taguchi L9 orthogonal array was calculated to be 197.03 N. Finite element analysis results obtained using ANSYS Workbench software for each beam under clamped-free boundary conditions were illustrated in Fig. 2. As can be seen from Fig. 2, the maximum affected areas of the beams for buckling load was detected for the free ends of the beams whereas the minimum affected fields for the buckling load was implemented for the clamped ends.

4.1. Selection of Optimum Levels

To obtain the optimum levels for each control factor, S/N ratio analysis was performed using Minitab R15 statistical software. Average numerical buckling value obtained using ANSYS software and their S/N ratio data for each level of each control factor were solved and the results were tabulated in Table 3.

Table 3. Response table for S/N ratio and means

Level	S/N ratio		Mean	
	A	B	A	B
1	43.75	46.07	154.20	204.20
2	45.89	45.74	197.20	196.80
3	47.59	45.42	239.70	190.10
Delta	3.84	0.65	85.50	14.10
Rank	1	2	1	2

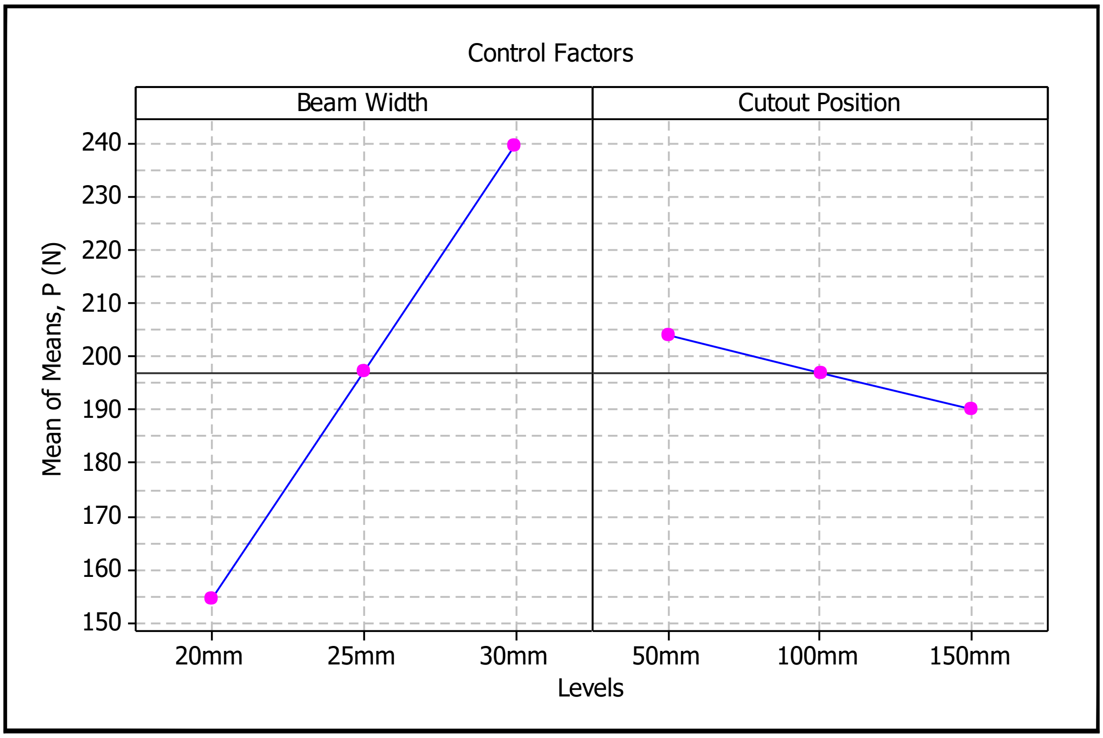


Figure 3. Effect of levels of control factors on buckling behavior

According to Table 3, the optimum level of the first control factor was determined as the third level whereas the optimal level of the second control factor was detect as the first level. To see the effect levels of the control factors on the buckling behavior of the beams, average data in Table 3 were plotted in Fig. 3.

The increase of the beam widths causes an increase in critical buckling load of the beams Also, cutout closer to fixed end decreases the critical buckling loads of the beams in accordance with free end. These situations can be explained by the increase in beam stiffness. To determine the significant control parameters on the buckling load of the beams, analysis of variance (ANOVA) was carried out at 95% confidence level. ANOVA result was listed in Table 4.

Table 4. ANOVA for buckling load

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Effect
A	2	10970.60	10970.60	5485.30	21033.11	0	97.34
B	2	299.10	299.10	149.50	573.42	0	2.65
Error	4	1.00	1.00	0.30			0.01
Total	8	11270.80					100

As can be seen from Table 4, the first and the second control factors have 97.34% and 2.65% effects on the critical buckling load of the beams for the first mode, respectively. Beam width and square cutout position were calculated to be significant control parameters due to P value < 0.005 data. The optimum value for the maximum critical load on buckling analysis of the beams were calculated using the significant control factors.

4.2. Estimation of Optimum Buckling Value

To estimate the combination of control factors with optimal levels, the powerful control factors were used. The powerful control factors were presented in ANOVA result in accordance with P<0.05 value. The estimated mean of buckling load for the first mode can be solved using Eq. 2 [14].

$$\mu_P = \overline{A_3} + \overline{B_1} - \overline{T_P} \tag{2}$$

Where, $\overline{T_P}$ = 197.03 was considered as the overall mean of critical buckling load of the beams in accordance with L9 orthogonal array. $\overline{A_3}$= 239.70 and $\overline{B_1}$= 204.20 were used as the third level of the first control factor and the first level of the second control factor, respectively. Substituting the finite element buckling load data of different terms based on Eq. 2, and so μ_P was calculated as 246.87 N. The optimal numerical and predicted result were given in Table 5.

Table 5. Optimal results for estimated and numerical calculations

Description	Estimated Result	Numerical Result	Residual
A_3B_1	246.87N	246.41N	±0.46

5. CONCLUSIONS

The is numerical and statistical study deals with the analysis of effect of square cutout and beam widths on eigenvalue buckling behavior of beams using finite element and Taguchi methods. Numerical buckling analysis was finite element software ANSYS Workbench based on Taguchi L9 orthogonal array. The beam widths and position of square cutout were used as control factors. Importance levels of control factors and their contribution ratios were determined using analyses of S/N ratio and variance. Based on the numerical and statistical analyses presented in this study the conclusions are as follows:

- The buckling value of the beams increase as the square cutout get closer to the free edge.
- Increase of the beam widths causes an increase on buckling result of the beams.
- Optimal buckling value for the maximum data was found to be A_3B_1 definition.
- The beam width and the square cutout have 97.34% and 2.65% impacts on the critical buckling load of the beams for the first mode, respectively.
- As can be understood from ANOVA, beam width and square cutout position were noticed as high-importance parameters due to P value < 0.005 data.
- The maximum affected areas of the beams for buckling load was occurred at the free ends whereas the minimum affected fields for buckling load was performed at the clamped ends.
- Estimated and numerical buckling results were calculated as 246.87N and 246.41N, respectively and residual between results was found as ±0.46.

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