Replacing arbitrary stiffener with regular stiffeners, based on vector analysis

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Abstract: ***— In order to simplify the analysis of arbitrary stiffeners, Yucheng Liu and Qingkui Wang [1] has proposed a hypothesis called vector analysis of stiffeners, which says that 'in a stiffened plate following a manner of ''vector analysis'' based on the geometric features(Figure 1) an arbitrary stiffener can be decoupled into two regular stiffeners'. The study proved this theory with simpler stiffener combinations, but its applications in complicated grid type stiffeners was unknown. This is an FEM analysis with Abaqus which is checking the possibility of extending the applications of vector analysis to complicated stiffener combinations. As a beginning, single units of grid stiffeners like longitudinal, triangular, rectangular and hexagonal are used, and are decouple to equivalent regular stiffeners. The strengthening effects of the single units of grids and its decoupled equivalent combinations were compared. The study proves that the theory is only applicable in simple forms of stiffeners.***

Keywords— ***Stiffened plates, vector analysis, buckling of plates, stiffener optimization.***

I. Introduction

Stiffened plates have vast applications in various branches of engineering like aeronautical, ship building and automobile etc. The analysis of stiffened plates is one of the most complicated structural problem in engineering. In comparison with regularly stiffened plates, arbitrary stiffened plates provide better buckling performance to biaxial and shear loading. But the analysis of arbitrarily stiffened plates is more complicated than the regularly stiffened plates. There were many previous efforts to solve this problem.

Vector analysis: In order to simplify the analysis of arbitrarily stiffened plates, Yucheng Liu and Qingkui Wang [1] in 2012 put forward a hypothesis that, 'In a stiffened plate following a manner of ''vector analysis'' based on the geometric features(Figure 1) an arbitrary stiffener can be decoupled into two regular stiffeners'. The hypothesis was also verified comparing the strengthening effect with some simple arbitrarily stiffening combinations on plates, and replacing them by orthogonal regular stiffeners.

Yucheng Lie's study was only in 3 simple forms of arbitrary stiffener combinations, and a study on complex combinations is absent. If the hypothesis can be generalized to complex stiffener combinations, the results can be extended to applications of the analysis of various types of grid type stiffener combinations which are being used general now a days. It would be useful to compare the effects of arbitrarily oriented stiffener and regular stiffener during the structural analysis, if the vector analysis can be further verified.

Several investigators have done studies in the field of stiffened plates. Brubak etal[2] in 2007 presented a semi analytical model using von Mises yield criterion. The model was able to estimate bending strain energy of arbitrary stiffeners on plates subjected to in plane loading.

$U_{stiff}^{b} = [EI_e/2L_s^4] \int (L_x^2 W_{,xx} + 2L_xL_y W_{,xy} + L_y^2 W_{,yy})^2 dL_s$

U_{stiff}^{b} : bending strain energy due to an arbitrarily oriented stiffener

$I_e = \int_{As} (Z - Z_c)^2 dA_s + tb_eZ_c^2$

$(X_1,Y_1),(X_2,Y_2)$: coordinates of the stiffener ends

$L_x = X_2 - X_1$

$L_y = Y_2 - Y_1$

Z_c : distance from the middle plane of the plate to the centroidal axis of a cross section consisting of the stiffener and an effective plate width

b_e: effective plate width

Several investigators have done verities of studies on stiffened plates. A computationally more efficient method for elastic buckling and buckling yield strength was later presented , which deals with the analysis of stiffened plates with varying, stepwise and constant thickness[3]. A numerical model for the local buckling and post buckling analysis of stiffened plates was derived by Byklum and Amdahl[4], which was more accurate than Non-linear finite element methods. For the analysis of global buckling and post buckling against in plane loads (axial, shear) and lateral pressure a computational model were also derived [5]. Y. Margaritis and M.Toulios studied the ultimate and collapse response of cracked stiffened plates subjected to uniaxial compression[6] and Eirik Byklum et.al published a study on developing a semi-analytical model for global buckling and post buckling analysis of stiffened panels [7]. Eurocode 3 Part 1-5 (EN 1993-1-5) says about the calculation of global critical buckling stress on Longitudinally stiffened plates [8] and it was experimentally studied by Y. Galéa, P.-O. Martin and published in 2010[9].

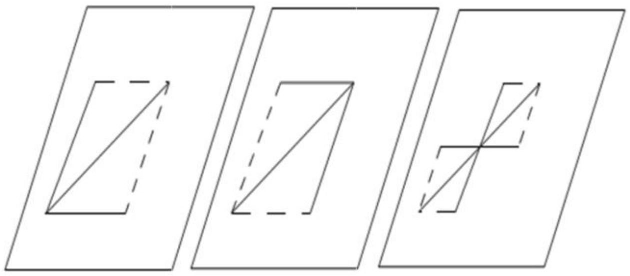


Fig 1. Different scenarios of replacing an arbitrary stiffener with two regular stiffeners (Yucheng Liue [1])

The models evaluates stiffened plate’s buckling performance. In order for a further investigation of the strengthening effects of the arbitrarily oriented stiffener, it would be useful to compare those effects of arbitrarily oriented stiffener and regular stiffener during the structural analysis.

Study is in thin stiffened steel square plates, with youngs modulus 210000 N and poisons ratio 0.3, having ‘I shaped single sided flat bar’ stiffeners placed on it. Since stiffeners were extruded from plate, the bondage between the plate and stiffener were considered ideal, and based on the study it’s found that 10mm structured meshes gives accurate results. Plates with each stiffener patterns and its ‘decoupled stiffener combinations’ were tested and the results were compared. The plates were modeled, and shell edge unit loads were applied and tested with buckling analysis in Abaqus. The buckling shapes, elastic buckling strength and modes from each plate models were noted. 10mm structured meshes were used for accurate results.. Stiffeners were placed on the top portion of the plates.

II. Vector analysis with Triangular stiffeners:

Triangular stiffeners are widely seen in grid patterns of stiffened plates. The analyses of arbitrary grid stiffener patterns are much more complicated than that of regular stiffener patterns. So the efforts to simplify this has wide applications in the field of stiffener design. This study is checking that, weather the strengthening effect of triangular stiffeners is equal to that of the equivalent rectangular stiffener provided by vector analysis. So in order to check the possibility of this, a comparative study was done on the strengthening effect of triangular stiffener and a rectangular stiffeners.

Triangular stiffener with height 35mm, and thickness 5mm was modeled on 1000mm square plates. The positioning of the stiffener triangle was kept as inserted equilateral triangle in a circle with radius 1000/3 mm centered at the center point of the plate. The buckling yield loads for in plane normal loads (axial in Z direction, in X direction, biaxial in X & Z direction) and shear are found out, and compared with that of a rectangular stiffener combination obtained by vector analysis.

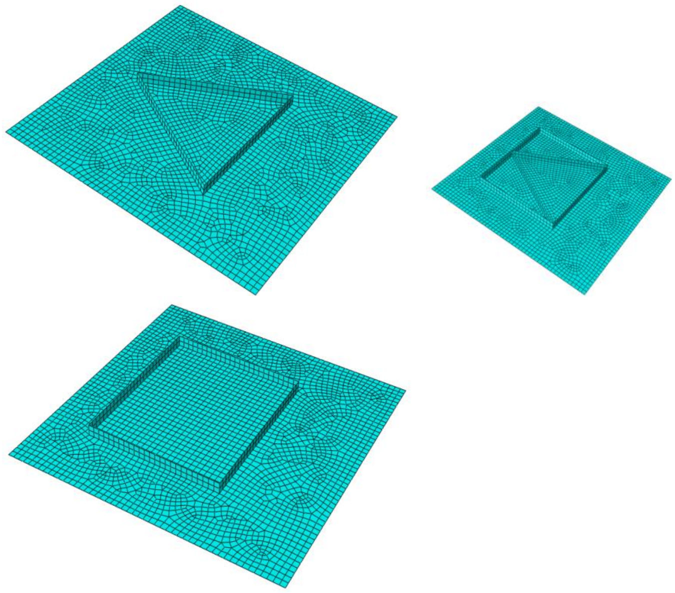


Fig 2: Top view of Triangular stiffener and equivalent rectangular stiffener.

Load cases	Triangular stiffened plate (Buckling load)	Rectangular (Buckling load)	Error %
Axial loaded Z axis	181.66	176.41	-2.89 %
Axially loaded, in edge perpendicular to X axis	180.21	179.81	-0.23 %
Bi axially Loaded	92.77	90.553	-2.39 %
Shear in two opposite edges	369.77	387.95	4.9 %
Biaxial Shear	437.84	390.13	10.9 %
Pressure load	0.1012	0.1148	13.4 %

Table 1: Buckling strength comparison, triangular and rectangular combinations under various loading conditions.

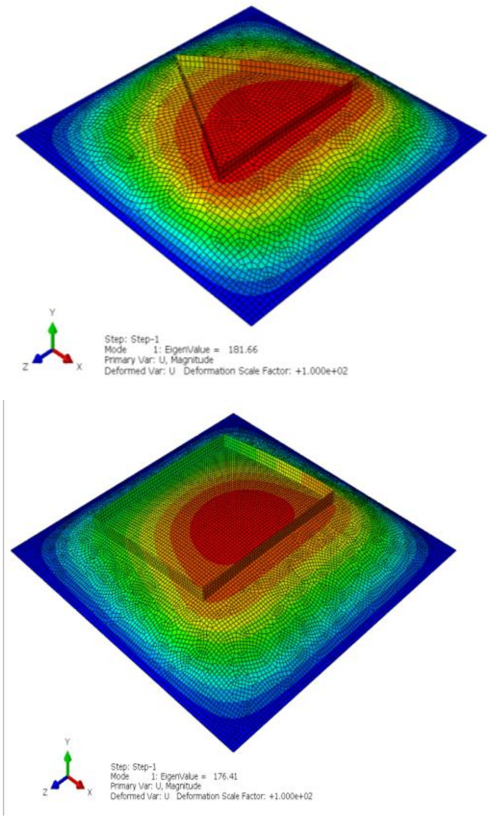


Fig: 3Buckling shapes under axial loading

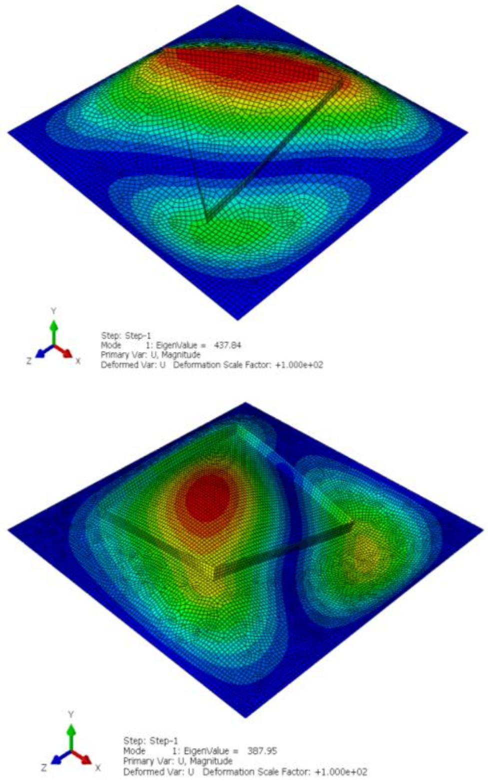


Fig 4: Buckling shapes under shear loading

Results (Size 10 & Bold)

Triangular stiffeners when decoupled to the two regular perpendicular axes,

1. Up on axial loading (perpendicular to the edges of the plate)the triangular and equivalent decoupled stiffener combination gave equal buckling yielding strength(with a very small error)
2. But the error % was comparatively higher in the case of shear loading, which proves that the decoupling in to the horizontal and vertical can be considered equivalent only if the loading is in the directions of the decoupled axes.

III. Vector Analysis, Decoupling Regular Stiffeners in to Diagonal Axes:

Stiffeners in the above case are decoupled to the normal lateral and longitudinal axes. Here they are decoupled to diagonal axes and the strengthening effects are compared.

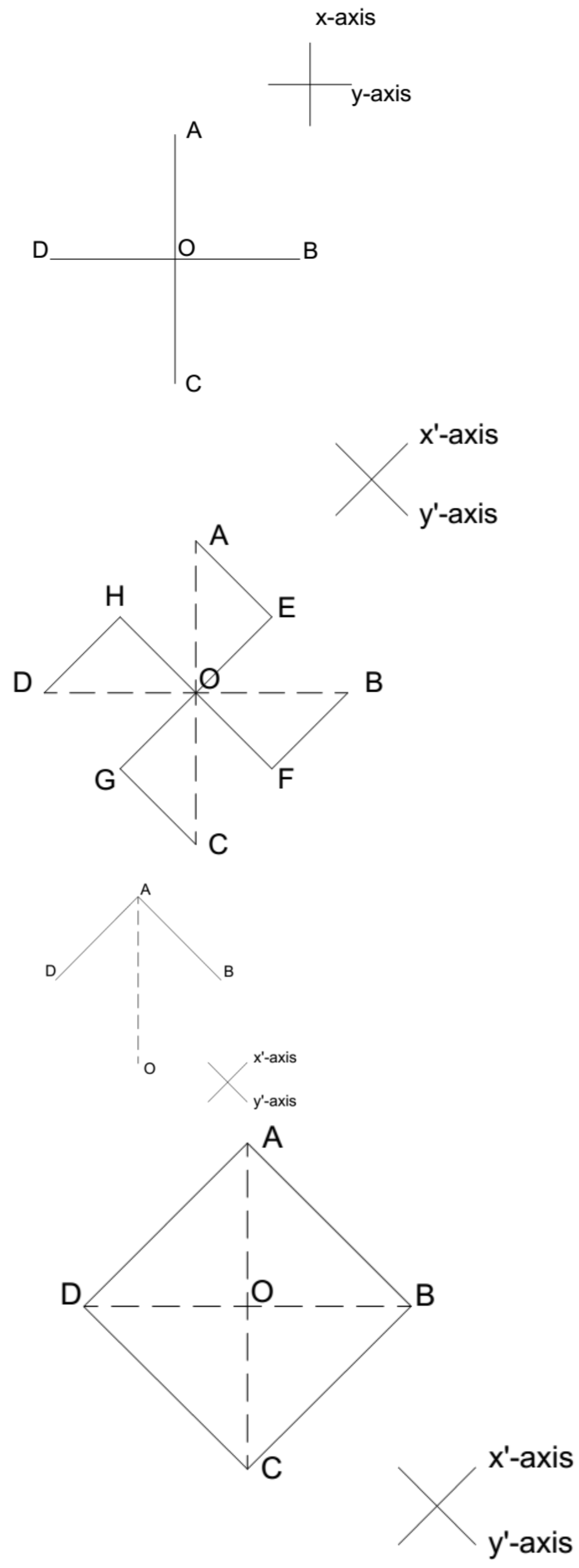


Fig 5: Scenarios of replacing two vertical stiffener to diagonal axis following vector analysis

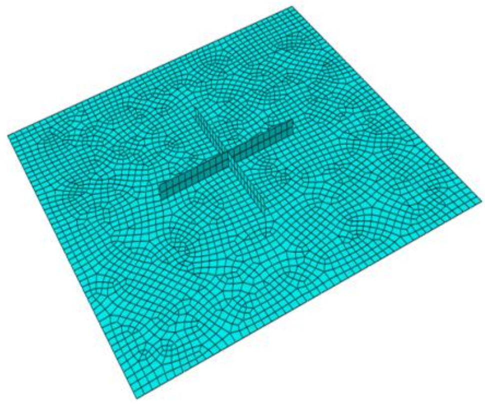


Fig 6: Top view of regular stiffened.

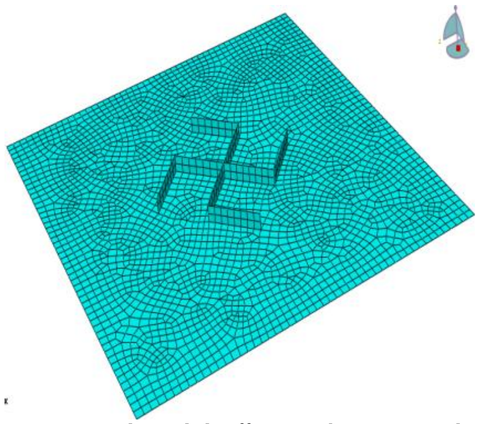


Fig 7: Top view decoupled stiffener combinations 1 to diagonal axis.

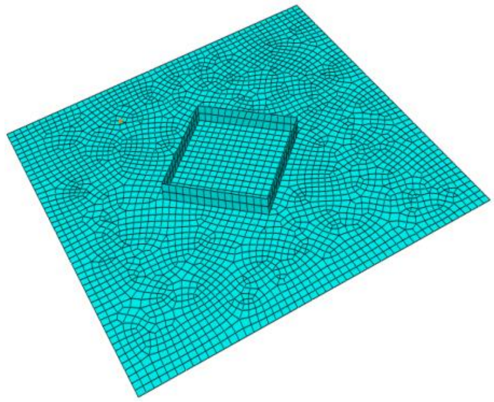


Fig 8: Top view of decoupled stiffener combinations 2 to diagonal axis.

Loading	Regular Stiffener	Equivalent stiffener 1	Error % of 1 with Regular	Equivalent stiffener 2	Error % of 2 with Regular
Biaxial shear	309.11	301.03	-2.61 %	310.74	0.52 %
Shear in two opposite edges	266.02	265.07	-0.357	255.02	4.13 %
Pressure loading	-0.15698	-0.20963	33.53 %	-0.15215	3.07 %
Axial Load in Z axis	131.61	117.71	-11.1 %	131.52	-0.068 %
Biaxial loading in X and Z axis	66.130	59.14	-10.57 %	66.41	0.42 %

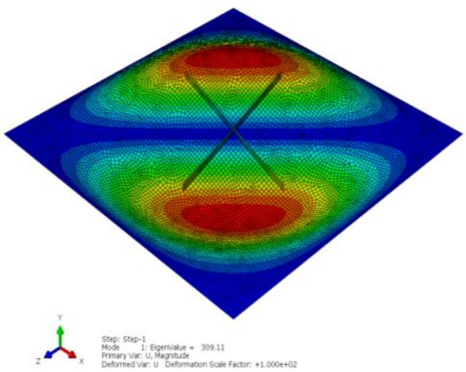
Table 2: Buckling strength comparison, regular and its two vector combinations in diagonal axis under various loading conditions.

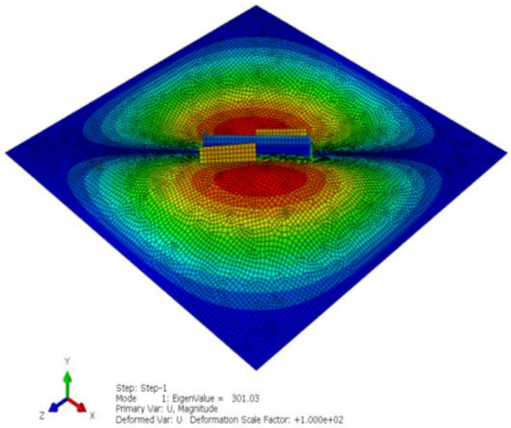
Results:

A stiffener combination when decoupled to the two diagonal axes, (45 degree to the X and Z axes)

1. Up on axial loading (perpendicular to the edges of the plate, X &Z) the regular stiffeners and the two decoupled stiffener combinations does not gives equal buckling yielding strength.
2. But in the case of shear loading, the diagonal decoupled pairs also provides equal strengthening effect.

which again proved that the decoupling can be considered equivalent only if the loading is in the directions of the decoupled axes.





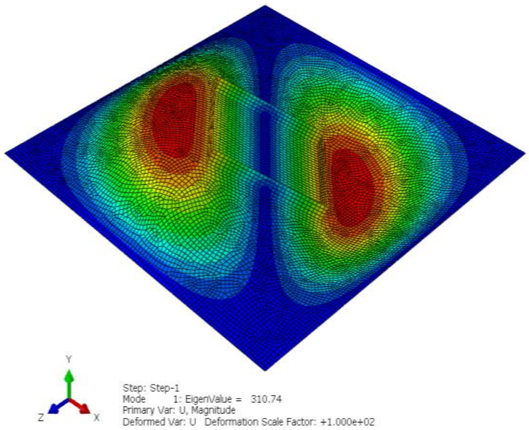


Fig 9: Buckling shape under shear loading

IV. Decoupling hexagonal stiffener

In order to check the vector analysis with complicated stiffener patterns, the strengthening effect of hexagonally stiffened plates and it's three vector equivalent patterns are tested.

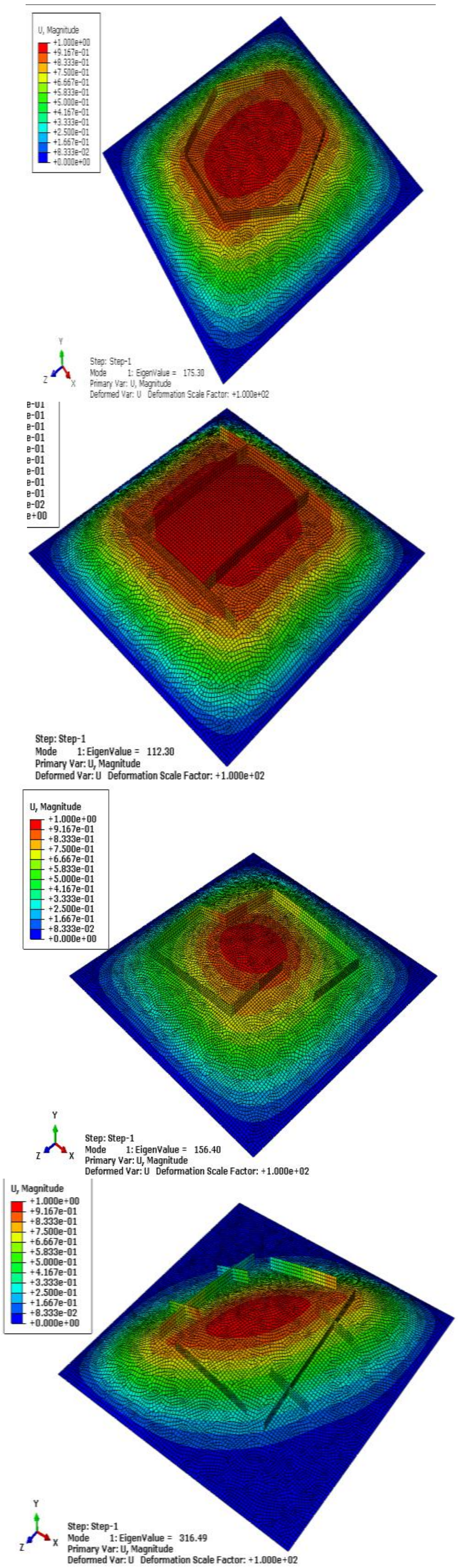


Fig 10: Examples of buckling shapes of hexagonal and equivalent stiffeners under axial and shear loading.

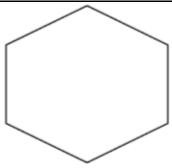
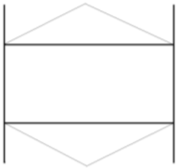
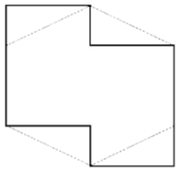
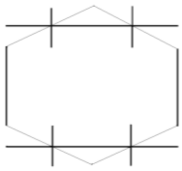
Stiffener patterns 1 to 4	Axial loading in Z axis Buckling Yield strength	Error % compared with Hexagonal
 1.	175.3	0
 2.	191.51	9.2
 3.	156.4	-10.78
 4.	217.3	24.13

Table 3: Buckling strength comparison, hexagonal stiffener and its three vector combinations under axial loading conditions

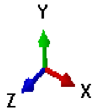
	Stiffener pattern 1	Stiffener pattern 2	Error (%)
Axial loading in Z direction	175.3	217.3	24.1
Biaxial Loading in X and Z direction	90.9	112.3	23.6
Biaxial Shear Loading	422.1	536.2	27

Table 4: Buckling strength comparison, hexagonal stiffener and its vector combination number 2 under axial and shear loading conditions

Results:

In the case of hexagonal stiffener, the theory of decoupling with vector analysis does not works, So it proves that this theory is not applicable in case of complicated stiffener patterns.

V. Conclusions

This paper discusses the possibility of decoupling arbitrary stiffened plates to regular stiffeners through a series of Abaqus buckling strength analysis. Axial and shear loads are considered in the study. Through the results following conclusions are made.

1. A triangular stiffener can be decoupled in to rectangular, following a manner of vector analysis, which gives exactly the equal buckling strength under axial loading.
2. But under shear the decoupled rectangular stiffener combination does not gives equal buckling strength.
3. When a simple type of stiffener combination (single longitudinal and single lateral) was decoupled to diagonal axis it gives equal buckling performance under shear, but not for axial loading. Hence For shear loading in a square plate, the simple type of stiffener combination can be decoupled to equivalent rectangular stiffeners through vector analysis. Which proves that decoupling can be only done to the axis of loading?
4. But the buckling strength results under axial and shear loading of hexagonally stiffened plates does not match with its decoupled stiffener combinations. Vector analysis is not applicable for complicated stiffener combinations.

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