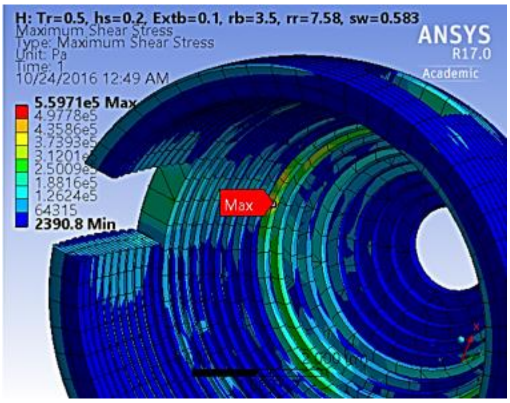
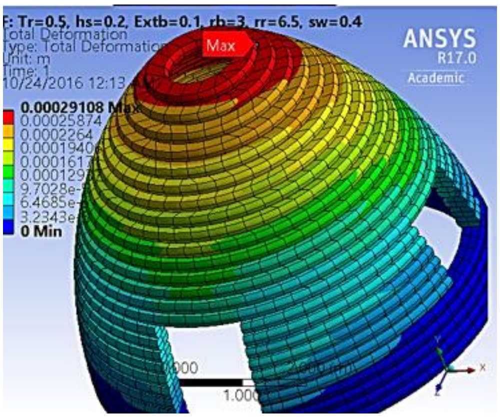




FINITE ELEMENT ANALYSES OF SUPERADOBE DOMES

ABSTRACT

This article shows Static structural analyses performed on 35 different Superadobe domed models. The dimensions of these models were defined according to a controlled variation of initial parameters, guided by previously derived equations. Maximum and Minimum principal stresses, Shear stresses and total deformations were measured assuming an idealized material with isotropic elasticity. Besides the dome's self-weight, wind loads are considered from the most dangerous angle with respect to the openings.

1. Criteria for selecting the main geometries for Static Structural Analyses:

Given the equation:

$$\left(\frac{1}{1-F}\right)\left(\sqrt{(tr+r_r-r_b)^2+2\left(\sqrt{r_r^2-(tr+r_r-r_b)^2}\right)(hs)-hs^2}+r_b-r_r-tr\right)-s_w+Extf=0 \quad (1)$$

Developed in [1] and showcased in [2], which consists of independent geometric parameters ($\boldsymbol{s_w, h_s, Extf, r_b, r_r}$ **and** $\boldsymbol{t_r}$), explained in [1], we will use this equation as shown in [2], Example 8, to produce four different sets of dome models to be subjected to F.E.M.

The two main questions that we will address in the following series of static structural analyses, is

1. How big can a Superadobe structure be, and
2. If there exists an optimal way of 'harmoniously' tweaking the set ($\boldsymbol{s_w, h_s, Extb, r_b, r_r, t_r, F}$) to obtain a set of domes of different sizes so that their stresses are lowest and most evenly distributed

Table 1. Geometries to be tested (All parameters are in meters, m, except F, which is a number)

Tr	hs	Extb	rb	rr	**(sw)**	**(F)**	sw	Solve for **(F)**	rr	F	Solve for **(sw)**	rr	sw	F	Solve for **(rr)**
0.5	0.2	0.1	2	4.33	0.333	0.074	0.4	0.28	4.33	0.33	0.423	4.33	0.4	0.25	4.13
0.5	0.2	0.1	2.25	4.88	0.375	0.182	0.4	0.25	4.88	0.33	0.436	4.88	0.4	0.25	4.874
0.5	0.2	0.1	2.5	5.42	0.417	0.266	0.4	0.226	5.42	0.33	0.447	5.42	0.4	0.25	5.62
0.5	0.2	0.1	2.75	5.96	0.458	0.335	0.4	0.205	5.96	0.33	0.456	5.96	0.4	0.25	6.365
0.5	0.2	0.1	3	6.5	0.5	0.391	0.4	0.188	6.5	0.33	0.464	6.5	0.4	0.25	7.11
0.5	0.2	0.1	3.25	7.04	0.542	0.438	0.4	0.172	7.04	0.33	0.471	7.04	0.4	0.25	7.855
0.5	0.2	0.1	3.5	7.58	0.583	0.478	0.4	0.159	7.58	0.33	0.477	7.58	0.4	0.25	8.6
0.5	0.2	0.1	3.75	8.13	0.625	0.513	0.4	0.147	8.13	0.33	0.482	8.13	0.4	0.25	9.346
0.5	0.2	0.1	4	8.67	0.667	0.543	0.4	0.137	8.67	0.33	0.487	8.67	0.4	0.25	10.09
0.5	0.2	0.1	4.25	9.21	0.708	0.571	0.4	0.13	9.21	0.33	0.491	9.21	0.4	0.25	10.84

Note: Domes which's parameters are marked in red, could not be modelled due to software license limitations. More than 50 bodies needed to be created in each model.

Note: Columns 1-4 (Yellow parameters) are set and fixed, (forced), and are common to every building to be modelled

Explanation of table 1:

- ***First group***: Columns 1-7 define the first way of tweaking parameters to progressively enlarge Superadobe domes, which is according to the equations of ***conventional*** Superadobe practices and recommendations [1], (formulas 3,4,5). Columns 5 comes from applying [1] equation (4) to column 4, and column 6 from applying [1] equation (5) on column 4. Column 7 is the result of solving the "geometric soundness equation" (1) for $\boldsymbol{F}$, given the values obtained in columns 1-6. The buildings arising from these 10 first parameter combinations will be referred to as ***the orange series.***

- ***Second group***: Columns 1-4, 8-10 define the progressive enlargement of a Superadobe dome according to the ***conventional*** Superadobe procedures but forcing $\boldsymbol{s_w}$ to be constant ($\boldsymbol{s_w}$ =0.4*m*, widely available sack dimensions typically used), hence, in these columns the structure is enlarged taking into account [1], formula (4) only: Column 10 is a copy of column 5. Column 8 is the forced (changed) parameter $\boldsymbol{s_w}$, fixed at 0.4*m*. Column 9 arises from solving (1) for $\boldsymbol{F}$ using the values at columns 1-4, 8 and 10. The buildings arising from these 10 second parameter combinations will be referred to as ***the blue series.***

- ***Third group:*** Columns 1-4, 11-13 define the progressive enlargement of a Superadobe dome according to the ***conventional*** Superadobe procedures but forcing $\boldsymbol{F}$ to be constant ($\boldsymbol{F}$ =0.33). In these columns the structure is enlarged taking into account formula (4) only: Column 13 is a copy of column 10 and column 5. Column 11 is the forced (changed) parameter $\boldsymbol{F}$, fixed at 0.33. Column 12 arises from solving (1) for $\boldsymbol{s_w}$ using the values at columns 1-4, 13 and 11. The buildings arising from these 10 parameter combinations will be referred to as ***the green series.***

- ***Fourth group:*** Columns 1-4, 14-16 define the progressive enlargement of a Superadobe dome according to the Geometrical soundness equation. In these columns the structure is enlarged taking into account equation (1): Column 14 and 15 are the changed (forced) parameters $\boldsymbol{s_w}$ and $\boldsymbol{F}$, fixed at 0.4*m* and 0.25 respectively. Column 16 arises from solving (1) for $\boldsymbol{r_r}$ using the values at columns 1-4, and 14-15. The buildings arising from these 10 last parameter combinations will be referred to as ***the brown series.*** As mentioned above, the two biggest models of this series were not be modelled due to license limitations.

2. Model general settings:

We will apply a static wind load of 2000Pa from the most dangerous face of the structures.

The idea for the upcoming static structural analyses is to model Superadobe domes with **varying (successively increasing) geometric parameters**, ($\boldsymbol{r_b}, \boldsymbol{r_r}$ and $\boldsymbol{s_w}$) and as mentioned above, this increase in size is always done according to equations (1), or [1] (3,4,5), hence the increase of the structure size follows planned criteria and the parameters will increase together, comprehensively, as four different systems.

All static structural analyses will have a given (constant) static wind pressure at a given (constant) angle, with a given (constant) friction coefficient between superblocks.

In each analysis, we will observe four main resulting structural responses to these gradual geometry changes.

The maps of Max principal stresses (tensions), Min principal stresses (compressions), Max shear stresses, and Max deformations will be presented as a basis to develop the buildings' destruction criteria and design.

The block or Superadobe fill material is idealized as having isotropic elasticity derived from an elastic modulus of 2.1213 E+10 Pa, Poisson's ratio of 0.215, Bulk modulus of 1.2405 E+10 Pa and a Shear modulus of 8.7295 E+09 Pa. Shear and Bulk modulus are automatically assigned by Ansys from the definition of elastic modulus and density, which was idealized as 2103.6 kg/m3. What follows is an explanation of these numbers.

3. Engineering Data

Engineering data refers to the material or materials to be considered as constituents of our Superadobe models for our finite element analyses. In our case, one main material will be modelled: ***Superadobe composite.***

This ideal material will be modelled as homogenous. This means that the composition of tensile polypropylene exterior together with the deformable fill content in the interior of the bags (deformability which is typical of the initial moment when superblocks are placed), will not be considered.

Instead, the composite is idealized as the brittle and cohesive – homogenous material which is formed, once the blocks cure and acquire their stiffness and strength, this is, the hardened interior of the sacks, without the exterior polypropylene interaction.

This is essentially, the final state of the constituent materials of the in-service structure after they have become hardened and no longer need to interact with the sack exteriors to be cohesive, because the composite is stiff and cohesive within itself after dry.

These considerations take into account, only the qualities of the in-service structure once the fill material of the superblock has acquired its typical strength and stiffness.

The stress-strain characteristics of the composite, are taken to be independent of the direction of measurement. This means that our idealized ***Superadobe composite*** is given **isotropic elasticity** as one of its fundamental attributes. The other fundamental attribute given to the composite, is **density**.

Isotropic elasticity in ANSYS WORKBENCH means that the fundamental stress-strain behaviours of the material (Young modulus, Bulk modulus, Shear modulus and Poisson's ratio), although different from one another, remain constant with respect to the direction in which they are measured.

In the case of isotropic elasticity, the complete set of moduli (Young modulus, Bulk modulus, Shear modulus and Poisson's ratio) is defined, once two of the moduli are given as input. This set of behaviours will be derived from Young's Modulus and Poisson's Ratio.

Hence, using the isotropic elasticity relations within ANSYS, we will give these two key mechanical parameter values as input, and the rest of the moduli of our composite are automatically calculated.

The assignment of Young's modulus, Poisson's ratio and density values for the ***Superadobe composite*** is as follows:

Superadobe Composite Mechanical Properties:

Superadobe Composite is the hardened block resulting from compacting/tamping a humid earthen mixture inside a propylene bag, and providing it time to cure.

Typical proportions of components in Superadobe composite earthen mixture, are as follows:

30% Clay, 30% Sand, 30% Gravel, 10% Cement.

Superadobe constructions are built around the world, and there exists a high variability with respect to local clay, sand, and gravel used, causing variability in the block's mechanical properties.

In order to set a most general guideline for Superadobe behavior, the modelling properties (Density, Young's Modulus, and Poisson's ratio) of Superadobe composite are derived from the modelling properties of its components (typical clay, typical sand, and typical gravel soils), as measured in their natural states and posted on broadly known tables.

Estimation of the modelling properties of Superadobe composite will also be influenced by our estimation of the modelling properties of typical hardened, Portland cement paste.

The rule used to estimate hardened cement paste's and Superadobe composite's modelling properties, is the rule of mixtures:

$P(composite) = \sum(PropVol_i * P(component_i))$, where $P(composite)$ is the estimated value for a given mechanical property of a composite material, $P(component_i)$ is the value for the given property of component i, and $PropVol_i$ is the volume proportion of component i on the total volume of the composite.

The following table contains values for modelling properties of typical soils, as well as estimated (idealized**) values for modelling properties of *pure* hardened cement:

Mechanical Property/ Soil type	Young's Modulus (MPa)	Poisson's Ratio	Density (Kg/m3)
Clay	50	0.3	1600
Sand	50	0.35	1600
Gravel	160	0.35	1500
Hardened Cement **	211345.5	-0.85	6936.4
Superadobe Composite Values (as estimated by the rule of mixtures, MPa)	21212.6	0.215	2103.64

**Young's Modulus, Poisson's ratio and Density of pure hardened cement paste were estimated (idealized) by using the rule of mixtures. Taking typical concrete composite with given proportions (cement: 0.14, sand: 0.33, gravel: 0.53) as recommended in [http://www.cement.org/cement-concrete-basics/how-concrete-is-made] and taking Young's Modulus, Poisson's ratio and Density of typical concrete to be 30000 MPa, 0.18 and 2300Kg/m3 respectively, the following relations resulted:

$$30000Mpa = \sum(PropVol_i * Young'sModulus(component_i))$$

$$0.18 = \sum(PropVol_i * Poisson'sRatio(component_i))$$

$2300Kg/m3 = \sum(PropVol_i * Density(component_i))$

Using, the above proportions of typical concrete as well as typical values of sand and gravel's modelling properties in each equation, and solving each equation for the unknown modelling property value of hardened cement paste, the values 211345.5MPa, -0.85, and 6936.4Kg/m3 were obtained.

Finally, estimated values for Superadobe composite's modelling properties respond to the following expressions:

- $21212.6Mpa = 0.3 * 50MPa + 0.3 * 50MPa + 0.3 * 160MPa + 0.1 * 211345MPa$
- $0.215 = 0.3 * 0.3 + 0.3 * 0.35 + 0.3 * 0.35 + 0.1 * (-0.85)$
- $2103.64Kg/m3 = 0.3 * 1600Kg/m3 + 0.3 * 1600Kg/m3 + 0.3 * 1500Kg/m3 + 0.1 * 6936.4Kg/m3$

We can observe that it is a composite material with mechanical properties comparable to those of typical concrete. Its Youngs modulus is approximately 29% smaller than the Young's modulus of typical concrete, its Poisson's Ratio is approximately 19% higher than Poisson's ratio of typical concrete, and its density is approximately 9% lower than the density of typical concrete.

4. Connections:

Contact Regions: Any surface which is shared among different bodies (superblocks) is a connection. In the models to be analyzed, the shared surfaces are horizontal, and occur between a superblock and the ones immediately above and below. A constant factor coefficient of 2, is set according to the experiments done in [3].

5. Mesh:

Meshing is done automatically by Ansys. A limit of 32000 nodes and 32000 elements is observed by the program in its academic version. Element shapes where set automatically, and their sizes were set manually as to accommodate the greatest number of nodes and elements in each geometry while respecting the version's restrictions.

6. Analysis (Static Structural) settings and Boundary Conditions:

- Analysis Settings:
  - Step Controls: One step, with end time 1 sec. (There is no time in this simulations, the deformations are the result of constant/static pressures and loads according to code, not considering inertial and damping effects)
  - Solver Controls: Weak springs were turned off.

- Loads, pressures and boundary conditions:
  - Gravity:

Standard earth gravity acceleration in the *y* direction. ($-9.8m/_{s^2}$)

  - Fixed Support:

The bottom ring is fixed to the ground (modelling foundation bed confinement).

  - Pressure:

A static pressure of 2 KPa is applied from the rear face of the buildings (which creates the greatest principal stresses and deformations).

7. Results:

35 different Superadobe buildings are successfully analyzed. A total of 140 maps produced. The results are graphical, and presented in matrix form.

Each matrix is a structural response. Each row in the matrix corresponds to a row in table 1, and each column represents a dome group: column one represents the *orange series*, column two represents the *blue series*, column three represents the *green series*, and column four represents the *brown series*.

The first matrix of 35 results represents the Maximum principal Stress values (Tensions) for each point of each building (represented by color gradients), and marks the location (point) of the buildings where the greatest tension occurs.

The second matrix of 35 results represents the total deformation (displacement) vector moduli for each point of each building (represented by color gradients), and marks the location (point) of the buildings where the greatest displacement occurs.

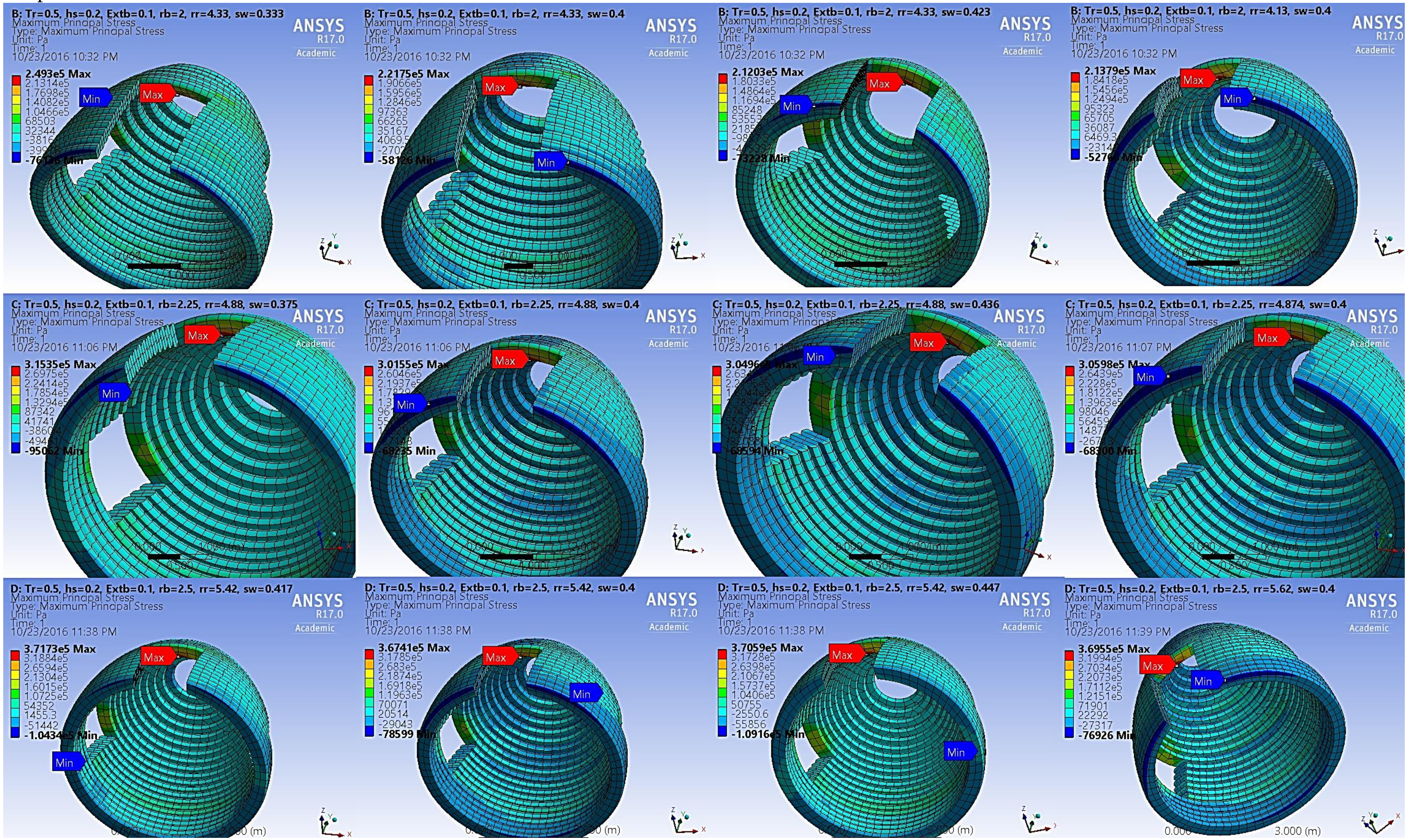
The third matrix of 35 results represents the Minimum principal Stress values (Compressions) for each point of each building (represented by color gradients), and marks the location (point) of the buildings where the greatest compression occurs.

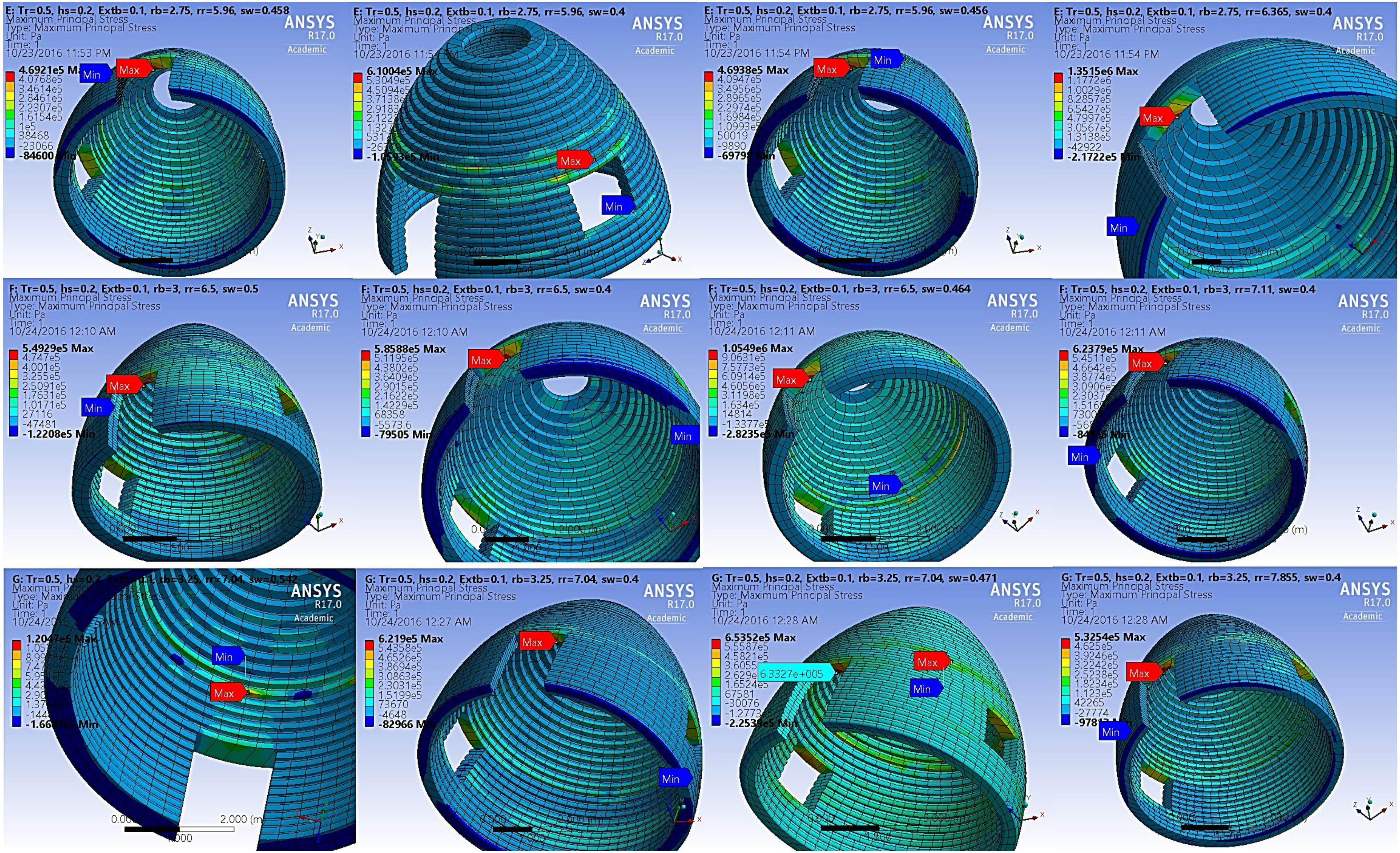
The fourth matrix of 35 results represents the Maximum Shear Stress values for each point of each building (represented by color gradients), and marks the location (point) of the buildings where the greatest shear stress occurs.

Please note that of the 40 different buildings that result from the combination of geometric parameters as stated in table 1, two of them (the two biggest buildings from the ***brown series***) were not modelled for they exceeded the number of bodies allowed, and three of them (the biggest three buildings of the ***blue series***) did not converge. This was due to rigid body motion (the top superblocks moved as rigid bodies), thus making the building to be not equilibrium. Hence, a total of 35 simulations (35 buildings) converged. Their stress and deformation maps under the wind loads and own weight are presented in this work as a first guideline to determine patterns, optimum geometric configurations if possible, and as a basis for general purpose and reinforcement design.

Please note that each building of the graphic results arrangements that follows is named according to its geometric parameter values, so they can be identified.

Graphical Results:

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ANSYS R17.0 Academic
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-84600 Min
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6.1004e5 Max
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.456
10/23/2016 11:54 PM
4.6938e5 Max
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10/23/2016 11:54 PM
1.3515e6 Max
-2.1722e5 Min
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10/24/2016 12:10 AM
5.4929e5 Max
-1.2208e5 Min
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10/24/2016 12:10 AM
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-79505 Min
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10/24/2016 12:11 AM
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-2.8235e5 Min
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10/24/2016 12:11 AM
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G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.542
1.2047e6 Max
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6.219e5 Max
-82966 Min
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6.3327e+005
-2.2539e5 Min
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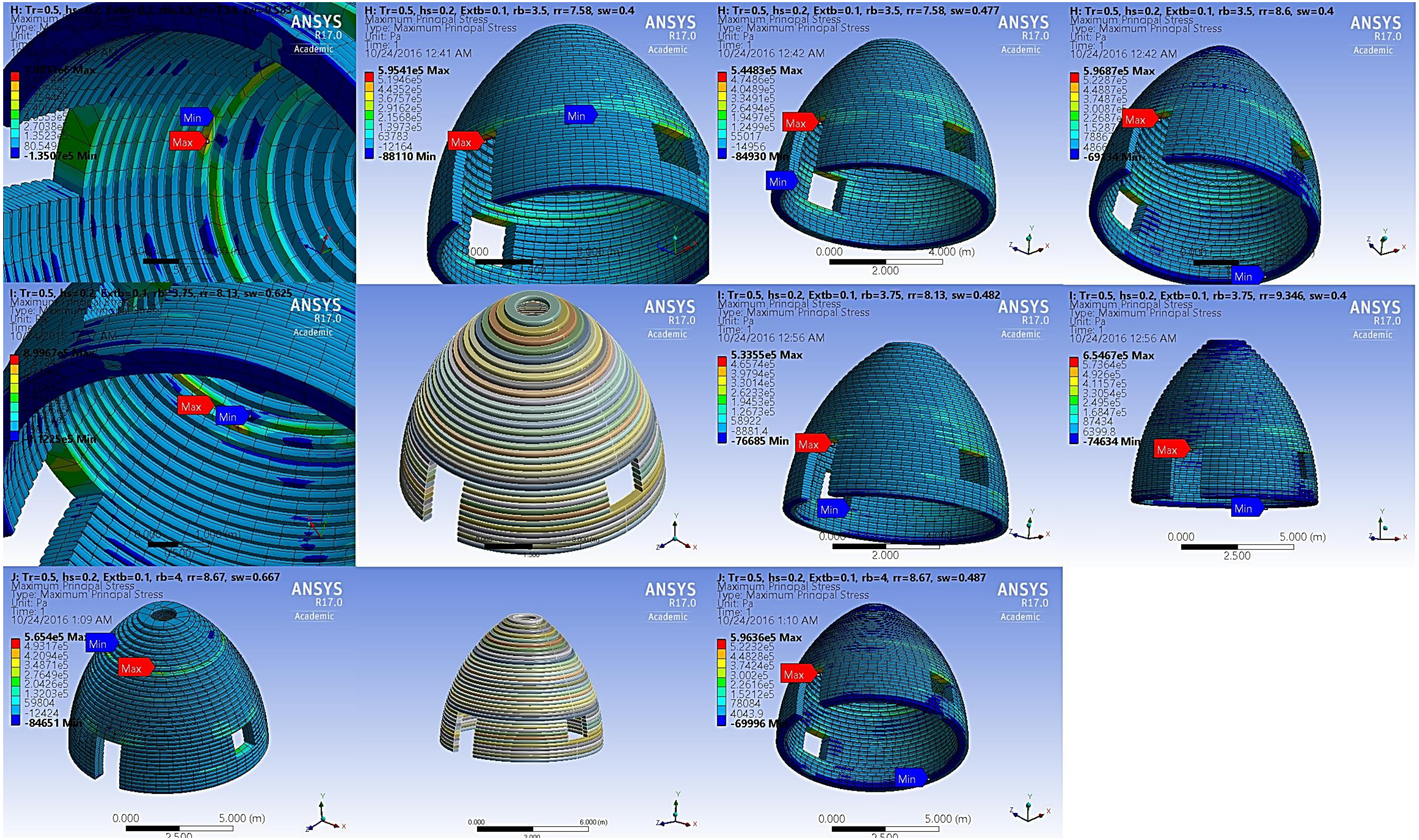
10/24/2016 12:28 AM
5.3254e5 Max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Type: Maximum Principal Stress
Unit: Pa
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10/24/2016 12:41 AM
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5.1946e5
4.4352e5
3.6757e5
2.9162e5
2.1568e5
1.3973e5
63783
-12164
-88110 Min
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Type: Maximum Principal Stress
Unit: Pa
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10/24/2016 12:42 AM
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4.0489e5
3.3491e5
2.6494e5
1.9497e5
1.2499e5
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Maximum Principal Stress
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Unit: Pa
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5.2287e5
4.4887e5
3.7487e5
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Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:56 AM
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4.6574e5
3.9794e5
3.3014e5
2.6233e5
1.9453e5
1.2673e5
58922
-8881.4
-76685 Min
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Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:56 AM
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5.7364e5
4.926e5
4.1157e5
3.3054e5
2.495e5
1.6847e5
87434
6399.8
-74634 Min
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.667
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
10/24/2016 1:09 AM
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4.2094e5
3.4871e5
2.7649e5
2.0426e5
1.3203e5
59804
-12424
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.487
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
10/24/2016 1:10 AM
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5.2232e5
4.4828e5
3.7424e5
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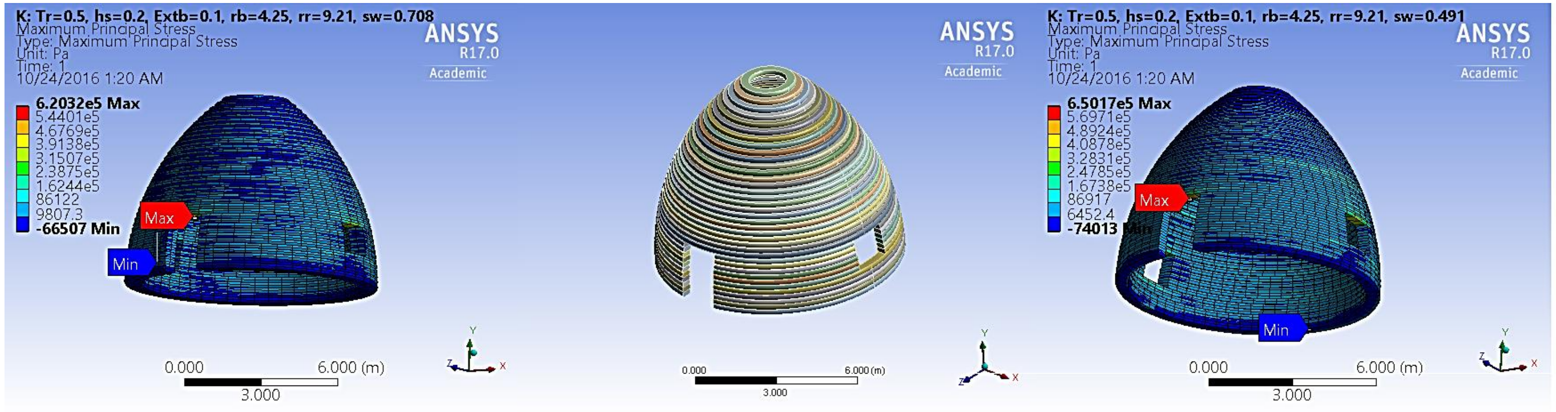
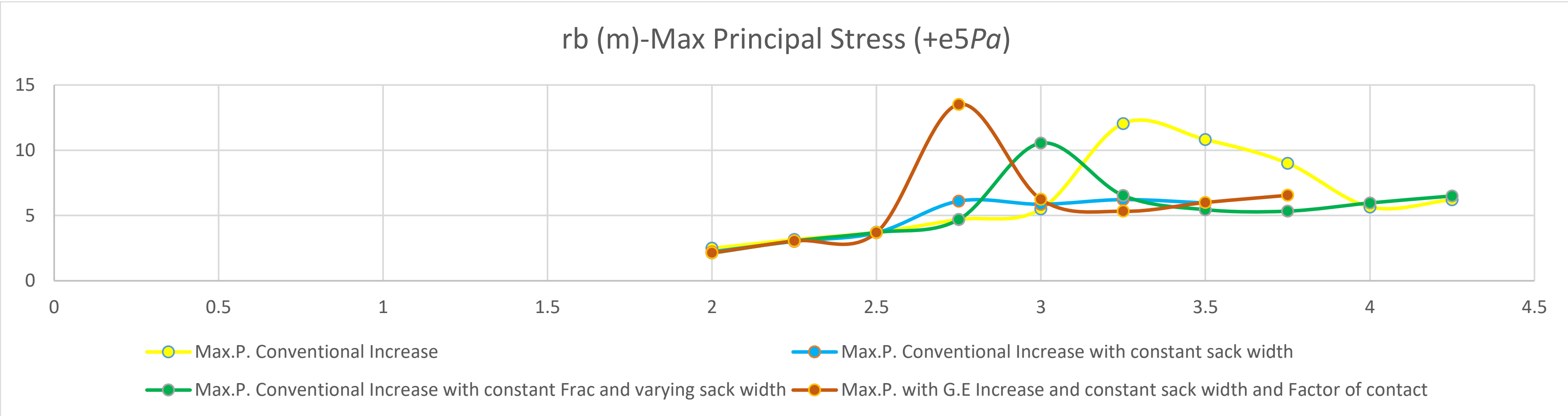
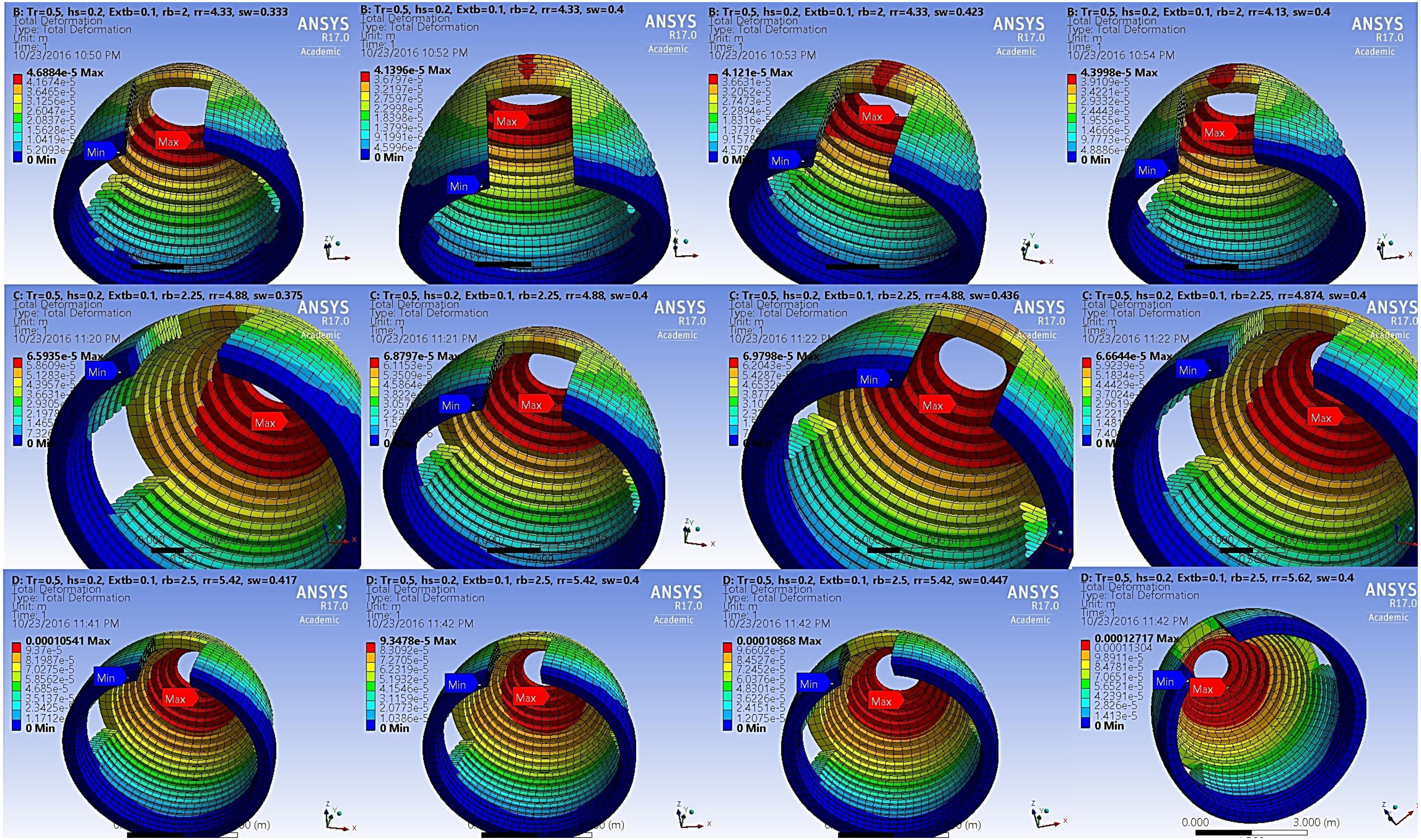
ANSYS
R17.0
Academic
Max
Min



Max Tensile Stress measured on each building with increasing building size





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Type: Total Deformation
Unit: m
Time: 1
10/23/2016 10:50 PM
4.6884e-5 Max
0 Min
ANSYS
R17.0
Academic
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10/23/2016 10:52 PM
4.1396e-5 Max
0 Min
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10/23/2016 10:53 PM
4.121e-5 Max
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10/23/2016 10:54 PM
4.3998e-5 Max
0 Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.375
10/23/2016 11:20 PM
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10/23/2016 11:21 PM
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10/23/2016 11:22 PM
6.6644e-5 Max
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.417
10/23/2016 11:41 PM
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0 Min
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0 Min
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0.00010868 Max
0 Min
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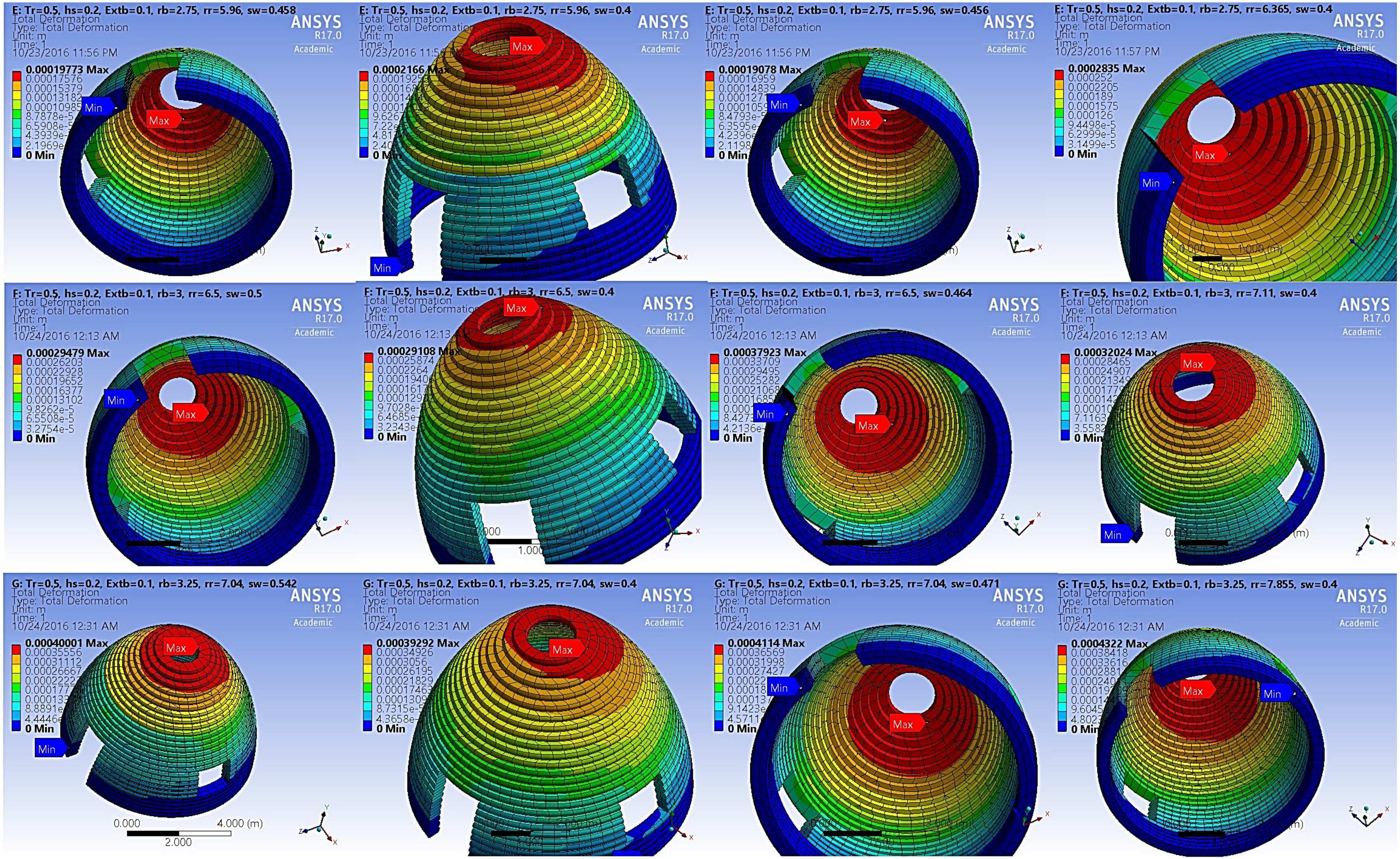
10/23/2016 11:42 PM
0.00012717 Max
0 Min
Max
Min
0.000
3.000 (m)



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Type: Total Deformation
Unit: m
Time: 1
10/23/2016 11:56 PM
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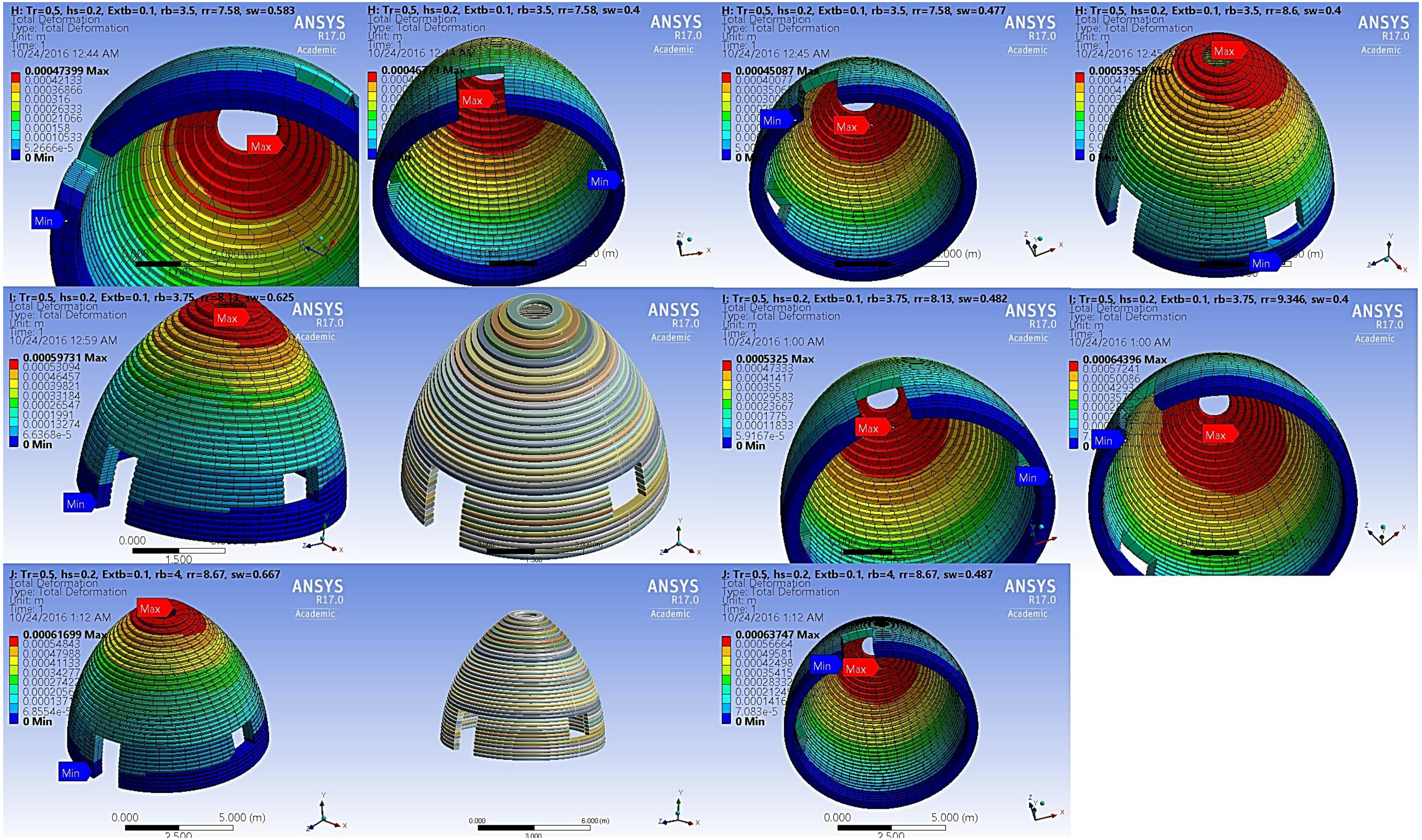
0 Min
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.4
0.0002166 Max
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.456
10/23/2016 11:56 PM
0.00019078 Max
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=6.365, sw=0.4
10/23/2016 11:57 PM
0.0002835 Max
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.5
10/24/2016 12:13 AM
0.00029479 Max
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.4
0.00029108 Max
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.464
0.00037923 Max
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=7.11, sw=0.4
0.00032024 Max
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.542
10/24/2016 12:31 AM
0.00040001 Max
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.4
0.00039292 Max
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.471
0.0004114 Max
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.855, sw=0.4
0.0004322 Max
ANSYS
R17.0
Academic



H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.583
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 12:44 AM
0.00047399 Max
0.00042133
0.00036866
0.000316
0.00026333
0.00021066
0.000158
0.00010533
5.2666e-5
0 Min
ANSYS
R17.0
Academic
Max
Min
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.4
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
ANSYS
R17.0
Academic
Max
Min
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.477
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 12:45 AM
0.00045087 Max
ANSYS
R17.0
Academic
Max
Min
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=8.6, sw=0.4
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
ANSYS
R17.0
Academic
Max
Min
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 12:59 AM
0.00059731 Max
0.00053094
0.00046457
0.00039821
0.00033184
0.00026547
0.0001991
0.00013274
6.6368e-5
0 Min
ANSYS
R17.0
Academic
Max
Min
0.000
1.500
ANSYS
R17.0
Academic
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=8.13, sw=0.482
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 1:00 AM
0.0005325 Max
0.00047333
0.00041417
0.000355
0.00029583
0.00023667
0.0001775
0.00011833
5.9167e-5
0 Min
ANSYS
R17.0
Academic
Max
Min
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=9.346, sw=0.4
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 1:00 AM
0.00064396 Max
0.00057241
0.00050086
ANSYS
R17.0
Academic
Max
Min
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.667
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 1:12 AM
0.00054843
0.00047988
0.00041133
6.8554e-5
0 Min
ANSYS
R17.0
Academic
Max
Min
0.000
5.000 (m)
2.500
ANSYS
R17.0
Academic
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.487
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
10/24/2016 1:12 AM
0.00063747 Max
0.00056664
0.00049581
0.00042498
0.00035415
7.083e-5
0 Min
ANSYS
R17.0
Academic
Max
Min
0.000
5.000 (m)
2.500

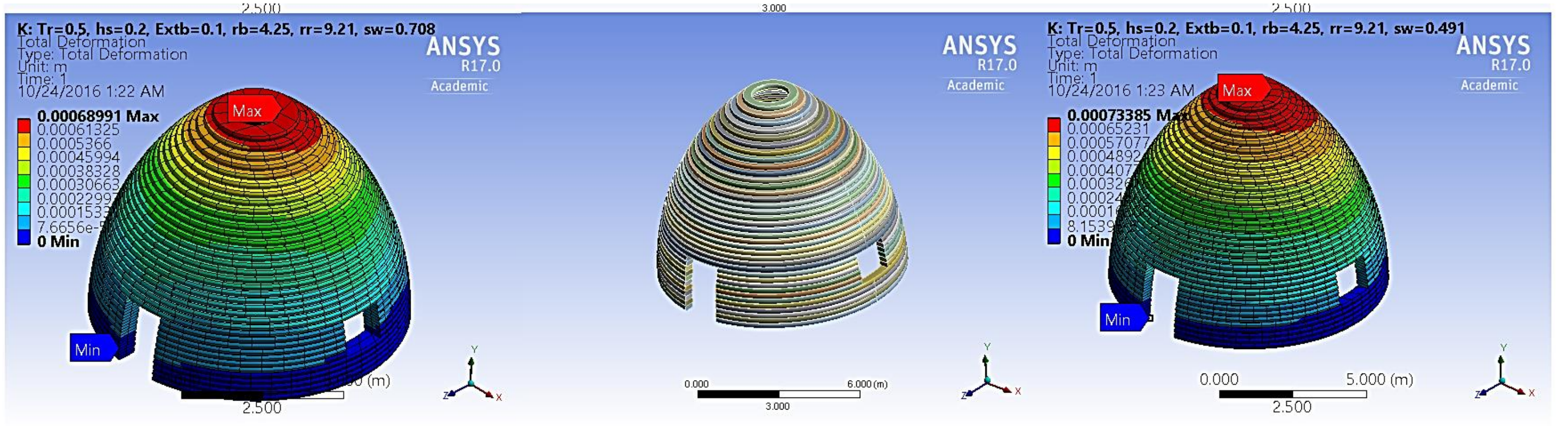
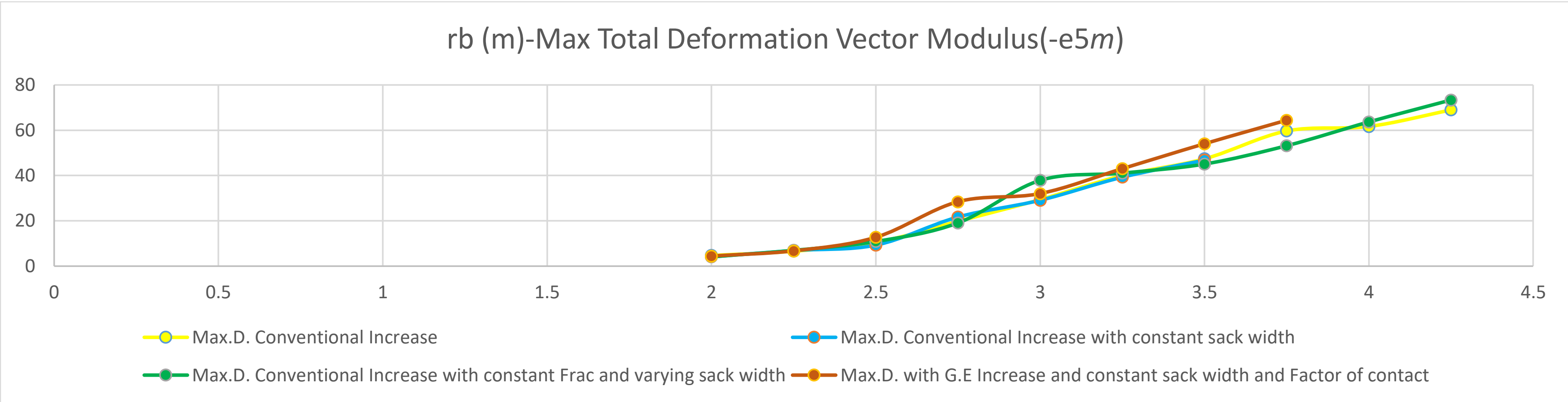
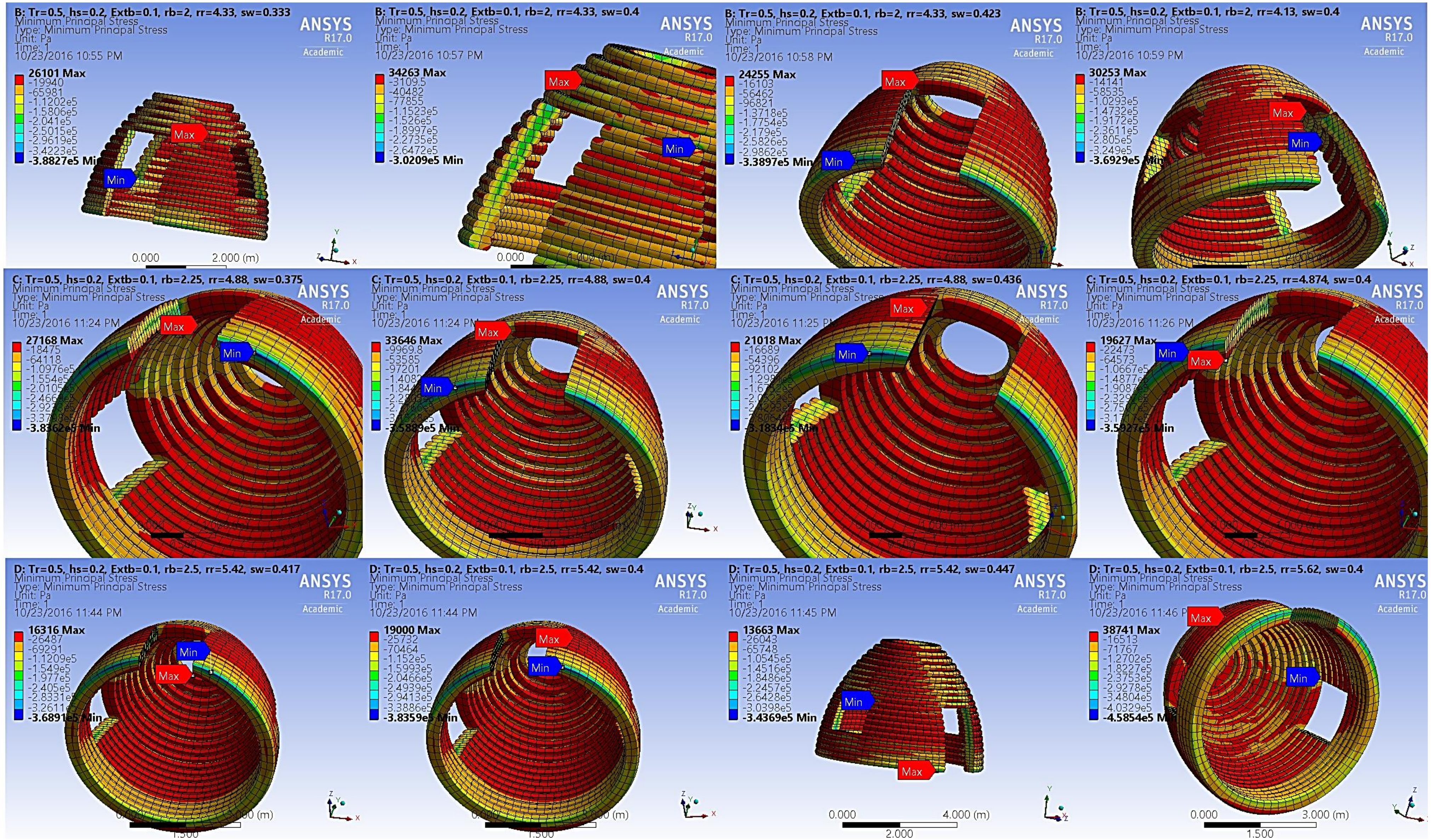
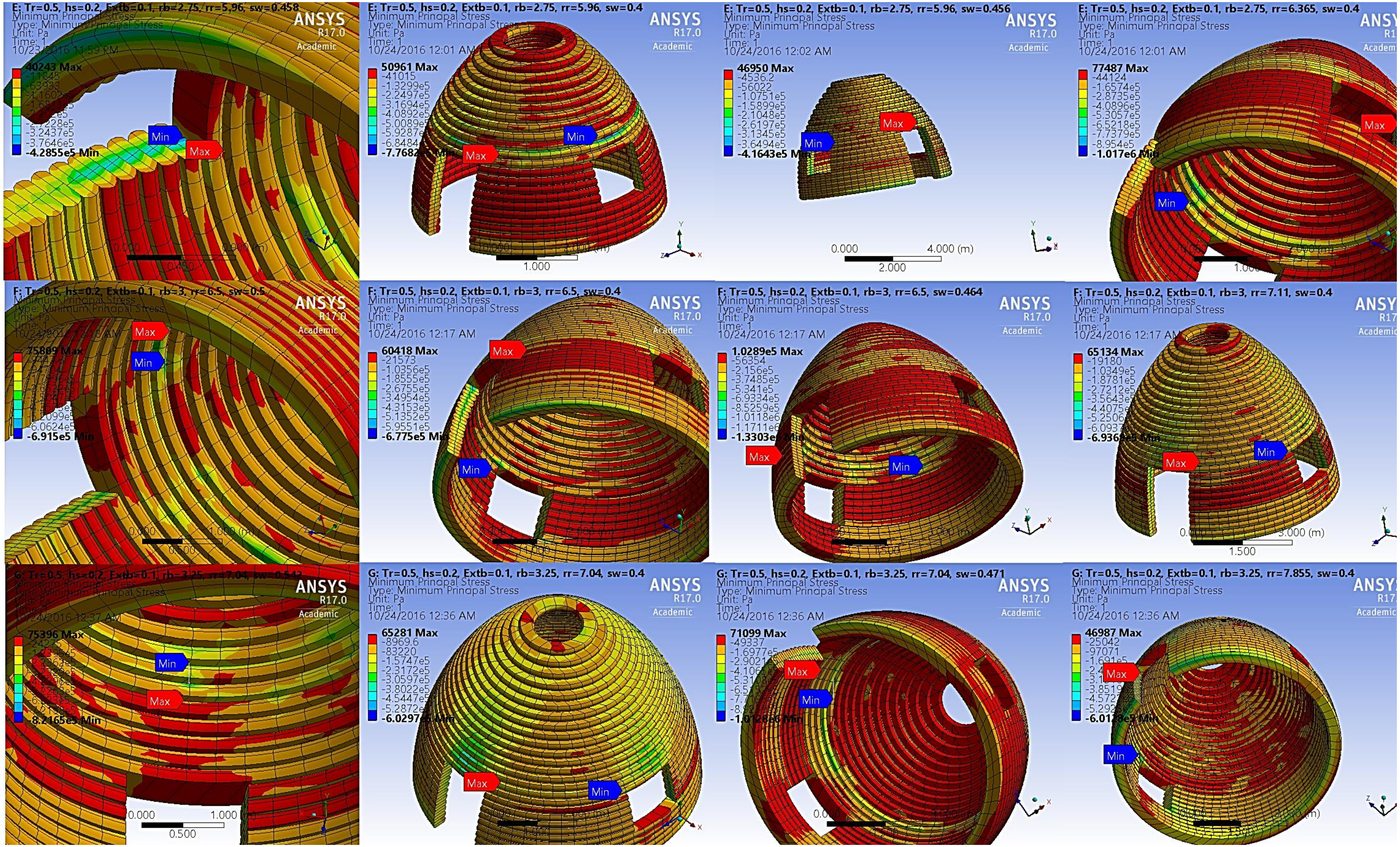


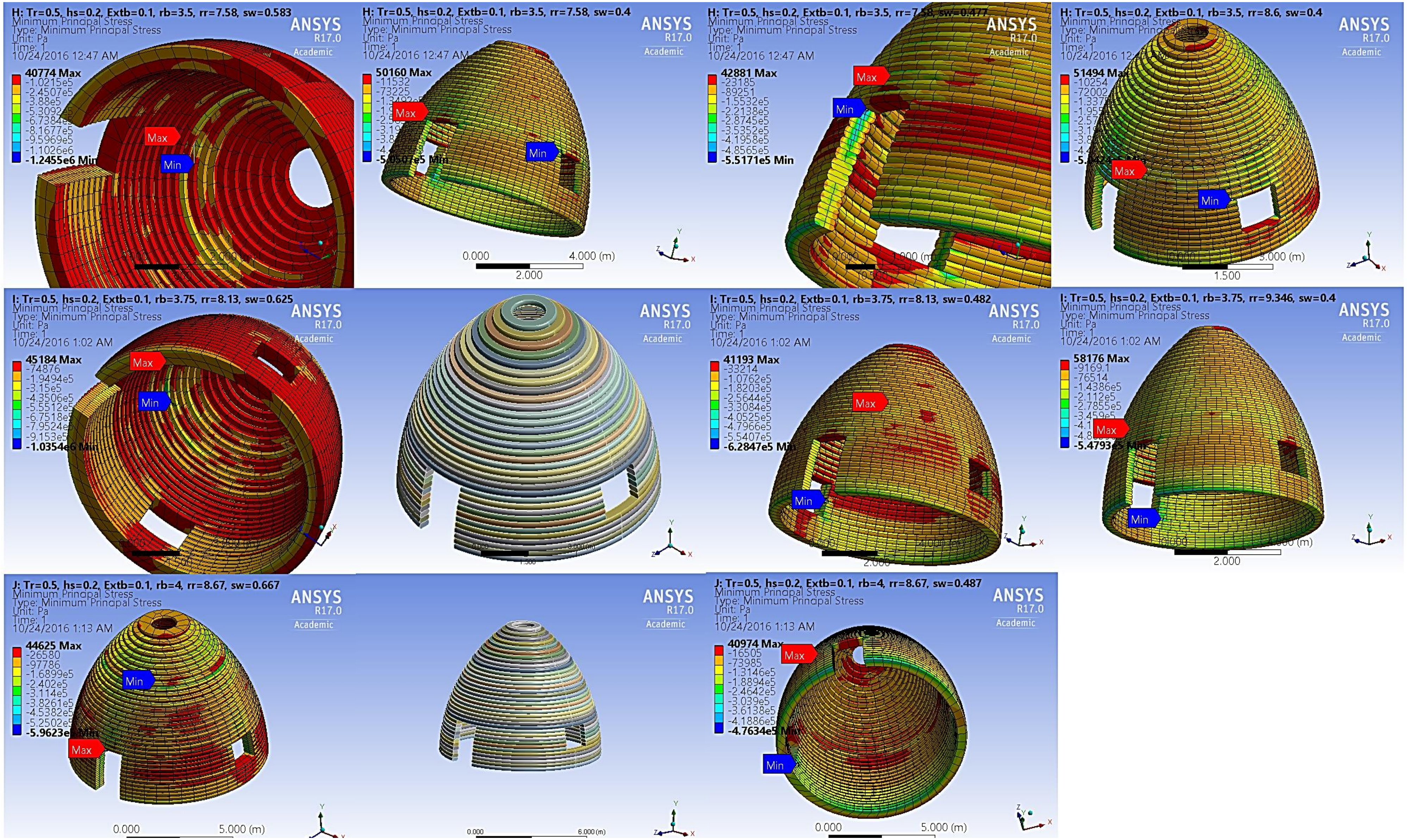
Table: Maximum Total Deformation on each building with increasing size





B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.333
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 10:55 PM
ANSYS R17.0 Academic
26101 Max
-19940
-65981
-1.1202e5
-1.5806e5
-2.041e5
-2.5015e5
-2.9619e5
-3.4223e5
-3.8827e5 Min
Max
Min
0.000
2.000 (m)
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 10:57 PM
ANSYS R17.0 Academic
34263 Max
-3109.5
-40482
-77855
-1.1523e5
-1.526e5
-1.8997e5
-2.2735e5
-2.6472e5
-3.0209e5 Min
Max
Min
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.423
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 10:58 PM
ANSYS R17.0 Academic
24255 Max
-16103
-56462
-96821
-1.3718e5
-1.7754e5
-2.179e5
-2.5826e5
-2.9862e5
-3.3897e5 Min
Max
Min
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.13, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 10:59 PM
ANSYS R17.0 Academic
30253 Max
-14141
-58535
-1.0293e5
-1.4732e5
-1.9172e5
-2.3611e5
-2.805e5
-3.249e5
-3.6929e5 Min
Max
Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.375
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:24 PM
ANSYS R17.0 Academic
27168 Max
-18475
-64118
-3.8362e5 Min
Max
Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:24 PM
ANSYS R17.0 Academic
33646 Max
-9969.8
-53585
-97201
-3.5889e5 Min
Max
Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.436
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:25 PM
ANSYS R17.0 Academic
21018 Max
-16689
-54396
-92102
-3.1834e5 Min
Max
Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.874, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:26 PM
ANSYS R17.0 Academic
19627 Max
-22473
-64573
-3.5027e5 Min
Max
Min
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.417
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:44 PM
ANSYS R17.0 Academic
16316 Max
-26487
-69291
-1.1209e5
-1.549e5
-1.977e5
-2.405e5
-2.8331e5
-3.2611e5
-3.6891e5 Min
Max
Min
1.500
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:44 PM
ANSYS R17.0 Academic
19000 Max
-25732
-70464
-1.152e5
-1.5993e5
-2.0466e5
-2.4939e5
-2.9413e5
-3.3886e5
-3.8359e5 Min
Max
Min
1.500
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.447
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:45 PM
ANSYS R17.0 Academic
13663 Max
-26043
-65748
-1.0545e5
-1.4516e5
-1.8486e5
-2.2457e5
-2.6428e5
-3.0398e5
-3.4369e5 Min
Max
Min
0.000
4.000 (m)
2.000
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.62, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/23/2016 11:46 PM
ANSYS R17.0 Academic
38741 Max
-16513
-71767
-1.2702e5
-1.8227e5
-2.3753e5
-2.9278e5
-3.4804e5
-4.0329e5
-4.5854e5 Min
Max
Min
0.000
3.000 (m)
1.500


E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.458
ANSYS R17.0 Academic
40243 Max
-4.2855e5 Min
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:01 AM
50961 Max
-41015
-1.3299e5
-2.2497e5
-3.1694e5
-4.0892e5
-5.0089e5
-7.7682e5 Min
1.000
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.456
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:02 AM
46950 Max
-4536.2
-56022
-1.0751e5
-1.5899e5
-2.1048e5
-2.6197e5
-3.1345e5
-3.6494e5
-4.1643e5 Max
0.000
4.000 (m)
2.000
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=6.365, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:01 AM
77487 Max
-44124
-1.6574e5
-2.8735e5
-4.0896e5
-5.3057e5
-6.5218e5
-7.7379e5
-8.954e5
-1.017e6 Min
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.5
75809 Max
-6.0624e5
-6.915e5 Min
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:17 AM
60418 Max
-21573
-1.0356e5
-1.8555e5
-2.6755e5
-3.4954e5
-4.3153e5
-5.1352e5
-5.9551e5
-6.775e5 Min
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.464
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:17 AM
1.0289e5 Max
-56354
-2.156e5
-3.7485e5
-5.341e5
-6.9334e5
-8.5259e5
-1.0118e6
-1.1711e6
-1.3303e6 Min
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=7.11, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:17 AM
65134 Max
-19180
-1.0349e5
-1.8781e5
-2.7212e5
-4.4075e5
-5.2506e5
-6.9369e5 Min
3.000 (m)
1.500
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.542
75396 Max
-8.2165e5 Min
0.000
1.000
0.500
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:36 AM
65281 Max
-8969.6
-83220
-1.5747e5
-2.3172e5
-3.0597e5
-3.8022e5
-4.5447e5
-5.2872e5
-6.0297e5 Min
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.471
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:36 AM
71099 Max
-49337
-1.6977e5
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.855, sw=0.4
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:36 AM
46987 Max
-25042
-97071
-6.0128e5 Min
Max
Min



H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.583
Minimum Principal Stress
Type: Minimum Principal Stress
Unit: Pa
Time: 1
10/24/2016 12:47 AM
40774 Max
-1.2455e6 Min
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.4
50160 Max
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.477
42881 Max
-5.5171e5 Min
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=8.6, sw=0.4
51494 Max
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=8.13, sw=0.625
10/24/2016 1:02 AM
45184 Max
-1.0354e6 Min
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=8.13, sw=0.482
41193 Max
-6.2847e5 Min
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=9.346, sw=0.4
58176 Max
-5.4793e5 Min
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.667
10/24/2016 1:13 AM
44625 Max
-5.9623e5 Min
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.487
40974 Max
-4.7634e5 Min
ANSYS
R17.0
Academic

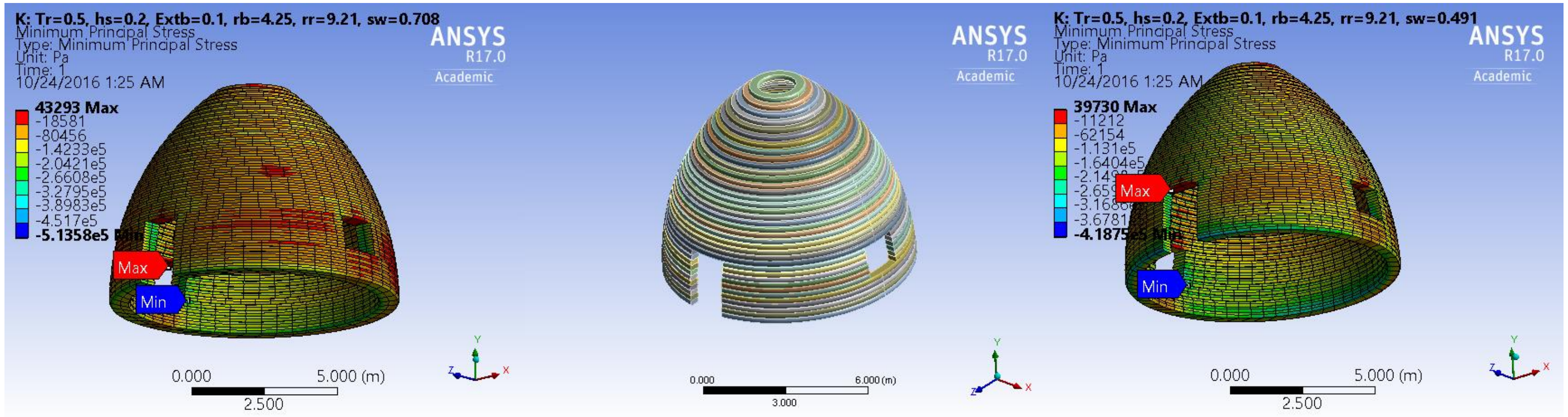
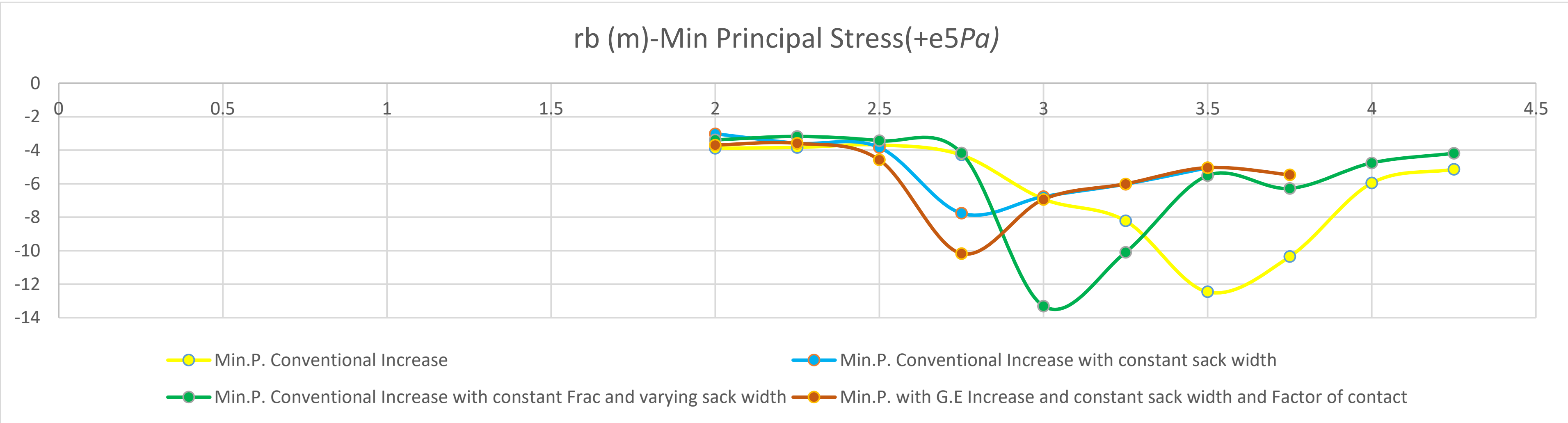
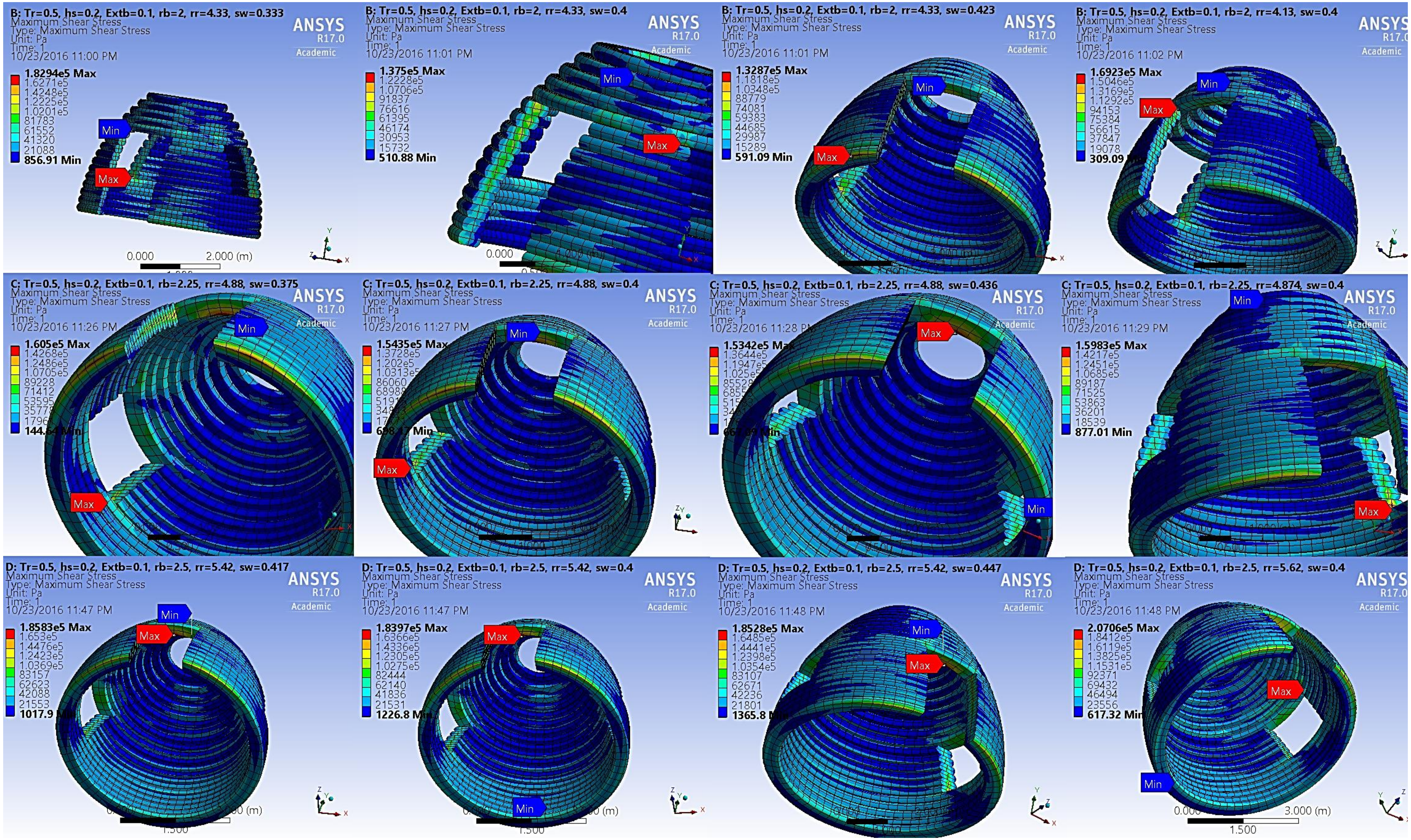
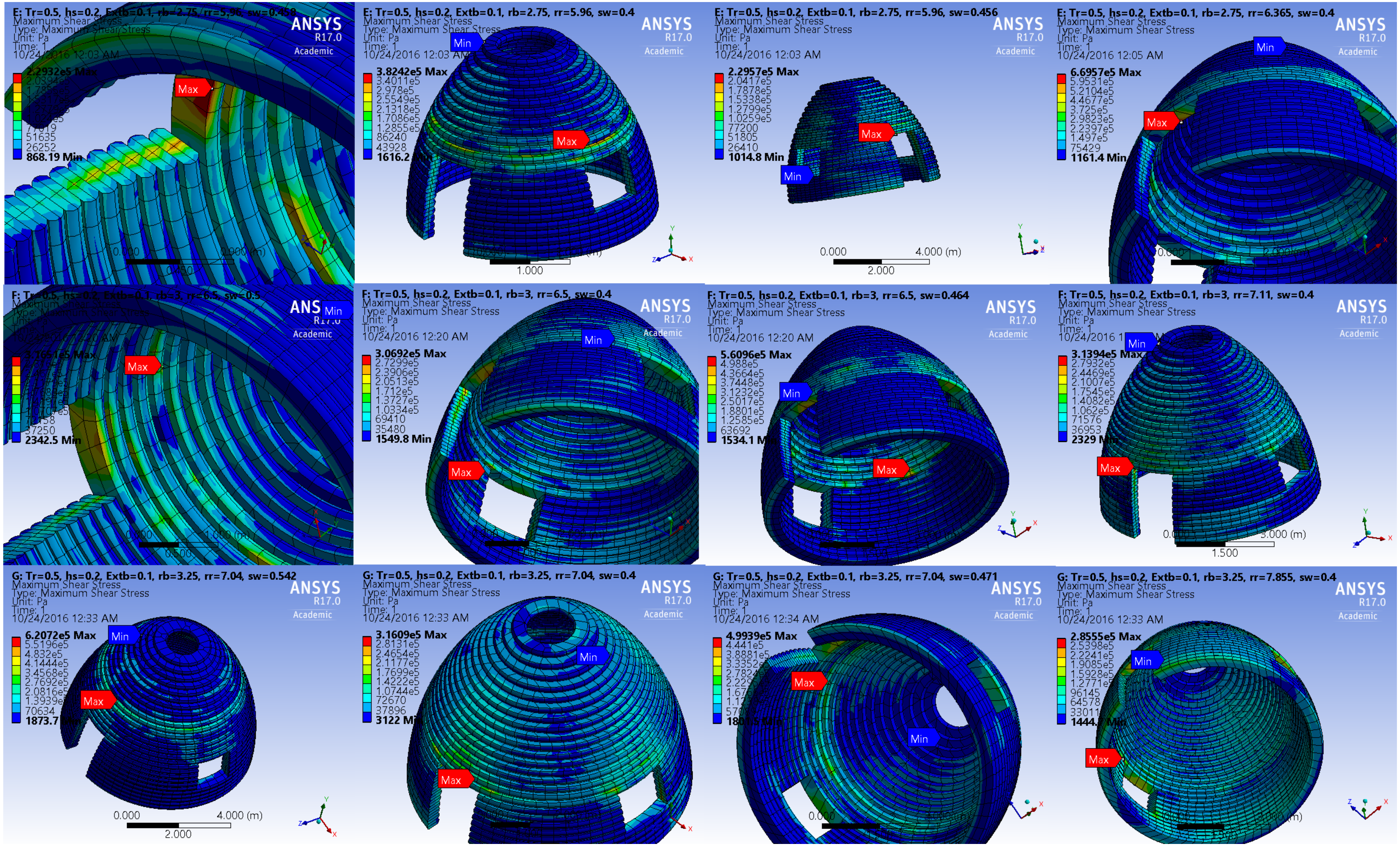


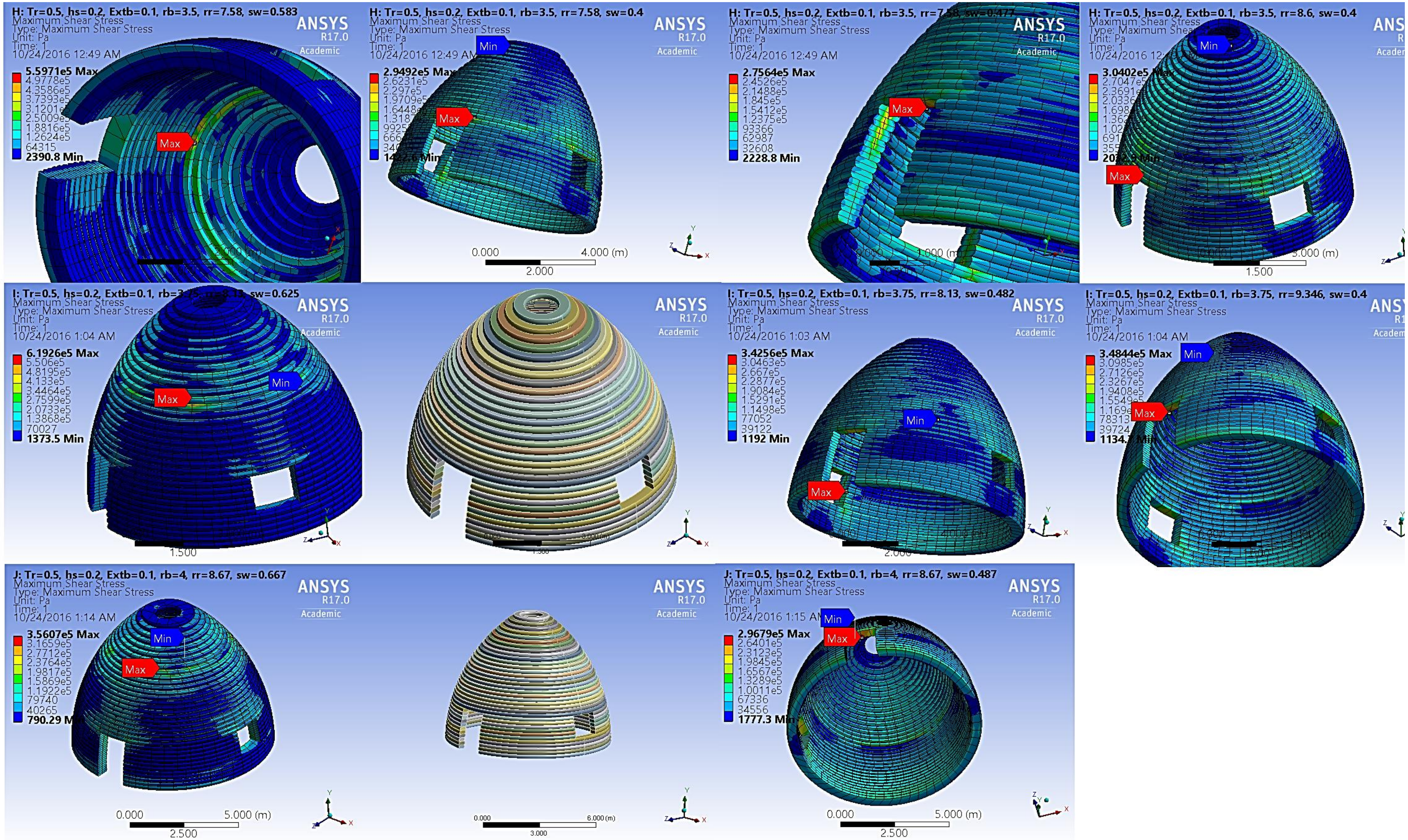
Table: Minimum Principal Stress on each building with increasing size




B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.333
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:00 PM
ANSYS
R17.0
Academic
1.8294e5 Max
1.6271e5
1.4248e5
1.2225e5
1.0201e5
81783
61552
41320
21088
856.91 Min
Min
Max
0.000
2.000 (m)
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:01 PM
ANSYS
R17.0
Academic
1.375e5 Max
1.2228e5
1.0706e5
91837
76616
61395
46174
30953
15732
510.88 Min
Min
Max
0.000
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.33, sw=0.423
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:01 PM
ANSYS
R17.0
Academic
1.3287e5 Max
1.1818e5
1.0348e5
88779
74081
59383
44685
29987
15289
591.09 Min
Min
Max
B: Tr=0.5, hs=0.2, Extb=0.1, rb=2, rr=4.13, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:02 PM
1.6923e5 Max
1.5046e5
1.3169e5
1.1292e5
94153
75384
56615
37847
19078
309.09
Min
Max
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.375
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:26 PM
ANSYS
R17.0
Academic
1.605e5 Max
1.4268e5
1.2486e5
1.0705e5
89228
71412
53595
Min
Max
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:27 PM
ANSYS
R17.0
Academic
1.5435e5 Max
1.3728e5
1.202e5
1.0313e5
86060
Min
Max
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.88, sw=0.436
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:28 PM
ANSYS
R17.0
Academic
1.3644e5
1.1947e5
1.025e5
Max
Min
C: Tr=0.5, hs=0.2, Extb=0.1, rb=2.25, rr=4.874, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:29 PM
ANSYS
R17.0
Academic
1.5983e5 Max
1.4217e5
1.2451e5
1.0685e5
89187
71525
53863
36201
18539
877.01 Min
Min
Max
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.417
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:47 PM
ANSYS
R17.0
Academic
1.8583e5 Max
1.653e5
1.4476e5
1.2423e5
1.0369e5
83157
62623
42088
21553
1017.9
Min
Max
1.500
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:47 PM
ANSYS
R17.0
Academic
1.8397e5 Max
1.6366e5
1.4336e5
1.2305e5
1.0275e5
82444
62140
41836
21531
1226.8
Max
Min
1.500
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.42, sw=0.447
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:48 PM
ANSYS
R17.0
Academic
1.8528e5 Max
1.6485e5
1.4441e5
1.2398e5
1.0354e5
83107
62671
42236
21801
1365.8
Min
Max
D: Tr=0.5, hs=0.2, Extb=0.1, rb=2.5, rr=5.62, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/23/2016 11:48 PM
ANSYS
R17.0
Academic
2.0706e5 Max
1.8412e5
1.6119e5
1.3825e5
1.1531e5
92371
69432
46494
23556
617.32 Min
Max
Min
0.000
3.000 (m)
1.500



E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.456
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:03 AM
2.2932e5 Max
868.19 Min
ANSYS R17.0 Academic
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:03 AM
3.8242e5 Max
3.4011e5
2.978e5
2.5549e5
2.1318e5
1.7086e5
1.2855e5
86240
43928
1616.2
ANSYS R17.0 Academic
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=5.96, sw=0.456
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:03 AM
2.2957e5 Max
2.0417e5
1.7878e5
1.5338e5
1.2799e5
1.0259e5
77200
51805
26410
1014.8 Min
0.000
4.000 (m)
2.000
ANSYS R17.0 Academic
E: Tr=0.5, hs=0.2, Extb=0.1, rb=2.75, rr=6.365, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:05 AM
6.6957e5 Max
5.9531e5
5.2104e5
4.4677e5
3.725e5
2.9823e5
2.2397e5
1.497e5
75429
1161.4 Min
ANSYS R17.0 Academic
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.5
2342.5 Min
ANSYS R17.0 Academic
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:20 AM
3.0692e5 Max
2.7299e5
2.3906e5
2.0513e5
1.712e5
1.3727e5
1.0334e5
69410
35480
1549.8 Min
ANSYS R17.0 Academic
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=6.5, sw=0.464
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:20 AM
5.6096e5 Max
4.988e5
4.3664e5
3.7448e5
3.1232e5
2.5017e5
1.8801e5
1.2585e5
63692
1534.1
ANSYS R17.0 Academic
F: Tr=0.5, hs=0.2, Extb=0.1, rb=3, rr=7.11, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
3.1394e5 Max
2.7932e5
2.4469e5
2.1007e5
1.7545e5
1.4082e5
1.062e5
71576
36953
2329
3.000 (m)
1.500
ANSYS R17.0 Academic
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.542
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:33 AM
6.2072e5 Max
5.5196e5
4.832e5
4.1444e5
3.4568e5
2.7692e5
2.0816e5
1.3939e5
70634
1873.7
0.000
4.000 (m)
2.000
ANSYS R17.0 Academic
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:33 AM
3.1609e5 Max
2.8131e5
2.4654e5
2.1177e5
1.7699e5
1.4222e5
1.0744e5
72670
37896
3122
ANSYS R17.0 Academic
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.04, sw=0.471
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:34 AM
4.9939e5 Max
4.441e5
3.8881e5
ANSYS R17.0 Academic
G: Tr=0.5, hs=0.2, Extb=0.1, rb=3.25, rr=7.855, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:33 AM
2.8555e5 Max
2.5398e5
2.2241e5
1.9085e5
1.5928e5
96145
64578
33011
ANSYS R17.0 Academic



H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.583
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:49 AM
ANSYS
R17.0
Academic
5.5971e5 Max
4.9778e5
4.3586e5
3.7393e5
3.1201e5
2.5009e5
1.8816e5
1.2624e5
64315
2390.8 Min
Max
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=7.58, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:49 AM
ANSYS
R17.0
Academic
2.9492e5 Max
2.6231e5
2.297e5
1.9709e5
Min
Max
0.000
4.000 (m)
2.000
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 12:49 AM
ANSYS
R17.0
Academic
2.7564e5 Max
2.4526e5
2.1488e5
1.845e5
1.5412e5
1.2375e5
93366
62987
32608
2228.8 Min
Max
H: Tr=0.5, hs=0.2, Extb=0.1, rb=3.5, rr=8.6, sw=0.4
Maximum Shear Stress
Unit: Pa
Time: 1
3.0402e5
2.7047e5
Min
Max
3.000 (m)
1.500
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, sw=0.625
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 1:04 AM
ANSYS
R17.0
Academic
6.1926e5 Max
5.506e5
4.8195e5
4.133e5
3.4464e5
2.7599e5
2.0733e5
1.3868e5
70027
1373.5 Min
Max
Min
1.500
ANSYS
R17.0
Academic
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=8.13, sw=0.482
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 1:03 AM
ANSYS
R17.0
Academic
3.4256e5 Max
3.0463e5
2.667e5
2.2877e5
1.9084e5
1.5291e5
1.1498e5
77052
39122
1192 Min
Min
Max
2.000
I: Tr=0.5, hs=0.2, Extb=0.1, rb=3.75, rr=9.346, sw=0.4
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 1:04 AM
3.4844e5 Max
3.0985e5
2.7126e5
2.3267e5
1.9408e5
Min
Max
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.667
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
10/24/2016 1:14 AM
ANSYS
R17.0
Academic
3.5607e5 Max
3.1659e5
2.7712e5
2.3764e5
1.9817e5
1.5869e5
1.1922e5
79740
40265
Min
Max
0.000
5.000 (m)
2.500
ANSYS
R17.0
Academic
0.000
6.000 (m)
3.000
J: Tr=0.5, hs=0.2, Extb=0.1, rb=4, rr=8.67, sw=0.487
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
ANSYS
R17.0
Academic
2.9679e5 Max
2.6401e5
2.3123e5
1.9845e5
1.6567e5
1.3289e5
1.0011e5
67336
34556
1777.3 Min
Min
Max
0.000
5.000 (m)
2.500

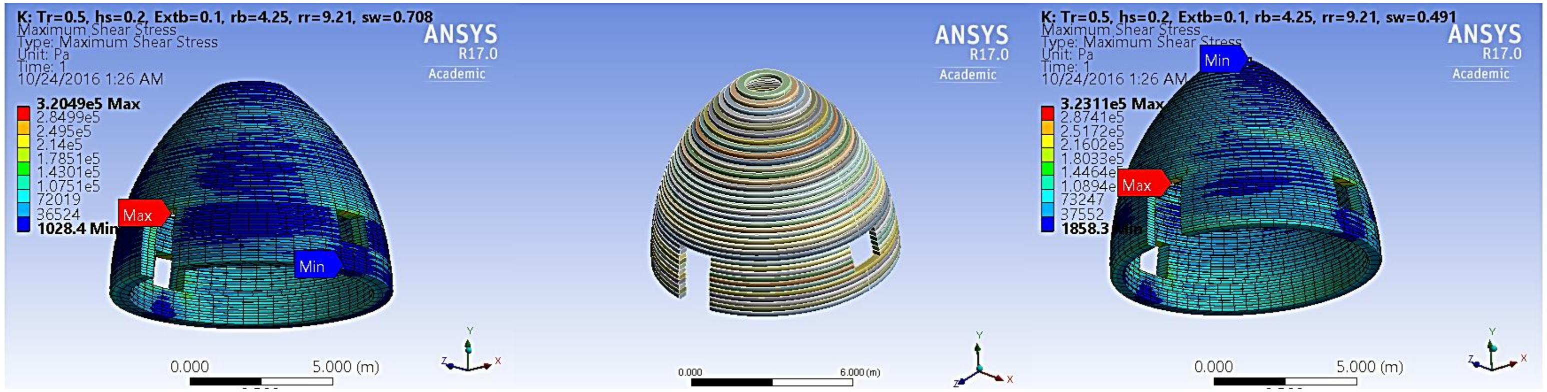
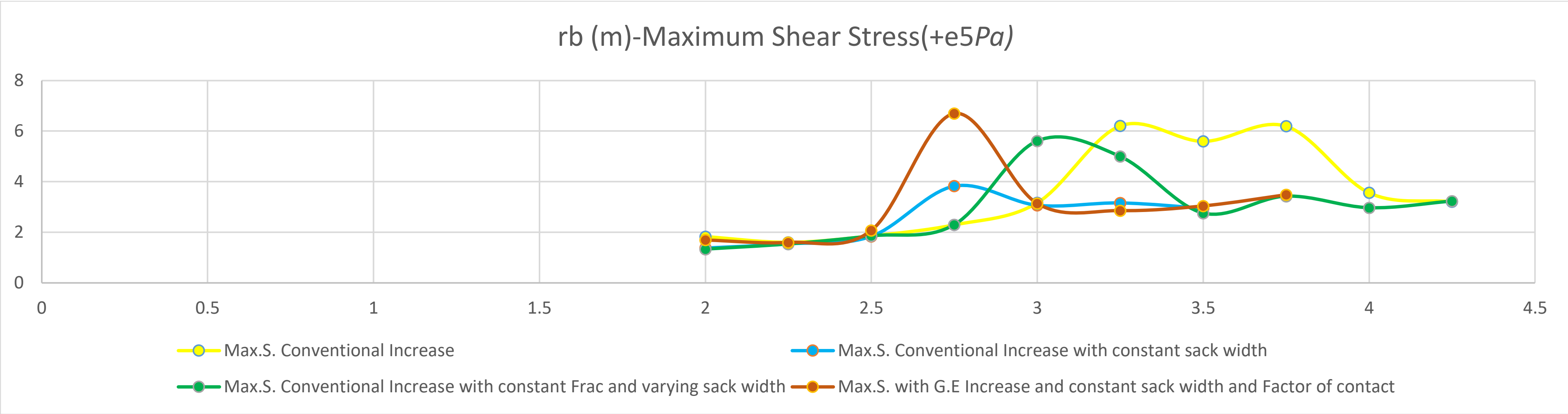


Table: Maximum Shear Stress on each building with increasing size



8. Final Observations:

- Observation 1: Location of greatest tensile stresses

The greatest tensile stress in the majority of buildings was located in the mid-span of the superblock portion over the main entrance.

- Observation 2: Greatest tensile stress among all models as a baseline for failure criteria

The greatest positive principal stress (tension) among all 35 buildings, occurred in the building of the brown series with radius 2.75m. The geometric parameters of this building are ***Tr=0.5m, hs=0.2m, Extb=0.1m, rb=2.75m, rr=6.365m, and sw=0.4m***. This stress measured less than 1.4 MPa.

This number is a guideline for estimating whether or not these configurations can fail in the face of code wind loads. Knowing this greatest tension, as well as knowing Superadobe composite's mean tensile strength and mode of destruction, will give a criteria for Superadobe failure (It is safe to assume that Superadobe composite is a brittle material, hence the determining factor in its destruction is its tensile strength). Although composite strength is not determined in this work (the composite is idealized and broad), we may be optimistic due to three facts:

- That the composite is *comparable* to concrete (in its composition, density, Young's modulus and Poisson's ratio), and hence, it is possible that its mean tensile strength lies nearby concrete's range (2-5 MPa, which is, with varying degree, greater than the Max tensile stresses measured on all of our simulations)
- That Superadobe composite has improved ductility because of its high clay content.

And:

- Observation 3: The location of greatest tensile stresses can be modelled as a statically determined structure

In the majority of building's modelled, the greatest tensile stress was located in the mid-span of the superblock portion over the main entrance, and the fact that this location could be modelled (approximately) as a statically determined structure (a simply supported beam with distributed loads on the top), implies that the stress values already obtained in these locations will not greatly change if we add reinforcements (strain/material composition will not influence on the resulting stresses in these locations). Providing very simple steel bar reinforcements to this element will not change the obtained tensile stresses in great measure, and these few steel bars will be more than enough to carry the tensile stress values already measured in these locations without reinforcement.

- Observation 4: Necessity of fine tuning geometric parameters

Neither of the curves of Table 3 are monotonous, this is, the greatest tensile stress values measured on each building do not strictly increase with building size. A local maximum occurs on the brown series for the building of ***rb=2.75m***, a local maximum occurs on the yellow series for the building of ***rb=3.25m***, a local maximum occurs on the green series for the building of ***rb=3***, and a local maximum occurs on the blue series for the building of ***rb=2.75m***.

Since the amount of tensile stress does not strictly increase with overall building size, (in all the different series, this happens), it becomes apparent that optimal and less than optimal combinations of geometric parameters exist, in relation to stress response.

This non monotonous behavior of stress, states the importance of a 'correct' combination of ***sw, rb***, and ***rr*** in a Superadobe building, and rules out a simplistic approach to describe the mechanical response based soley on overall building size. Bigger and heavier buildings with 'better' ***rb-rr-sw*** configurations had 50% lower Max tensile stresses than smaller buildings with less than optimal geometric parameter configurations, and this necessity of 'fine tuning' is one of the most important observations in this work.

- Observation 5: Exceptional locations of greatest tensile stresses

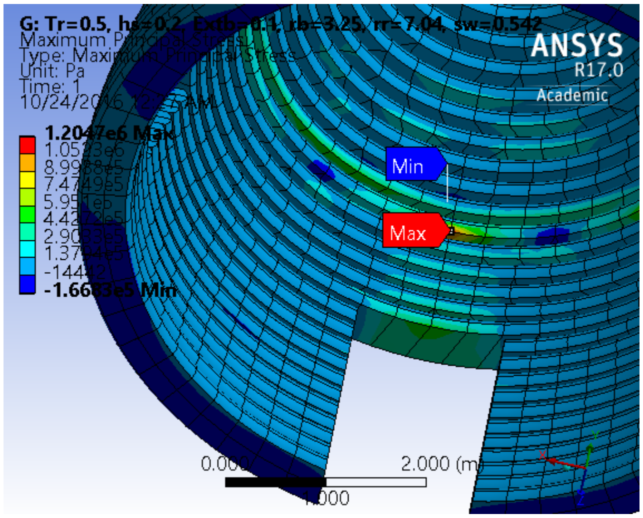
It is a desirable behavior (that which generally happens), that strain is transmitted from the top-rear part of the structure towards the mid-front part (towards the mid - span of the block portion over the main entrance), localizing the maximum tensile stresses here.

The above behavior is desirable because simple and straight-forward reinforcement with steel rebar can be used in this specific location of tensile stress accumulation. Yet, some buildings (generally those in the mid part of the ***rb*** range) experimented their greatest tensile stress, not as usually, on a point in the mid-span of the block portion over the main entrance, but rather many blocks above, near the building's mid height.

The above exceptions happen in the case of the blue series and yellow series maximums, as well as in other buildings. The greatest tensile stresses on these buildings (6 out of 35), are located on intermediate blocks, many blocks above the entrance. It seems that such blocks cannot transmit their usual stress pattern on to the blocks below, because they have too much displacement inwards in relation to the weight they have to carry.

On these 'problematic' blocks, it seems that stresses get transmitted within the same element rather than passed down to the supporting blocks, and the element in question accumulates stress on the lower edge of its innermost side. Whenever this behavior was observed in a building, the superblock in question had an important displacement inwards, as well as important weights to carry, and a criteria for predicting this kind of exceptional behavior could involve these factors.

Example of Tensile Stress Concentrations in exceptional locations



When ***rr*** and ***rb*** increase, producing bigger buildings, we can see that this behaviour starts to diminish:

A block on a given building is less displaced inwards than an analogous block at the same height in a smaller building, and has a greater factor of contact with the block below, transmitting the stresses better. This can be thought of as a better 'supported portion -to-imposed weight' relation: Having a larger area of themselves supported on the block below, these bigger blocks can transmit stresses below instead of accumulating them. This factor might change the amount of stress 'leaving' the blocks.

Also, a block on a given building has a greater radius circumference than an analogous block at the same height on a smaller-building, hence, in spite of having to support a bigger load, these bigger blocks have a different 'bearing area - for - total weight above' relation. This factor might change the amount of stress 'entering' the blocks.

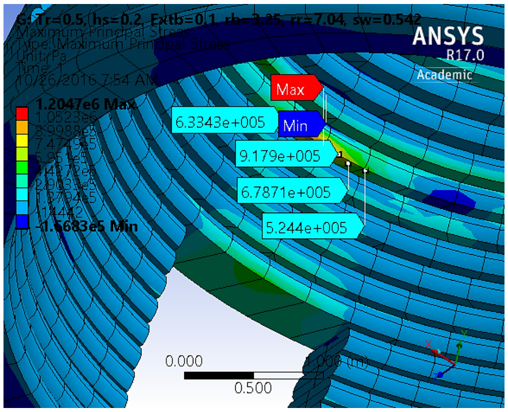
These factors (supported portion -to-imposed weight relation and bearing area - for - total weight above) arise in each superblock of a structure as a result of the corresponding ***rr-rb-sw*** initial configuration of that given building.

This is another observation which states the importance of a correct combination or 'fine tuning' of geometric parameters for more regular stress distribution.

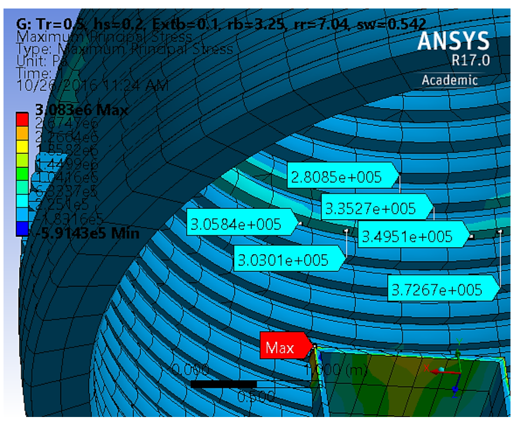
- Observation 6: Modelling buildings with a steel door frame support reduces overall tensile stresses throughout Superadobe elements

As we can see in the following figures, a random sample of Max tensile stresses from a problematic superblock's bottom face with no steel support frame at the entrance, averages 7.9+e5Pa, while a random sample of Max tensile stresses on that same element's face when the dome entrance is supported by a steel frame, averages 3.25+e5Pa.

Random Sample of Max Tensile Stresses in a "Problematic" Superblock, without door Support



Random Sample of Max Tensile Stresses in a "Problematic" Superblock, with door Support



This suggests that steel reinforcements in the openings will concentrate stresses which would be suffered by regular non-reinforced elements if the supports were not present. Reinforcing openings will decrease overall Max tensile stresses throughout the Superadobe elements, improving the functionality of the buildings and increasing its factors of safety.

- Observation 7: Absence of rigid body motions and small Maximum Total deformations

Modelled Superadobe's block - to - block interfaces were modelled using a static friction coefficient of 2. This value was obtained from different experiments referenced in [3], and captures the steel barbed wire effect between superblocks. 35 out of 38 simulations converged, hence, no rigid body motion (superblock displacements) were observed. The state of static equilibrium was satisfied.

The Maximum modulus of total deformation vectors within a building, increases with building size, in a quasi linear manner for all building series, and in all buildings this maximum deformation occurred among the uppermost superblocks.

The Maximum modulus of total deformation vectors of all buildings, measured 7.5 tenths of a millimeter, which can be well within permissible deformation ranges.

- Observation 8: Small Minimum Principal stresses (Compressions):

The Minimum compressive stress within a building, changes with building size, in a manner which reflects that of the Maximum tensile stress curves. For Minimum compressions within each building series, local minima are observed in a building on which local maxima were observed for Maximum tensions, yet minimum compressions did not occur within buildings on the same locations, but rather, in varied edges and corners.

The Maximum modulus of compressive stress of all buildings, measured less than 1.4 MPa, which is well below concrete's mean compressive stress range (20-40 MPa), and which can also be well below Superadobe composite mean compressive strength.

- Observation 9: Small Maximum Shear stresses

The Maximum Shear stress within a building, changes with building size, in a manner which also resembles that of the Maximum tensile stress curves. For Maximum shear within each building series, local maxima are observed in buildings where local maxima were observed for Maximum tensions, and maximum shear stresses within a building usually, but not always, occurred in the same locations as minimum compressions.

The Maximum modulus shear stress of all buildings, measured less than 0.7 MPa, which is well below concrete's mean shear stress range (6-17 MPa), and which can also be well below Superadobe composite mean shear strength.

- Observation 10: The most Linear group of models:

Domes from the blue group experimented the most linear increases of tensile, compressive and shear stresses with respect to their increase in size.

9. References

[1] Gomez, Marco A. L. 2019. “EQUATIONS THAT DESCRIBE THE GEOMETRY OF SUPERADOBE DOMED STRUCTURES.” engrXiv. March 14. doi:10.31224/osf.io/ptq47.

[2] Gomez, Marco A. L. 2019. “APPLICATIONS OF A “GEOMETRICAL SOUNDNESS EQUATION” FOR SUPERADOBE DOMES.” engrXiv. March 14. doi:10.31224/osf.io/d3em6.

[3] Stouter, Patti. 2010. “FRICTION & TENSILE STRENGTH OF EARTHBAG COMPONENTS”. https://www.scribd.com/document/38259520/Friction-Tensile-Strength-of-Earthbag-Components