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The behavior of angle steel section used as a stiffener in plates under axial load with lateral pressure for various plate slenderness ratios and with simple and fixed supported conditions

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Abstract

The current study offers a non-linear elastoplastic FEM analysis utilizing the ABAQUS program of the experimentally investigated collapse behavior of stiffened steel plates. Twelve samples are used in the experiment with a range of 76 and 100 slenderness ratio. The test specimens' stresses, axial shortening, and lateral deflections are also measured. The elements are classified as being of type S4R in ABAQUS nomenclature by the analysis using ABAQUS. The FEM findings were contrasted with experimental data published in the literature. The previous research studies used the rectangular section as stiffeners so the purpose of this research is to use an angle section instead of a rectangular as a stiffener and investigate the benefit of angle steel sections to resist the load and increase the strength of the plates in two cases simple and fixed support.

Keywords: Angle steel section, stiffened plates, lateral pressure, axial load, nonlinear, Abaqus software.

Introduction

Stiffened steel plates are widely utilized for offshore and aerospace structures, box girder components, bridge decks, and ship decks and hulls. In maritime and offshore structures, stiffened plates often experience the combined effects of lateral and in-plane loads. Stiffeners can be offered in either longitudinal or transverse orientations or both. Stiffening helps create designs that are affordable and lightweight. The final load capacity of the plate is greatly increased by the presence of stiffeners, but the design is difficult because more parameters are involved. Angle sections are frequently employed in contemporary roof buildings and they frequently undergo biaxial bending and torsion. Their behavior can be exceedingly complex, making it challenging to estimate their strengths with any degree of accuracy as shown in the figure:

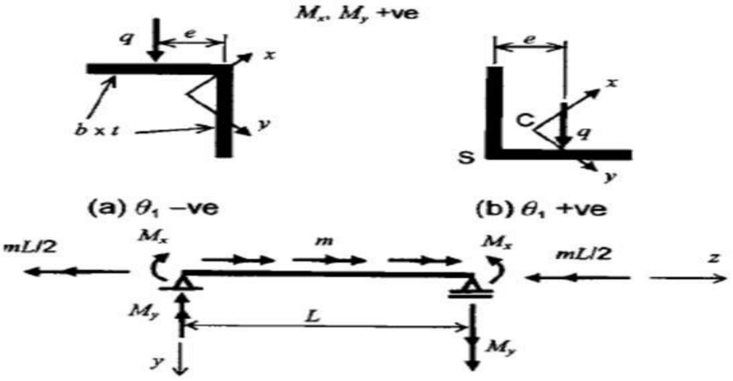


Fig.1 *Torsion in angle section due to eccentricity e (Trahair, 2001, 2005).*

Research gap

There are many papers studied the steel plate subjected to various actions studying it under shear in the plane when the plate is unstiffened and stiffened (Alinia et al., 2009; Alinia & Dastfan, 2007) and also unstiffened plate under axial compression load (Saad-Eldeen et al., 2015) and stiffened plate under lateral pressure and axial load (Shanmugam et al., 2014) but most of the recent paper was studying the plate when the stiffeners are rectangular shape or other shapes (Paik, Thayamballi, Pedersen, et al., 2001; Suneel Kumar et al., 2009) so in this paper will study the angle stiffeners shape and their behavior with axial and lateral pressure in two cases simple and fixed support because they are widely using in modern steel construction in these days.

Materials and Dimensions: (Shanmugam et al., 2014).

A- Using the slenderness ratio, the plates were split into groups, group A and group B, which is equal to 100(b/t=290/2.9=100) and 76(b/t=220/2.9=76) for groups A and B respectively.

B- Plate dimensions for both groups as the figures (1), (2).

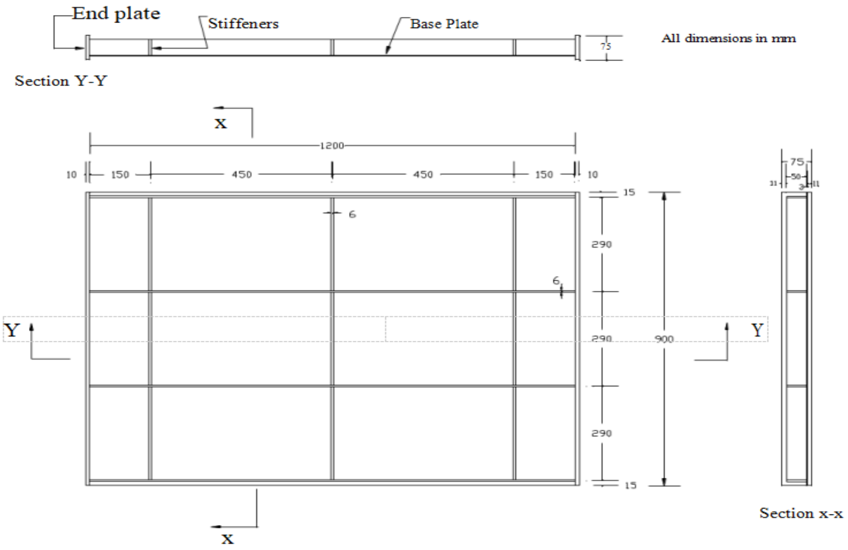


Fig.2 *A plates' dimensions (mm).*

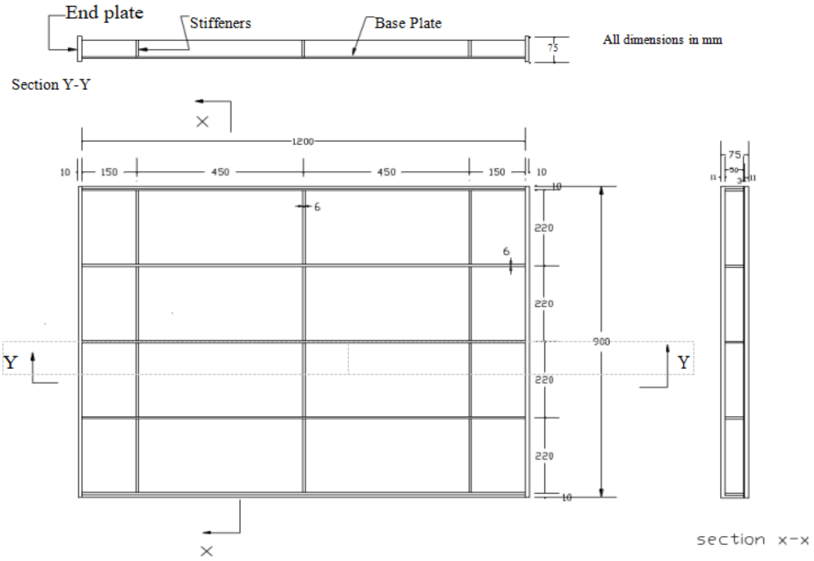


Fig.3 *A plates' dimensions (mm).*

C- Base plate and stiffener material properties

Table 1 *Material specifications for plate and stiffeners.*

	Sample no.				
	1	2	3	4	Average
Base plate					
yield strength(N/mm2)	343	368	335	341	**347**
Young's modulus E (Gpa)	204	190	197	172	**191**
Stiffeners					
yield strength(N/mm2)	333	335	327	337	**333**
Young's modulus E (Gpa)	185	191	199	199	**194**

Experiment study (Shanmugam et al., 2014)

In this study, stiffened plates could be examined using a test apparatus that could withstand both lateral pressure and an in-plane load. Figure 3 depicts the test rig in the section. The axial loading frame has an extraordinarily rigid thrust girder to entirely transfer the specimen's axial load from hydraulic jacks. The specimen was subjected to lateral pressure using a bag that fills the air with over of 914 mm x 914 mm.

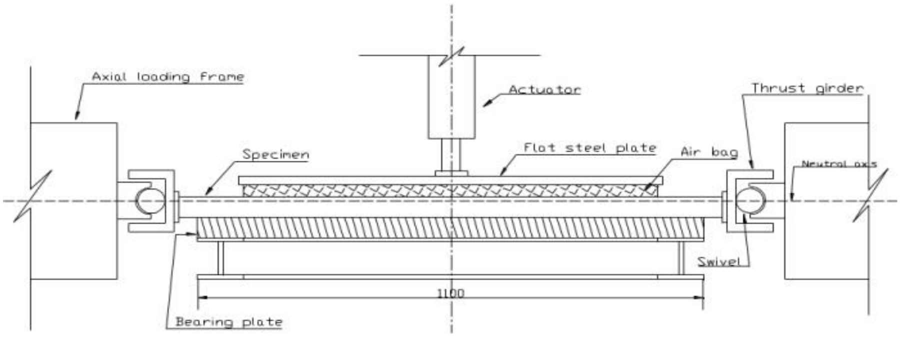
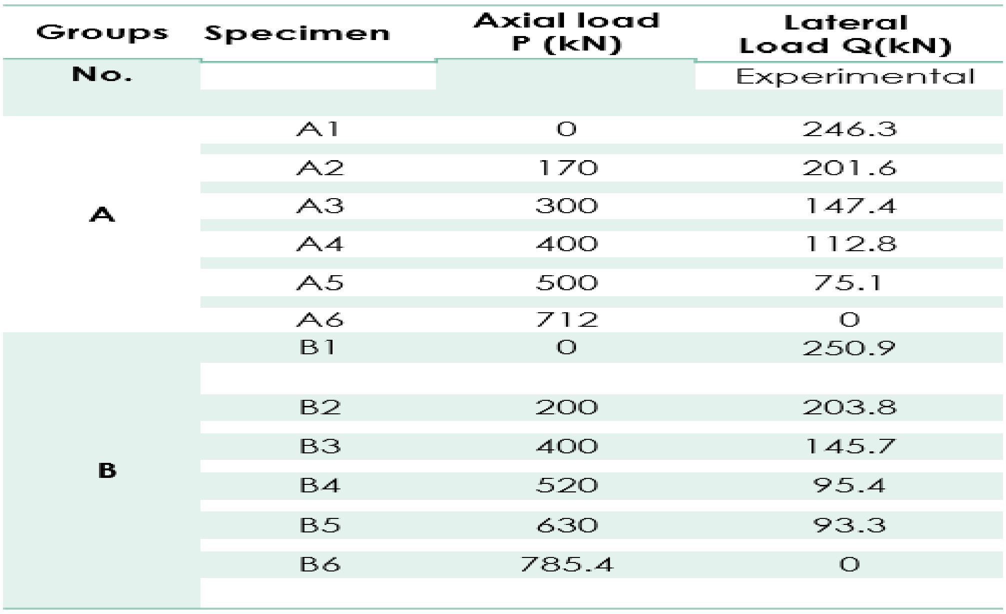


Fig. 4 *Device's section is used in the experiment*

All of the specimens for both series were put to the test until they failed under various loading configurations. Only lateral pressure was used to test A1 and B1 until they failed. Only axial loads were used in the tests on A6 and B6. The remaining specimens were put to the test until they broke under various combinations of axial force and lateral pressure.

Table 2 *Axial and lateral load from the experiments.*



Groups No.	Specimen	Axial load P (kN)	Lateral Load Q(kN)
			Experimental
A	A1	0	246.3
	A2	170	201.6
	A3	300	147.4
	A4	400	112.8
	A5	500	75.1
	A6	712	0
B	B1	0	250.9
	B2	200	203.8
	B3	400	145.7
	B4	520	95.4
	B5	630	93.3
	B6	785.4	0

1- **FEM analysis** (Cho et al., 2013; Ghavami & Khedmati, 2006; Paik et al., 1999; Paik, Thayamballi, & Kim, 2001; Paik & Kim, 2002; Pan & Louca, 1999; Smith, 2021; Srivastava et al., 2013).

The elements are classified as being of type S4R in ABAQUS nomenclature by the analysis using ABAQUS. The S4R element was selected because it is a potent four-node standard ABAQUS plate-bending element that considers thickness changes and finite membrane strain into account. The right choice of material model in ABAQUS can account for material non-linearity. The analysis of general collapse is appropriate for the classical metal plasticity model. The traditional von Mises yield surface models with the related plastic flow are used in the ABAQUS classical metal plasticity models. According to this yield surface, the metal's yield is independent of the corresponding pressure stress. As the material yields, associated plastic flow indicates that the inelastic deformation rate is in the direction perpendicular to the yield surface. Perfect plasticity and a non-linear elastoplastic model were both used in the current investigation. Non-linear analysis was carried out during the analysis step to take into account significant non-linearity. To validate the accuracy of the FEM research, boundary conditions are modeled as closely as feasible to the real experimental conditions. Models of stiffened plates merely supported the plate along the edge stiffeners. To mimic the real boundary circumstances in the experiment, all nodes along the boundaries were constrained in the vertical direction, while the nodes along one of the transverse edges were restrained in the longitudinal direction. In the model, two corner nodes along one of the longitudinal edges were constrained to stop stiffened plates from freely moving in the transverse direction.

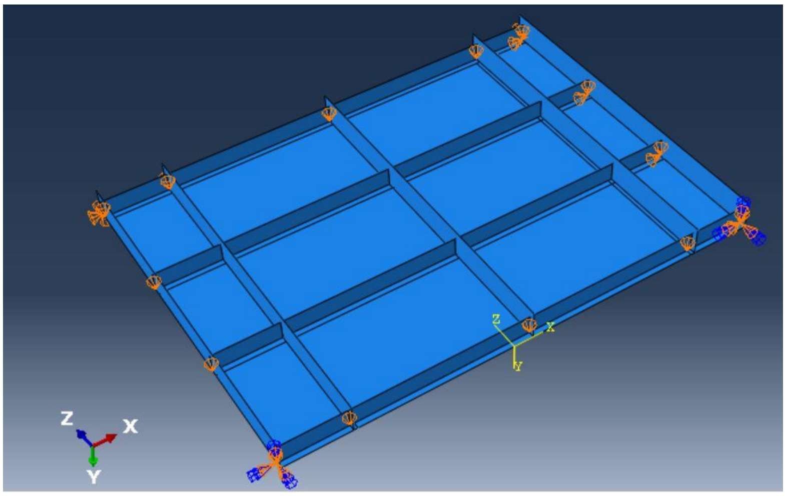


Fig.5 *Edge Angle section stiffener and pale's boundary conditions.*

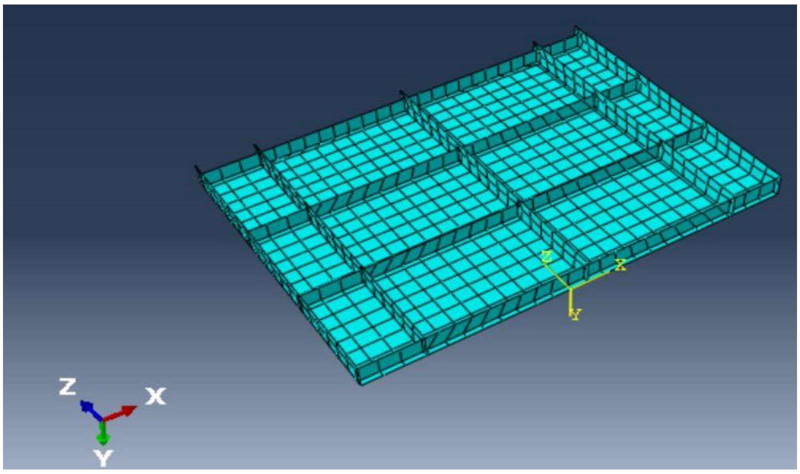


Fig.6 *Modeling mesh*

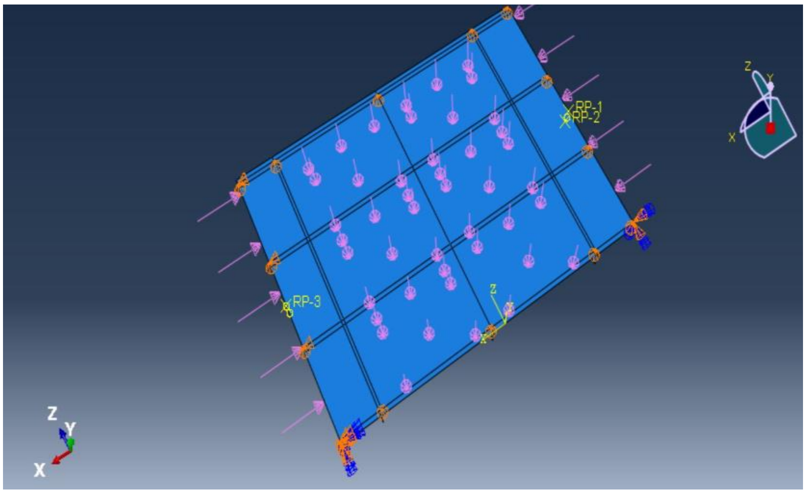


Fig.7 Acting loads in modeling

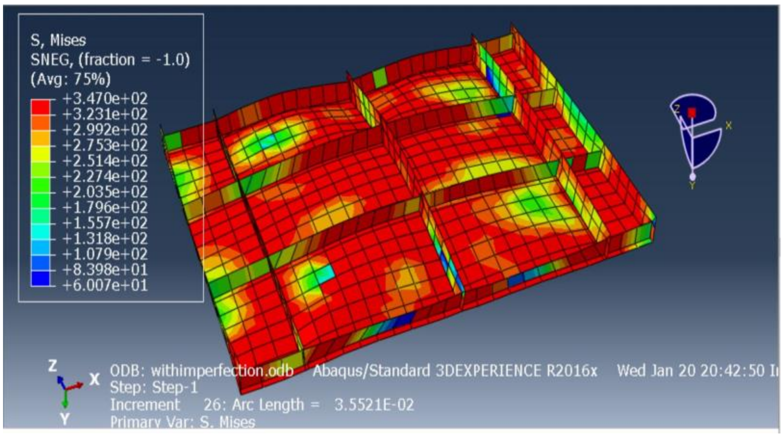


Fig.8 *Abaqus' failure mode.*

Fig.9 *Experiment's failure shape (Shanmugam et al., 2014).*

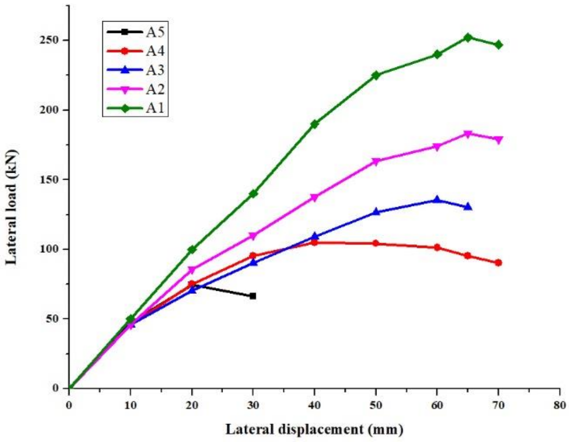


Fig.10 *Relationship between lateral load and displacement in A group*

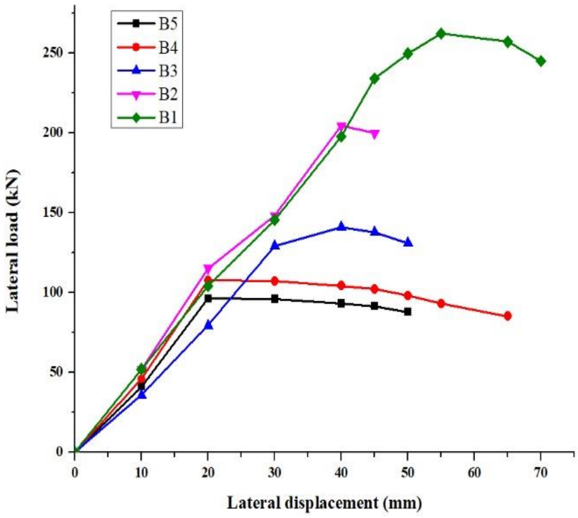


Fig.11 *Relationship between lateral load and displacement in B group*

Table 3 *Experiment and Abaqus comparison result*

Specimen No.	Axial Load P (kN)	Lateral Load Qu (kN) Exp.	Lateral Load Qu (kN) ABAQUS	Q_{abq}/Q_{exp}
A1	0	246.3	252.1	1.02
A2	170	201.6	183	0.91
A3	300	147.4	135.2	0.92
A4	400	112.8	105.8	0.94
A5	500	75.1	74.7	0.99
B1	0	250.9	262.6	1.05
B2	200	203.8	204.8	1
B3	400	145.7	141.2	0.97
B4	520	95.4	107.7	1.13
B5	630	93.3	96.4	1.03
Specimens under axial load only				
Specimen No.	Lateral load P (kN)	Axial load Pu (kN) Exp.	Axial load Pu (kN) ABAQUS	P_{abq}/P_{exp}
A6	0	712	769	1.08
B6	0	785.4	819.5	1.04

Results from the current investigation's specimens' Abaqus finite element analysis were contrasted with those from the experiments. In Table 3, experimental results are contrasted with those obtained by utilizing finite elements with nominal error. It is shown that there is a strong correlation between the Abaqus and the experimental results.

The parameter is modified from rectangular stiffener sections to angle stiffener sections after the simulation research. Table 4 provides a summary of the angle stiffener section dimensions.

Table 4: *Plate and angle stiffeners' dimensions*

Angle section stiffener (longitudinal and transverse directions)	Plate thickness	Slenderness ratio	Longitudinal spacing	Transverse spacing
ISA 75*50*10	18	25	575	1350
ISA 75*50*8	14	32		
ISA 80*50*10	8	36		
ISA 100*75*12	11	46		

Table 5 *Parametric results*

Angle section stiffener (longitudinal and transverse stiffeners)	Plate thickness	Slenderness ratio	P1: Failure load (kN) Abaqus software (simply supported)	P2: Failure load (kN) Abaqus software (fixed supported)	P2/P1
ISA 100*75*12	18	25	17856	18570.24	1.04
ISA 80*50*10	14	32	14634	16975.44	1.16
ISA 75*50*10	8	36	10467	13607.1	1.3
ISA 75*50*8	9	46	9847	10930.17	1.11

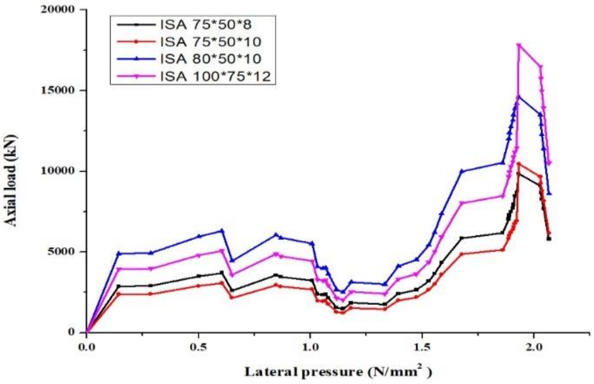


Fig.12 *Failure axial loads for various angle sections with lateral pressure for simple supported*

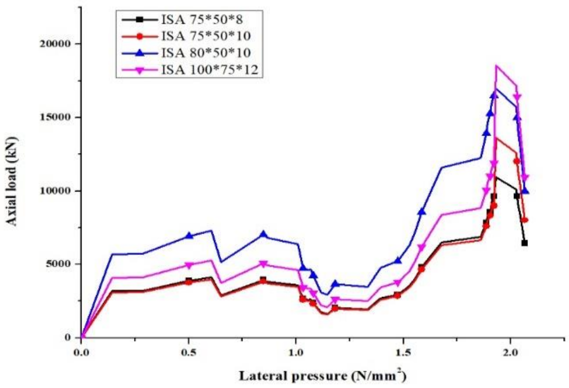


Fig.13 *Failure axial loads for various angle sections with lateral pressure for fixed supported*

Results and Discussion

In general, increasing the slenderness ratio causes the column strength of the stiffener-plate assembly as well as the plate strength to drop. The strength of the plate increases with the increase of the angle section dimensions and with an increase in the thickness of the plate as shown in Figure 10. Using an angle section as a stiffener increased the local base plate buckling for stiffened plates with a Slenderness ratio and the width of a stiffened panel becomes less effective due to local buckling. Figures 12 and 13 show that the ultimate loads increase when the support is fixed compared to simple.

Conclusion

The strength of stiffened plates subjected to both in-plane load and lateral pressure is significantly influenced by the plate slenderness ratios. The maximum load capacity of stiffened plates decreases as the plate slenderness ratio increases. The capacity of the plate can be greatly increased by using angle steel sections as stiffeners, but doing so requires unique techniques, especially because of the significant impact of torsional moments due to the eccentric relationship between the CG (center of gravity) and shear center. The ultimate loads of stiffened plates with fixed-ended boundary conditions are often greater than those of plates with simply supported boundary conditions. According to parametric research, the ultimate load can increase by up to 15.25 % when the boundary condition is switched from simply supported to fixed-ended. The position of failure is influenced by the boundary condition change in addition to the ultimate load.

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References

Alinia, M. M., & Dastfan, M. (2007). Cyclic behaviour , deformability and rigidity of stiffened steel shear panels. Journal of Constructional Steel Research, 63(4), 554–563. https://doi.org/10.1016/j.jcsr.2006.06.005

Alinia, M. M., Gheitasi, A., & Erfani, S. (2009). Plastic shear buckling of unstiffened stocky plates. Journal of Constructional Steel Research, 65(8–9), 1631–1643. https://doi.org/10.1016/j.jcsr.2009.04.001

Cho, S.-R., Kim, H.-S., Doh, H.-M., & Chon, Y.-K. (2013). Ultimate strength formulation for stiffened plates subjected to combined axial compression, transverse compression, shear force and lateral pressure loadings. Ships and Offshore Structures, 8(6), 628–637. https://doi.org/10.1080/17445302.2013.810492

Ghavami, K., & Khedmati, M. R. (2006). Numerical and experimental investigations on the compression behaviour of stiffened plates. Journal of Constructional Steel Research, 62(11), 1087–1100. https://doi.org/10.1016/j.jcsr.2006.06.026

Paik, J. K., & Kim, B. J. (2002). Ultimate strength formulations for stiffened panels under combined axial load, in-plane bending and lateral pressure: A benchmark study. In Thin-Walled Structures (Vol. 40, Issue 1). https://doi.org/10.1016/S0263-8231(01)00043-X

Paik, J. K., Thayamballi, A. K., & Kim, B. J. (2001). Large deflection orthotropic plate approach to develop ultimate strength formulations for stiffened panels under combined biaxial compression/tension and lateral pressure. Thin-Walled Structures, 39(3), 215–246. https://doi.org/10.1016/S0263-8231(00)00059-8

Paik, J. K., Thayamballi, A. K., & Kim, D. H. (1999). An analytical method for the ultimate compressive strength and effective plating of stiffened panels. Journal of Constructional Steel Research, 49(1), 43–68. https://doi.org/10.1016/S0143-974X(98)00207-7

Paik, J. K., Thayamballi, A. K., Pedersen, P. T., & Park, Y. Il. (2001). Ultimate strength of ship hulls under torsion. In Ocean Engineering (Vol. 28, Issue 8). https://doi.org/10.1016/S0029-8018(01)00015-4

Pan, Y., & Louca, L. A. (1999). Experimental and numerical studies on the response of stiffened plates subjected to gas explosions. Journal of Constructional Steel Research, 52(2), 171–193. https://doi.org/10.1016/S0143-974X(99)00022-X

Saad-Eldeen, S., Garbatov, Y., & Guedes Soares, C. (2015). Stress-strain analysis of dented rectangular plates subjected to uni-axial compressive loading. Engineering Structures, 99, 78–91. https://doi.org/10.1016/j.engstruct.2015.04.041

Shanmugam, N. E., Dongqi, Z., Choo, Y. S., & Arockiaswamy, M. (2014). Experimental studies on stiffened plates under in-plane load and lateral pressure. Thin-Walled Structures, 80, 22–31. https://doi.org/10.1016/j.tws.2014.02.026

Smith, M. (2021). ABAQUS / standard user's manual: Vols. 6.21-6. ABAQUS INC.

Srivastava, A. K. L., Pandey, S. R., & Kumar, A. (2013). Dynamical Analysis of Stiffened Plates under Patch Loading. Ijame, 18(2), 537–553. https://doi.org/10.2478/ijame-2013-0032

Suneel Kumar, M., Alagusundaramoorthy, P., & Sundaravadivelu, R. (2009). Ultimate strength of stiffened plates with a square opening under axial and out-of-plane loads. Engineering Structures, 31(11), 2568–2579. https://doi.org/10.1016/j.engstruct.2009.06.003

Trahair, N. S. (2001). Bending, shear and torsion capacities of steel angle sections. Research Report - University of Sydney, Department of Civil Engineering, 128(810), 1–16. https://doi.org/10.1061/(asce)0733-9445(2002)128:11(1394)

Trahair, N. S. (2005). Buckling and Torsion of Steel Unequal Angle Beams. Journal of Structural Engineering, 131(3), 474–480. https://doi.org/10.1061/(ASCE)0733-9445(2005)131:3(474)