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Division V

ADVANCED STRESS ANALYSES IN THICK TUBE PLATES

Dr. François Billon[1] , Erwan Jourden[2]

[1] Principal Expert, ONET Technologies, Marseille, France (fbillon@onet.fr)
[2] Specialist Design Engineer, ONET Technologies, Marseille, France (ejourden@onet.fr)

ABSTRACT

The innovative approach developed here is addressing the precise determination of the stresses in and around the holes of the Interfaces Zones (IZ) of a Tube Plate (TP).

In the paper, Josserand and Billon (2008), three IZ had been identified in the TP as representative of the particular local drilling and in each zone a set of multiplier functions had been determined on the basis of the loading of an Elementary Representative Portion (ERP) in the same way of the concept based on the Elementary Representative Volume (ERV) developed in the thesis, Billon (1986).

The advanced studies we are presenting here are in the continuity of the captioned studies with the innovative approach that consist in modeling explicitly the drilled holes in a 3D model of the TP in order to access directly to the stresses at the inner surface of the holes and around them.

The entire studied PT therefore includes the areas of interest with the explicitly modelled holes and the areas without explicitly modelled holes are modelled by an equivalent homogeneous medium, Billon (1986).

These studies are applied to a TP of a Steam Generator (but could also cover the TP of any tubular heat exchanger) with a particular focus on the interfaces zones which are the interfaces of the holes with the peripheral solid ring, the interfaces along the tube-lane and the mixed interfaces of the solid ring and the tube-lane.

The TP model with holes in the interfaces and no holes elsewhere is shown on the Figure **1**.

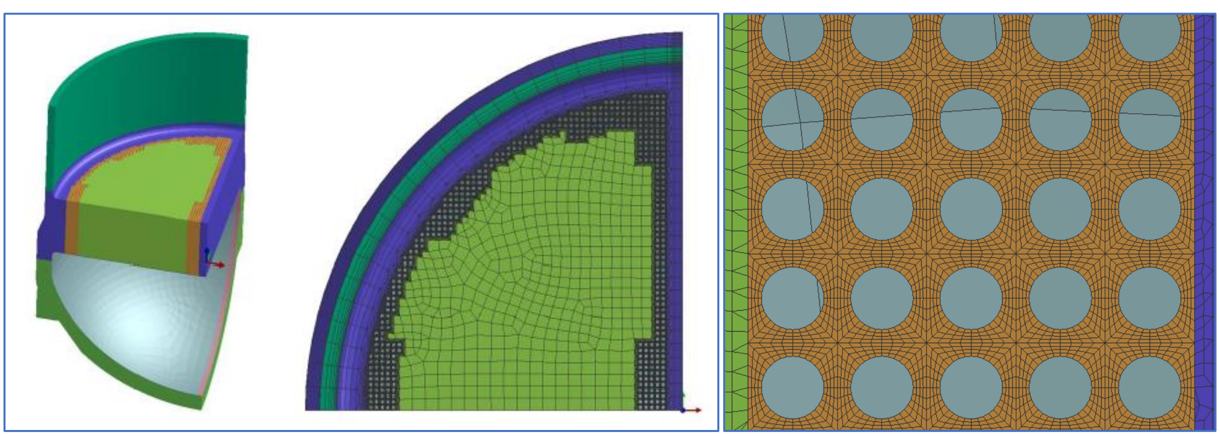

Figure 1 – Global model with the TP and explicitly modelled holes

The study loads applied to the TP are the primary pressure and the secondary pressure that can be combined and the stationary thermal loadings combining primary temperature and secondary temperature with a differential which highlights the so called “thermal skin effect” at the secondary surface of the TP.

The stresses are directly calculated and post treated in the modeled holes in order to be compared with the stresses obtained with the ERP multiplier functions.

According to the results we can either show that the multiplier functions provide correct stresses or to be adjusted if necessary compared to direct calculation. An overview of the results obtained in several interface holes is given on the Figure 2.

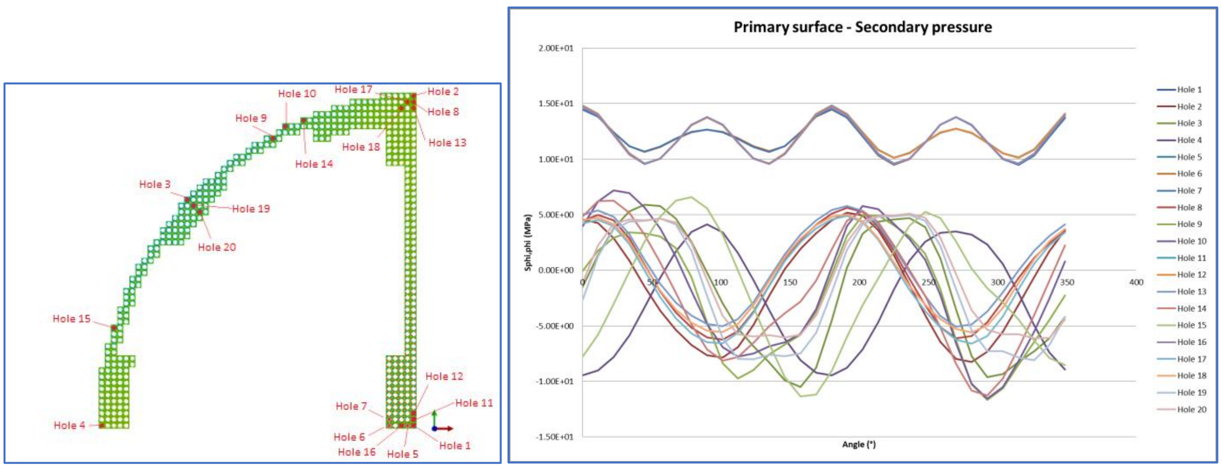

Figure 2 – Tangential stresses at the inner surface line of the holes as a function of the angle around holes (primary surface under secondary pressure)

As a notice, the regulatory analyses done until now with the approach Billon and Josserand (2008) for the holes located in the interfaces zones are confirmed even if some multiplier functions will be adjusted in order to decrease a little the conservatism of it.

INTRODUCTION

In order to perform the analyses required by the nuclear regulations, codes and standards (ASME, RCC-M, etc…) for Steam Generator Tube Plates, the practice is to model the perforated medium of the TP by a homogeneous material to which equivalent properties are assigned.

Indeed, the modeling of all the holes of the TP would make the calculation time prohibitive or even impossible.

In order to analyze the stresses in the TP, especially in the interface areas between perforated part and homogeneous medium, multiplicative functions (aφ, bφ and cφ) were determined on Elementary Representative Portion (ERP).

These multiplier functions allow to go from the calculated stresses in the equivalent medium to the concentrated stresses at the edges of the holes and have been determined in several interface areas see Figure 3:

- Interface with the tube lane (TIZ)
- Interface with the TP solid rim (SIZ)
- Double interface with the tube lane and solid rim (DIZ)

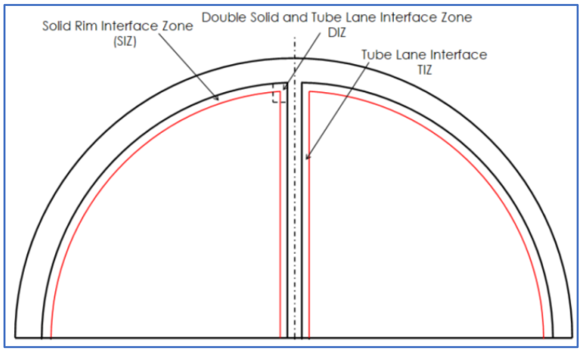

Figure 3 - Representation of interface zones

They were determined on the basis of representative local models, see Figure 4.

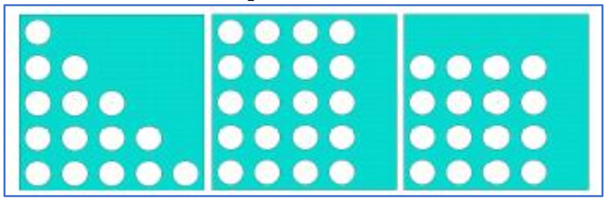

Figure 4 - Local models used for multiplier functions determination

The general expression for the tangential stress concentrated at the edge of the hole Sφ,φ is given by equation (1) :

$$S\varphi,\varphi = a\varphi \times Sxx + b\varphi \times Syy + c\varphi \times Sxy \tag{1}$$

The stresses Sxx, Syy and Sxy are the tensile/compressive and shear stresses in the TP plane.

The objectives of the study conducted here are multiple:

1) First, we present the calculations that have been performed on a perforated TP model. Only a few rows of holes, in the interface zones, are modeled. Two pressure loads are treated (primary and secondary pressure), as well as a stationary thermal load.

2) In a second step, the tangential stresses at the edge of the holes, obtained on the perforated model, are recorded.

3) In a third step, the results obtained in this way are compared with those obtained via the multiplier functions and the stress recorded in the homogenized model.

4) Finally, in a fourth and last step, we propose optimizations of the multiplier functions currently used for TP analyses.

CALCULATIONS ON THE PERFORATED MODEL AND POST-PROCESSING OF THE STRESSES AT THE EDGE OF THE HOLES

The calculations are carried out on a quarter model of the SG lower part in which tube holes have been explicitly represented, see Figure 1. The tubes are not modeled.

The boundary between homogenized (equivalent characteristics assignment) and non-homogenized part of the TP (real characteristics assignment) is taken at the edge of the drill patterns, see boundary in red on the Figure 5.

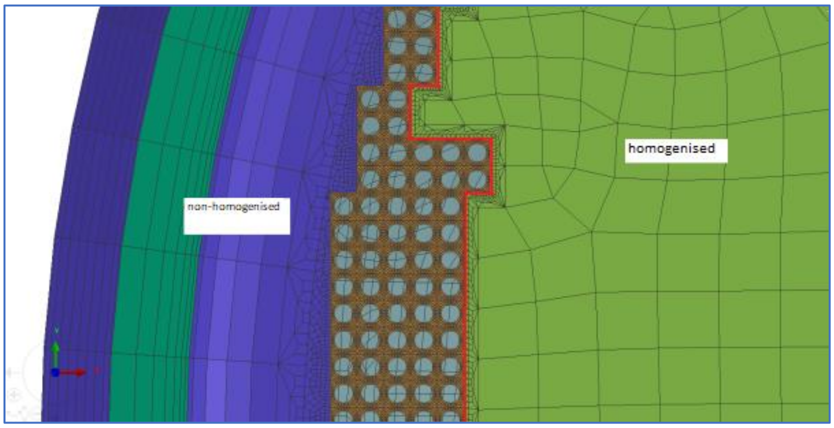

Figure 5 - Limit between homogenized and non-homogenized part

Pressure loading

Two pressure loads are treated: unit primary pressure (1 MPa) and unit secondary pressure (1 MPa).

The Figure 6 represents the isodisplacements under unit primary pressure (left) and unit secondary pressure (right).

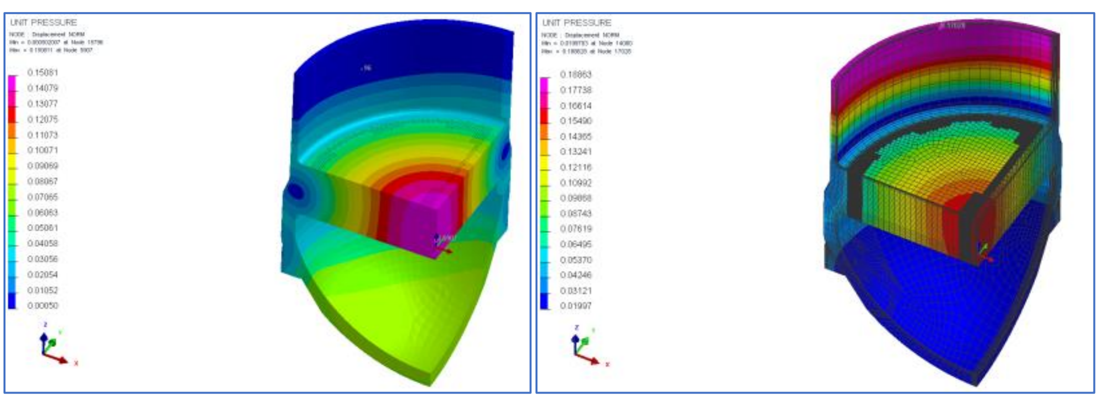

Figure 6 - Isodisplacements (in norm) under unit primary pressure (left) and unit secondary pressure (right) - Perforated model

The Figure 7 represents the Tresca isostress under unitary primary pressure while the Figure 8 represents the isostress under unitary secondary pressure.

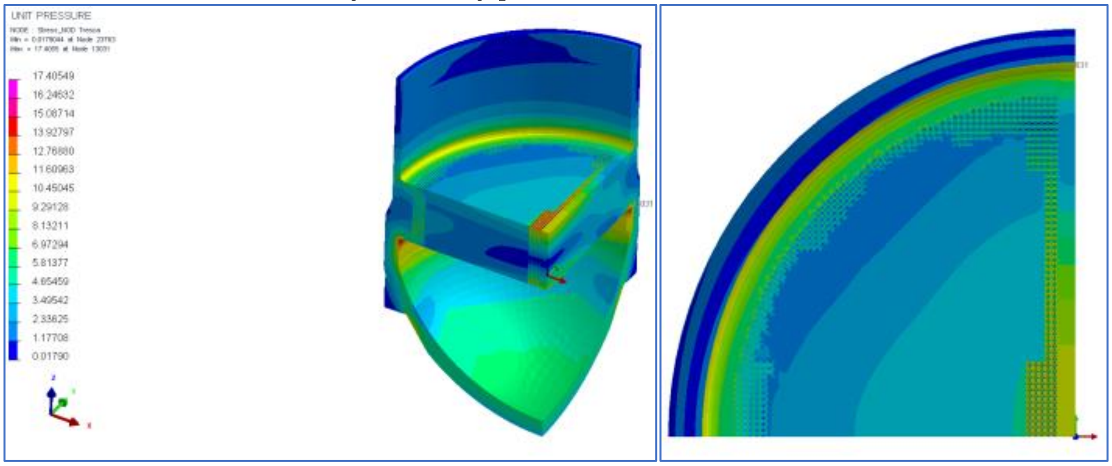

Figure 7 - Isostress (Tresca) under unitary primary pressure - Perforated model

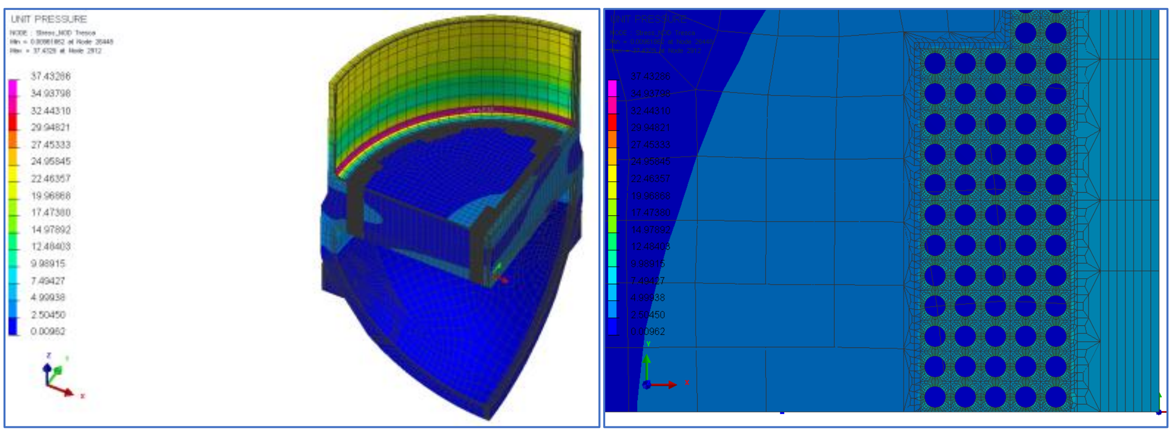

Figure 8 - Isostress (Tresca) under unitary secondary pressure - Perforated model

For each of the 2 pressure loads, the tangential stresses are post-treated at the edge of each of the 20 numbered holes on the Figure 2.

As an example, the Figure 9 provides a summary of the stresses Sφ,φ taken directly at the edge of each hole in the TIZ zone on the primary face side under secondary pressure loading.

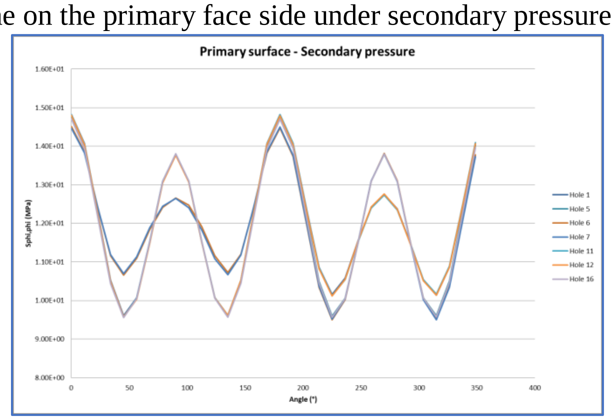

Figure 9 - Tangential stresses at the inner surface line of the holes (TIZ zone) as a function of the angle around holes at primary surface with PT under secondary pressure

Stationary thermal loading

The thermal loading consists in applying a secondary side temperature of 254°C and a primary side temperature (as well as in the TP holes) of 325°C. A steady state is calculated. The heat exchange coefficients used are 20000 W/(m^2 .°C) on the secondary side and 40000 W/(m^2 .°C) on the primary side. A heat flux density is also applied in the homogenized medium of the TP, Kv = 458113 W/(m^3 .°C).

At steady state, the isotemperatures are represented on the Figure 10.

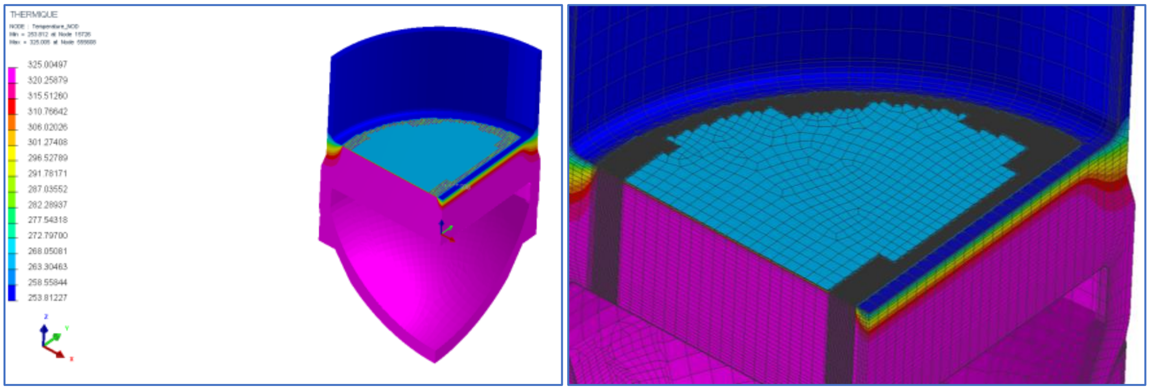

Figure 10 - Steady state temperature isolation - Perforated model

In the same way as for the pressure loads, the tangential stresses are taken at the edge of each of the 20 numbered holes on the Figure 2.

As an example, the Figure 11 provides a summary of the stresses Sφ,φ found at the edge of each hole in the TIZ on the secondary face side for thermal loading.

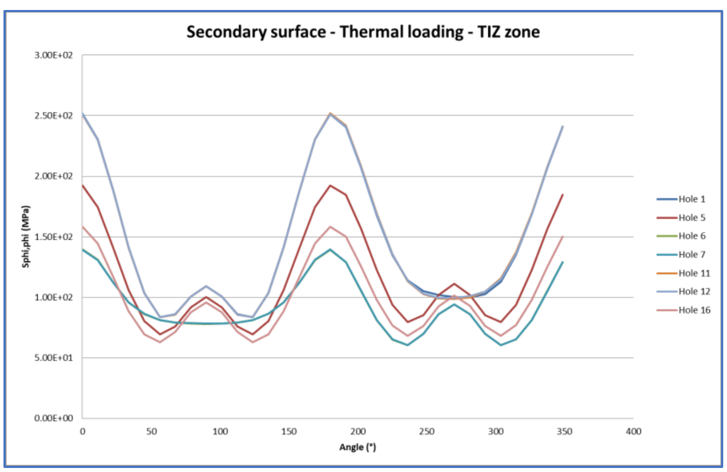

Figure 11 - Tangential stresses at the inner surface line of the holes (TIZ zone) as a function of the angle around holes at secondary surface with PT under thermal loading

CALCULATIONS ON THE MODEL WITHOUT HOLES AND DETERMINATION OF THE STRESSES AT THE EDGE OF THE HOLES VIA THE MULTIPLIER FUNCTIONS

After having carried out calculations on the TP model with explicitly modeled holes, calculations are now carried out on a model where the perforated part of the TP is entirely modeled by a homogeneous medium via equivalent characteristics. This type of model is currently used to perform regulatory analyses according to the RCC-M code.

These calculations are carried out under the same conditions as before: calculation of a unitary primary pressure loading, unitary secondary pressure loading and thermal loading (steady state).

The Figure 12 represents the isodisplacements under unit primary pressure (left) and unit secondary pressure (right), on the non-perforated model.

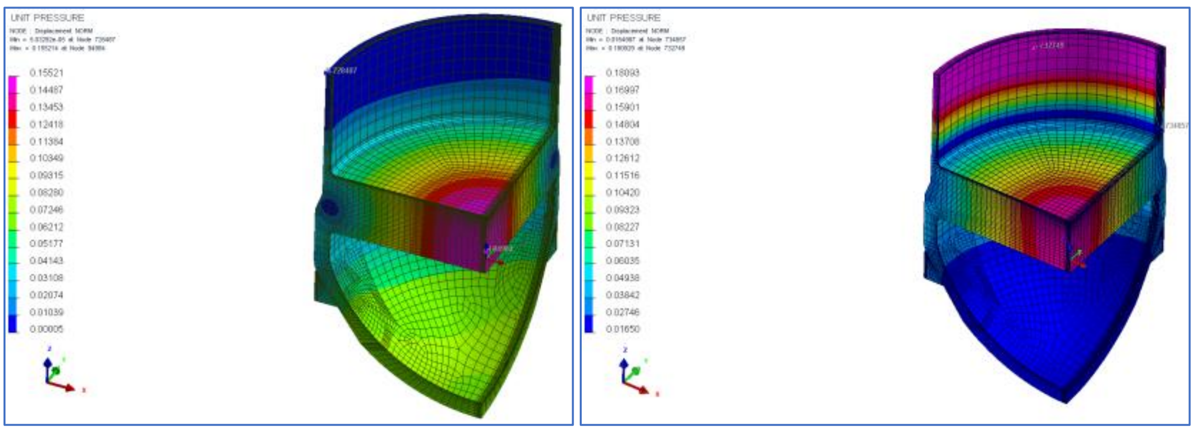

Figure 12 - Isodisplacements (in norm) under unit primary pressure (left) and unit secondary pressure (right) - Non-perforated model

The Figure 13 represents the Tresca isostress under unit primary pressure (left) and unit secondary pressure (right), on the non-perforated model.

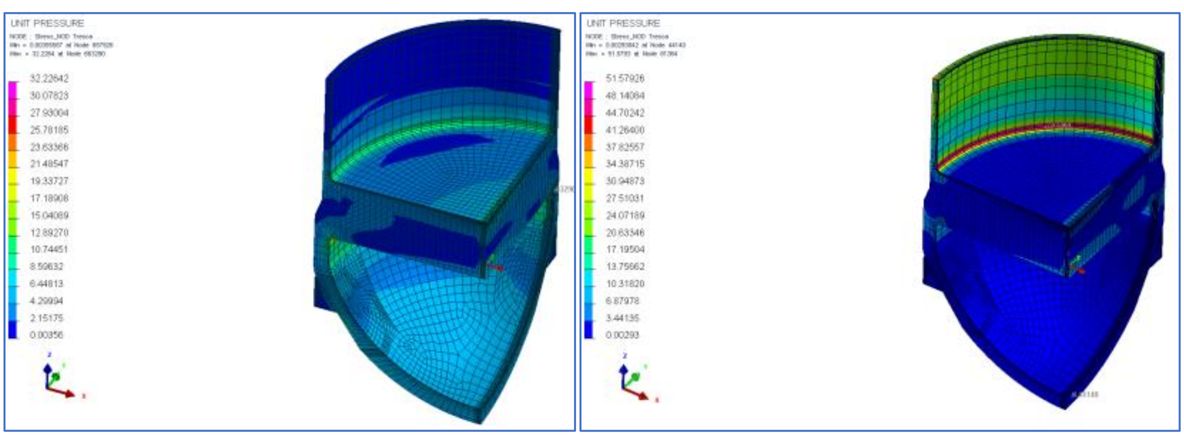

Figure 13 - Isostress (Tresca) under unit primary pressure (left) and unit secondary pressure (right) – Non-perforated model

The elementary stresses of interest Sxx, Syy and Sxy (see Formula (1)) are then recorded at the location of the 20 analyzed holes, on the primary side of the TP as well as on the secondary side.

These elementary stress are then linearly combined with each other via the multiplier functions so as to access the hole edge stress Sφ,φ.

The obtained stresses are then compared to those post-processed directly on the perforated model.

COMPARISON OF THE STRESS OBTAINED VIA THE DRILLED MODEL AND VIA THE MULTIPLIER FUNCTIONS

Comparisons are made for each of the calculated loads (primary pressure, secondary pressure and stationary thermal).

The comparisons show that the multiplier functions can provide results in very good consistency with those obtained on the perforated model. This is illustrated on the Figure 14 for some holes.

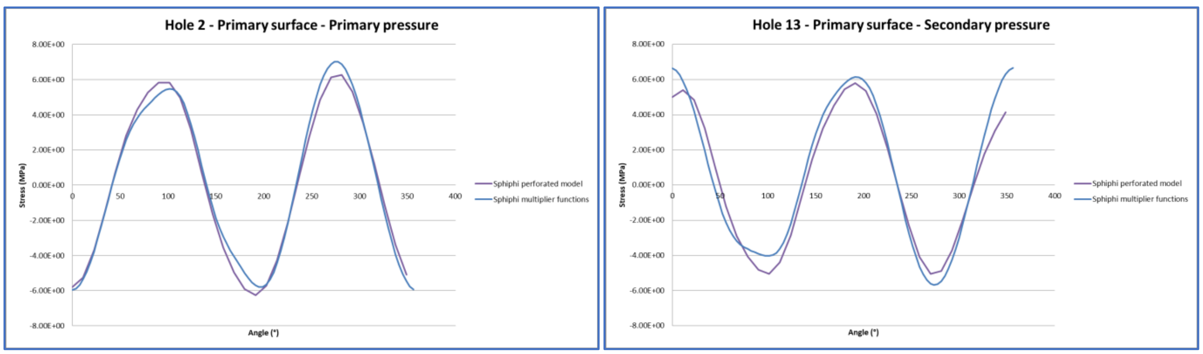

Figure 14 - Comparison of stresses (perforated model vs. multiplier functions) for some holes (pressure loading)

For other holes, the multiplier functions must be adjusted to provide more realistic results, compared to those found on the perforated model. In particular for thermal loading, the multiplier functions tend to overestimate the stress levels found on the perforated model, see examples on Figure 15.

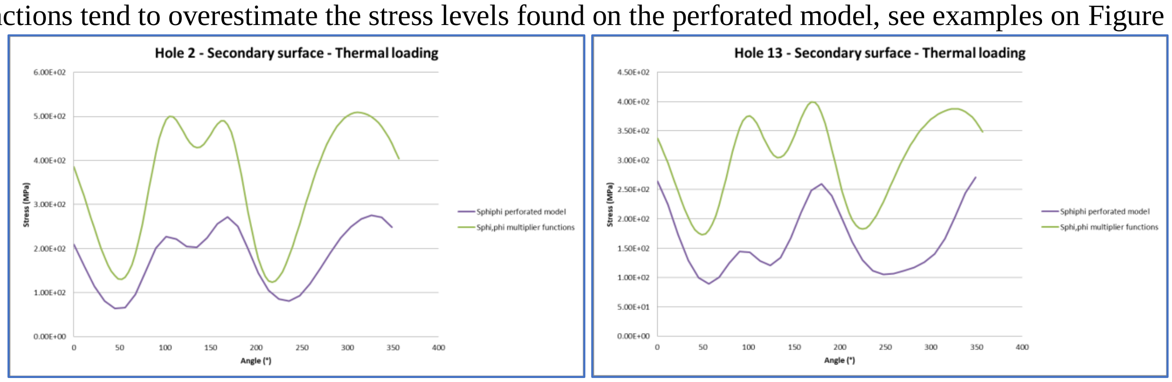

Figure 15 - Comparison of stresses (perforated model vs. multiplier functions) for some holes (thermal loading)

OPTIMIZATION OF MULTIPLIER FUNCTIONS

The optimization of the multiplier functions, for a given interface zone (TIZ, SIZ or DIZ) consists in determining a triplet [aφ; bφ; cφ], in mechanical and thermal terms, which on the one hand is independent of the angle φ around the hole, which simplifies the analyses, and on the other hand, which makes it possible to obtain a majorant of the maximum stress measured directly on the perforated model for a given zone, while minorizing the one obtained via the current multiplier functions. The triplets thus obtained are given in the Table 1.

Zone	Loading	A_{phi}	B_{phi}	C_{phi}
TIZ	Mechanics	3.83	-0.12	-0.61
	Thermal (FTE)	3.33	-0.19	-1.84
SIZ (theta=0°)	Mechanics	5.88	-0.23	-6.00
	Thermal (FTE)	3.33	-0.19	-1.84
SIZ (theta=45°)	Mechanics	8.28	-3.09	0.41
	Thermal (FTE)	3.84	-0.26	-0.26
DIZ	Mechanics	3.26	-0.37	6.03
	Thermal (FTE)	3.33	-0.19	-1.84

Table 1 - Mechanical and thermal triples for each zone

DAMPING DISTANCE OF THE INTERFACE EFFECT

In this last part, we evaluate the distance (= number of rows of holes) beyond which the holes can be considered as belonging to the common zone of the TP, these being then analyzed with the multiplier functions relative to this zone and not with the multiplier functions relative to the interface zones.

For the 45° SIZ, the visualization of the multiplier functions for holes 1, 2 and 3 (see Figure 16) shows that for holes 1 and 2, these functions do not have the characteristics of the common zone multiplier functions in terms of period and symmetry / antisymmetry. On the other hand from hole 3 onwards this is indeed the case (see Figure 17). Thus from the 3rd row of holes, these can be considered as belonging to the common zone.

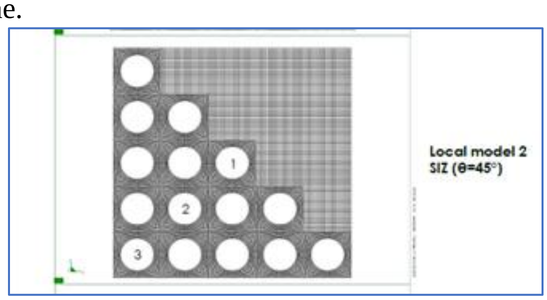

Figure 16 - Interface Effect Damping Distance - 45° SIZ - Hole Locations

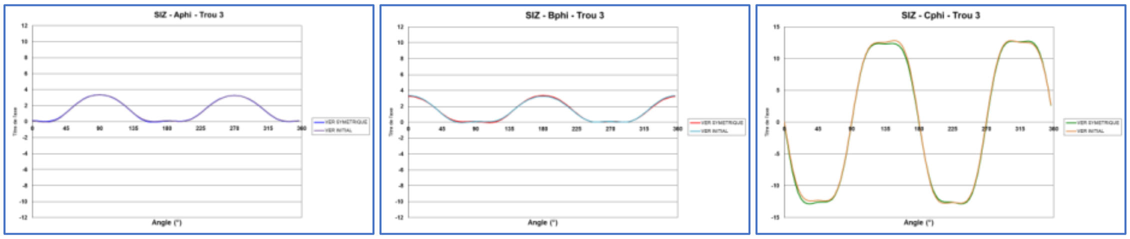

Figure 17 - Damping distance of the interface effect - SIZ at 45° - Multiplier functions hole n°3

The same analysis is conducted for the DIZ and TIZ / SIZ zones at 0° for which the damping distances are 3 rows and 2 rows respectively.

CONCLUSION

Calculations conducted on a model of the lower part of a SG with explicit modeling of the holes in the interface zones (see Figure 1) allowed direct access to the stresses concentrated at the edges of the holes. These stresses could be compared to those obtained with the multiplier functions determined in the paper, Josserand and Billon (2008).
These comparisons show that the multiplier functions can provide results in very good consistency with those obtained on the model with explicitly modeled holes, see Figure 14. On the other hand, for other holes, the multiplier functions must be adjusted, especially for the thermal loading for which they tend to give higher stresses than those obtained on the model with the explicitly modeled holes, see Figure 15.

The optimization of the multiplier functions led to the determination of so-called "mechanical" and "thermal" triplets, for each interface zone. These triplets [aφ; bφ; cφ] are on the one hand independent of the angle φ around the hole, which simplifies the analyses, and on the other hand allow us to obtain a majorant of the maximum stress measured directly on the perforated model for a given zone, while minorizing the one obtained via the current multiplier functions.

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