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The shell structures of the Baroque

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Abstract

The Baroque has been traditionally a style minimized by its tendency to decoration and its lack of the systematic. Gradually it has left demonstrating that this was a prejudice and that the architectural values were of first magnitude, comparable to the biggest landmarks of classic styles. As for the structural aspects we want to demonstrate that they overcome to as much as it was made previously by their space wealth, their economy of means and the intelligence of their solutions. Somehow they represent an antecedent of the shell architecture that so much it would make an exhibition with the Reinforced Concrete and the analytic techniques of dimensioning. With less means but with great intuition, the Baroque, invented forms of a complexity that today is still difficult to understand, at least geometrically. Paradoxically there are no investigations that help us to clarify the structural miracle of the Baroque since up to now it has been in historians' hands and not those of architects or engineers. This article tries to open the road in this unexplored field.

1. Introduction

To speak of shell structures in the mathematical and modern sense of the term, in designs previous to 1900 and in materials different to the reinforced concrete it seems an excessive license.

However, since in the XIX century the brick vaults already demonstrated a good capacity to adopt capricious forms in absence of flexions and with the brick and the mortar like only materials. It is logical to think that the construction of this shells is previous to their analytic tools, so previous justification that it can be extrapolated to the Byzantine construction in that churches like Serlio and Bacchus or Sta. Sofía, they have been able to be designed like membranes, with great precision if we compare them with the results obtained by Finite Elements.

However the first properly shells are not found until the Baroque architecture, and not in fact in the Italian where architects like Brunelleschi, Miguel Ángel or Palladio did great achievements to overcome the structural challenges of the

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antiquity. It is later, when the economy of means that the XVIII Century imposed to the construction, when a great quantity of apprentices, that were formed in San Pedro's factory, were disseminated by Europe to create some national styles, rich in way, splendid of concept and good structurally.

2. The Baroque structures

The new generation that was in Italy, following Miguel Angelo and Borromini guidelines, preferred to materialize their structures in nerves and complex laces very of the medieval style. Guarini (Fig. 1) or Vittone (Fig. 2) they go in this line.

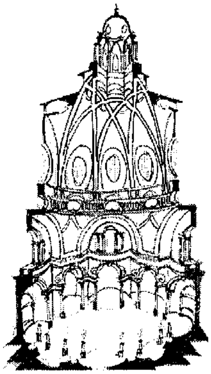
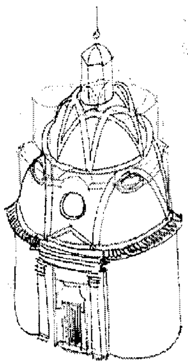
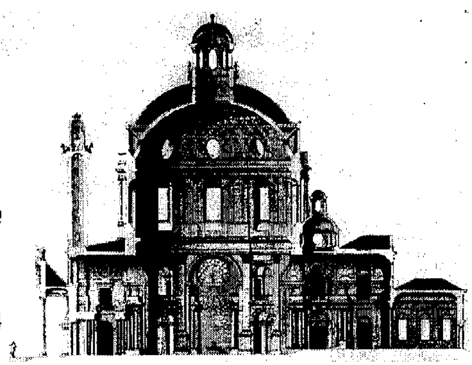

Fig.1. St. Laurence in Turin by Guarino Guarini
Fig.2. St. Bernardino in Chieri by Vittone
Fig.3. St. Charles in Vienna Fischer von Erlach.

Who moved to the north they preferred to still use continuous forms more complex than the mentioned nerves, although masked under a dense ornamental layer of stuccos and paintings. Fischer von Erlach, patriarch of all them, in Austria, the family Dientzenhofer in Prague and Neuman in Germany are some few ones of among the dozens of architects that we could mention that, with its differences they dedicated to create suggestive and complex spaces with minimum structures.

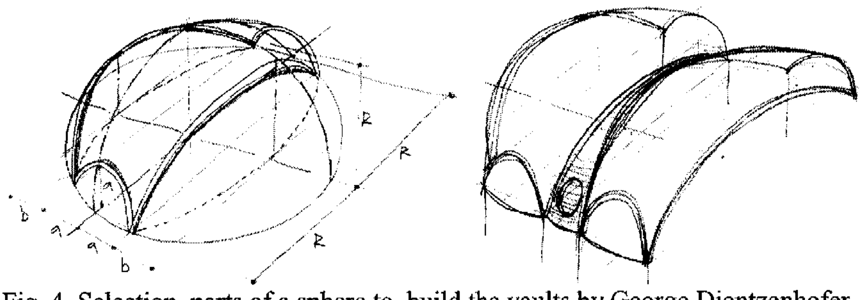

Fig. 4. Selection parts of a sphere to build the vaults by George Dientzenhofer.

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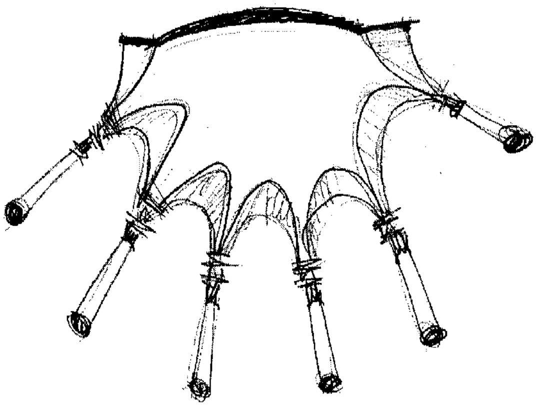
While Fischer was devoted to explore the elliptic spaces (Fig.3) and the Dientzenhofer family the intersected geometries (Fig. 4), Neuman manages with ease the most difficult spaces, mixture of ellipsoids and cylinders on punctual supports (Fig. 5). Zimmerman gets geometries that don't have recognisable forms (Fig, 6).



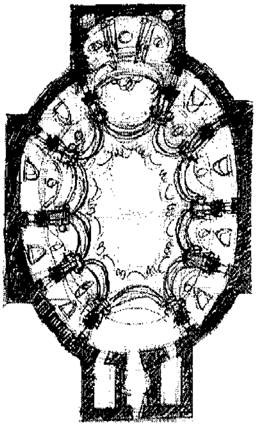
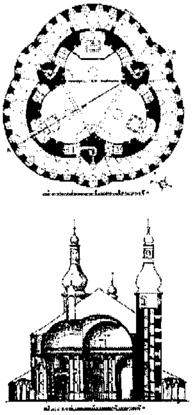
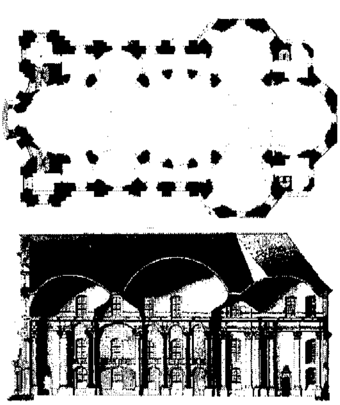


Fig. 5. Type of Neuman Construction. Fig.6. Zimmerman's Steinhausen Church.

When we begun the study on the structures of the Baroque, we were surprised by the lack of bibliography and of specific studies. It is accentuated it in the case of the Central European Baroque, in the which, apart analysis made for consolidation works and repair or reconstruction, doesn't exist practically any research. We except Jager and Croci although they have not intervened in particular aspects of shells. It is for it that we contribute the data that continue with intention of to open the road and to demonstrate the great structural interest that has a recently valued style.

The work is wide and it will embrace the different types of Baroque membrane. But at this time it is logical to begin with important and very well-known monuments, like they can be:





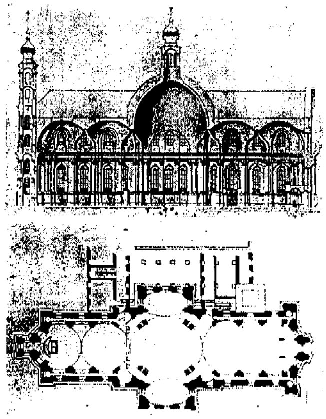


Fig.7. Sanctuary of Kappel. Fig.8.Church of Vierzhenheiling.Fig. 9. Neresheim.

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1) Sanctuary of Kappel near Waldhsassen of George Dienzenhofer (Fig. 7).
2) Church of pilgrimage of Steinhausen of Zimmerman (Fig. 6).
3) Franciscan church of Verzhenheiling, by Neuman (Fig. 8).
4) Benedictine church of Neresheim, by Neuman (Fig. 9)

In all these cases we will make the same suppositions:

a) For lack of data we consider that the vaults are built with bricks to thread and therefore with a thickness of 0.25 m.

b) The characteristics of the fabric are the following ones:

1. $\gamma = 1.7$ Ton/m^3
2. E = 10 E^6 Ton/m^2 and the material is elastic and lineal in the considered range.
3. $\upsilon = 1/6$

c) The vaults are supported by hinges on the cornices and only the part upon them are calculated starting from this level. It is necessary to keep in mind that the cornices, in the Baroque, define the form in plant and that what there are under them is well rested.

d) The only actions that we will consider they are those of own weight.

e) The mathematical pattern that we will use is to consider the medium surface of the vault as the geometry for analysis.

f) The method used to calculation is that of Finite Elements. The resulting graphics will represent the efforts and displacements in the considered surface.

3. Sanctuary of Kappel in Waldsassen: by George Dientzenhofer

In this case we have a estrange functional distribution with a triangular plan with curved sides, according to the geometric outline of the Fig. 7. It has odd number of sides, with solid walls perforated with chapels and stabilizing towers.

The dome is formed by a sphere that intersects with other three, and the group is supported in all its contour. There are not more perforations than some small chimneys that provide a soft clarity (Fig. 10).

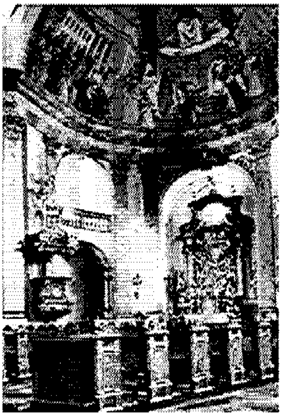

Fig. 10. Interior of the Sanctuary of Kappel.

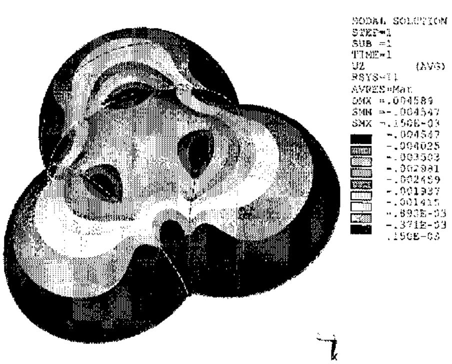

Fig. 11. Scheme of deflections.

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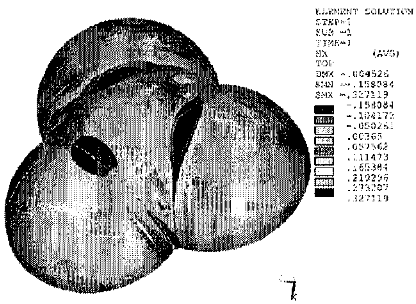
If we calculate in elastic condition we see:

a) The maximum deflections are, in this case, of 4.5 mm. (Fig. 11)

b) The maximum moments are of 0.32 Tonxm in a punctual case that is rested by the towers, that have not been considered in the calculation in the practice. In general, in significant areas the maximum moments are of 50% of this value (Fig. 12).



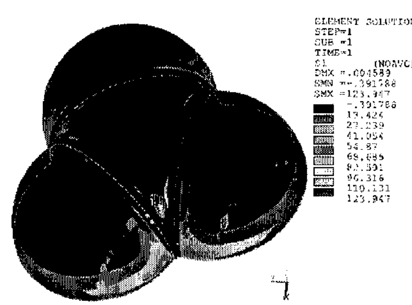


Fig. 12 Scheme of bending moments. Fig. 13 Principal stresses I

c) The maximum tensions are, in general, smaller than 13 ton/m^2, although, locally, in areas that in fact go reinforced and that we have not considered they arrive to 82 Ton/m^2 (Figs. 13).

This cover, of great size and form, misses it is extraordinarily effective whenever they stay its reinforcement nerves.

4. Church of pilgrimage of Steinhausen: by Nicholas Zimmerman

The used geometric pattern is an ellipsoid upon ten supports (Fig. 6). If we calculate in elastic state, we obtain the following conclusions:

a) The maximum deflections are of 0.226 mm. to own weight (Fig. 14).

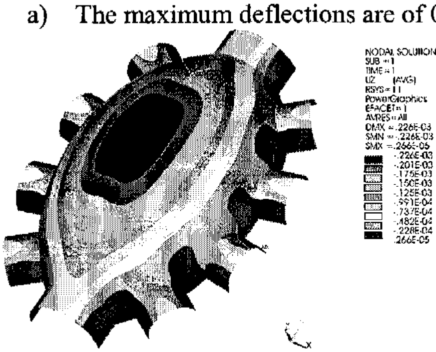


Fig. 14 Deflections

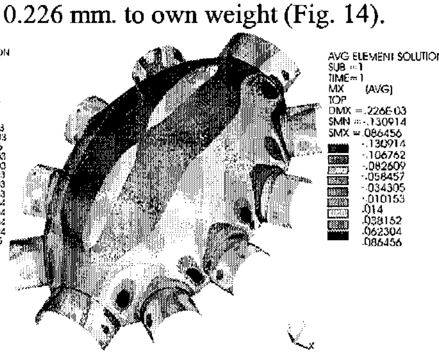


Fig. 15. Bending Moments. X axis.

b) As for the maximum moments, except for due punctual areas to the grid of the mathematical pattern, the maxima are of 0.13 Tonxm. in the area among cylindrical openings (Fig. 15) or of 0.3 Tonxm. in the same

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perforations reinforcement. This is false in our case since they have areas specially reinforced by ornamental elements. (Fig. 16).

Fig. 16. Dome of the Steinhausen church

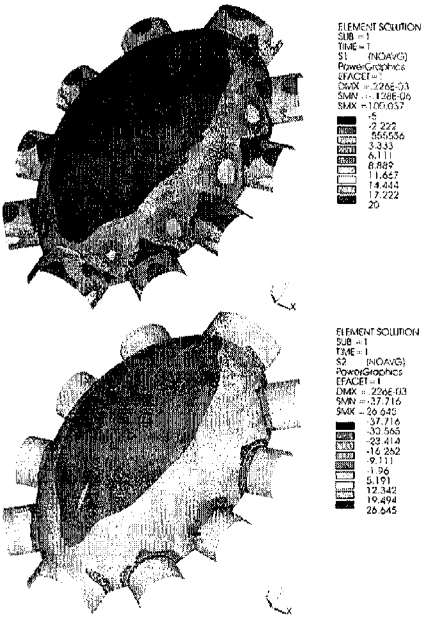

Fig.17 and 18 Principal stresses.

c) As for the tension stresses, you leave in the Figs. 17 and 18 that the 9 Ton/m2 doesn't surpassed in any point.

On the whole it means it that it stops own weight and static loads give a safe state. This structure cannot have pathology and its design is good.

5. Franciscan Church of Vierzhenheiling: by Balthasar Neuman

The geometry is extremely complex and the vault is formed by the intersection of three ellipsoids, two spheres, two cylinders and twenty-two cylindrical openings, in such a way that the whole group supports on twenty-four points (Fig. 8). All the intersections and borders are considered finished off by nerves of 0.5x0.5 m. (Fig. 19 and 20). The analysis reveals behaviour as a shell with very good results that approaches to the membrane state, with the exception of some points.

a) In the Fig. 21 are appreciated the displacements that, in the worst in the cases, they don't overcome the 0 .7 mm. in the key of the intersection cylinders.

b) As for the tension stresses we have a widespread state that it oscillates between 3 and -3 Ton/m2. In the intersection nerves we even have 30 Ton/m^2 of traction stresses (Fig. 22). For compression stresses, in the kidneys of the domes, it arrives to 30 Ton/m2 (Fig. 23).

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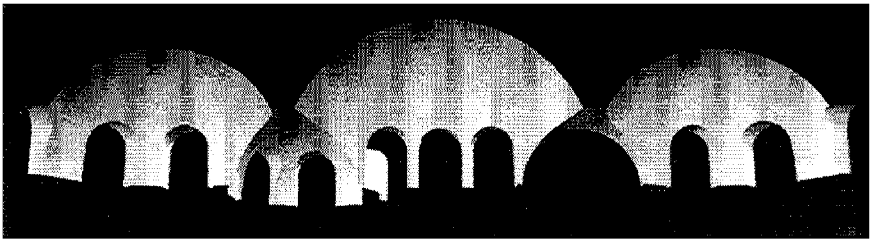

Fig. 19. Drawing of a longitudinal section.

Fig. 20. Internal view of the shell

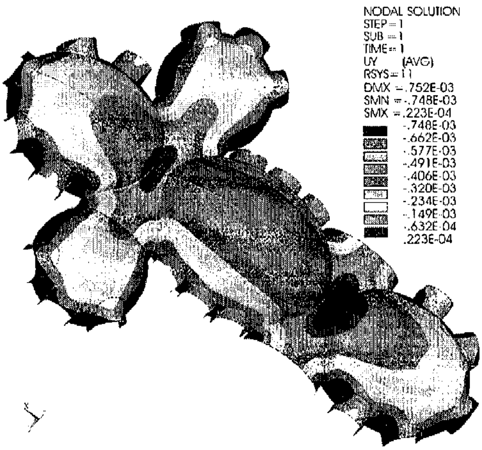

Fig 21. Scheme of displacements.

c) For the bending moments they oscillate among +/-0.15 Tonxm in the X direction (Fig. 24). Something greatest are in the nerves in the Y direction (Fig. 25), although inside the acceptable range.

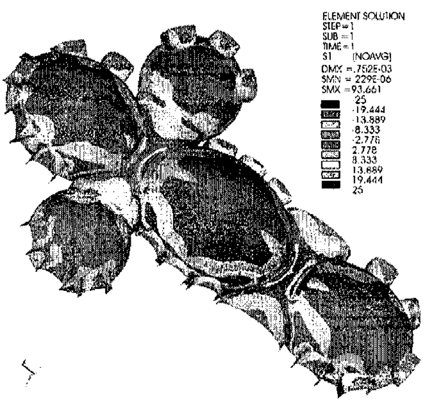

Fig. 22. Principal Tension stresses I

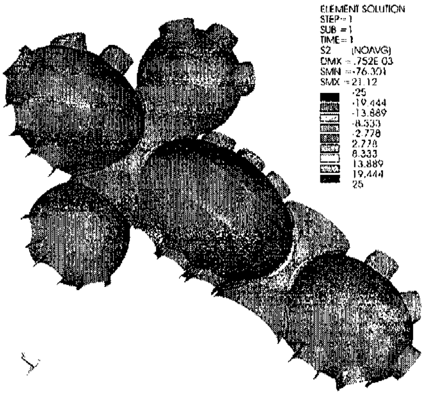

Fig. 23. Principal tension stresses II.

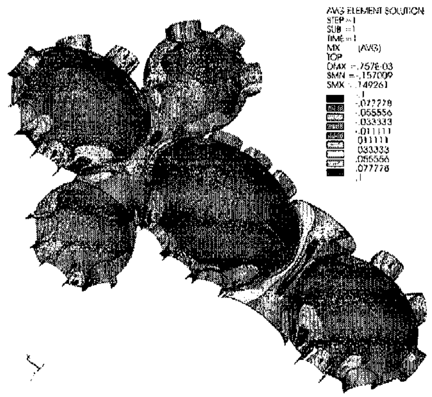

Fig. 24. Bending Moments X

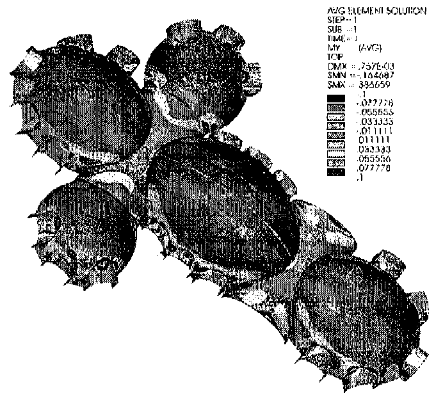

Fig. 25. Bending Moments Y

6. Benedictine Church of Neresheim: by Baltasar Neuman

The architecture of this church is extremely complex and it is one in the most complicated masterpiece in the whole Baroque (Fig. 9). Here we have the intersection of seven ellipsoids of different size and height with spherical canyons, in accordance with the geometry of the Fig. 26. The whole is surprising (Fig. 27). The structural behaviour of the group is deduced from the calculation by means of Finite Elements with the following results:

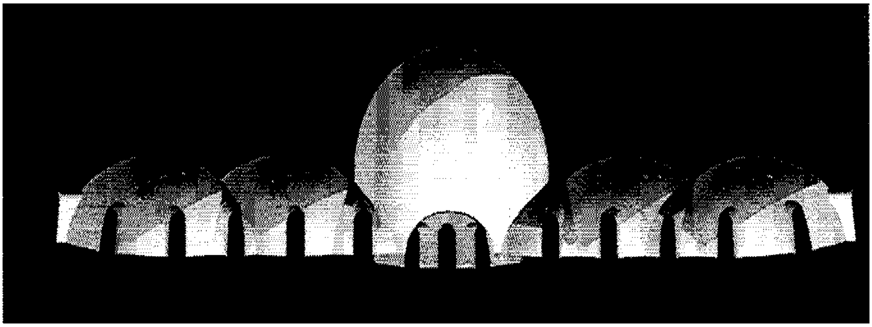

Fig. 26 Longitudinal section of the Neresheim Church.

a) In the Fig. 28 are appreciated the displacements that, in the worst in the cases, they don't overcome the 16 mm. in the key of the intersection cylinders.

b) As for the tension stresses we have a widespread state that it oscillates between -9 and 3 Ton/m^2. In the pendentifs we even have 60 Ton/m^2 of traction stresses (Fig. 29 and 30).

c) For the bending moments they oscillate among +/-0.20 Tonxm in the X direction (Fig. 31). Something greatest are in the nerves in the Y direction (Fig. 32), although inside the acceptable range. (0.50 Tonxm.).

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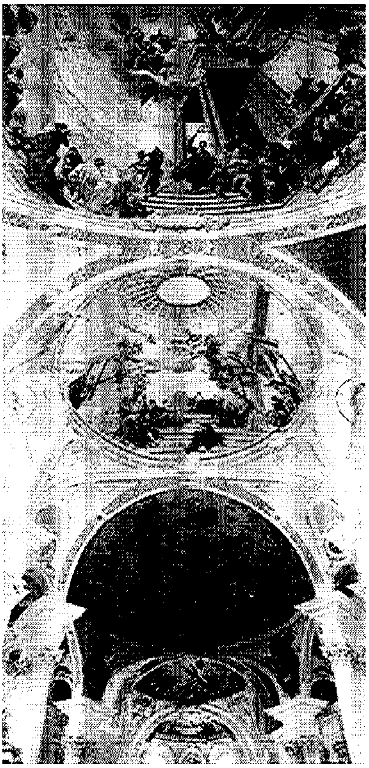

Fig. 27 Internal view of the Neresheim vaults.

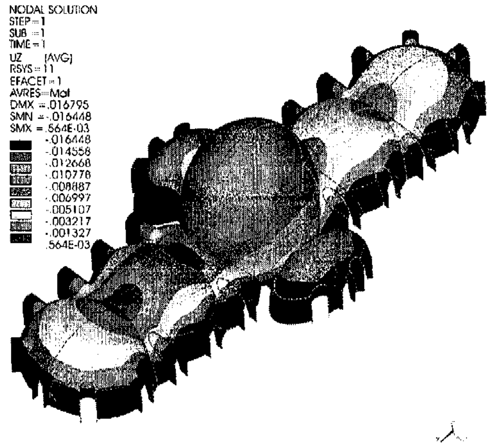

Fig. 28. Deflections scheme.

7. Conclusions

Although it is difficult to establish some conclusions at the present state of the research we want point on the interest of this kind of construction so little studied and so interesting. Our interest is to extend the study to all the Baroque proposals that are so differentiated of other styles, developed before or after.

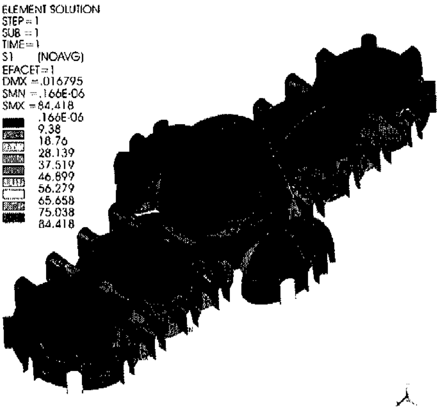

Fig. 29. Principal estreses I

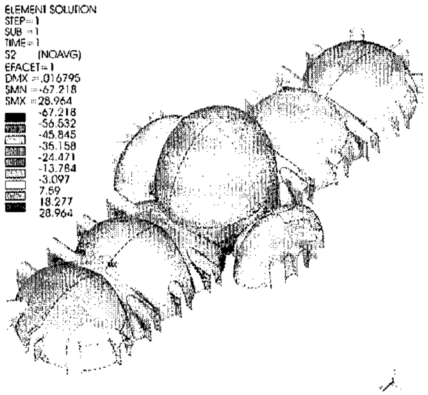

Fig. 30. Principal estreses II

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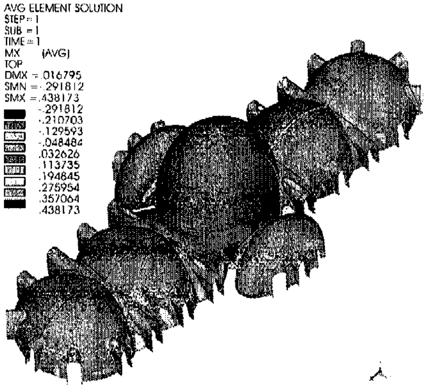

Fig. 31. Bending Moments X.

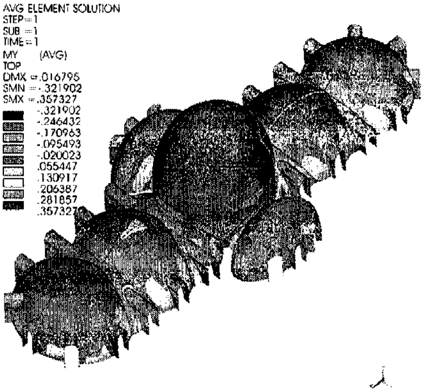

Fig.32. Bending Moments Y.

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