Compressive Tests on Stocky Panels with Different Configurations

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ABSTRACT

The results of 8 tests on panels under axial compression until collapse are presented. The panels are three bay panels with associated plate made of high tensile steel S690. Four different configurations are considered for the stiffeners, which are made of mild or high tensile steel for bar stiffeners and mild steel for 'L' and 'U' stiffeners. The influence of the stiffener's geometry on the ultimate strength of the stiffened panels under compression is analyzed.

KEY WORDS: Ultimate strength; stiffened plates; tests; uniaxial compression; buckling.

INTRODUCTION

New, fast, large, efficient and safe ship structures require the adoption of new structural concepts and materials with high strength weight ratio. The application of Very High Tensile Steel may be considered as a solution but it requires explicit consideration of the failure mechanisms, primarily fatigue and buckling (Janssen, 2000).

The objective of these tests is to compare different structural solutions for panels under compression. Comparison between the performance of S690, mild steel and hybrid solutions are made. The results presented are part of a large series of tests on stiffened plates under compression that include more slender panels, but with the same plate slenderness.

The base geometry is the one used on the box girders tests. On that regard, the results can be compared with those of similar stiffened plates belonging to much large structures.

Four series of experiments were carried on using two different types of steel as follow:
- Fully S690 structure. S690 on plating and bar stiffeners.
- Hybrid bar structure. S690 on plating and mild steel on bars.
- Hybrid L structure. S690 on plating and mild steel on L stiffeners.
- Hybrid U structure. S690 on plating and mild steel on U stiffeners.

The use of 3-bay panels instead of single bay panels allow to have more realistic results by avoiding boundary conditions problems related to eccentricity of load and including the interference between adjacent panels.

DESCRIPTION OF THE MODELS

The S69 steel was supplied by Dillinger Hütterwerke in sheet of 4mm thick and the mild steel was supplied by Lisnave. The stiffened plates were manufactured at Lisnave according to the standard techniques of the shipyiard.

Fully S690 structure (FS) geometry

These panels are similar to those used on the box girders (Gordo and Guedes Soares, 2004). The spacing between longitudinal stiffeners, which are bars of B20*4, is 150 mm. The spacing between supporting points (frames) is 200 mm. The number of spans is 3. The material is 4mm thick S690 steel. The panels have the overall dimensions 300mm wide and 600 mm, respectively with two and four stiffeners and 600 mm in length.

Hybrid Bar Structure (BS)

The spacing between longitudinal stiffeners (mild steel, B33*7) is 150. The spacing between supporting points (frames) is 200 mm. The number of spans is 3. The plating is 4mm S690 steel. The panels have the overall dimensions 300mm wide and 600, respectively with two and four stiffeners and 600 mm in length.

Hybrid L Structure (LS)

The spacing between longitudinal stiffeners (mild steel, L38x19x4) is 150 mm. The spacing between supporting points (frames) is 200 mm. The number of spans is 3. The plating is 4mm S690 steel. The panels have the overall dimensions 300mm wide and 600, respectively with two and four stiffeners and 600 mm in length.

Hybrid U Structure (US)

The spacing between longitudinal stiffeners (mild steel, U (40+150+40)x2mm) is 150 mm. The spacing between supporting points (frames) is 200mm. The number of spans is 3. The plating is 4mm S690 steel. The panels have the overall dimensions 300mm wide and 600mm, respectively with two and four stiffeners and 600mm in length.

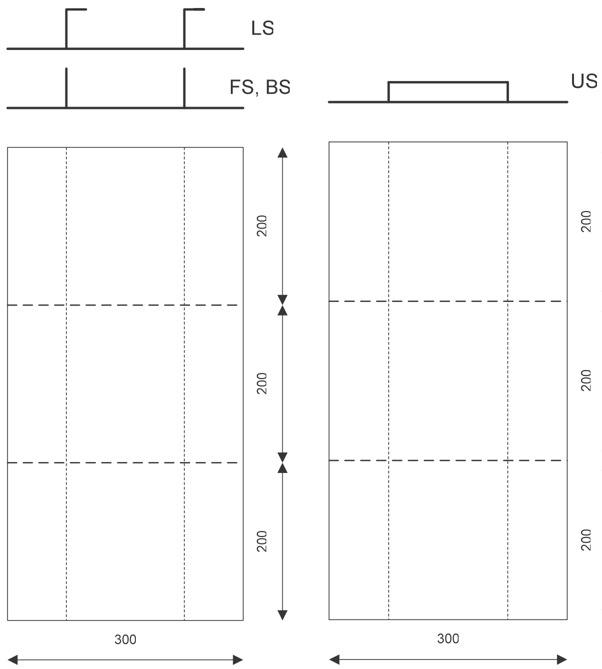

Figure 1- Geometry of narrow stiffened panels for fully S69 steel (FS), mild bar stiffeners (BS), 'L' and 'U' mild steel stiffeners.

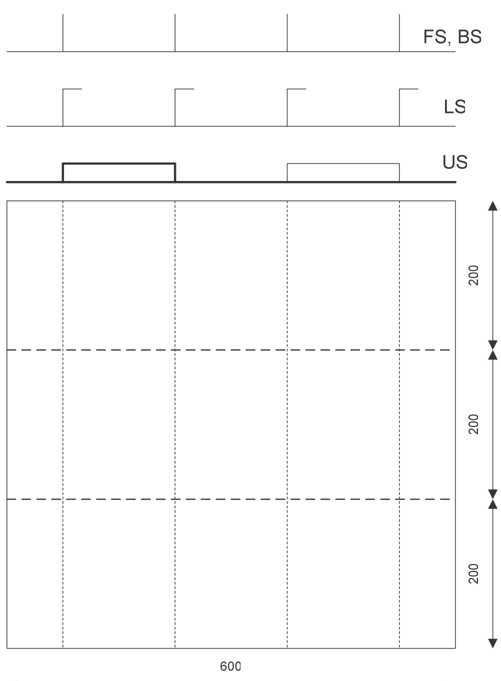

Figure 2 - Geometry of wide stiffened panels.

The models have the following reference related to their overall dimensions:

- FS150x200A. L=600mm; B=300mm
- BS150x200A. L=600mm; B=300mm
- LS150x200A. L=600mm; B=300mm
- US150x200A. L=600mm; B=300mm
- FS150x200B. L=600mm; B=600mm
- BS150x200B. L=600mm; B=600mm
- LS150x200B. L=600mm; B=600mm
- US150x200B. L=600mm; B=600mm

Setup

A 300 t press was used to perform the tests of the panels under uniaxial compression. Figure 3 shows the general arrangement of the tests and the next figure gives a detailed view of the support for the framing systems which intends to reproduce simply supported boundary conditions. The lateral edges of the panels are totally free to move and rotate. This means that large panels (B series) should be less affected by the eventual lack of effectiveness at the lateral edge plating.

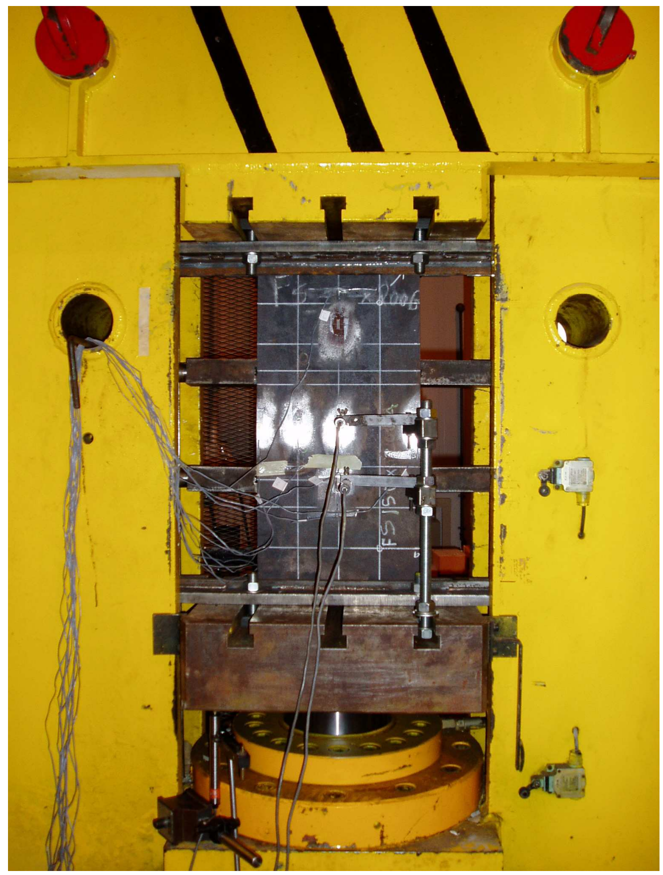

Figure 3 – Setup of the 200 series test of stiffened plates

EXPERIMENTAL RESULTS

FS series results

The panel FS150200A and FS150200B were loaded twice with a total unloading between the two cycles.

The former had a first cycle of loading until 200MPa followed by unloading and reloaded beyond collapse. The ultimate average stress achieved was 264 MPa. The collapse was sudden resulting from the yielding of the stiffeners that could be classified as typical column induced failure.

The latter was loaded initially until 250 MPa and then discharged. The collapse was achieved at 362 MPa average stresses in a smooth way, as it may be seen from the graphics of Figure 6 and 8. It was a typical column induced failure with some magnification of the residual deflections of the plate in the unsupported edges.

The initial shortening at low stresses shown on the tests is due to the rearrangement of the test setup until every parts of the panel, support and hydraulic machine are in full contact.

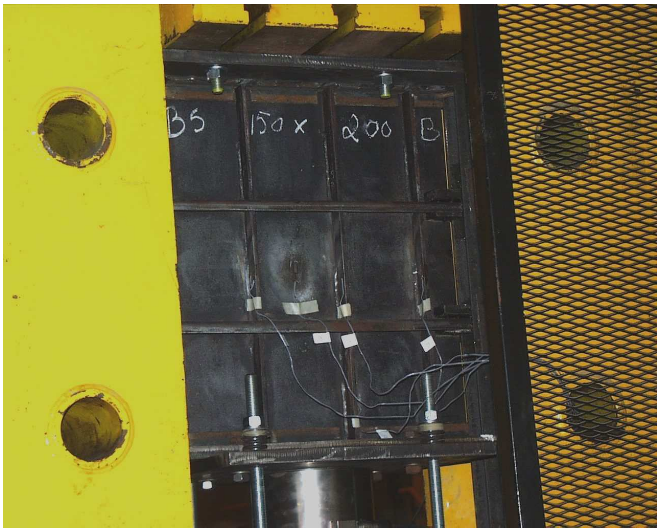

Figure 4 – Details of the lateral support of the frames in vertical guides.

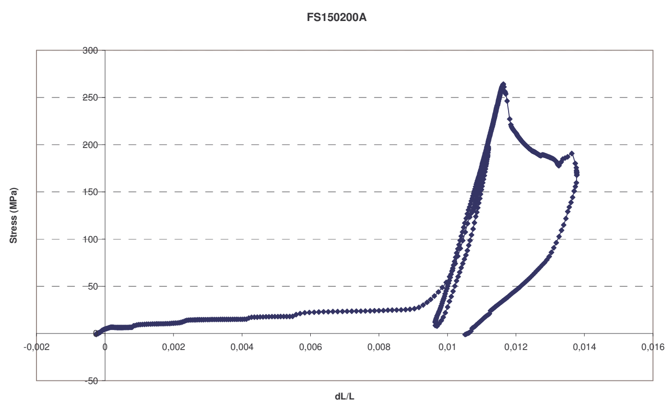

Figure 5– Stress shortening curve of the FS150200A specimen test. All cycles of loading

The final cycle of loading of panel FS150200A shows a linear behavior until the ultimate compressive stress was achieved as may be seen in Figure 7. The unloading after collapse was very quick involving large deflections on the intermediate supports and this could be the main reason for the low value of the ultimate stress when compared with the FS150200B test result.

The structural elastic tangent modulus in the range where it has its highest values is very low compared to the elastic modulus of steel obtain from tensile tests. It has a value of 128GPa and 101GPa, respectively for A and B specimen, which is almost half of the 200GPa expected.

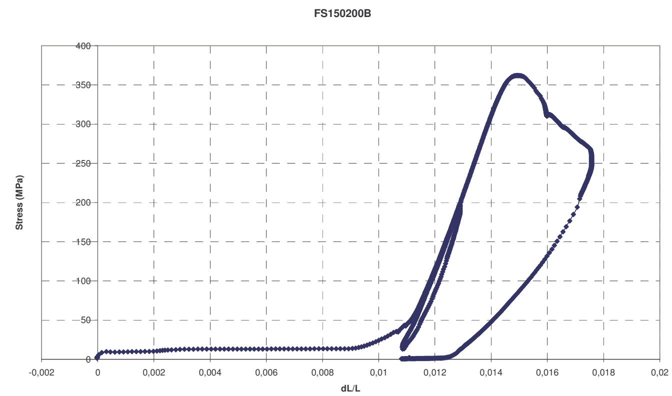

Figure 6 – Stress shortening curve of the FS150200B specimen test. All cycles of loading

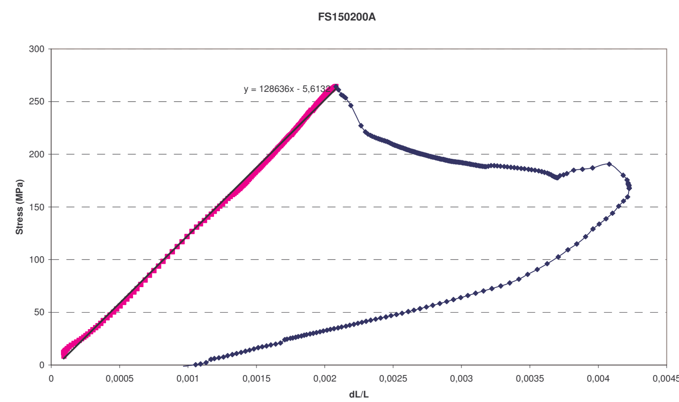

Figure 7 – Final loading and collapse of panel FS150200A

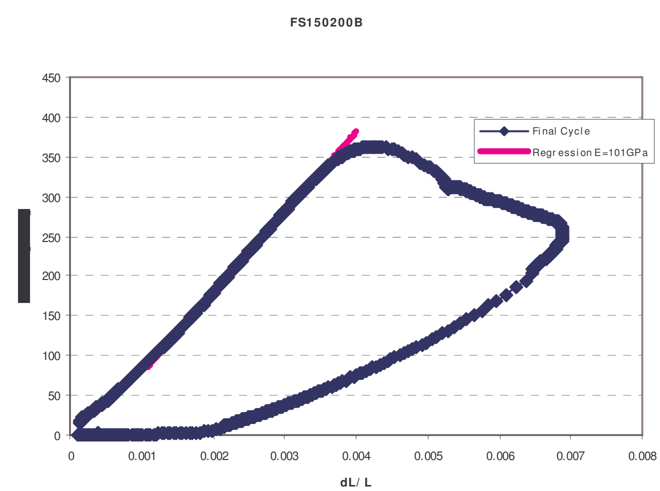

Figure 8 – Final loading and collapse of panel FS150200B

However one may observe that in certain regions the tangent modulus is much higher than in others. This should result from the evolution of the panel's deformed shape with the increase of the compressive loading. In the large panel (series B) that observation is not so marked due to its geometry. However three regions may be defined: the initial one where the rigidity seems to be increasing due to the imperfection of the contact edges with the end supports and the stiffeners end tolerances, the middle one with a linear relation between stress and shortening and a non linear relation near the collapse load due to the increasing deformations of the panel and eventually some plasticity.

BS series results

The BS series shows two different results for the two tests due to some problems on the loading at the supports. The stiffeners are thick bars made of mild steel and the associated plate is made of S69 steel. Thus one may expect large plasticity on the bars while the plate is still in the elastic range, assuming that the whole panel remains nearly flat.

Figure 9 presents the stress shortening curve of panel of panel BS150200A and the next figure relates to panel BS150200B.

The shortest panel, series A, has a very high ultimate stress (577MPa), which means that the stiffeners were able to maintain the configuration, flatness, of the panel after suffering large plastic deformations allowing the plate to continue supporting more load. The computed equivalent squash stress of the whole panel is 594 MPa thus the effectiveness of the panel is 0.971, which is very close to full effectiveness.

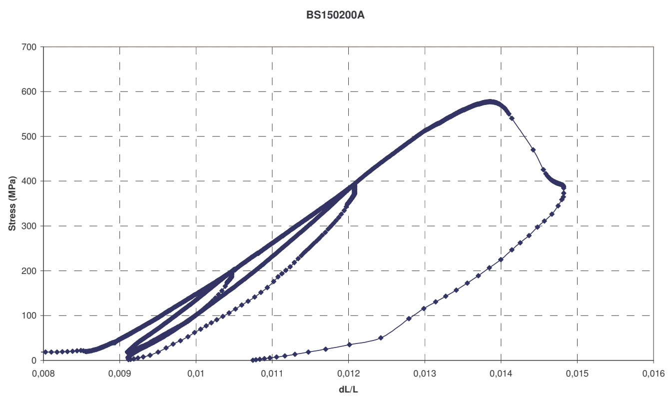

Figure 9 - Stress shortening curve of the BS150200A specimen test. All cycles of loading.

The equivalent squash stress σ_{Yeq} is defined as following:

$$\sigma_{Yeq} = \frac{\sigma_{Yp} A_p + \sigma_{Yst} A_{st}}{A_p + A_{st}} \tag{1}$$

where σ_{Yp} is the yield stress of the plate, σ_{Yst} is the yield stress of the stiffeners, A_p the cross section area of the plate and A_{st} is the cross section area of the stiffeners. One may define an equivalent yield strain as:

$$\varepsilon_{Yeq} = \frac{\sigma_{Yeq}}{E} \tag{2}$$

E is the Young modulus of the material assuming it is the same for S69 and mild steel.

However both concepts cannot be applicable with high accuracy but they can be used to compare the normalized stress strain curves of different panel made of different materials. The difference on the material behavior of the equivalent material and the overall material behavior of the hybrid BS panels may be observed in Figure 10, where the structural modulus of the real panel reduces above the yield stress of the stiffeners and the equivalent yield strain is lower than the truly global yield strain which equal to the yield strain of the S69 steel.

The collapse was due to plate induced failure at the middle span that has induced some global deformations towards the stiffeners on the adjacent span. These deformations, associated with some lack of efficiency of the frames support conducted to a secondary permanent deformed shape close to the column induced failure. This last failure originated the sudden discharge of load at the 0.0142 shortening with a sudden increase of shortening. After that discharge from 550 MPa to 410 MPa, the structure presented a smooth shedding of load with the increasing of shortening showing that the configuration of panel had stabilized.

On the BS150200B test the ultimate average stress achieved was very low compared to the expected result, Figure 11. It was expected that the ultimate stress was higher than that obtained on the BS150200A experiment because the panel was larger and thus, the free end edges effects were not so important. However the geometry of the support used on this experiment was not appropriated and one had a premature collapse on the middle part of one of the external spans of the panel due to a non uniform distribution of load, especially near the supports (Figure 12). As result the following experiments on large panels used a different geometry for the supports. But even with those problems the ultimate average stress was 366 MPa.

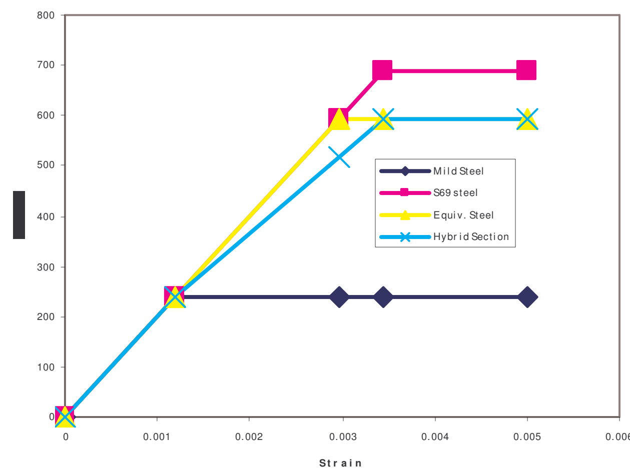

Figure 10 – Material behaviour of mild, S69 steel and comparison with equivalent material of hybrid BS specimens.

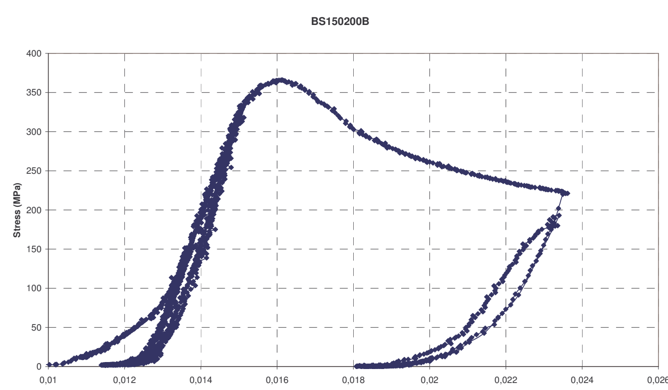

Figure 11 - Stress shortening curve of the BS150200B specimen test. All cycles of loading.

With respect to the structural modulus the values found on the elastic domain were 130 GPa for the series A specimen and 158 GPa for the B specimen, during the final loading path. They confirm that the structural modulus in compression is lower than the Young modulus of the material and that larger panels tend to be more representative of the real situation than shorter ones.

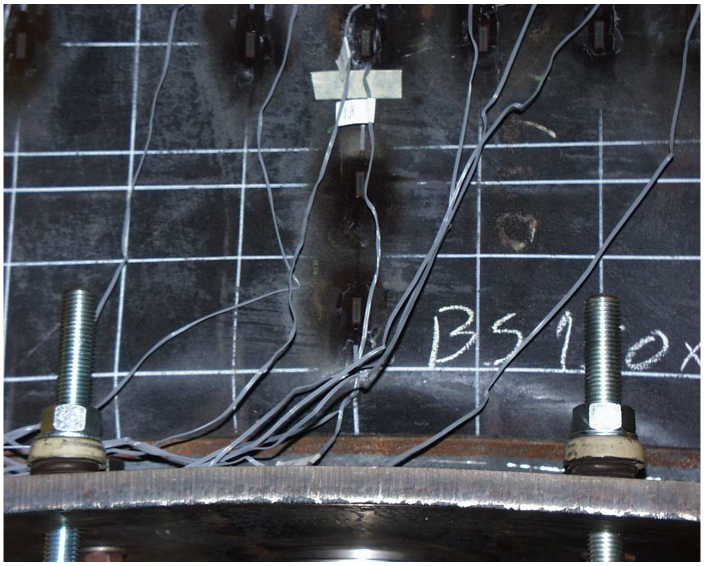

Figure 12 – Premature failure of the loading support leading to premature collapse on the adjacent span of the panel.

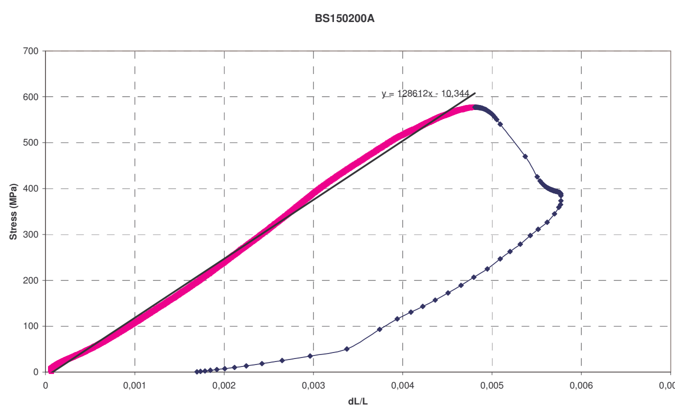

Figure 13 – Final loading and collapse of panel BS150200A.

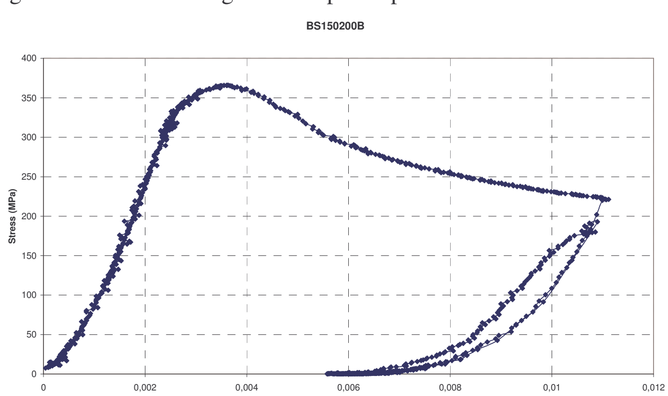

Figure 14 – Final loading and collapse of panel BS150200B.

From Figure 13 it may be observed that this average value of the structural modulus is lower than the highest value. For instance in the range of 300-400 MPa one may read a structural modulus of 154 GPa which is very close to the one found on series B. These changes on the value of the structural modulus are due to the variation of the deformed geometry of the panel with the increase of the compression load.

LS series results

The series of panels reinforced with L stiffeners allowed obtaining results as expected related to the relative value of ultimate average stress. Both panels supported more than 500 MPa, respectively 500 MPa for the A model and 541 MPa on the larger model. The large panel has an 8.2% higher ultimate stress than the A type panel showing the influence of the end plating effectiveness.

Figure 15 shows the results obtained in the several cycles of loading and the post buckling behavior after collapse of panel LS150200A and Figure 16 refers to the final cycle of loading on panel LS series B.

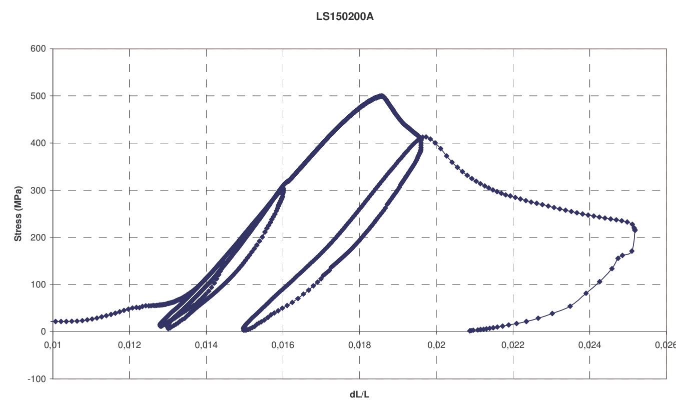

Figure 15 - Stress shortening curve of the LS150200A specimen test. All cycles of loading.

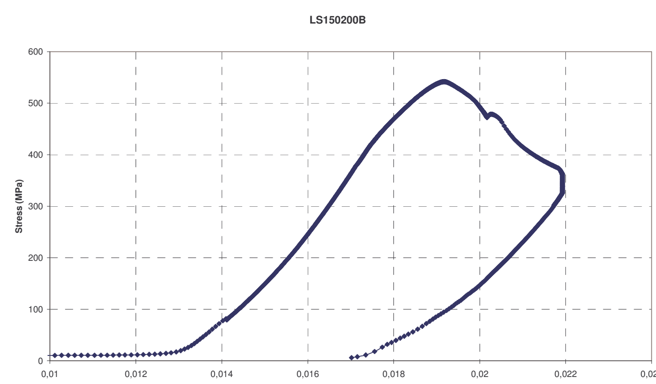

Figure 16 - Stress shortening curve of the LS150200B specimen test. Final cycle of loading.

The collapse of both panels was due to plate induced failure and it happens in the middle span of the panels. The semi waves of the buckling shape have approximately 100 mm length which is half of the span between frames, Figure 18.

Figure 17 compares the last cycles of both experiments and it possible to identify the variations of the structural modulus during the loading path due to the modifications on the shape of the out-of-plane deformations of the plating and panels.

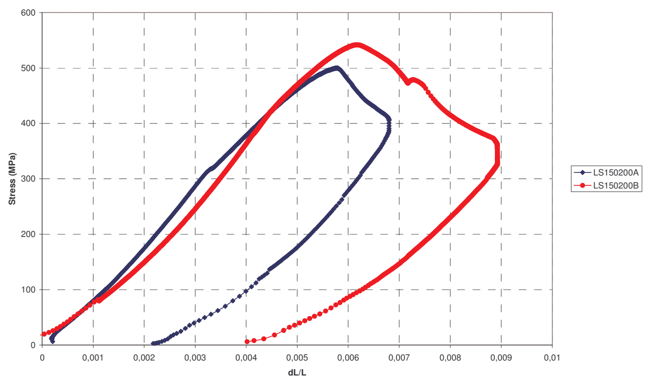

Figure 17 – Comparison between LS150200A and LS150200B panels

Figure 18 – Collapse shape of LS150200B panel.

US series results

The series US has U stiffeners of 2 mm thick. Thus the slenderness of the flange plating is very high when compared with the slenderness of the associated plating and it buckles first. It happened in both experiments and, because of the nature of the connections to the supports, the flange failure was located in the external flange of the stiffeners near the ends of the panels. However, after this local failure the panels could continue to support the load through the associated plating.

The panel of series A had a premature global collapse in one of the external span and near the supports induced by the first failure of the flange plating. The other two spans are apparently intact which means that they could support more load. The ultimate load achieved was 323 MPa and after some shedding the panel the panel regain some ability to sustain more load, Figure 19.

The B series panel presented the same local failure but the final global failure was located on the middle span by plate induced failure with half wave length of 100 mm, Figure 20.

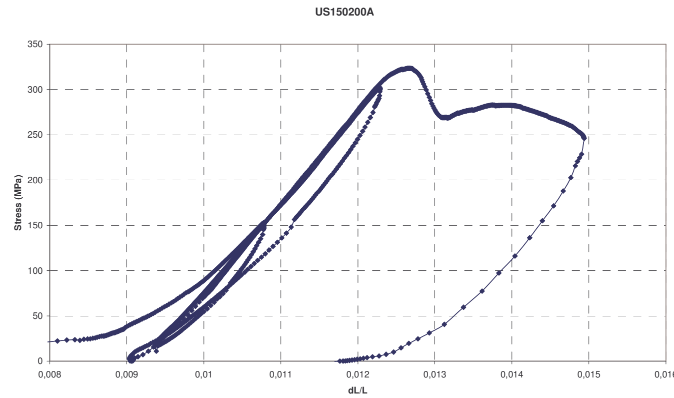

Figure 19 - Stress shortening curve of the US150200A specimen test. All cycles of loading.

Figure 20 – Final collapse shape of US150200B panel on the plating.

The ultimate stress was 462 MPa meaning that after the collapse of the flange the stiffener could continue ensuring the necessary support to the plating of S69. The development of the collapse shape was at almost constant stress. During this phase the panel was discharged and reloaded again and the same maximum stress was reached again, Figure 21.

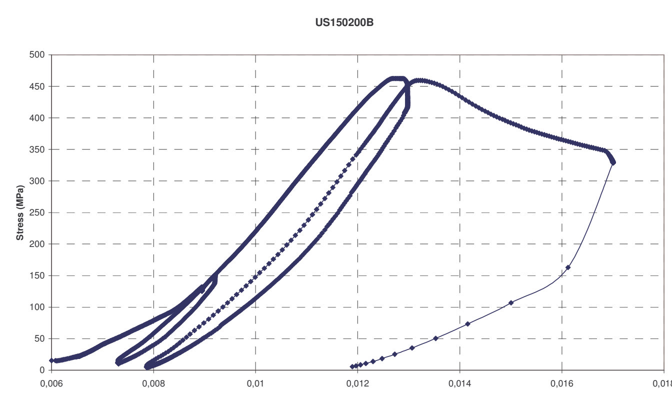

Figure 21 - Stress shortening curve of the US150200B specimen test. All cycles of loading.

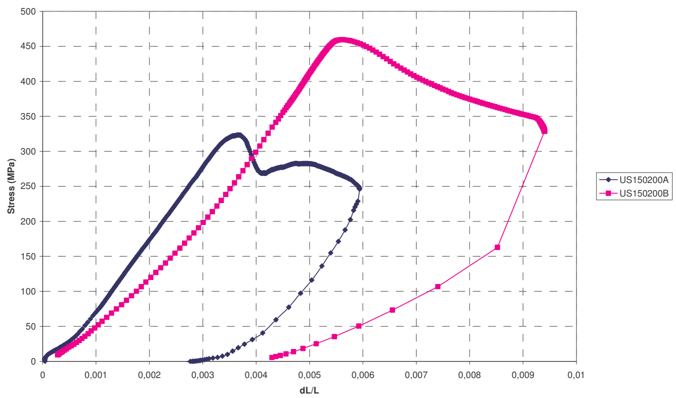

Figure 22 - Comparison between US150200A and US150200B panels

Figure 22 compares both tests showing that the structural modulus is very similar at the middle of loading and the large difference on the ultimate stress due to the premature collapse of external span of A panel.

Summary of results

Figure 23 compares the average stress average shortening curves of the eight experiments. The three lower curves correspond to the tests that had premature collapse. The four curves with highest ultimate stress are plates which failed by plate induced collapse and the remained plate (FS-B) collapses by column induced failure.

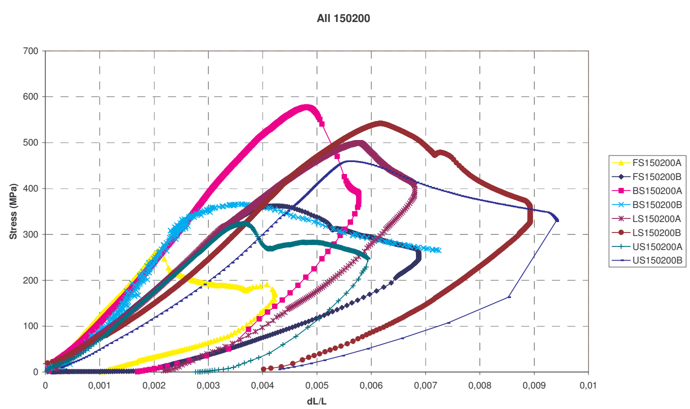

Figure 23 – Average stress strain curves for all 200 series

In Table 1 it is presented the summary of results in this series of tests with some remarks about the quality of the tests and results.

Table 1 – Summary of results

Panel	Ultimate stress (MPa)	Equivalent yield stress (MPa)	Type of collapse	Observations about test and collapse
FS-A	264	690	Stiffener	Lateral support
FS-B	362	690	Stiffener	Good
BS-A	577	594	Plate	Good
BS-B	366	594	Load support	Premature
LS-A	500	594	Plate	Good
LS-B	541	594	Plate	Good
US-A	323	594	Plate	Premature
US-B	462	594	Plate	Good

The premature collapse on panel BS-B was due to bending on the bottom support inducing local failure at nearest plating and stiffeners. The premature collapse on panel US-A was due failure at the loading region where some degree of clamping is present.

CONCLUSIONS

The hybrid panels show better performance than full S69 panels, because of the applied criteria of design and its implication on the column slenderness and strength for FS panels.

The use of S69 on the plating of the panel increases the average ultimate strength in the order of 2 or above when compared to mild steel plating. Several modes of collapse were observed for each panel like:

- Plate induced collapse
- Column induced collapse
- Stiffener flange collapse on US models

The boundary conditions affect the results and their influence was detected with the different width of the panel (series A and B), the support of the transverse stiffeners through the framing system and the moment of inertia of the frames.

Multi-span panel models are much more adequate for testing panels under compression and give more reliable results due to a better control of boundary conditions on the supports. The premature plasticity of the stiffeners did not originate the collapse of panels, but on single span model this is not necessarily true.

The transverse forces generated by axial compression may reach very high values, which may be detected by the noisy collapse, the plastic deformation of the frames and the degradation of the supporting structure.

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