Appendix to report:

SBJ-33-C5-OON-22-RE-019

DESIGN OF CABLE STAYED BRIDGE

Appendix title:

APPENDIX F – SHELLDESIGN

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CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

Table of Content

1 INTRODUCTION

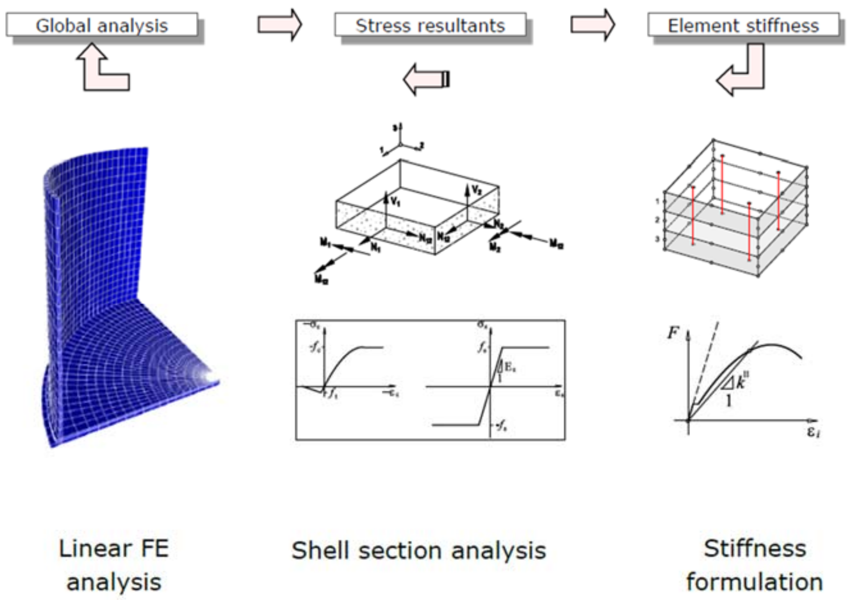
This appendix includes most of the results from analysis used as a basis for design of the concrete tower.

ULS/SLS of operational phase according to [1]
Free standing cable stayed bridge according to [3]
Free standing tower according to [3]
Free standing in construction phase according to [3]

A short summary describing ShellDesign is presented below. ShellDesign performs design calculations (ULS, ALS, SLS, FLS code checks) based on section geometry, section forces, amounts of reinforcement and material properties. Section geometry and forces can either be user defined or results from a finite element analysis where the model has been modelled with shell and/or solid elements. The nonlinear material behavior of reinforced concrete is included in the sectional design. ShellDesign is based on plate- and shell theory.

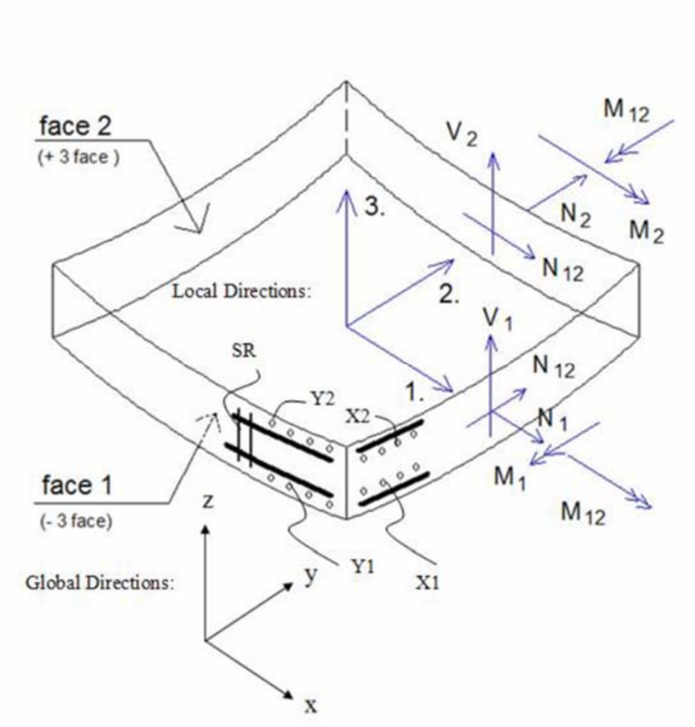
The common practice is to use the Conventional Design Method (CDM) where the design calculations are based on results from linear elastic structural FE analyses. This allows for use of the principle of superposition, which is convenient when there are a lot of loads that must be combined to several load combinations. The design calculations accounts for the nonlinear behavior of reinforced concrete due to cracking etc. when establishing the response of the cross-section.

ShellDesign has also the capability to include the non-linear material behavior of reinforced concrete into the structural FE analysis (nonlinear FE-analysis). The method is based on an iterative analysis/design process. The method is named the Consistent Stiffness Method (CSM) and is illustrated in the figure below.



The model is divided into shell sections for each gauss point in the element model. The 1,2,3-axis system below controls the direction of reinforcement and printing of sectional forces.

For the tower “face1” is facing inwards in to the center of the cross section. X-reinforcement is placed horizontally, and Y-reinforcement is vertical i.e. reinforcement layer and corresponding utilization for X1 is for the horizontal direction inwards toward the center.

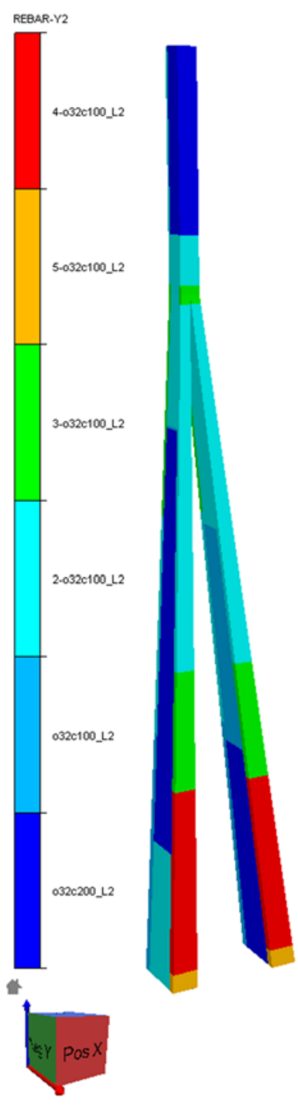


2 TOWER

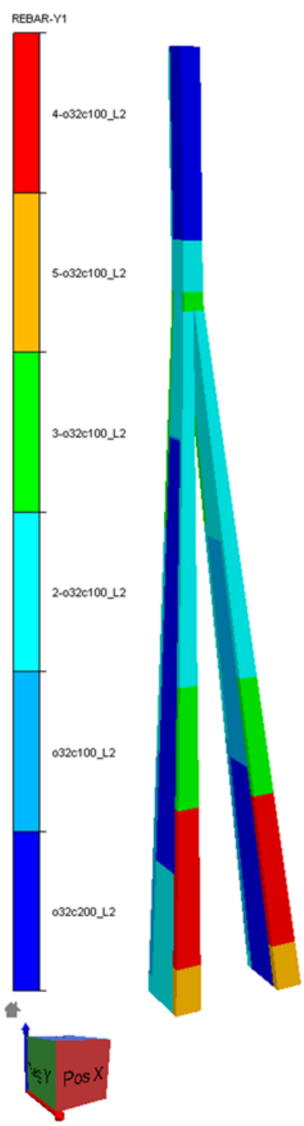
Design code check in accordance with EC 1992 is done for the tower in different stages, operational, free standing tower, free tower before the legs meet and tower with stay-cables before connection to the rest of the bridge is done. These material properties used and the utilization of the concrete and reinforcement in these different phases are shown in the following.

2.1 Material properties and intensities

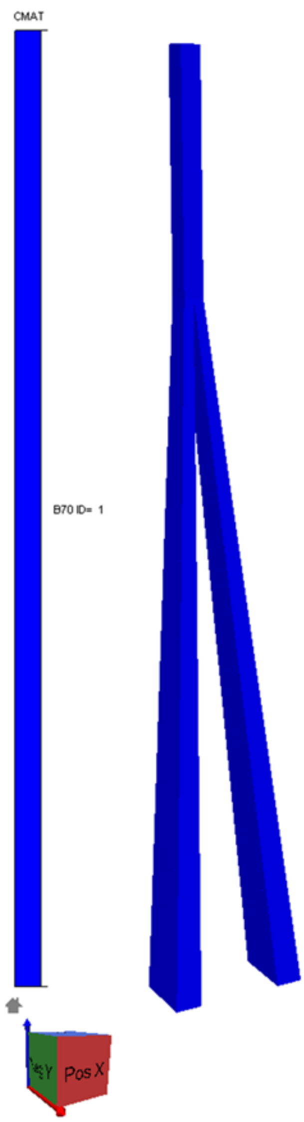
The figures below show the actual reinforcement in the tower. This will give an average reinforcement intensity just shy of 300kg/m3. There are quite a lot of reinforcement in some section, in a later phase it could be investigated whether the total posttensioning should be increased in order to reduce the amount of regular reinforcement.



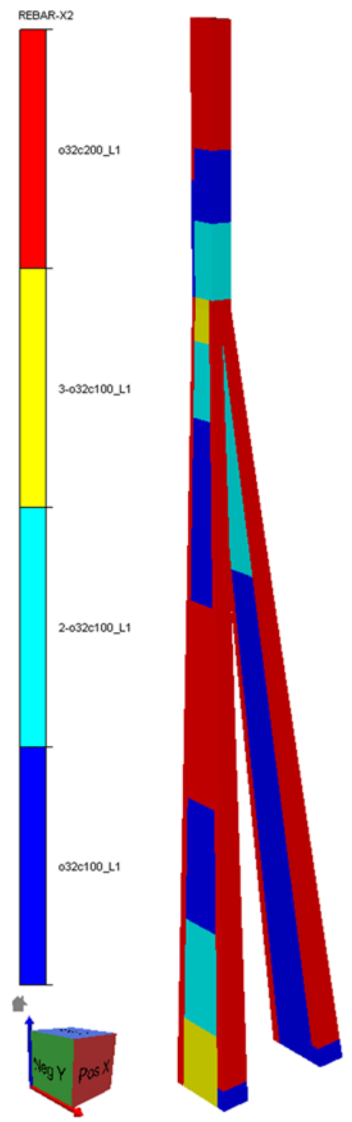
Vertical reinforcement, outside



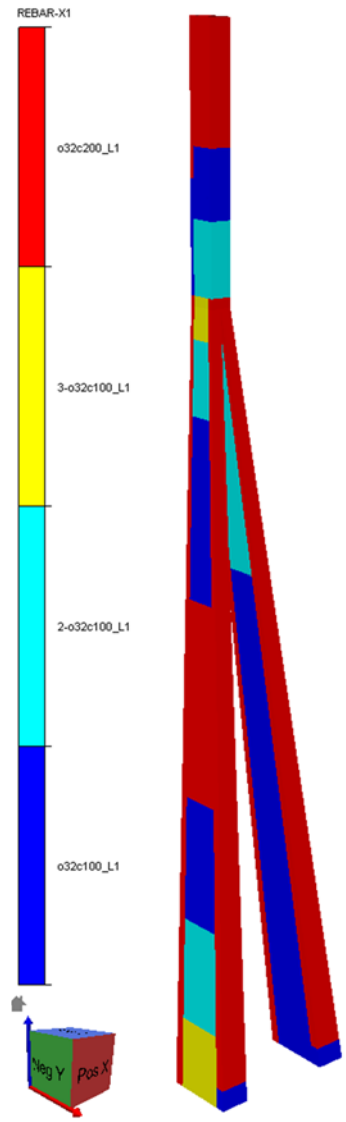
Vertical reinforcement, inside



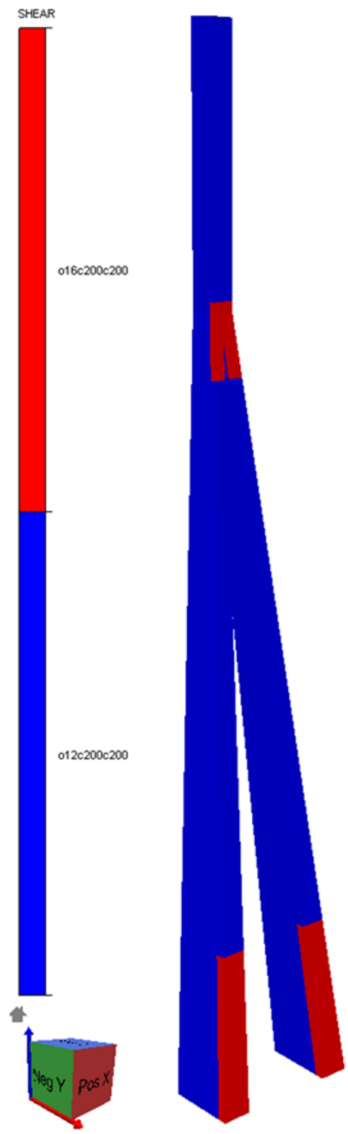
Concrete material



Horizontal reinforcement, outside



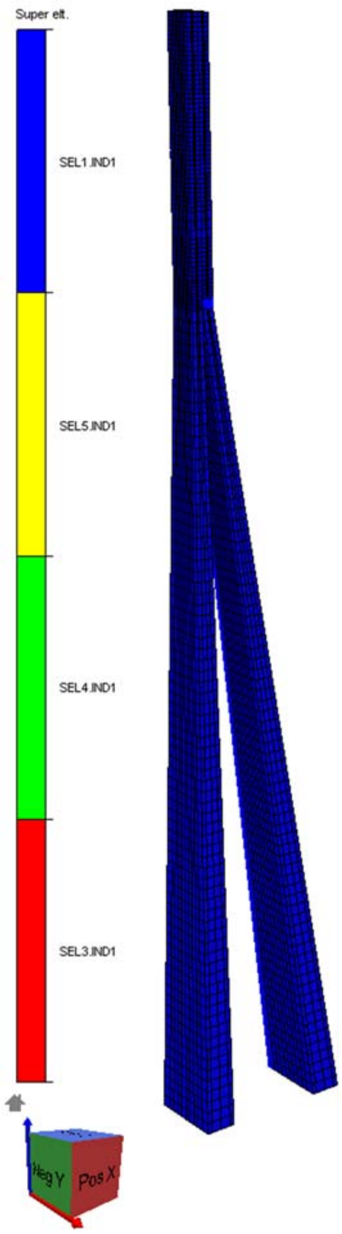
Horizontal reinforcement, inside



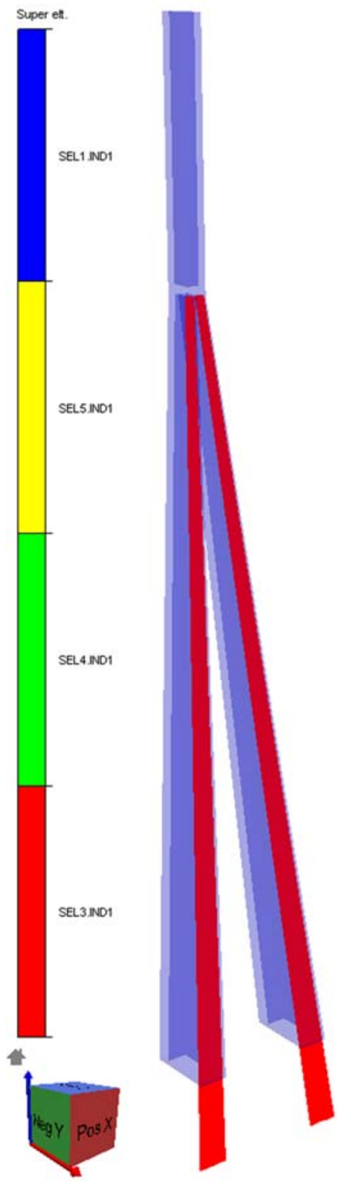
Shear reinforcement

2.2 Tower in operational phase

The operational phase is generally the dominant phase for the tower utilization. Below utilization is given for concrete compression, shear reinforcement, crack width and reinforcement in both directions. For phase 1 and 2 (se figure on previous page) the worst of them is presented here as they are quite similar. The color scale is equal for all following pictures from blue (UR=0) to red (UR0=1.0). All sections with purple color have an UR > 1. The utilization rations shown are the largest (peak) values in each section points in the model from each load case.

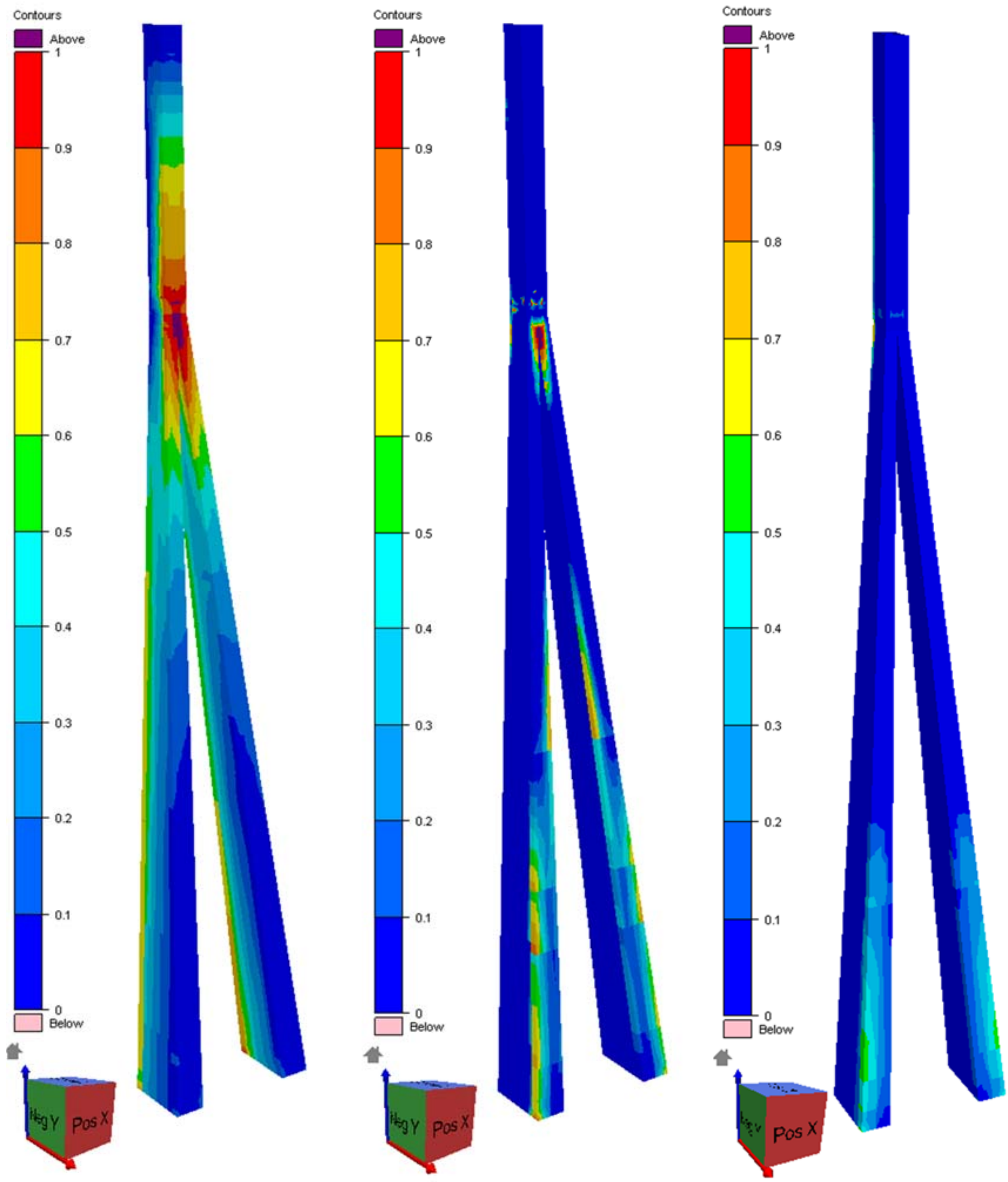


FEM analysis model



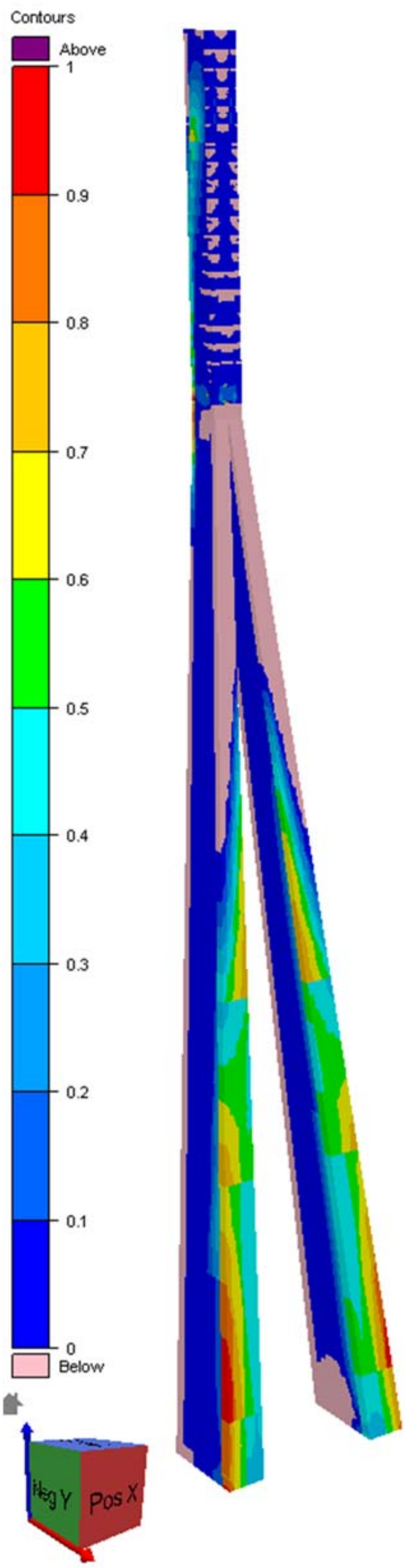
Post-tensioning layout

2.2.1 Utilization levels

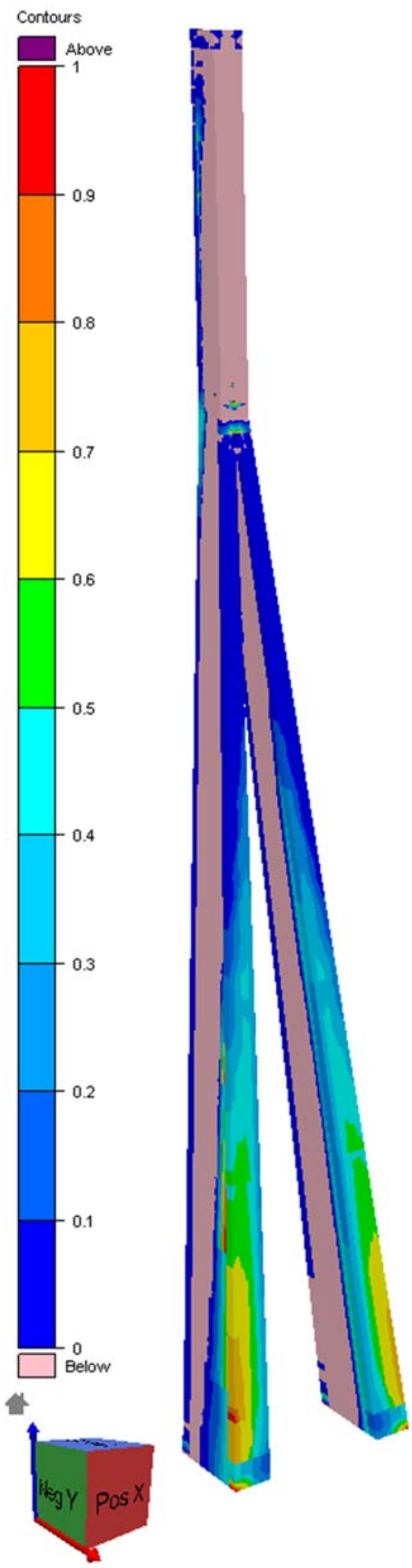


Concrete compression Shear reinforcement Crack width

The area where the two towers meet is solid concrete (and not a hollow section as the rest) and does not fulfill the assumptions necessary for this kind of analysis. The over utilization shown in this very local area is expected here.

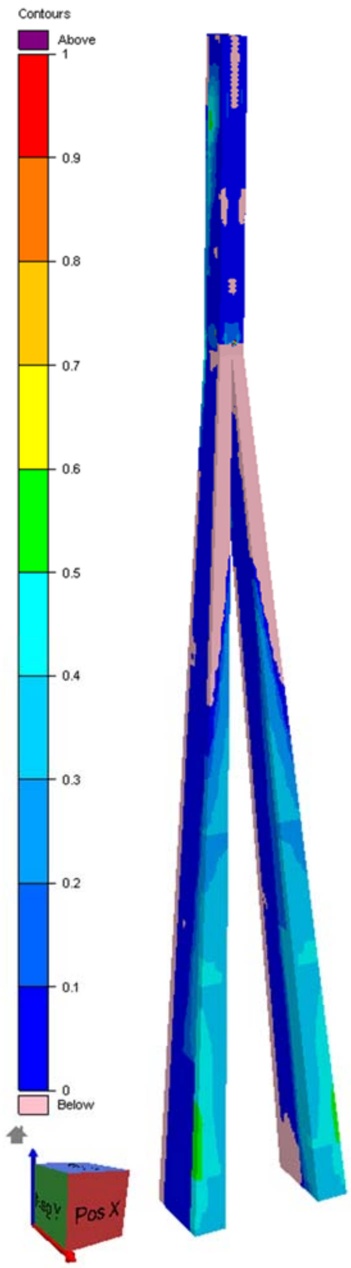


Vertical reinforcement

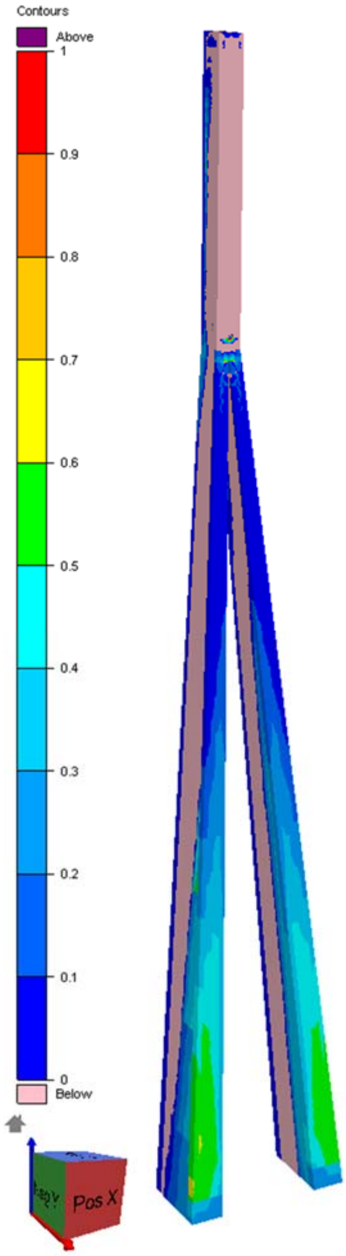


Horizontal reinforcement

In the figures below are the utilization from the non-linear iterative analysis/design process (Consistent Stiffness Method) shown. For each iteration the stiffness in each design point is evaluated based upon the sectional forces and the reinforcement, concrete and tendon at that section. The proses stops when the maximum deflection converges to a set criterion. As can be seen be comparing these pictures with the one on the previous page is that the peaks have disappeared. This is possible because the forces have been redistributed to a place in the section with a higher stiffness and capacity. The intensity of reinforcement needed from a linear analysis is much higher and this shows that the tower has a lage capacity for redistribution.



Vertical reinforcement, non-linear analysis

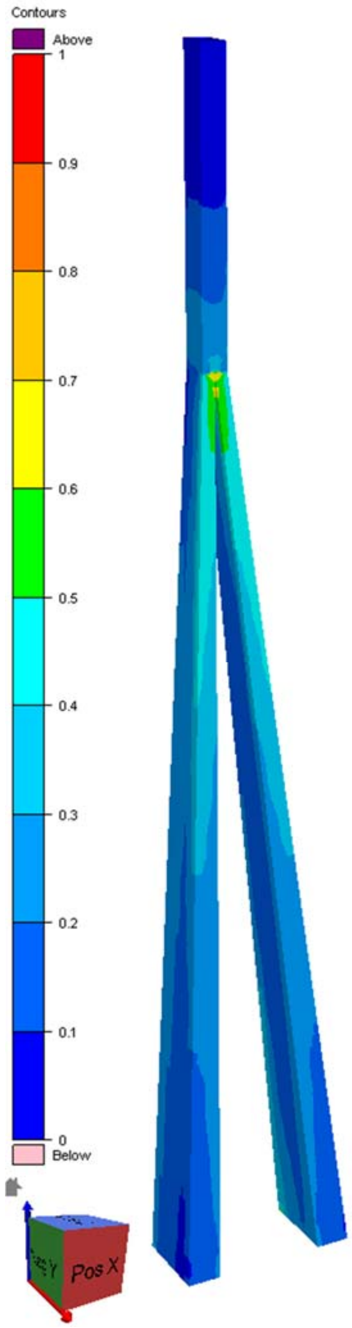


Horizontal reinforcement, non-linear analysis

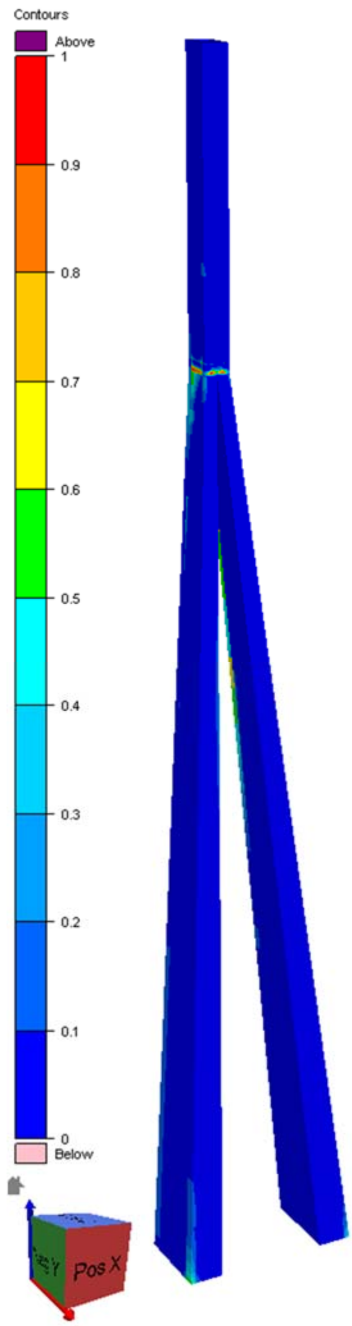
2.3 Tower free standing

2.3.1 Utilization levels

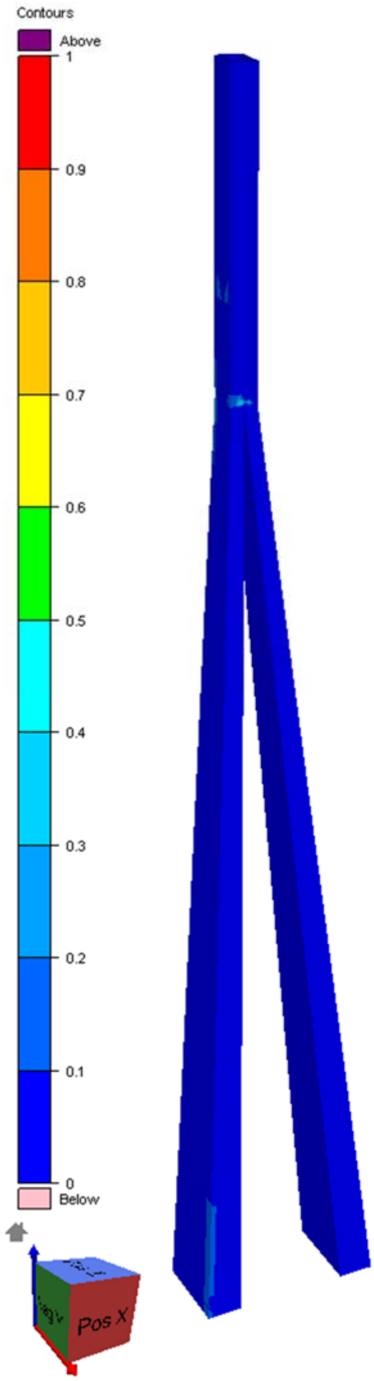
The vertical reinforcement in the south facing wall is dimensioning for this phase. The post tensioning corrects for the horizontal component of the self-weight and with a high wind pressure from the south the tension is high here.



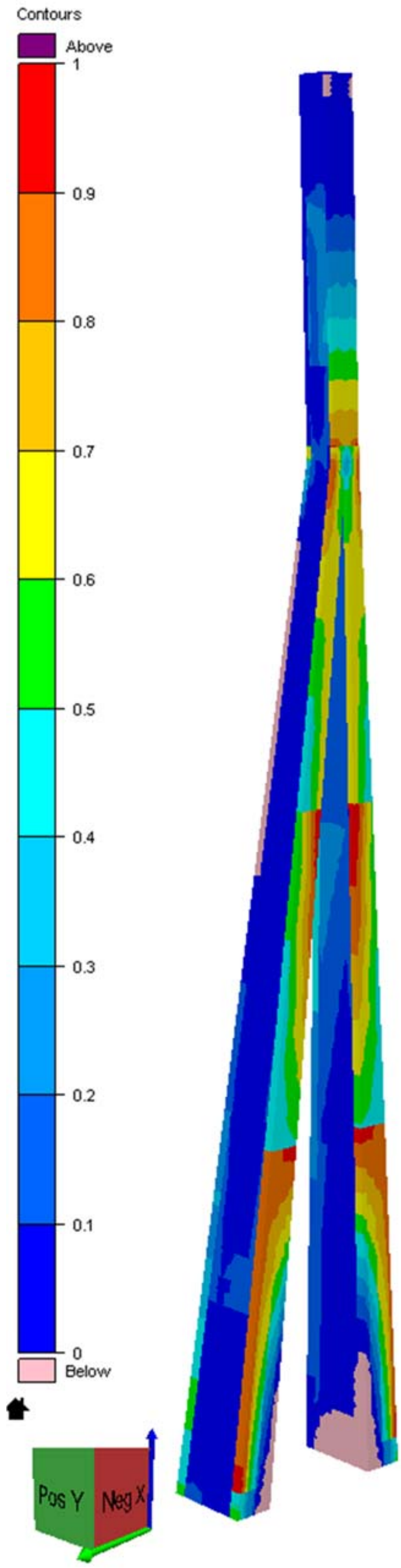
Concrete compression



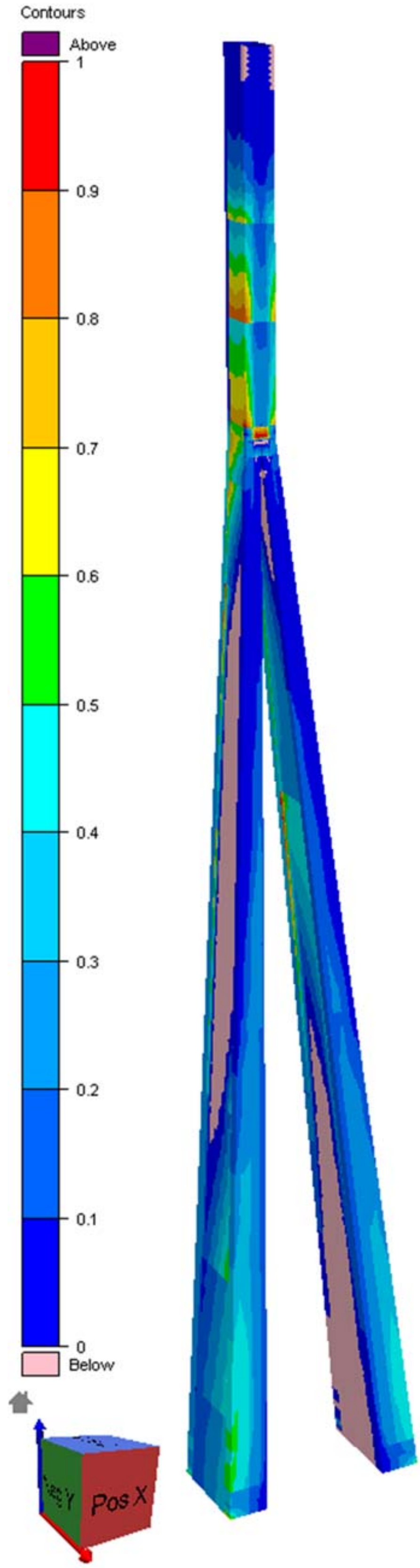
Shear reinforcement



Crack width

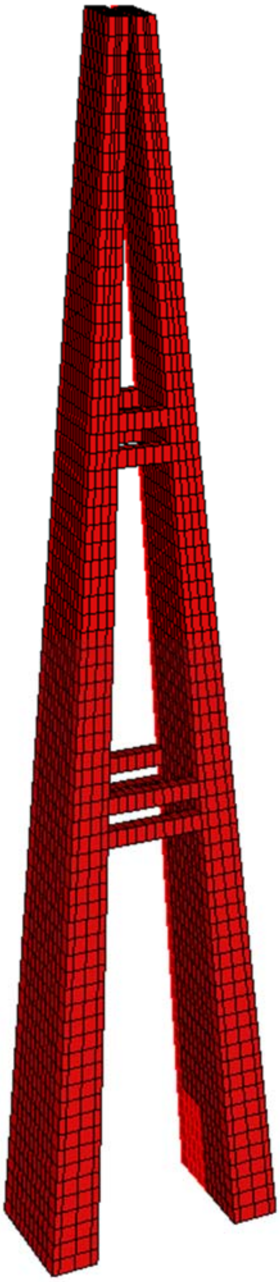


Vertical reinforcement

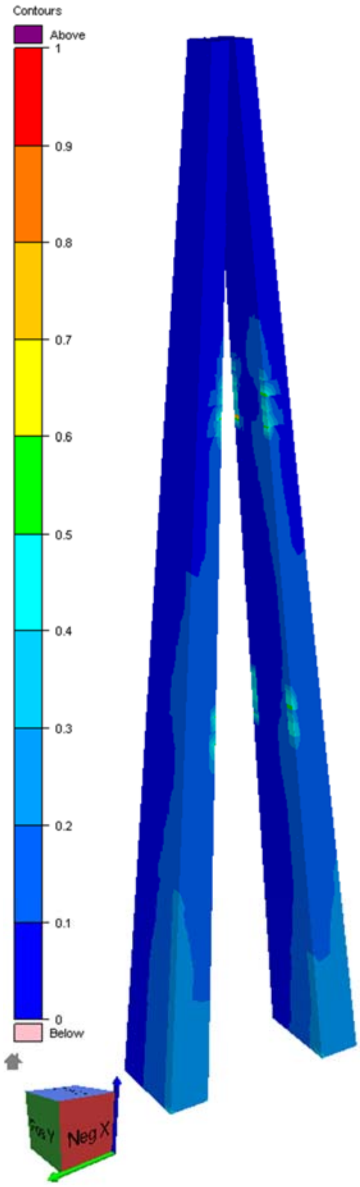


Horizontal reinforcement

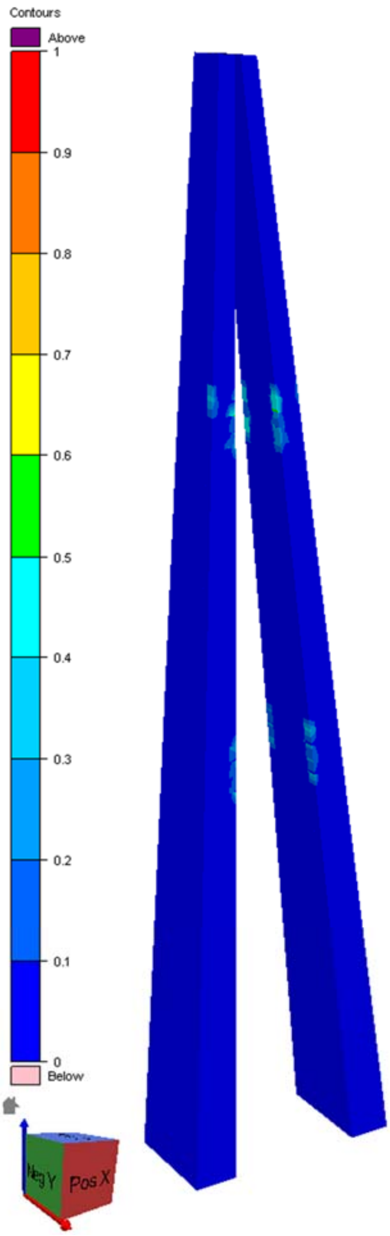
2.4 Tower free standing, temporary phase



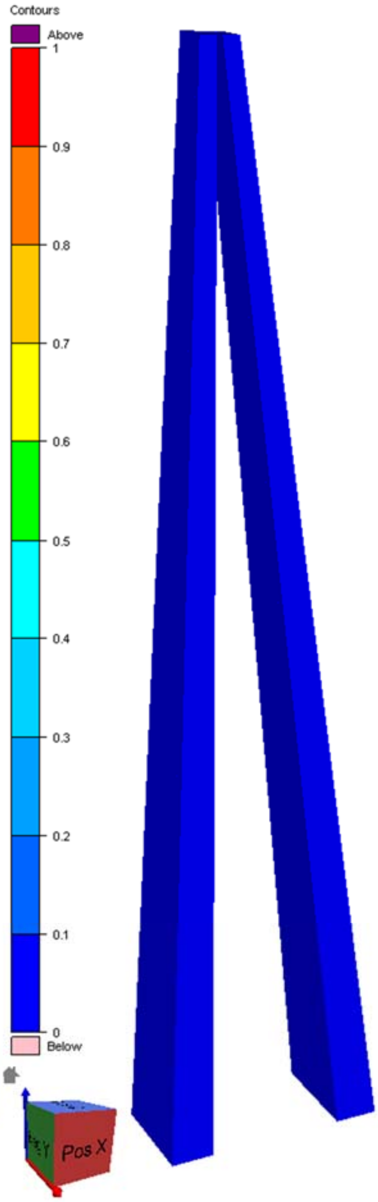
2.4.1 Utilization levels



Concrete compression

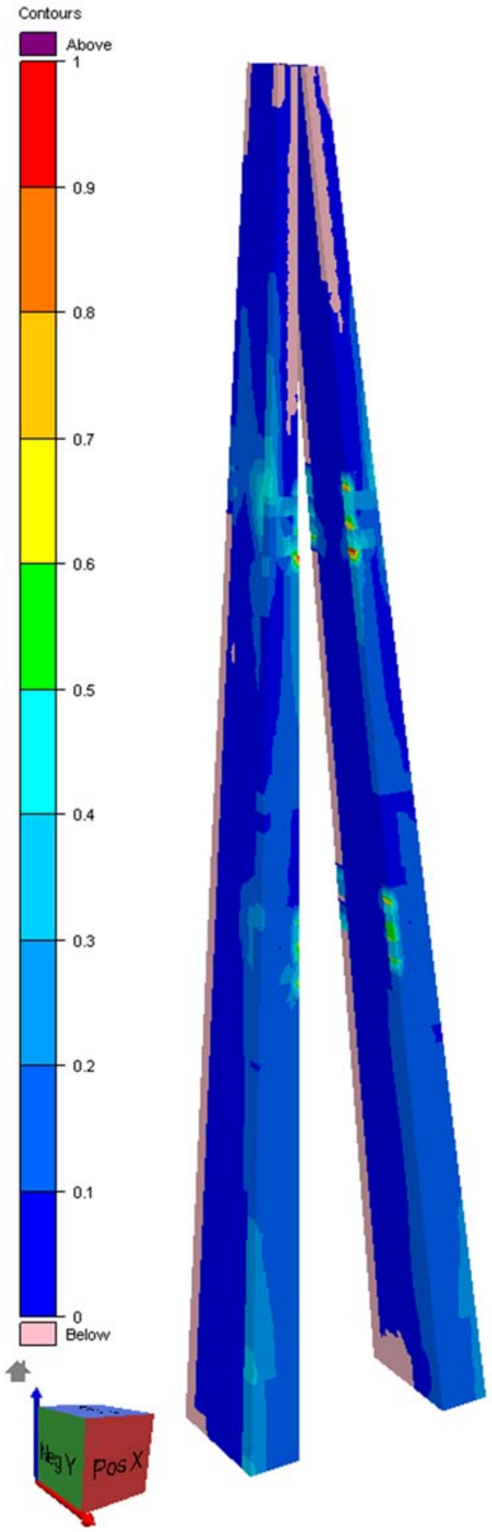


Shear reinforcement

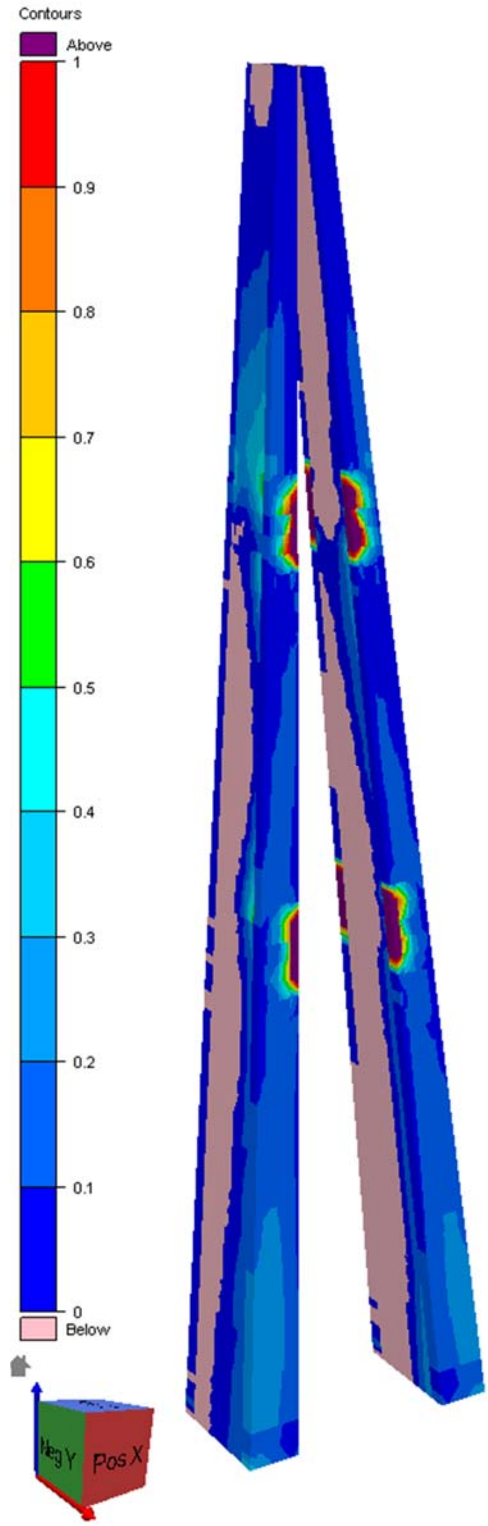


Crack width

The local areas that are over utilized (purple area in horizontal reinforcement) corresponds with the temporary bracing. The temporary bracing is included in the FEM analysis, but not shown here.



Vertical reinforcement

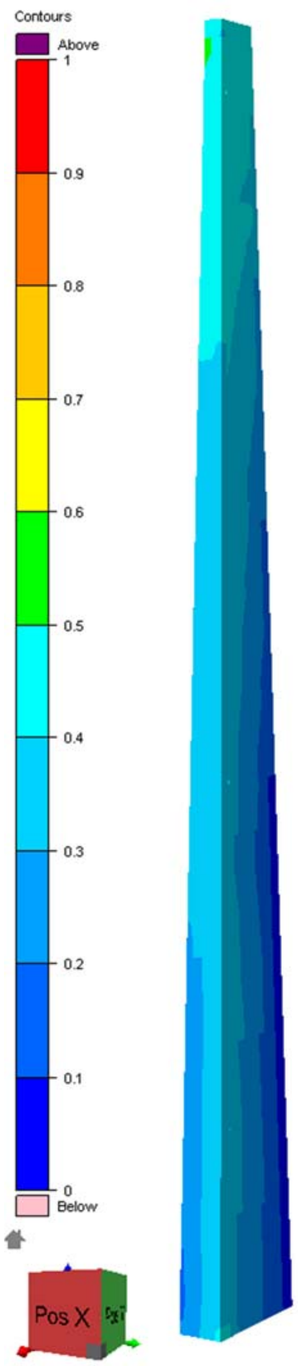


Horizontal reinforcement

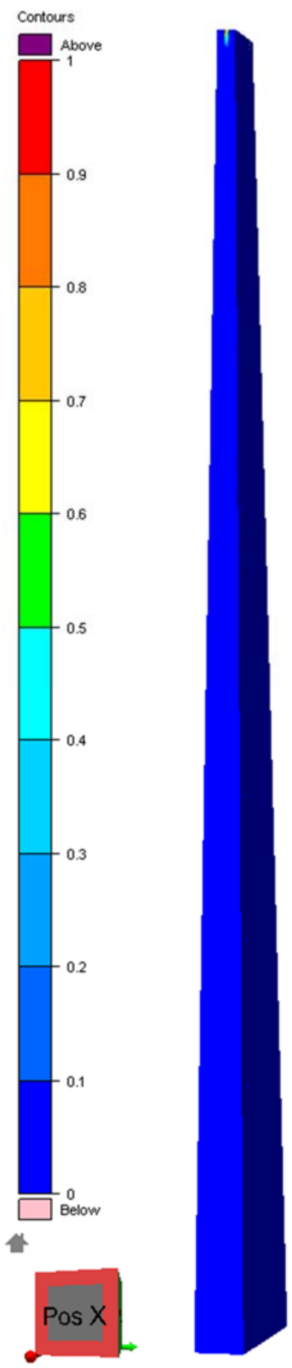
2.5 Tower in free standing stay-cable phase

2.5.1 Utilization levels

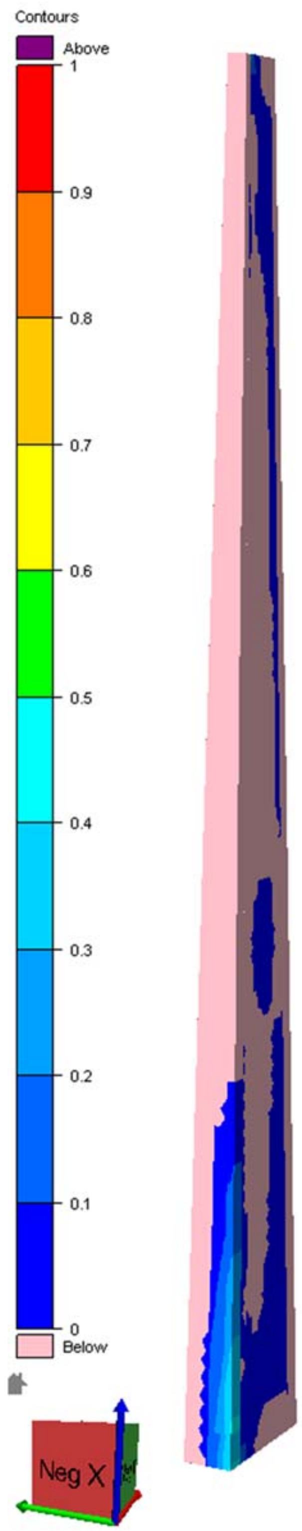
For this phase the sectional forces from the bottom of the tower is matched with the forces from the dynamic model. For this reason, the only interesting section in this model is the lower part. The rest of the sections are not investigated further because of the low utilization ratio.



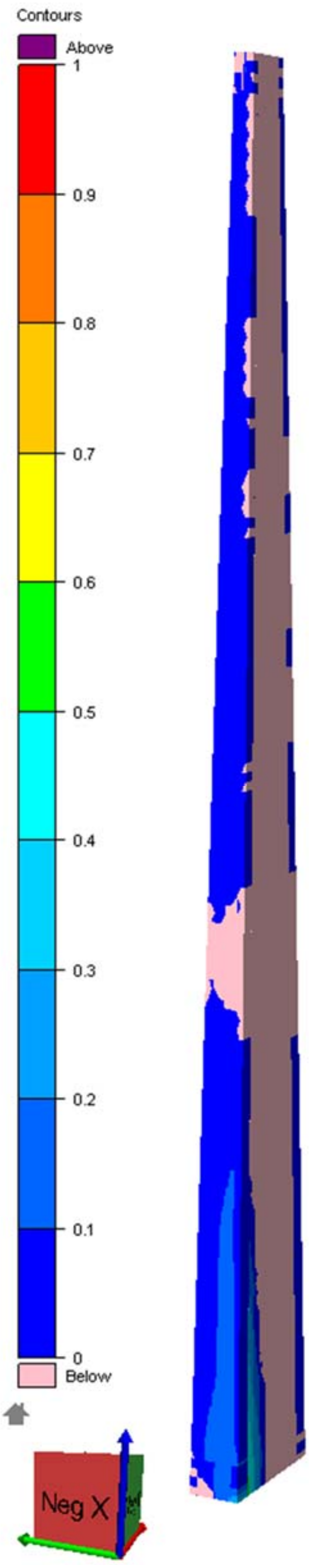
Concrete compression



Shear reinforcment



Vertical reinforcment



Horizontal reinforcment

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