Structural design of helicopter landing platform for super-yacht

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ABSTRACT

Structural design of helicopter landing platform for super-yacht

By Daniel **Heredia Chávez**

Owner's request of having on their yacht the facilities to allow helicopter landing, is getting more frequent regardless of the yacht size. It is of primary importance, at a contract stage to understand what owners want and, based on this to verify his request.

Three different uses could be achieved. *Emergency landing*, occasional touch and go, were it is not possible to transfer guess. *Private yacht*, with no requirements, were helicopter pilot operate at his risk. *Commercial use*, were it is possible to transfer guess, and are constructed fully in compliance with Large Yacht Code.

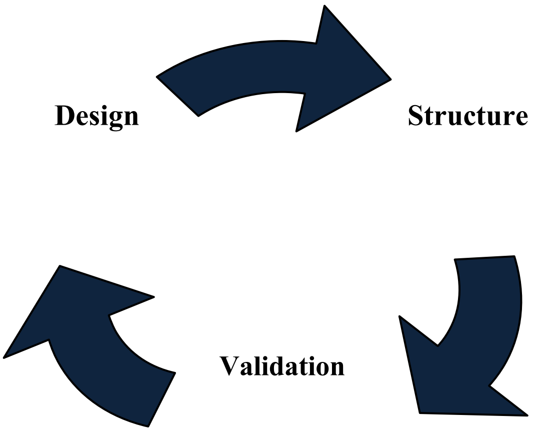
Many helicopter platforms are already in use for private or emergency porpoises. The challenge presented is to develop a platform large enough to comply with the requirements of the Large Yacht Code.

The aim of this Thesis is to design a state of the art helicopter platform in a super-yacht for commercial use. After completing the design, the insurance approve will be essential for the success of the project. The development of the new platform is presented in three different steps.

Location, at the very first part of the design is necessary to find an optimum accommodation for the platform. Many rules are analyzed according to the requirements, of landing visibility, space available for this purpose on the yacht. At this stage is important to solve problems like, interaction of columns with garage exits, or even the fact of moving columns for aesthetical reasons.

Structure, this is the main part of the work, were analysis is performed for the extreme landings. This section is based in a mix of rules approach with direct structure calculation. The main members of the structure like, transverses, primary stiffeners and pillars are designed according to direct calculation. Different diagrams of loads shear stress and maximum bending moments were necessary to calculate the section modulus of the girders. The columns are analyzed based on Euler´s approach. For secondary stiffeners and plate a rule approach is presented.

Validation is performed in order to review the structural calculation. At this stage is necessary to realize an analysis, to confirm that, the structure will really support the extreme landings at different locations of the helicopter platform. After several loops the final design is presented.



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1.0 INTRODUCTION

The aim of this thesis is to present a totally new structural design of a heli-deck in a super yacht. After completing the design is necessary to be approved from the insurance company. The first part presented is an analysis of the different locations available and the proposal of the optimum location according to the structural and flight restrictions. The second part presents a set of structures developed and refined to reach a light and strength heli-deck. Finally a validation is performed to confirm the calculus.

1.1 DEFINITIONS

Is possible to define three different porpoises of helicopter platforms:

Occasional / Emergency landing/Touch and go
Where helicopters land or conduct winching operations on an occasional or emergency basis on Ships without heli-deck. It is applicable to a “commercial yacht” but it is not possible to transfer guests.

Private use
No requirements therefore, only for private yacht or for commercial yacht not operating commercially. Helicopter pilot operates at his risk. A structural assessment of the Landing area is highly recommended

Commercial use
Fully in compliance with requirements Large Yacht Code 3 Annex 6.

Many helicopter platforms were developed for private use. The challenge presented in this work is to develop a totally new platform that complies with the requirements of the Large Yacht Code. The advantage between the commercial uses versus the private uses is the possibility to certify the platform and obtain an insurance that allows the vessel to transfer guests.

1.2 CONCEPTS

The next paragraphs explain a set of concepts that are fundamental for the well understanding of this work.

DIMENSIONS
For any particular type of single main rotor helicopter, the heli-deck should be sufficiently large to contain a circle of diameter D equal to the largest dimension of the helicopter when the rotors are turning. This D circle should be totally unobstructed.

STRUCTURE
In general the construction of heli-decks should be of steel or other equivalent material (could be Al alloy properly insulated) and in case forms the deck-head of a deckhouse or superstructure it should be insulated to A-60 standard.

FIRE FIGHTING
A suitable foam application system consisting of monitors or foam making branch pipes capable of delivering foam to all parts of the heli-deck in all weather conditions in which helicopters can operate.

CERTIFICATION
After locate the heli-deck, develop the structure and validate it, the aim is to receive a certification for commercial use from the classification society selected.

THE HELICOPTER
Different helicopters were analyzed. The first analysis was performed according to the Eurocopter145 further information will show the problems generated for the weight of this helicopter. The most advantageous helicopter for yacht operations is the eurocopter130.

HELICOPTER LANDING AREA
A generic term referring to any area primarily intended for the landing or take-off of aircraft. (Civil Aviation Authority CAP 437)
Area on a Ship designed for emergency Landing of helicopters. (MSC/Circular 895)

HELIDECK
A purpose built Helicopter Landing Area located on a ship including all structure, fire fighting appliances and other equipment necessary for the safe operation of helicopters
(IMO Res A.855(20))

HELICOPTER FACILITY
A heli-deck including any refuelling and hangar facility
(IMO Res A.855(20))

D-VALUE
The Largest overall dimension of the helicopter when rotors are turning

D-CIRCLE
A circle, usually imaginary unless the heli-deck itself is circular, the diameter of which is the D-Value of the largest helicopter the heli-deck is intended to serve.

LY3 The Large Commercial Yacht Code
“Code of Practice for the Safety of Large Commercial Sailing and Motor Vessels”
The Code applies to vessels in commercial use for sport or pleasure, which are 24 metres in “load line” length and over. Or, if they were built before July 1968, are 150 gross tons and over, according to the tonnage measurement regulations at that date. Such vessels are not permitted to carry cargo, or more than 12 passengers

LY3 has been developed by an industry working group in order to keep up with developments in the industry and amendments which have subsequently taken place with the international conventions for which the codes provide an alternative means of achieving compliance, more suited to these particular types of vessels.[1]

CAP 437
Standards for Offshore Helicopter Landing Areas
This publication provides the criteria applied by the CAA in assessing the standards of offshore helicopter landing areas for worldwide use by helicopters registered in the United Kingdom. Incorporating the full and final specification for the heli-deck lighting scheme comprising perimeter lights, lit Touchdown/Positioning Marking Circle and lit Heliport Identification 'H' Marking.[2]

1.3 THE FIRST APPROACH

On the basis of the original design presented by the shipyard, the helicopter selected was the EC145 with the next characteristics:

Capacity	11 passengers
Length	13 m
Maximum take-off mass	3585 kg
Turbine engines	2
Maximum range	680 km

The decision to select this helicopter was based on the space available in the owner's deck for the helicopter platform. The D value of 13m was the maximum available space to locate the heli-deck. Consequently the Eurocopter145 was the largest possible helicopter to locate.

After running the first structural calculation for the secondary stiffeners and plates it was clear that a big structure will be required to support the Maximum takeoff mass of 3585kg. The previous value should be multiplied by the emergency coefficient of 2.5, and then by the structural response factor of 1.3, with a drastically increment in the mass supported.

The proposal for the structure is show in the next figure

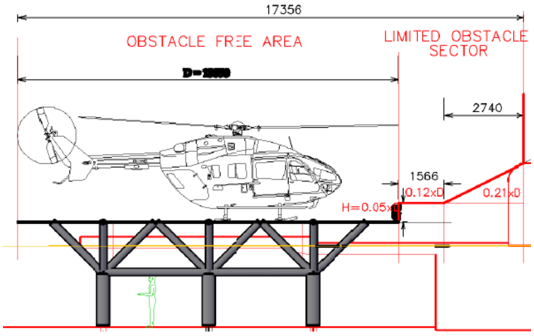
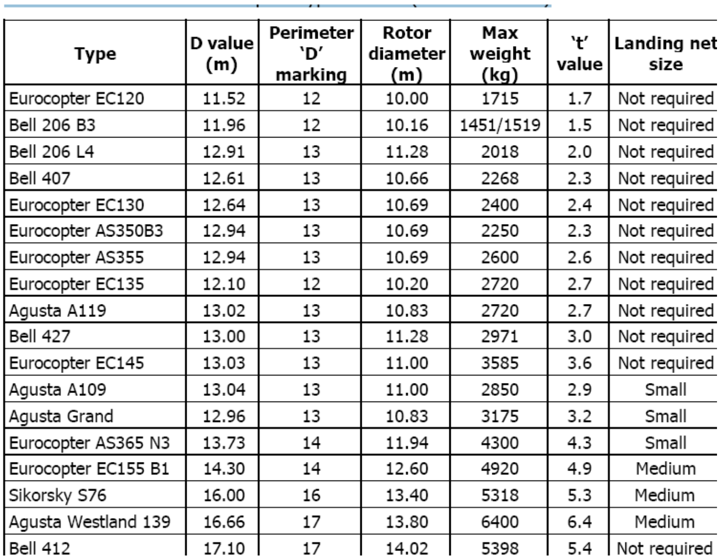


Figure 1, Structural proposal for EC145

The proposal presented for the EC145, was designed on the idea to support the weight of the double engine helicopter. The design was based on similar structures presented for this kind of helicopter in the offshore industry.

Finally the proposal was rejected for aesthetic reasons. The next research were focused to find another helicopter lighter but still with enough capacity for transportation of passengers. The next table presents different helicopters with his respective characteristics;



Type	D value (m)	Perimeter 'D' marking	Rotor diameter (m)	Max weight (kg)	't' value	Landing net size
Eurocopter EC120	11.52	12	10.00	1715	1.7	Not required
Bell 206 B3	11.96	12	10.16	1451/1519	1.5	Not required
Bell 206 L4	12.91	13	11.28	2018	2.0	Not required
Bell 407	12.61	13	10.66	2268	2.3	Not required
Eurocopter EC130	12.64	13	10.69	2400	2.4	Not required
Eurocopter AS350B3	12.94	13	10.69	2250	2.3	Not required
Eurocopter AS355	12.94	13	10.69	2600	2.6	Not required
Eurocopter EC135	12.10	12	10.20	2720	2.7	Not required
Agusta A119	13.02	13	10.83	2720	2.7	Not required
Bell 427	13.00	13	11.28	2971	3.0	Not required
Eurocopter EC145	13.03	13	11.00	3585	3.6	Not required
Agusta A109	13.04	13	11.00	2850	2.9	Small
Agusta Grand	12.96	13	10.83	3175	3.2	Small
Eurocopter AS365 N3	13.73	14	11.94	4300	4.3	Small
Eurocopter EC155 B1	14.30	14	12.60	4920	4.9	Medium
Sikorsky S76	16.00	16	13.40	5318	5.3	Medium
Agusta Westland 139	16.66	17	13.80	6400	6.4	Medium
Bell 412	17.10	17	14.02	5398	5.4	Not required

Table 1, "D"-value and Helicopter Type Criteria (Not exhaustive)

After further research the next proposal was the Eurocopter EC130 with a decrement in mass of almost 1.2 tons. This significant reduction in the Maximum Take-Off Mass will decrease the weight and the size of structure required to support the helicopter.

2.0 LOCATION OF THE HELIDECK

2.1 DIMENSION REGULATIONS

Many regulations most be fitted in order to locate the heli-deck. The first one is the size of the landing area.

Due to the actual shape of most helicopter landing areas the “D” circle will be ‘imaginary’ but the helicopter landing area shape should be capable of accommodating such a circle within its physical boundaries. It is possible to reduce the width to a value equivalent of 0.83D but the longitudinal length must be at least equivalent to 1.0D.

The diameter presented is 12650mm not 12640mm because it is necessary to prevent a slack for the drainage.

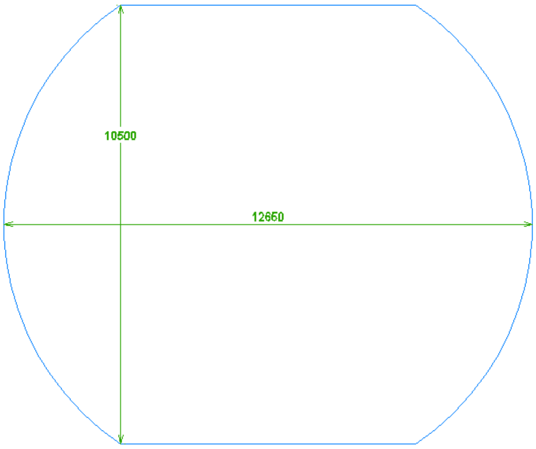


Figure 2, Landing area for EC130

2.2 LIMITED OBSTACLE SECTORS

The next step is to review the Obstacle Protected Surfaces. The diagram at Figure 3 shows the extent of the two segments of the 150° Limited Obstacle Sector and how these are measured from the centre of the (imaginary) ‘D’ circle and from the perimeter of the Safe Landing Area. This diagram assumes, since helicopter landing areas are designed to the minimum requirement of accommodating a 1 ‘D’ Circle, that the ‘D’ circle perimeter and safe landing area perimeter are coincidental.

No objects above 0.05D are permitted in the first (hatched area in Figure 3) segment of the Limited Obstacle Sector. The first segment extends out to 0.62D from the centre of the ‘D’ Circle or 0.12D from the Safe Landing Area perimeter marking. The second segment of the Limited Obstacle Sector, in which no obstacles are permitted within a rising 1:2 slope from the upper surface of the first segment, extends out to 0.83D from the centre of the ‘D’ Circle, or a further 0.21D from the edge of the first segment of the Limited Obstacle Sector.

The exact point of origin of the Limited Obstacle Sector is assumed to be at the periphery of the ‘D’ Circle.

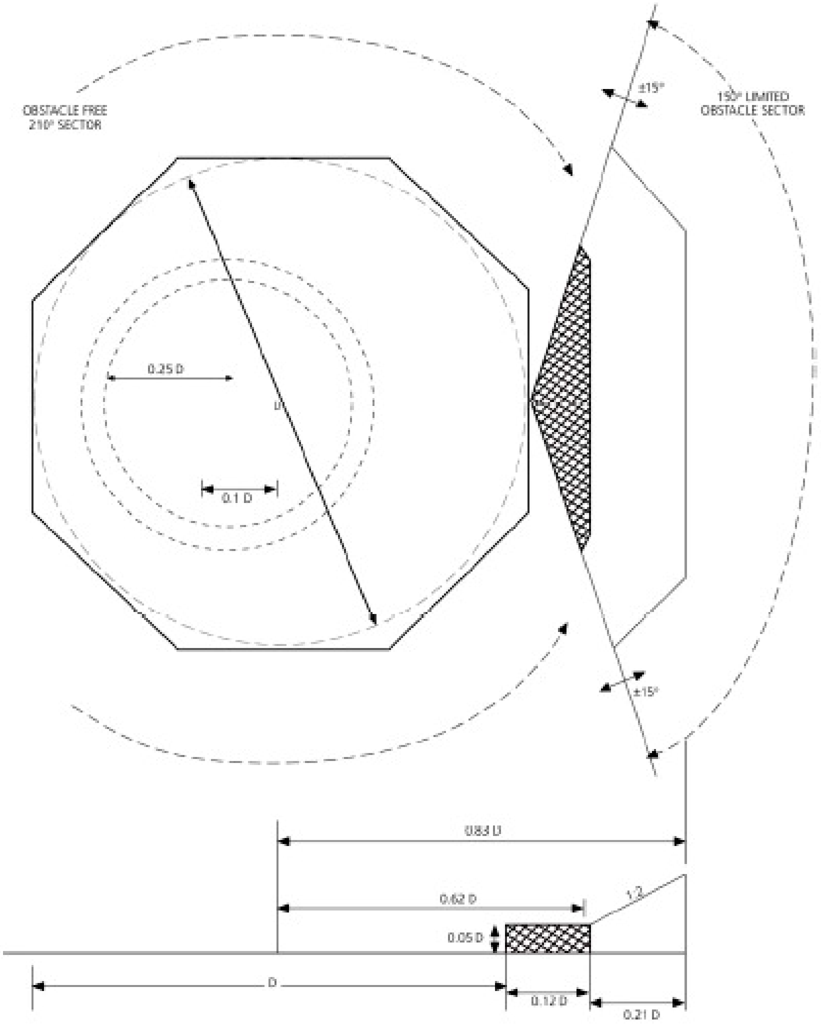


Figure 3, Obstacle Limitation showing position of Aiming Circle

Figure 4 shows that the location of the Limited Obstacle Sector does not represent a limitation. The owner's office is correctly located inside the 150° Limited Obstacle Sector, from the upper view. However the exit of the stairs should be moved at least half a meter forward.

One solution to solve the interference between the exit of the stairs and the heli-deck, was to move the heli-deck into a higher position that allows a normal use of the stairs. But this solution will imply higher pillars and heavier structure. Another problem is that the heli-deck will be disconnected from the deck structure.

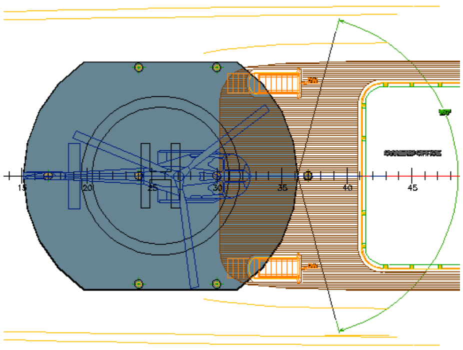


Figure 4, 150º Limited Obstacle Sector for EC130 (upper view)

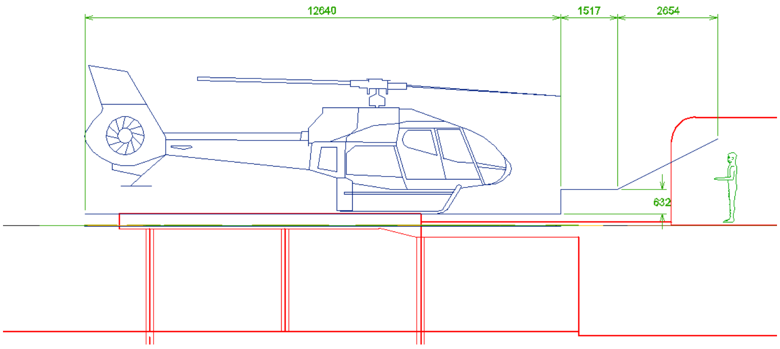


Figure 5, Limited Obstacle Sector for EC130 (starboard view)

Figure 5, shows that the owner's deck is a limitation for the Obstacle Free Sector, from the starboard view. There are two basic options to solve this problem, the first one, to move the heli-deck aft, and the second one to move the owner's deck forward.

The first option will require extending the cantilever beams, increasing the weight of the structure, and decreasing the strength of the heli-deck. If instead of increasing the cantilever beam, another pillar is located in the aft part the solution will have higher aesthetical implications than decreasing one meter the owner's office.

The final suggest is to move the owner's office one meter, or redesign the aft part of the office within a rising 1:2 slope. However this is not the main part of the work. On the other hand the structural designs and calculations are the core of this work.

3.0 STRUCTURAL DESIGN AND CALCULATION

For the initial structural design one simple rule apply. The minimum distance between pillars, the lighter the structure will be. Therefore it was necessary to locate enough pillars in order to reduce the weight of the structure. On the other hand these pillars should be connected to the bottom of the hull, and this will represent limitations on the lower decks.

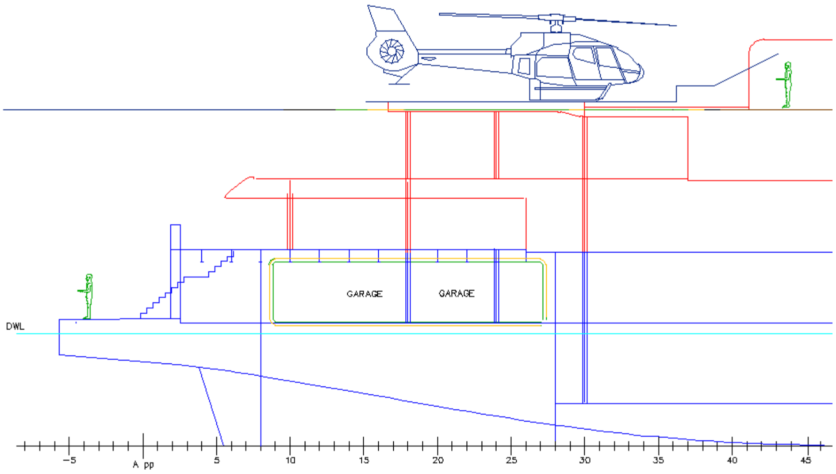


Figure 6, Garage conflict with pillars

From figure 6 is possible to realize that the pillars located in the frame 17 will obstruct the exit of the garage, if they were located at the sides. Even so is possible to locate one pillar in the centre of the garage at frame 17 that will not obstruct the exit at the sides.

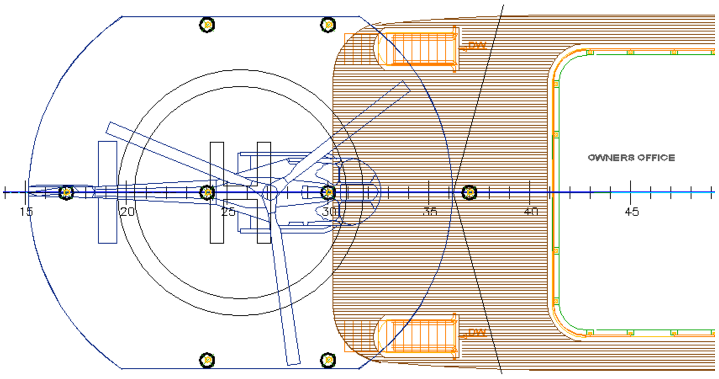


Figure 7, Location of pillars

This limitation of side pillars at frame 17, increase the distances of the central pillar at frame 17 with the next pillars at the side located on frame 24 shown in figure 7. Similar problems appear with the stairs, therefore it was necessary to locate the side pillars at frame 30 connected with one central pillar at frame 37.

3.1 STRUCTURAL MEMBERS

After the analysis of these limitations, the final design of the main members of the structure is a hexagon with two sides shorter, and aligned with the original pillars at frames 24 and 30. Figure 8 shows the final arrangement of the main transverse in dark blue and primary stiffeners in light blue.

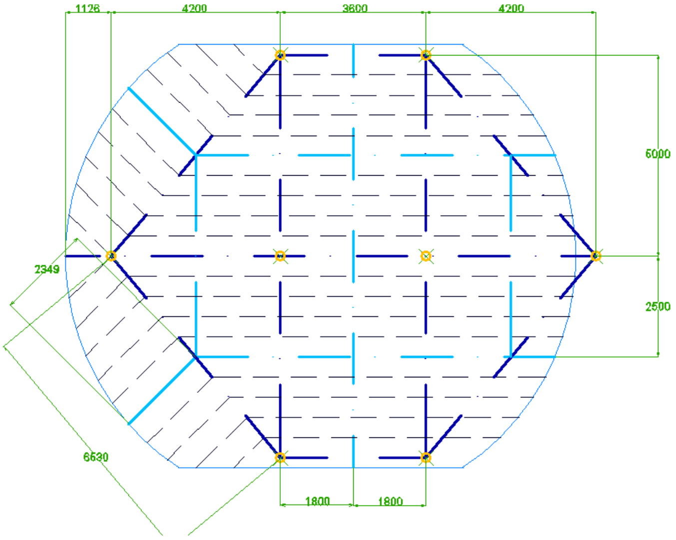


Figure 8, Design of structural members

The plate of the heli-deck is displaced one meter aft for aesthetical porpoises and also for the obstruction with the stairs showed in figure 7. After the location of main transverses and primary stiffeners, is possible to start with the calculation of the plate thickness.

3.2 PLATE

Plate thickness by rules calculation

The plating is to be designed for the emergency landing case taking the values from the next concepts and formulas, defined by rules.

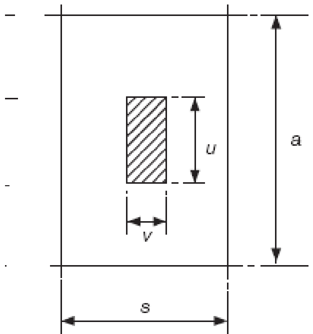
P_h = the maximum all up weight of the helicopter, in tonnes
= 2.4 tonnes
P_w = landing load on the tyre print, in tonnes
For helicopters with a single main rotor, P_w is to be taken as P_h divided equally between the two main undercarriage wheels.
P_w = 1.2 tonnes

γ = a location factor

Location	γ
On decks forming part of the hull girder: (a) within $0,4L_R$ amidships (b) at the F.P. or A.P.	0,71 Values for intermediate locations are to be 0,6 determined by interpolation
Elsewhere	0,6

Table 2, Location factor

γ = 0.6 (Elsewhere)
For the next step is necessary to obtain the values of panel and print dimensions, as required in figure 9. The panel dimensions are already holding from the primary stiffeners and main transverses.



s and a are panel dimensions, in mm
u and v are print dimensions, in mm

Figure 9, Panel and print dimensions

Because the primary stiffeners are not located exactly at the same distance, the dimension selected in this case for "*a*" is the longest dimension. Nevertheless the space between secondary stiffeners "*s*" will remain almost constant, except in the cantilever position. Therefore figure 10 represents the values selected for the calculation.

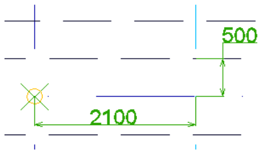


Figure 10, Panel dimensions

s = secondary stiffener spacing, in mm
= 500mm
a = panel vertical dimension
= 2100mm

The values for the print dimension "*u*", length supporting the weight of the helicopter EC130, were obtained from Eurocopter. The value of "*v*" is taken from the rules.

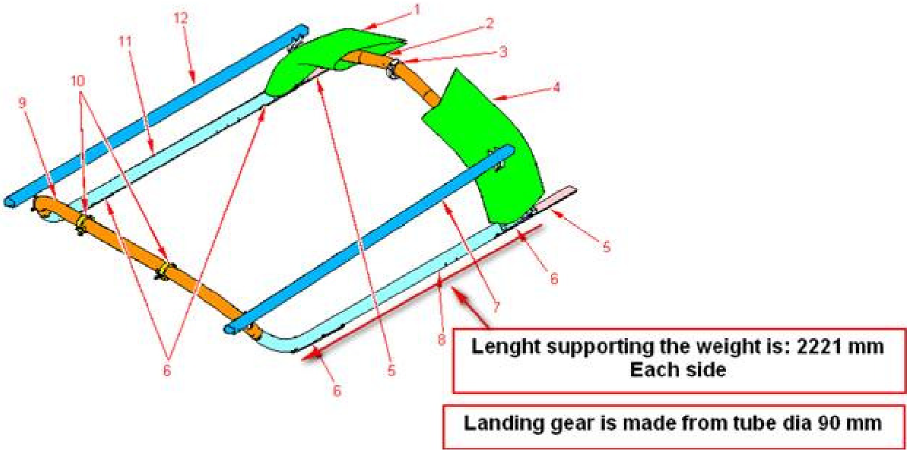


Figure 11, Length supporting the weight

u = landing gear vertical dimension
= 2221mm
v = landing gear horizontal dimension
= 10mm

After having solved panel and print dimensions, the patch and panel aspect ratios area analyzed. Then the "*f*" factor for landing decks over manned spaces is applied.

ϕ_1 = patch aspect ratio correction factor

$$\phi_1 = \frac{2v_1 + 1{,}1s}{u_1 + 1{,}1s} \qquad v_1 = v, \text{ but} \leq s \qquad u_1 = u, \text{ but} \leq a$$

= 0.21509434

ϕ_2 = panel aspect ratio correction factor

$$\phi_2 = 1{,}0 \qquad \text{for } u \leq (a - s)$$

$$= \frac{1}{1{,}3 - \frac{0{,}3}{s}(a - u)} \qquad \text{for } a \geq u > (a - s)$$

$$= 0{,}77\,\frac{a}{u} \qquad \text{for } u > a$$

=0.72805043

ϕ_3 = wide patch load factor

$$\phi_3 = 1{,}0 \qquad \text{for } v < s$$

$$= 0{,}6\,(s/v) + 0{,}4 \qquad \text{for } 1{,}5 > (v/s) > 1{,}0$$

$$= 1{,}2\,(s/v) \qquad \text{for } (v/s) \geq 1{,}5$$

= 1

f= 1.15 for landing decks over manned spaces

With all these previous values and the next formula, P_1 is obtained for the emergency landing case.

$$P_1 = 2{,}5\phi_1\,\phi_2\,\phi_3\,f\,\gamma\,P_w \text{ tonnes}$$
$$= 0.5 \text{ tonnes}$$

With P_1 is possible to calculate β_p, and with the line load and β_p, is possible to obtain the thickness coefficient from figure 1.

β_p = tyre print coefficient used in

$$= \log_{10}\left(\frac{3{,}5\,P_1\,k_a^2}{s^2} \times 10^7\right)$$
$$= 1.87873757$$

Line load = v/s
= 0.02

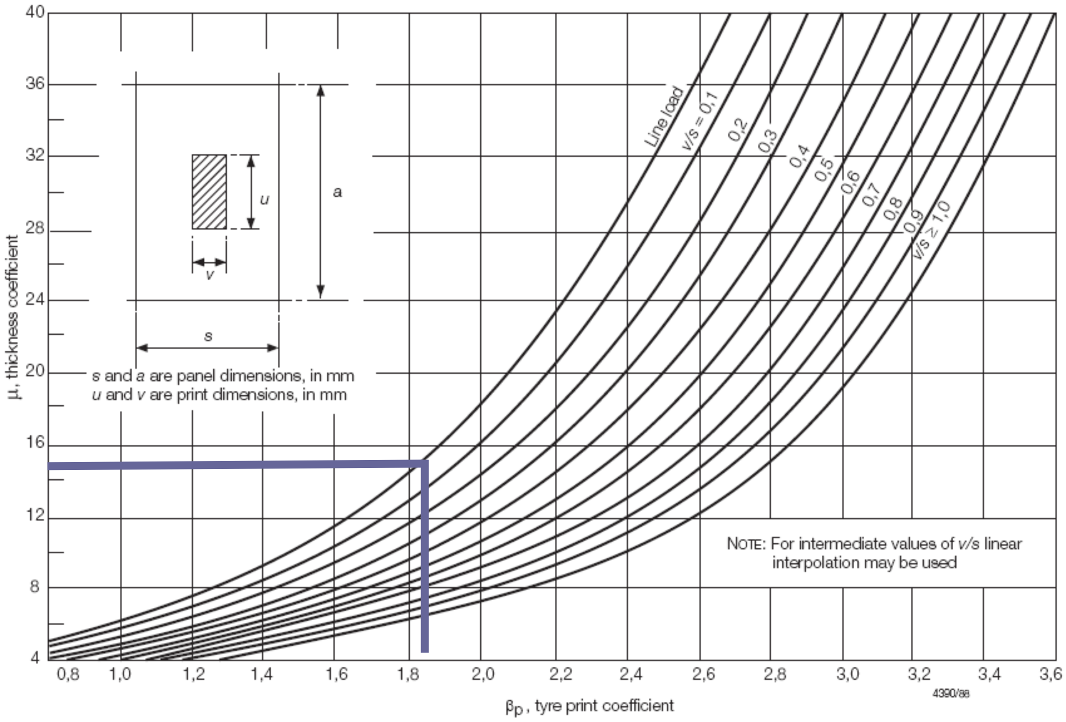


Figure 12, Tyre print chart

αLgear = thickness coefficient
= 15

tp = thickness plate

$$t_p = \frac{\alpha\, s}{1370\sqrt{k_a}}$$
$$= 5.47\text{mm}$$

Finally the nominal value for the plate thickness is 6mm. This value will be necessary for the design and calculation of the stiffeners.

3.3 SECONDARY STIFFNESS

Secondary Stiffness by rules calculation

To obtain the minimal inertia and section modulus, for secondary stiffener we need to define the next values:

P = maximum effective load per wheel or group of wheels, in kN
= MTOM by 2.5 (emergency case) by 1.3 (Structural response factor)
= 38.245935kN
l = overall secondary stiffener length, in metres
= 2.1m
s = stiffener spacing, in metres
= 0.5m
d = dimension of load area parallel to stiffener axis, in metres
= 2.221m
E = Young's modulus of elasticity of material, in N/mm2
= 275 N/mm2
w = dimension of load area perpendicular to stiffener axis, in metres
= 0.01m
k_w = lateral loading factor
= 1 for $w \leq s$
f_σ = limiting bending stress coefficient
=1 Helicopter/flight decks for emergency landing secondary stiffening
f_τ = limiting shear stress coefficient taken
=1 Helicopter/flight decks for emergency landing secondary stiffening
f_δ = limiting deflection coefficient taken
= 625
σ_a = 0,2% proof stress of material, in N/mm2
= 125 N/mm2
τ_a = shear stress of the alloy, in N/mm2

$$= \frac{\sigma_a}{\sqrt{3}}$$

= 72.16878365 N/mm2
$m = d / l$
= 1.057619048

Formula to calculate the minimal section modulus (Z) (cm3) for secondary stiffeners:

$$Z = \left(\frac{k_w P l^2}{10\, d\, f_\sigma\, \sigma_a} \right) \times 10^3 + Z_{dk}$$

=60.75266037cm3

Formula to calculate the minimal Inertia (I) (cm4) for secondary stiffeners:

$$I = \left(\frac{f_\delta k_w P l^3}{384\, E\, d} \right) \times 10^5 + I_{dk}$$

= 151.018687cm4

Formula to calculate the minimal web area (Aw) (cm2) for secondary stiffeners:

$$A_W = \frac{k_w P l}{2\, d\, f_\tau\, \tau_a} + A_{dk}$$

= 0.250539749 cm2

To calculate the effective breadth of attached plating, the next formula is used to find the reduction factor "*f*":

l = largest secondary stiffener
= 2300mm
b = distance between secondary stiffener
= 500mm

$$f = \left(\frac{l}{b}\right)^{\frac{2}{3}}$$

= 0.829
bf = 415mm
The nominal factor of the effective breadth of attached plating is 400mm

With the values already found is possible to define the next plate stiffener arrangement.
Table 3 present the values for the flange, web and plate for secondary stiffeners:

	Verticalm(mn	Horizontal (mm)						Itot
Element	bi	ei	Ai=ei*bi	Zi	(Ai*Zi)	$ei*bi^3/12$	$Ai*(Zi-Zg)^2$	ei*bi3/12+Ai*(Zi-Zg)2
Flange	6	60	360	119	42840	1.08E+03	3086679.67	3.09E+06
Web	110	6	660	61	40260	6.66E+05	789965.355	1455465.355
Plate	6.00	400	2400	3	7200	7.20E+03	1314538.13	1321738.135
			3420		90300	6.74E+05	5191183.16	5.86E+06

Table 3, Design of Secondary Stiffener

Section modulus	61.35	cm^3
	60.75	
The shear sectional area	6.60	cm^2
	0.25	
Inertia	586.50	cm^4
	151.02	

Table 4, Values of Secondary stiffener

Table 4 shows in the upper part of the line the main values suggested for the design of the secondary stiffener. And below the line, the minimal values required to succeed according to the rules previously presented.

In figure 13 is possible to look at the design of the Secondary Stiffener that is proposed according to the minimal values required for rules for heli-deck porpoise.

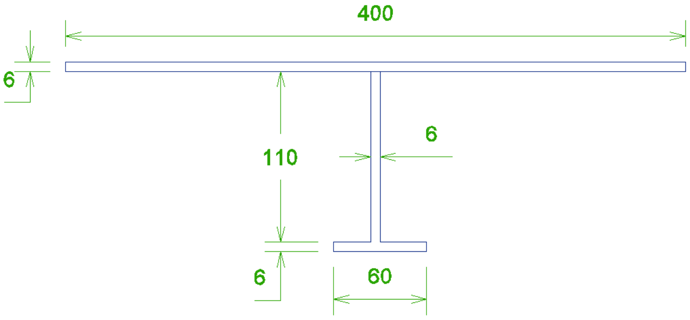


Figure 13, Dimensions of plate stiffener arrangement

3.4 PRIMARY STIFFENER

Primary Stiffener by Direct Calculation

In order to design the primary stiffener of heli-deck for the super-yacht, direct calculation is required for the development of this structural member. Figure 14 represents the "Extreme load case for the primary stiffener". The light blue line in the middle represents the primary stiffener. The location of the helicopter in the centre of the primary stiffener is the extreme load case that we will analyze.

The maximum length of the primary stiffener is 5000mm and this will be the case studied to find the minimum inertia and section modulus for the beam.

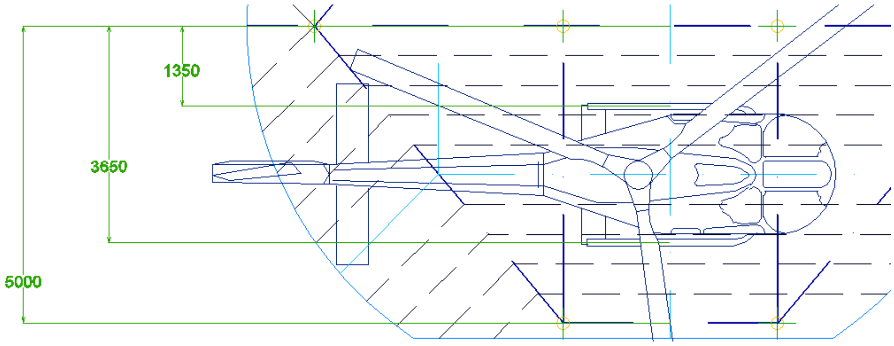


Figure 14, Extreme load case for the primary Stiffener

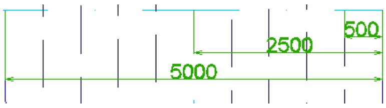


Figure 15, Study case for primary stiffener

Figure 15 shows de distance between secondary stiffener (500mm), primary stiffener (2500mm), and the maximum span of the primary stiffener (5000mm). The loads of the plate (blue), secondary stiffener (green), and transversal primary stiffener (highest green point) are transferred to the primary stiffener (red) visualized in Figure 16.

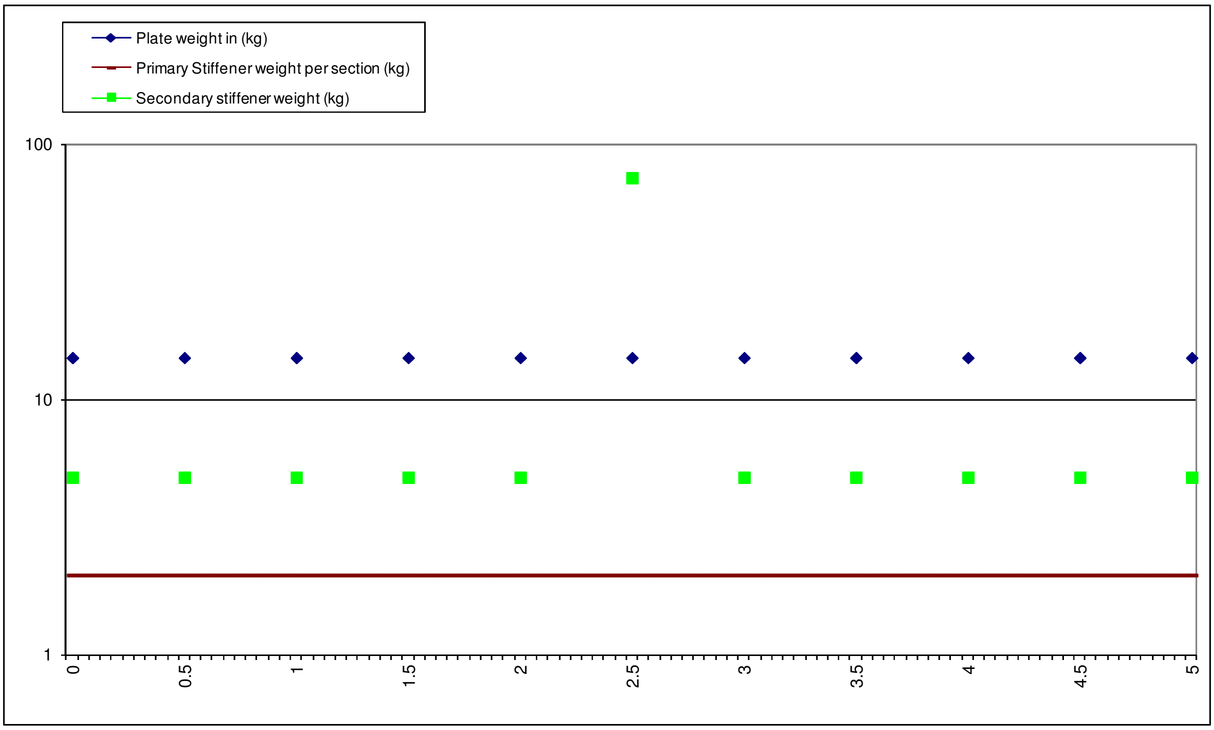


Figure 16, Transfer of loads to the primary stiffener

Subsequent to sum all the upper loads on the beam is necessary to divide this sum of loads at both ends of the beam. With the values transferred at both ends, and the upper loads presented in figure 16, a final understanding of the maximum loads for emergency landing is presented in figure 17.

To generate the maximum bending moment is necessary to locate the load of the helicopter at the centre of the beam. Figure 18 and 19 show the shear force and maximum bending moment applied on the primary stiffener studied.

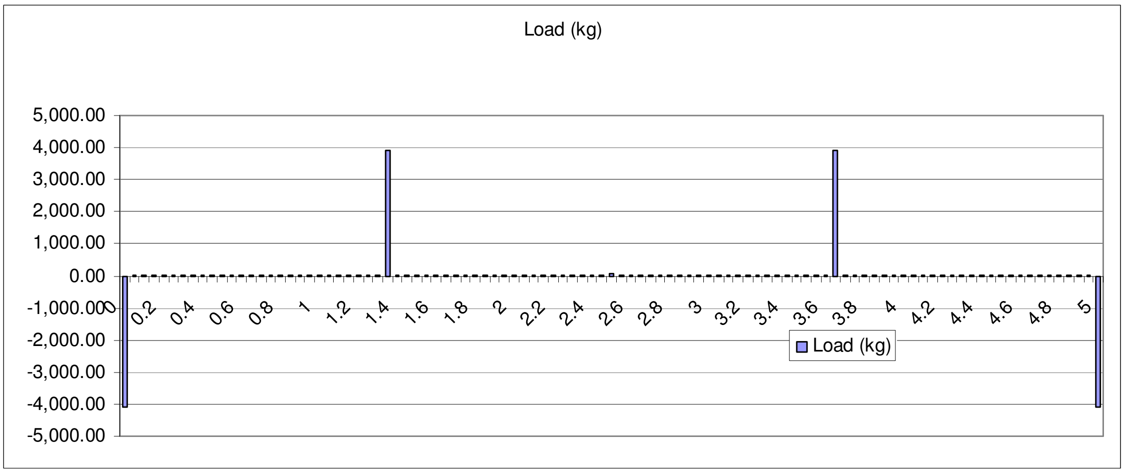


Figure 17, Loads applied on the primary stiffener

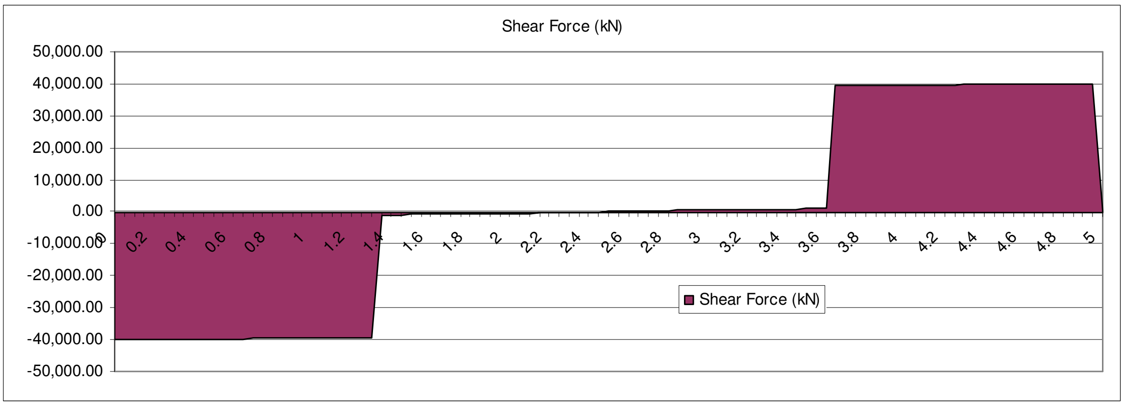


Figure 18, Shear force presented in the primary stiffener

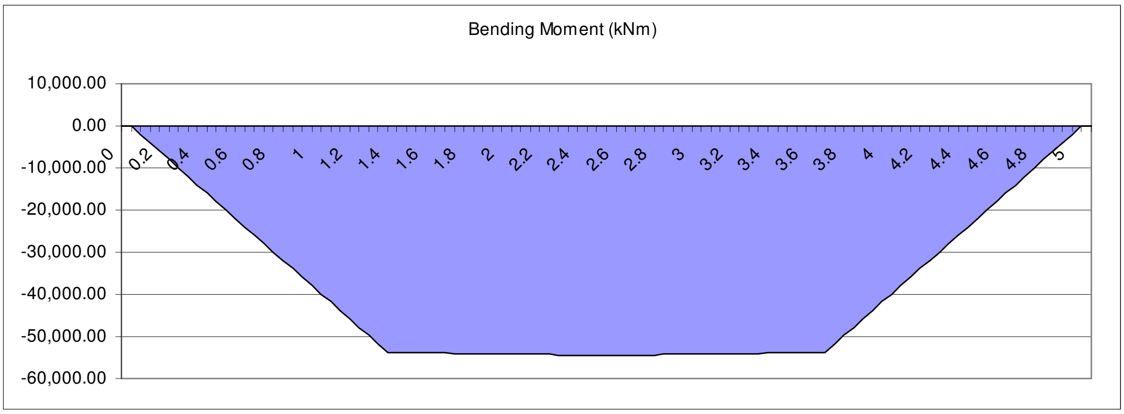


Figure 19, Bending moment presented in the primary stiffener

The maximum Bending moment M located in the middle of the beam is equal to 54948.77kNm and the required Section modulus of the beam is calculated with the next formula.

$$\text{Required } Z_x = \frac{M}{0.6 * \sigma_{YS}}$$

The value of the 55E6 MPa is used for Aluminium yield strength σ_{YS}

Finally the minimum plastic section modulus Z_x required for the primary stiffener is equal to 1665.11cm^3

To calculate the effective breadth of attached plating, the next formula is used to find the reduction factor "*f*":

l = largest primary stiffener
= 5000mm
b = distance between primary stiffener
= 2500mm

$$f = \left(\frac{l}{b}\right)^{\frac{2}{3}}$$

= 0.476
bf = 1190.55mm

The nominal factor of the effective breadth of attached plating is 1200mm

With this Plastic Section Modulus and the effective width of the attached plate, is possible to design the primary stiffener

Element	bi	ei	Ai=ei*bi	Zi	(Ai*Zi)	ei*bi^3/12	Ai*(Zi-Zg)^2	ei*bi3/12+Ai*(Zi-Zg)2
Flange	16	200	3200	414	1324800	6.83E+04	216933487	217001753.6
Web	400	12	4800	206	988800	6.40E+07	13163767.3	77163767.31
Plate	6.00	1200	7200	3	21600	2.16E+04	163367083	163388682.5
	422		15200 mm^2		2335200	6.41E+07	393464337	457554203.5

Table 5, Design of Primary Stiffener

Section modulus	1704.95	cm^3
	-1665.11	
The shear sectional area	48	cm^2
Inertia	45755.42	cm^4

Table 6, Values of Primary stiffener

Table 6, shows in the upper part of the line the main values suggested for the design of the Primary stiffener. And below the line, the minimal value required for Plastic section modulus in order to succeed according to the direct calculation previously presented.

In figure 20, is possible to look at the design of the Primary Stiffener that is proposed according to the minimal values required in direct calculation.

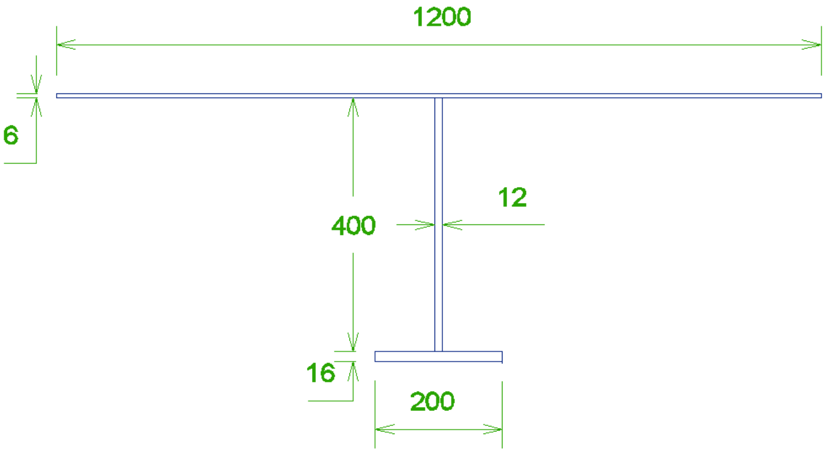


Figure 20, Dimensions in mm of Primary Stiffener arrangement

3.5 MAIN BEAM

Main Beam by Direct Calculation

The next figure 21 shows the extreme load case of the main beam. This beam, with a span of 6.53m, is the largest beam of the heli-deck and the helicopter in the middle apply the maximum load in the beam.

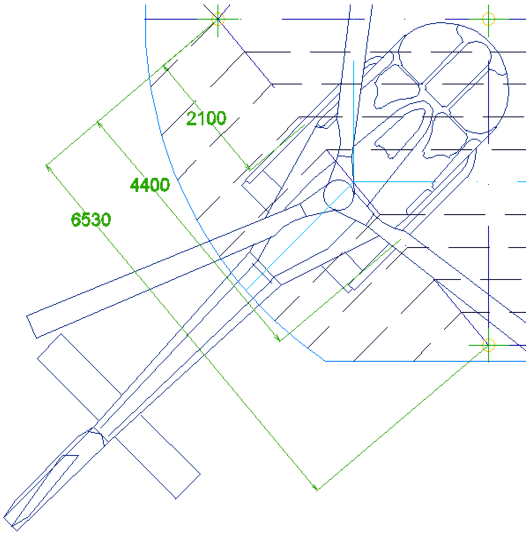


Figure 21, Extreme load case for the main beam

Figure 22, shows the weights transferred to the main beam from the whole structure applied by the plate (blue), secondary stiffeners (green), primary stiffeners (pink) and self weight of the main beam (brown). Is possible to realize that the maximum weight of the structure is presented in the middle of the beam, and this represents the transferred weights of the primary stiffener to the main beam.

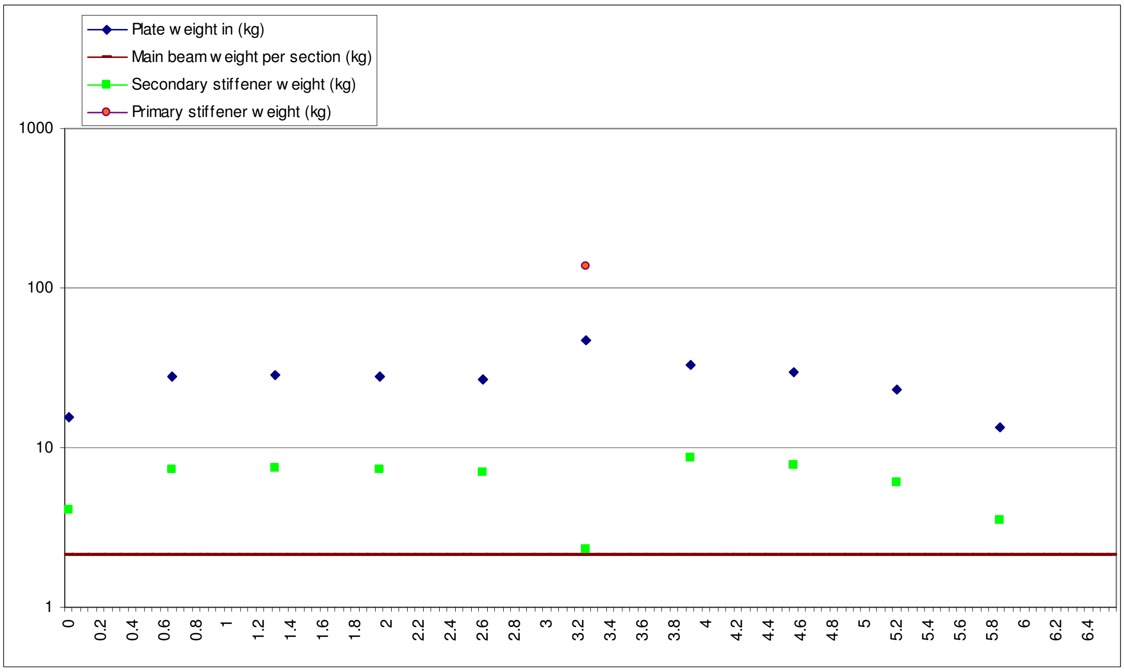


Figure 22, Loads transferred to the main beam

In order to generate the maximum bending moment applied in the main beam is necessary to calculate the load and the shear force that are presented from figure 23 to 25.

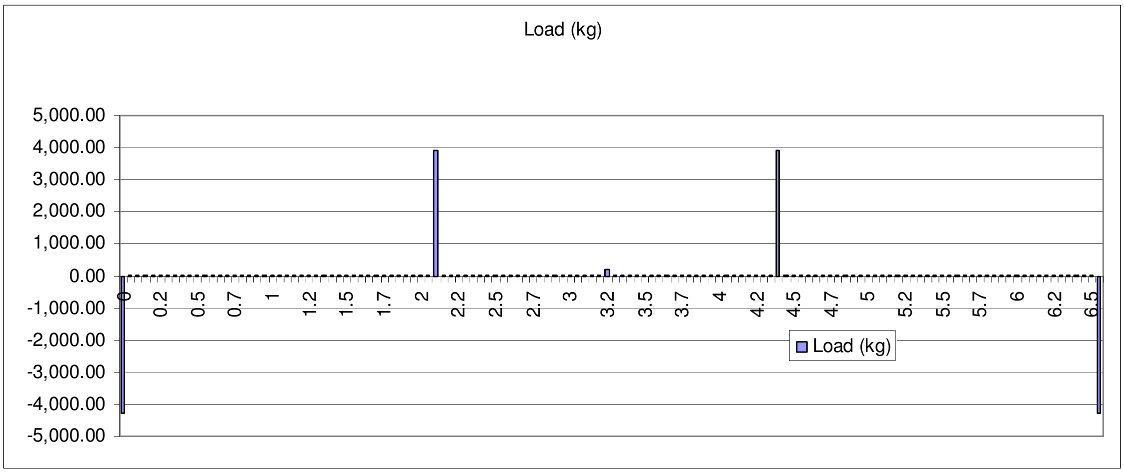


Figure 23, Loads applied on the main beam

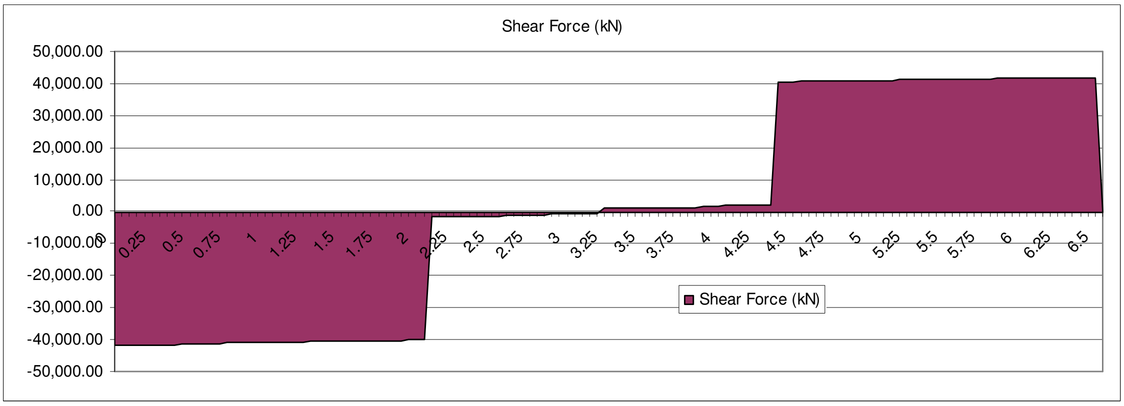


Figure 24, Shear force presented in the main beam

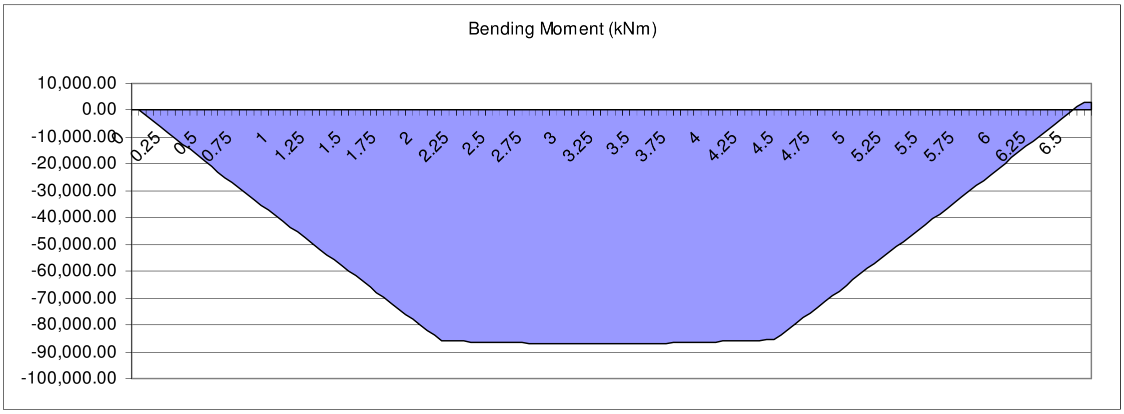


Figure 25, Bending moment presented in the main beam

The maximum bending moment M located in the middle of the main beam is equal to 88825.24kNm and the required section modulus Z_x of the beam is calculated with the next formula.

$$\text{Required } Z_x = \frac{M}{0.6 * \sigma_{YS}}$$

The value of the 55E6 MPa is used for Aluminium yield strength σYS

Finally the minimum plastic section modulus Z_x required for the main beam is equal to $2691.67 cm^3$

To calculate the effective breadth of attached plating, the next formula is used to find the reduction factor "*f*":

l = largest main beam
 = 6530mm
b = distance between main beams
 = 5000mm

$$f = \left(\frac{l}{b}\right)^{\frac{2}{3}}$$

 = 0.358
bf = 1792.2mm
The nominal factor of the effective breadth of attached plating is 1800mm
With this plastic section modulus and the effective breadth of attached plating is possible to design the main beam

Element	bi	ei	Ai=ei*bi	Zi	(Ai*Zi)	$ei*bi^3/12$	$Ai*(Zi-Zg)^2$	ei*bi3/12+Ai*(Zi-Zg)2
Flange	18	250	4500	491	2209500	1.22E+05	454982816	455104316.4
Web	476	12	5712	244	1393728	1.08E+08	28772887.7	136623063.7
Plate	6.00	1800	10800	3	32400	3.24E+04	312216473	312248873.5
	500		21012 mm^2		3635628	1.08E+08	795972177	903976253.5

Table 7, Design of Main beam

Section modulus	2764.68	cm^3	
	-2691.67		
The shear sectional area	57.12	cm^2	◄
Inertia	90397.63	cm^4	

Table 8, Values of Main beam

Table 8, shows in the upper part of the line the main values suggested for the design of the Main beam. And below the line, the minimal value required for plastic section modulus in order to succeed according to the direct calculation previously presented.

In figure 26, is possible to look at the design of the main beam that is proposed according to the minimal values required in this direct calculation.

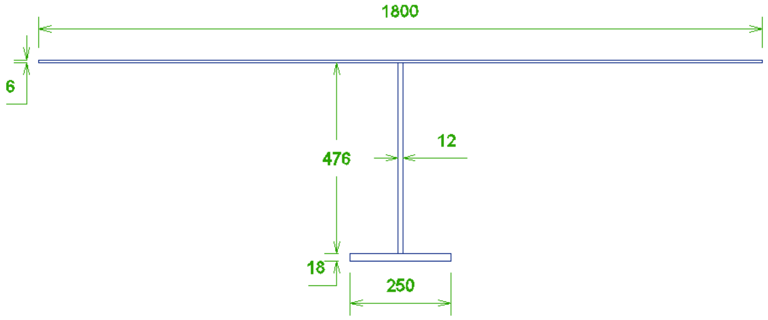
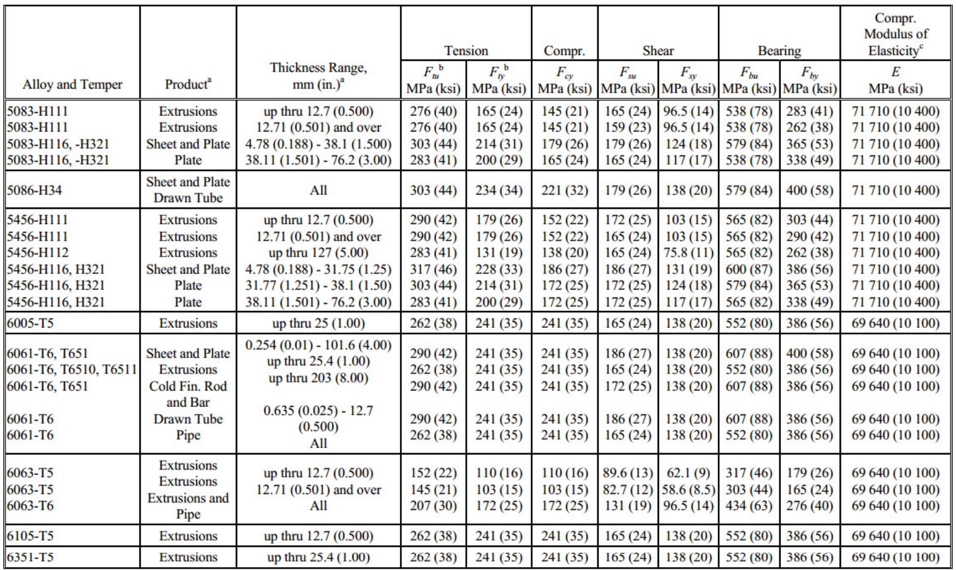


Figure 26, Dimensions in mm of Main beam arrangement

3.6 COLUMNS

Columns by Direct Calculation

The columns require an effective length of 2500mm and should be designed for a maximum pressure of 43500kN. A 6061-T6 aluminium bar is selected from the shipyard, with the next properties;



Alloy and Temper	Product[a]	Thickness Range, mm (in.)[a]	Tension		Compr.	Shear		Bearing		Compr. Modulus of Elasticity[c]
			F_{tu}[b] MPa (ksi)	F_{ty}[b] MPa (ksi)	F_{cy} MPa (ksi)	F_{su} MPa (ksi)	F_{sy} MPa (ksi)	F_{bu} MPa (ksi)	F_{by} MPa (ksi)	E MPa (ksi)
5083-H111	Extrusions	up thru 12.7 (0.500)	276 (40)	165 (24)	145 (21)	165 (24)	96.5 (14)	538 (78)	283 (41)	71 710 (10 400)
5083-H111	Extrusions	12.71 (0.501) and over	276 (40)	165 (24)	145 (21)	159 (23)	96.5 (14)	538 (78)	262 (38)	71 710 (10 400)
5083-H116, -H321	Sheet and Plate	4.78 (0.188) - 38.1 (1.500)	303 (44)	214 (31)	179 (26)	179 (26)	124 (18)	579 (84)	365 (53)	71 710 (10 400)
5083-H116, -H321	Plate	38.11 (1.501) - 76.2 (3.00)	283 (41)	200 (29)	165 (24)	165 (24)	117 (17)	538 (78)	338 (49)	71 710 (10 400)
5086-H34	Sheet and Plate Drawn Tube	All	303 (44)	234 (34)	221 (32)	179 (26)	138 (20)	579 (84)	400 (58)	71 710 (10 400)
5456-H111	Extrusions	up thru 12.7 (0.500)	290 (42)	179 (26)	152 (22)	172 (25)	103 (15)	565 (82)	303 (44)	71 710 (10 400)
5456-H111	Extrusions	12.71 (0.501) and over	290 (42)	179 (26)	152 (22)	165 (24)	103 (15)	565 (82)	290 (42)	71 710 (10 400)
5456-H112	Extrusions	up thru 127 (5.00)	283 (41)	131 (19)	138 (20)	165 (24)	75.8 (11)	565 (82)	262 (38)	71 710 (10 400)
5456-H116, H321	Sheet and Plate	4.78 (0.188) - 31.75 (1.25)	317 (46)	228 (33)	186 (27)	186 (27)	131 (19)	600 (87)	386 (56)	71 710 (10 400)
5456-H116, H321	Plate	31.77 (1.251) - 38.1 (1.50)	303 (44)	214 (31)	172 (25)	172 (25)	124 (18)	579 (84)	365 (53)	71 710 (10 400)
5456-H116, H321	Plate	38.11 (1.501) - 76.2 (3.00)	283 (41)	200 (29)	172 (25)	172 (25)	117 (17)	565 (82)	338 (49)	71 710 (10 400)
6005-T5	Extrusions	up thru 25 (1.00)	262 (38)	241 (35)	241 (35)	165 (24)	138 (20)	552 (80)	386 (56)	69 640 (10 100)
6061-T6, T651	Sheet and Plate	0.254 (0.01) - 101.6 (4.00)	290 (42)	241 (35)	241 (35)	186 (27)	138 (20)	607 (88)	400 (58)	69 640 (10 100)
6061-T6, T6510, T6511	Extrusions	up thru 25.4 (1.00)	262 (38)	241 (35)	241 (35)	165 (24)	138 (20)	552 (80)	386 (56)	69 640 (10 100)
6061-T6, T651	Cold Fin. Rod and Bar	up thru 203 (8.00)	290 (42)	241 (35)	241 (35)	172 (25)	138 (20)	607 (88)	386 (56)	69 640 (10 100)
6061-T6	Drawn Tube	0.635 (0.025) - 12.7 (0.500)	290 (42)	241 (35)	241 (35)	186 (27)	138 (20)	607 (88)	386 (56)	69 640 (10 100)
6061-T6	Pipe	All	262 (38)	241 (35)	241 (35)	165 (24)	138 (20)	552 (80)	386 (56)	69 640 (10 100)
6063-T5	Extrusions	up thru 12.7 (0.500)	152 (22)	110 (16)	110 (16)	89.6 (13)	62.1 (9)	317 (46)	179 (26)	69 640 (10 100)
6063-T5	Extrusions	12.71 (0.501) and over	145 (21)	103 (15)	103 (15)	82.7 (12)	58.6 (8.5)	303 (44)	165 (24)	69 640 (10 100)
6063-T6	Extrusions and Pipe	All	207 (30)	172 (25)	172 (25)	131 (19)	96.5 (14)	434 (63)	276 (40)	69 640 (10 100)
6105-T5	Extrusions	up thru 12.7 (0.500)	262 (38)	241 (35)	241 (35)	165 (24)	138 (20)	552 (80)	386 (56)	69 640 (10 100)
6351-T5	Extrusions	up thru 25.4 (1.00)	262 (38)	241 (35)	241 (35)	165 (24)	138 (20)	552 (80)	386 (56)	69 640 (10 100)

Table 9, Minimum mechanical properties for aluminium alloys[3]

E = 69640 MPa

$\sigma_Y = 241$ MPa

$\tau_Y = 138$ MPa

Insure that our geometry has large enough cross section area so that

$$\frac{P_{des}}{A} \leq \sigma_{all}$$

But first a safety factor for material and buckling is defined.

$FS_{material} = 1.1$

$FS_{buckling} = 2$

Then

$$\sigma_{all} = \frac{\sigma_Y}{FS_{material}}$$

= 219 MPa

$$\tau_{all} = \frac{\tau_Y}{FS_{buckling}}$$

= 125 MPa

The diameter found for this cross sectional area is 502mm, and the nominal value selected is 500mm. We can check that the pressure designed for the column over the area is smaller than the overall axial strength.

$$\frac{P_{des}}{A} \leq \sigma_{all}$$

221,544.15 MPa < 245,000.00 MPa

The second analysis for the column will be fail by buckling. Columns usually fail by buckling when their critical load is reached. Long columns are analyzed using Euler's column formula, namely:

$$P_{cr} = \frac{\pi^2 EI}{L_{eff}^2}$$

$$= 688.57 \text{ MPa}$$

$$\frac{P_{cr}}{FS_{buckling}} \leq P_{des}$$

334.29 MPa < 43,500 MPa

$$\text{Slenderness ratio } = \frac{l_{eff}}{d}$$

$$= 5$$

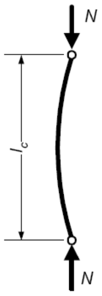


Figure 27, Fail by buckling

Figure 27, shows a typical fail by buckling. However this is not the case, because the effective length of the column is not quite big compared to the diameter of the column. Buckling normally is not the case for a slenderness ratio of 5. After the design of all the structural members and columns the next step is to connect it by brackets. All the structural members and columns, without brackets or connections are shown in figure 28.

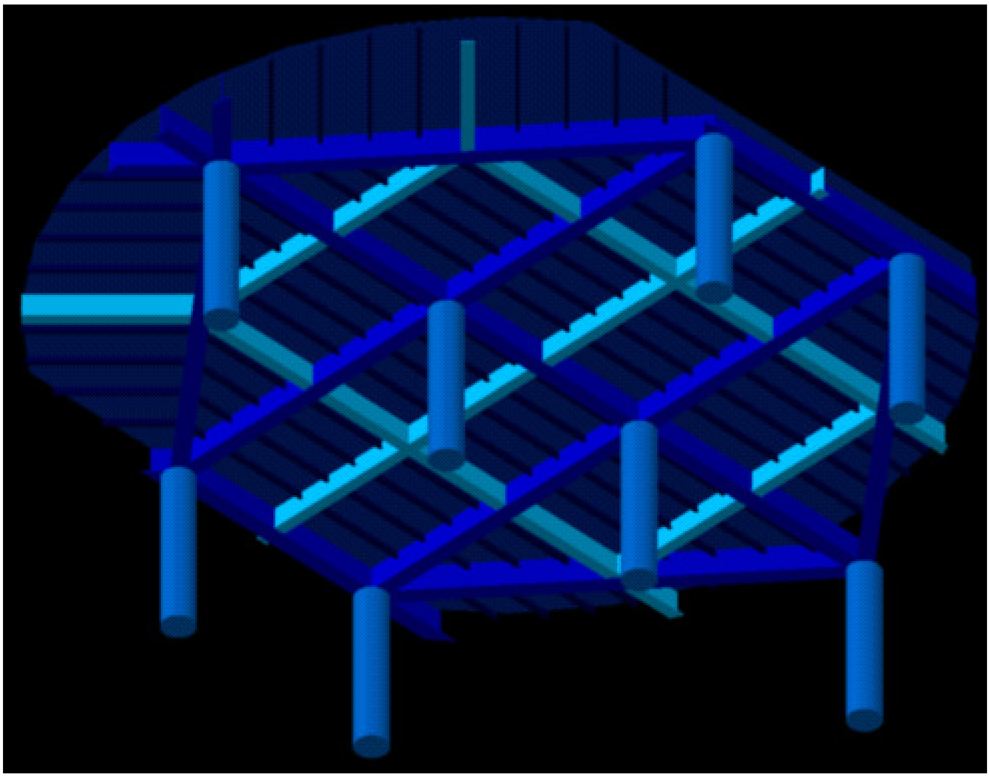


Figure 28, Structure without brackets

3.7 BRACKETS

Brackets by rules

Where a longitudinal strength member is cut at a primary support, the continuity of the strength is provided by the brackets. Figure 29 shows different arrangement for the brackets. The dimensions of *"a"* and *"b"* are fundamental to determine the size of the bracket.

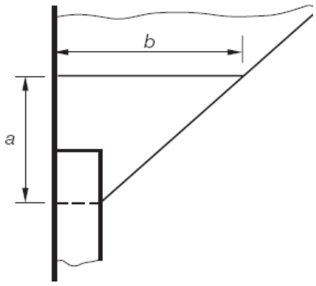


Figure 29, Bracket dimensions

To calculate the dimensions of *"a"* and *"b",* for the brackets is necessary to define l_b as:

$$l_b = 90\left(2\sqrt{\frac{Z}{14+\sqrt{Z}}}-1\right)\ \text{mm}$$

Z = Section modulus of the secondary member

$a + b \geq 2l_b$

The first bracket to be calculated is for the connection of the end of the secondary stiffener.

Then $l_b = 212$mm
$a = 106$mm
$b = 106$mm

3.8 DETAIL DESIGN

Detail Design Improvement

Connection between secondary stiffeners and primary stiffeners webs

Figure 30, shows a lug connection between secondary stiffeners and primary stiffeners webs. The failure mechanism analysed in this case, is fatigue cracking of shell plate in way of hard spot, buckling and shear failure of the web of the primary member.[4]

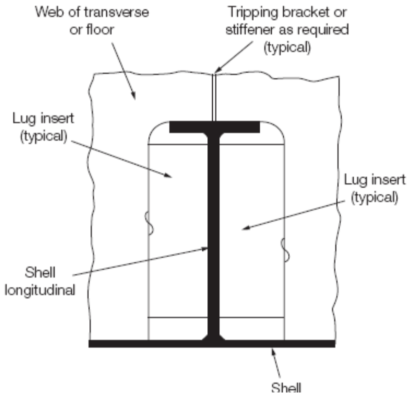


Figure 30, Connection between SS and PS

After designing the connection between the secondary stiffener and the primary stiffener, the next connection is the primary stiffener and the main beam

3.9 CONNECTIONS

3.9.1 Connection between primary stiffeners and main beams

Figure 31, shows the detail of a connection between primary stiffeners and main beams

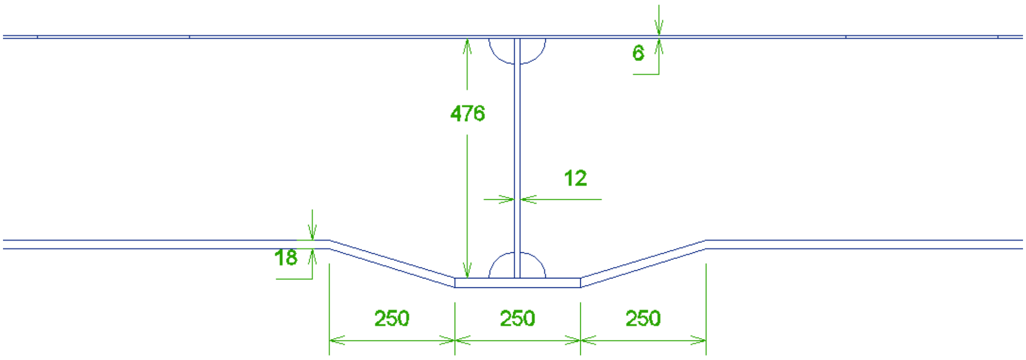


Figure 31, Connection between PS and main beam

3.9.2 Connection of Pillars and Main Beams

To connect the pillars with the general structure, it will be necessary to use stiffened brackets. The failure mechanism taking into consideration is buckling of webs of cross-deck beams, and fracturing of deck plating in way of end connection due to hard spot. The free edge of the bracket is to be stiffened where the section modulus, Z, exceeds 500 cm^3.

Where a longitudinal strength member is cut at a primary support and the continuity of strength is provided by brackets, the scantlings of the brackets are to be such that their section modulus and effective cross-sectional area are not less than those of the member. Care is to be taken to ensure correct alignment of the brackets on each side of the primary member.

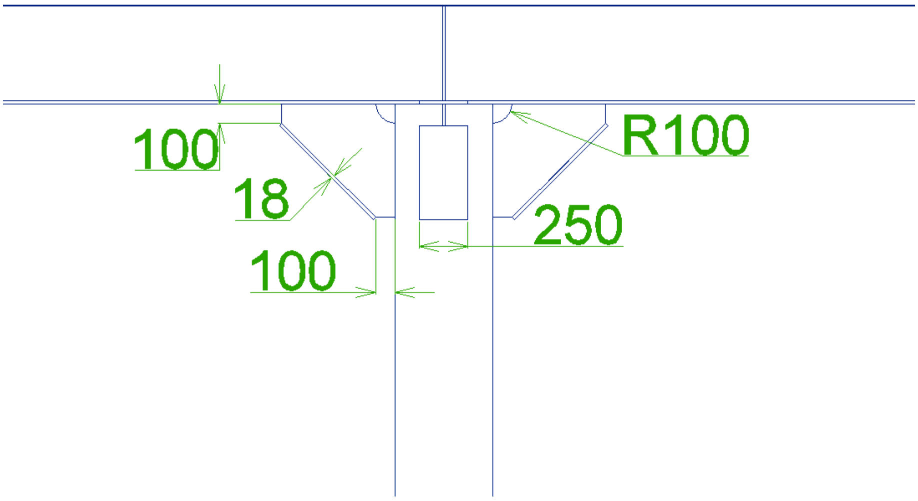


Figure 32, Connection between pillar and main beam

4.0 VALIDATION

To validate the structural calculation a finite element method is developed in ansys. The results form these experiment will be compared with the expected ones. The aim of this analysis is not to redesign the whole helicopter platform, but to improve it and ensure the capabilities of this design.

Figure 33, shows a general view of the structural arrangement. The two red arrows in the centre represent the forces applied by the helicopter, in a normal landing case.

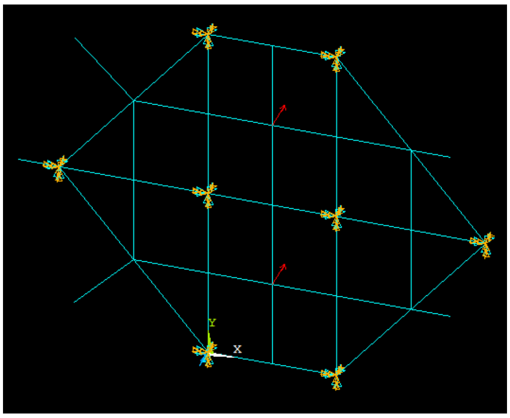


Figure 33, FEM General Structure

4.1 EXTREME CASE VALIDATION

Extreme Emergency Case Analysis

A specific emergency case analysis for the main beam is presented in the next section. This case is the extreme, because it represents an emergency landing, defined as 2.5 times the Maximum Take-Off Mass, in the medium of the largest main beam. Figure 34, and table 10, characterizes the beam analyzed.

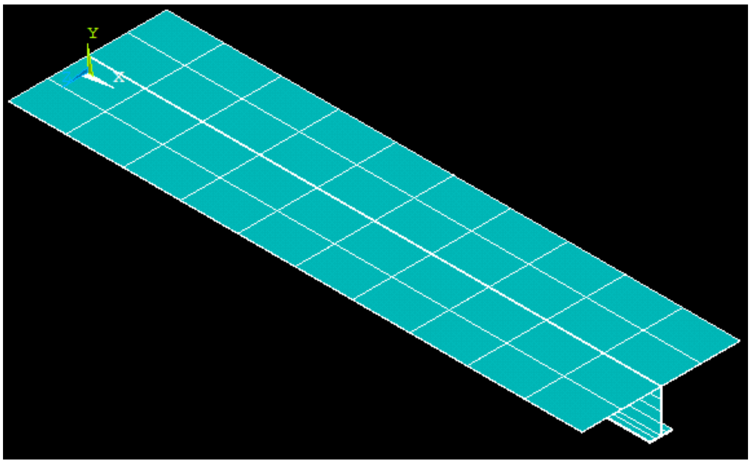


Figure 34, Main Beam analysis

Area = 21012
Iyy = 0.90398E+09

Iyz =-0.34608E-05
Izz = 0.29395E+10
Warping Constant = 0.55416E+13
Torsion Constant = 0.90013E+06
Centroid Y =-0.96265E-12
Centroid Z = 326.97
Shear Center Y =-0.18568E-08
Shear Center Z = 493.05
Shear Correction-yy = 0.43972
Shear Correction-yz = 0.61064E-11
Shear Correction-zz = 0.17406

Table 10, Main Beam values

Figure 35, shows the two forces applied by the helicopter in the centre of the line. At the left of the beam the 3 arrows, characterize a fixed point in all degrees of freedom. At the right the vertical arrow characterize a point just fixed in the UY degree of freedom. This degree of freedom corresponds to the very aft part of the helideck where only degree or freedom is just fixed vertically from the aft pillar.

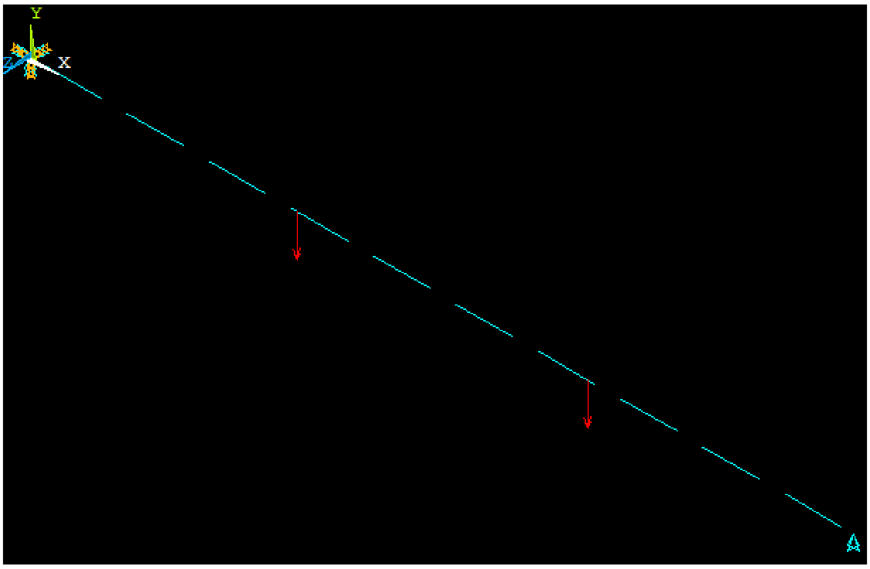


Figure 35, Main Beam analysis

The aluminium selected for the analysis was specified from the shipyard as Aluminium common grade 6063 with T6 temper, with a modulus of elasticity of 68.9GPa and a Poisson’s ratio of 0.33. The structural material model is linear elastic isotropic.

The force of the helicopter is 76440N divided between the two contact surfaces of the landing gear. The location of the landing gear is assumed to be in the middle of the beam. The longitude of the beam is 6530mm.

After defining the entire beam model the reactions found in both nodes representing the helicopter landing gear are presented in the global coordinate system as shown in table 11.

NODE	FX	FY	FZ
1	0.0000	49727.0	0.26981E-16
2	0.0000	26713.0	0.0000

Table 11, Reaction solutions per node

The sum of forces FY is 76440 that is exactly the expected weight of the helicopter applied in the opposite direction. The value of FZ at node 1, is almost 0, the expected value in FZ.

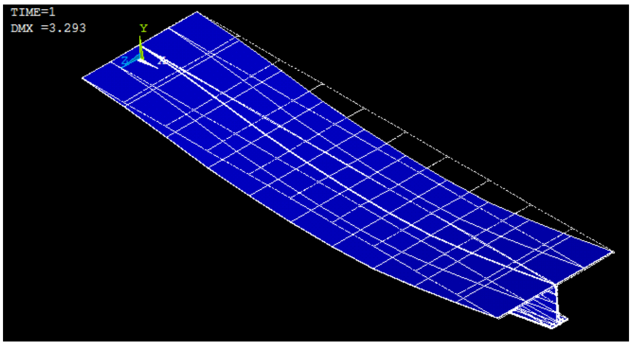


Figure 36, Deformed shape plus undeformed edge

In figure 36, is possible to observe that the constrained degrees of freedom appear to have a deflection of 0 as expected. Nevertheless there is maximum displacement DMX=3.293mm. Not really significant even that the image can increase visual effect of deformation.

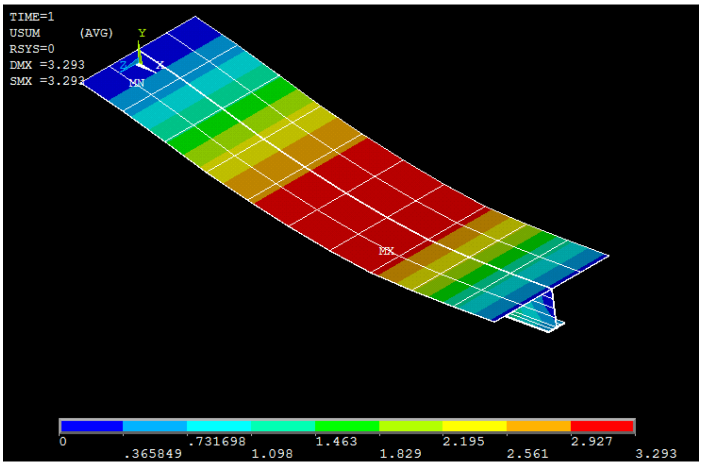


Figure 37, Detailed version of deflection

Figure 37, plot the results in a nodal solution, in this case there are 10 nodes. The deflection is represented with blue at the minimal values of the undeformed edges, until red at the maximum value of 3.293 at the centre of the beam.

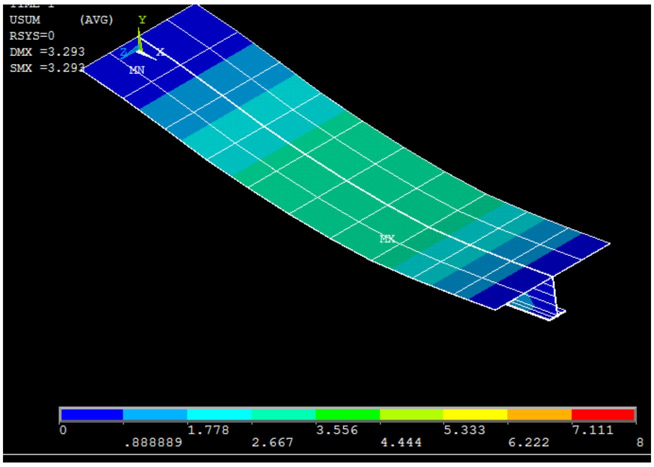


Figure 38, Specified contours

Figure 38, represents in red a top value of 8mm of deformation. However this limited value is never reached in the actual configuration. Table 12, list a deformation values by node in the global coordinate system.

NODE	UX	UY	UZ	USUM
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	-0.35560E-07	0.35560E-07
3	0.0000	-0.23106	-0.38827E-08	0.23106
4	0.0000	-0.56294	-0.77654E-08	0.56294
5	0.0000	-0.96785	-0.11352E-07	0.96785
6	0.0000	-1.4180	-0.14939E-07	1.4180
7	0.0000	-1.8856	-0.18037E-07	1.8856
8	0.0000	-2.3429	-0.21134E-07	2.3429
9	0.0000	-2.6339	-0.23796E-07	2.6339
10	0.0000	-2.8803	-0.26458E-07	2.8803
11	0.0000	-3.0757	-0.28448E-07	3.0757
12	0.0000	-3.2137	-0.30439E-07	3.2137
13	0.0000	-3.2879	-0.31743E-07	3.2879
14	0.0000	-3.2918	-0.33047E-07	3.2918
15	0.0000	-3.2190	-0.33711E-07	3.2190
16	0.0000	-3.0631	-0.34375E-07	3.0631
17	0.0000	-2.6894	-0.34737E-07	2.6894
18	0.0000	-2.2411	-0.35099E-07	2.2411
19	0.0000	-1.7331	-0.35214E-07	1.7331
20	0.0000	-1.1803	-0.35329E-07	1.1803
21	0.0000	-0.59759	-0.35445E-07	0.59759

Table 12, Deformation values by node

The maximum value of deformation, is located in the node 14, not exactly in the middle, but a little bit moved to the direction of horizontally unrestricted edge. As shown in table 13.

NODE	UX	UY	UZ	USUM
NODE	0	14	2	14
VALUE	0.0000	-3.2918	-0.35560E-07	3.2918

Table 13, Maximum absolute values

Fire Fighting systems and Drainage

A full explanation of the fire fighting systems and drainage regulations are presented in the appendix attached to this file. Therefore this thesis will not present a highly detailed system for fire fighting and drainage; however all of the interconnection problems are consider during the design of the main structure.

5.0 CONCLUSIONS

A set of difference conclusions are presented according to the related topics analyzed on this master:

1. The rules and regulation developments for helideck structure on super-yacht, are not generated as a result of an experience in super-yacht, but as an interpolation of the limits applied for very big ships, as tankers or oil carriers.

2. The drastically incremented areas used for commercial helideck purposes compared, with the areas used for private helideck purposes, represent dramatically increment in weight and cost for the super yacht.

3. The dimensions used in the commercial helideck have always big conflicts with the space required for other pleasure purposes. This space is always presented as multipurpose space but the rigidity of the rules implies very difficult transformations.

4. The very big structural supports as pillars and beams required for commercial helideck generate a bad aspect of the yacht. These represent a set of limitations for aesthetical reasons. Where the conflicts are not just generated in at the deck were the helicopter platform is located, but even in the lower spaces where the lower pillars obstruct the garage exits.

5. The design of the structure is mainly based for a specific helicopter EC130, this imply that is not suggested for the use of other kind of helicopter even if their Maximum Take-Off Mass is smaller. This is because the dimensions of the landing gear make a ideal connection with the main structural supports as primary stiffeners and main beams.

6. The support of secondary stiffeners in this helicopter structure interaction does not have major importance compare to the main structural members. However they are designed according to the rules, in order to fulfil the requirements of the register company.

7. The structure is symmetrical. Even that a connection to the main structure of the ship is suggested in the aft part. The interaction with the rest of the structure was not presented in this work for confidential reasons.

8. Further Computational Fluid Dynamic studies will be necessary according to the winds registered in the zone where the yacht and the helicopter are expected to be used.

9. The validation of the structure is presented in the extreme case, where the distance between pillars is the largest one. Therefore in the rest of the structure the helicopter impact will have lower effects on the helicopter platform.

10. A complete calculation of the structure is presented; nevertheless there is always space for improvement.

6.0 BIBLIOGRAPHY

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[4] Guidance Notes for the Classification of Special Service Craft, Design Details, July 2012

A more extensive research sources are attached in the appendix one Initiation to research