Calculation No:<u>NSTXU-CALC-11-23-00</u> **Revision No: <u>0</u>**

Title Halo Current Force Restraints for OBD12 Tile Assemblies

Purpose of Calculation: (Define why the calculation is being performed.)

The purpose of this calculation was to optimize the design of the restraints that support the OBD12 tile assemblies against inplane halo current forces.

Codes and versions: (List all codes, if any, used)
ANSYS 17.2

References (List any source of design information including computer program titles and revision levels.)

PFC Material Comparison, Art Brooks Spreadsheet
Grafoil Engineering Manual, 2nd Edition, Copyright 2002
20170818 Halo Forces spreadsheet by Art Brooks
E-ED1408, Row 1 and 2 Outboard Divertor Tiles Assembly and Details

Assumptions (Identify all assumptions made as part of this calculation.)
Halo current forces applied to the old 1.0" tiles can be scaled up by the thickness ratio (1.911)
The outermost restraint resists radial and toroidal forces; the innermost restraint resists toroidal forces only.
A reduced model, encompassing the outer support, with half of the toroidal forces applied, and the full radial force, will be sufficient to achieve the purpose of this calculation.
Grafoil pads transfer reaction forces to the tile, as in the design.
Constraints (radial or toroidal) are applied to the free Grafoil surfaces that provide restraint in this direction.

Calculation (Calculation is either documented here or attached)

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)
The maximum and minimum principal stresses in the support area are 3.29ksi and -7.70ksi. Tensile and compressive allowable stresses are 2.97ksi and -7.97ksi, respectively.

Cognizant Individual (or designee) printed name, signature, and date

Robert Ellis Digitally signed by Robert Ellis Date: 2018.09.24 09:58:34 -04'00'

Preparer's printed name, signature and date

Robert Ellis Digitally signed by Robert Ellis Date: 2018.09.24 09:58:59 -04'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Jiarong Fang

Jiarong Fang Digitally signed by Jiarong Fang Date: 2018.09.27 09:48:39 -04'00'

Introduction
The OBD12 tile assemblies experience halo current forces during disruptions. Art Brooks prepared a spreadsheet with halo current forces on the old (1" thick) tiles. The inplane forces (radial and toroidal) have been scaled by the thickness ratio of the new tiles to the old (1.911) in order to obtain force estimates for the OBD12 tile assemblies, each of which replaces a pair of the old Row 1 tiles and a pair of Row 2 tiles.

Pockets on the bottom of the graphite tile engage a pair of stainless steel keys with 1/16" thick Grafoil bumpers on their perimeter. The Grafoil is a soft material that distributes the load uniformly over the mating surfaces, eliminating line contact between stainless steel and graphite. The toroidal halo current force is split between two keys; the radial force is resisted by the outboard key only.

Calculation
A reduced model has been used to optimize the design of the halo current restraints. It is a 4.0" square block, 0.60" thick, with a 2.4" * 1.3" pocket in the bottom. The inner vertical faces of the keys are 2.21" * .125" and 1.11" * .125". The corner radii are 3/32", and there is a 1/16" radius between the roof and the sides. Grafoil pads, 1/16" thick, are added to two vertical faces.

The Brooks spreadsheet gives radial forces of 771N and 520N on rows 1 and 2, 519N and 495N toroidally. This scales to 554 lbf radial and 436 lbf toroidal forces. Since our model only contains one restraint, it experiences half of the toroidal force, or 218 lbf. These forces are applied as pressures, so on one face of the model we have 231psi (554lbf/2.4in2) and on the other we have 91psi (218/2.4).

Solid187 ANSYS elements are used in the model. There are 173,006 elements and 249,196 nodes.

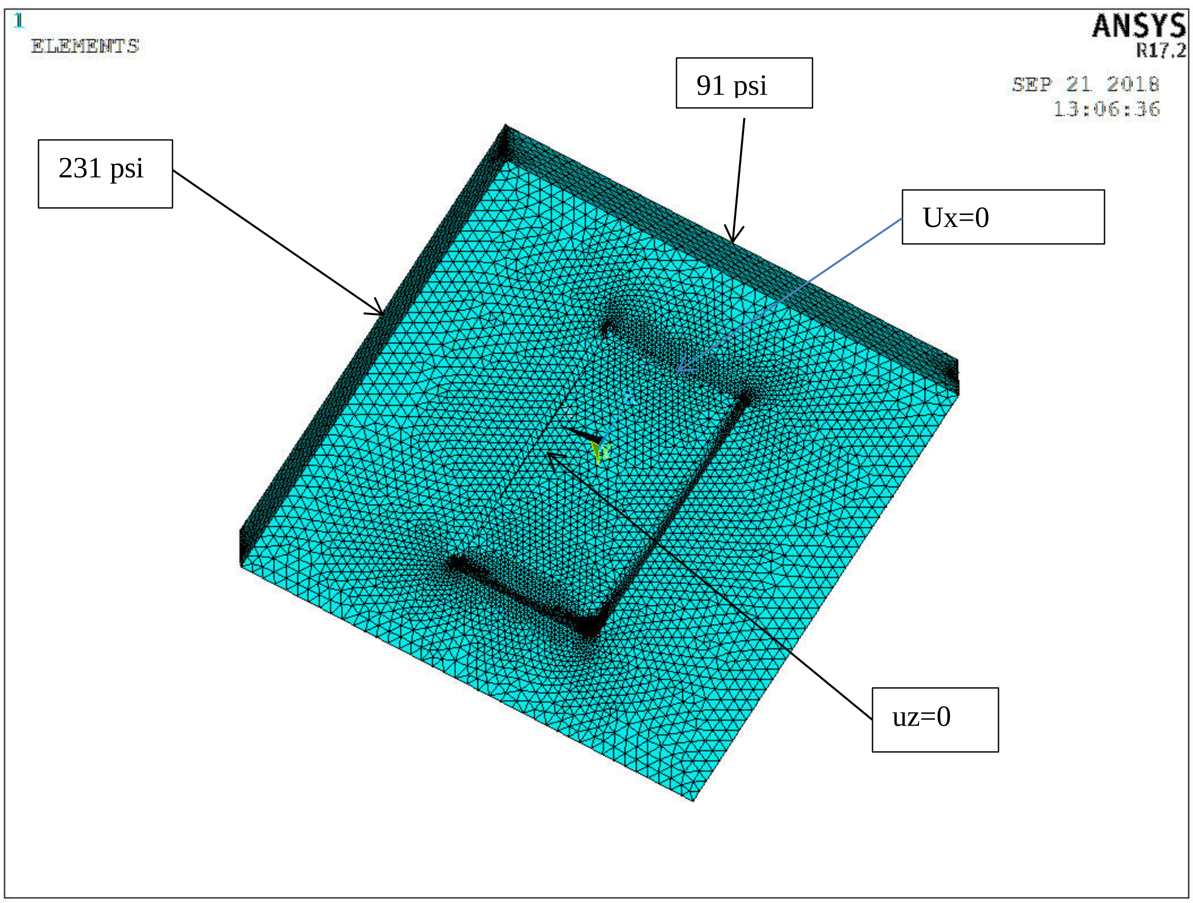

Figure 1. Model and constraints

The bottom surface is constrained in the vertical, or y, direction. Pressure loads are applied in the x-direction and z-direction as shown. X and Z displacement constraints are applied to the Grafoil pads as shown in figure 1.

Material properties used are: for graphite, $E=1.52*10^6$psi, ν=.3. For Grafoil, $E=2.9*10^4$ and ν=.3.

A linear elastic solution was run. Plots of maximum and minimum principal stress follow.

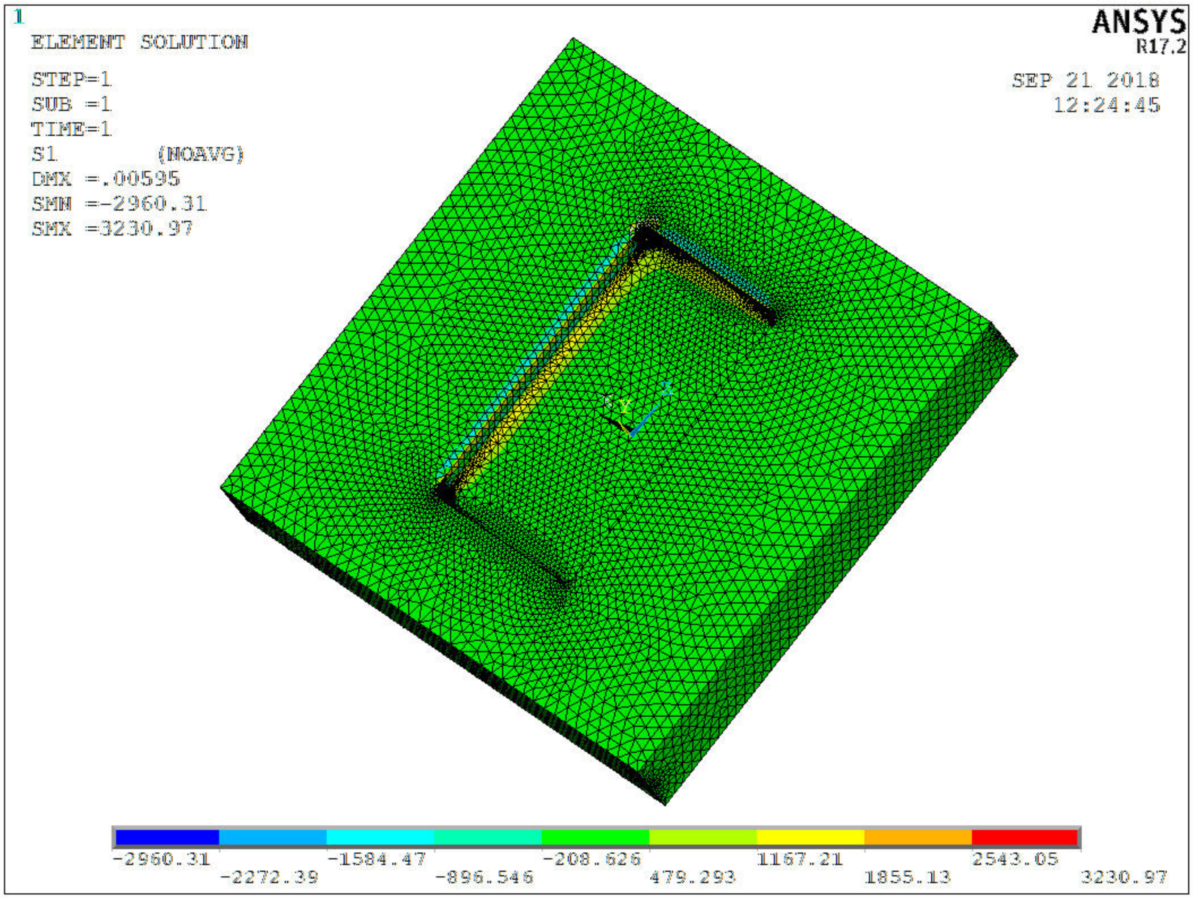

Figure 2. Maximum principal stress in graphite

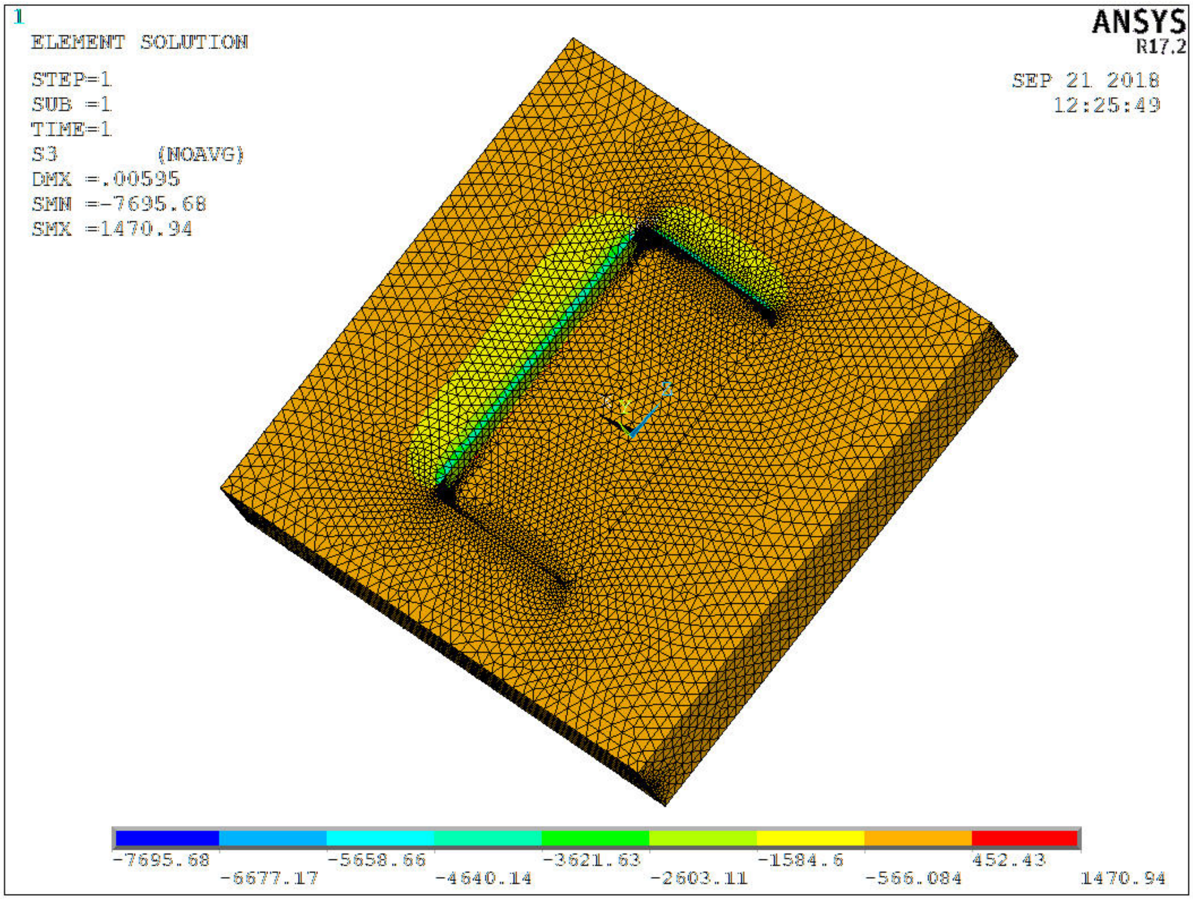

Figure 3. Minimum principal stress in graphite.

Conclusions

The minimum principal stress is within the allowable value for Sigrafine SGL R6510. The maximum principal stress is slightly above the allowable value, and could be reduced by increasing the roof radius.