Internship DAMEN
The analysis and redesign of a ship cradle

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DAMEN internship

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Preface

This report is written for the internship of the master mechanical engineering at the Univeristy of Twente, that has the objective to give the student a first impression of engineering in practice. This project concerns the analysis and redesign of a ship cradle for DAMEN shipyards Singapore (DSSi). The report is written in a technical jargon and is meant for people with an engineering or technical background. For illustration a traditional ship cradle used by DAMEN is shown in Figure 1.

Figure 1: *Traditional ship cradle used by DAMEN*

Special thanks to André de Boer for assessing this report, Edwin de Smet for assessing and supporting the internship overall, Auke Steenkamp for the engineering support, Maarten Jongen for giving a new perspective in the research and the rest of DAMEN for making the internship possible.

Abstract

The goal of this research was to see if the existing cradles could be improved on storage space, floor space and cost. After a cost analysis the goal seemed not to be economically viable, so the goal had to be redefined in order for the research to be useful for DAMEN. The new research goal became; to find a better solution for the cradle for all DAMEN's future vessels. In order to do this the research was divided in three phases; a preliminary phase where the old methods and the basics of a cradle were researched, a conceptual phase where solutions were generated and formed into concepts and finally a final concept was chosen and the detailed phase were final concept was optimized and sketched as a first impression.

In the preliminary phase the functions of the cradle were researched first. The most important functions of a cradle were; Fixation of the vessel in x- and y- direction, fixation of the vessel in z-rotation and creating extra room for the multi wheeler and workers. After that the methods DAMEN uses to move the cradles were researched. Together three different types of methods were found caused by the ship type dependency. The same dependency was true for the cradles which result in a huge stock of cradles at DSSi. And finally an analytical analysis was introduced to get an understanding of how loads on the structure work. This was a simplified model that views the cradle as v-shape with supporting beams on the side standing on a cradle bed. The analysis showed that the critical failure mode was bending in the cradle bed and side beams.

In the conceptual phase the function defined in the preliminary phase were used to generate solutions. These solutions were then mixed together to form five different concepts. The first concept was a LEGO solution that uses basic modules to assemble a cradle for a random ship type. The second concept was a cradle bed with on top two adjustable modules. This concept was tested on two different types of supports; the keel support and the bulk head support. In all cases the keel support was worse than the bulkhead support, so the keel support was not researched any further. The third concept started with an unmodified modified cradle and had elongations on each side. Two different options have been researched and in the end the framework was the best option. The fourth concept was a sling concept where the ship lays in a sling that was supported by two pinned adjustable beams. The cradle bed was the same as concept II. The last concept was the use of the old cradles on the new ship types. This seemed even after minor adjustments not very feasible. Finally a mix between concept I and concept IV has been chosen as the final concept due to the best combined properties.

In the last phase the front and rear cradle was further tweaked for a FF 3808 vessel. These analyses showed that both the front cradle as the rear cradle could improve if the modules were moved more to the stool support, but have an optimum before it reaches the stool support. The profiles have also been researched in this phase and according to the analysis the I-beam is the best to use in this situation. The rectangular beam is the best option for the adjustable beams because the I-beam is not possible over there.

In overall this report showed that there are solutions that are lighter, interchangeable and less spacial than the solution used at the moment. Though the model that is used is very limited and can only show which solution is better and can not be used to deliver an end result. For that further research is needed in the form of a FEM analysis. This analysis can also be used to further optimize the weight of the cradle.

Another solution that came up during the end presentation was to connect the adjustable beam to the lifting hooks instead of using a sling. This will not only positively effect the stability but will also remove any change of slicing of the sling, which could happen when a ship drops to hard in the sling. So far the feasibility of the concept has not been researched yet, but the advantages of this possible outcome makes it worthwhile for future research.

Personal evaluation

Table of symbols and definitions

Terminology	
Term	Explanation
Cradle	A framework that let a ship rest on land
D.o.f.	Degrees of freedom
DSSi	Damen shipyard Singapore
FBD	Free body diagram
Hull type	Ships differentiated by their hull
FCS 1605	Fast crew supplier ship that is 16m long and 5m wide.
FCS 2206	Fast crew supplier ship that is 22m long and 6m wide.
FCS 2610	Fast crew supplier ship that is 26m long and 10m wide.
FCS 3307	Fast crew supplier ship that is 33m long and 7m wide.
FCS 4212	Fast crew supplier ship that is 42m long and 12m wide.
FF 3808	Fast ferry ship that is 42m long and 12m wide.
Ship type	Ships differentiated by their name/ length and width
Vessel	Other word for ship

Contents

1 Introduction

At the moment ship type specific cradles are used at DAMEN Singapore to hold and move the vessels. The use of the cradles starts at the hull construction and is used full time until the launch of the vessel or until the vessel is shipped, depending on the ship type. The transportation of the vessels is done by a multi wheeler (m.w.). This transportation is done either for moving the vessels from the production hall to hall 2 (where the vessels are finished), launching the vessels (shown in Figure 1.1)or simply rearranging the vessels to create more room on the shipyard.
In 2015 [1] a study was performed to see if all the different cradles could be combined into one universal cradle that could hold any ship type. This resulted in an eight tonne framework, that was considered too cumbersome to have any practical use on the yard. This still left DAMEN Singapore with the old cradles that take up a lot of storage space and according to FCS3307 FEA structure verification of the cradles ([2] and [3]) are far from optimized. Another problem that occurs with the use of the old single hull cradles is that the cradles take up more floor space than is needed for simple support. This extra space is needed to make it possible for the m.w. to move under the cradles, however this extra space makes it more difficult for the painters to get near the hull with a jerry picker and makes it impossible to place the vessel nose-to-nose.
To see if other solutions are possible a new research is performed. The goal of this research is to find a solution that will improve the cradles on storage space, floor space and cost for the following ship types:

- FCS 1606
- FCS 2206
- FCS 2610
- FCS 3307

The research will be divided in phases starting with the preliminary phase. The preliminary phase is meant to explore the subject and to test the feasibility of the research question. Based on these findings a research method will be proposed. The rest of the content will be explained in the research method.

Figure 1.1: *Transport of a FCS 3307 on a m.w..*

2 Preliminary phase

This chapter is devoted to the Preliminary phase. In this phase the function of the cradle is studied. After this the old methods of DAMEN, to get a ship on a multi wheeler, will be researched. Next a cost analyses is made to see what the potential profit can be if the old cradle methods are replaced by a more efficient method. Subsequent the research method will be defined. Finally an understanding of the used cradles is aimed at.This is done by analyzing the front and rear cradle in a free body diagram (FBD).

2.1 Function and requirements of the cradle

At DAMEN the cradle has two functions: Fix the vessel in place and create room under the ship. These functions can be split further. In case of the fixation this means the ship had to be fixed in x-direction, y-direction (note: only downwards gravity fixes the ship in upward direction) and rotation along the z-axes, see Figure 2.1 for clarification. Rotation along the y- and x-direction will automatically be solved when more than one cradle is used. Because this is always the case these are considered no point of interest in this research. The degree of freedom (D.o.f.) in the z-direction will not be fixed by the cradle, but friction between the cradle and the ship will prevent the vessel from moving.
The second function can be split in creating room for the workers to work under the ship and creating room for the m.w.. How DAMEN fulfills the latter is explained in the next section. The extra room for the workers is achieved by placing stools under the cradle. The ships types also have specific requirements. The functions and requirements are summarized in Table 2.1

Requirment or function /shiptype		FCS 1605	FCS 2206	FCS 2610	FCS 3307	FF 3808	FCS 4212
Functions	Fix in x-direction	✓	✓	✓	✓	✓	✓
	Fix in y-direction	✓	✓	✓	✓	✓	✓
	Fix in z-rotation	✓	✓	✓	✓	✓	✓
	Extra room for workers	✓	✓	✓	✓	✓	✓
	Extra room for m.w.	✓	✓	✓	✓	✓	✓
Requirements	Cradle will be shipped	✓	✓	✓	-	-	-
	Base needs to be broadened for m.w.	✓	✓	-	✓	✓	-

Table 2.1: *Functions and requirements per ship type*

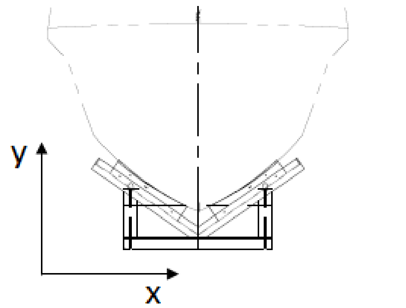


Figure 2.1: *Illustration of ship on cradle.*

2.2 Old methods

This section shows all the old methods of DAMEN to create room for the m.w. and to place the vessel onto the m.w..

2.2.1 Old method 1

In the first method the cradle stands on four stools slightly placed from the outside, so there is still room to place an H-beam. First free stools (1.5m high) are placed on a 3.25m distance from the center line. Next HEB0320 beams with jacks are placed on the stools and under the cradle as is shown in Figure 2.2. Finally the beams are jacked up and the middle stools are removed to make room for the m.w.. Currently this method is used for the ship type FCS 2206 an was used for the FCS 1605.When finished this vessel will be placed with cradles on a larger ship to be shipped to the costumer.

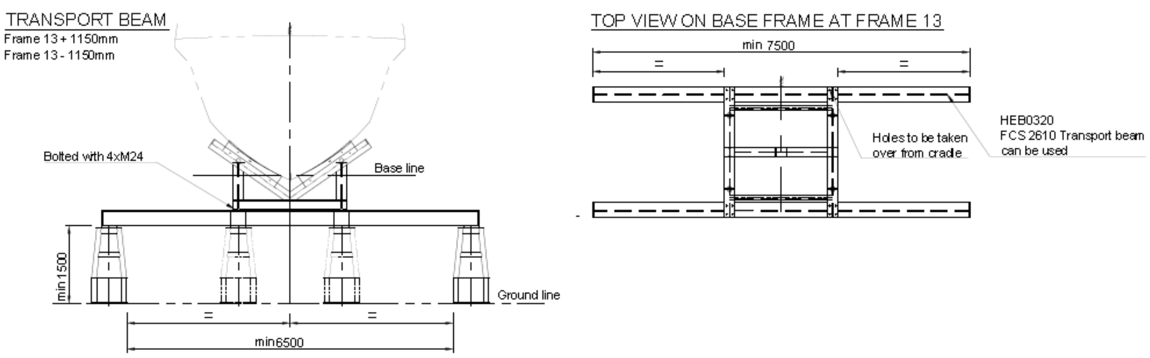


Figure 2.2: *Transport method I front and top view [4].*

2.2.2 Old method 2

In the second method the cradles are mounted on a cradle bed. This is shown in Figure **??** 3. The cradle bed has a length of 10m and when standing on the stools has enough room for the m.w. to move under the vessel. This method is used for the ship type FCS 2610.When finished this ship will be placed with cradles on a larger ship to be shipped to the costumer. This method has the advantage that the cradle can be removed from the cradle bed, so when the FCS 2610 gets shipped no extra weight of the cradle bed will be on board.

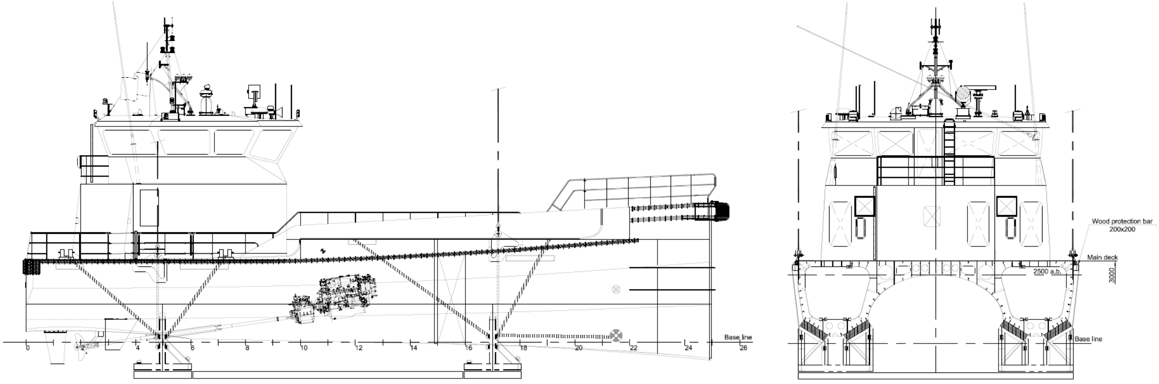


Figure 2.3: *Transport cradle formation for the FCS 2610 [5].*

2.2.3 Old method 3

For the third method the original cradle (Figure 2.4) is modified to create a broader base. Because the customer only wants an unmodified cradle with the ship, the modified cradle has to be financed out of the shipyards budget. This method also needs extra floor surface and this limits ship placement and working around the ship with a jerry picker. This method is used for the FCS 3307.

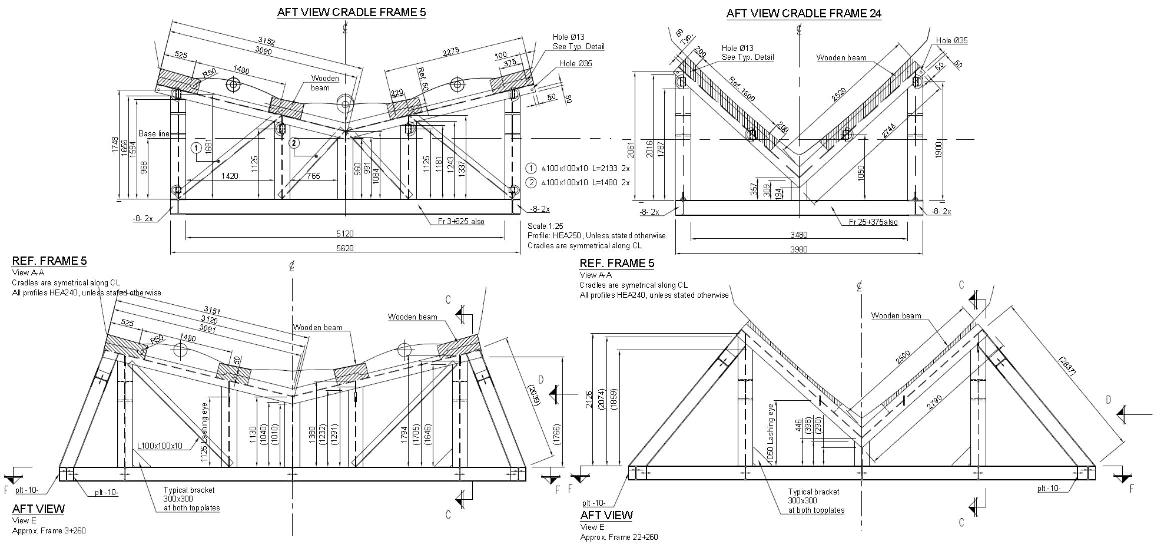


Figure 2.4: *Old and new cradle for transport of 33m vessels [3] and [6].*

2.3 Costs

This section gives an overview of the cost concerning the cradles in each method.

Produced/ ship type	FCS 1605	FCS 2206	FCS 2610	FCS 3307	FCS 3808	FCS 4212
2016 expected	0	4	4	4/5	1	2
2015	0	3	11	5	0	0
2014	2	0	3	4	0	0
2013	10	0	9	1	0	0
2012	6	0	6	2	0	0
2011	4	0	1	0	0	0
Total build	22	3	30	12	0	0

Table 2.2: *Ships production DAMEN Singapore [7].*

Table 2.2 shows the amount of produced ship types per year and the expected ship types for 2016. This table is important to determine the amount of needed cradles for the near future. DSSi doesn't have ship orders available for the years after 2016, so assumptions have to be made concerning the future demand of ship cradles.
In the table it can be seen that the FCS 1605 was not produced in 2015 and will not be produced in 2016, for that reason it will be assumed that cradles won't be needed for the FCS 1605 in the near future and it will be considered out of the scope of this research. The FCS 2206 is a line that is just started but DAMEN expects to produce more of these ship types, therefore this ship type will be considered in the scope of the research. The FCS 2610 and FCS 3307 show a production for the last 4 to 5 years and are expected to be build in 2016, therefore they will be in the scope of the research. Finally the FCS 3808 and FCS 4212. It is expected that the FCS 3808 will be moved similarly to the FCS 3307, but with different cradles. And the FCS 4212 like the FCS 2610, again with different cradles. Therefore these will also be taken into account in this research.

Specs/method	Method I	Method II	Method III
Ship type	FCS 2206	FCS 2610 FCS 4212	FCS 3307 FCS3808
Weight front cradle(kg)			3565
Weight rear cradle (kg)			3745
Capital cost(SGD)	15.000	14.500	40.500
Specific cost (SGD/kg)			5.54
Setting time(h)	2	5	5
Amount of workers	6	5	5
Worker wage(SGD/h)	51	51	51
Setting cost(SGD)	612	1,275	1,275
Total expected setting cost 2016	2,448	7,650	7,038

Table 2.3: *Specification per method [8],[9], [10],[11] ,[12], [13] and [14].*

In Table 2.3 the weight, cost and process estimation are all based on the currently existing ship types. The expected ship types don't have a cradle plan yet and thus no estimation can be made. The setting time is the time that is needed for cradle standing on the stools till the m.w. starts moving with the cradles and ship. The setting costs is the cost needed to move one ship with each method, this is based on the setting time, amount of workers and labour wage. The total expecting setting cost 2016 is a worst case scenario whereby it is assumed that ships needed only to be moved once per production. It is called a worst case scenario, not a best case, because in this case an alternative will give the least amount of profit.
In the same table it can be seen that the setting cost are a lot lower than the capital cost. To see if the goal of this research "To find cost efficient alternative solutions" will be met, a payback time has to be calculated. The ship type FCS 2610 will be used as an example because the whole setup procedure has been observed (see appendix A). Appendix A shows that only step 3 and 4 would have a benefit from an improved cradle, which takes only a small hour(1/5 of the total setup time). This cradle related operational time will shortened as operational time from here on. Considering that ships are moved more often than once in production and the new alternative will be more efficient than the traditional creates the following table:

Operational improvement/ Movement per production	1	2	3
1.00 operational time	255.00	510.00	765.00
0.75 operational time	191.25	382.50	573.75
0.50 operational time	127.50	255.00	382.50
0.25 operational time	63.75	127.50	191.25

Table 2.4: *Cradle related operational cost in SGD*

Table 2.4 shows that even if the cradle is used three times to move per ship and the alternative is four times as efficient the profit will only be 573.75 SDG per ship. Which gives a payback time of more than 6 years if one cradle is used for all the production. And this is only considering method II which has the cheapest cradles and one of the largest operational time. In other words even in an unlikely best case scenario as above is presented, it is not economically viable to replace the existing cradle with new more efficient ones, due to the high capital cost in comparison to the operation cost.

2.4 Redefining the research goal

Looking at the previous section this means that the main goal of this study is not a valid argument to replace the existing cradles and that the goal of this research has to be redefined in order for the result of this research to have any practical application for DAMEN. Considering Table 2.2 again it can be seen that two new ship types are expected in 2016. These vessel have no cradles yet and therefore every optimization of the cradles is directly translated in profit. Seeming that the research will only be profitable for future projects, DAMEN wishes to broaden the range of the research again from the FCS 1605 till the FCS 4212. The new goal of this research will be; to find a better solution for the cradles for all of the potential future vessel produced at DSSi.

2.5 Research method

Normally the research method is placed after problem definition but seeming the research goal had to be redefined this is chronologically more suitable. Figure 2.5 shows the research method. This is divided into: Introduction, Preliminary phase, Conceptual phase and Detailed phase. At first the potential of a new solution will be tested in the Preliminary phase. The goal of the research will be adjusted accordingly to the potential and a research in the old methods and cradles is done. In the conceptual phase the procedure will diverge into several concepts that will each be parallel tested for feasibility and cost. In the end this will converge into one procedure. In the detailed phase the procedure/design is finalized with a profile/production selection, detailed cost and strength analyses, and a CAD-model. And lastly this is followed by a conclusion and recommendation on the authors behalf.

In the diagram the squares functions as tasks that the researcher will solve on itself while the ovals will function as gateways for the researcher and DAMEN to evaluate the research done so far. When both parties are satisfied with the result the researcher will continue to the next step.

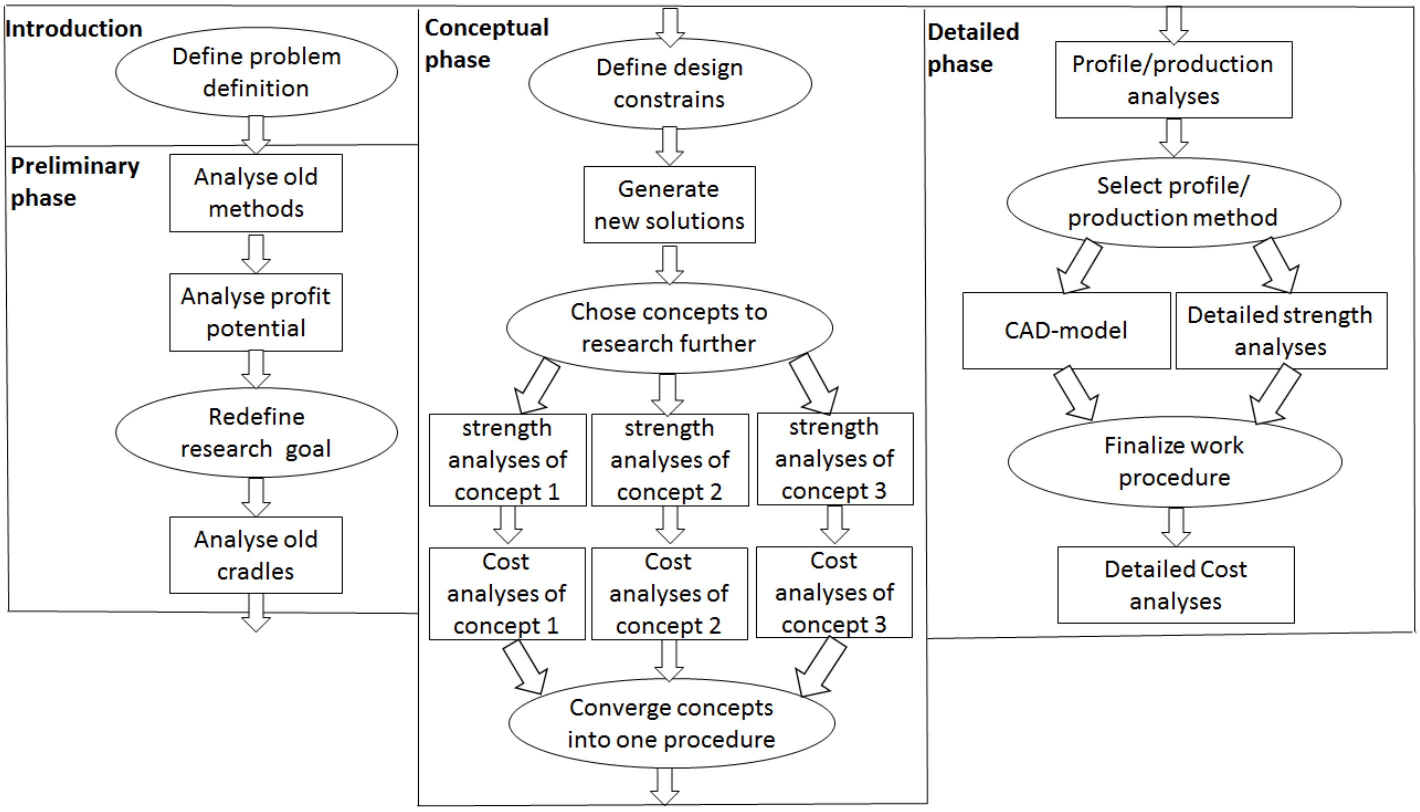


Figure 2.5: *Research method.*

2.6 Old cradle analysis

Although DAMEN has cradles from all kind of shapes and sizes their principle remains the same that can be traced back to the functions defined earlier. With this in mind the cradle is designed based on the load case and geometry of the hull of the ship type that is supposed to be carried by the cradle. For the load case this means that the type of quasi-statical load cases remains the same for each ship type, after all they all have to be moved by the m.w. with really low speed and flatness deviation, only the magnitude differs per ship type. When looking at the geometry of the hull of the ship type it can be observed that it only defines the angle of the v-shape and the length of the beams. Wooden blocks fitted in the v-shape ensure a tight fit with the vessel. Therefore a simple model can be constructed that defines the cradle for all kind of ship types with: the length of the beam(L_1), the angle of the v-shape(α) and the magnitude of the load(W). The goal of this model is not to capture all the load cases of a cradle, but to get a simple understanding of how the cradle work. For a full strength analysis analytical models will not be sufficient and a FEM analyses should be done such as done in Universal cradle analysis [15] and [16]. The model starts with front a view of an unmodified 3307 cradle, because this on is still analytically solvable. The following assumptions are made:

- Connection points are assumed infinitely stiff.
- The load in this case is only carried by the beams in the cross section plane, not by beams perpendicular to the cross section.
- That normally the cradle is carried by 2 or 3 stools on each side won't effect this model.

In Figure 2.6 a FBD is illustrated of the cradle in operation.Here the global coordinate system is introduced denoted as x and y. In the FBD 'W' is the partial weight of the vessel that the front cradle is subjected to. The force on the outer stools is equal due to symmetry, this force is denoted as 'F_1'. In operation the middle stool is only used as a safety measure. Therefore the $F_1 >> F_2$ and 'F_2' can be neglected in the FBD. This leaves a statically determined structure that can be described by the following equation:

$$\sum F_y = 2F_1 - W = 0$$
$$\Rightarrow F_1 = \frac{1}{2}W$$

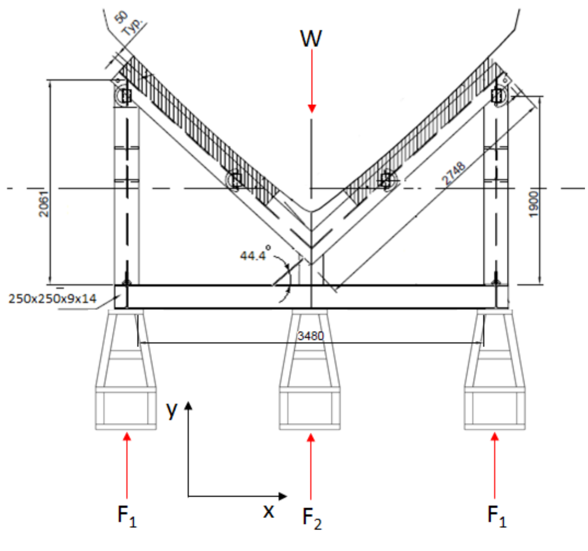


Figure 2.6: *FBD front cradle setup[5]*

In order to get an understanding of the whole cradle in operation it needs to be cut up in beam sections, so for each beam the specific loads can be determined. Also the connection on B and C are considered separately. A local coordinate system is introduced to facilitate the calculations. On the left the section division is illustrated. An uniform distributed load 'W^*' is assumed that results from the load 'W' from the ship. The distributed load starts at the cover and for convenience sake ends when beam A-B first reaches Beam B-C. Lastly the cradle is assumed perfect symmetric, so only one side has to be calculated. When finally the loads are known the beam profile and beam can be designed.
First the magnitude of the distribution has to be determined. From Figure 2.6 and 22 follows:

$$W^* = \frac{W}{2 \cdot cos(\alpha) L_1}$$

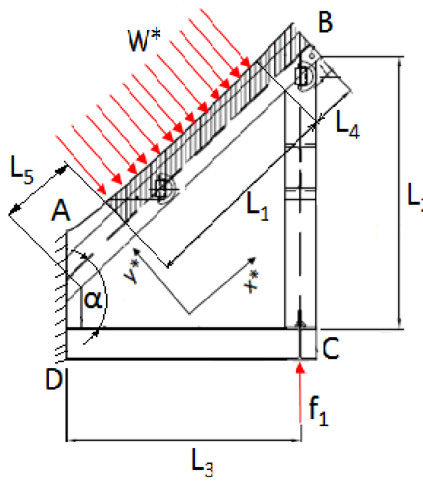


Figure 2.7: *Cradle scheme symmetric section*

The sections use two FBD's each. Where one is to calculate the reaction forces at the edge and one to calculate the internal forces. From the internal forces a V- and M- diagram will follow. In order to determine the reaction forces and moments for section A-B shown in Figure 2.8, a derivation is needed for a fixed beam with a partial uniform distributed load. This derivation can be seen in appendix B.

$$A_y = \frac{W^* L_1^3}{2L^3}(2L_5 + L_1)$$
$$B_y = \frac{W L_1^2}{24L^3}(12L_5^2 + 10L_5 L_1 + 12L_1^2)$$
$$M_A = \frac{W L_1^2}{24L^3}(12L_5^2 + 10L_5 L_1 - 9L_1^2)$$
$$M_B = \frac{W^* L_1^3}{12L^2}(4L_5 + L_1)$$

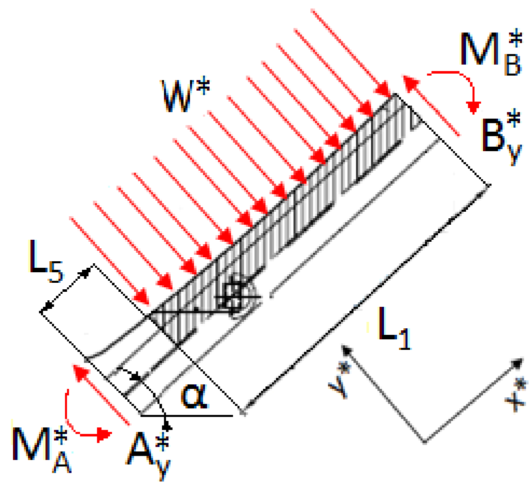


Figure 2.8: *FBD front cradle section A-B*

Using the geometry of the 33m cradle the following case is true $L_1 = 5L_1 = \frac{5}{6}L$. With this the reaction forces and moments can be written in terms of load W^* and beam length L, so the equation can be applied to any cradle with the same type of loading and geometry.

$$A_x = \frac{875}{2592}LW; B_y = \frac{1285}{2592}LW; \qquad M_A = \frac{125}{1728}L^2W; M_B = \frac{425}{5184}L^2W$$

With this in mind V- and M-equations can be determined.

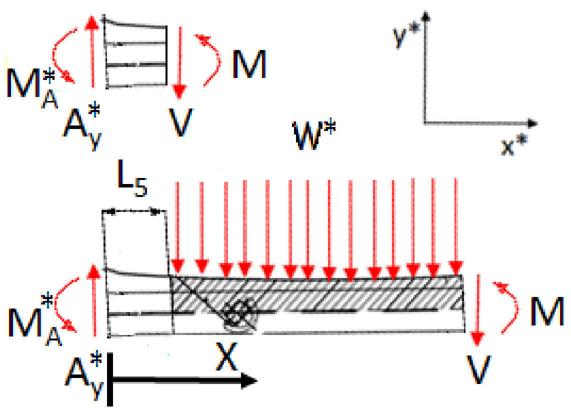


Figure 2.9: *Internal FBD front cradle section A-B*

From the top FBD in Figure 2.9:

$$\sum F_y = A_y - V = 0$$
$$\sum M = A_y x - M_a - M = 0$$

From the bottom FBD in Figure 2.9:

$$\sum F_y = A_y - W^*(x - L_5) - V = 0$$
$$\sum M = A_y x - M_a - W^*(x - L_5)(\frac{(x - L_5)}{2} + L_5) - M = 0$$

Summarized:

$$\begin{aligned} V &= A_y && 0 \le x \le L_5 \\ V &= A_y - W^*(x - L_5) && L_5 \le x < L \\ M &= A_y x - M_a && 0 \le x \le L_5 \\ M &= A_y x - M_a - W^* \frac{(x - L_5)^2}{2} && L_5 \le x < L \end{aligned}$$

With the V- and M- equations known the V and M- diagrams can be drawn. These are shown on the end of this section.

Next the forces in connection B will be determined of the FDB shown in Figure 2.10

$$\sum F_x = B_y^* sin(\alpha) - B_x = 0$$
$$\sum F_y = B_y - B_y^* cos(\alpha) = 0$$
$$\sum M = M_B^* + B_y^* \frac{L_4}{2} - M_B = 0$$

Filling in M_b^*, B_y^* and $L_4 = \frac{1}{10}L$:

$$B_x = \frac{WL_1^2}{24L^3}(12L_5^2 + 10L_5L_1 + 12L_1^2)sin(\alpha) = \frac{1285}{2592}LW^* sin(\alpha)$$
$$B_y = \frac{WL_1^2}{24L^3}(12L_5^2 + 10L_5L_1 + 12L_1^2)cos(\alpha) = \frac{1285}{2592}LW^* cos(\alpha)$$
$$M_B = \frac{425}{5184}L^2W^* + \frac{1285}{2592}LW^*(\frac{L}{20}) = \frac{41}{384}L^2W^*$$

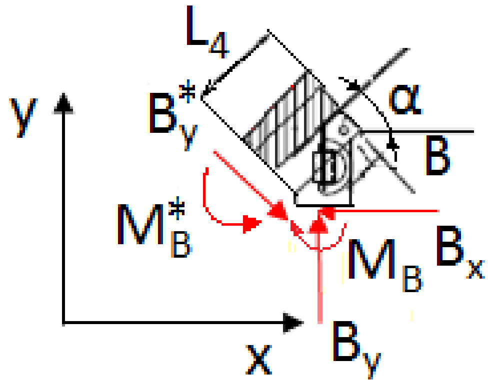


Figure 2.10: *FBD connection B*

Following the previous results the external and internal forces of section B-C from Figure 5 can be determined.

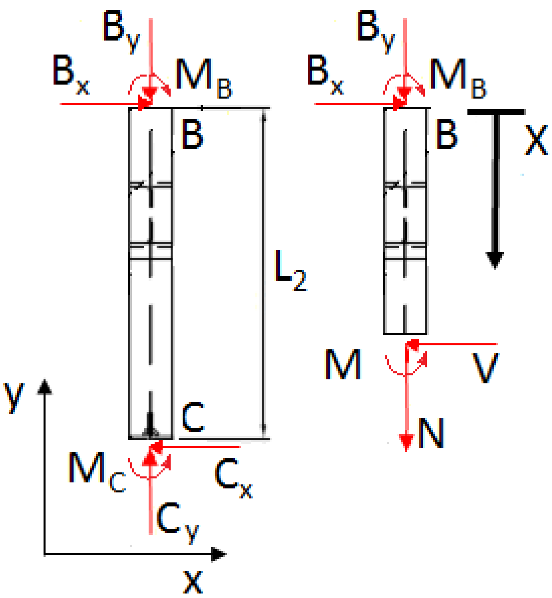


Figure 2.11: *FBD front cradle section B-C*

From the equilibrium equations follows:

$$C_x = B_x; \qquad C_y = B_y$$
$$\sum M = M_B + B_xL_2 - M_c = 0$$

Filling in $L_2 = \frac{4}{5}L$ follows:

$$\Rightarrow M_C = M_B + B_xL_2 = \frac{5219}{10368}L^2W$$

Next the V- and M-equations are derived form the right FBD.

$$V = B_x$$
$$M = M_B + B_xX$$

And last connection D shown in Figure 2.12 is determined.

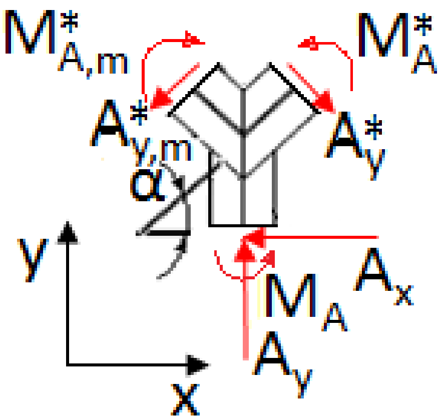


Figure 2.12: *FBD connection A*

In Figure 2.12 the FBD of connection A can be seen. Due to symmetry $A_{y,m}^* = A_y^*$ and $M_{A,m}^* = M_A^*$.

$$\sum F_x = A_y^* sin(\alpha) - A_{y,m}^* sin(\alpha) - A_x = 0$$
$$\sum F_y = -A_y^* cos(\alpha) - A_{y,m}^* cos(\alpha) + A_y = 0$$
$$\sum M = M_{A,m}^* - M_A^* - A_{y,m}^* L_6 + A_y^* L_6 - M_A = 0$$

Filling in $A_{y,m}^*$ and $M_{A,m}^*$ leaves:

$$A_x = 0$$
$$A_y = 2A_y^* cos(\alpha) = 2\frac{W^*L_1^3}{2L^3}(2L_5 + L_1)cos(\alpha)$$
$$M_A = 0$$

With no V-force or moment an extra FDB for the internal moment and forces is not necessary.

With all the unknowns determined the cradle bed from Figure 2.13 can be calculated.

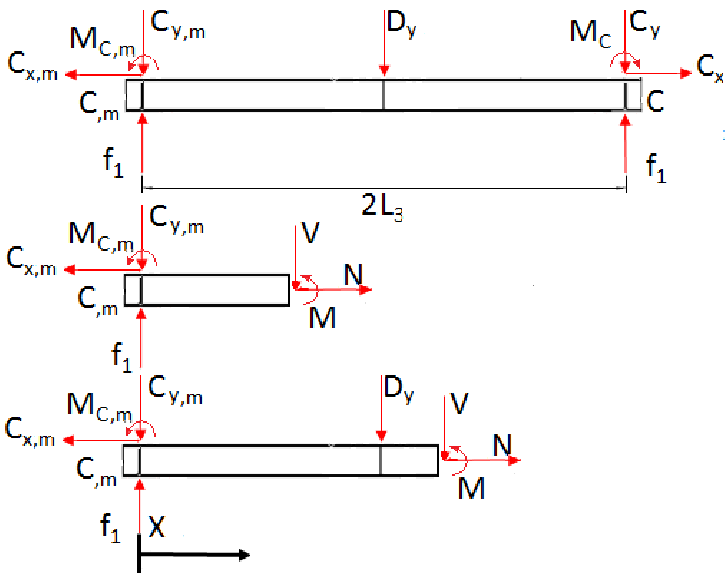


Figure 2.13: *FBD section C-D*

Calculating the general FDB:

$$\sum F_x = C_{x,m} - C_X = 0 \Rightarrow C_{x,m} = C_X$$

$$\sum F_y = 2f_1 - D_y - C_{y,m} - Cy,m = 0$$

$$\Rightarrow f_1 = (\frac{W^* L_1^3}{2L^3}(2L_5 + L_1)) + \frac{W^* L_1^2}{24L^3}(12L_5^2 + 10L_5L_1 + 12L_1^2))cos(\alpha)$$

$$\sum M = M_{C,m} - M_C + L_3(f_1 + C_y - C_{y,m} - f_1) = 0$$

$$\Rightarrow M_{C,m} = M_C$$

Filling in L_5 and L_1 from previous assumptions gives:

$$f_1 = \frac{5}{6} LW^* cos(\alpha)$$

With $W^* = \frac{W}{2 \cdot cos(\alpha) L_1}$

$$f_1 = \frac{5}{6} Lcos(\alpha) \frac{W}{2 \cdot cos(\alpha) L_1} = \frac{1}{2} W$$

Determining the V- and M- diagrams:
for: $0 \leq x < L_3$

$$\sum F_x = C_{x,m} - N = 0$$

$$\sum F_y = f_1 - C_{y,m} - V = 0$$

$$\sum M = M_{C,m} - M + (f_1 - C_{y,m})x - = 0N \quad = C_{x,m}$$

$$V = f_1 - C_{y,m}$$

$$M = -M_{C,m} + (f_1 - C_{y,m})x$$

for: $L_3 \leq x \leq 2L_3$

$$\sum F_y = f_1 - C_{y,m} - V - D_y = 0$$

$$\sum M = -M_{C,m} - M + (f_1 - C_{y,m})x - D_Y(x - L_3) = 0$$

$$N = C_{x,m}$$

$$V = f_1 - C_{y,m}$$

$$M = -M_{C,m} + (f_1 - C_{y,m})x - D_Y(x - L_3)$$

The Matlab model that is used is shown in appendix E. The Results of the N-,V-,M-diagrams are shown in Figure 2.14. The graphs are shown in unit length and unit force/moment. This is done so that the model is universal and the critical loads will be universal no matter what ship type will be used. When the values of the forces and moments are introduced to the buckling, shear and bending formula with the profiles used for this unmodified FCS 3307 cradle, the moment becomes dominant by a factor of ten. In other words looking back at the diagrams the critical part is in side ends of the cradle bed and the lowest end of section B-C.

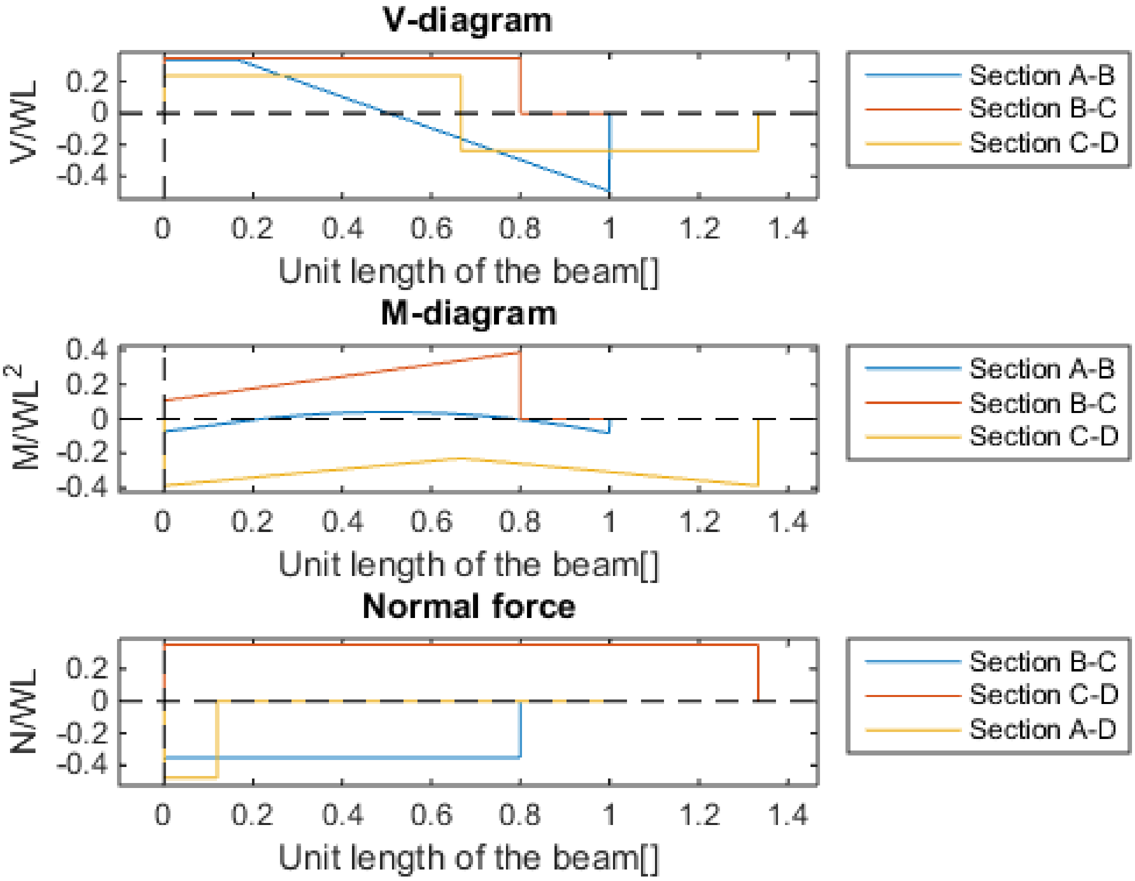


Figure 2.14: *V-,M- and normal diagrams*

3 Conceptual phase

This chapter is devoted to the conceptual phase. In this phase a morphological overview is generated to explore as many solutions as possible. Based on a quantitative consideration several solutions will be selected from this. These solutions will be worked out into concept. After this, the V-,M- and normal diagrams will determined for each concept following the procedure used in the preliminary phase. Lastly a final concept will be selected based on the V-,M- and normal diagrams and other requirements.

3.1 Design constrains

DAMEN Singapore has two type of ships; the single hull ship and the catamaran. So far all the ships type cradles can be described in general functions, but the different sort of ship can still give entirely different solutions. In this research two types of solutions will be considered:

- *Separate*: Here the solution for the single hull and the catamaran will be a different solution.
- *Universal*: Here the solution for the single hull and the catamaran will be an uniform solution.

Later analysis will determine which solution is best. Further DAMEN has only used v-shaped cradles that support the vessels on the body in the resent past. The advantage is that the vessel is fixed in the desired d.o.f.. The disadvantage is that the v-shape is ship type dependent and the cradle has to be placed on bulkhead locations in order not to damage the body of the vessel. In order to fix the vessel in y-direction the cradle will still be limited to the bulkhead locations, but keel supports will still be considered in order to avoid the v-shape dependency. DAMEN has at the moment a huge stock of old cradles (see appendix D).

3.2 Morphological overview

This section uses a morphological overview(Table 3.1) to use as a design tool to generate concepts that can be a possible solution to the problem. First the morphological overview systemically creates sub solutions for each defined function that the cradle has to fulfill. Later on these solutions will be used to construct several concepts.

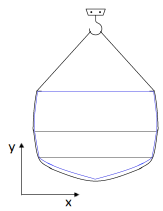
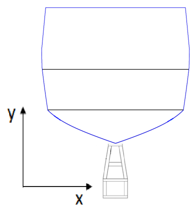
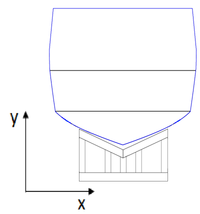
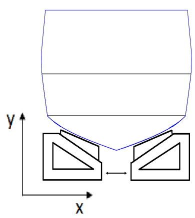
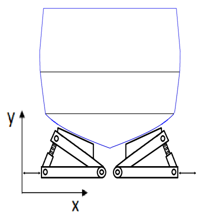
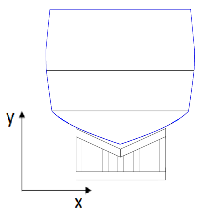
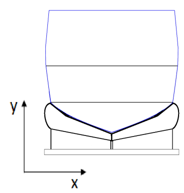
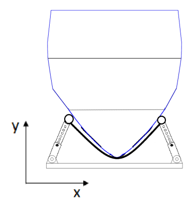
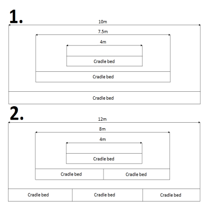
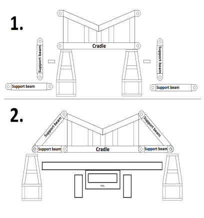
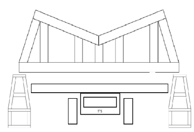
Func /sol.	No	I	II	III	IV	V
Fix in y-direction	A					
Fix in x-direction and z-rotation	B					
Broaden bed	C					

Table 3.1: *Morphological overview*

3.2.1 Explanation of the solutions

Solutions row A The first solution is suspending the vessel with a crane. This is not a very feasible solution because the cranes in hall 2 are limited to 15 tonnes and therefore can not lift most of the vessels as a whole. The second solution is a schematic sketch of a keel support. This can be either a stool, block or the cradle bed as long as it supports on the keel. And the last solution is a bulkhead support. The solution that is used at the moment but can also be struts or other kinds of supports that excise force on the bulkheads.

Solutions row B This row has two functions combined because all of the generated solutions fulfill both functions. The first solution is a modular framework. This allows the user to construct different types of v-shapes with the same cradle bed. However the modules will be a welded framework so the only shape flexibility will come from the wooden blocks. This solution can either be in combination with a keel support or function as a bulkhead support on it own. The next solution is similar

to the previous one except that it is adjustable and therefore has more shape flexibility. The solution also looks really similar to the solution from Universal cradle analysis [1], which turned up to be to bulky for real application. The reason why this solution is considered again is that this solution will not be fixed to one cradle bed, but instead be modular, and therefor the majority of the weight is avoided in case of the smaller vessel where a smaller bed can be used. Also if a keel support is used in combination with this solution than maybe the module can be much lighter. This will be researched in the next section. The third solution is same as the solution above because it restricts all the d.o.f. at ones. The fourth solution is a vessel resting on an airbag. This solution gives perfect fit no matter what shape of the hull is, however a small hand calculation based on the data from [17], shows that the resting surface at least has to increase three times to lift the vessel. Also the solution has stability problems when dynamic situations are considered e.g. when moving with the m.w.. The last solution is the use of struts. Struts are usually only used for small boats and will become bulky to compensate the moment the bigger vessels generate in the struts. For that a sling is added so the struts will only be subjected to a normal force. This results in a very light and adjustable solution and is probably the best static solution there is, though stability problems will occur when dynamic situations are considered.
Solutions row C The fist solution is using cradle beds of different lengths, still multiple ship types can fit on one cradle bed but smaller ships won't have the disadvantage of the added length of the cradle. The downside is that the cradles have to be moved by old methods again and concerning storage you still have a small form of ship type dependency. The latter can be solved to make the cradle bed modular so a big cradle bed can be assembled by three small cradle bed,as depicted in two. The second solution is a plug-and-play solution for the cradle bed. This allows the cradle bed to be small while the vessel is under construction and when it is finished the cradle bed can be extended so the m.w. will fit under it. The downside of this solution is that due to the different widths (stern and bow also for single hulls) it has total ship type dependency. The third solution has the same principle but applies to unmodified cradle of the single hulls, this can not be applied to the catamaran. And the last solutions summarizes all the conventional methods i.e. method I to III.

3.3 Alternative support method

In the previous chapter the method that is used at DAMEN Singapore called a 'Bulkhead support' has been analyzed. Another method to support a vessel on land is called a 'Keel support'. To see if this has any potential as a new solution the method will be analyzed in this section. The keel support will have extra modules in order to fix it in x-direction when the vessel is moved by a m.w..

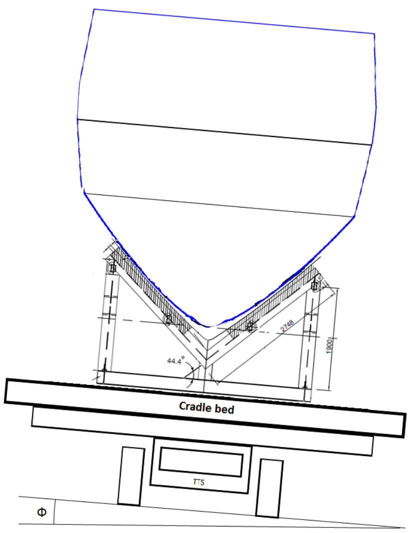


Figure 3.1: *Schematic overview hull support*

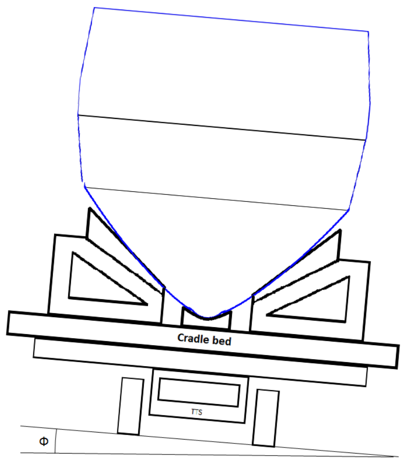


Figure 3.2: *Schematic overview keel support*

To determine if the keel support is more effective than the bulkhead support the load on the bulkhead support and the v-shape modules of the keel support have to be compared. In a normal situation the majority of the ships load will be distributed on the keel support and the modules will only be loaded if the vessel tends to move in x-direction(pretension not considered), and therefore the keel support would be an obvious winner. But when the vessel is loaded on the m.w. it can be subjected to rotation (see 3.1 and 3.2) and the load distribution between the keel support and the module will change. Bearing in mind that the goal is only to determine which support type is better the following assumptions are made:

- Full friction force works on the cradle, due to deformation of the vessel on micro scale.
- Friction is not effected by the rotation only by the normal force, due to small rotation(max 10°).
- The friction coefficient is 0.3 [18].
- The keel support is approximated as a roll support.
- The point of engagement for the reaction force W_1 is equal for both support systems.
- When tilted the vessel only exercise load on one of the modules of the keel support.
- Single hulls are worst case scenario. The FCS 3808 and FCS 1605 will be inspected to give an overview of the full range.
- Worst case scenario the hull angle has a constant angle of the front cradle (not in real life).

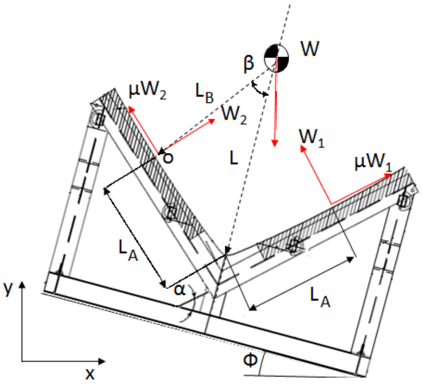


Figure 3.3: *FBD bulkhead support*

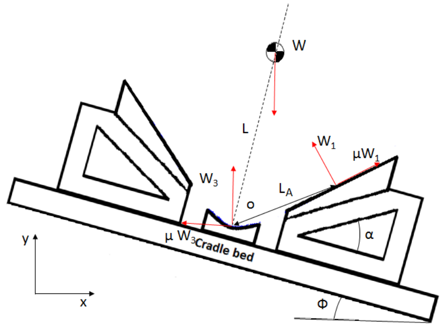


Figure 3.4: *Schematic overview keel support*

Equilibrium equations of the bulkhead support (Figure 3.3):

$$L_B = \sqrt{(L - L_A sin(\alpha))^2 + L_A^2 cos^2(\alpha)}$$

$$\beta = atan\frac{L_A cos(\alpha)}{L - L_A sin\alpha}$$

$$\sum M_o = 0 = 2L_A cos(\alpha)W_1(cos(\alpha) + \mu sin(\alpha)) - L_B W sin(\beta + \phi)$$

$$\Rightarrow W_1 = \frac{L_B W sin((\beta + \phi))}{2L_A(cos(\alpha) + \mu sin(\alpha))}$$

Equilibrium equations keel support (Figure 3.4):

$$\sum M_o = 0 = W_1 L_A - W L sin(\phi)$$

$$\Rightarrow W_1 = W\frac{L}{L_A} sin(\phi)$$

Filling in: $\alpha = 45^\circ$, $\mu = 0.3$ and $0, \frac{L}{L_1} = 1.667$ for the FCS 1605 ([19]) and $\frac{L}{L_1} = 1.575$ for the FCS 3808 ([20]) we find:

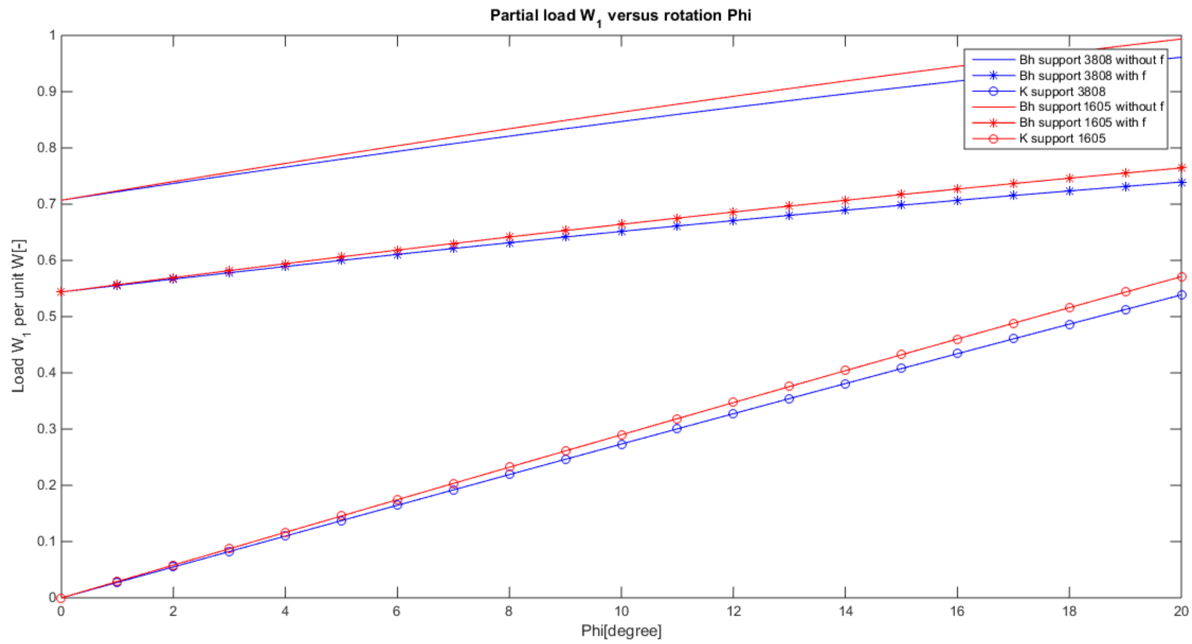


Figure 3.5: *Partial load W_1 versus rotation ϕ*

The graphs in Figure 3.5 show that the load on the module is up to three times lower (for small rotations) in comparison to the frictionless bulkhead support and two times lower in comparison to the maximum friction for the bulk head support. In real life the expected partial load for the bulkhead support shall be in between frictionless and maximum friction values. It can also be seen that the slope of the keel support is much steeper than the slope of the bulkhead support and therefore the keel support will surpass bulkhead support at larger rotation. However this is of no concern because when this happens the safety angle is already long surpassed and will therefore never happen in a m.w. operation.

So far only the operation in x-y-plane has been considered, not the longitudinal or z-direction. But in case of the m.w. hitting the brakes it could happen that the vessel tends to move in the z-direction. In this case it is better to have a higher partial load because this will automatically result in a higher statical friction force.

A worst case scenario is considered again where $\theta = 0$ this means the total load for the bulkhead support is $2 \cdot \frac{W}{\sqrt{2}} = \sqrt{2}W$ (two sided) while the total load for the keel support is only W. Using $W = mg$ and $ma = mg\mu \Rightarrow a = g\mu$ the maximum allowable ac(/de)celeration in z-direction of the m.w. can be found. For the bulkhead support this results in $\sqrt{2}g\mu = 4.16\frac{m}{s^2}$ and for the keel support it is $g\mu = 2.94\frac{m}{s^2}$. Comparing these results to the maximum braking force of the m.w. reported in [15] which is 0.507 $\frac{m}{s^2}$ it can be concluded that both supports are safe to use considering braking of the m.w. in z-direction.

Concluding concerning the load the keel support is better than the bulkhead support while for braking in the z-direction both supports will suffice. Therefore the keel should be considered in the new concepts.

3.4 Concept generation

In the previous section the morphological overview suggested several solutions for each stated function. This section is dedicated to converge these solutions into concepts. To enhance the change of the best final solution the concepts will not be considered final and it could be that the final concept could be a mix of sub solutions of the individual concepts.

3.5 Concept 1

The first concept will be a combination of AII, BI and CI. This concept will form a LEGO solution where a cradle bed for a random ship type can be formed out of standards modulus. The V-shape will be constructed out of a welded side frames that will be (mostly) ship type specific. An illustration is drawn in Figure 3.6 and 3.7.

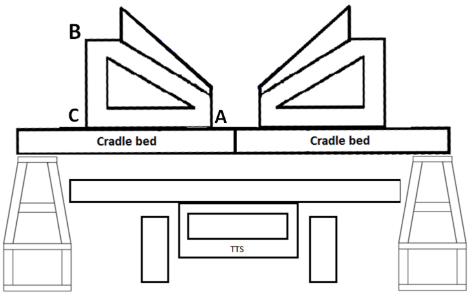


Figure 3.6: *Illustration concept 1 single hull configuration*

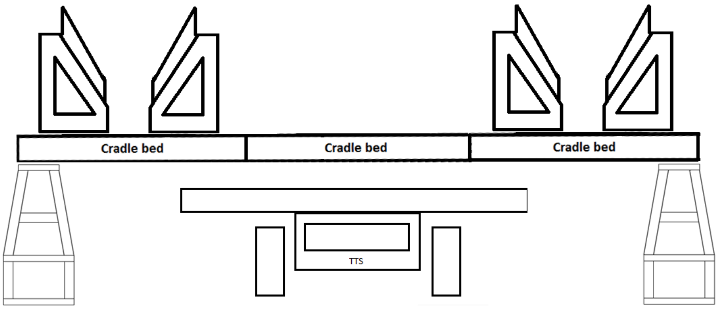


Figure 3.7: *Illustration concept 1 catamaran configuration*

To Determine the internal loads this concept is subjected to, it has to be divided into the cradle bed and the modules on top of it in bulkhead configuration. First the V-shape modules will be analyzed so the reaction forces on the cradle bed can be determined. The V-shape module can be analyzed in a similar way as the old cradle has been analyzed. For convenience the whole derivation can be seen in appendix E. To make each concept comparable with each other the following general assumption are used for each concept to determine the internal loads:

- Single hulls are considered a worst case scenario.
- For the cradle bed the worst case scenario happens at $\theta = 0^{\circ}$
- The connection are rigid and considered not critical.

The results of the analysis are shown below:

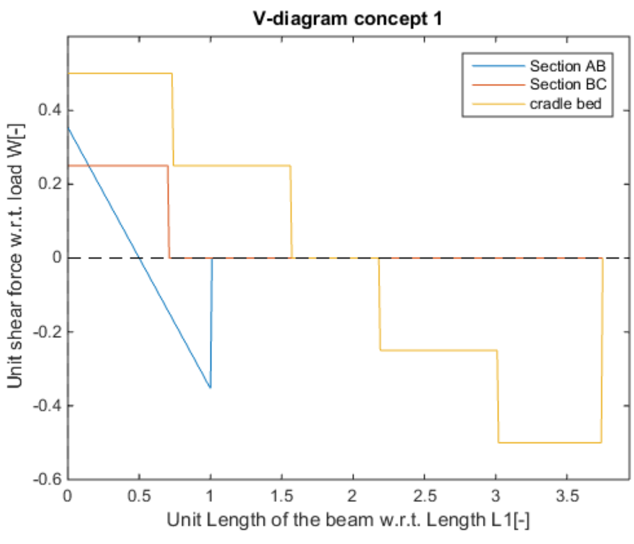


Figure 3.8: *V-line per section concept 1*

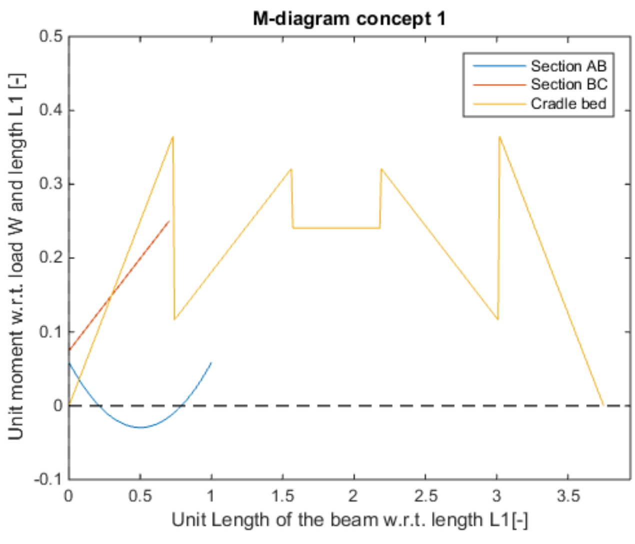


Figure 3.9: *M-line per section concept 1*

The results in the graph from Figure 3.8 and 3.13 are expressed with respect to length L_1 (the length of the uniform distribution) and load W (the weight force of the vessel on the cradles) so the graphs can be applied to any vessel with any type of weight distribution. This also means that for each section the lines only go as far as the ratio between the length of the section and L_0.

Both graphs show that the worst shear forces and moments take place in the cradle bed. For this concepts the Cradle bed should be the focus the ensure proper strength. If the cradle will be build out of uniform beams then the other sections will be over dimensioned.

In the preliminary phase it was determined that the moment was critical compared to buckling by a factor of ten. In these concepts the lengths of the beams are smaller then the model used in the preliminary phase and therefore buckling will occur even later. Because of this the normal force in the concepts was checked in the MATLAB model but not computed in this report due to lack of critical loads.

3.6 Concept 2

The second concept will be a combination of AII, BII and CII. This concept will have a cradle bed that consist out of a ship type specific base frame that can be elongated with a plug when a m.w. needs to move the frame. The v-shape will consist out of a keel support that can be adjusted to fit the vessels geometry. For illustration see Figure 3.10 and 3.11.

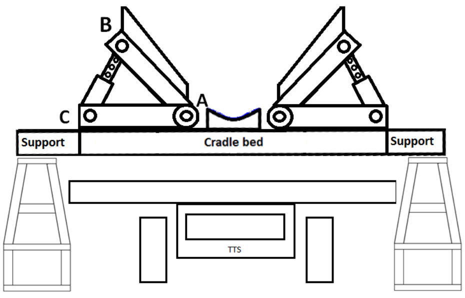


Figure 3.10: *Illustration concept 2 single hull configuration*

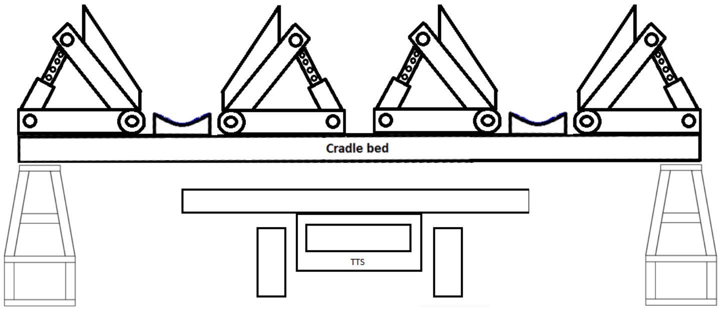


Figure 3.11: *Illustration concept 2 catamaran configuration*

At first a Keel support is analyzed. In this concept the worst case scenario for the V-shape modules is different from the worst case scenario of the cradle bed. While for the V-shape modules the worst case occurs at the safety angle of 5°, after all that is the moment most of weight leans on one of the modules. This is not the case for the cradle bed because then it is almost fully covered by the m.w. and therefore almost no bending will occur. Thus the worst case scenario for the cradle bed will occur when it is standing on the stools.

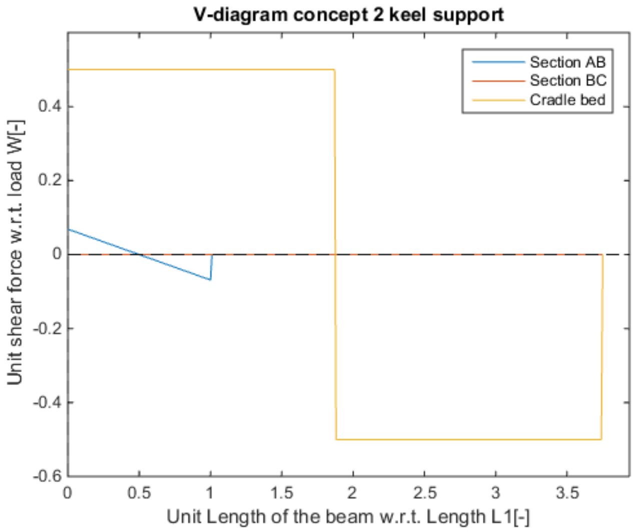


Figure 3.12: *V-line concept 2 per section keel support*

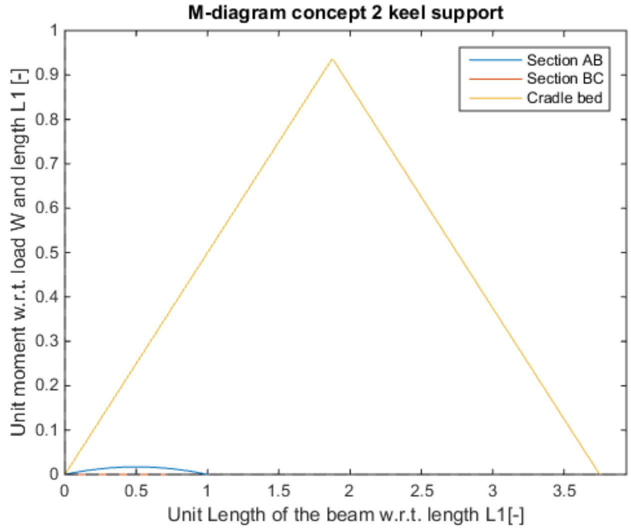


Figure 3.13: *M-line concept 2 per section keel support*

While the V-diagram in Figure 3.12 shows a similar maximum as the previous concept this is definitely not the case for the M-diagram in Figure 3.12. The explanation is that all of the weight is now concentrated on the middle of the cradle bed instead of spread across the cradle bed through the v-shape modules. High moments like this will need a very bulky bed to hold. This is not desirable because this will automatically resolve in a heavy and expensive structure. The benefit of this approach is that V-shape modules carry almost no weight and can be made very light, so it is still possible to keep them adjustable. To see what the effect is of the keel support the same analysis is run but now with a bulkhead support.

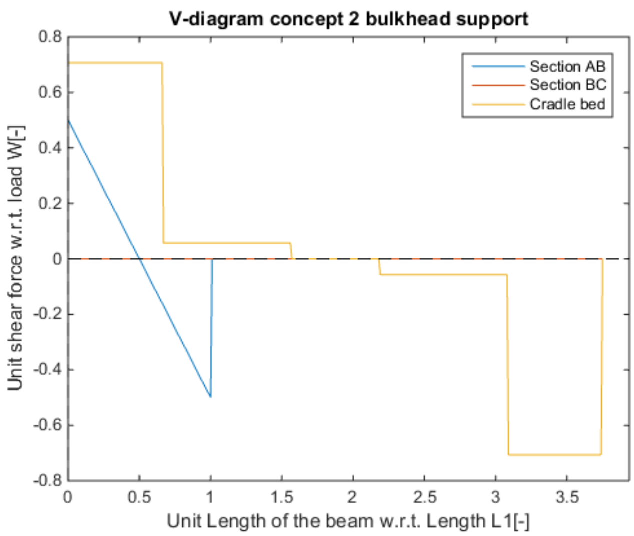


Figure 3.14: *V-line concept 2 per section Bulkhead support*

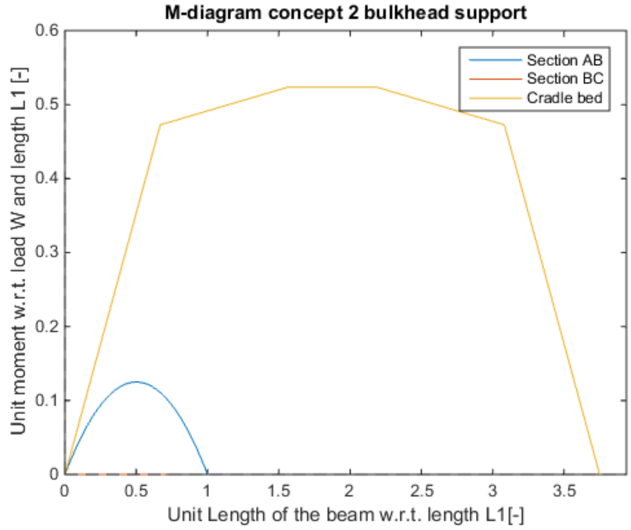


Figure 3.15: *M-line concept 2 per section Bulkhead support*

Figure 3.14 and 3.15 show the results when adjustable V-shape modules are used in a bulkhead support. At first in Figure 3.14 it can be seen that the shear force is bigger than in first concept. This can be explained because ship functions like a wedge that creates a moment in the v-shape model, because the module is only constructed out of pin connections it is not able to create an inner moment and therefor has to create a larger reaction force to compensate for the moment created. In other words if the v-shape would have an angle of zero, so the ship will no longer function as a wedge, it will result in similar results as concept 1. This is not a solution however because the whole function of the v-shape would be gone (it would just be a flat surface). The higher reaction forces in turn create a higher M-line compared to concept I.

3.7 Concept 3

The third concept will consist out of sub solutions AIII,BIII and CIII. In this concept only the basis cradles will be used that will be outfitted with detachable elongations that will be used when the cradle will be moved by the m.w.. Two different solutions have been found for the elongation. The first option is a beam with a pin connection to the cradle. A knee on top of the beam will prevent the beam from rotating to far. The Second option will be a framework connected to the cradle with pin connections.

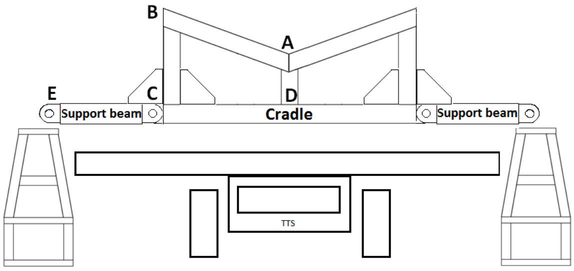


Figure 3.16: *Illustration concept 3 option 1*

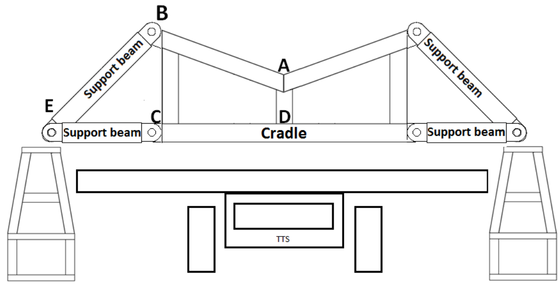


Figure 3.17: *Illustration concept 3 option 2*

To see what effect these elongations will have on the basis cradle an analysis is necessary. The goal of this analysis will be to determine if the basis cradle is strong enough to be carried by the elongations. The starting point of the analysis will be model that has been introduced in the preliminary phase.

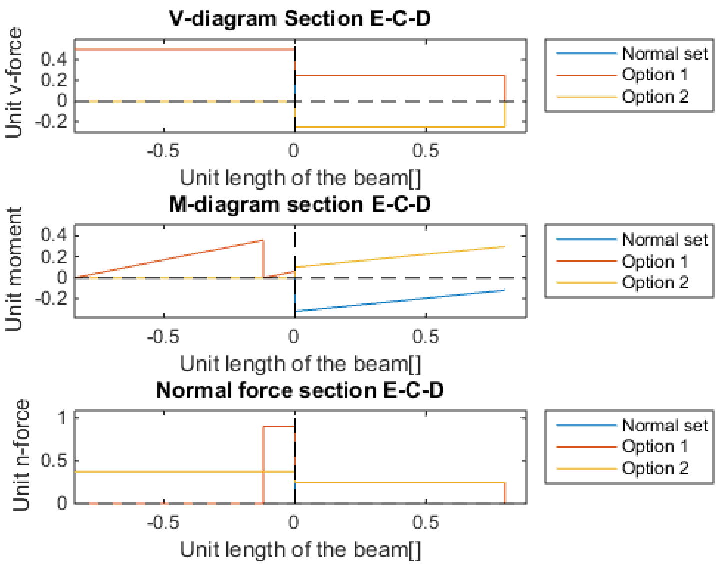


Figure 3.18: *V,M and N-line per option*

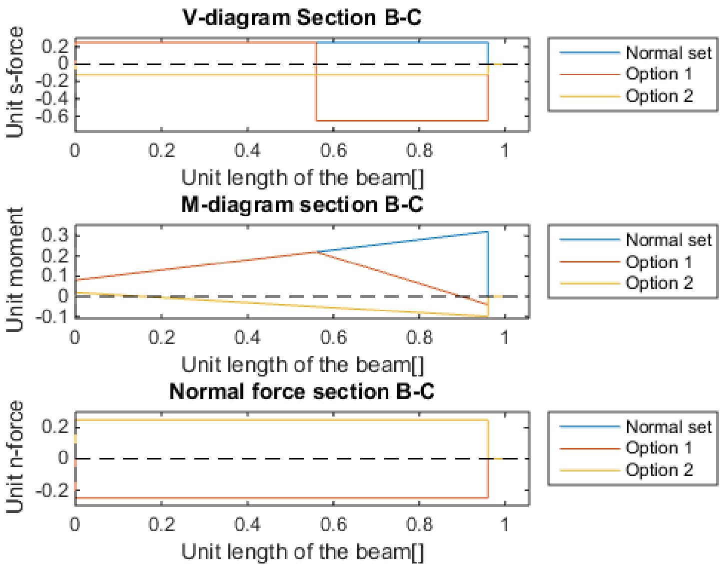


Figure 3.19: *V,M and N-line per option*

The graphs shown in Figure 3.18 start at a minus x-value instead of the origin of the axes. This is to make a distinction between the added extensions and the original cradle. In this case the x=0 value is the boundary line between the extension and cradle. Also the total length of the x-axis is only half of the length compared to the graphs in the other concepts. Due to symmetry in the model the graphs will be the same on the other side of the symmetry line and therefore for it is chosen to only show the first part for a better overview.
In Figure 3.18 both options and the normal set are shown. The normal set is when a normal cradle is placed on stools as depicted in the preliminary phase. The normal set has no normal force, shear force or moment in minus x-domain simply because the point of engagement is on x=0. The first thing that can be seen is that both alternative options reduce the internal moment in the C-D part. The normal force seems to remain the same in C-D part. However the large peak of option one should be noted in the E-C part, this can create high unwanted concentration stresses. The V-diagram shows that option two forms a positive value into a negative value, this of no real concern because the absolute value remains the same.
In Figure 3.19 the effect of the option on section B-C are shown. Here it can clearly be seen that option 2 is the best option, because option 1 creates higher shear forces than the normal set, while option 2 scores better than the normal set and option one for the shear force an moments. For the normal force the value of option 2 is the same but in opposite direction.

3.8 Concept 4

The fourth concept is a combination of AII, BV and CI. The concept will start with struts aligned perpendicular to the cradle bed due to the springs. The sling will prevent the struts from going beyond the 90 °. When the hull is lowered the sling and strut will form to the hull shape and will capture it in its own weight. This principle will be applied to both the catamaran and the single hulls. Because the single hull is considered as a worst case scenario and the information will else be repetitive it is chosen to only show the single hull case.

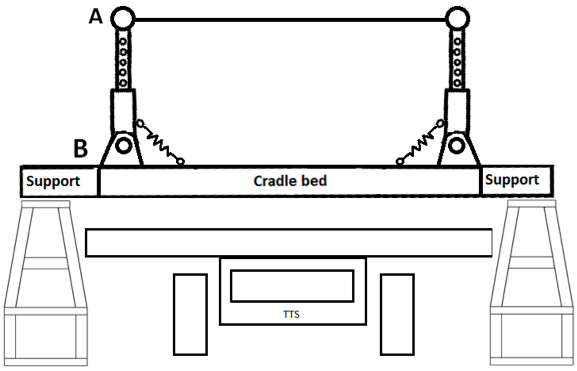


Figure 3.20: *Illustration concept 4 unloaded*

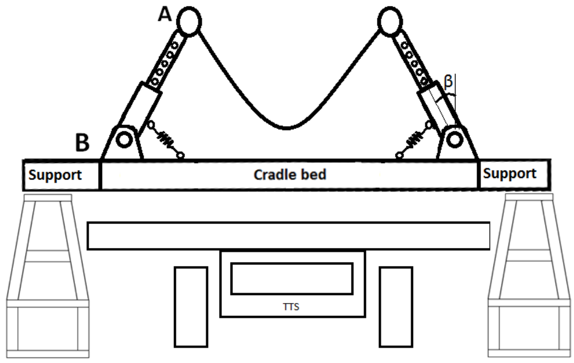


Figure 3.21: *Illustration concept 4 loaded*

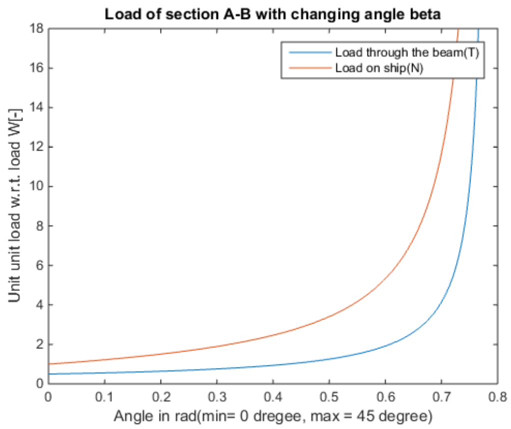


Figure 3.22: *Loads at changing angle β*

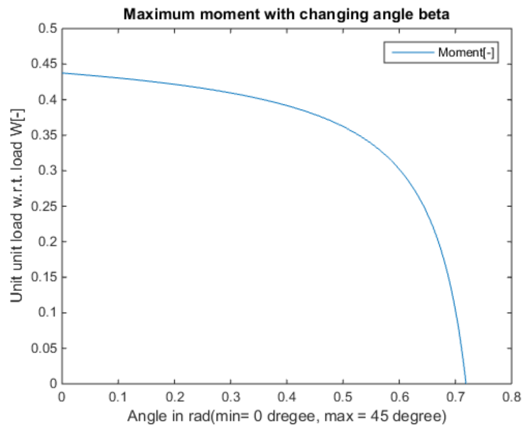


Figure 3.23: *Moment at changing angle β*

The moment in the cradle shown in Figure3.20 will go to zero if the origin of the adjustable beam will go to the location of the stools. To make things comparable to the other concepts this is achieved by moving the angle of the adjustable beam and considering the point of engagement with the vessel at the same location as the ending of the cradle in the other concepts. However changing this same angle will result in a higher normal force on the vessel and force in the adjustable beam. Besides of reaching an equilibrium between those to point stability also has to be considered. For example if the adjustable beam has an angle of 0°the cradle will topple with the slightest inclination while if it is past 45°the adjustable beam will slight off and not carry the weight of the ship at all. For this reason an angle of 15 °is chosen.

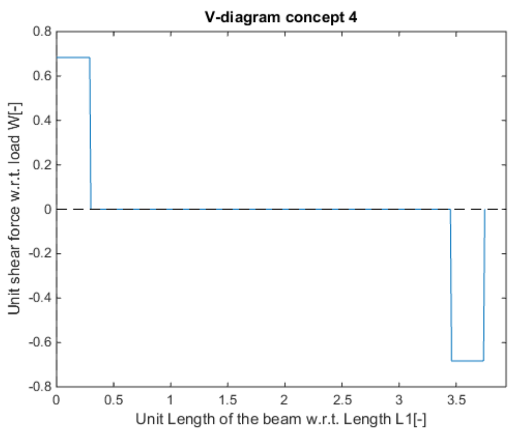


Figure 3.24: *V-line cradle bed concept 4*

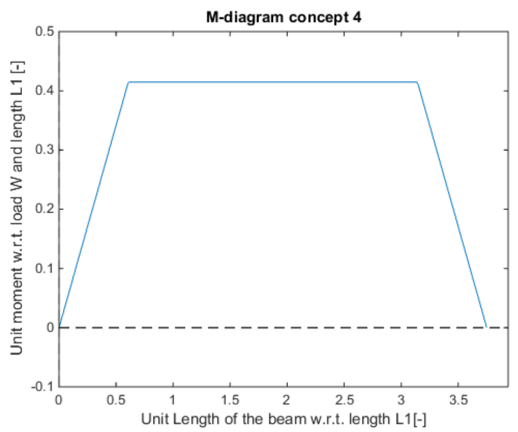


Figure 3.25: *M-line cradle bed concept 4*

Filling that in will give similar strength results shown in Figure 3.25 as concept I while still being adjustable for different ship types. The concept does have its limitations, since the concept will only work on hulls with an acute angle. Therefore this concept is only suited for front cradles in general.

3.9 Concept 5

The last concept will consider the old cradles that are already on hand at DAMEN. This concept will research if the old cradles can be applied on the FF 3808 and the FCS 4312. First a quick look will determine if the hulls will fit in the cradles. After this a strength analysis of will be performed if the cradles are strong enough to carry the vessels.

3.9.1 Geometry fit

First the FF 3808 is considered on a 3307 cradle as is shown in Figure 3.26 and 3.27. The cradles always have to be placed on a bulkhead of the vessel. On the FF 3808 the bulkheads on a frame spacing of 6m and 11m can be used for the rear cradle and 27m and 33m for the front cradle. However the section lines depicted in Figure 3.26 and 3.27 are shown in the old frame spacing from drawing [21]. The following old frame spacing lines correspond to the bulkheads, for the rear: 3 and 6, and for the front: in between 14 and 15, and 18.

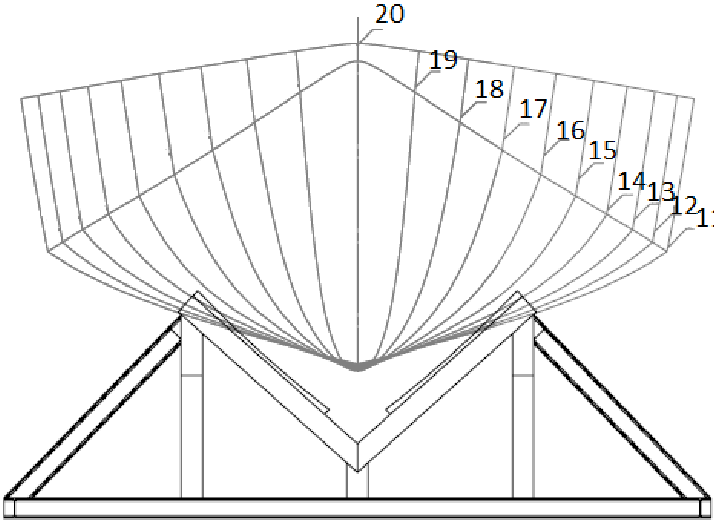


Figure 3.26: *FF 3808 on a 3307 front cradle*

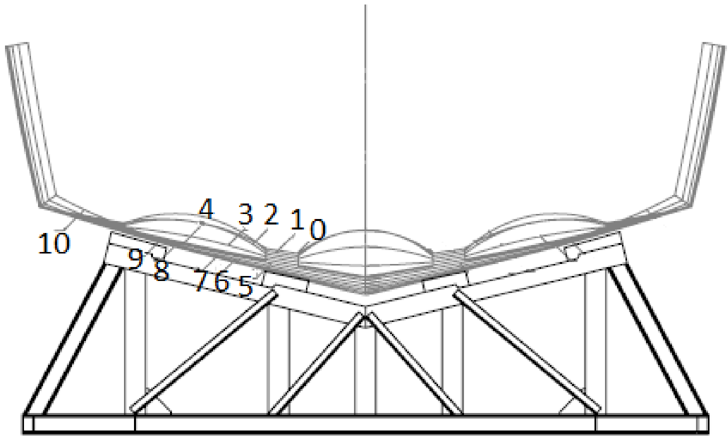


Figure 3.27: *FF 3808 on a 3307 rear cradle*

For the front the section line 18 and the area in between section line 14 and 15 show a very weak fit with the cradle v-shape. The gap in between the cradle and the vessel could be filled with wooden blocks, but one could argue about the feasibility of this. The rear however shows a tight fit no matter which section line is taken. Only the propeller shaft could be very inconvenient therefore section line 6 should be used for the cradle placement.

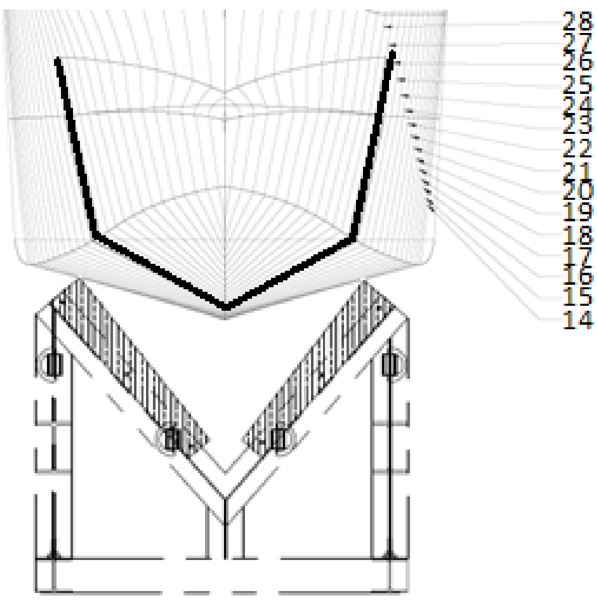


Figure 3.28: *FCS 4212 on a 2610 front cradle*

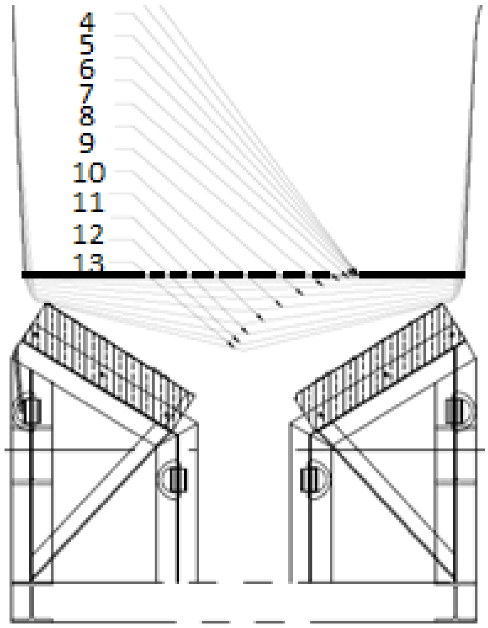


Figure 3.29: *FCS 4212 on a 2610 rear cradle*

According to [22] the cradles have to be placed between line 3 and 4 for the rear cradle and 26 and 27 for the front cradle. In Figure 3.28 and 3.27 the cradles of the FCS 2610 are shown underneath a 4212. These lines for the cradles highlighted for a better overview. In the front cradle the angle of the cradle, previously defined as α, has to be changed from approximately 55°to 30 °. This is quite cumbersome but not unfeasible, strength analysis later on will show if the front cradle of the 2610 should be used for the 4212.

However for the rear cradle ship lines show a near flat surface compared to an angle α of approximately 35°of the cradle. Besides of the feasibility one should ask what the added value would be to place it on a 2610 cradle because it will not fix the ship in x-direction after adjustments. Therefore a simple and cheap wooden block as depicted in [22] will fulfill the same function. Placing the FCS 4212 on a 2610 cradle would be useless and over complicate matters for no reason.

3.9.2 Strength analysis

In the preliminary phase it has been explained that an analytical analysis on the FCS 3307 modified cradle is to complex to pay off in comparison to a FEM analysis. To determine if the existing cradles will be strong enough the weight values of the expected ships will be compared to the strength analysis [16].
For the single hulls the FCS 3808 is taken again as worst case scenario. The intact and stability report [20] states that ships weighs around 105 tonnes and the LGG/total length ratio is similar to the FCS 3307. This means that the partial load on the cradles is only a fraction bigger than the 3307 (105 tonnes instead of 100 tonnes) and according to strength report [16] the cradle will as able to hold this.
For the catamaran the FCS 4212 is taken as a worst case scenario. In the previous subsection it was already determined that only the front cradle needs a strength check because the rear cradle has no useful potential. With a L.C.G. of 14.5 m, the front cradles on 26.5m and the rear cradle on 2.5m the fractional load on the front cradles result in approximately 0.5W which is 37.5 tonnes per cradle. Filling in this load, the angle $\alpha = 30°$and the geometry of the cradle in the model introduced in preliminary phase we find:

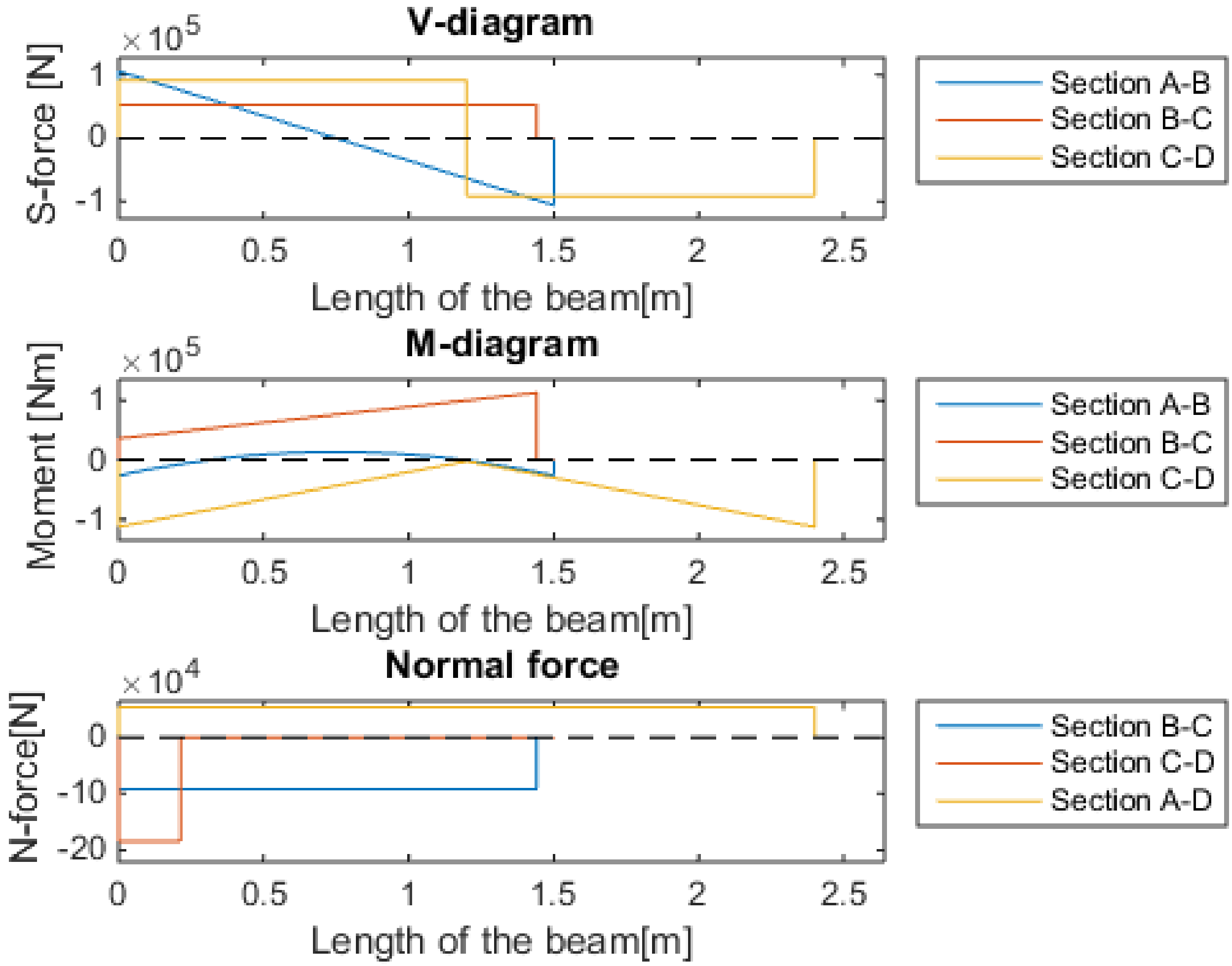


Figure 3.30: *V,M,N-lines 4212 on a 2610 cradle*

Figure 3.30 shows the highest values are: $1.1 \cdot 10^5$Nm for the shear force and $1.1 \cdot 10^5$Nm for the moment. The I-beams that are used have a second moment of inertia I_x of $1.8 \cdot 10^{-4} m^4$[23], first moment of inertia S_y of $9.2 \cdot 10^{-4} m^3$, y of 0.125m and are made out of plane carbon steel with an allowable stress σ of 156.7 MPa. Filling this in the shear and bending formula[24] and [25] we find the allowable shear and moment for the 2610 cradle:

$$V = \frac{\tau t I}{Q} \approx \frac{0.7\sigma t I}{Q} \approx 5.36 \cdot 10^6 N$$
$$M = \frac{\sigma I}{y} \approx 1.5 \cdot 10^5 Nm$$

This shows again that bending is the critical load type. Although bending is still beneath the allowable bending stress the margin leaves no room for Leniency. Considering the inaccuracy of the model stated before and the possibility of unpredictable situations this is not a risk that should be taken.

3.10 Concept selection

To choose the best solutions a table is setup to compare the concepts to each other. Each concept will be graded on the specification formulated. Each specification will have a different weight based on the importance of the specification. These grades will be multiplied by the weight and summed. This total will give an indication which is the best solution to use. The specifications that are used are:

Strength One of the most important factors because it is directly related to the capital cost of the concept.

V-shape flexibility The ability of the concept to fit the hulls shape without using new cradles.

Applicable flexibility The ability of the concept to be applied to different hull types and also as front and rear cradle.

Floor space The amount of space it will take when a vessel is mounted on it (in use).

Storage The amount of space when no vessel is mounted on it (out of use).

Capital cost While this is directly related to the strength some of the concepts are already produced and therefore the capital cost should be taken in account separately.

Setup time The time that is needed to setup the cradle. In the preliminary phase it was shown that this was only portion of the whole operation time so it has only a small weight.

Concept/ specification	Weight	Concept I	Concept II	Concept III	Concept IV	Concept V
Strength	3	3	1	3	5	2
V-shape flexibility	1	4	5	2	5	2
Applicable flexibility	2	5	5	2	1	1
Floor space	1	1	5	5	5	1
Storage space	3	5	4	2	4	1
Capital cost	3	3	2	3	2	5
Setup time	1	1	2	2	2	5
Total		46	43	37	47	34

Table 3.2: *Concept comparison table*

The table shows that concept IV would be the best solution. But this solution is limited to hull shapes with an angle of 45°or less, so this solution will not be suited for most rear cradles. This means for the rear cradle another solution have to be sought after. Here concept I comes into play. This concept scores second best, but looking into detail it can be seen it scores high on entire different specification than concept VI. This is due to the different cradles the concepts use. Looking at the cradle bed specific specifications(Floor space, Storage space, capital cost and setup time) it can be seen that concept I scores high on all the high prioritized specifications while concept VI scores high on the lower prioritized specifications. In other words concept VI would score even higher in the comparison table if it was outfitted with the cradle bed from concept I. For that reason and the fact that concept VI is only suited for front cradles the final concept will be a combination of concept I and VI. Where cradle bed will be as in concept I, the front cradle as concept VI and the rear cradle as concept I.
The reason why concept V scores so badly is that strength calculation didn't leave any room for leniency. According to Auke Steenkamp the first weight estimate of the FF 3808 could be an underestimate and thus the cradle cradle could still fail due to lack of margin. Also the shape fit was very bad and a lot of adjustments needed to be made for a good fit.

4 Detailed Phase

So far the concepts have only been considered in a very generic way. No tweaking of the geometry was done so all concepts could be compared to each other. With a final concept chosen it is no longer necessary to keep the model generic and tweaking of the geometry can begin. The goal of this chapter is to tweak the geometry of the concept into an optimum to minimize the load and see if the load of each module can be reduced far enough that it will be feasibly to apply to all ship types. The chapter will start with minimizing the load for the front cradle followed by the rear cradle. Due to the limited time frame of the research only the single hull will be considered. Next a profile selection will be done based on the different load types the cradle is exposed to. And finally an impression of the cradle will be shown.

4.1 Front cradle load optimization

For the front cradle the angle of the adjustable beams have been determined on 15°. In order to bring the origin closer to the stool support the length of the beam can also be adjusted. An illustration of this is shown in Figure 4.1 and 4.2. Here the numbers on the side and top are given in meters to give an impression of the effect of the changing beam length.

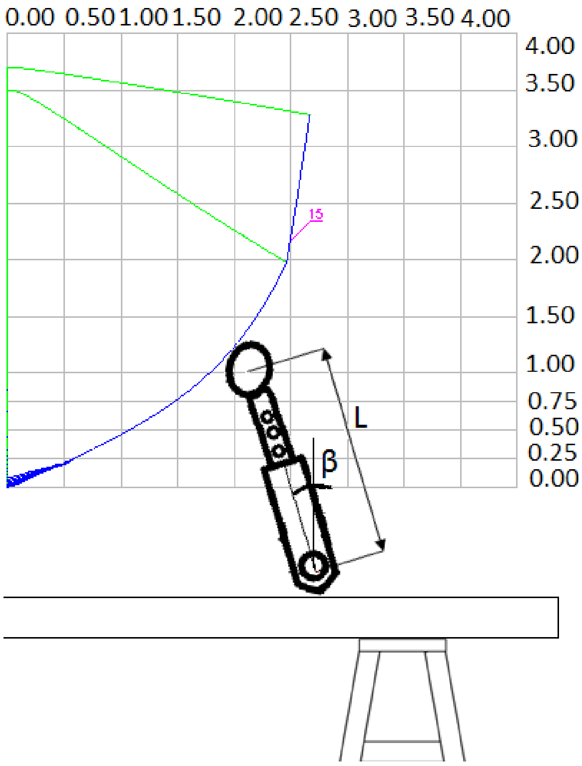


Figure 4.1: *Initial configuration front concept*

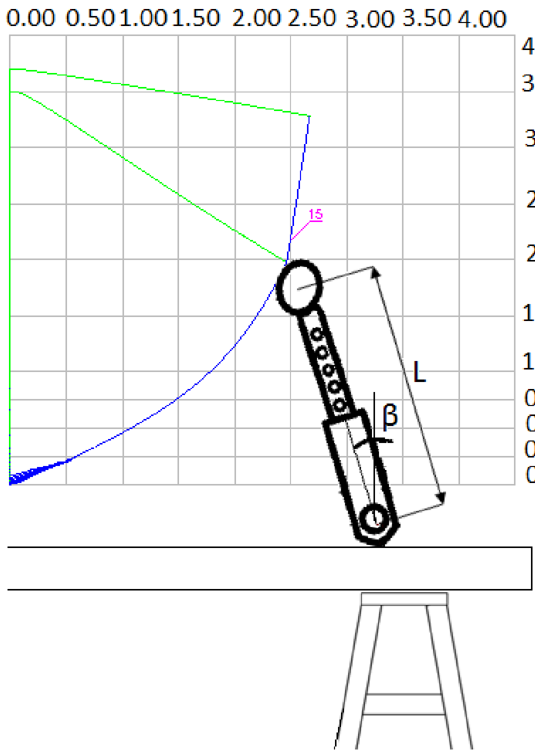


Figure 4.2: *Increased length L*

The load on the cradle is needed in order to make estimations of the minimum needed geometry of the profiles. Based on the position of the cradles stated in the preliminary phase and the longitudinal center of gravity the load(LCG) out of intact and stability [20] the load is determined as $\frac{9W}{21}$. Where W is the load which is 105 tonnes.

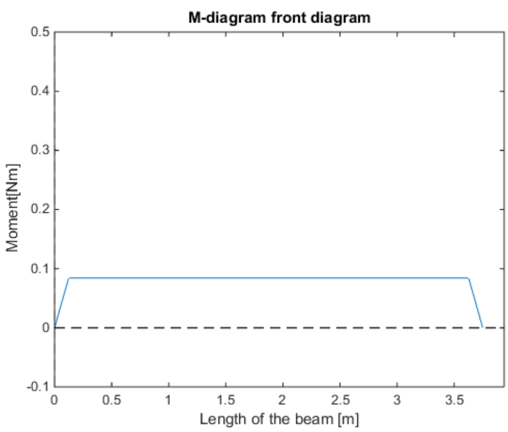


Figure 4.3: *New unit moment diagram*

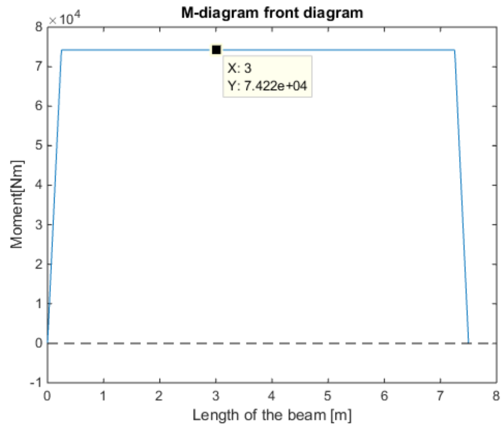


Figure 4.4: *Real moment when the vessel is a FF 3808*

Figure 4.3 shows the unit moment of the cradle bed with the new configuration. In theory the moment could be reduced to zero, but then the load case with the cradle on the m.w. would be the critical load case. Therefore it is chosen to place the origin of the beam in the middle of point of engagement with the stool and the m.w. This configuration shows a decrease of the moment by a factor four. But with an increase in the length of the beam, buckling should be checked. The angle has not been changed and thus the V-force does not change. It is therefore assumed that bending remains the critical failure mode.

Figure 4.4 shows the moment when real values are filled in. The highest value of the moment is $7.4 \cdot 10^4$Nm and for the normal force $8 \cdot 10^5$N in the adjustable beam. The profiles are considered to be made of plane carbon steel with an allowable stress σ of 156.7 MPa with a safety factor of 1.5. Filling this in the bending and buckling formula [26] we find the minimum needed second moment of inertia divided by the height of the beam. With this known a profile selection can be made out of universal beams and columns [23] .

$$\frac{I}{y} = \frac{M}{\sigma} \approx 4.1628 \cdot 10^{-4} m^3$$

This value means that a single I-beam of 26X26X1.4cm, used at the moment for small ships, with an $\frac{I}{y} = 9.2 \cdot 10^{-4} m^3$ is all that is needed to hold the load.
For buckling the buckling formula [26] is used. For this a hinged situation assumed with a K of 1.0.

$$F = \frac{\pi^2 EI}{KL} \Rightarrow I_{min} = \frac{FKL^2}{\pi^2 E} \approx 6.7 \cdot 10^{-7} m^4$$

The result shows that buckling is still far from critical compared to bending if similar profiles are used.

4.2 Rear cradle load optimization

The rear cradle can be optimized in a similar way. To keep the vessel straight in the cradles the concept can not only use triangles, but has to add some height as well. An illustration of this is shown in Figure 4.5 and 4.6

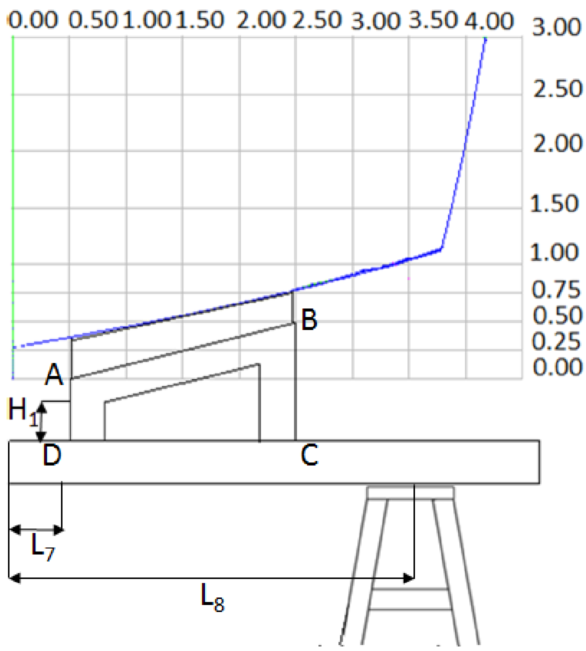


Figure 4.5: *Initial configuration*

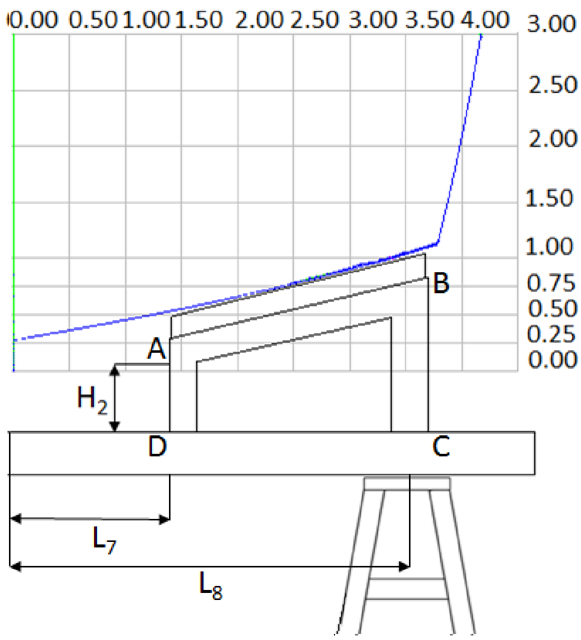


Figure 4.6: *Increased length L*

In the same way as the front the cradle the load is determined as $\frac{12W}{21}$.

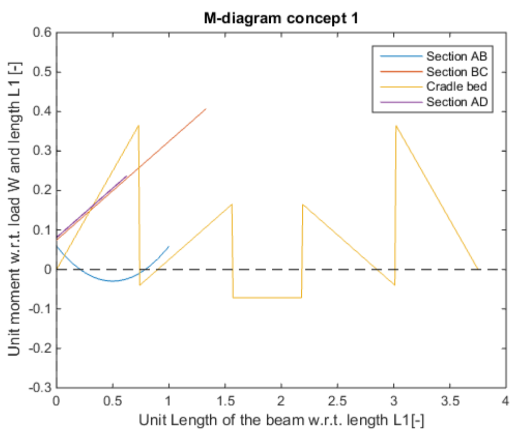


Figure 4.7: *Initial configuration* $L_7 = \frac{L_8}{6}$

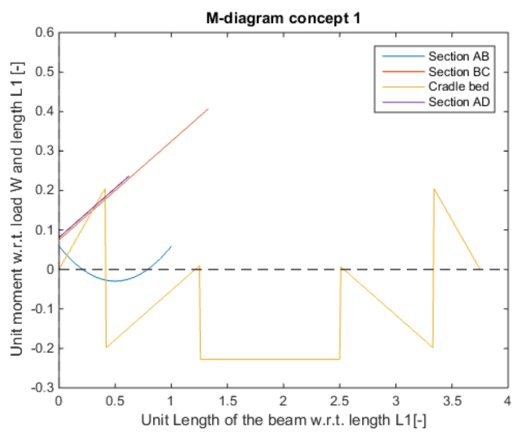


Figure 4.8: *New configuration* $L_7 = \frac{L_8}{3}$

Figure 4.7 shows that the moment drops at each beam section due to the counter moment in these beams. Moving these beams towards the stool support will lower the graph of the cradle bed, but will bring the graph also further into the minus y-domain. Therefore the position of the v-module in total should be when the absolute value of the graph is minimal. Figure 4.8 shows when the absolute value is minimum. The starting position of the v-module is at the first moment drop.
Moving the v-module towards the stool support will increase the length in the beam sections and therefore the moment in these beams will increase to higher moments than the cradle bed. These moments can easily be handled with other beams but that

would make the model to complex to solve analytically. For this reason and that the cradle bed is the main point of interest due to interchangeability, it is assumed the support beams will be added later and the cradle bed is still the worst case scenario.

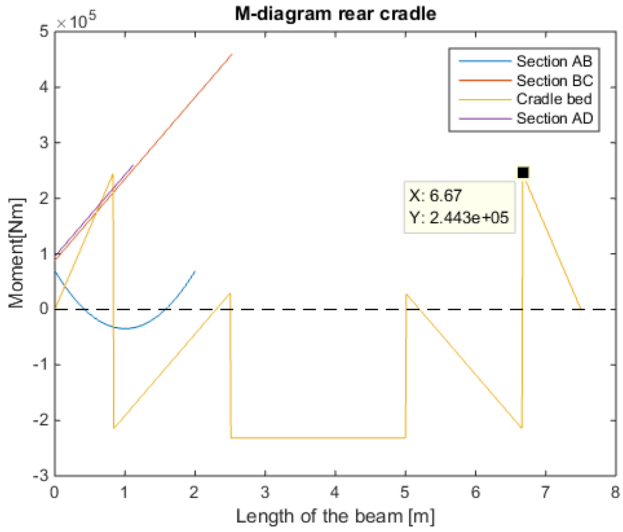


Figure 4.9: *New configuration wit a FF 3808 vessel*

Figure 4.9 shows the moment of the cradle bed when real values are filled in. The highest moment that occurs is $2.2 \cdot 10^5$Nm. With the same assumption made in the previous section the result is:

$$\frac{I}{y} = \frac{M}{\sigma} \approx 1.6 * 10 \cdot 10^{-4} m^3$$

This means according to universal beams and columns one I beam 31x31x2.0 with an with an $\frac{I}{y} = 1.9 * 10 \cdot 10^{-4} m^3$ is needed to hold the load.

4.3 Profile selection

Except for the front cradle's adjustable beam, bending is the dominant factor in the cradles. To see which profile is best suited for this failure mode a profile analyses will be performed. The four profiles that will be tested are shown below:

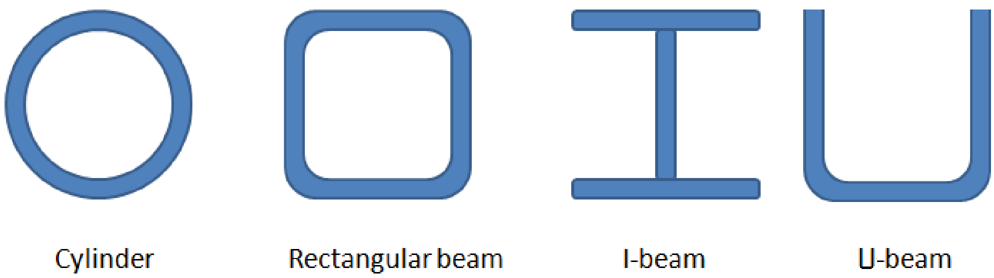


Figure 4.10: *Profile cross sections*

The second moment of inertia determines the bending strength of a profile. These formulas are shown in the following:

$$I_{cyl} = \frac{\pi \left(r_o^4 - r_i^4\right)}{4} \qquad I_{rect.beam} = \frac{1}{12} bh_{out}^3 - \frac{1}{12} bh_{in}^3$$

$$I_{I-beam} = \frac{1}{12} th_{vert}^3 + 2\left(\frac{1}{12} bt^3 + bt\left(\frac{h}{2}\right)^2\right)_{hor} \qquad I_{U-beam} = \frac{2}{12} bh_{vert}^3 + \frac{1}{12} bt^3 + bt\left(\frac{h}{2}\right)^2_{hor}$$

To acquire an indication of the strength of those profiles, the formulas from above have to be filled in to make a first comparison between those shapes. Therefore, there is assumed that $r_0 = \frac{b}{2}, r_i = \frac{b}{2} - t$ and $b = h$. Thereafter, b is assumed to be $250mm$ and t to be $20mm$. Lastly the main point of interest is not the overall bending strength but the bending strength compared to the amount of material because this will result in less needed material and thus a cheaper and lighter cradle. Table 4.1 arises:

	I($10^{-5} m^4$)	A(mˆ4)	I/A
Cylinder	9.6	0.0145	0.0067
Rectangular	28.8	0.0184	0.0089
I-beam	18.1	0.0150	0.0099
U-beam	20.8	0.0150	0.0065

Table 4.1: *Comparison between different profiles*

Table 4.1 clearly shows that the I-beam is the best option for the cradle due to the highest ratio. However as was stated before the dominant factor for the adjustable beam is not bending, but buckling. In case of buckling the strength is still determined by the second moment of inertia (when the length is already determined), considering that the geometry of the I-beam is not an option, the rectangular beam would be the wisest choice.

4.4 Final design

The Final design is meant to give an impression on how the solution could turnout. Due to the limited time frame of the research, detailed calculations for the connections and point of engagement with the vessel have not been performed in both the cradles. Therefore this model is just an impression, not production ready.

Figure 4.11: *Impression sketch front cradle*

In Figure 4.11 an impression sketch of the front cradle can be seen. The cradle consist out of a cradle bed, two adjustable beams and belt. The cradle bed consist out of two sections that has to be assembled. The beams can also be removed so that the cradle bed can be used for the rear cradle or different ship types. A simple video is made that illustrates this assembly and will be attached to the digital form of this report.
The profiles used in this sketch are the I-beam of 26X26X1.4cm suggested in the Front cradle optimization. The bed is therefore bigger than is necessary in the previous calculations. This is done because the diagonal support struts on the adjustable beams, the beams that add strength in z-direction case of braking, need anchor point to the cradle bed. Because no calculation have been done in this research for that type of scenario the cradle bed has been designed similar to the old cradles. The total weight of the impression sketch is estimated at 3000 kg.

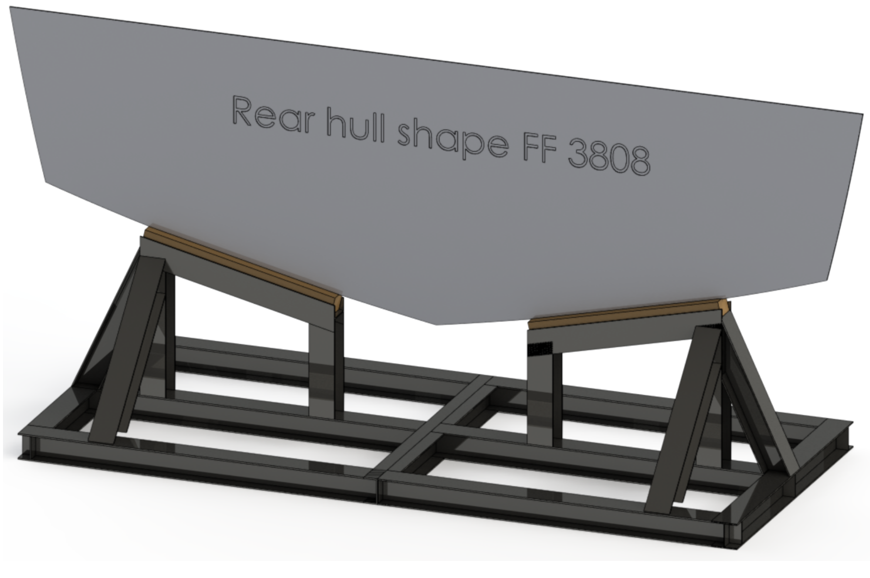


Figure 4.12: *Impression sketch rear cradle*

In Figure 4.12 an impression sketch of the rear cradle is illustrated. The cradle consist out of a cradle bed, two modules to form the v-shape and two wooden blocks to ensure the fit with the vessel. Modules can be disassembled form the cradle bed to use the bed for other purposes. The rear cradle is made out of 26X26X1.4cm I-beams for exactly the same reasons as for the front cradle An extra diagonal is added to carry the high moment that goes through section B-C. The total weight of the impression sketch is estimated at 3200 kg. This is an overestimate and it is expected that weight will reduce drastically when optimization is done.

5 Conclusion

The goal of the research was to find a better solution for the cradles of all the potential future vessel produced at DAMEN Singapore. For this two different support types have been analyzed. According to this analysis the best support is the bulkhead support due a better load distribution.

The conceptual analyses showed that when the cradles are made modular, huge storage spaces can be saved. Not only the footprint will reduce drastically (when unused), but making the cradles modular will make the cradle bed interchangeable no matter what ship type cradle it has to be. The downside of this buildup is that the footprint in use, will remain the same. However as determined in the conceptual phase this does not compare to the benefits of a general solution such as the standard modular cradle bed.

For the v-shape modules the best solution is not the general solution for all ship types but the ship type specific solution, due to the lighter load transfered from the v-shape module, the cradle bed can be much lighter. The solution of the v-shape modules will be divided into an acute angle solution (such as the front of a single hull) and obtuse angle solution (such as the rear of single hull). It was shown in the conceptual phase that the interchangeability and the load transfer is most in favour with the sling solution, but was only applicable for acute angle hulls. For the obtuse angle another solution had to be sought. For this the welded frames scored best because the load transfer was the least. The downside of this solution is the applicability with changing angle, but because this solution is applied at the rear cradle it is expected that the angle deviation will not differ much and that most of the angle changes can be compensated with wooden blocks.

The detailed phase showed that extending the adjustable beams, so the origin will come closer to the stools, result in a more favourable moment in the cradle bed and thus a lighter cradle bed. The same is true for the welded v-shape frames. However the optimal point of the origin for the adjustable beam will be in the middle of the last point of engagement of the m.w. and the stool, while for the welded frames this point is determined by the moment true beam B-C. One thing has to be noted though, moving the welded frames will cause section B-C to be critical instead of the cradle bed. This can easily be solved to add an extra beam (just like the traditional FCS 3307 rear cradle) but this can not be solved by the analytical model used in this research.

Looking at the load case the cradles are subjected to, this research proofs that the I-beams used at the moment for the cradles are the best type of profiles concerning the weight to bending strength ratio. Lastly an impression is given of how the cradles will look. The catamaran cradles were not worked out into further detail nor have an impression sketch, due to the limited time frame of the research. The initial weight of the front and rear cradle is around 3500 and 3750kg. The new solution's front and rear cradle is estimated around 3000 and 3200kg. Although no detailed calculations have been performed for the pin connections and the point of engagement with the ship and therefore the design is not finished for production yet, the goal of this research was to search for better solution and with a lighter, interchangeable and less spatial solution this research has proven that better solutions do exist.

6 Recommendation & discussion

The analytical model that is used is very limited and should never 'only' be used to design a cradle, but in this research the only point of interest was if one concept was better than another and for that the model is very well suited. While a FEM analysis could tell exactly the same with an higher accuracy the computational time is also something that has to be taken into account. Considering the limited time frame the research had and the amount of concepts that had to be tested, the FEM approach became less and less attractive to use. Another disadvantage of the FEM approach is that amount of insight of the cradle as a concept it creates is very limited and may be even none exciting, it only gives the stress concentration after a certain load which can be very depended of micro geometry not the concept in overall. This makes it very hard to see relations in order to create new concepts. For these reasons it is chosen to compare the concepts in an analytical model.

The limitation is that the final solution presented can not be seen as a final product. For this it is highly advised to use the FEM analysis for several reasons. The first is that a more complicated structures can be analyzed, therefore it will be possible to add extra beams as is needed for the rear cradle in order to optimize. The second is that even further optimization of the weight can be obtained as Elena already showed in cradles analysis and optimization [15]. And lastly the FEM analysis will be able to capture micro stress concentration that the analytical model was not able to capture.

Another remark is that the amount of load cases that are researched are very limited. In this case mainly the most important load case on the cradle, the static situation on the stools, has been used to compare each concept. This could be critical when force on the vessel is considered. The sling concept increases this force with a changing angle of the adjustable beams and with a larger angle could exceed the maximum force on the vessel. In this research the maximum force on vessel has been assumed on a 15°of the adjustable beam, roughly estimated on the stool mounting that is performed in the shipyard. In order to do this properly the contact point on the vessel should be looked at in a detailed calculations/ FEM analysis. Looking at the other load cases i.e. braking and transportation of the m.w. it is not expected to bring other best concepts/solutions. However these load cases will be needed to guarantee safety of the diagonal beams out of the x-y-plane. This also applies for stability, this has only been researched in a zero tilting angle and for safety the angle of the adjustable beams have been assumed as 15°, so the adjustable beams won't tilt after a minor inclination of the m.w.. But because the vessel will lean in a sling it is hard to say if the sling cradle will remain an equilibrium after tilting. The fact that a single hull will be supported by a cradle with welded v-shape modules as well will help stability, but in order to make the concept work one should guarantee the removal of any possible disastrous outcome and therefore the stability should be researched further to guarantee safety.

A solution that came up during the end presentation was to connect the adjustable beam to the lifting hooks instead of using a sling. This will not only positively effect the stability but will also remove any change of slicing of the sling, which could happen when a ship drops to hard in the sling. So far the feasibility of the concept has not been researched yet, but the advantages of this possible outcome makes it worthwhile for future research.

Finally the catamaran, this ship type cradle has not been researched in the detailed phase due to the limited time frame of the research. Meaning that no decisions have been made concerning configurations of the cradle. A sling cradle could have less advantages because the hull has to be suspended by two slings on each side of the cradle. This will result that only one of the adjustable beams will come near the stool or m.w. and possibly losing the advantage it creates in the single hull. Further research will point out if the welded frames or the sling will be best in this situation. For the cradle bed chances are that it has to become bigger due to the higher load and longer distance between the multi wheeler. First further research should find out if this is the case and if so make a decision to either separate the single hull's cradle of the catamaran's or stick to an universal with the consequence that it heavier and more expensive.

Concluding the research showed that there are better solutions than the old cradle solutions, but these concepts still need a lot of research before they can guarantee safety and can be produced accurately. When that is finished a configurator could be build so no new cradle has to be designed anymore with the arrival of a new ship type. Because the only parameters that change are the load and the angle of the hull, a configurator will not be hard to make.

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Appendix A

Observation moving ship procedure		
Moving:	FCS 2610	
Date:	14-01-2016	
Cradles:	Doc: 1590073	
Step	**Action**	**Time window**
1	Briefing	08:00 - No info
2	Getting tools and mw ready	No info - 09:24
3	Placing beams including wedge plates	09:24 - 10:10
4	Removing gear	10:10 - 10:17
5	Cleaning/ clearing the passageway for the mw and ship	10:17 - 11:08
6	Workmen seem to work on different projects (not movement related)	11:08 -12:00
7	Lunch break workmen	12:00 - 12:30
8	My own lunch break (no info)	12:30 - 13:00
9	Placing the mw	13:00 - 13:13
10	Placing ballast	13:13 - 13:18
11	Lifting the vessel with the mw, then removing the stools and gangplank	13:18 - 13:45
12	Pass out reflective vests and start moving	13:45 - 13:47
13	The movement	13:47 - 13:54
14	Placing stools under cradle	13:54 - 14:10
15	Clamps beam to mw removed	14:10 - 14:14
16	Mw out	14:14 - 14:27
17	Beams removed	14:27 - 14:53

Appendix B

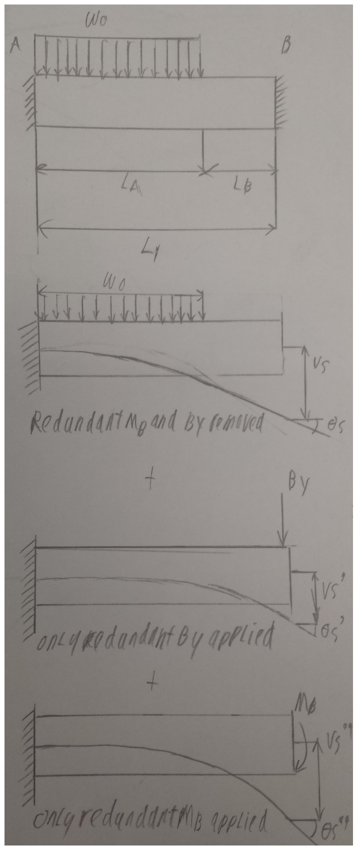
Product	**Dimensions(m) /Type**	**Amount**
Stool	1.00	54
	1.30	3
	1.50	68
Easel	0.93	3
	1.30	34
	1.45	38
Cradle	FCS 1605	16
	FCS 2206	16
	FCS 2610	40
	FCS 3307	16
Cradle bed	10.6	12
	11.0	2
Mod cradle bed	8	1
	9	1
I-beam	10x0.31x0.31x0.02	8
	10x0.26x0.26x0.03	6
Cradle car	FCS 1605	1
Ships	FCS 1605	6
	FCS 2206	5
	FCS 2610	2
	FCS 3307	3

Table 1: *Stock inventory*

Appendix C

Derivation fixed beam reactions(partially uniform distributed load)

[28] and [29]



$$\theta_{B,s1} = \frac{-WL_A^3}{6EI}$$
$$V_{B,s1} = \frac{-WL_A^3(4L_B + 3L_A)}{24EI}$$
$$\theta_{B,s2} = \frac{-B_y L^2}{2EI}$$
$$V_{s,2} = \frac{-B_y L^3}{3EI}$$
$$\theta_{B,s3} = \frac{-M_B L}{EI}$$
$$V_{B,s3} = \frac{-M_B L^2}{2EI}$$

Compatibility equations [30] referring to the displacement and slope at B, we require:

$$0 = \theta_{B,s1} + \theta_{B,s2} + \theta_{B,s3} \tag{1}$$
$$0 = V_{B,s1} + V_{B,s2} + V_{B,s3} \tag{2}$$

Filling in 1 and 2 we get:

$$-\frac{WL_A^3}{6EI} - \frac{B_y L^2}{2EI} - \frac{M_B L}{EI} = 0 \tag{3}$$
$$-\frac{WL_A^3(4L_B + 3L_A)}{24EI} - \frac{B_y L^3}{3EI} - \frac{M_B L^2}{2EI} = 0 \tag{4}$$

We can rewrite 3:

$$\Rightarrow M_B = -\frac{B_y L}{2} - \frac{WL_A^3}{6L} \tag{5}$$

Filling equation 5 back in 4 gives:

$$-\frac{WL_A^3(4L_B + 3L_A)}{24EI} - \frac{B_y L^3}{3EI} + \frac{L^2}{2EI}\left(\frac{B_y L}{2} + \frac{WL_A^3}{6L}\right) = 0 \tag{6}$$
$$\Rightarrow -\frac{WL_A^3(4L_B + 3L_A)}{24EI} - \frac{B_y L^3}{3EI} + \frac{B_y L^3}{4EI} + \frac{WL_A^3 L}{12EI} = 0 \tag{7}$$
$$\Rightarrow -\frac{WL_A^3(4L_B + 3L_A)}{24EI} - \frac{B_y L^3}{12EI} + \frac{WL_A^3 L}{12EI} = 0 \tag{8}$$
$$\Rightarrow B_y = -\frac{WL_A^3(4L_B + 3L_A - 2L)}{2L^3} = -\frac{WL_A^3}{2L^3}(2L_B + L_A) \tag{9}$$

Filling 9 back in 5 we find the moment in support B:

$$M_B = -\frac{WL_A^3(2L_B + L_A)}{4L^2} - \frac{WL_A^3}{6L} \tag{10}$$
$$\Rightarrow -\frac{WL_A^3}{12L^2}(4L_B + L_A) \tag{11}$$

Following the same procedure (or checking the equilibrium) A_y and M_A can also determined:

$$A_y = -\frac{WL_A}{L^3}\left(L_A L_B^2 + L_B^3 + \frac{L_A^3}{2} + 2L_A^2 L_B + 2L_A L_B^2\right) \tag{12}$$
$$M_A = -\frac{WL_A^2}{12L^2}(L_A^2 + 4L_A L_B + 6L_B^2) \tag{13}$$

Note all the forces and moments have negative value this means they work in opposite direction from that they are drawn.

Appendix D

Analyses concept 1

V-shapes module

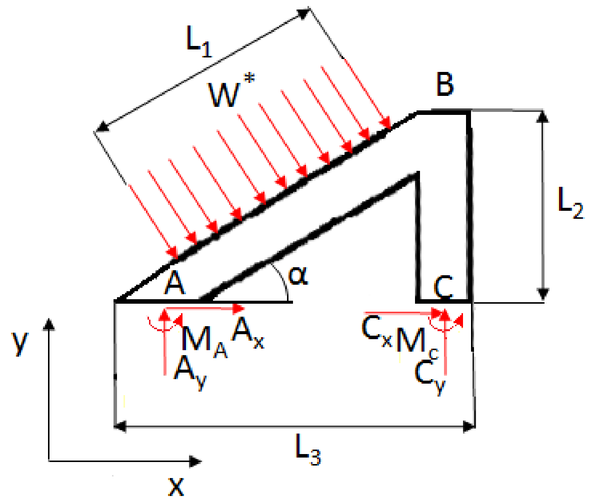


Figure 1: *V-shape modules FBD*

The module is bolted on point A and C and therefore considered fixed on point A and C. This leaves a statical indeterminate solution, in oder to solve this the FBD has to be cut in different pieces. The FBD will be divided in section A-B, B-C and connections A and B. The section B-C will be considered in the cradle bed analyses.

From the table of fixed end moments all the values for the reaction forces can be found so no equations of equilibrium will be needed.

$$A_y^* = B_y^* = \frac{W^* L_1}{2}$$

$$M_A^* = -M_B^* = \frac{W^* L_1^2}{12}$$

Consequently V and M will be:

$$V = A_y - W^* x$$

$$M = M_a - A_y x - \frac{W^*}{2} x^2$$

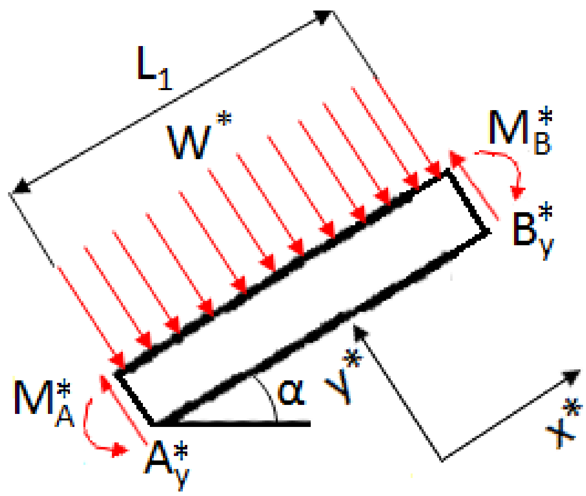


Figure 2: *FBD section A-B*

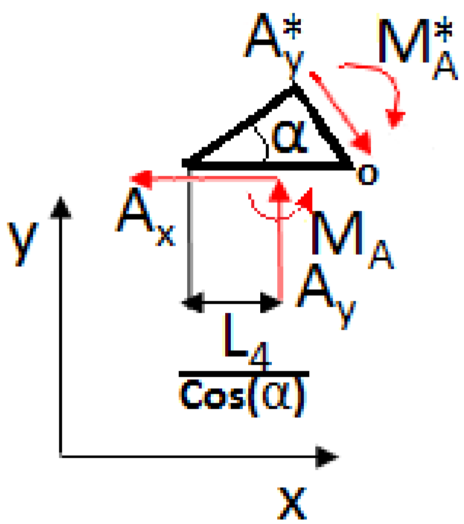


Figure 3: *FBD connection A*

$$\sum F_x = 0 = A_y^* sin(\alpha) - A_x$$

$$\sum F_y = 0 = A_y - A_y^* cos(\alpha))$$

$$\sum M_o = 0 = M_A - M_A^* - A_y \frac{L_4}{cos(\alpha)}$$

$$\Rightarrow A_x = A_y^* sin(\alpha)$$

$$\Rightarrow A_y = A_y^* cos(\alpha)$$

$$\Rightarrow M_A = A_y^* L_4 + M_A^*$$

$$\sum F_x = 0 = B_y^* sin(\alpha) - B_x$$
$$\sum F_y = 0 = B_y - B_y^* cos(\alpha))$$
$$\sum M_o = 0 = M_B - M_B^* - B_y L_4$$
$$\Rightarrow B_x = B_y^* sin(\alpha)$$
$$\Rightarrow B_y = B_y^* cos(\alpha)$$
$$\Rightarrow M_B = B_y^* cos(\alpha) L_4 + M_B*$$

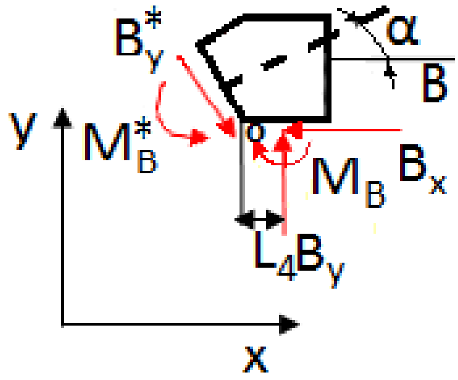


Figure 4: *FBD connection B*

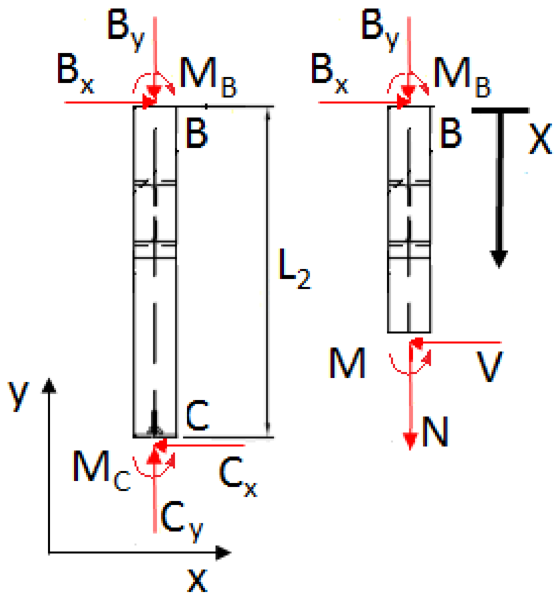


Figure 5: *FBD front cradle section B-C*

From the equilibrium equations follows:

$$C_x = B_x; \qquad C_y = B_y$$
$$\sum M = M_B + B_x L_2 - M_c = 0$$
$$\Rightarrow M_C = M_B + B_x L_2$$

Next the V- and M-equations are derived form the right FBD.

$$V = B_x$$
$$M = M_B + B_x X$$

Cradle bed

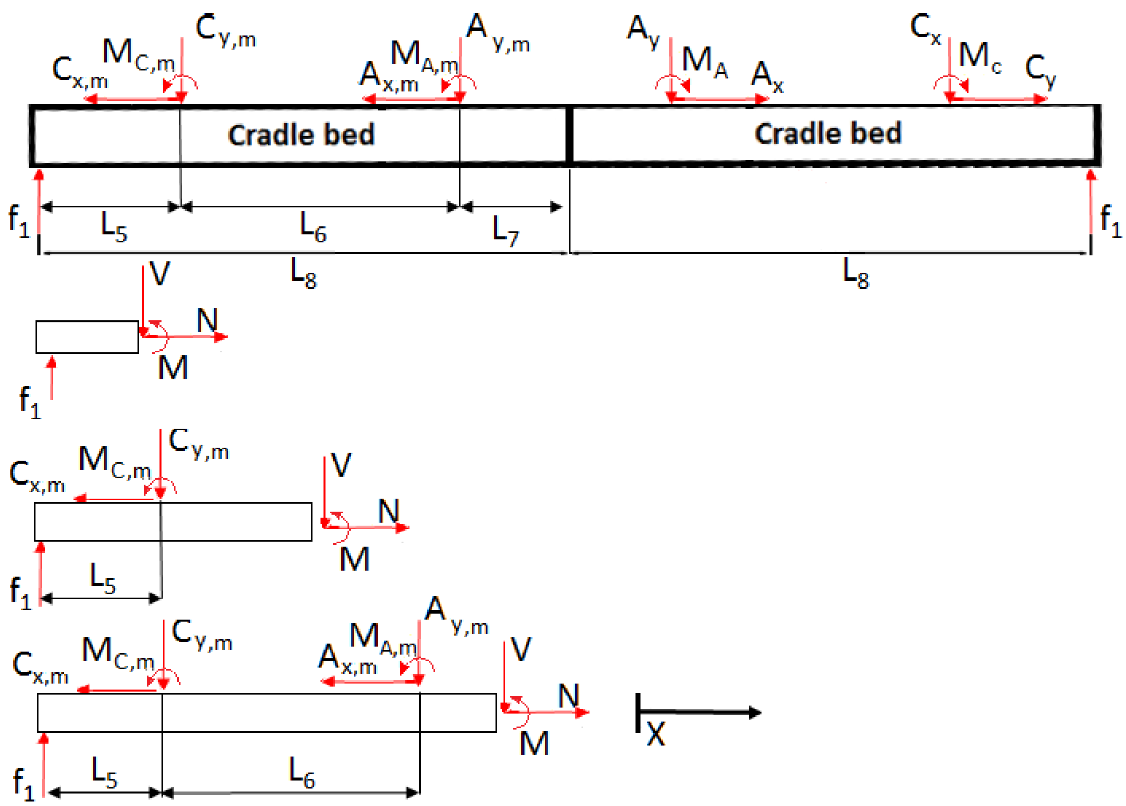


Figure 6: *FBD cradle bed*

$$f_1 = \frac{W}{2}$$
$$L_6 = L_3 - 2L_4$$

$0 \leq x \leq L_5$	$L_5 \leq x \leq L_5 + L_6$	$L_5 + L_6 \leq x \leq L_8 + L_7$
$V = f_1$	$V = f_1 - C_{y,m}$	$V = f_1 - C_{y,m} - A_{y,m}$
$M = f_1 x$	$M = f_1 x - C_{y,m}(x - L_5)$	$M = f_1 x - C_{y,m}(x - L_5) - A_{y,m}(x - L_5 - L_6)$
$N = 0$	$N = C_{x,m}$	$N = C_{x,m} + A_{x,m}$

Analyses concept 2

V-shapes module

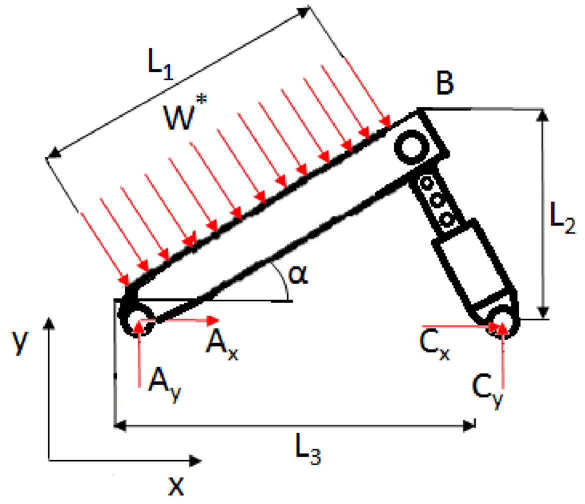


Figure 7: *V-shape modules FBD*

The module is bolted on point A and C and therefore considered fixed on point A and C. This leaves a statical indeterminate solution, in oder to solve this the FBD has to be cut in different pieces. The FBD will be divided in section A-B, B-C and connections A and B. The section B-C will be considered in the cradle bed analyses.

From the table of fixed end moments all the values for the reaction forces can be found so no equations of equilibrium will be needed.

$$\sum F_x = 0 = W^* L_1 sin(\alpha) - A_x + T sin(\beta)$$
$$\sum F_y = 0 = W^* L_1 cos(\alpha) - A_x + T cos(\beta)$$
$$\sum M_A = 0 = W^* \frac{(L_1)^2}{2} - T L_1 cos(\beta - \alpha)$$
$$\Rightarrow T = \frac{W^* L_1}{2cos(\beta - \alpha)}$$

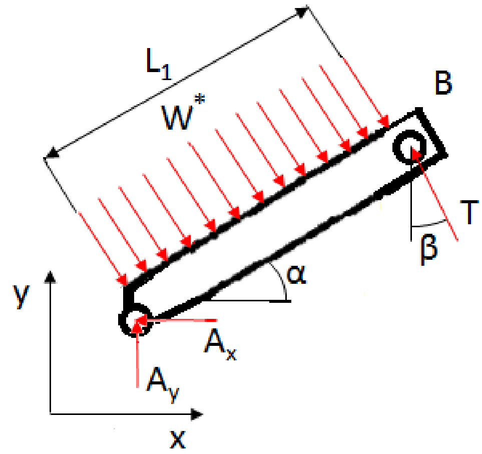


Figure 8: *FBD section A-B*

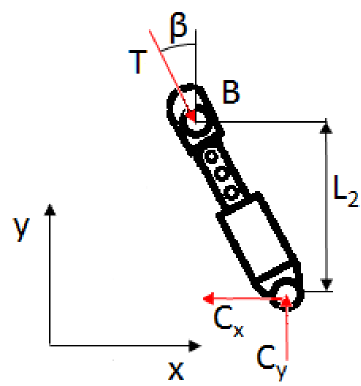


Figure 9: *FBD section B-C*

$$\sum F_x = 0 = T^* sin(\alpha) - C_x$$
$$\sum F_y = 0 = A_y - T cos(\beta))$$
$$\Rightarrow A_x = T sin(\beta)$$
$$\Rightarrow A_y = T cos(\beta)$$

Cradle bed

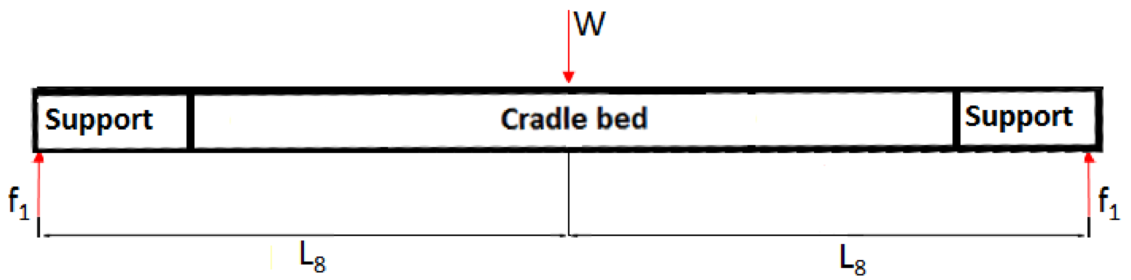


Figure 10: *FBD cradle bed*

$$f_1 = \frac{W}{2} \qquad \begin{aligned} 0 \leq x &\leq L_7 \\ V &= -0.5W \\ M &= 0.5Wx \end{aligned} \qquad \begin{aligned} L_7 \leq x &\leq 2L_7 \\ V &= 0.5W \\ M &= 0.5WL_7 - 0.5W(x - L_7) \end{aligned}$$

Analyses concept 3

Option 1

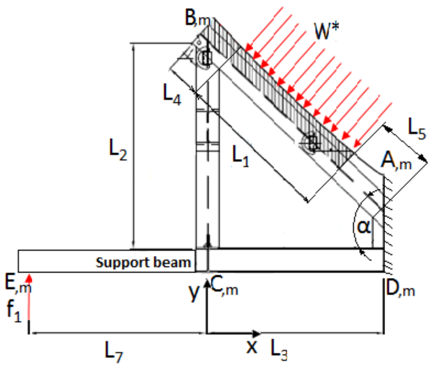


Figure 11: *Cradle scheme symmetric section Concept 1*

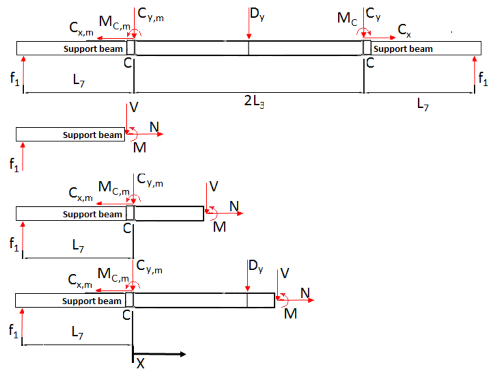


Figure 12: *FBD Beam D-C-E*

Determining the V- and M- diagrams:

for: $-L_7 \leq x < 0$

$$\sum F_y = f_1 - V = 0$$
$$\sum M = f_1 x - M = 0$$
$$N = 0$$
$$V = f_1$$
$$M = f_1|x|$$

for: $0 \leq x < L_3$

$$\sum F_x = C_{x,m} - N = 0$$
$$\sum F_y = f_1 - C_{y,m} - V = 0$$
$$\sum M = M_{C,m} - M + f_1 x - C_{y,m}(x - L_7) = 0$$
$$N = C_{x,m}$$
$$V = f_1 - C_{y,m}$$
$$M = -M_{C,m} + f_1(x + L7) - C_{y,m}(x)$$

Option 2

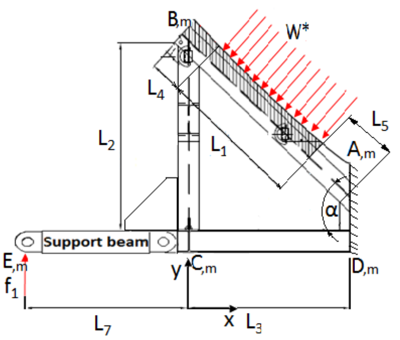


Figure 13: *Cradle scheme symmetric section Concept 1*

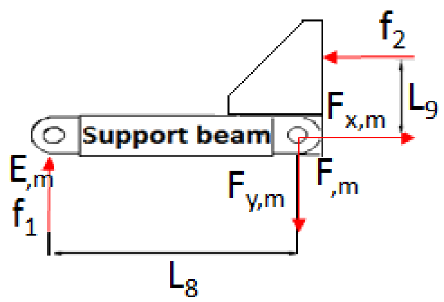


Figure 14: *FBD Beam E-F*

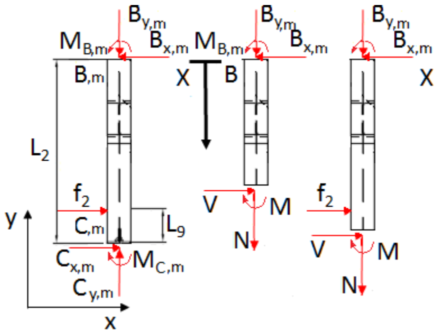


Figure 15: *Cradle scheme symmetric section Concept 1*

Equation of equilibrium beam E-F:

$$\sum F_x = F_{x,m} - f_2 = 0$$
$$\sum F_y = f_1 - F_{y,m} = 0$$
$$\sum M = f_1 L_8 - f_2 L_9 = 0$$
$$F_{x,m} = f_2$$
$$F_{y,m} = f_1$$
$$f_2 = f_1 \frac{L_8}{L_9}$$

Equation of equilibrium beam B-C:

$$\sum F_x = f_2 + C_{x,m} - B_{x,m} = 0$$
$$\sum F_y = C_{y,m} - B_{y,m} = 0$$
$$\sum M = f_2 L_9 + M_{C,m} - B_{x,m} L_2 - M_{B,m} = 0$$
$$C_{x,m} = B_{x,m} - f_1 \frac{L_8}{L_9}$$
$$C_{y,m} = B_{y,m}$$
$$M_{C,m} = B_{x,m} L_2 + M_{B,m} - f_2 L_9$$

Determining the V- and M- diagrams:

for: $0 \leq x < L_2 - L_9$

$$\sum F_x = B_{y,m} - N = 0$$
$$\sum F_y = B_{x,m} - V = 0$$
$$\sum M = B_{x,m} x + M_{b,m} - M = 0$$
$$N = -B_{y,m}$$
$$V = B_{x,m}$$
$$M = B_{x,m} x + M_{b,m}$$

for: $L_2 - L_9 \leq x < L_2$

$$\sum F_y = B_{x,m} - V - f2 = 0$$
$$\sum M = B_{x,m} x + M_{B,m} - M - f2(x - (L_2 - L9)) = 0$$
$$N = -B_{y,m}$$
$$V = B_{x,m} - f_2$$
$$M = B_{x,m} x + M_{b,m} - f_2(x - (L_2 - L_9))$$

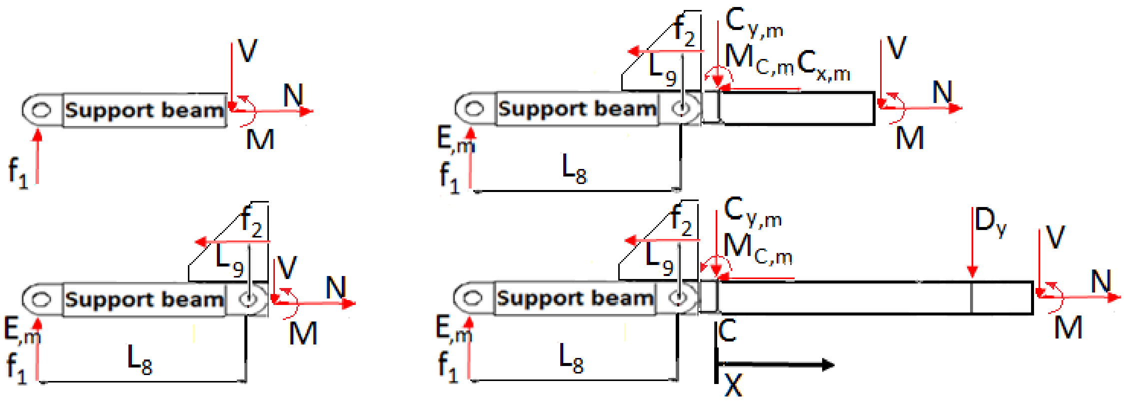


Figure 16: *FBD Beam E-F*

Determining the V- and M- diagrams:

for: $-L_7 \leq x < L_7 - L_8$

$$\sum F_y = f_1 - V = 0$$
$$\sum M = f_1(L_7 - |x|) - M = 0$$
$$N = 0$$
$$V = f_1$$
$$M = f_1(L_7 - |x|)$$

for: $L_7 - L_8 \leq x < 0$

$$\sum F_x = N - f_2 = 0$$
$$\sum F_y = f_1 - V = 0$$
$$\sum M = F_{m,y}((L_7 - L8)) - |x|) - M = 0$$
$$N = f_2$$
$$V = f_1$$
$$M = F_{y,m}((L_7 - L8) - |x|)$$

for: $0 \leq x < L_3$

$$\sum F_x = N - C_{x,m} - f_2 = 0$$
$$\sum F_y = f_1 - C_{y,m} - V = 0$$
$$\sum M = f_1(x + L_7) - M_{C,m} - M - C_{y,m} x = 0$$
$$N = f_2 + C_{x,m}$$
$$V = f_1 - C_{y,m}$$
$$M = F_{y,m}(x + (L_7 - L_8)) - M_{C,m} - C_{y,m} x$$

Option three

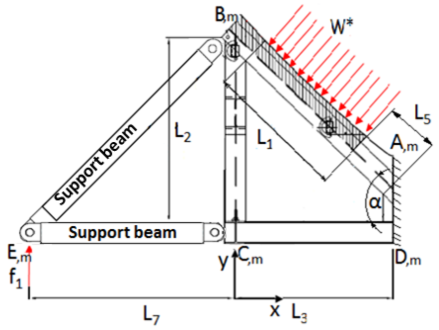


Figure 17: *Cradle scheme symmetric section Concept 1*

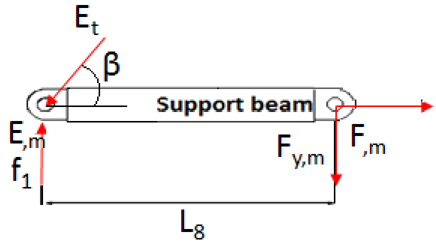


Figure 18: *FBD Beam E-F*

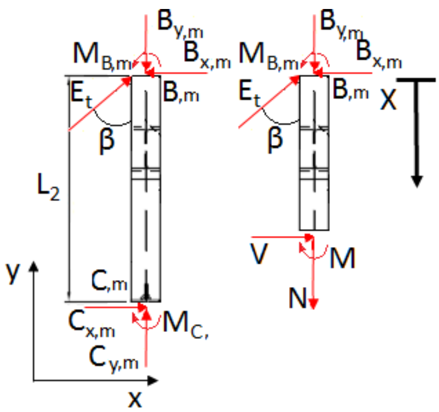


Figure 19: *Cradle scheme symmetric section Concept 1*

Equation of equilibrium beam E-F:

$$\sum F_x = F_{x,m} - E_t cos(\beta) = 0$$

$$\sum F_y = f_1 - F_{y,m} - E_t sin(\beta) = 0$$

$$\sum M = f_1 L_8 - E_t cos(\beta) L_8 = 0$$

$$sin(\beta)\frac{L_2}{\sqrt{L_2^2 + L_8^2}}; cos(\beta) = \frac{L_8}{\sqrt{L_2^2 + L_8^2}};$$

$$F_{x,m} = E_t cos(\beta) = f_1 \frac{L_8}{\sqrt{L_2^2 + L_8^2}}$$

$$F_{y,m} = f_1 - E_t sin(\beta) = 0$$

$$E_t = \frac{f_1}{sin(\beta)} = f_1 \frac{\sqrt{L_2^2 + L_8^2}}{L_2}$$

Equation of equilibrium beam B-C:

$$\sum F_x = E_t cos(\beta) + C_{x,m} - B_{x,m} = 0$$

$$\sum F_y = E_t sin(\beta) + C_{y,m} - B_{y,m} = 0$$

$$\sum M = E_t cos(\beta) L_2 + E_t sin(\beta)(L_7 - L_8) + M_{C,m} - B_{x,m} L_2 - M_{B,m} = 0$$

$$C_{x,m} = B_{x,m} - E_t cos(\beta) = B_{x,m} - f_1 \frac{L_8}{L_2}$$

$$C_{y,m} = B_{y,m} - E_t sin(\beta) = B_{y,m} - f_1$$

$$M_{C,m} = -E_t cos(\beta) L_2 - E_t sin(\beta)(L_7 - L_8) + B_{x,m} L_2 + M_{B,m}$$

$$= -f_1 L_8 - f_1 (L_7 - L_8) + B_{x,m} L_2 + M_{B,m}$$

Determining the V- and M- diagrams:
for: $0 \leq x \leq L_2$

$$\sum F_x = -E_t sin(\beta) + N + B_{y,m} = 0$$

$$\sum F_y = -E_t cos(\beta) + B_{x,m} - V = 0$$

$$\sum M = E_t cos(\beta) x + E_t sin(\beta)(L_7 - L_8) + M - B_{x,m}$$

$$N = E_t sin(\beta) - B_{y,m} = f_1 - B_{y,m}$$

$$V = B_{x,m} - E_t cos(\beta) = B_{x,m} - f_1 \frac{L_8}{L_2}$$

$$M = -E_t cos(\beta) x - E_t sin(\beta)(L_7 - L_8) + B_{x,m} x -$$

$$= -f_1 \frac{L_8}{L_2} x - f_1 (L_7 - L_8) + B_{x,m} x + M_{B,m}$$

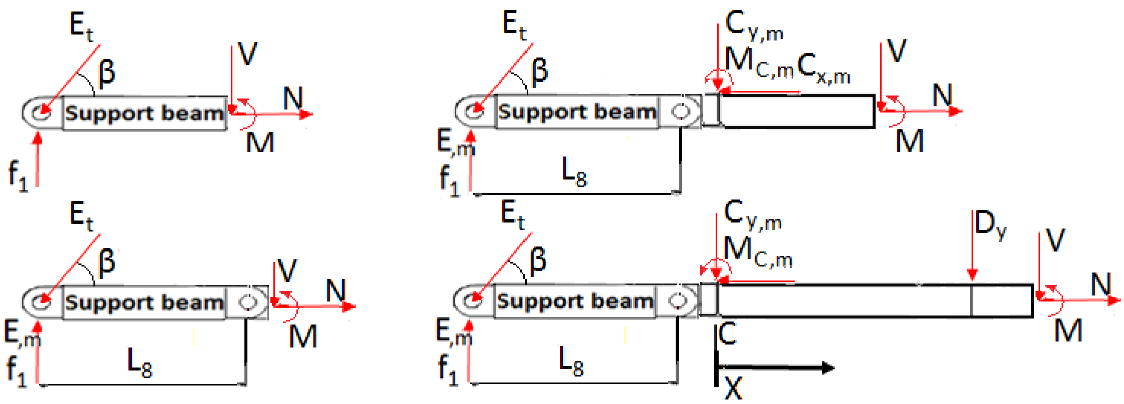


Figure 20: *FBD Beam E-F*

Determining the V- and M- diagrams:

for: $-L_7 \leq x < 0$

$$\sum F_x = N - E_t cos(\beta)$$
$$\sum F_y = f_1 - E_t sin(\beta) - V = 0$$
$$\sum M = f_1(L_7 - |x|) - E_t sin(\beta)(L_7 - |x|) - M = 0$$
$$N = E_t cos(\beta) = f_1 \frac{L_8}{L_2}$$
$$V = f_1 - E_t sin(\beta) = 0$$
$$M = f_1(L_7 - |x|) - E_t sin(\beta)(L_7 - |x|) = 0$$

for: $0 \leq x < L_3$

$$\sum F_x = N - C_{x,m} - E_t cos(\beta) = 0$$
$$\sum F_y = f_1 - E_t sin(\beta) - C_{y,m} - V = 0$$
$$\sum M = f_1(L_7 + x) - E_t sin(\beta)(L_7 + x) - M_{C,m} - C_{Y,m}x - M =$$
$$N = C_{x,m} + E_t cos(\beta)$$
$$V = f_1 - E_t sin(\beta) + C_{y,m} = 0$$
$$M = f_1(L_7 + x) - E_t sin(\beta)(L_7 + x) - M_{C,m} - C_{Y,m}x - M$$

Analyses concept 4

Equation of equilibrium beam E-F:

$$W^* = \frac{w}{2cos(\alpha)}$$

$$\sum F_x^* = W^* cos(\alpha - \beta) - N sin(\alpha - \beta)$$
$$\sum F_y^* = T - W^* sin(\alpha - \beta) - N cos(\alpha - \beta)$$
$$\Rightarrow N = \frac{W^* cos(\alpha - \beta)}{sin(\alpha - \beta)}$$
$$\Rightarrow T = W^*(sin(\alpha - \beta) + \frac{cos^2(\alpha - \beta)}{sin(\alpha - \beta)})$$

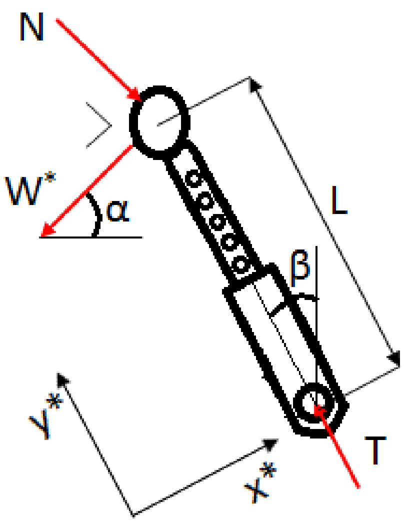


Figure 21: *Cradle scheme symmetric section Concept 1*

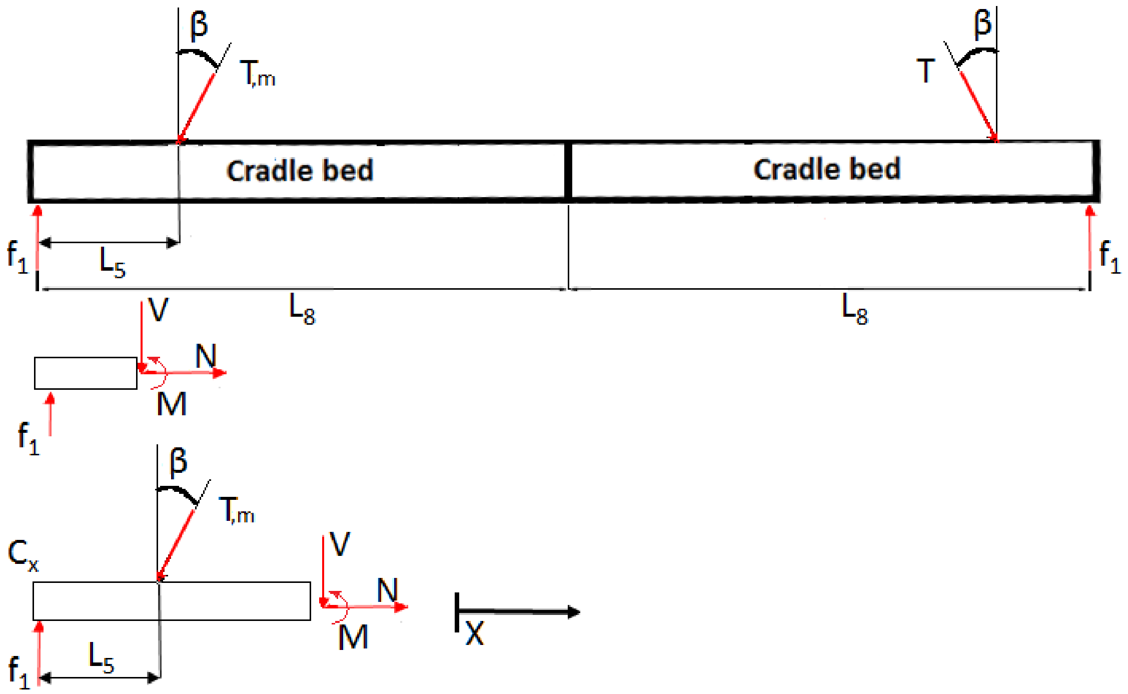


Figure 22: *FBD cradle bed*

$$f_1 = \frac{W}{2}$$

$$L_5 = L_8 - L_3 - L_2 tan(\beta)$$

$0 \leq x \leq L_5$	$L_5 \leq x \leq L_5 + L_6$	$L_5 + L_6 \leq x \leq L_8 + L_7$
$V = f_1$	$V = f_1 - C_{y,m}$	$V = f_1 - C_{y,m} - A_{y,m}$
$M = f_1 x$	$M = f_1 x - C_{y,m}(x - L_5)$	$M = f_1 x - C_{y,m}(x - L_5) - A_{y,m}(x - L_5$
$N = 0$	$N = C_{x,m}$	$N = C_{x,m} + A_{x,m}$

Appendix E

Basic cradle model + Concept 3

```
clc
clear all
close all
% Parameters
L1                  =   5/6;
L2                  =   4/5;
L3                  =   2/3;
L4                  =   1/10;
L5                  =   1/6;
L6                  =   5/42;
L7                  =   7/10;
L8                  =   L7-1/10;
L9                  =   1/3;
alpha               =   45;
Numb                =   10000; % minimum of a 1/1000
%% Matlab script derivation parial uniform distributed load on fixed beam

syms W d L a b L_B L_A
A_y                 =   ((W*d)/L^3)*((2*a+L)*b^2+((a-b)/4)*d^2);
B_y                 =   ((W*d)/L^3)*((2*b+L)*a^2-((a-b)/4)*d^2);
M_A(W,d,L,a,b)      =   ((W*d)/L^2)*(a*b^2+(((a-2*b)*d^2)/12));
M_B(W,d,L,a,b)      =   ((W*d)/L^2)*(a^2*b+(((b-2*a)*d^2)/12));

% Change the measure leaders form the middle of the uniform load to the
% side of the load where L_A is the lenght of the load.
A_y(W,d,L,b)        =   subs(A_y,a,0.5*d+L_A);
A_y(W,d,L,L_B)      =   subs(A_y,b,0.5*d);
A_y(W,L_A,L,L_B)    =   subs(A_y,d,L_B);
A_y                 =   simplify(A_y);

B_y(W,d,L,b)        =   subs(B_y,a,0.5*d+L_A);
B_y(W,d,L,L_B)      =   subs(B_y,b,0.5*d);
B_y(W,L_A,L,L_B)    =   subs(B_y,d,L_B);
B_y                 =   simplify(B_y);

M_A(W,d,L,b)        =   subs(M_A,a,0.5*d+L_A);
M_A(W,d,L,L_B)      =   subs(M_A,b,0.5*d);
M_A(W,L_A,L,L_B)    =   subs(M_A,d,L_B);
M_A                 =   simplify(M_A);

M_B(W,d,L,b)        =   subs(M_B,a,0.5*d+L_A);
M_B(W,d,L,L_B)      =   subs(M_B,b,0.5*d);
M_B(W,L_A,L,L_B)    =   subs(M_B,d,L_B);
M_B                 =   simplify(M_B);

%% Fill in ratios for L_A And L_B to express the eq's in W and L
A_ynew              =   A_y;
A_ynew(W,L,L_B)     =   subs(A_ynew,L_A,(L)*L5);
A_ynew(W,L)         =   subs(A_ynew,L_B,(L)*L1);
A_ynew              =   simplify(A_ynew);

B_ynew              =   B_y;
B_ynew(W,L,L_B)     =   subs(B_ynew,L_A,(L)*L5);
B_ynew(W,L)         =   subs(B_ynew,L_B,(L)*L1);
B_ynew              =   simplify(B_ynew);

M_Anew              =   M_A;
M_Anew(W,L,L_B)     =   subs(M_Anew,L_A,(L)*L5);
M_Anew(W,L)         =   subs(M_Anew,L_B,(L)*L1);
```

```
M_Anew              =   simplify(M_Anew);

M_Bnew              =   M_B;
M_Bnew(W,L,L_B)     =   subs(M_Bnew,L_A,(L)*L5);
M_Bnew(W,L)         =   subs(M_Bnew,L_B,(L)*L1);
M_Bnew              =   simplify(M_Bnew);

%% Create V- and M-diagram for normal situation
% Create real ratios of the forces
A_ynew1(L)          =   subs(A_ynew,W,1);
A_ynew1             =   subs(A_ynew1,L,1);
A_ynew1             =   double(A_ynew1);
B_ynew1(L)          =   subs(B_ynew,W,1);
B_ynew1             =   subs(B_ynew1,L,1);
B_ynew1             =   double(B_ynew1);
% Create real ratios of the moments
M_Anew1(L)          =   subs(M_Anew,W,1);
M_Anew1             =   subs(M_Anew1,L,1);
M_Anew1             =   double(M_Anew1);
M_Bnew1(L)          =   subs(M_Bnew,W,1);
M_Bnew1             =   subs(M_Bnew1,L,1);
M_Bnew1             =   double(M_Bnew1);
% Section A-B
x                   =   0:1/Numb:1;
x2                  =   0:1/Numb:2*L3;
V(x<=L5)            =   A_ynew1;                    % reaction force in point A
V(x>L5)             =   A_ynew1-(x(x>L5)-L5);       % uniform load
V(1)                =   0;
V(length(x))        =   0;

M(x<=L5)            =   -M_Anew1+A_ynew1*x(x<=L5);
M(x>L5)             =   -M_Anew1+A_ynew1*x(x>L5)-0.5*(x(x>L5)-L5).^2;
M(1)                =   0;
M(length(x))        =   0;
% Section B-C
Bx                  =   B_ynew1*sind(alpha);
By                  =   B_ynew1*cosd(alpha);
Mb                  =   B_ynew1*L4/2+M_Bnew1;

V1(x<=L2)           =   Bx;
V1(x>L2)            =   0;
V1(1)               =   0;
V1(length(x))       =   0;

M1(x<=L2)           =   Mb+ Bx*x(x<=L2);
M1(x>L2)            =   0;
M1(1)               =   0;
M1(length(x))       =   0;

N1(x<=L2)           =   -By;
N1(1)               =   0;
N1(x>L2)            =   0;
Cx                  =   Bx;
Cy                  =   By;
Mc                  =   Mb+ Bx*L2;
% Section A-D
Dy                  =   2*A_ynew1*cosd(alpha);
N3(x<=L6)           =   -Dy;
N3(x>L6)            =   0;
N3(1)               =   0;

% Section D-C
f1                  =   (2*Cy+Dy)/2;
V2(x2<=L3)          =   f1-Cy;
V2(x2>L3)           =   f1-Cy-Dy;
V2(1)               =   0;
V2(length(x2))      =   0;
```

```
M2(x2<=L3)            =   -Mc+(f1-Cy)*x2(x2<=L3);
M2(x2>L3)             =   -Mc+(f1-Cy)*x2(x2>L3)-Dy*(x2(x2>L3)-L3);
M2(1)                 =   0;
M2(length(x2))        =   0;


N2(x2<=2*L3)          =   Cx;
N2(1)                 =   0;
N2(length(x2))        =   0;

figure(1)
subplot(3,1,1)
plot(x,V)
hold on
plot(x,V1)
plot(x2,V2)
axis([ -0.1 1.1*2*L3 -1.1*(abs(min([V1 V2 V]))) 1.1*(max([V1 V2 V]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('V/WL')
title('V-diagram')
legend('Section A-B', 'Section B-C','Section C-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off


subplot(3,1,2)
plot(x,M)
hold on
plot(x,M1)
plot(x2,M2)
axis([ -0.1 1.1*2*L3 -1.1*(abs(min([M1 M2 M]))) 1.1*(max([M1 M2 M]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('M/WL^2')
title('M-diagram')
legend('Section A-B', 'Section B-C','Section C-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x,N1)
hold on
plot(x2,N2)
plot(x,N3)
axis([ -0.1 1.1*2*L3 -1.1*(abs(min([N1 N2 N3]))) 1.1*(max([N1 N2 N3]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('N/WL')
title('Normal force')
legend('Section B-C','Section C-D','Section A-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

%% Create V- and M-diagram for concept 1
x3=-L7:1/Numb:L3;
Vcon1(x3<0)              =   f1;
Vcon1(0<=x3)             =   f1-Cy;
Vcon1(1)                 =   0;
Vcon1(length(x3))        =   0;
```

```
Mcon1(x3<0)              =   f1*(L7+x3(x3<0));
Mcon1(0<=x3)             =   f1*(x3(0<=x3)+L7)-Cy*(x3(0<=x3))-Mc;
Mcon1(1)                 =   0;
Mcon1(length(x3))        =   0;

Ncon1(x3<=0)             =   0;
Ncon1(0<=x3)             =   Cx;
Ncon1(1)                 =   0;

%% Create V- and M-diagram for concept 2
% Calculate new forces and moments
f2                       =   f1*L8/L9;
Cxcon2                   =   Bx-f2;
Mccon2                   =   Bx*L2+Mb-f2*L9;
Lnew                     =   L2-L9;

N1con2(x<=L2)            =   -By;
N1con2(1)                =   0;
N1con2(x>L2)             =   0;

V1con2(x<=Lnew)          =   Bx;
V1con2(Lnew<x)           =   Bx-f2;
V1con2(1)                =   0;
V1con2(x>L2)             =   0;

M1con2(x<=Lnew)          =   Mb+ Bx*x(x<=Lnew);
M1con2(Lnew<x)           =   Mb+ Bx*x(Lnew<x)-f2*(x(Lnew<x)-Lnew);
M1con2(1)                =   0;
M1con2(x>L2)             =   0;

N2con2(x3<=(L8-L7))      =   0;
N2con2((L8-L7)<x3   )    =   f2;
N2con2(0<=x3)            =   f2+Cxcon2;
N2con2(length(x3))       =   0;

V2con2(x3<=(L8-L7))      =   f1;
V2con2((L8-L7)<x3)       =   f1;
V2con2(0<=x3)            =   f1-Cy;
V2con2(length(x3))       =   0;

M2con2(x3<=(L8-L7))      =   f1*(L7-abs(x3(x3<=(L8-L7))));
M2con2((L8-L7)<x3)       =   f1*((L7-L8)-abs(x3((L8-L7)<x3)));
M2con2(0<=x3)            =   f1*(x3(0<=x3)+(L7-L8))-Mccon2-Cy*x3(0<=x3);

%% Create V- and M-diagram for concept 3
% Calculate new forces and moments
Et                       =   f1*(L2^2+L^8)/L2^2;
Cxcon3                   =   Bx-f1*L8/L2;
Cycon3                   =   By-f1;
Mccon3                   =   -f1*L8-f1*(L7-L8)+Bx*L2+Mb;

N1con3(x<=L2)            =   f1-By;
N1con3(1)                =   0;
N1con3(x>L2)             =   0;

V1con3(x<=L2)            =   Bx-f1*(L8/L2);
V1con3(1)                =   0;
V1con3(length(x))        =   0;

M1con3(x<=L2)            =   -f1*(L8/L2)*x(x<=L2)-f1*(L7-L8)+Bx*x(x<=L2)+Mb;
M1con3(1)                =   0;
M1con3(length(x))        =   0;

N2con3(x3<=L2)           =   f1*(L8/L2);
N2con3(0<=x3)            =   f1*(L8/L2)+Cxcon3;
```

```
V2con3(x3<=L2)            =   0;
V2con3(0<=x3)             =   f1-f1+Cycon3;
V2con3(length(x3))        =   0;

M2con3(x3<=L2)            =   0;
M2con3(0<=x3)             =   f1*(L7+x3(0<=x3))-f1*(L7+x3(0<=x3))-Mccon3-Cycon3*(x3(0<=x3));
figure(2)
subplot(3,1,1)
plot(x2(x2<=L3),V2(x2<=L3),'r')
hold on
plot(x3,Vcon1,'g')
plot(x3,V2con2,'b')
plot(x3,V2con3,'c')
axis([ -1.1*L7 1.1*L3 1.1*((min([V2 Vcon1 V2con2]))) 1.1*(max([V2 Vcon1 V2con2]))])
plot([-1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('V/WL')
title('V-diagram Section E-C-D')
legend('Normal set', 'Concept 1','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,2)
plot(x2(x2<=L3),M2(x2<=L3),'r')
hold on
plot(x3,Mcon1,'g')
plot(x3,M2con2,'b')
plot(x3,M2con3,'c')
axis([ -1.1*L7 1.1*L3 1.1*((min([M2 Mcon1 M2con2]))) 1.1*(max([M2 Mcon1 M2con2]))])
plot([ -1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('M/WL^2')
title('M-diagram section E-C-D')
legend('Normal set', 'Concept 1','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x2(x2<=L3),N2(x2<=L3),'r')
hold on
plot(x3,Ncon1,'g')
plot(x3,N2con2,'b')
plot(x3,N2con3,'c')
axis([ -1.1*L7 1.1*L3 1.1*((min([N2 Ncon1 N2con2]))) 1.1*(max([N2 Ncon1 N2con2]))])
plot([ -1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('N/WL')
title('Normal force section E-C-D')
legend('Normal set', 'Concept 1','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

figure(3)
subplot(3,1,1)
plot(x,V1,'r')
hold on
plot(x,V1con2,'g')
plot(x,V1con3,'c')
axis([ -0.1 1.1*L2 1.1*((min([V1 V1con2 V1con3]))) 1.1*(max([V1 V1con2 V1con3]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
```

```
xlabel('Unit length of the beam[]')
ylabel('V/WL')
title('V-diagram Section B-C')
legend('Normal set','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,2)
plot(x,M1,'r')
hold on
plot(x,M1con2,'g')
plot(x,M1con3,'c')
axis([ -0.1 1.1*L2 1.1*((min([M1 M1con2 M1con3]))) 1.1*(max([M1 M1con2 M1con2]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('M/WL^2')
title('M-diagram section E-C-D')
legend('Normal set','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x,N1,'r')
hold on
plot(x,N1con2,'g')
plot(x,N1con3,'c')
axis([ -0.1 1.1*L2 1.1*((min([N1 N1con2  N1con3]))) 1.1*(max([N1 N1con2 N1con3]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('N/WL')
title('Normal force section B-C')
legend('Normal set','Concepts 2','Concepts 3')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off
```

.1 Concept 1

```
clc
clear all
close all
% V-shape module
syms w LA L0 theta
Load        =   w*(L0/LA)*sin(theta);
%% FBD A-B rotated axes
syms  W L1
A_yr        =   W*L1/2;
B_yr        =   W*L1/2;
M_Ar        =   W*L1^2/12;
M_Br        =   W*L1^2/12;
%% FBD connection A
syms alpha ax ay ma L4
% equation of equilibruim
F_xA        =   A_yr*sin(alpha)-ax;
F_yA        =   ay-A_yr*cos(alpha);
M_oA        =   ma-M_Ar-ay*L4/cos(alpha);
% Solve values A_X and A_y
A_x         =   solve(F_xA==0,ax);
A_y         =   solve(F_yA==0,ay);
% Subsitute value A_y in moment equation
M_oAsub     =   subs(M_oA,ay,A_y);
% Solve values M_A
M_A         =   solve(M_oAsub==0,ma);
```

```
%% FBD connection B
syms alpha bx by mb
% equation of equilibruim
F_xB        =   B_yr*sin(alpha)-bx;
F_yB        =   by-B_yr*cos(alpha);
M_oB        =   mb-M_Br-by*L4;
% Solve values A_X and A_y
B_x         =   solve(F_xB==0,bx);
B_y         =   solve(F_yB==0,by);
% Subsitute value A_y in moment equation
M_oBsub     =   subs(M_oB,by,B_y);
% Solve values M_b
M_B         =   solve(M_oBsub==0,mb);
%% Create vectors of V- and M-line
% Parameters
L_0         =   3.15;               % Verticle center of mass 3808 (m)
L_A         =   2;                  % Point of engagement with vessel (m)
unit        =   2;
L_1         =   2/unit;             % Length of load distribution (m)
Theta       =   5*pi/180;           % Maximum tilting angle(Rad)
Alpha       =   45*pi/180;          % Angle of  the V-shape modules(Rad)
L_2         =   L_1*sin(Alpha);     % Length of section B-C
W1          =   1;                  % Load of the vessel[kN]
L_4         =   0.125/unit;         % Half of beam width in respect to L_1
L_8         =   7.5/(2*unit);       % Half of cradle length in respect to L_1
L_3         =   L_1*cos(Alpha);     % Indside triangle module
L_6         =   L_3+2*L_4;          % Distance point of engagement
L_7         =   L_8/6;              % Distance module from center
L_5         =   L_8-L_6-L_7;        % Distance module from side
f1          =   W1/2;               % Reaction force
% Subsitute values in earlier dirived equations
Loadsub     =   W1/(2*cos(Alpha));  % Partial load
distribution=   Loadsub/L_1;
A_yrsub     =   subs(A_yr,[L1,W],[L_1,distribution]);
B_yrsub     =   subs(B_yr,[L1,W],[L_1,distribution]);
A_xsub      =   subs(A_x,[L1,W,alpha],[L_1,distribution,Alpha]);
A_ysub      =   subs(A_y,[L1,W,alpha],[L_1,distribution,Alpha]);
B_xsub      =   subs(B_x,[L1,W,alpha],[L_1,distribution,Alpha]);
B_ysub      =   subs(B_y,[L1,W,alpha],[L_1,distribution,Alpha]);
M_Arsub     =   subs(M_Ar,[L1,W],[L_1,distribution]);
M_Brsub     =   subs(M_Br,[L1,W],[L_1,distribution]);
M_Bsub      =   subs(M_B,[L1,W,alpha,L4],[L_1,distribution,Alpha,L_4]);
M_Asub      =   subs(M_A,[L1,W,alpha,L4],[L_1,distribution,Alpha,L_4]);

% Define vector for plotting
int             =   0.01;
x               =   1:(2*L_8/int)+1;
xval            =   0:int:(length(x)-1)*int;
% V and M section A-B
V_AB(x(xval<=L_1))  =   A_yrsub-distribution*xval(xval<=L_1);
V_AB(x(xval>L_1))   =   0;
M_AB(x(xval<=L_1))  =   M_Arsub-A_yrsub*xval(xval<=L_1)+distribution*xval(xval<=L_1).^2/2;

% V, N and M section B-C
V_BC(x(xval<=L_2))  =   B_xsub;
V_BC(x(xval>L_2))   =   0;
C_y                 =   B_ysub;
M_BC(x(xval<=L_2))  =   M_Bsub+B_xsub*xval(xval<=L_2);
M_C                 =   M_Bsub +B_xsub*L_2;


%%
% Cradle bed
V_AC(x(xval<=L_5))          =   f1;
V_AC(x(xval>L_5))           =   f1-C_y;
V_AC(x(xval>L_5+L_6))       =   f1-C_y-A_ysub;
```

```
V_AC(x(xval>L_7+L_8))         =   f1-C_y-2*A_ysub;
V_AC(x(xval>L_6+L_7+L_8))     =   f1-2*C_y-2*A_ysub;
V_AC(x(xval>=2*L_8))          =   0;

M_AC(x(xval<=L_5))            =   f1*xval(xval<=L_5);
M_AC(x(xval>L_5))             =   f1*xval(xval>L_5)-C_y*(xval(xval>L_5)-L_5)-M_C;
M_AC(x(xval>L_5+L_6))         =   f1*xval(xval>L_5+L_6)-C_y*(xval(xval>L_5+L_6)-L_5)-M_C- A_ysub
M_AC(x(xval>L_7+L_8))         =   f1*xval(xval>L_7+L_8)-C_y*(xval(xval>L_7+L_8)-L_5)-M_C- A_ysub
M_AC(x(xval>L_6+L_7+L_8))     =   f1*xval(xval>L_6+L_7+L_8)-C_y*(xval(xval>L_6+L_7+L_8)-L_5)- A_

%% Plot results
 figure(1)
 plot(xval,V_AB)
 hold on
 plot(xval,V_BC)
 plot(xval,V_AC)
 plot([ 0 2.1*L_8], [0 0],'k--')
 plot( [0 0],[ -1.1 1.1],'k--')
 axis([ 0 2.1*L_8 -0.6 0.6])
 legend('Section AB','Section BC','Cradle bed')
 title('V-diagram concept 1')
 xlabel('Unit Length of the beam w.r.t. Length L1[-]')
 ylabel('Unit shear force w.r.t. load W[-]')
 hold off

 figure(2)
 plot(xval(xval<=L_1),M_AB)
 hold on
 plot(xval(xval<=L_2),M_BC)
 plot(xval,M_AC)
 axis([ 0 2.1*L_8 -0.1 0.5])
 plot([ 0 2.1*L_8], [0 0],'k--')
 plot( [0 0],[ -1.1 1.1],'k--')
 legend('Section AB','Section BC', 'Cradle bed')
 xlabel('Unit Length of the beam w.r.t. length L1[-]')
 ylabel('Unit moment w.r.t. load W and length L1 [-]')
 title('M-diagram concept 1')
 hold off
```

Concept 2

```
 clc
 clear all
 close all
% V-shape module
syms w LA L0 theta
Load          =   w*(L0/LA)*sin(theta);
%% FBD section A-B
syms alpha beta W ax ay ma L4 L1 T
% Equation of equilibruim section A-B
F_xA          =   W*L1*sin(alpha)-ax-T*sin(beta);
F_yA          =    ay+T*cos(beta)-W*L1*cos(alpha);
M_oA          =   W*(L1^2)/2-T*L1*cos(alpha-beta);
% Solve the force T in section B-C
Tsol          =    solve(M_oA==0, T);
% Subsitute value T in other equations
F_xAsubs      =    subs(F_xA,T,Tsol);
F_yAsubs      =    subs(F_yA,T,Tsol);
% Solve values A_X and A_y
A_x           =    solve(F_xAsubs ==0,ax);
A_y           =    solve(F_yAsubs ==0,ay);
%% FBD section B-C
syms cx cy
% equation of equilibruim
F_xB          =    Tsol*sin(beta)-cx;
F_yB          =    Tsol*cos(beta)-cy;
% Solve values A_X and A_y
```

```
C_x          =   solve(F_xB==0,cx);
C_y          =   solve(F_yB==0,cy);
%% Create vectors of V- and M-line
% Parameters
L_0          =   3.15;                % Verticle center of mass 3808 (m)
L_A          =   2;                   % Point of engagement with vessel (m)
unit         =   2;
L_1          =   2/unit;              % Length of load distribution (m)
Theta        =   5*pi/180;            % Maximum tilting angle(Rad)
Alpha        =   45*pi/180;           % Angle of  the V-shape modules(Rad)
Beta         =   5*pi/180;            % Angle of section B-C
L_2          =   L_1*sin(Alpha)/cos(Beta);     % Length of section B-C
W1           =   1;                   % Load of the vessel[kN]
L_4          =   0.125/unit;          % Half of beam width in respect to L_1
L_8          =   7.5/(2*unit);        % Half of cradle length in respect to L_1
L_3          =   L_1*cos(Alpha)+L_2*sin(Beta);     % Indside triangle module
L_6          =   L_3+2*L_4;           % Distance point of engagement
L_7          =   L_8/6;               % Distance module from center
L_5          =   L_8-L_6-L_7;         % Distance module from side


% Subsitute values in earlier dirived equations
Loadsub      =   W1;%subs(Load,[L0,LA,theta,w],[L_0,L_A,Theta,W1]);  % Partial load
distribution=    Loadsub/L_1;
A_xsub       =   subs(A_x,[L1,W,alpha,beta],[L_1,distribution,Alpha,Beta]);
A_ysub       =   subs(A_y,[L1,W,alpha,beta],[L_1,distribution,Alpha,Beta]);
Tsub         =   subs(Tsol,[L1,W,alpha,beta],[L_1,distribution,Alpha,Beta]);
C_xsub       =   subs(C_x,[L1,W,alpha,beta],[L_1,distribution,Alpha,Beta]);
C_ysub       =   subs(C_y,[L1,W,alpha,beta],[L_1,distribution,Alpha,Beta]);

f1           =   A_ysub+C_ysub;       % Reaction force (Bulkhead support)
% % Define vector for plotting
int                 =   0.01;
x                   =   1:(2*L_8/int)+1;
xval                =   0:int:(length(x)-1)*int;
% % V and M section A-B
V_AB(x(xval<=L_1))  =   A_ysub*cos(Alpha)+A_xsub*sin(Alpha)-distribution*xval(xval<=L_1);
V_AB(x(xval>L_1))   =   0;
M_AB(x(xval<=L_1))  =  (A_ysub*cos(Alpha)+A_xsub*sin(Alpha))*xval(xval<=L_1)-distribution*xval
% V, N and M section B-C
V_BC(x(xval<=L_2))  =   0;
V_BC(x(xval>L_2))   =   0;
M_BC(x(xval<=L_2))  =   0;
N_BC                =   Tsub;

% V, N and M section A-C
V_AC(x(xval<=L_5))                  =   f1;
V_AC(x(xval>L_5))                   =   f1-C_ysub;
V_AC(x(xval>L_5+L_6))               =   f1-C_ysub-A_ysub;
V_AC(x(xval>L_7+L_8))               =   f1-C_ysub-2*A_ysub;
V_AC(x(xval>L_6+L_7+L_8))           =   f1-2*C_ysub-2*A_ysub;
V_AC(x(xval>=2*L_8))                =   0;

M_AC(x(xval<=L_5))              =   f1*xval(xval<=L_5);
M_AC(x(xval>L_5))               =   f1*xval(xval>L_5)-C_ysub*(xval(xval>L_5)-L_5);
M_AC(x(xval>L_5+L_6))           =   f1*xval(xval>L_5+L_6)-C_ysub*(xval(xval>L_5+L_6)-L_5)-  A_ysub*
M_AC(x(xval>L_7+L_8))           =   f1*xval(xval>L_7+L_8)-C_ysub*(xval(xval>L_7+L_8)-L_5)-  A_ysub*
M_AC(x(xval>L_6+L_7+L_8))       =   f1*xval(xval>L_6+L_7+L_8)-C_ysub*(xval(xval>L_6+L_7+L_8)-L_5)-


%% Plot results
figure(1)
plot(xval,V_AB)
hold on
plot(xval,V_BC)
plot(xval,V_AC)
plot([ 0  2.1*L_8], [0  0],'k--')
```

```
plot( [0 0],[ -1.1 1.1],'k--')
axis([ 0 2.1*L_8 -0.8 0.8])
legend('Section AB','Section BC','Cradle bed')
title('V-diagram concept 2 bulkhead support')
xlabel('Unit Length of the beam w.r.t. Length L1[-]')
ylabel('Unit shear force w.r.t. load W[-]')
hold off

figure(2)
plot(xval(xval<=L_1),M_AB)
hold on
plot(xval(xval<=L_2),M_BC)
plot(xval,M_AC)
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
axis([ 0 2.1*L_8 0 0.6])
legend('Section AB','Section BC', 'Cradle bed')
xlabel('Unit Length of the beam w.r.t. length L1[-]')
ylabel('Unit moment w.r.t. load W and length L1 [-]')
title('M-diagram concept 2 bulkhead support')
hold off
```

Concept 4

```
clc
clear all
close all

syms w alpha beta t n
% Equilibrium equations
W        =   w/2*cos(alpha);
Fy       =   w*cos(alpha-beta)-n*sin(alpha-beta);
Fx       =   t-w*sin(alpha-beta)-n*cos(alpha-beta);

N        =   solve(Fy ==0,n);

Fysubs   =   subs(Fx,n,N);
T        =   solve(Fysubs ==0,t);
Tsubs    =   subs(T, w,W);

% Parameters
Alpha    =   45*pi/180;
xval     =   1:45;
Beta     =   15*pi/180;
W1       =   1;
unit          =   2;
L_1           =   2/unit;
L_2           =   3.0/unit;
L_3           =   (2.7/unit);
L_8           =   3.75/unit;
L5            =   L_8-L_3-L_2*tan(beta);
% forces in section A-B
Tnew     =   subs(Tsubs,[ alpha w],[Alpha W1]);
Nnew     =   subs(N,[ alpha w],[Alpha W1]);
% Maximum internal forces and moment in section E-C-B
N_ecb         =   sin(beta)*Tnew;
V_ecb         =   cos(beta)*Tnew;
M_ecb         =   cos(beta)*Tnew*L5;

% Reaction force
Texact        =   subs(Tsubs,[ alpha w beta],[Alpha W1 Beta]);
f1            =   vpa(cos(Beta)*Texact);
W1            =   vpa(cos(Beta)*Texact);
L_5           =   vpa(L_8-L_3-L_2*tan(Beta));
int           =   0.01;
x             =   1:(2*L_8/int)+1;
xval1         =   0:int:(length(x)-1)*int;
```

```
% Create N,V and M-line vectors
V_AC(x(xval1<=L_5))              =    f1;
V_AC(x(xval1>L_5))               =    f1-W1;
V_AC(x(xval1>=2*L_8-L_5))        =    f1-2*W1;
V_AC(x(xval1>=2*L_8))            =    0;

M_AC(x(xval1<=L_5))              =    f1*xval1(xval1<=L_5);
M_AC(x(xval1>L_5))               =    f1*xval1(xval1>L_5)-W1*(xval1(xval1>L_5)-L_5);
M_AC(x(xval1>(2*L_8-L_5)))       =    f1*xval1(xval1>(2*L_8-L_5))-W1*(xval1(xval1>(2*L_8-L_5))-L

figure(1)
ezplot(Tnew,[0, length(xval)*pi/180])
hold on
ezplot(Nnew,[0, length(xval)*pi/180])
axis([ 0 0.8 0 18])
legend('Load through the beam(T)','Load on ship(N)')
title('Load of section A-B with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(2)
ezplot(L5,[0, length(xval)*pi/180])
hold on
title('Length L5 with rotation beta ')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(3)
ezplot(M_ecb,[0, length(xval)*pi/180])
hold on
axis([ 0 0.8 0 0.5])
legend('Moment[-]')
title('Maximum moment with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(4)
ezplot(N_ecb,[0, length(xval)*pi/180])
hold on
ezplot(V_ecb,[0, length(xval)*pi/180])
axis([ 0 0.8 0 18])
legend('Normal','Shear')
title('Maximum unit internal forces w.r.t. W')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(5)
plot(xval1,V_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
axis([ 0 2.1*L_8 -0.8 0.8])
title('V-diagram concept 4')
xlabel('Unit Length of the beam w.r.t. Length L1[-]')
ylabel('Unit shear force w.r.t. load W[-]')
hold off

figure(6)
plot(xval1,M_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -0.1 1.1],'k--')
```

```
%axis([ 0 2.1*L_8 -0.1 0.5])
xlabel('Unit Length of the beam w.r.t. length L1[-]')
ylabel('Unit moment w.r.t. load W and length L1 [-]')
title('M-diagram concept 4')
hold off
```

Concept 5

```
clc
clear all
close all

syms w alpha beta t n
% Equilibrium equations
W       =   w/2*cos(alpha);
Fy      =   w*cos(alpha-beta)-n*sin(alpha-beta);
Fx      =   t-w*sin(alpha-beta)-n*cos(alpha-beta);

N       =   solve(Fy ==0,n);

Fysubs  =   subs(Fx,n,N);
T       =   solve(Fysubs ==0,t);
Tsubs   =   subs(T, w,W);

% Parameters
Alpha   =   45*pi/180;
xval    =   1:45;
Beta    =   15*pi/180;
W1      =   1;
unit        =   2;
L_1         =   2/unit;
L_2         =   3.0/unit;
L_3         =   (2.7/unit);
L_8         =   3.75/unit;
L5          =   L_8-L_3-L_2*tan(beta);
% forces in section A-B
Tnew    =   subs(Tsubs,[ alpha w],[Alpha W1]);
Nnew    =   subs(N,[ alpha w],[Alpha W1]);
% Maximum internal forces and moment in section E-C-B
N_ecb       =   sin(beta)*Tnew;
V_ecb       =   cos(beta)*Tnew;
M_ecb       =   cos(beta)*Tnew*L5;

% Reaction force
Texact      =   subs(Tsubs,[ alpha w beta],[Alpha W1 Beta]);
f1          =   vpa(cos(Beta)*Texact);
W1          =   vpa(cos(Beta)*Texact);
L_5         =   vpa(L_8-L_3-L_2*tan(Beta));
int         =   0.01;
x           =   1:(2*L_8/int)+1;
xval1       =   0:int:(length(x)-1)*int;

% Create N,V and M-line vectors
V_AC(x(xval1<=L_5))             =   f1;
V_AC(x(xval1>L_5))              =   f1-W1;
V_AC(x(xval1>=2*L_8-L_5))       =   f1-2*W1;
V_AC(x(xval1>=2*L_8))           =   0;

M_AC(x(xval1<=L_5))             =   f1*xval1(xval1<=L_5);
M_AC(x(xval1>L_5))              =   f1*xval1(xval1>L_5)-W1*(xval1(xval1>L_5)-L_5);
M_AC(x(xval1>(2*L_8-L_5)))      =   f1*xval1(xval1>(2*L_8-L_5))-W1*(xval1(xval1>(2*L_8-L_5))-L

figure(1)
ezplot(Tnew,[0, length(xval)*pi/180])
hold on
ezplot(Nnew,[0, length(xval)*pi/180])
axis([ 0 0.8 0 18])
```

```
legend('Load through the beam(T)','Load on ship(N)')
title('Load of section A-B with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(2)
ezplot(L5,[0, length(xval)*pi/180])
hold on
title('Length L5 with rotation beta ')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(3)
ezplot(M_ecb,[0, length(xval)*pi/180])
hold on
axis([ 0 0.8 0 0.5])
legend('Moment[-]')
title('Maximum moment with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(4)
ezplot(N_ecb,[0, length(xval)*pi/180])
hold on
ezplot(V_ecb,[0, length(xval)*pi/180])
axis([ 0 0.8 0 18])
legend('Normal','Shear')
title('Maximum unit internal forces w.r.t. W')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(5)
plot(xval1,V_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
axis([ 0 2.1*L_8 -0.8 0.8])
title('V-diagram concept 4')
xlabel('Unit Length of the beam w.r.t. Length L1[-]')
ylabel('Unit shear force w.r.t. load W[-]')
hold off

figure(6)
plot(xval1,M_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -0.1 1.1],'k--')
%axis([ 0 2.1*L_8 -0.1 0.5])
xlabel('Unit Length of the beam w.r.t. length L1[-]')
ylabel('Unit moment w.r.t. load W and length L1 [-]')
title('M-diagram concept 4')
hold off
```

Concept 5

```
clc
clear all
close all
% Parameters
L_1                    =    5/6;
L_2                    =    4/5;
L_3                    =    2/3;
L_4                    =    1/10;
```

```
L_5                     =    0;
L_6                     =    5/42;
L_7                     =    7/10;
L_8                     =    L_7-1/10;
L_9                     =    1/3;
% Creating unit vectors w.r.t. L_1
L1                      =    L_1/L_1;
L2                      =    L_2/L_1;
L3                      =    L_3/L_1;
L4                      =    L_4/L_1;
L5                      =    L_5/L_1;
L6                      =    L_6/L_1;
L7                      =    L_7/L_1;
L8                      =    L_8/L_1;
L9                      =    L_9/L_1;

alpha                   =    45;
Numb                    =    10000; % minimum of a 1/1000
%% Matlab script derivation partial uniform distributed load on fixed beam

syms W d L a b L_B L_A
A_y                     =    ((W*d)/L^3)*((2*a+L)*b^2+((a-b)/4)*d^2);
B_y                     =    ((W*d)/L^3)*((2*b+L)*a^2-((a-b)/4)*d^2);
M_A(W,d,L,a,b)          =    ((W*d)/L^2)*(a*b^2+(((a-2*b)*d^2)/12));
M_B(W,d,L,a,b)          =    ((W*d)/L^2)*(a^2*b+(((b-2*a)*d^2)/12));

% Change the measure leaders form the middle of the uniform load to the
% side of the load where L_A is the lenght of the load.
A_y(W,d,L,b)            =    subs(A_y,a,0.5*d+L_A);
A_y(W,d,L,L_B)          =    subs(A_y,b,0.5*d);
A_y(W,L_A,L,L_B)        =    subs(A_y,d,L_B);
A_y                     =    simplify(A_y);

B_y(W,d,L,b)            =    subs(B_y,a,0.5*d+L_A);
B_y(W,d,L,L_B)          =    subs(B_y,b,0.5*d);
B_y(W,L_A,L,L_B)        =    subs(B_y,d,L_B);
B_y                     =    simplify(B_y);

M_A(W,d,L,b)            =    subs(M_A,a,0.5*d+L_A);
M_A(W,d,L,L_B)          =    subs(M_A,b,0.5*d);
M_A(W,L_A,L,L_B)        =    subs(M_A,d,L_B);
M_A                     =    simplify(M_A);

M_B(W,d,L,b)            =    subs(M_B,a,0.5*d+L_A);
M_B(W,d,L,L_B)          =    subs(M_B,b,0.5*d);
M_B(W,L_A,L,L_B)        =    subs(M_B,d,L_B);
M_B                     =    simplify(M_B);

%% Fill in ratios for L_A And L_B to express the eq's in W and L
A_ynew                  =    A_y;
A_ynew(W,L,L_B)         =    subs(A_ynew,L_A,L5);
A_ynew(W,L)             =    subs(A_ynew,L_B,L1);
A_ynew                  =    simplify(A_ynew);

B_ynew                  =    B_y;
B_ynew(W,L,L_B)         =    subs(B_ynew,L_A,L5);
B_ynew(W,L)             =    subs(B_ynew,L_B,L1);
B_ynew                  =    simplify(B_ynew);

M_Anew                  =    M_A;
M_Anew(W,L,L_B)         =    subs(M_Anew,L_A,L5);
M_Anew(W,L)             =    subs(M_Anew,L_B,L1);
M_Anew                  =    simplify(M_Anew);

M_Bnew                  =    M_B;
M_Bnew(W,L,L_B)         =    subs(M_Bnew,L_A,L5);
M_Bnew(W,L)             =    subs(M_Bnew,L_B,L1);
```

```
M_Bnew                  =   simplify(M_Bnew);

%% Create V- and M-diagram for normal situation
W1            = 1;
Loadsub       =  W1/(2*cosd(alpha))/L1;
% Create real ratios of the forces
A_ynew1(L)              =   subs(A_ynew,W,Loadsub);
A_ynew1                 =   subs(A_ynew1,L,L5+L1);
A_ynew1                 =   double(A_ynew1);
B_ynew1(L)              =   subs(B_ynew,W,Loadsub);
B_ynew1                 =   subs(B_ynew1,L,L5+L1);
B_ynew1                 =   double(B_ynew1);
% Create real ratios of the moments
M_Anew1(L)              =   subs(M_Anew,W,Loadsub);
M_Anew1                 =   subs(M_Anew1,L,L5+L1);
M_Anew1                 =   double(M_Anew1);
M_Bnew1(L)              =   subs(M_Bnew,W,Loadsub);
M_Bnew1                 =   subs(M_Bnew1,L,L5+L1);
M_Bnew1                 =   double(M_Bnew1);
% Section A-B
x                       =   0:1/Numb:1;
x2                      =   0:1/Numb:2*L3;
V(x<=L1+L5)             =   A_ynew1;                         % reaction force in point A
V(x>L5)                 =   A_ynew1-(x(x>L5)-L5)*Loadsub;           % uniform load
V(1)                    =   0;
V(length(x))            =   0;

M(x<=L1+L5)             =   -M_Anew1+A_ynew1*x(x<=L5);
M(x>L5)                 =   -M_Anew1+A_ynew1*x(x>L5)-0.5*(x(x>L5)-L5).^2*Loadsub;
M(1)                    =   0;
M(length(x))            =   0;
% Section B-C
Bx                      =   B_ynew1*sind(alpha);
By                      =   B_ynew1*cosd(alpha);
Mb                      =   B_ynew1*L4/2+M_Bnew1;

V1(x<=L2)               =   Bx;
V1(x>L2)                =   0;
V1(1)                   =   0;
V1(length(x))           =   0;

M1(x<=L2)               =   Mb+ Bx*x(x<=L2);
M1(x>L2)                =   0;
M1(1)                   =   0;
M1(length(x))           =   0;

N1(x<=L2)               =   -By;
N1(1)                   =   0;
N1(x>L2)                =   0;
Cx                      =   Bx;
Cy                      =   By;
Mc                      =   Mb+ Bx*L2;
% Section A-D
Dy                      =   2*A_ynew1*cosd(alpha);
N3(x<=L6)               =   -Dy;
N3(x>L6)                =   0;
N3(1)                   =   0;

% Section D-C
f1                      =   (2*Cy+Dy)/2;
V2(x2<=L3)              =   f1-Cy;
V2(x2>L3)               =   f1-Cy-Dy;
V2(1)                   =   0;
V2(length(x2))          =   0;

M2(x2<=L3)              =   -Mc+(f1-Cy)*x2(x2<=L3);
M2(x2>L3)               =   -Mc+(f1-Cy)*x2(x2>L3)-Dy*(x2(x2>L3)-L3);
```

```
M2(1)                =    0;
M2(length(x2))       =    0;


N2(x2<=2*L3)         =    Cx;
N2(1)                =    0;
N2(length(x2))       =    0;

figure(1)
subplot(3,1,1)
plot(x,V)
hold on
plot(x,V1)
plot(x2,V2)
axis([ 0 1.1*2*L3 -1.2*(abs(min([V1 V2 V]))) 1.2*(max([V1 V2 V]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit s-force')
title('V-diagram')
legend('Section A-B', 'Section B-C','Section C-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off


subplot(3,1,2)
plot(x,M)
hold on
plot(x,M1)
plot(x2,M2)
axis([ 0 1.1*2*L3 -1.2*(abs(min([M1 M2 M]))) 1.2*(max([M1 M2 M]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit moment')
title('M-diagram')
legend('Section A-B', 'Section B-C','Section C-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x,N1)
hold on
plot(x2,N2)
plot(x,N3)
axis([ 0 1.1*2*L3 -1.2*(abs(min([N1 N2 N3]))) 1.2*(max([N1 N2 N3]))])
plot([ -0.1 1.1*2*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit n-force')
title('Normal force')
legend('Section B-C','Section C-D','Section A-D')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

%% Create V- and M-diagram for concept 1
x3=-L7:1/Numb:L3;
Vcon1(x3<0)              =    f1;
Vcon1(0<=x3)             =    f1-Cy;
Vcon1(1)                 =    0;
Vcon1(length(x3))        =    0;

Mcon1(x3<0)              =    f1*(L7+x3(x3<0));
Mcon1(0<=x3)             =    f1*(x3(0<=x3)+L7)-Cy*(x3(0<=x3))-Mc;
```

```
Mcon1(1)                    =    0;
Mcon1(length(x3))           =    0;

Ncon1(x3<=0)                =    0;
Ncon1(0<=x3)                =    Cx;
Ncon1(1)                    =    0;

%% Create V- and M-diagram for concept 2
% Calculate new forces and moments
f2                          =    f1*L8/L9;
Cxcon2                      =    Bx-f2;
Mccon2                      =    Bx*L2+Mb-f2*L9;
Lnew                        =    L2-L9;

N1con2(x<=L2)               =    -By;
N1con2(1)                   =    0;
N1con2(x>L2)                =    0;

V1con2(x<=Lnew)             =    Bx;
V1con2(Lnew<x)              =    Bx-f2;
V1con2(1)                   =    0;
V1con2(x>L2)                =    0;

M1con2(x<=Lnew)             =    Mb+ Bx*x(x<=Lnew);
M1con2(Lnew<x)              =    Mb+ Bx*x(Lnew<x)-f2*(x(Lnew<x)-Lnew);
M1con2(1)                   =    0;
M1con2(x>L2)                =    0;

N2con2(x3<=(L8-L7))         =    0;
N2con2((L8-L7)<x3   )       =    f2;
N2con2(0<=x3)               =    f2+Cxcon2;
N2con2(length(x3))          =    0;

V2con2(x3<=(L8-L7))         =    f1;
V2con2((L8-L7)<x3)          =    f1;
V2con2(0<=x3)               =    f1-Cy;
V2con2(length(x3))          =    0;

M2con2(x3<=(L8-L7))         =    f1*(L7-abs(x3(x3<=(L8-L7))));
M2con2((L8-L7)<x3)          =    f1*((L7-L8)-abs(x3((L8-L7)<x3)));
M2con2(0<=x3)               =    f1*(x3(0<=x3)+(L7-L8))-Mccon2-Cy*x3(0<=x3);

%% Create V- and M-diagram for concept 3
% Calculate new forces and moments
Et                          =    f1*(L2^2+L^8)/L2^2;
Cxcon3                      =    Bx-f1*L8/L2;
Cycon3                      =    By-f1;
Mccon3                      =    -f1*L8-f1*(L7-L8)+Bx*L2+Mb;

N1con3(x<=L2)               =    f1-By;
N1con3(1)                   =    0;
N1con3(x>L2)                =    0;

V1con3(x<=L2)               =    Bx-f1*(L8/L2);
V1con3(1)                   =    0;
V1con3(length(x))           =    0;

M1con3(x<=L2)               =    -f1*(L8/L2)*x(x<=L2)-f1*(L7-L8)+Bx*x(x<=L2)+Mb;
M1con3(1)                   =    0;
M1con3(length(x))           =    0;

N2con3(x3<=L2)              =    f1*(L8/L2);
N2con3(0<=x3)               =    f1*(L8/L2)+Cxcon3;

V2con3(x3<=L2)              =    0;
V2con3(0<=x3)               =    f1-f1+Cycon3;
V2con3(length(x3))          =    0;
```

```
M2con3(x3<=L2)              =    0;
M2con3(0<=x3)               =    f1*(L7+x3(0<=x3))-f1*(L7+x3(0<=x3))-Mccon3-Cycon3*(x3(0<=x3));
figure(2)
subplot(3,1,1)
plot(x2(x2<=L3),V2(x2<=L3))
hold on
plot(x3,V2con2)
plot(x3,V2con3)
axis([ -L7 1.1*L3 1.2*((min([V2 Vcon1 V2con2]))) 1.2*(max([V2 Vcon1 V2con2]))])
plot([-1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit v-force')
title('V-diagram Section E-C-D')
legend('Normal set','Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,2)
plot(x2(x2<=L3),M2(x2<=L3))
hold on
plot(x3,M2con2)
plot(x3,M2con3)
axis([ -L7 1.1*L3 1.2*((min([M2 Mcon1 M2con2]))) 1.2*(max([M2 Mcon1 M2con2]))])
plot([ -1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit moment')
title('M-diagram section E-C-D')
legend('Normal set', 'Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x2(x2<=L3),N2(x2<=L3))
hold on
plot(x3,N2con2)
plot(x3,N2con3)
axis([ -L7 1.1*L3 1.2*((min([N2 Ncon1 N2con2]))) 1.2*(max([N2 Ncon1 N2con2]))])
plot([ -1.1*L7 1.1*L3], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit n-force')
title('Normal force section E-C-D')
legend('Normal set', 'Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

figure(3)
subplot(3,1,1)
plot(x,V1)
hold on
plot(x,V1con2)
plot(x,V1con3)
axis([ 0 1.1*L2 1.2*((min([V1 V1con2 V1con3]))) 1.2*(max([V1 V1con2 V1con3]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit s-force')
title('V-diagram Section B-C')
legend('Normal set','Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
```

```
hold off

subplot(3,1,2)
plot(x,M1)
hold on
plot(x,M1con2)
plot(x,M1con3)
axis([ 0 1.1*L2 1.1*((min([M1 M1con2 M1con3]))) 1.1*(max([M1 M1con2 M1con2]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit moment')
title('M-diagram section B-C')
legend('Normal set','Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off

subplot(3,1,3)
plot(x,N1)
hold on
plot(x,N1con2)
plot(x,N1con3)
axis([ 0 1.1*L2 1.2*((min([N1 N1con2  N1con3]))) 1.2*(max([N1 N1con2 N1con3]))])
plot([ -0.1 1.1*L2], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
xlabel('Unit length of the beam[]')
ylabel('Unit n-force')
title('Normal force section B-C')
legend('Normal set','Option 1','Option 2')
lh=findall(gcf,'tag','legend');
set(lh,'location','northeastoutside');
hold off
```

Profiles

```
clc
clear all
close all
% Parameters
b               =   0.250;
t               =   0.02;
r0              =   b/2;
ri              =   b/2-t;
h               =   b;
hin             =   h-2*t;
bin             =   b-2*t;
%  Second moment of inertia
Icyc            =   (pi*(r0^4-ri^4))/4;
Irect           =   (1/12)*(b*h^3-bin*hin^3);
IIbeam          =   1/12*t*hin^3+2*(1/12*b*t^3+b*t*((h-t)/2)^2);
IUbeam          =   2/12*t*hin^3+1*(1/12*b*t^3+b*t*((h-t)/2)^2);
% Surfaces
Acys            =   pi*(r0^2-ri^2);
Arect           =   h*b-(h-2*t)*(b-2*t);
AIbeam          =   2*b*t+h*t;
AUbeam          =   2*h*t+b*t;
% Ratios
Ratiocys        =   Icyc/Acys;
Rationrect      =   Irect/Arect;
RatioIbeam      =   IIbeam/AIbeam;
RatioUbeam      =   IUbeam/AUbeam;
```

Final design front cradle

```
clc
clear all
close all
```

```
syms w alpha beta t n
% Equilibrium equations
W        =   w/2*cos(alpha);
Fy       =   w*cos(alpha-beta)-n*sin(alpha-beta);
Fx       =   t-w*sin(alpha-beta)-n*cos(alpha-beta);

N        =   solve(Fy ==0,n);

Fysubs   =   subs(Fx,n,N);
T        =   solve(Fysubs ==0,t);
Tsubs    =   subs(T, w,W);

% Parameters
Alpha    =   45*pi/180;
xval     =   1:45;
Beta     =   15*pi/180;
W1       =   1; % load front cradle
unit          =   2;
L_1           =   2/unit;
L_2           =   3/unit;
L_3           =   (2.7/unit);
L_8           =   3.75/unit;
L5            =   L_8-L_3-L_2*tan(beta);
% forces in section A-B
Tnew     =   subs(Tsubs,[ alpha w],[Alpha W1]);
Nnew     =   subs(N,[ alpha w],[Alpha W1]);
% Maximum internal forces and moment in section E-C-B
N_ecb         =   sin(beta)*Tnew;
V_ecb         =   cos(beta)*Tnew;
M_ecb         =   cos(beta)*Tnew*L5;

% Reaction force
Texact        =   subs(Tsubs,[ alpha w beta],[Alpha W1 Beta]);
f1            =   vpa(cos(Beta)*Texact);
W1            =   vpa(cos(Beta)*Texact);
L_5           =   vpa(L_8-L_3-L_2*tan(Beta));
int           =   0.01;
x             =   1:(2*L_8/int)+1;
xval1         =   0:int:(length(x)-1)*int;

% Create N,V and M-line vectors
V_AC(x(xval1<=L_5))                =   f1;
V_AC(x(xval1>L_5))                 =   f1-W1;
V_AC(x(xval1>=2*L_8-L_5))          =   f1-2*W1;
V_AC(x(xval1>=2*L_8))              =   0;

M_AC(x(xval1<=L_5))                =   f1*xval1(xval1<=L_5);
M_AC(x(xval1>L_5))                 =   f1*xval1(xval1>L_5)-W1*(xval1(xval1>L_5)-L_5);
M_AC(x(xval1>(2*L_8-L_5)))         =   f1*xval1(xval1>(2*L_8-L_5))-W1*(xval1(xval1>(2*L_8-L_5))-I

figure(1)
ezplot(Tnew,[0, length(xval)*pi/180])
hold on
ezplot(Nnew,[0, length(xval)*pi/180])
% axis([ 0 0.8 0 18])
legend('Load through the beam(T)','Load on ship(N)')
title('Load of section A-B with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(2)
ezplot(L5,[0, length(xval)*pi/180])
hold on
title('Length L5 with rotation beta ')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
```

```
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(3)
ezplot(M_ecb,[0, length(xval)*pi/180])
hold on
% axis([ 0 0.8 0 0.5])
legend('Moment[-]')
title('Maximum moment with changing angle beta')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(4)
ezplot(N_ecb,[0, length(xval)*pi/180])
hold on
ezplot(V_ecb,[0, length(xval)*pi/180])
% axis([ 0 0.8 0 18])
legend('Normal','Shear')
title('Maximum unit internal forces w.r.t. W')
xlabel('Angle in rad(min= 0 dregee, max = 45 degree)')
ylabel('Unit unit load w.r.t. load W[-]')
hold off

figure(5)
plot(xval1,V_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
% axis([ 0 2.1*L_8 -0.8 0.8])
title('V-diagram concept 4')
xlabel('Unit Length of the beam w.r.t. Length L1[-]')
ylabel('Unit shear force w.r.t. load W[-]')
hold off

figure(6)
plot(xval1,M_AC)
hold on
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -0.1 1.1],'k--')
axis([ 0 2.1*L_8 -0.1 0.5])
xlabel('Length of the beam [m]')
ylabel('Moment[Nm]')
title('M-diagram front diagram')
hold off
```

Final design rear cradle

```
clc
clear all
close all
% V-shape module
syms w LA L0 theta
Load        =   w*(L0/LA)*sin(theta);
%% FBD A-B rotated axes
syms  W L1
A_yr        =   W*L1/2;
B_yr        =   W*L1/2;
M_Ar        =   W*L1^2/12;
M_Br        =   W*L1^2/12;
%% FBD connection A
syms alpha ax ay ma L4
% equation of equilibruim
F_xA        =   A_yr*sin(alpha)-ax;
F_yA        =   ay-A_yr*cos(alpha);
M_oA        =   ma-M_Ar-ay*L4/cos(alpha);
% Solve values A_X and A_y
```

```
A_x           =   solve(F_xA==0,ax);
A_y           =   solve(F_yA==0,ay);
% Subsitute value A_y in moment equation
M_oAsub       =   subs(M_oA,ay,A_y);
% Solve values M_A
M_A           =   solve(M_oAsub==0,ma);

%% FBD connection B
syms alpha bx by mb
% equation of equilibruim
F_xB          =   B_yr*sin(alpha)-bx;
F_yB          =   by-B_yr*cos(alpha);
M_oB          =   mb-M_Br-by*L4;
% Solve values A_X and A_y
B_x           =   solve(F_xB==0,bx);
B_y           =   solve(F_yB==0,by);
% Subsitute value A_y in moment equation
M_oBsub       =   subs(M_oB,by,B_y);
% Solve values M_b
M_B           =   solve(M_oBsub==0,mb);
%% Create vectors of V- and M-line
% Parameters
L_0           =   3.15;                 % Verticle center of mass 3808 (m)
L_A           =   2;                    % Point of engagement with vessel (m)
unit          =   1;
L_1           =   2/unit;               % Length of load distribution (m)
Theta         =   5*pi/180;             % Maximum tilting angle(Rad)
Alpha         =   45*pi/180;            % Angle of  the V-shape modules(Rad)
H1            =   1/unit;               % Length from cradle bed to top midpoint
H2            =   0.125/unit;            % Added lenght due to placing v-module side ways
H             =   H1+H2;                % Added length to keep the vessel straight
L_2           =   L_1*sin(Alpha)+H;     % Length of section B-C
W1            =   9.81*105000*12/21;    % Load of the vessel[kN]
L_4           =   0.125/unit;           % Half of beam width in respect to L_1
L_8           =   7.5/(2*unit);         % Half of cradle length in respect to L_1
L_3           =   L_1*cos(Alpha);       % Indside triangle module
L_6           =   L_3+2*L_4;            % Distance point of engagement
L_7           =   L_8/3;                % Distance module from center
L_5           =   L_8-L_6-L_7;          % Distance module from side
f1            =   W1/2;                 % Reaction force

% Subsitute values in earlier dirived equations
Loadsub       =   W1/(2*cos(Alpha));    % Partial load
distribution=   Loadsub/L_1;
A_yrsub       =   subs(A_yr,[L1,W],[L_1,distribution]);
B_yrsub       =   subs(B_yr,[L1,W],[L_1,distribution]);
A_xsub        =   subs(A_x,[L1,W,alpha],[L_1,distribution,Alpha]);
A_ysub        =   subs(A_y,[L1,W,alpha],[L_1,distribution,Alpha]);
B_xsub        =   subs(B_x,[L1,W,alpha],[L_1,distribution,Alpha]);
B_ysub        =   subs(B_y,[L1,W,alpha],[L_1,distribution,Alpha]);
M_Arsub       =   subs(M_Ar,[L1,W],[L_1,distribution]);
M_Brsub       =   subs(M_Br,[L1,W],[L_1,distribution]);
M_Bsub        =   subs(M_B,[L1,W,alpha,L4],[L_1,distribution,Alpha,L_4]);
M_Asub        =   subs(M_A,[L1,W,alpha,L4],[L_1,distribution,Alpha,L_4]);

% Define vector for plotting
int                =   0.01;
x                  =   1:(2*L_8/int)+1;
xval               =   0:int:(length(x)-1)*int;
% V and M section A-B
V_AB(x(xval<=L_1))   =   A_yrsub-distribution*xval(xval<=L_1);
V_AB(x(xval>L_1))    =   0;
M_AB(x(xval<=L_1))   =   M_Arsub-A_yrsub*xval(xval<=L_1)+distribution*xval(xval<=L_1).^2/2;

% V, N and M section B-C
V_BC(x(xval<=L_2))   =   B_xsub;
V_BC(x(xval>L_2))    =   0;
```

```
C_y                    =    B_ysub;
M_BC(x(xval<=L_2))     =    M_Bsub+B_xsub*xval(xval<=L_2);
M_C                    =    M_Bsub +B_xsub*L_2;

% V, N and M section A-D
V_AD(x(xval<=H))       =    A_xsub;
V_AD(x(xval>H))        =    0;
D_y                    =    A_ysub;
M_AD(x(xval<=H))       =    M_Asub+A_xsub*xval(xval<=H);
M_Dsub                 =    M_Asub +A_xsub*H;


%%
% Cradle bed
V_AC(x(xval<=L_5))             =    f1;
V_AC(x(xval>L_5))              =    f1-C_y;
V_AC(x(xval>L_5+L_6))          =    f1-C_y-A_ysub;
V_AC(x(xval>L_7+L_8))          =    f1-C_y-2*A_ysub;
V_AC(x(xval>L_6+L_7+L_8))      =    f1 -2*C_y-2*A_ysub;
V_AC(x(xval>=2*L_8))           =    0;

M_AC(x(xval<=L_5))             =    f1*xval(xval<=L_5);
M_AC(x(xval>L_5))              =    f1*xval(xval>L_5)-C_y*(xval(xval>L_5)-L_5)-M_C;
M_AC(x(xval>L_5+L_6))          =    f1*xval(xval>L_5+L_6)-C_y*(xval(xval>L_5+L_6)-L_5)-M_C- A_ysub
M_AC(x(xval>L_7+L_8))          =    f1*xval(xval>L_7+L_8)-C_y*(xval(xval>L_7+L_8)-L_5)-M_C- A_ysub
M_AC(x(xval>L_6+L_7+L_8))      =    f1*xval(xval>L_6+L_7+L_8)-C_y*(xval(xval>L_6+L_7+L_8)-L_5)- A_




%% Plot results
figure(1)
plot(xval,V_AB)
hold on
plot(xval,V_BC)
plot(xval,V_AC)
plot(xval,V_AD)
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -1.1 1.1],'k--')
% axis([ 0 2.1*L_8 -0.6 0.6])
legend('Section AB','Section BC','Cradle bed','Section AD')
title('V-diagram concept 1')
xlabel('Unit Length of the beam w.r.t. Length L1[-]')
ylabel('Unit shear force w.r.t. load W[-]')
hold off

figure(2)
plot(xval(xval<=L_1),M_AB)
hold on
plot(xval(xval<=L_2),M_BC)
plot(xval,M_AC)
plot(xval(xval<=H),M_AD)
% axis([ 0 2.1*L_8 -0.1 0.5])
plot([ 0 2.1*L_8], [0 0],'k--')
plot( [0 0],[ -.3 0.6],'k--')
legend('Section AB','Section BC', 'Cradle bed','Section AD')
xlabel('Length of the beam [m]')
ylabel('Moment[Nm]')
title('M-diagram rear cradle')
hold off
```

Final design front cradle

```
clc
clear all
close all
```

```
syms alpha phi mu W_1 W_2 W L_1 L_2 L beta
%% Equilibrium equitions bulkhead support
sum_mb      =   2*L_1*cos(alpha)*W_1*cos(alpha)-L_2*W*sin(beta+phi); % Without friction
sum_mbf     =   2*L_1*cos(alpha)*W_1*(cos(alpha)+mu*sin(alpha))-L_2*W*sin(beta+phi); % With fr
% Solve W_1 from bulk support
solW_1b      =   solve(sum_mb==0,W_1);
solW_1bf     =   solve(sum_mbf==0,W_1);

%% Equilibrium equation keel support
sum_mk      =   W_1*L_1-L*sin(phi);
% Solve W_1 from keel support
solW_1k     =   solve(sum_mk==0,W_1);

%% Parameters
Alpha       =   45*pi/180;                                     % V-shape angle
x           =   1:21;                                          % Indice vector
Phi         =   0:pi/180:(length(x)-1)*pi/180;                 % Angle Phi in rad
Theta       =   Phi*180/pi;                                    % Angle phi in degrees
Mu          =   0.3;                                           % Friction coefficient
L_1_3808    =   2;                                             % Point of engagement cradle 3
L_3808      =   3.15;                                          % Verticle center of mass 3808
L_1_1605    =   1.2;                                           % Point of engagement cradle 1
L_1605      =   2.004;                                         % Verticle center of mass 1605

% Determining length L_2
L_2_3808    =   pythagoras(L_1_3808*cos(Alpha),L_3808-L_1_3808*sin(Alpha));
L_2_1605    =   pythagoras(L_1_1605*cos(Alpha),L_1605-L_1_1605*sin(Alpha));

% Determining Starting angle beta
Beta_3808       =   atan(L_1_3808*cos(Alpha)/(L_3808-L_1_3808*sin(Alpha)));
Beta_1605       =   atan(L_1_1605*cos(Alpha)/(L_1605-L_1_1605*sin(Alpha)));

% Subsitute bulkhead support
subW_1b3808     =   subs(solW_1b,[L_2,W,beta,L_1,alpha],[L_2_3808,1,Beta_3808,L_1_3808,Alpha])
subW_1bf3808    =   subs(solW_1bf,[L_2,W,beta,L_1,alpha,mu],[L_2_3808,1,Beta_3808,L_1_3808,Alp

subW_1b1605     =   subs(solW_1b,[L_2,W,beta,L_1,alpha],[L_2_1605,1,Beta_1605,L_1_1605,Alpha])
subW_1bf1605    =   subs(solW_1bf,[L_2,W,beta,L_1,alpha,mu],[L_2_1605,1,Beta_1605,L_1_1605,Alp

% Subsitute keel support
sub_1k3808      =   subs(solW_1k,[L,L_1],[L_3808,L_1_3808]);
sub_1k1605      =   subs(solW_1k,[L,L_1],[L_1605,L_1_1605]);

% Create vectors with solution with defined theta
phi             =   Phi;

W_1bulk3808(x)  =   eval(subW_1b3808);
W_1bulkf3808(x) =   eval(subW_1bf3808);
W_1bulk1605(x)  =   eval(subW_1b1605);
W_1bulkf1605(x) =   eval(subW_1bf1605);

W_1keel3808(x)  =   eval(sub_1k3808);
W_1keel1605(x)  =   eval(sub_1k1605);

figure(1)
plot(Theta,W_1bulk3808,'b')
hold on
plot(Theta,W_1bulkf3808,'-b*')
plot(Theta,W_1keel3808, '-bo')

plot(Theta,W_1bulk1605,'r')
hold on
plot(Theta,W_1bulkf1605,'-r*')
plot(Theta,W_1keel1605, '-ro')

title('Partial load W_1 versus rotation Phi')
```

```
xlabel('Phi[degree]')
ylabel('Load W_1 per unit W[-]')
legend('Bh support 3808 without f','Bh support 3808 with f','K support 3808','Bh support 3808
hold off
```

Bulkhead vs keel support

```
clc
clear all
close all

syms alpha phi mu W_1 W_2 W L_1 L_2 L beta
%% Equilibrium equitions bulkhead support
sum_mb      =   2*L_1*cos(alpha)*W_1*cos(alpha)-L_2*W*sin(beta+phi); % Without friction
sum_mbf     =   2*L_1*cos(alpha)*W_1*(cos(alpha)+mu*sin(alpha))-L_2*W*sin(beta+phi); % With fr
% Solve W_1 from bulk support
solW_1b      =   solve(sum_mb==0,W_1);
solW_1bf     =   solve(sum_mbf==0,W_1);

%% Equilibrium equation keel support
sum_mk      =   W_1*L_1-L*sin(phi);
% Solve W_1 from keel support
solW_1k     =   solve(sum_mk==0,W_1);

%% Parameters
Alpha       =   45*pi/180;                                  % V-shape angle
x           =   1:21;                                       % Indice vector
Phi         =   0:pi/180:(length(x)-1)*pi/180;              % Angle Phi in rad
Theta       =   Phi*180/pi;                                 % Angle phi in degrees
Mu          =   0.3;                                        % Friction coefficient
L_1_3808    =   2;                                          % Point of engagement cradle 3
L_3808      =   3.15;                                       % Verticle center of mass 3808
L_1_1605    =   1.2;                                        % Point of engagement cradle 1
L_1605      =   2.004;                                      % Verticle center of mass 1605

% Determining length L_2
L_2_3808    =   pythagoras(L_1_3808*cos(Alpha),L_3808-L_1_3808*sin(Alpha));
L_2_1605    =   pythagoras(L_1_1605*cos(Alpha),L_1605-L_1_1605*sin(Alpha));

% Determining Starting angle beta
Beta_3808       =   atan(L_1_3808*cos(Alpha)/(L_3808-L_1_3808*sin(Alpha)));
Beta_1605       =   atan(L_1_1605*cos(Alpha)/(L_1605-L_1_1605*sin(Alpha)));

% Subsitute bulkhead support
subW_1b3808     =   subs(solW_1b,[L_2,W,beta,L_1,alpha],[L_2_3808,1,Beta_3808,L_1_3808,Alpha])
subW_1bf3808    =   subs(solW_1bf,[L_2,W,beta,L_1,alpha,mu],[L_2_3808,1,Beta_3808,L_1_3808,Alp

subW_1b1605     =   subs(solW_1b,[L_2,W,beta,L_1,alpha],[L_2_1605,1,Beta_1605,L_1_1605,Alpha])
subW_1bf1605    =   subs(solW_1bf,[L_2,W,beta,L_1,alpha,mu],[L_2_1605,1,Beta_1605,L_1_1605,Alp

% Subsitute keel support
sub_1k3808      =   subs(solW_1k,[L,L_1],[L_3808,L_1_3808]);
sub_1k1605      =   subs(solW_1k,[L,L_1],[L_1605,L_1_1605]);

% Create vectors with solution with defined theta
phi             =   Phi;

W_1bulk3808(x)  =   eval(subW_1b3808);
W_1bulkf3808(x) =   eval(subW_1bf3808);
W_1bulk1605(x)  =   eval(subW_1b1605);
W_1bulkf1605(x) =   eval(subW_1bf1605);

W_1keel3808(x)  =   eval(sub_1k3808);
W_1keel1605(x)  =   eval(sub_1k1605);

figure(1)
plot(Theta,W_1bulk3808,'b')
```

```
hold on
plot(Theta,W_1bulkf3808,'-b*')
plot(Theta,W_1keel3808, '-bo')

plot(Theta,W_1bulk1605,'r')
hold on
plot(Theta,W_1bulkf1605,'-r*')
plot(Theta,W_1keel1605, '-ro')

title('Partial load W_1 versus rotation Phi')
xlabel('Phi[degree]')
ylabel('Load W_1 per unit W[-]')
legend('Bh support 3808 without f','Bh support 3808 with f','K support 3808','Bh support 3808
hold off
```