Optimization of aluminium stressed skin panels in offshore applications

Optimization of Aluminium Stressed Skin Panels in Offshore Applications

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Abstract: Since the introduction of Eurocode 9 specific design rules for the calculation of aluminium stressed skin panels are available. These design rules have been used for optimization of two extrusions: one for explosions and wind loading governing and one for explosions and floor loading governing.

The optimized extrusions are fulfilling class 3 section properties leading to weight reductions up to 25% of regularly used shear panel sections. When the design would have been based on class 4 section properties even more weight reduction might have been reached.

The failure mode depends on the height of the hat stiffeners. For sections using relatively high hat stiffeners failure is introduced by yielding of the heat affected zone. For these kind of cross sections the Eurocode 9 design rules and numerical calculations show very good agreement. For sections using relatively low hat stiffeners failure is introduced by global buckling. For these kind of cross sections Eurocode 9 gives rather conservative results.

Keywords: Stressed skin panels, offshore living quarters

INTRODUCTION

For many years steel as well as aluminium alloys are used as a load bearing material in the structural design of helicopter decks, platforms, bridges and ships. Nowadays also living quarters on oil platforms are designed in aluminium. Main reasons are its low self weight as well as its excellent corrosion resistance during lifetime in unfavorable environmental conditions.

Until now aluminium structures in living quarters on platforms are designed using guidelines mainly based on experience and on design rules for steel structures. However, since the introduction of Eurocode 9 [1] specific design rules are available for the calculation of aluminium stressed skin panels. These shear panels are often used for the stabilization of frames as used in living quarters on platforms.

In this research the design of aluminium stressed skin panels is optimized using the design regulations in Eurocode 9 [1].

DESIGN CONDITIONS

The design conditions for the investigated stressed skin panels are extensively described in [2] and can be summarized as follows. The aluminium alloy used is AA6082-T6, which was chosen for its beneficial properties: good corrosion resistance, relatively high mechanical properties, well behaviour of connections under dynamic loading conditions and ability for friction stir welding. The panels are composed by aluminium extrusions which can be realized by a die fulfilling the geometrical conditions of SAPA dies (see [2)]. Maximum width of the cross section is 620 mm. Dependant on the sectional design (especially wall thicknesses) several conditions should be met, see [2] for further details.

From extended literature studies [2] it is concluded that hat profiles as shown in Fig. 1 are most efficient when comparing minimum weight versus maximum strength. Only these types of cross-sections where investigated further.

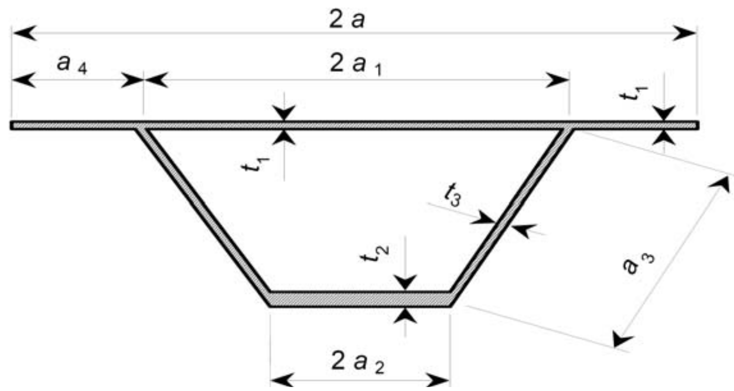

Figure 1 Basic cross section of a hat profiled shear panel section.

The extrusions are welded together to arrive at a shear panel using friction stir welding. This welding procedure enables high speeds which reduces the costs of the welds. For the strength of the friction stir welds the design strength proposed by Ogle [3] is used, see table 1.

	f_o (N/mm^2)	f_u (N/mm^2)	ε_u%
AA6082-T6	250	290	8,00
FSW (Friction Stir Welding)	160	254	4,85

Table 1 Material properties alloy 6082 T6 and FWS

Panel measurements are derived from a standard housing depth including services of 4 metres; the width of the panels are 4 meters as well. The panels are welded on both sides of the main bearing structures, usually built up by I-sections, using MIG welding procedure. These welded connections can be schematized as hinges (see Fig. 2).

The panels are designed for loading configurations parallel to the plane as well as loading combinations perpendicular to the plane. The loads can be divided in next categories: self weight, wind loading, floor loading and explosions. Load combinations, safety factor and load combinations are according to [4].

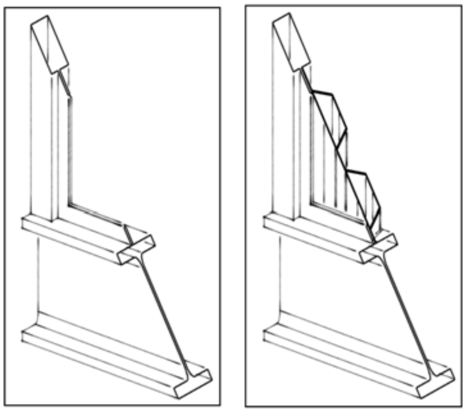

Figure 2 Frames with or without shear panels

OPTIMIZATION PROCEDURE

Using the design conditions mentioned in 2 and using hat profiles as the most efficient cross section, optimization for extrusion measurements (width, height and thickness) has been carried out for different loading conditions. Optimization has been worked out using next boundary conditions:

- Minimum wall thickness 2.5 mm;
- Cross section class 3 according to [1].

For in plane stiffness and strength the shear plane loads are decisive for optimal profile measurements. The calculations (see [2]) have been worked out for a shear panel of 4 times 4 m^2 resulting in the minimum cross sectional area as given in Fig. 3.

The same has been done for the case that out of plane loading (for example explosions) are governing. These calculations (see [2]) have also been worked out for a panel of 4 times 4 m^2 resulting in the minimum cross sectional area as given in Fig. 4 fulfulling strength conditions as well as deformation conditions.

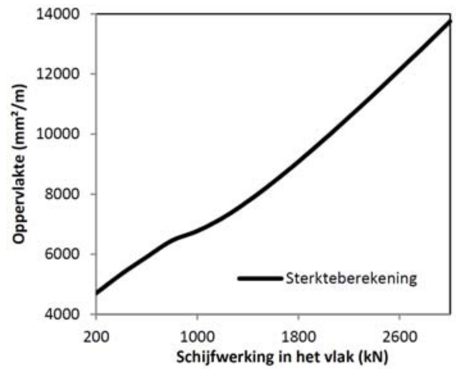

Figure 3 Minimum cross section for shear load combinations

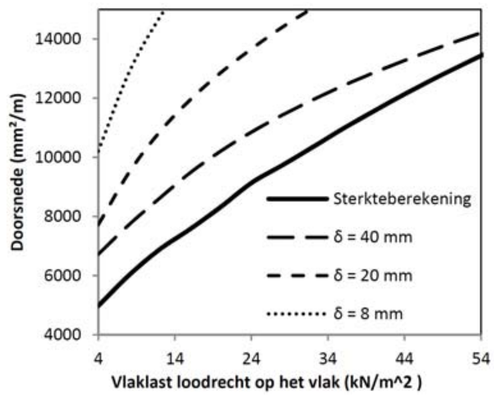

Figure 4 Minimum cross section necessary for out of plane load combinations

Loads have to be combined for several load combinations. Interaction of both optimization procedures results in interaction graphs as shown in Fig. 5 and Fig. 6, in which strength calculations have been mixed. The optimum cross section can be derived from the combination of shear load and out of plane load. When deformations are relevant (see Fig. 4) then the minimum area will be more governed by out of plane loading dependent on the deformation criterion used.

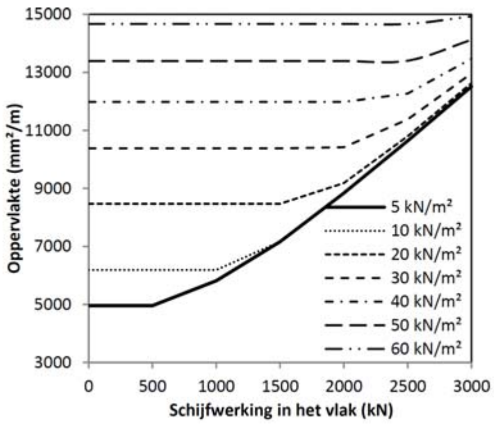

Figure 5 Minimum cross sectional area for out of plane loading dependent on the shear loading

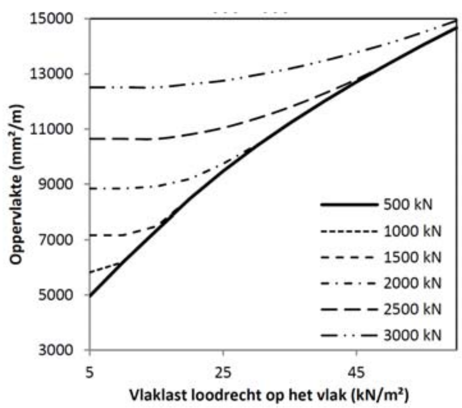

Figure 6 Minimum cross sectional area for in shear loading dependent on the out of plane loading

The design of the stressed skin panels is based on application in a six story living quarter with a height of 24 meters (6 panels) and a floor area of 8 by 12 meters (2 by 3 panels). The design loads are according to [1] and [4] worked out for three different loadings:

- permanent loading 2.0 kN/m^2 (self weight, piping and floor finishing);
- variable loading (wind 2.0 kN/m^2 , floor 5.0 kN/m^2);
- special loadings (explosions 10 kN/m^2 or 25 kN/m^2, based on [4])

Four governing panels have been investigated:

- Wall panel loaded by static pressure due to explosions 25 kN/m^2
- Wall panel loaded by static pressure due to explosions 10 kN/m^2
- Floor panel
- Combination panel

The aluminium alloy used is 6082 T6, according to Eurocode 9 [1] having a design 0.2% yield strength $f_{0,d}$ = 250 N/mm^2 , a HAZ strength $f_{0,HAZ}$ = 160 N/mm^2 or a HAZ factor ρ_{HAZ} = 0.64. Length of the HAZ zone equals 20 mm. Deformation limits are set to 20 mm (0.5 % of span length) for total deflections δ_{max} and 13.3 mm (0,.33% of span length) for additional deflections δ_2.

For load combinations including explosions serviceability limit states are not taken into account. For all other load combinations ultimate limit states as well as serviceability limit states are relevant, see [2].

OPTIMIZATION OF CROSS-SECTION

Strength and stiffness calculations according to [1] have resulted in optimized panels fitting maximum extrusion mearuments ([2]). The following optimal cross-sections can be distinghuished (Fig. 7 to 10):

- Panel 1 optimized for explosions 25 kN/m^2 and wind loading 2.0 kN/m^2;
- Panel 2 optimized for explosions 10 kN/m^2 and wind loading 2.0 kN/m^2;
- Panel 3 optimized for self weight 2.0 kN/m^2 and floor loading 5.0 kN/m^2;
- Panel 4 optimized for load conditions of panel 1 (thickness of upper plate) and load conditions of panel 3 (hat stiffener of panel 3).

Afm.	(mm)
a	118
a_1	65
a_2	59
a_3	74
a_4	53
t_1	4.9
t_2	5.3
t_3	2.5
h	74
Opp.	9124 mm^2/m^1

$\rho_{c.g}$	0.81
$\rho_{o.haz}$	0.64
W_{eff}	$52*10^3$ mm^3
I_{eff}	$231.5*10^4$ mm^4

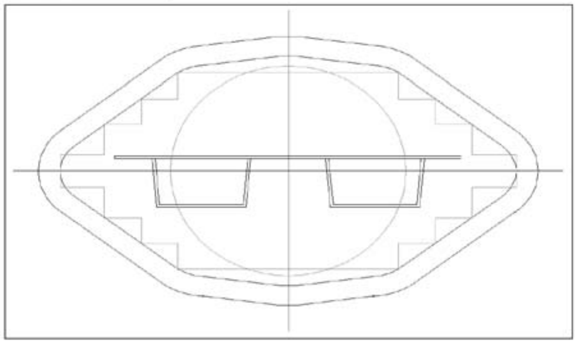

Figure 7 Optimized section panel 1 (see Fig. 1 for explanation)

Afm.	(mm)
a	64
a_1	35
a_2	32
a_3	79
a_4	29
t_1	2.7
t_2	2.9
t_3	2.5
h	79
Opp.	7240 mm^2/m^1

$\rho_{c.g}$	0.79
$\rho_{o.haz}$	0.64
W_{eff}	$21*10^3$ mm^3
I_{eff}	$93*10^4$ mm^4

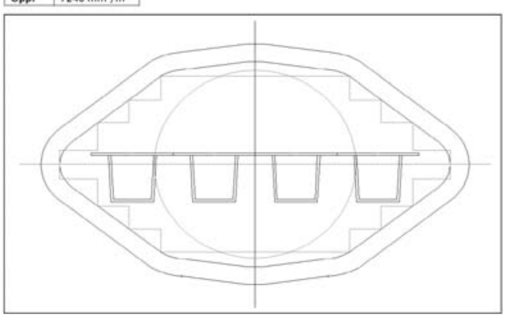

Figure 8 Optimized section panel 2 (see Fig. 1 for explanation)

Afm.	(mm)
a	96
a_1	53
a_2	48
a_3	106
a_4	43
t_1	4.1
t_2	4.4
t_3	2.7
h	105
Opp.	9234 mm^2/m^1

$\rho_{c.g}$	1.00
$\rho_{o.haz}$	0.64
W_{eff}	$57*10^3$ mm^3
I_{eff}	$350*10^4$ mm^4

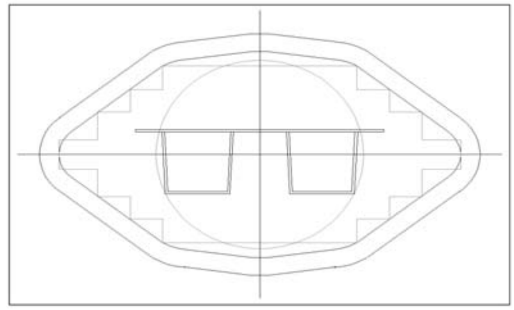

Figure 9 Optimized section panel 3 (see Fig. 1 for explanation)

Afm.	(mm)
a	116
a_1	64
a_2	58
a_3	99
a_4	52
t_1	4.9
t_2	5.3
t_3	2.5
h	99
Opp.	9742 mm^2/m^1

$\rho_{c.g}$	1.00
$\rho_{o.haz}$	0.64
W_{eff}	$72*10^3$ mm^3
I_{eff}	$427*10^4$ mm^4

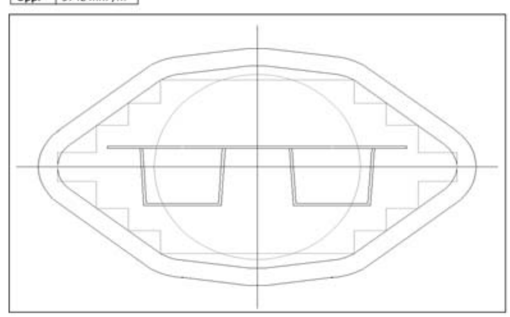

Figure 10 Optimized section panel 4 (see Fig. 1 for explanation)

A comparison of the optimized cross sections of panels 1 and 2 with existing shear panels [2] results in a 10 to 25 % weight reduction. Most weight reduction is realized by optimized dimensions of the hat stiffener. It should be mentioned that even more weight reduction could be realized by designing class 4 cross sections instead of class 3 cross sections. However, in that case production and fabrications limits for very slender section parts should be taken into account.

FEM ANALYSIS

For the verification of the analytical results a FEM analysis using ANSYS version 12.0.1 [2] has been carried out. The infill hat profiled plates have been simulated using SHELL181 elements, the edge beams of the frame have been simulated using BEAM188 elements, see [2] for further details. As the geometry of the edge beam is unknow the BEAM elements are introduced by ASEC section types, which facilitates to introduce arbitrary geometric properties.

In [1] several failure modes are distuinghuished:

- Global panel buckling, governed by buckling of the hat sections parts(fig. 11);
- Local panel buckling, governed by local buckling of the flat parts between the sections (fig. 12);
- Yielding of panel material in HAZ zone (fig. 13).

As the optimized panel is supposed to be a class 3 section the second failure mode will not occur in practice for the considered profiles.

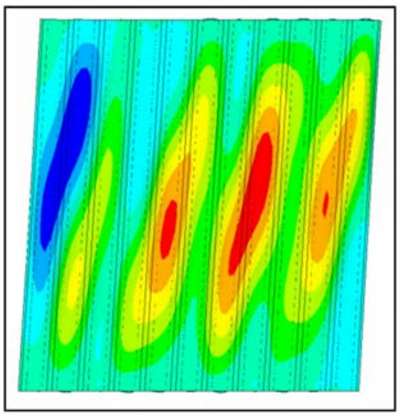

Figure 11 Global buckling

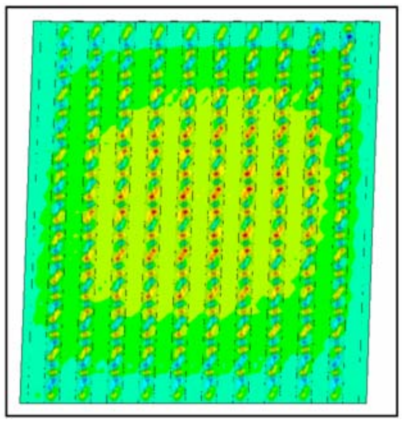

Figure 12 Local buckling

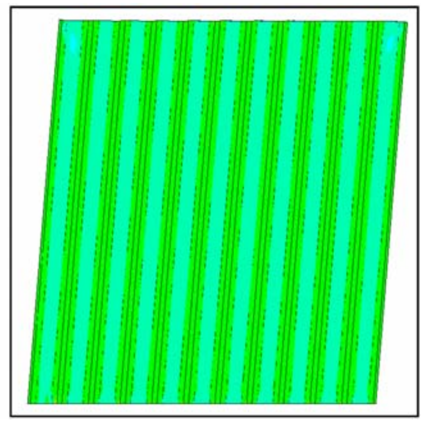

Figure 13 Yielding HAZ zone

The FEM analysis is carried out in three steps:

- linear elastic analysis (LEA)
- linear local buckling analysis (LPA)
- geometrically and physically non-linear analysis (GMNIA)

LEA determines the best mesh measurements needed for reliable results. LPA determines the magnitude and mode of the geometric imperfection model, which is generally based on superposition of one or more local buckling modes. Finally, GMNIA results in solutions using geometrical as well as physical non linearities.

In the FEM analysis the material behavior of the 6082 T6 alloy is based on the experimentally determined stress-strain relationship of Scialpi [5]. A comparison between the bi-linear Eurocode 9 model without strain hardening [1] and the Scialpi model [5] is shown in Fig. 14, where the width of the FSW heat affected zone is supposed to be equal to the width of a MIG welded heat affected zone, i.e. 20 mm for plate thicknesses up to 6 mm and 30 mm for plate thicknesses between 6 and 12 mm.

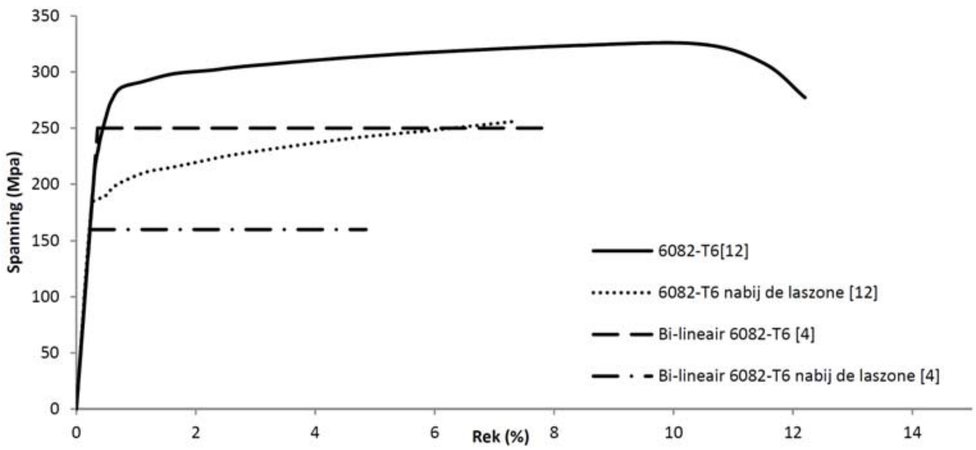

Figure 14 Stress-strain diagram of alloy 6082 T6

The numerical model is further verified by comparison to numerical research on the influence of stiffeners on steel shear panels [6]. Fig. 15 shows the agreement between the Pater analysis [2] and the Alinia analysis [6] when modeling using the same geometrical and physical properties. As Fig. 15 shows the agreement is 100% when no stiffeners are used. The small difference for panels with stiffeners can be clarified by the use of SHELL elements in the Pater model versus BEAM elements in the Alinia model.

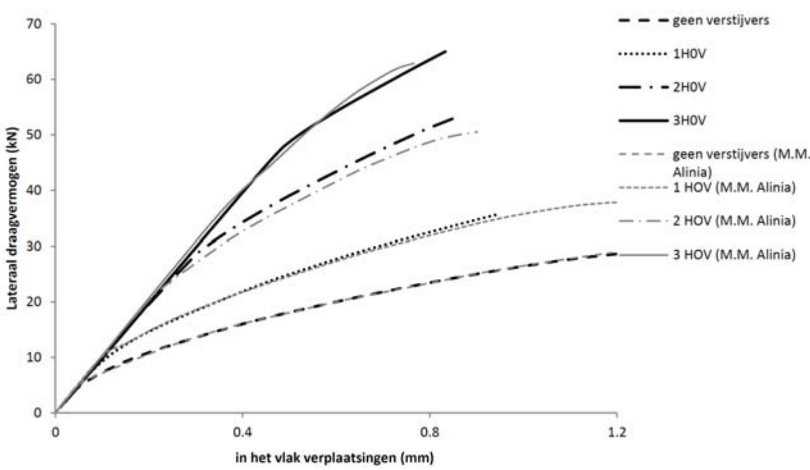

Figure 15 Comparison of lateral shear resistance for several geometries.

PARAMETRIC STUDIES

Parametric studies are carried out to be able to analyse the influence of imperfections, edge beams and plate stiffeners on the resistance of the investigated shear panels.

The influence of the magnitude of geometrical imperfections is given in Fig. 16, which shows that this influence is very small. Rather arbitrarily an imperfection of 1/666 of the span length is chosen to be representative for further research.

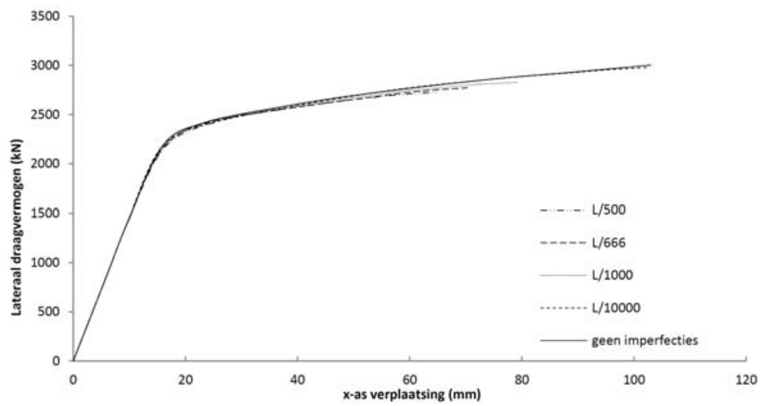

Figure 16 Influence of geometrical imperfections on lateral shear panel resistance

However, the influence of the stiffness properties of the edge beams is relatively high (see fig. 17). The influence had been investigated for a five different edge beam, only differing in the second moment of inertia I_{yy}. Other properties (cross section A and second moment of inertia I_{zz}) are the same for the considered calculations. The maximum lateral resistance can only be reached by edge beams too stiff for practical situations.

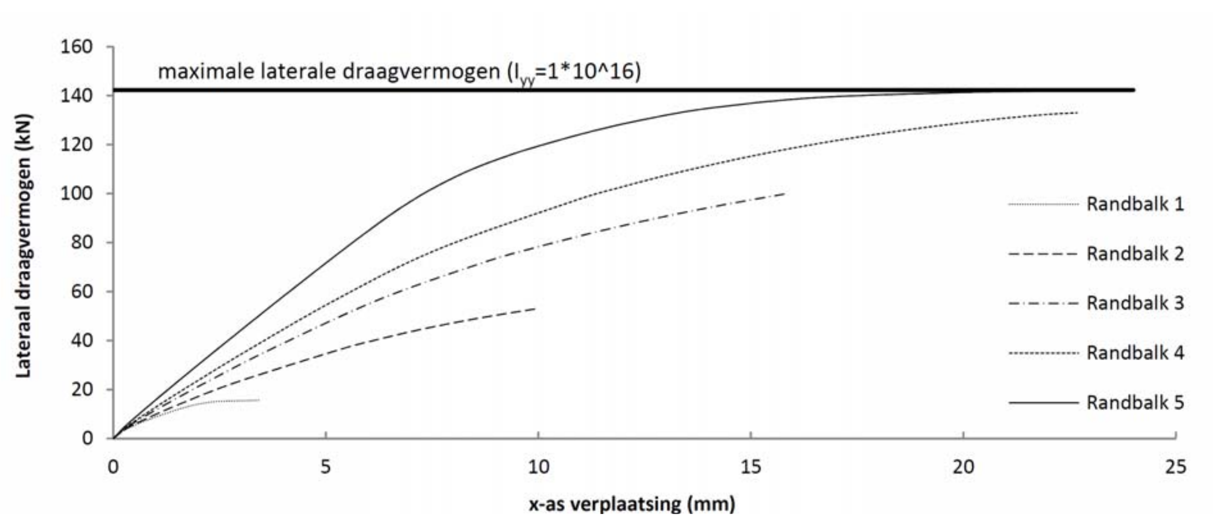

Figure 17 Lateral shear resistance for edge beams differing in second moment of inertia I_{yy}

At last the influence of the height of the stiffeners using stiffener models 2 and 4 (see fig. 8 and 10) is investigated . Figure 18, which is worked out for panel 4, shows that lateral shear resistance hardly increases when the height of the profiles is larger than 60 mm, which seems to be the upper limit for shear panel resistance.

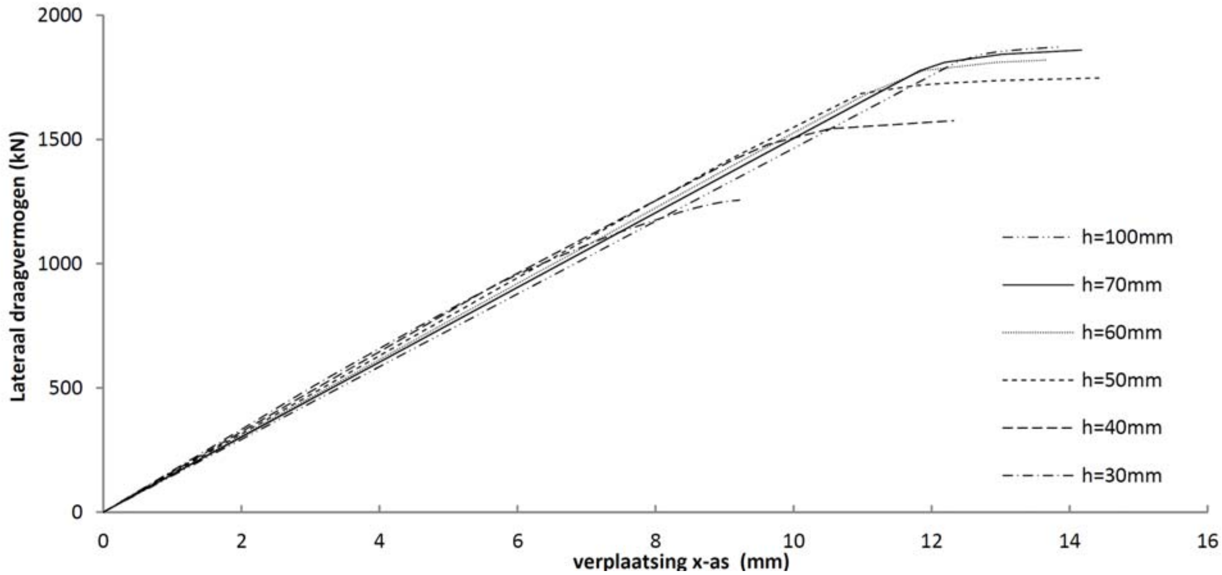

Figure 18 Lateral shear resistance of panel 4 with varying profile heights.

Determining optimum shear stiffened plates panel 4 has been further optimized to panel geometries 5 to 8 (fig. 19). The relevant shear resistances and its typical deformation behavior are given in Fig. 20 and 21).

Afmetingen	Paneel 5	Paneel 6	Paneel 7	Paneel 8
Lengte (mm)	4000	4000	4000	4000
Breedte (mm)	4012	4096	4032	4064
a_1 (mm)	32	35	53	70
a_2 (mm)	28	30	45	60
a_4 (mm)	27	29	43	57
t_1 (mm)	2.5	2.7	4.1	5.4
t_2 (mm)	2.5	2.7	4.1	5.4
t_3 (mm)	2.5	2.5	2.5	2.5
h (mm)	43	68	65	61
$\rho_{c;g}$	0.347	0.64	0.64	0.64
ρ_{haz}	0.64	0.64	0.64	0.64

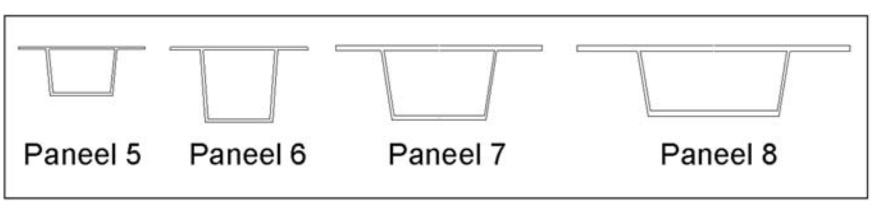

Figure 19 Optimized shear panels 5 to 8

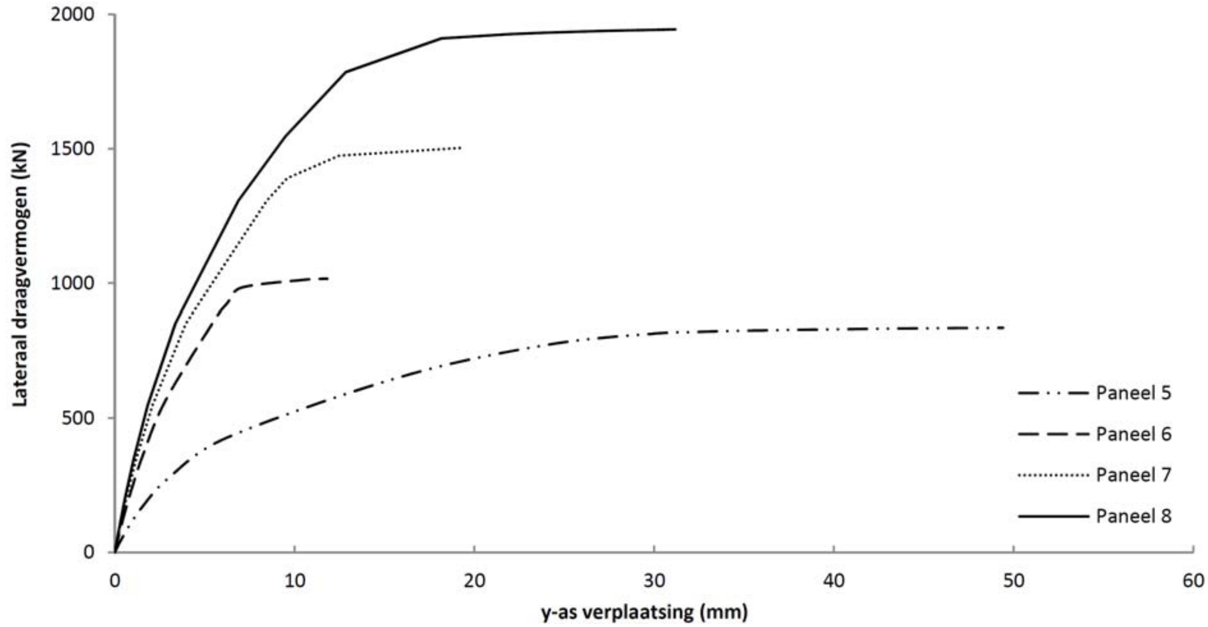

Figure 20 Lateral shear resistance versus in plane deformations for panels 5 to 8

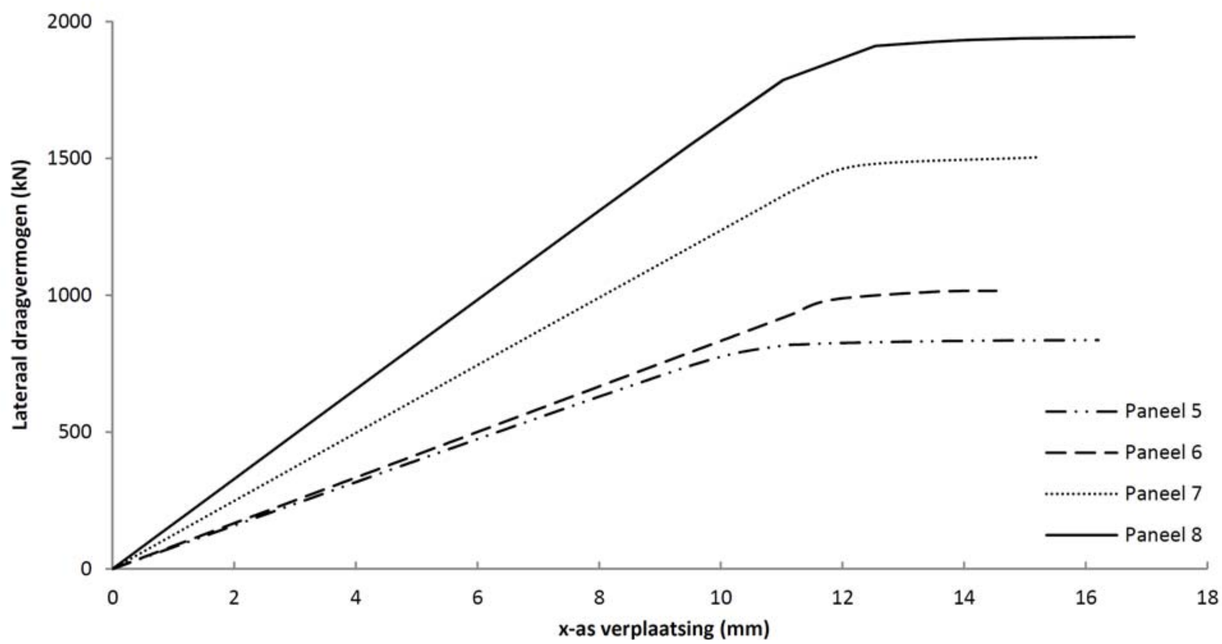

Figure 21 Lateral shear resistance versus out of plane deformations for panels 5 to 8.

COMPARISON DESIGN RULES AND FEM RESULTS

Fig. 22 shows the shear panel resistance of panel type 4 using three different analysis methods:
design rules according to Eurocode 9 [1], numerical analysis using ANSYS [2] and rational design according to [8]. Fig. 22 also clearly shows that lateral shear resistance is governed by the plastic capacity of the panels. Global buckling instability is not governing for the considered panel types, while local buckling was already excluded by the application of wall thickness not smaller than 2.5 mm. The advised rules according to Solland and Frank [8] are very safe.

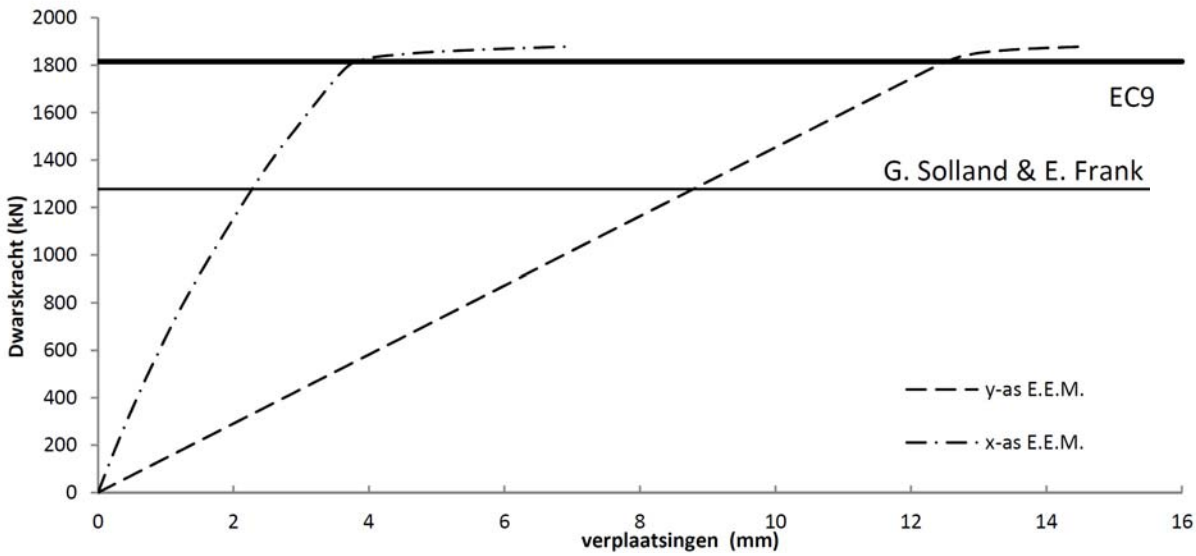

Figure 22 Load versus deformations panel 4.

Comparison of Eurocode 9 to Ansys show very well agreement for panel types 6 to 8. Very small deviations occur due to geometrical imperfections used in the FEM model. Panel 5 shows a relatively large difference due to a deviating failure mode (global instability).The results have been worked out in a graph (Fig. 23) which shows the lateral shear panel strength dependent on the cross sectional panel.

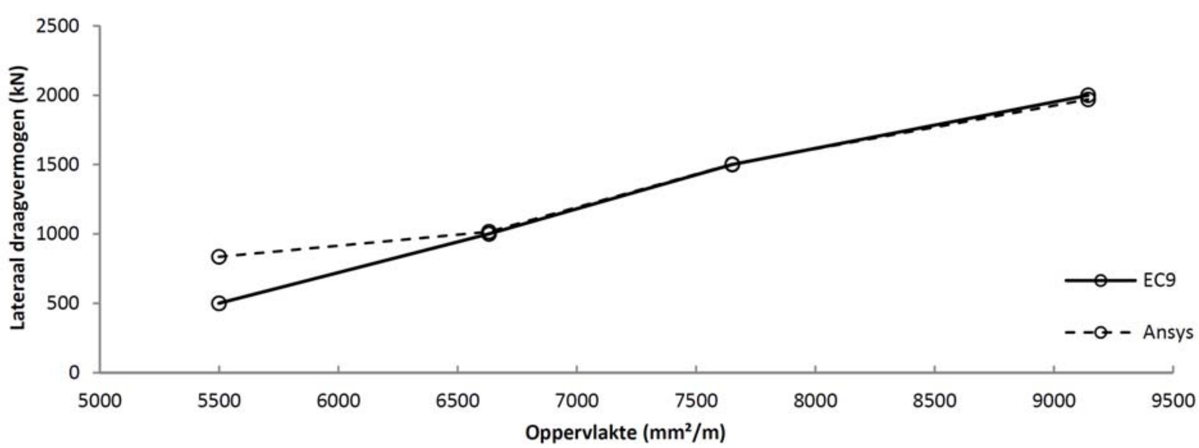

Figure 23 Comparison of shear panels optimized according to Eurocode 9 versus Ansys.

CONCLUSIONS

The optimized cross sectional design for shear panels applied in living areas on oil platforms have resulted in two section geometries: panel 2 for wind load governing and panel 4 (Fig. 8 and 10) for explosion and/or floor load governing. Comparison with existing shear panels leads to a material reduction of 10 to 25%. The optimization has been worked out for class 3 cross sections, using a minimum wall thickness of 2.5 mm.

Parametric studies show that the influence of geometric imperfections on the load bearing strength is very small. However, the stiffness of edge beams is significant. To reach maximum lateral shear strength the edge beam stiffness should be very high, resulting in unrealistic beam dimensions.

The failure mode depends on the height of the hat stiffeners. For sections using relatively high hat stiffeners failure is introduced by yielding of the heat affected zone. For these kind of cross sections the Eurocode 9 design rules and numerical calculations show very good agreement. For sections using relatively low hat stiffeners failure is introduced by global buckling. For these kind of cross sections Eurocode 9 gives rather conservative results.

RECOMMENDATIONS

It is recommended to investigate the shear strength for panels with relatively low stiffener heights further by analytical and/or experimental research. For these panels global buckling of the stressed skin panels determines ultimate limit strength. The Eurocode 9 design rules seem to be rather conservative for this type of panels. Further it is recommended to expand the research to class 4 cross sections which will reduce the optimized cross sectional area even more.

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