

# AUTOMATIC METHOD TO DEVELOP PLATES, SUITABLE TO THE PRODUCTION PROCESSES

## ABSTRACT

*This paper presents the study for the generation of a computer program that enables the development of the hull shell plating, considering the manufacturing processes.*

*The program's aim is to increase the degree of automatization in the production lines of the ship's hull, more precisely, the quality of the plate development prior to its forming.*

*The program uses the key points of the plate as input data. These points are obtained from the body plan of the ship and correspond to basic geometry of shell in the vertical plan. The program applies the geodesic method of plate development and in the case of a double curvature plate development, the program takes into account the manufacturing process, applying the necessary corrections in the plate development due to plasticity.*

## 1. INTRODUCTION

The objective of this work is to improve part of a ship production by making plate's expansions in a automatic mode.

The geodesic method plate expansion has been developed in a MATLAB program [1]. The two main advantages of this automatic implementation in relation to the manual application of the method are: the processing speed of the results and the implementation of possible corrections in the plate development.

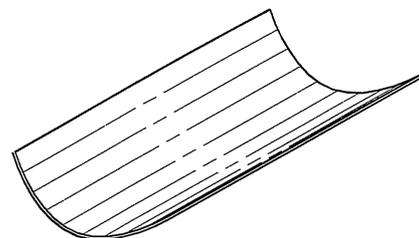
For the geodesic method, it is used essentially the vertical plan of the vessel for the necessary geometric calculations. Having the information of the plate expansion, the flat plating can be marked for subsequent cut and shape's change.

## 2. EXISTING PLATES IN THE HULL

The hull of a ship is made of several kinds of plates: flat plates, plates with single curvature, which are developable, and plates with double curvature, which are not developable.

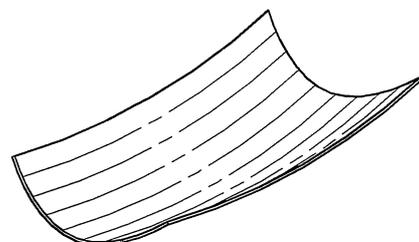
The flat plates are usually located at the bottom and sides of the cylindrical body of the ship.

The single curvature plates have usually a cylindrical shape (Fig. 1), and the most common are located in the bilge of the parallel body of the ship.

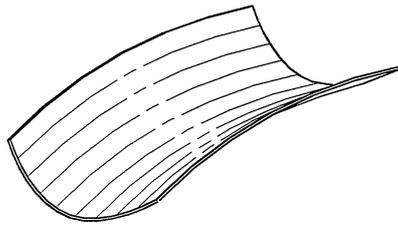


**Fig. 1** Cylindrical shaped plate

The double curved plates can be shaped like a shell (Fig. 2) or shaped like a saddle (Fig. 3), these types of plates are located in the forward and aft ends of the hull.

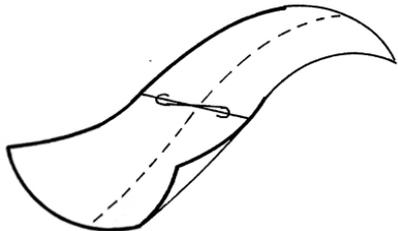


**Fig. 2** Shell shaped Plate



**Fig. 3** Saddle shaped plate

In some areas of the hull it can exist the union of shell plates with saddle plates (Fig. 4).



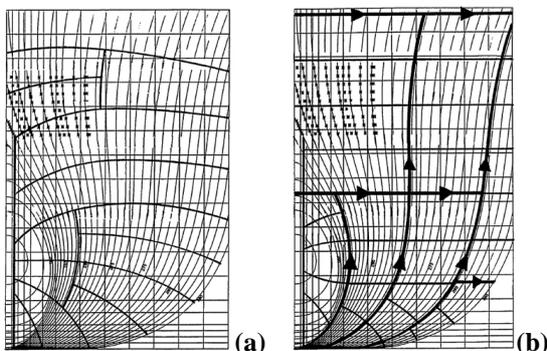
**Fig. 4** Union of a shell plate with a saddle plate

### 3. DISTRIBUTION OF PLATES IN THE HULL

Currently in shipbuilding the construction is made by blocks. This type of construction is faster and more efficient than the traditional way, although it has some disadvantages, requiring greater care in the construction preparation and planning.

Traditionally, the distribution of plates in the vessel's hull was done with a larger number of plates following the shape of the hull (Fig. 5 a). The advantages were: better results in the plate's development methods and easier to make the double curvature shapes.

In modern times, the traditional distribution of plates is made only for small ships. In large vessels, the plates are larger and almost all seams are in a horizontal plan (Fig. 5 b). The disadvantages are the lower quality of results in the plate's expansion methods and greater difficulty to make forms of double curvature.



**Fig. 5** Distribution of plating in the stem of a ship: **a)** Traditional, **b)** Modern

According to Rodrigues Branco [2], for large ships, between 60% and 80% of the hull's plates are either flat or

have a single curvature and the rest are double curved plates.

Example of this is given by Kim [3] for a tanker with 336 plates in the hull, from which 66% are flat, 23% have single curvature, and 11% are double curved.

### 4. PLATE DEVELOPMENT

If the plates are flat, they can be located in transverse planes, in longitudinal planes, or in an inclined plane in the body plan. In the first and the second case, no method is necessary for development of the plate. In the third case, it's used a development method similar to the geodesic method where the geodesic is any straight line in the plane of the plate.

Plates with single and double curvature are normally located in inclined planes in relation to the vertical plan and one may use the geodesic method [4] for the plate development.

In general terms, the geodesic method is based on the use of a geodesic of the conical surface where the plate can belong. The geodesic is used as a guideline for the seams expansions. The geodesic should be perpendicular at least to one of the frame plane and it will become a straight line during the plate development, maintaining the perpendicularity of the reference frame plane.

The development of a conical surface depends on the geodesic that is chosen as a reference. The number of geodesics passing through a point of a conical surface is infinite, so there are several possible situations when applying the geodesic method. The two most relevant situations are:

1. Use of a geodesic at a point of a conical surface, which coincides with the generatrix of the conic that passes through that point.
2. Use of a geodesic at a point of a conical surface, which doesn't coincides with the generatrix of the conic that passes through that point.

The first case is also known as the "French method" and it is used primarily in the elements located in the bilge of the ship.

The second case has the greatest scope in application for the elements of the hull, especially for the plates of double curvature.

In this study, only the second case mentioned in the geodesic method was developed. This case, in practical terms, has three major steps in its application:

1. Draw of the geodesic projection on the vertical plan.
2. Draw of the developments of the seams and the geodesic.
3. Draw of the plate development.

In the first step it is considered the geodesic that is perpendicular to a given point. The point is near the mid of the central frame line. This is the beginning of the construction drawing.

The second step corresponds to the calculation of the true size of the seams and the geodesic.

The last step is to turn the geodesic into a straight guideline. This guideline it use for the operations in the development plate.

### 5. APPLICATION OF THE GEODESIC METHOD

In this work, the geodesic method was developed in MATLAB. The structure of the program algorithm is simple: input data is entered, the program processes the geodesic method, and finally output data are provided. If plates have double curvature, the program adds a correction to the development of the plate.

The input data has the following contents:

- Coordinates of key points of a plate in the body plan draw (Fig. 6).
- The value of the spacing between frames.
- The longitudinal values of the various steps in frames.
- A code value of 0 if the value of the spacing between frames is equal across the plate, or 1 if the value of the spacing between frames has a change in the value over the plate.
- A code value of 0 if the plate belongs in the forward of the hull, or 1 if the plate belongs in the aft of the hull.

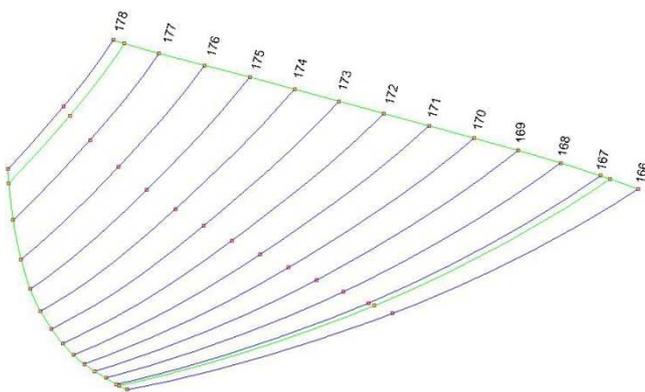


Fig. 6 Key points of a plate in the body plan draw

The program solves the geodesic method in the three steps mentioned in the previous chapter.

The output data provided by the program are:

- 3D model of the plate.
- Draw of the geodesic projection on the vertical and longitudinal plane.

- Draw of the developments of the seams and the geodesic.
- Draw of the plate development.
- Coordinates of the expansion plate points in a numerical format.

The software was tested in a plate of a chemical tanker project. The plate chosen belongs to the bulb of the vessel. The results are shown in Fig. 7 and in Table 1.

For the same plate, the geodesic method was manually applied using a CAD system, the results were used as reference to the results obtained in MATLAB. The coordinates of the development plate points are in Table 2.

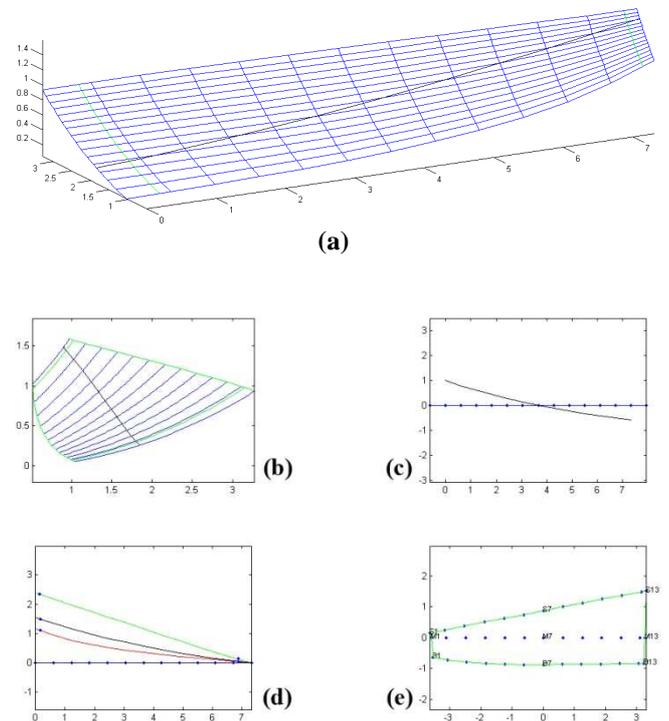


Fig. 7 Output data obtained for a bulb plate of a chemical tanker: a) 3D model of the plate, b) Draw of the geodesic projection on the body plan, c) Draw of the geodesic in a longitudinal plane, d) Draw of the developments of the seams and the geodesic, e) Draw of the plate development.

The absolute errors obtained for the results in MATLAB are in Table 3.

The existence of these errors comes from the approximations made in the program. The frames and the seams are approximate by circular arcs.

(a)	x [m]	y [m]	(b)	x [m]	y [m]	(c)	x [m]	y [m]
B1	-3,552	-0,639	M1	-3,600	0	S1	-3,632	0,155
B2	-3,084	-0,725	M2	-3,121	0	S2	-3,155	0,248
B3	-2,464	-0,801	M3	-2,488	0	S3	-2,524	0,374
:	-1,846	-0,846	:	-1,858	0	:	-1,893	0,500
:	-1,229	-0,864	:	-1,231	0	:	-1,263	0,624
:	-0,614	-0,871	:	-0,608	0	:	-0,631	0,747
	0,000	-0,872		0,014	0		0,000	0,872
	0,614	-0,868		0,635	0		0,631	0,999
	1,227	-0,861		1,255	0		1,261	1,127
	1,840	-0,854		1,873	0		1,891	1,254
	2,452	-0,846		2,489	0		2,520	1,374
	3,065	-0,840		3,105	0		3,147	1,487
	3,221	-0,839		3,260	0		3,304	1,512

**Table 1** Coordinates of the development plate points in the Excel file named "Planif\_Placa\_Pts.xls".

a) Lower seam, b) Geodesic guideline, c) Upper seam

(a)	x [m]	y [m]	(b)	x [m]	y [m]	(c)	x [m]	y [m]
B1	-3,570	-0,638	M1	-3,617	0	S1	-3,630	0,156
B2	-3,110	-0,725	M2	-3,136	0	S2	-3,160	0,250
B3	-2,470	-0,801	M3	-2,499	0	S3	-2,520	0,376
:	-1,850	-0,846	:	-1,866	0	:	-1,890	0,501
:	-1,230	-0,866	:	-1,237	0	:	-1,260	0,623
:	-0,615	-0,873	:	-0,6101	0	:	-0,631	0,747
	0,000	-0,873		0,01352	0		0,000	0,872
	0,614	-0,869		0,6351	0		0,631	0,999
	1,230	-0,862		1,255	0		1,260	1,130
	1,840	-0,854		1,873	0		1,890	1,250
	2,450	-0,845		2,489	0		2,520	1,380
	3,060	-0,839		3,104	0		3,150	1,490
	3,220	-0,837		3,265	0		3,300	1,510

**Table 2** Coordinates of the development plate points in a CAD system.

a) Lower seam, b) Geodesic guideline, c) Upper seam

(a)	x [m]	y [m]	(b)	x [m]	y [m]	(c)	x [m]	y [m]
B1	0,018	0,001	M1	0,017	0	S1	0,002	0,003
B2	0,026	0,000	M2	0,015	0	S2	0,005	0,002
B3	0,006	0,000	M3	0,011	0	S3	0,004	0,002
:	0,004	0,000	:	0,008	0	:	0,003	0,001
:	0,001	0,002	:	0,006	0	:	0,003	0,001
:	0,001	0,002	:	0,002	0	:	0,000	0,000
	0,000	0,001		0,000	0		0,000	0,000
	0,000	0,001		0,000	0		0,000	0,000
	0,003	0,001		0,000	0		0,001	0,003
	0,000	0,000		0,000	0		0,001	0,004
	0,002	0,001		0,000	0		0,000	0,006
	0,005	0,001		0,001	0		0,003	0,003
	0,001	0,002		0,005	0		0,004	0,002

**Table 3** Absolute errors obtained for the results in MATLAB.

a) Lower seam, b) Geodesic guideline, c) Upper seam

## 6. CORRECTION IN THE EXPANSION PLATES FOR DOUBLE CURVATURE SHAPES

If the plates have double curvature, the program adds a correction to the development of the plate obtained in the geodesic method. This procedure can be called "development method by plastic deformation" and is an extension of the geodesic method. The method analyzes the passage of two stages in the shape of the hull plates during manufacturing:

1. When the plate is in a conical or cylindrical shape.
2. When the plate is in final form, shell shaped or saddle shaped.

In shipyards, the shapes in stage 1 are obtained by mechanical processes. In the stage 2, thermal processes may be used by applying heat through the thickness of the plate.

The thermal process causes a shortening in plating edges dimension, so the development obtained in geodesic method should be corrected in the way that there is more material in the plate.

In the development method by plasticity, the calculations of the corrections are made through the formulas: (1-a), (1-b), and (1-c).

$$\delta_{bainha\_inf} = C_{long} \times d_s \times d_{i\_inf} \times \cos \beta \quad (1-a)$$

$$\delta_{bainha\_sup} = C_{long} \times d_s \times d_{i\_sup} \times \cos \beta \quad (1-b)$$

$$\delta_{bainha\_geo} = \frac{\delta_{bainha\_sup} + \delta_{bainha\_inf}}{2} \quad (1-c)$$

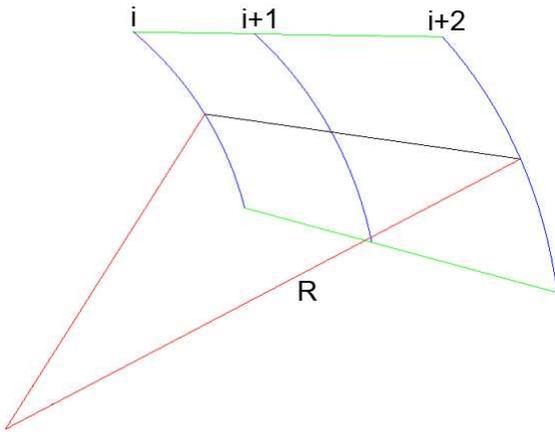
Where:

$C_{long}$  - Is the curvature of the geodesic along the plate, calculated as the inverse of the radii of curvature of the geodesic (1/R).

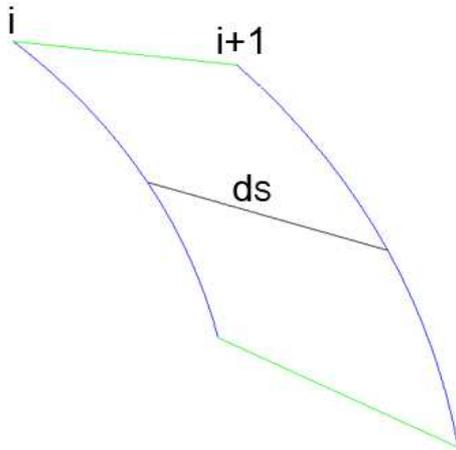
$d_s$  - Segments of the geodesic in the intervals between frames (Fig. 9).

$d_{i\_inf}$  and  $d_{i\_sup}$  - Distances in the frames planes according to the Fig. 10.

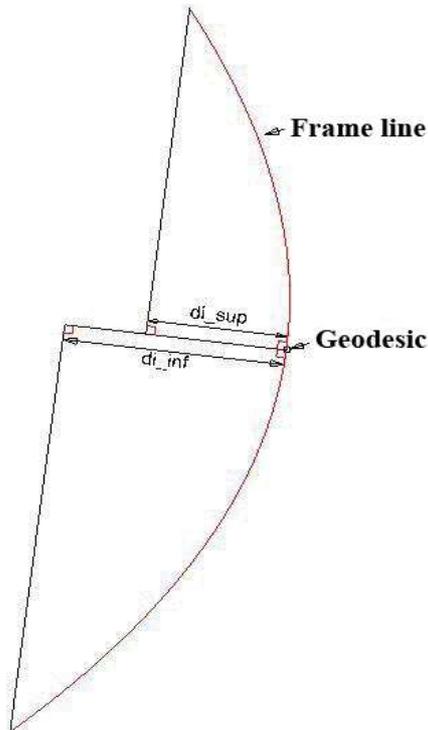
$\beta$  - It is the angle between two planes: the plane normal to the beacon plane, and the plane tangent to the geodesic (Fig. 11).



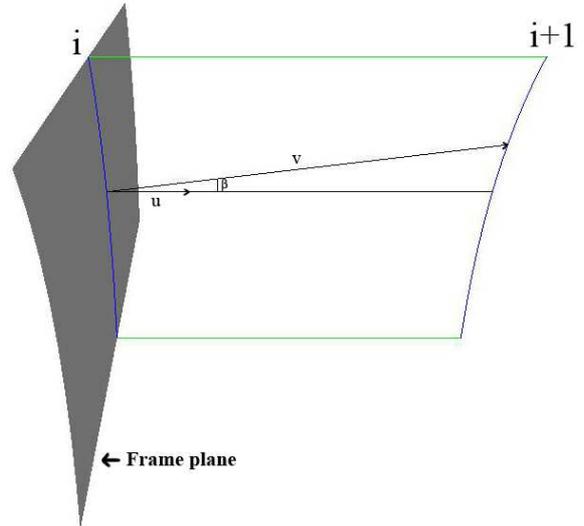
**Fig. 8** Curvature's radii of the geodesic (R) between three frame planes (i, i+1, and i+2)



**Fig. 9** Segment of the geodesic (ds) between two frame planes (i and i+1)



**Fig. 10** Distances  $d_{i\_inf}$  and  $d_{i\_sup}$  measures in the body plan of the plate



**Fig. 11**  $\beta$  angle, between the plane normal to the frame plane, and the plane tangent to the geodesic

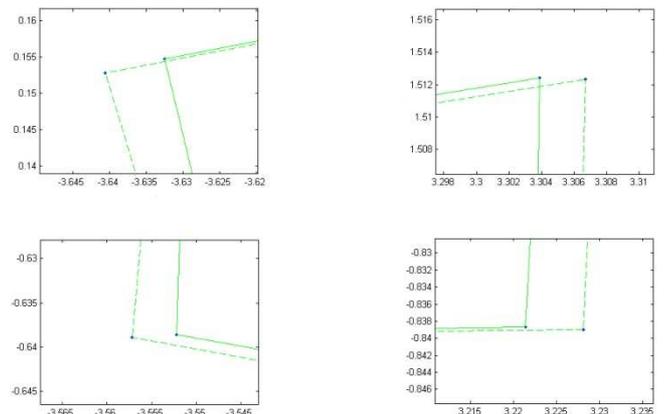
If the plates have double curvature, the program will insert the corrections (1-a), (1-b), and (1-c), in the lengths of the developments obtained for the seams and the geodesic.

If the plate is shell shaped, the values obtained by (1-a) and (1-b) are added to the values obtained in the developments of the seams.

If the plate has a saddle shape, the values obtained by (1-c) are added to the values obtained in the developments of the geodesic.

With the new values of the developments, the third step of the geodesic method is repeated, resulting in a new development of the plate.

The plate mentioned in the last chapter (bulb plate of the chemical tanker) has double curvature and shell shape, so the program corrects the developments obtained for the seams of the plate. In Fig. 12, it's showed the results of the development in the four corners of the plate.



**Fig. 12** New development in the four corners of the plate belonging to bulb of a chemical tanker

The results show the extra material on the plate for shortening that will occur during heat application in the shipyard.

With the developments obtained in the geodesic method (D), and with the developments obtained in the

development method by plastification (d), the plastic strain can be calculated by formula (2).

$$\varepsilon = \frac{d - D}{D} \quad (2)$$

The plastic strain can be normalized by the yield strain ( $\varepsilon_0$ ) in order to have a term of comparison. The yield strain is defined as equal to the yield stress divided by the modulus of elasticity. The plates used in this ship are made of steel, so it is assumed an yield stress of 240 MPa and a modulus of elasticity of 200 GPa, resulting in a value of  $1.2 \times 10^{-3}$  for the yield strain.

In the bulb plate of the chemical tanker vessel, the results for developments, plastic extensions, and plastic extensions normalized are in Table 4 and Table 5. The values show that the plastic extensions are bigger (in average) 1.5 more than the elastic-plastic extension.

Frames	$d_B$ [m]	$D_B$ [m]	$\varepsilon_B$	$\varepsilon_B/\varepsilon_0$
166-167	0,651	0,650	0,001	1,025
167-168	0,636	0,635	0,001	1,050
168-169	0,626	0,625	0,001	1,066
169-170	0,620	0,619	0,002	1,346
170-171	0,618	0,617	0,002	1,351
171-172	0,616	0,615	0,001	1,219
172-173	0,615	0,614	0,002	1,764
173-174	0,615	0,613	0,003	2,311
174-175	0,614	0,613	0,002	1,904
175-176	0,614	0,613	0,002	1,496
176-177	0,613	0,612	0,002	1,361
177-178	0,613	0,612	0,001	1,089

**Table 4** Developments ( $d_B$  and  $D_B$ ) for the lower seam with the two methods (plastification and geodesic); Plastic extensions ( $\varepsilon_B$ ) and plastic extensions normalized ( $\varepsilon_B/\varepsilon_0$ )

Frames	$d_S$ [m]	$D_S$ [m]	$\varepsilon_S$	$\varepsilon_S/\varepsilon_0$
166-167	0,648	0,645	0,004	3,619
167-168	0,647	0,644	0,004	3,234
168-169	0,646	0,643	0,003	2,849
169-170	0,645	0,643	0,003	2,851
170-171	0,644	0,643	0,003	2,204
171-172	0,645	0,643	0,002	1,554
172-173	0,645	0,644	0,002	1,295
173-174	0,644	0,643	0,001	1,036
174-175	0,643	0,642	0,001	0,649
175-176	0,640	0,640	0,000	0,391
176-177	0,638	0,637	0,000	0,131
177-178	0,634	0,634	0,000	0,131

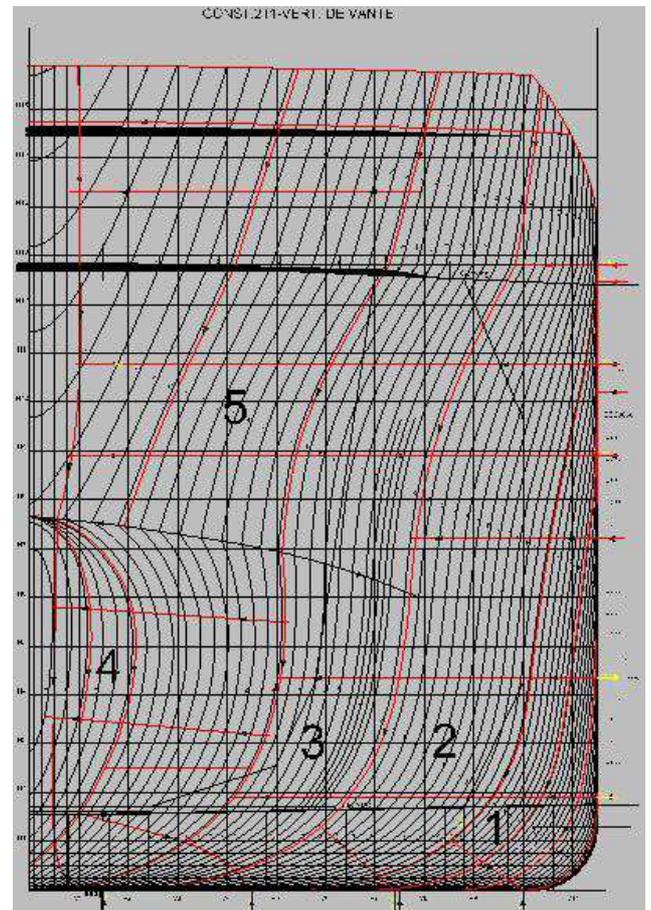
**Table 5** Developments ( $d_S$  and  $D_S$ ) for the upper seam with the two methods (plastification and geodesic); Plastic extensions ( $\varepsilon_S$ ) and plastic extensions normalized ( $\varepsilon_S/\varepsilon_0$ ).

## 7. RESULTS

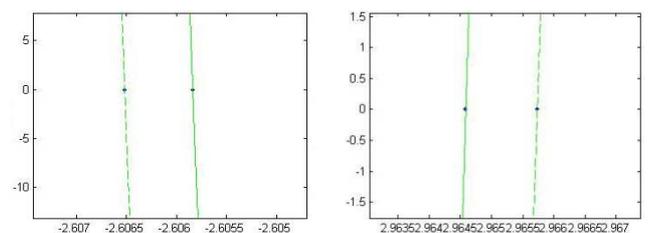
For the same chemical tanker, the software was tested on more five plates: four of them with a shell shape (number 1 to 4 in Fig. 13), and one of them with a saddle shape (number 5 in Fig.13).

For the shell plates, the results were similar to the results obtained in the last chapter.

In the saddle plate, the program made the corrections only for the developments of the geodesic. The new plate's development is shown in Fig. 14. The values of the developments for the geodesic with the two methods (plastification and geodesic), and the values of the plastic extensions and plastic extensions normalized are in Tab. 6.



**Fig. 13** Forward of a chemical tanker hull in the body plan



**Fig. 14** New development in the two lateral seams of the plate

The results in Fig. 14 show the extra material on the plate on the geodesic zone.

In terms of plastic extensions, the results are show in the Table 6.

Frames	$d_M$ [m]	$D_M$ [m]	$\epsilon_M$	$\epsilon_M/\epsilon_o$
166-167	0,705	0,705	0,000	0,118
167-168	0,701	0,701	0,000	0,119
168-169	0,701	0,700	0,000	0,238
169-170	0,699	0,699	0,000	0,238
170-171	0,697	0,697	0,000	0,239
171-172	0,695	0,695	0,000	0,120
172-173	0,692	0,692	0,000	0,120
173-174	0,689	0,688	0,001	0,605
174-175	0,687	0,687	0,001	0,485

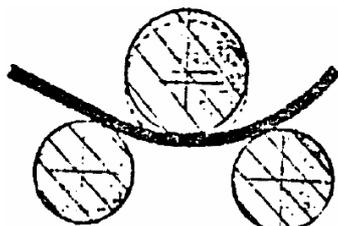
**Table 6** Developments ( $d_M$  and  $D_M$ ) for the geodesic with the two methods (plastification and geodesic); Plastic extensions ( $\epsilon_M$ ) and plastic extensions normalized ( $\epsilon_B/\epsilon_o$ )

**8. PROCESSES IN SHAPE CHANGE**

The processes in shape change can be made by the mechanical way or by the thermal way, or by mixing the two technologies [5].

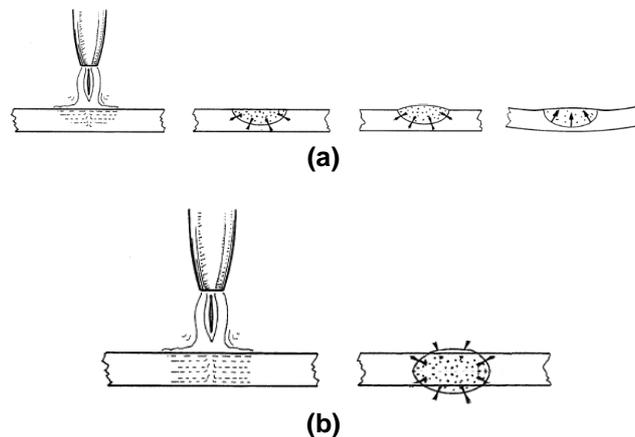
Using the mechanical process, the plate can be changed by forces in traction, compression, or flexion.

In shipyards, to transform a flat plate into a cylindrical or a conical shape, it's used the rolling machine (Fig. 15). This machine changes the form of the plate by applying flexion forces and there are no plastic extensions. The rolling machine it's used for plates with a single curvature and for double curvature plates in the first phase of its shape process.



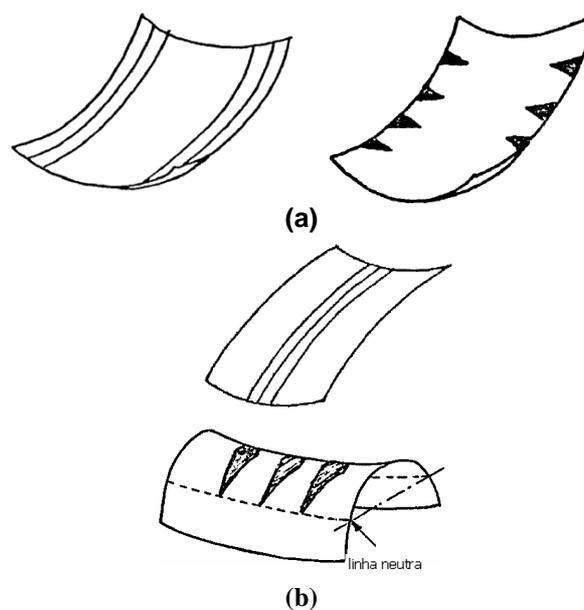
**Fig. 15** Rolling machine

Using the thermal process, the plate can be changed by heating certain areas at high temperatures, implying a lower elastic limit. When the heated area cools, the material goes in to perpendicular contractions because of the bending moments, became deformed in the end of the process. If the heat it's applied in half thickness of the plate (Fig.16 a), the bending moments are less balanced, so the deformed shape it's bigger and bent. If the heat it's applied in all thickness of the plate (Fig.16 b), the bending moments are more balanced, so the deformed shape it's smaller.



**Fig. 16** Kinematics of thermal process: a) In half thickness of the plate, b) In all thickness of the plate

In shipyards, to change a cylindrical or conic plate in to a double curvature plate, its use a blowtorch in a line trace or in a V area (Fig. 17), in all thickness of the plate.



**Fig. 17** Application heat by lines or V areas, for plates: a) In shell shape, b) In saddle shape

The reason for the development method by plastification to consider more material on the plate is the compensation that must be accounted for the shortening that will exist after the heat application and subsequent cooling of the plate.

In terms of qualitative analysis, the plates discussed in the previous chapter could be processed as follows:

1. The longitudinal curvature could be made by rolling machines.
2. The transverse curvature could be made by heat applied in V areas and in all thickness,

increasing the intensity distribution from the center to the edges of the plate.

## 9. CONCLUSIONS

The program made in MATLAB uses the geodesic method, with a geodesic at a point of conical surface that is not equal to the generatrix of the conic that passes by that point. This method has application in single and double curvature plates of the ship's hull. The approximation made by the program, considering the frame lines in to circular arcs, is less important because the errors are minimum as show in Table 3.

If the plates have double curvature, the program analyzes the longitudinal and transverse curvatures to determine if the plate is shell or saddle shape. Then the program applies the development method by plastification. The important issue is that the program will deal with double curvature situations, where the results of the geodesic method are not so accurate, bringing new results with development method by plastification.

## 10. BIBLIOGRAPHY

1. Knight, A., *Basis of MatLab and Beyond* (London: Chapman & Hall/CRC, 2000).
2. Rodrigues Branco, J. N., Guedes Soares, C., *Mapping of Shell Plates of Double Curvature Into Plane Surfaces*, Journal of Ship Production Vol. 21 No. 4 (2005) 249-257.
3. Kim, S. Y., *Automation of hull plates classification in ship design system using neural network method*, Mechanical Systems and Signal Processing 20 (2006) 463-504.
4. Rodrigues Branco, J. N., *Lições de Traçagem - apontamentos de apoio à disciplina Tecnologia de Estaleiros Navais*, Departamento de Engenharia e Arquitectura Naval, Instituto Superior Técnico, 1988.
5. Gordo, J. M., *Enformação - apontamentos de apoio à disciplina Tecnologia de Estaleiros Navais*, Departamento de Engenharia e Arquitectura Naval, Instituto Superior Técnico, 2005.