Ultimate Strength Analysis of FS Series Stiffened Panel

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Abstract

Notation:

A_{0ij} : amplitude of initial deflection;
A_{0mn} : amplitude of a component of initial deflection similar to buckling mode;
A_0 : amplitude of initial deflection when buckling mode is both only one half wave along longitudinal and transverse direction $A_0/t \approx 0.1\beta^2$;
B : breadth of the plate, type A: $B = 2b$, type B: $B = 4b$;
a : length of plate and stiffener between transverse girders;
b : breadth of plate between longitudinal stiffeners;
E : Young's modulus $E = 2.06 \times 10^5\ MPa$;
m : number of half buckling waves of the buckling mode along longitudinal direction;
n : number of half buckling waves of the buckling mode along transverse direction;
t : plate thickness;
w_0 : initial deflection;
β : plate slenderness $\beta = b/t\ \sqrt{\sigma_Y/E}$.
ε_Y : yield strain $\varepsilon_Y = \sigma_Y/E$;
ε_u : ultimate strain $\varepsilon_u = \sigma_u/E$;
ϕ_u : non-dimensional parameter of ultimate strength $\phi_u = \sigma_u/\sigma_Y$;
μ : Poisson's ratio $\mu = 0.3$;
σ_Y : yield stress MPa;
σ_u : ultimate stress MPa;

1. Introduction

2. Description of panel

FS series is one of four series stiffened panels which are calculated in the panels' collapse analysis under compression. FS series mean fully S690 structure series, that is, the material of the plating and bar stiffeners are high tensile steel S690. There are two type panels in the series, i.e. Type A and Type B. Each type includes three different panels because of different framing space (200mm, 300mm, 400mm). The detail names of these six models are FS150_200A, FS150_300A, FS150_400A, FS150_200B, FS150_300B, FS150_400B.

2.1 Materials of Calculation Models

In order to simplify analysis, the actual stress-strain curve of materials is idealized as the curve in Fig.1.

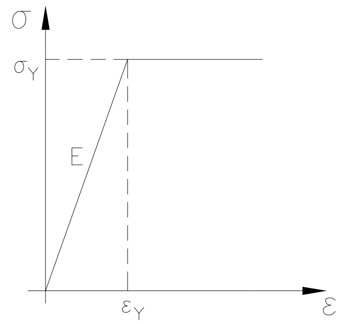
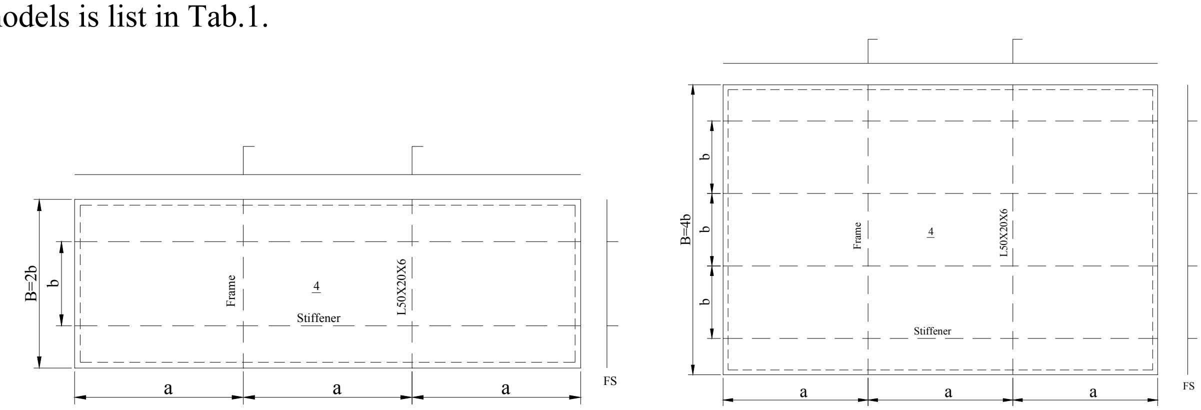


Fig.1 Idealized typical tensile stress-strain curve of materials

The yield stress of S690 is 732MPa according to the final report supplied by the shipyard of LISNAVE[1]. And the yield stress of normal steel is 235MPa.

2.2 Typical Dimension of FS Series Panels

The material of both plate and stiffeners is S690 steel. The panels have the overall dimensions 300mm and 600mm wide (TypeA and TypeB), respectively with two and four stiffeners supported on two frames, and 600mm, 900mm and 1200mm in length. The thickness of plate is 4mm. The spacing between longitudinal stiffeners (-20×4, S690) is 150mm. The spacing between frames ($L50\times20\times6$, normal steel) is 200mm, 300mm, 400mm. The number of spans is 3. The typical drawing of FS series panels are shown in Fig.2. And the detail dimension of these models is list in Tab.1.



(a) TypeA (b) Type B

Fig.2 Typical drawing of FS series panels

Tab.1 Detail dimension of each panel of FS series

Model Types	a (mm)	b (mm)	Plate		Stiffener		Frame	
			t (mm)	Material	Type (mm)	Material	Type (mm)	Material
FS150_200A	200	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel
FS150_300A	300	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel
FS150_400A	400	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel
FS150_200B	200	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel
FS150_300B	300	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel
FS150_400B	400	150	4	S690	-20×4	S690	$L50\times20\times6$	Normal Steel

3. Finite Element Modeling

Displacement Increment Method is used in the finite element models' analysis, which is organized in ANSYS. That is to say, the panels are shortened according to an assigned displacement increment at the longitudinal direction ends of plate. Then the structure response, which equals to the total reaction forces of the every node on the central line of the plate, is obtained under these loads.

3.1. Initial deflection influence

The initial deflection is a large factor which influences the ultimate strength of the panels. The shape of initial deflection for stiffened panel is usually quite complex. The initial deflection configuration can be approximated by the following Fourier Series function [2]:

$$w_0 = \sum_i \sum_j A_{0ij} \sin\left(\frac{i\pi x}{a} + \frac{\pi}{2}\right)\sin\left(\frac{j\pi y}{B} + \frac{\pi}{2}\right) \tag{1}$$

When a plate with initial deflection is subjected to axial compression, it exhibits an increase of deflection from the beginning of the loading process. At the beginning, the magnitudes of all Fourier Components of the initial deflection increase. Close to the critical buckling load, unless some other component has an extremely large magnitude, the magnitude of the component similar to the buckling mode of the corresponding perfect plate continues to increase at a higher rate, while the magnitudes of other components start to decrease. The behavior is accompanied with the effect of a large deflection from the beginning of loading. Yielding starts at a load lower than that for a perfectly flat plate (without initial deflection) and ultimate strength is also reduced. Only one component of initial deflection similar to the buckling mode has an appreciable effect on plate behavior and needs to be taken into account. Therefore, initial deflection may then be expressed as follows:

$$w_0 = A_{0mn} \sin\left(\frac{m\pi x}{a} + \frac{\pi}{2}\right)\sin\left(\frac{n\pi y}{B} + \frac{\pi}{2}\right) \tag{2}$$

To the panels, the buckling is always happened when it is subjected to the smallest compression. Therefore, initial deflection may be expressed as follows when $m = 1,\ n = 1$:

$$w_0 = A_0 \sin\left(\frac{\pi x}{a} + \frac{\pi}{2}\right)\sin\left(\frac{\pi y}{B} + \frac{\pi}{2}\right) \tag{3}$$

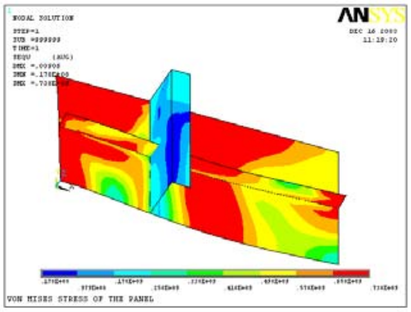
4. Results

The results obtained from two cases, Case2 and Case4, which are performed in the analysis, are compared with that of test. The detail descriptions of the cases are list as following.

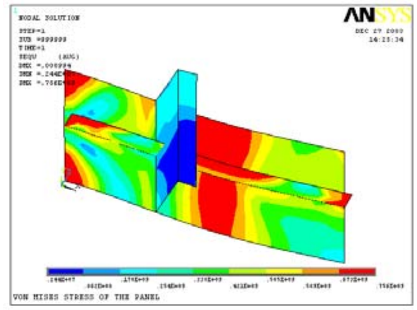
Case2: A quarter part of model is calculated according to symmetry. The initial deflection is determined by Eq(3). The boundary condition is four ends of plate are simply supported;

Case4: A quarter part of model is calculated. The initial deflection is determined by Eq(3). The boundary condition: the two ends of plate longitudinal direction are simply supported, another two ends of plate are free and transverse and vertical directions of the four ends of frame are restrained.

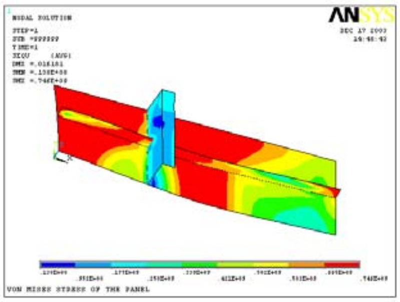
In order to compare the results better, a non-dimensional parameter ϕ_u, ultimate strength of the stiffened plate, i.e. $\phi_u = \sigma_u / \sigma_Y$, is introduced in the result analysis of case2 and case4 and test data. And the strain is also written as $\varepsilon_u / \varepsilon_Y$, responsively. The von Mises stress obtained from the FEM calculation of Case2 and Case 4 for each panels of FS series are shown in Fig.3. And comparison of non-dimension stress-strain curve among Case2, Case4 and model test data are shown in Fig.4, respectively.



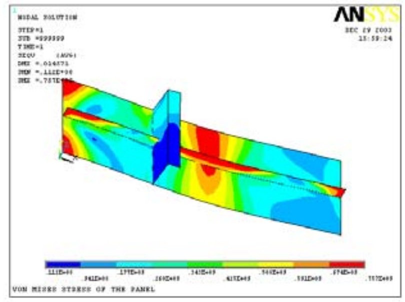
(a1) Case2 of FS150_200A



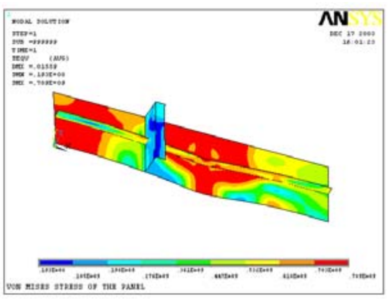
(a2) Case4 of FS150_200A



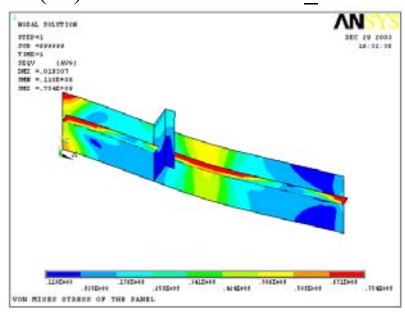
(b1) Case2 of FS150_300A



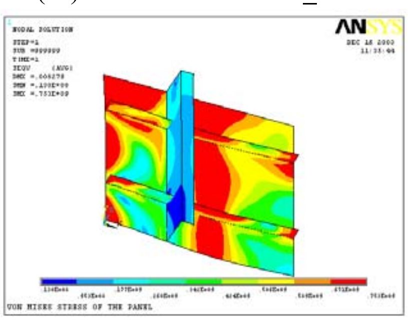
(b2) Case4 of FS150_300A



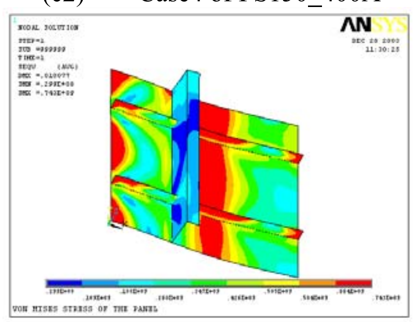
(c1) Case2 of FS150_400A



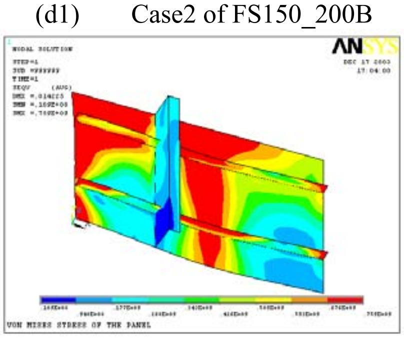
(c2) Case4 of FS150_400A



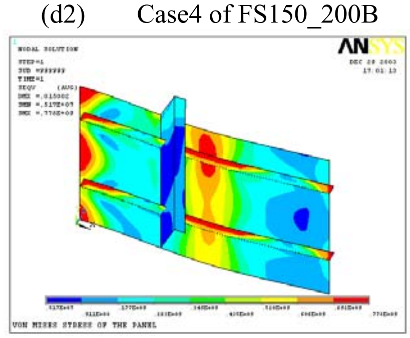
(d1) Case2 of FS150_200B



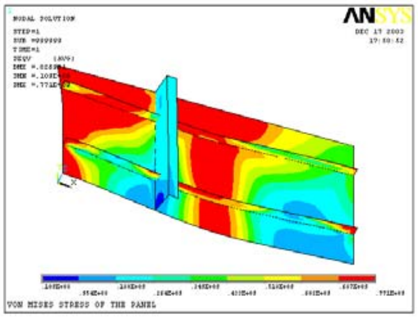
(d2) Case4 of FS150_200B



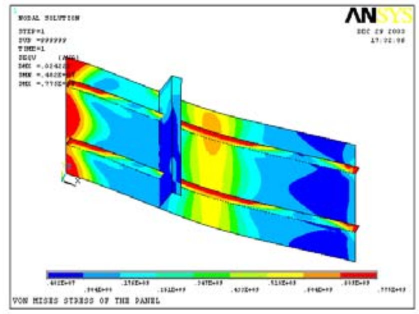
(e1) Case2 of FS150_300B



(e2) Case4 of FS150_300B

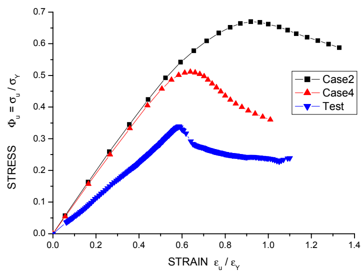


(f1) Case2 of FS150_400B

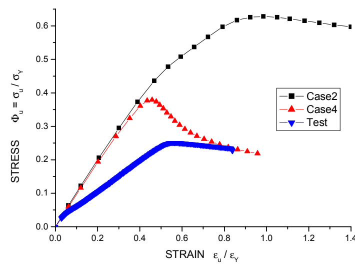


(f2) Case4 of FS150_400B

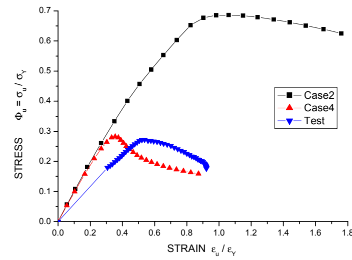
Fig.3 Von Mises stress of Case2 and Case4 for each panels



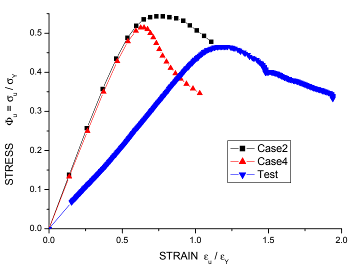
(a) FS150_200A



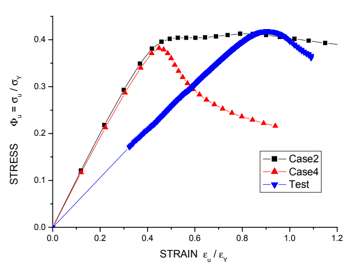
(b) FS150_300A



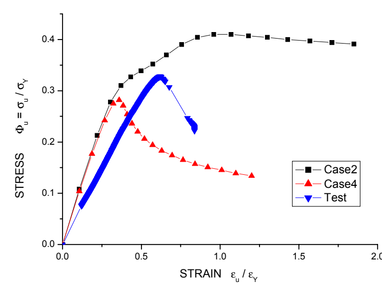
(c) FS150_400A



(d) FS150_200B



(e) FS150_300B



(f) FS150_400B

Fig.4 Comparison of non-dimension curve ϕ_u

It is shown that the tendency between the FEM calculation and test is almost the same in Fig.3 and Fig.4. But the different of result between Case2 and test for Type A is obviously, especially for FS150_400A. The reason maybe lies in the different collapse mode result from the different boundary condition.

In order to ensure the correctness of the data obtained from calculation and test, some additional calculation according to the theory methods [3], Johnson-Ostenfeld formulation and Perry-Robertson formulation, and some experiential methods, such as GL rules [4], BV rules [5], ABS rules [6], are performed. The ultimate strength of these FS series panels obtained from FEM calculation, test and other additional calculation are list in Tab2.

Tab.2 Comparison of each FS series panels' ultimate strength ϕ_u between calculation and model test

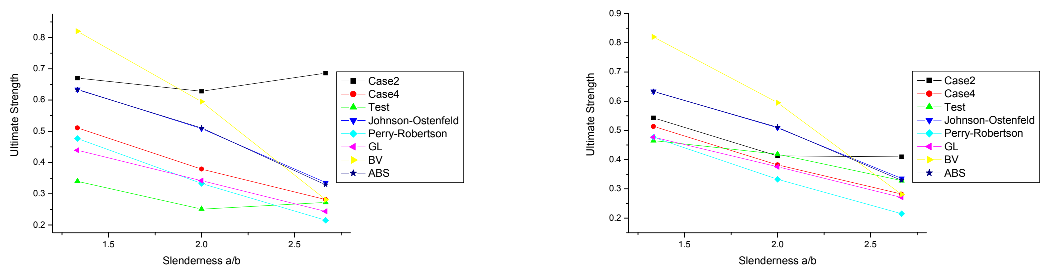
Model types	Case2	Case4	Model Test	Johnson-Ostenfeld	Perry-Robertson	GL	BV	ABS
FS150_200A	0.670	0.511	0.340	0.634	0.477	0.439	0.820	0.633
FS150_300A	0.628	0.379	0.251	0.509	0.333	0.342	0.595	0.511
FS150_400A	0.686	0.282	0.272	0.336	0.215	0.244	0.281	0.329
FS150_200B	0.543	0.514	0.465	0.634	0.477	0.477	0.820	0.633
FS150_300B	0.413	0.382	0.419	0.509	0.333	0.376	0.595	0.511
FS150_400B	0.410	0.282	0.328	0.336	0.215	0.271	0.281	0.329

These tolerances of these calculations for each FS series panels based on the test are listed in Tab.3.

Tab.3 Tolerances of calculations for each FS series panels based on the test

Model types	Model Test ϕ_u	$\frac{\phi_{u,case2}}{\phi_{u,test}}$	$\frac{\phi_{u,case4}}{\phi_{u,test}}$	$\frac{\phi_{u,J-O}}{\phi_{u,test}}$	$\frac{\phi_{u,P-R}}{\phi_{u,test}}$	$\frac{\phi_{u,GL}}{\phi_{u,test}}$	$\frac{\phi_{u,BV}}{\phi_{u,test}}$	$\frac{\phi_{u,ABS}}{\phi_{u,test}}$
FS150_200A	0.340	1.971	1.503	1.865	1.403	1.291	2.412	1.862
FS150_300A	0.251	2.502	1.510	2.028	1.327	1.363	2.371	2.036
FS150_400A	0.272	2.522	1.037	1.235	0.790	0.897	1.033	1.210
FS150_200B	0.465	1.168	1.105	1.363	1.026	1.026	1.763	1.361
FS150_300B	0.419	0.986	0.912	1.215	0.795	0.897	1.420	1.220
FS150_400B	0.328	1.250	0.860	1.024	0.655	0.826	0.857	1.003

The relationship between frame spacing and non-dimension ultimate strength for each type is obtained in Fig.5 according to the Tab.2 respectively.



(a) Type A (b) Type B

Fig.5 Relationship between frame spacing and ultimate strength

From Fig.5, it can be seen that the different among the results for Type A is larger than Type B. That is to say, FS series Type A isn't as stable as Type B. The result of Johnson-Ostenfeld and that of ABS rules are almost same. The result of Case4 and those of Perry-Robertson and GL rules are almost parallel and small different. The decrease of BV rules with the increase of slenderness is larger than the others. For Case2 and test, it seem not very reasonable that ultimate strength increase with lengthen the frame spacing. The results of test for Type A are almost smallest. It seems also abnormal for Case2 of FS150_400B compared with other type B panels. From Tab.2, ultimate strength is almost same between Type A and Type B, except for Case2. That means, FS series panels aren't sensitive to the breadth. But they are sensitive to boundary condition.

5. Conclusions

In this paper, the finite element analysis for ultimate strength of FS series panels, are presented. The analysis is the series calculation of four series panels under compression in high tensile steel S690. The comparison between the results of FEM and that of test is also performed.

The results show that the ultimate strength of numerical calculation is closed to that of test and other theory and experiential methods basically, especially for Type B panels. There are also a bit abnormal for some panels compared with other results, such as Case2 of FS150_400A and FS150_400B and test of FS150_400A. The reason maybe lie in the sensitivity to the influence factors increases with the increase of the slenderness.

In a word, the FEM analysis for ultimate strength of panels is effective. But several results seem unreasonable. These models should be checked carefully, and some of them should be recalculated or retested if it is necessary.

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