

RFS-CT-2006-00031 - HISTWIN
High-Strength Steel Tower for Wind Turbine

**WP3.4 – STIFFENERS TO THE DOOR OPENING OF THE
TOWER**

BACKGROUND DOCUMENT

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1. WORK PACKAGE DESCRIPTION

WP leader: AUTH

Contractors: FCTUC

Task: Evaluation of the contribution of the most common stiffening configurations around the door opening to the stability of the tower.

Deliverables: Background document

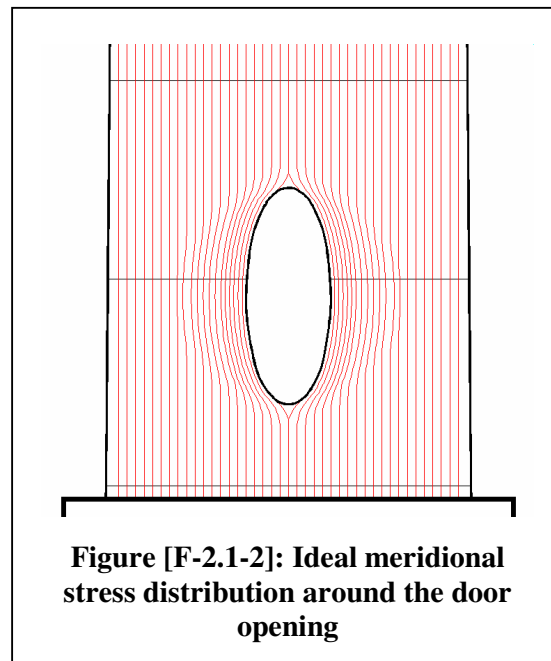
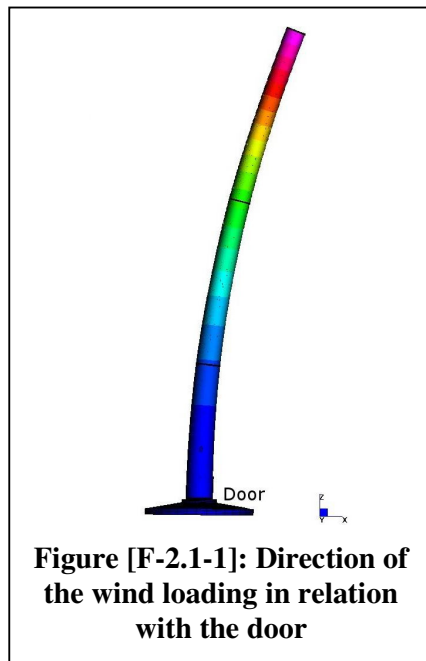
Starts: 10/06/2008

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2. BACKGROUND DOCUMENT

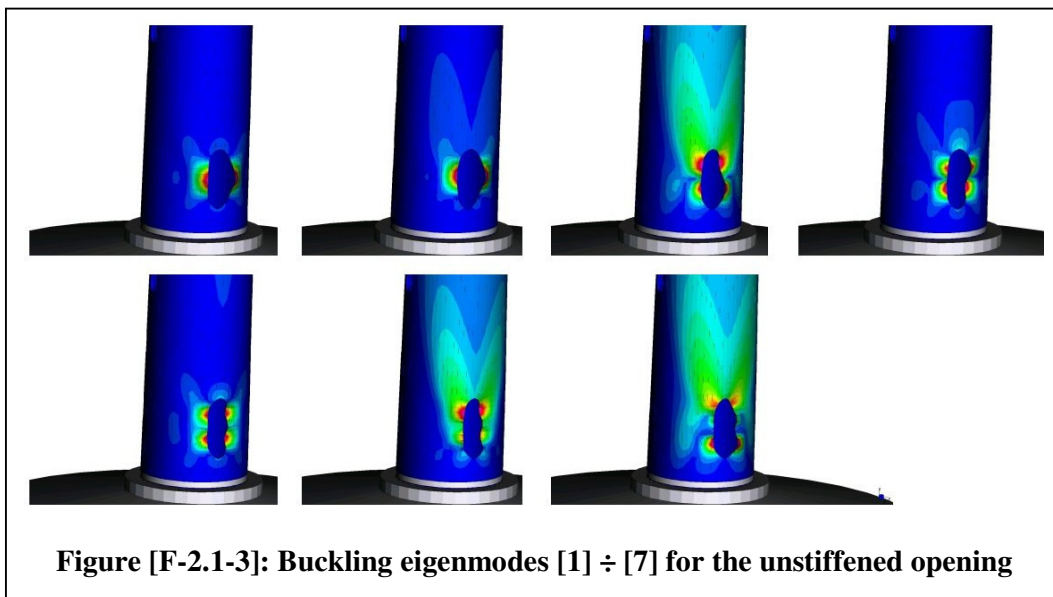
2.1. General aspects

1. The present document deals with the impact of the most commonly applied in practice types of door stiffening configurations to the resistance of the tower shell.
2. The door opening induces a significant dissipation of the shell stresses and at the same time an inevitable magnification of their magnitude, as shown in Figure [F-2.1-2] for the meridional $[\sigma_{zz}]$ component. It must be noted that the later is the critical stress at the vicinity of the door opening, as demonstrated in [WP3.1] & [WP3.2].



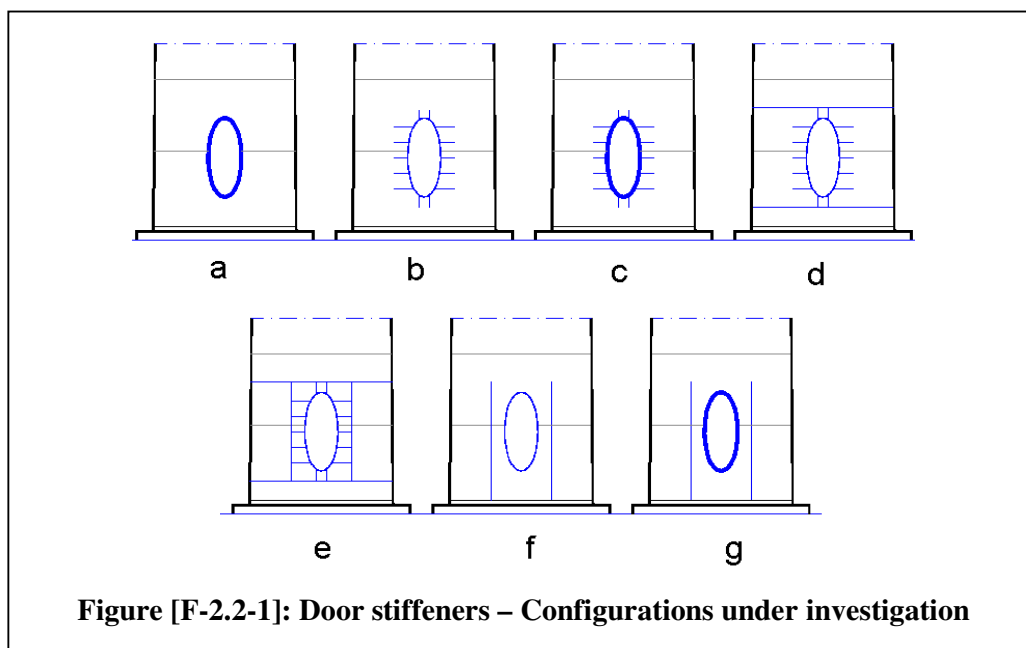
3. The ultimate limit states under examination in the present text are the plastic limit state [LS1] and the buckling limit state [LS3]. The main objective of stiffening the area around the door is to:
 - Control the local stresses, in order to prevent the excessive loading of the relevant shell courses.
 - Provide adequate lateral support to the shell and establish thus adequate resistance against buckling.
4. In [WP3.2] it was evidenced that, when performing a buckling analysis at the tower, the first ten buckling eigenmodes are detected at the upper part of the tower (courses [22] & [27]). In the case that the door stiffeners are removed, the elastic critical buckling resistance is noticeably reduced and the first seven eigenmodes are now

transferred around the door (see Figure [F-2.1-3]). This fact constitutes a direct confirmation of the contribution of the stiffeners to the buckling capacity of the shell.



2.2. Stiffening configurations

1. In order to determine the optimum stiffening arrangement around the door of the tower, seven of the most characteristic configurations are tested (see Figure [F-2.2-



1)). In all cases the extreme wind load combination was applied: $F_{Ed} = G + 1.50W$ and the response of the structure was obtained by the analyses:

- Geometrically and materially non-linear analysis [GMNA], for the plastic limit state [LS1] design.
 - The same [GMNA] analysis, for the estimation of the plastic reference resistance (plastic limit load) of the tower.
 - Linear elastic bifurcation analysis [LBA], for the local buckling assessment.
2. The configurations of the stiffeners examined are described in the following paragraphs and the corresponding figures [F-2.2-2] ÷ [F-2.2-8], where:
- The plasticized areas are represented as white
 - The Von Mises stresses of the figures at the left refer to the plastic limit state, where these at the right are derived by the application of the plastic limit load.

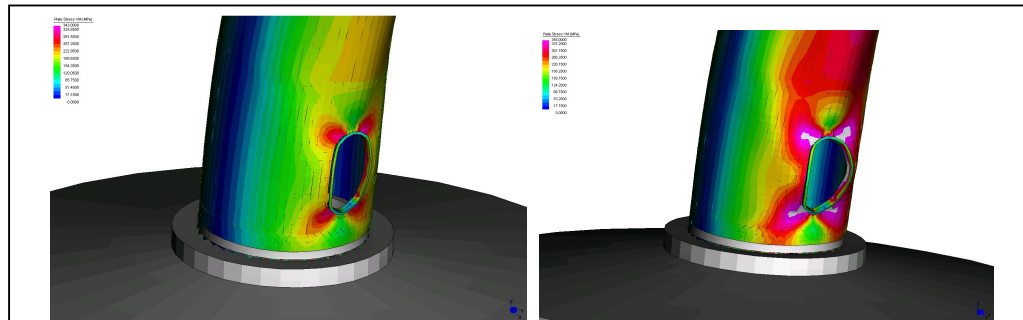


Figure [F-2.2-2]: Type [a]

- Rigid ring (t=70mm) adjusted to the opening

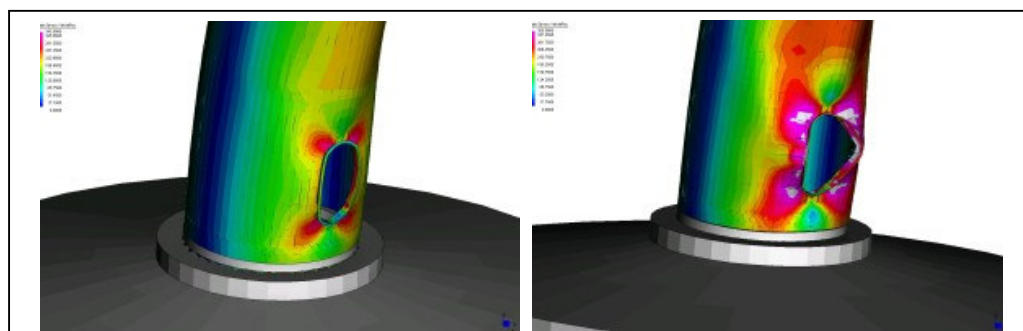
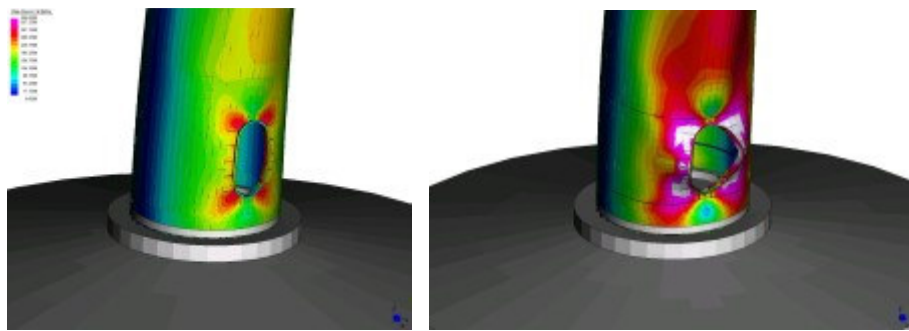
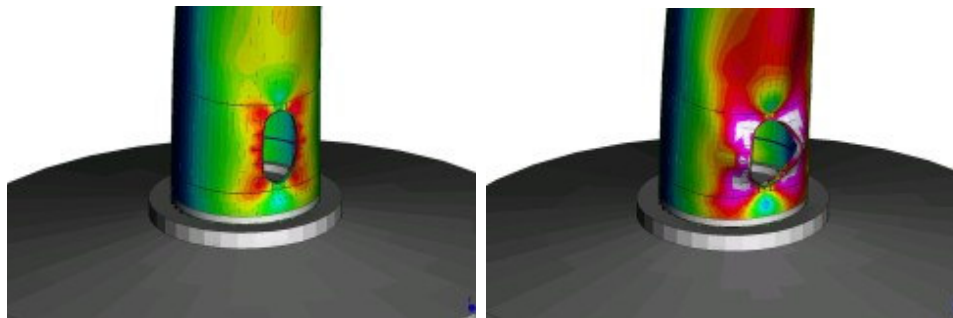


Figure [F-2.2-3]: Type [b]

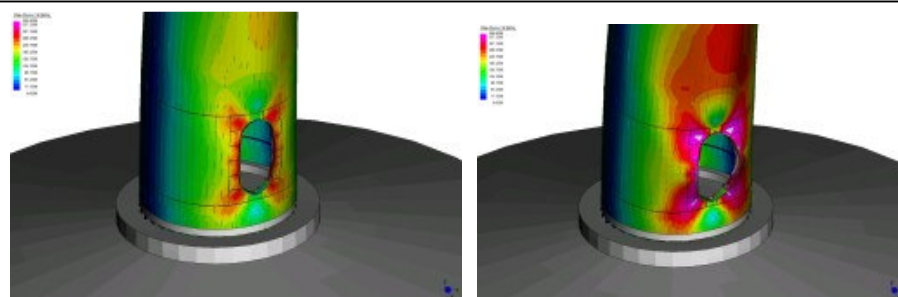
- Weak ring (t=30mm) adjusted to the opening
- Set of horizontal and vertical stiffeners locally around the ring

**Figure [F-2.2-4]: Type [c]**

- Rigid ring (t=60mm) adjusted to the opening
- Set of horizontal and vertical stiffeners locally around the ring

**Figure [F-2.2-5]: Type [d]**

- Weak ring (t=30mm) adjusted to the opening
- Set of horizontal and vertical stiffeners locally around the ring
- Two circumferential rings above and below the door

**Figure [F-2.2-6]: Type [e]**

- Weak ring (t=30mm) adjusted to the opening
- Set of horizontal and vertical stiffeners locally around the ring
- Two circumferential rings above and below the door
- Vertical stiffeners between the circumferential rings, at both sides of the door

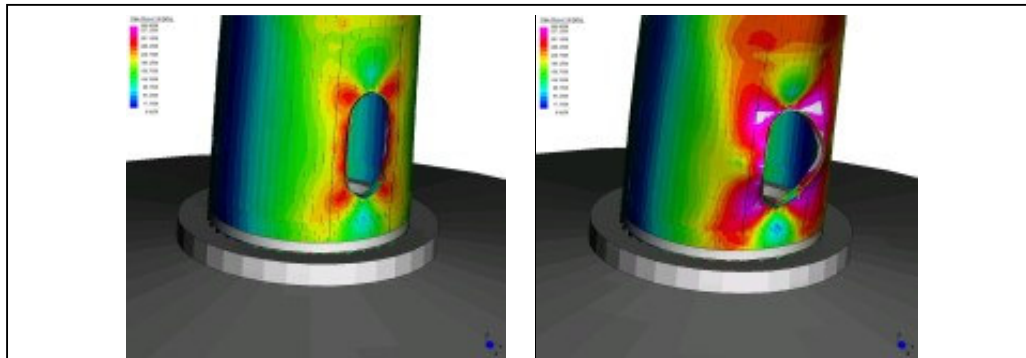


Figure [F-2.2-7]: Type [f]

- Weak ring (t=30mm) adjusted to the opening
- Vertical stiffeners at both sides of the door

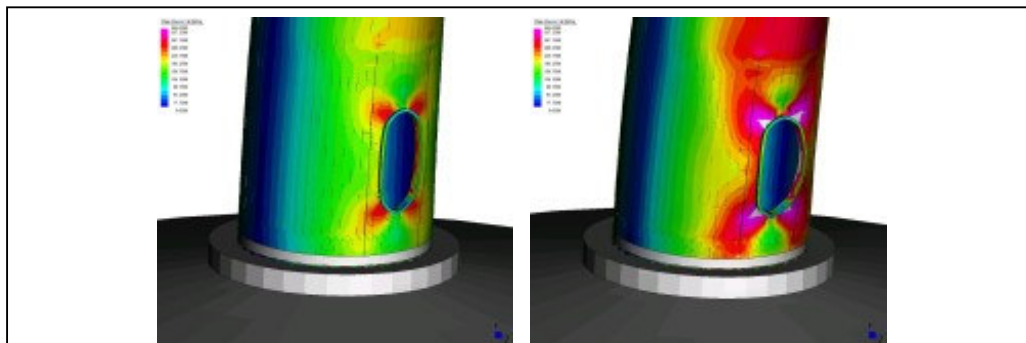


Figure [F-2.2-8]: Type [g]

- Rigid ring (t=70mm) adjusted to the opening
- Vertical stiffeners at both sides of the door

2.3. Evaluation of the results

1. All types of stiffening arrangements examined seem to be satisfactory and are adequate in preventing the elastic buckling of the shell around the door opening. As a cogent evidence of this fact, it is remarked that the first 10 buckling eigenmodes have been found at the higher courses of the tower (see Figure [F-2.3-2]) and not at the door courses.
2. As a consequence, the plastic limit state [LS1] remains the only ultimate limit state to be considered for the dimensioning of the lower part of the tower. A comparison of the Von Mises stresses to the shell and to the stiffening components of this specific area is presented for each case in Table [T-2.3], together with the global limit load factor of the tower.

3. By the investigation of the relative results of the analyses, a rigid ring around the door opening is always mandatory, even if additional stiffening plates are installed. The governing stress in all cases is the meridional $[\sigma_{zz}]$ and the vertical segment of the ring accumulates the major part of the stresses that otherwise would pass through the opening area (see Figure [F-2.3-1]).

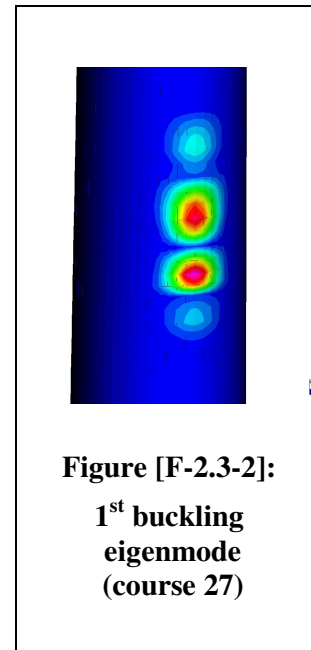
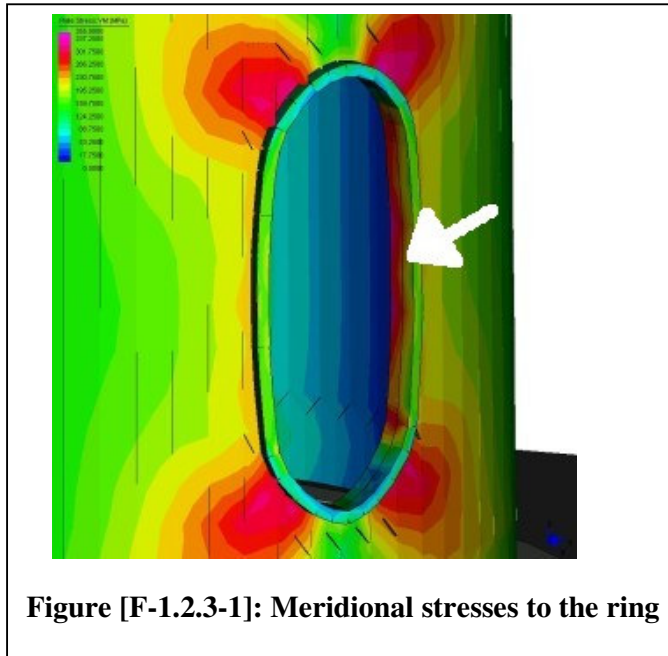
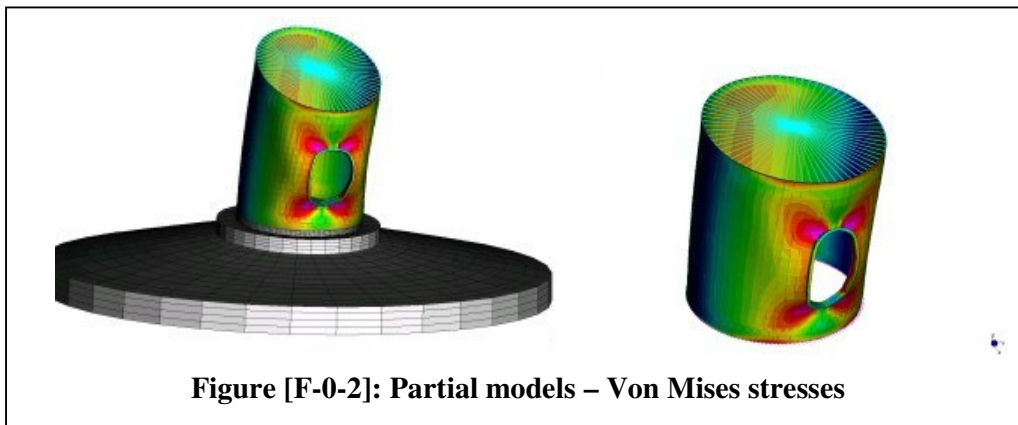
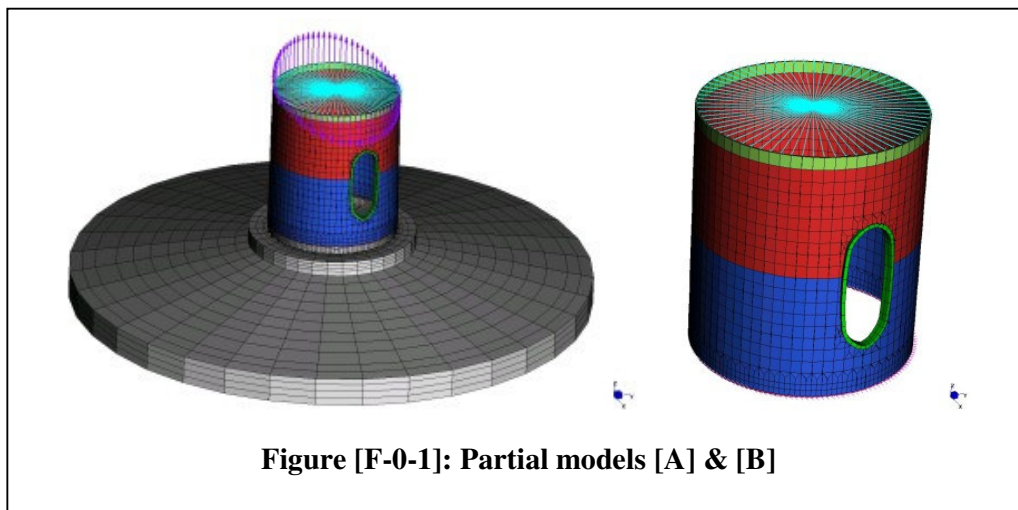


Table [T-2.3]: Stresses around the door				
Type	Von Mises stresses (Mpa)			Plastic resistance ratio (r_{Rpl})
	Shell	Ring	Stiffeners	
[a]	340	348	---	2.05
[b]	349	466	147	1.95
[c]	316	356	229	2.05
[d]	350	465	159	1.95
[e]	326	448	295	2.00
[f]	327	467	298	1.95
[g]	291	302	248	2.10

2.4. Analyses with the aid of partial FE models

1. The tower under examination has been modeled with all the structural parts and elements included in detail. However, two additional models have been developed, incorporating the lower part of the overall model, the scope of which is the investigation of the accuracy of the analyses, when the calculations are performed by hand or by the use of a linear model. These models are:
 - Model [A]: The model comprises the first two bottom courses, the anchoring system and the foundation.
 - Model [B]: The model comprises the first two bottom courses, clamped to the base. The foundation is not implemented.



2. The section forces $[M_x]$, $[M_y]$, $[V_x]$, $[V_y]$ and $[N]$, as derived by hand calculation or from the linear model, are applied to the top, along the free boundary circumference of course [2].

3. Although this procedures require less modeling and computational effort, certain assumptions are inevitably introduced the models, such as:

- Using section forces provided by hand or a linear model, the influence of the circumferential stresses to the shell, induced by the specific load distribution on the tower stem (see [WP 3.1] & [WP 3.2]), has been ignored.
- In linear model calculations, the Euler-Bernoulli assumption (beam section remains undeformed in its plane and vertical to the theoretical axis) is directly adopted. With the objective of realizing this assumption to the partial FE model, all the nodes of the force application level the are connected to each other by means of special rigid links. At the same time, the implementation of this technique allows the smooth transfer of the sectional forces to the shell.

4. As evidenced by the analyses results in Table [T-2.4], the convergence between the stress state of the global and the partial models can be considered satisfactory in general, the Von Mises stresses derived from the partial models being no more than 7% lower.

Table [T-2.4]: Von Mises stresses (Mpa)		
Model.	shell	ring
Global	340	348
Partial [A]	331	334
Partial [B]	320	325

2.5. Concluding remarks

1. In all types of stiffening arrangements that have been tested, the ultimate load for the tower is located at the vicinity of the door opening and is stimulated by the plastic limit state [LC1].
2. As results from the above analyses, the presence of a rigid ring around the door provides the best reinforcement to the opening, in contradiction to the other types of stiffeners, the contribution of which is comparatively less effective.
3. Stiffening by means of horizontal stiffeners around the door has not significant impact to the resistance of the opening. Vertical stiffeners are more effective, since they efficiently undertake the meridional stresses. Even to the door ring, it is the vertical segment which is fully stressed.
4. For the specific tower, the use of a linear model or a hand-calculation approach, along with an additional FE model for the door detailing, results to a 5% ÷ 7% decreased stress state, compared to the one corresponding to the more accurate full model.

2.6. References

- [1] EN 1993-1-1: Design of steel structures – General rules and rules for buildings, 2005
- [2] EN 1993-3-1: 2006: Design of steel structures – Towers, masts and chimneys – Towers and masts, 2006
- [3] EC 3-1-6: Design of steel structures – Strength and stability of shell structures, 2006
- [4] GL Wind 2003 IV – Part1: Guideline for the Certification of Wind Turbines, 2004