ENGINEERING ANALYSIS OF FlexiBin S3 AND CONTAINER

IN THIS STUDY FORCES ON CONTAINER STRUCTURES, PRIMARILY SIDE WALLS, ARE EVALUATED. LOADS OR FORCES IMPOSED BY FLEXITANKS CARRYING LIQUID LOADED INTO THE CONTAINER ARE THE FOCUS OF THIS STUDY.

FLEXITANKS LOADED WITH UP TO 24 000 LITERS (AND POSSIBLY HIGHER) OF LIQUID CAN CAUSE STRUCTURAL DAMAGE TO THE CONTAINER UNDER VARIOUS OPERATIONAL SCENARIOS. IF A SIDE WALL IS DAMAGED IT MAY REDUCE THE LATERAL SUPPORT IT PROVIDES TO THE CORNER POSTS AND POSSIBLE CORNER POST COLLAPSE BY BUCKLING COULD OCCUR. THIS CAN RESULT IN STACK FAILURE.

THE FlexiBin S3 IS A DEMOUNTABLE MECHANISM WHICH PHYSICALLY REMOVES LOAD FROM THE CONTAINER SIDE WALLS AND SURROUNDING STRUCTURES BY CONTAINING THE LOWER PORTION OF THE LIQUID WITHIN IT'S STRUCTURE. THE FlexiBin S3 PROTECTS THE STRUCTURAL INTEGRITY OF THE SIDE WALL AND THE CONTAINER AS A WHOLE WHILE ALSO ALLOWING FOR INCREASED PAYLOADS.

HERE WE WILL LOOK AT THE FOLLOWING SCENARIOS AND DETERMINE THE IMPOSED VON MISES STRESSES ON THE SIDE WALL STRUCTURES AS A METHOD OF ANALYSIS:

- CONTAINER LEVEL AND STATIC
- VERTICAL LIFT AT 2g
- STATIC ROLL TO 30^0
- DYNAMIC ROLL AND HEAVE TO 30^0 AND A PERIOD OF 6s WITH A ROLL RADIUS OF 10m

EACH OF THE ABOVE WILL BE EVALUATED WITH AND WITHOUT A FlexiBin S3 AND FOR VOLUMES OF WATER RANGING BETWEEN 18 000 LITERS AND 27 000 LITERS.

THE MAXIMUM SAFE LOAD WILL BE THAT WHICH DOES NOT CAUSE MATERIAL YIELDING OF ANY CONTAINER COMPONENT UNDER ANY OF THE OPERATING SCENARIOS.

THEORETICAL MODELING OUTPUTS VERY CLOSELY RESEMBLE ACTUAL PHYSICAL TESTS CARRIED OUT ON FULL SIZE CONTAINER/FlexiBin S3/FLEXITANK COMBINATIONS AND ARE DEEMED ACCURATE AND RELIABLE MODELS BY WHICH TO ANALYZE THESE FORCES.

THE YIELD STRENGTH OF THE CONTAINER MATERIAL ,CORTEN A, IS CONSIDERED TO BE 340MPa. THE ULTIMATE TENSILE STRENGTH OF THE CORTEN A IS 490 MPa. A FAILURE IS DEFINED AS ANY STRESS LEVEL IN ANY MEMBER OF THE CONTAINER AT OR ABOVE 340MPa. ALL INDICATED STRESSES ARE REPRESENTATIVE OF THE GENERAL STRESS LEVELS IN THE AREA OF THE SOFTWARE PROBE.

STANDARD SIDE WALL DESIGN IS APPLIED – 2mm THICK END PANELS, 1.6mm THICK INTERMEDIATE PANELS AND 36mm CORRUGATION DEPTH. ALLOWANCE HAS BEEN MADE FOR SMALL IMPERFECTIONS IN THE PANELS.

SLIDES 1 THROUGH 10 PROVIDE A SUMMARY OF THE ENGINEERING ANALYSIS AND FINDINGS. SLIDES 11 THROUGH 34 PROVIDE FEA OUTPUT DETAILS OF VARIOUS SCENARIOS FO REFERENCE.

THE PRIMARY FOCUS IS TO DESIGN AND DELIVER A METHOD TO RESPONSIBLY AND SAFELY INCREASE PAYLOADS WHILE IMPROVE OPERATING ECONOMICS OF FLEXITANKS.

METHOD OF ANALYSIS …

THE FOLLOWING SLIDES CONTAIN SELECTED SCENARIOS OF VON MISES STRESSES AND DEFLECTIONS IN A STANDARD ISO TYPE 22G1 SHIPPING CONTAINER CONTAINING A FLEXITANK UNDER VARIOUS LOAD CONDITIONS. THE ENTIRE CONTAINER STRUCTURE IS ANALYZED AS THE DESIGN IS TYPICALLY A MONOCOQUE TYPE STRUCTURE WITH VARIOUS LOAD TRANSFER PATHS THAT DETERMINE INDIVIDUAL COMPONENT LOADINGS. THIS IS A FAR MORE ROBUST APPROACH THAN, FOR EXAMPLE, ANALYZING ONLY A SIDE WALL ASSEMBLY ON ITS OWN.

SPECIFICALLY, COMPARISONS ARE DRAWN BETWEEN THOSE SCENARIOS WHERE THE CONTAINER IS FITTED WITH THE FlexiBin S3 AND THOSE WHERE NO FlexiBin S3 IS FITTED.

MODELING OF THE CONTAINERS WAS CARRIED OUT USING A CAD 3D MODEL AND FEA SOFTWARE TO APPLY LOADINGS AND DETERMINE RESULTING VON MISES STRESSES AND DEFLECTIONS. UNLESS SPECIFICALLY STATED ALL CONTAINERS ARE ASSUMED TO HAVE SIDE WALLS IN GOOD CONDITION CONSISTING OF 2mm THICK END PANELS AND 1.6mm THICK INTERMEDIATE PANELS. TO ENSURE ACCURATE AND RELIABLE MODEL MESHING AND OUTPUTS SHELL ANALYSIS WAS APPLIED TO ALL THIN SECTION MEMBERS INCLUDING SIDE WALL MEMBERS.

DYNAMIC ROLL LOADING CALCULATIONS ARE BASED ON *THE AMERICAN BUREAU OF SHIPPING GUIDE FOR CERTIFICATION OF CONTAINER SECURING SYSTEMS NOVEMBER 2010 (UPDATED SEPTEMBER 2014) SECTION 6, CLAUSE 3.7.1 CONDITION A – ROLL AND HEAVE. CONTAINER ON BOW SECTION OF VESSEL. UNRESTRICTED.*

WITH REGARD TO TANGENTIAL ACCELERATIONS DUE TO VESSEL ROLLING A NATURAL ROLLING PERIOD OF 24s (6s PER 30^0) IS ASSUMED ALONG WITH A ROLL RADIUS OF 10m TO THE CENTER OF GRAVITY OF THE LOADED CONTAINER. A ROLL ANGLE OF 30^0 WAS APPLIED IN ALL CASES WHERE A LATERAL ACCELERATION WAS REQUIRED. ROLL PERIOD AND ACCELERATIONS COULD VARY DEPENDING ON VARIABLES SUCH AS METACENTRIC HEIGHT, CENTER OF GRAVITY OF THE VESSEL, ETC.

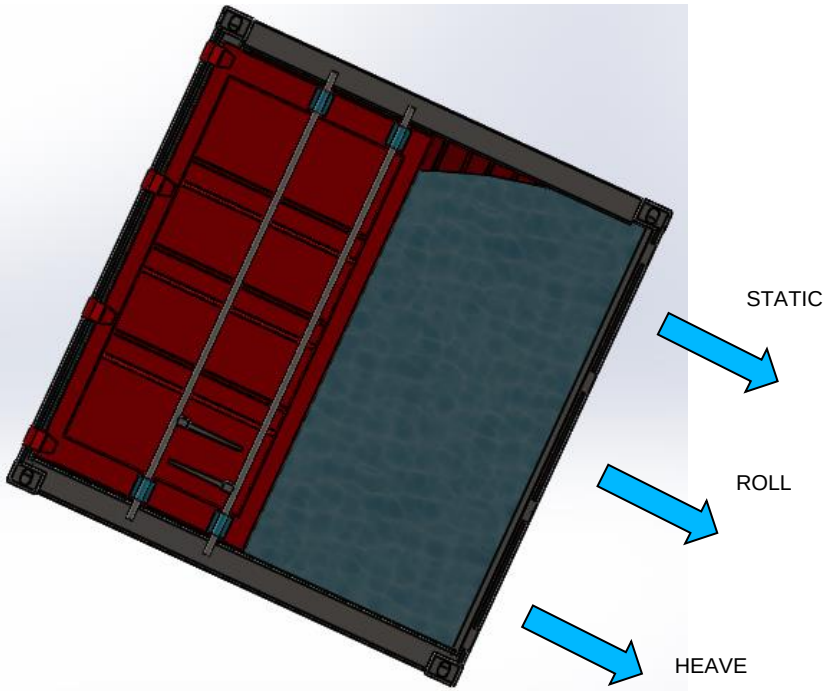
IN THOSE CASES WHERE THE CONTAINER IS FITTED WITH A FlexiBin S3 FORCE INPUTS ARE APPLIED TO THE CONTAINER SIDE WALL ABOVE THE HEIGHT OF THE FlexiBin S3 SIDE WALLS WHICH ARE 750mm IN THE VERTICAL PLANE. IN THOSE CASE WHERE NO FlexiBin S3 IS FITTED THE FORCE INPUTS ARE APPLIED TO THE ENTIRE SIDE WALL FROM FLOOR LEVEL. IN ALL CASES THE AREA OF FORCE AND PRESSURE APPLICATION IS ON THE AREA OVER WHICH THE LIQUID LOAD MAKES CONTACT WITH THE CONTAINER SIDE WALL.

LATERAL ACCELERATION INPUTS:

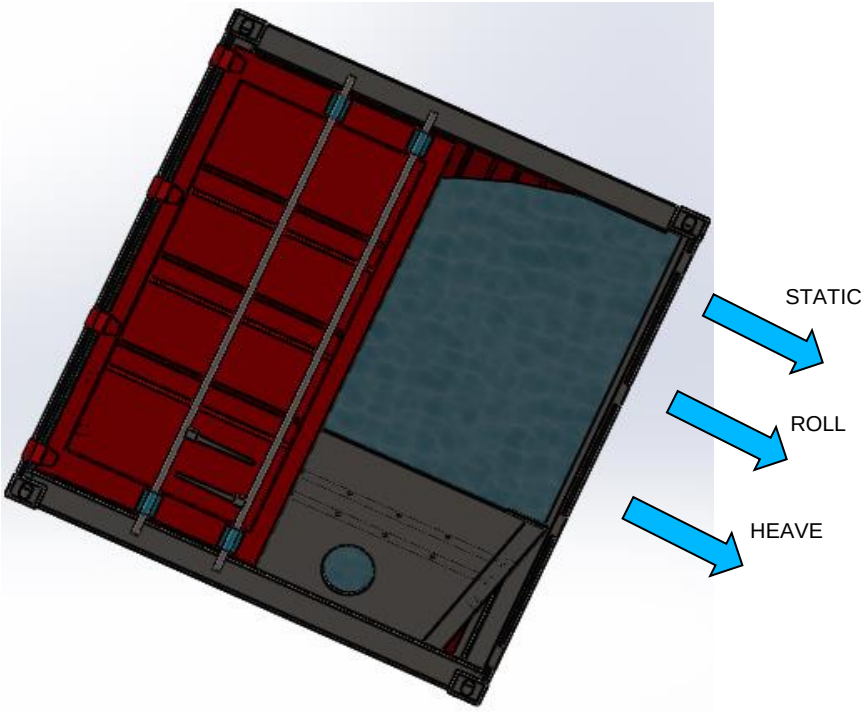
STATIC PRESSURE
TANGENTIAL ACCEL (USING ROLL ANGLE AND ROLL RADIUS)
HEAVING

OUTPUTS = COMPOUND LATERAL ACCELERATION IN g's

ACTUAL COMPOUND LATERAL ACCELERATION FACTOR = 0.673g



FULL SIDE WALL CONTACT – NO FlexiBin S3

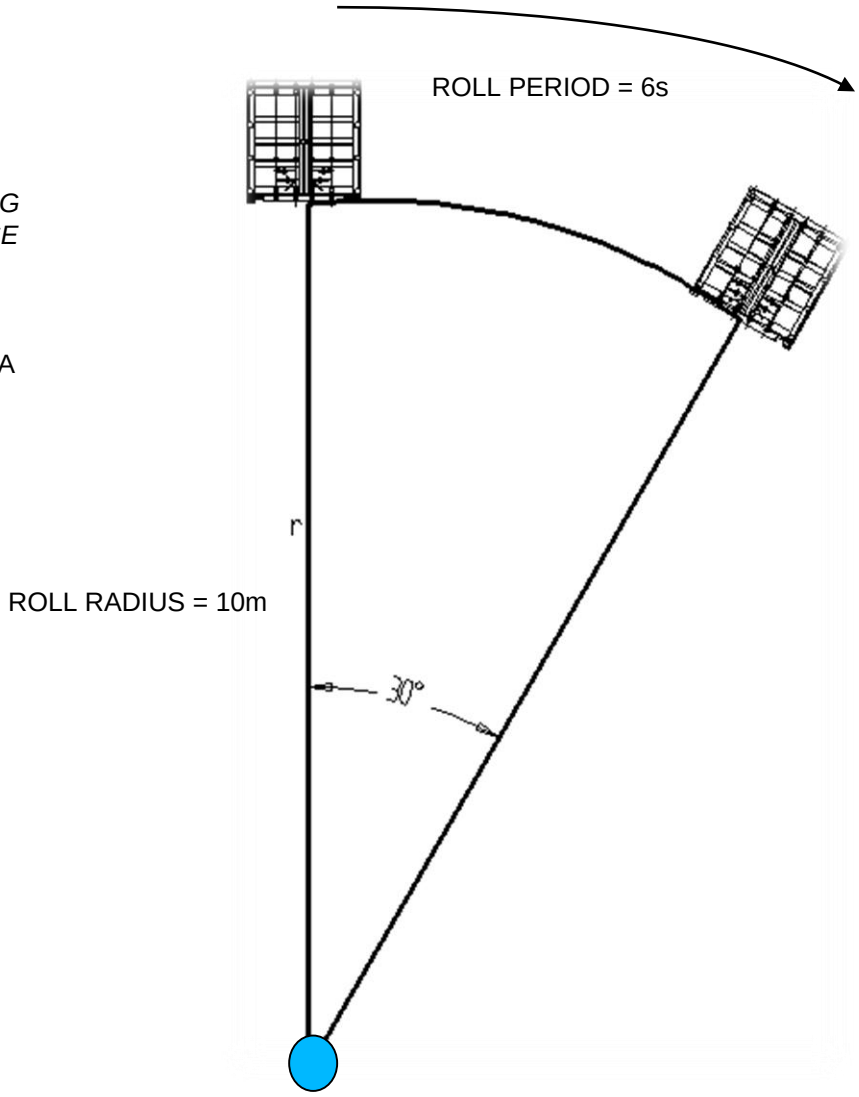


PARTIAL SIDE WALL CONTACT ABOVE FlexiBin S3 – WITH FlexiBin S3

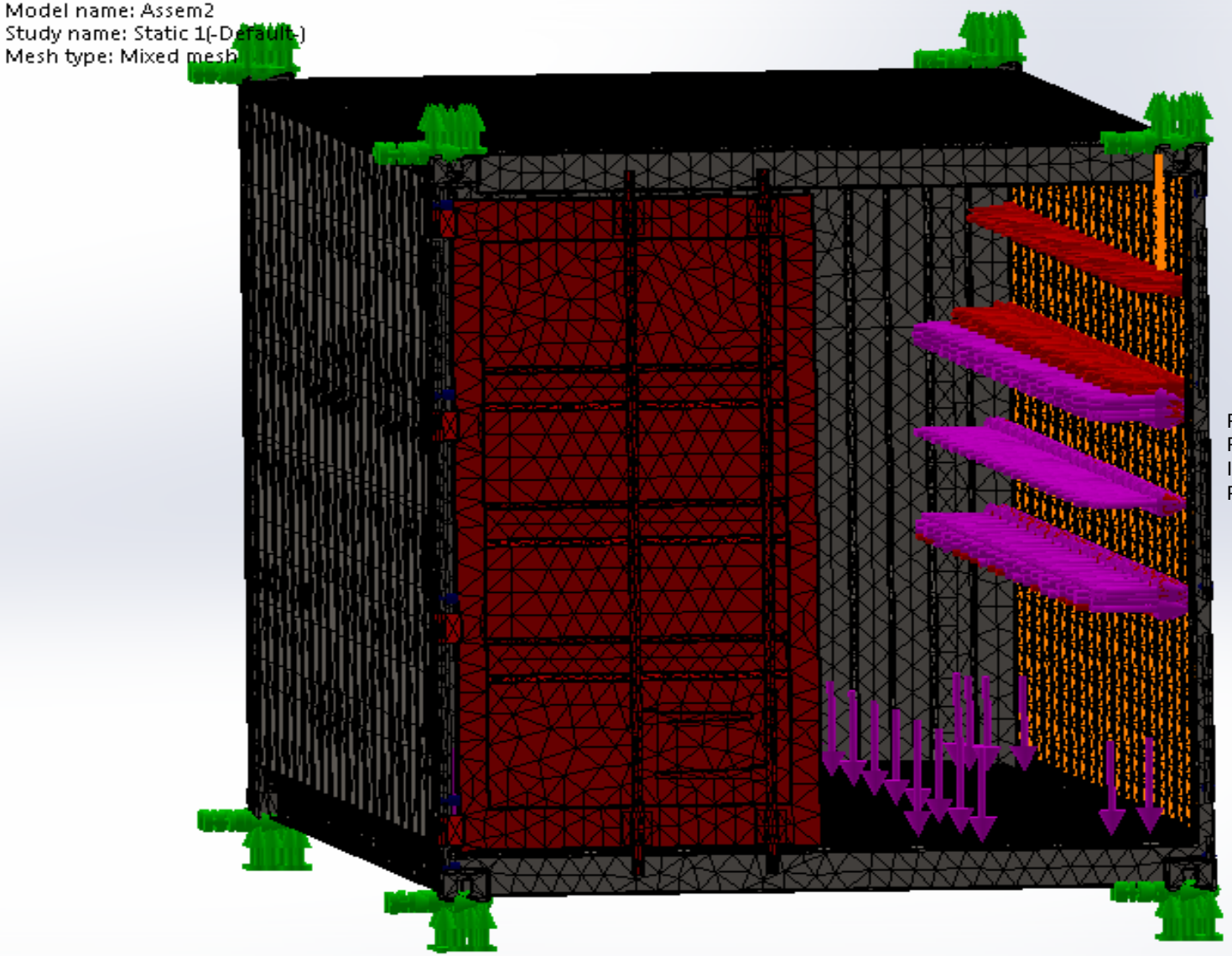
THE MECHANICS OF VESSEL ROLL

DYNAMIC ROLL LOADING CALCULATIONS ARE BASED ON *THE AMERICAN BUREAU OF SHIPPING GUIDE FOR CERTIFICATION OF CONTAINER SECURING SYSTEMS NOVEMBER 2010 (UPDATED SEPTEMBER 2014) SECTION 6, CLAUSE 3.7.1 CONDITION A – ROLL AND HEAVE. CONTAINER ON BOW SECTION OF VESSEL. UNRESTRICTED.*

WITH REGARD TO TANGENTIAL ACCELERATIONS DUE TO VESSEL ROLLING A NATURAL ROLLING PERIOD OF 24s (6s PER 30^0) IS ASSUMED ALONG WITH A ROLL RADIUS OF 10m TO THE CENTER OF GRAVITY OF THE LOADED CONTAINER. A ROLL ANGLE OF 30^0 WAS APPLIED IN ALL CASES.



MESHED CONTAINER MODEL AND NON-UNIFORM PRESSURE LOADING EXAMPLE



RH DOOR REMOVED FOR ILLUSTRATION PURPOSES ONLY

SUMMARY TABLE OF VON MISES STRESS RESULTS IN MPa FOR EACH SCENARIO MODELED

ONLY SELECTED STRESS VALUES INDICATED. MATERIAL YIELD STRENGTH = 340MPa

NO FlexiBin S3

		Load condition			
Container side wall type*	**Payload (Liters)**	Static	2g Vertical lift	30^0 Static roll	30^0 Static roll dynamic
Standard	18 000	✓	✓	✓	! 345
Standard	24 000	✓ 237	✗ 445	✗ 372	✗
Standard	25 000		✗	✗	✗
Standard	26 000		✗	✗	✗
Heavy duty	26 000		✗	✗	✗
Standard	26 700		✗	✗	✗
Standard	27 000		✗	✗	✗
Heavy duty	27 000		✗	✗	✗

WITH FlexiBin S3

		Load condition			
Container side wall type*	**Payload (liters)**	Static	2g Vertical lift	30^0 Static roll	30^0 Static roll dynamic
Standard	24 000				✓ 302
Standard	25 000				✓ 324
Standard	26 000		✓ 320	✓ 289	! 346
Heavy duty	26 000		✓	✓	✓ 312
Standard	26 700		✓ 327		✗ 354
Standard	27 000		✗		✗
Heavy duty	27 000		✓ 320	✓	✓ 329

* Standard = 2mm thick end panels and 1.6mm thick intermediate panels

Heavy duty = 2mm thick panels throughout

SUGGESTED PAYLOADS FOR FLEXITANKS BASED ON OUTLINED ANALYSIS

MINIMUM PAYLOAD IS THE LIMITING PAYLOAD IN EACH ROW OF THE TABLE

Suggested payloads							
NO FlexiBin S3							
				Load condition			
Container side wall type*	**Payload (Liters)**	Static	2g Vertical lift	30^0 Static roll	30^0 Static roll dynamic	Suggested safe loads	
Standard		24000	18000	18000	18000	18000	
Heavy duty		26000	22500	23000	23000	22500	
WITH FlexiBin S3							
				Load condition			
Container side wall type*	**Payload (liters)**	Static	2g Vertical lift	30^0 Static roll	30^0 Static roll dynamic		% Increase in payload when using the FlexiBin S3
Standard		26500	26500	26500	26500	26500	**47.22%**
Heavy duty		27000	27000	27000	27000	27000	**20.00%**

* Standard = 2mm thick end panels and 1.6mm thick intermediate panels

Heavy duty = 2mm thick panels throughout

RECOMMENDATIONS …

- WHILE SOME PROGRESS HAS BEEN MADE THE CURRENT INDUSTRY MAXIMUM ALLOWABLE LOAD VOLUME OF 24 000 LITERS NEEDS TO BE RE-ASSESSED TO INCLUDE OPERATIONAL SCENARIOS BEYOND A RAIL IMPACT TEST. THE IMPACT TEST MAY NOT BE AN ACCURATE OR RELIABLE INDICATOR FOR CONTAINER/FLEXITANK SYSTEM PERFORMANCE UNDER TYPICAL OPERATING ENVIRONMENTS

- WITH A FlexiBin S3 INSTALLED THE SAFE PAYLOAD FOR FLEXITANKS COULD BE SAFELY RAISED TO 26 500 LITERS FOR A STANDARD SIDE WALL CONSTRUCTION OR TO 27 000 LITERS USING A CONTAINER WITH 2mm THICK STEEL SECTIONS THROUGHOUT. THESE PAYLOADS WOULD IMPART STRUCTURAL STRESSES BELOW THE MATERIAL YIELD POINT OF THE CONTAINER AND ALSO ALLOW FOR MINOR FORMS OF EXISTING DAMAGE TO THE CONTAINER SIDE WALLS

- THE SUGGESTED PAYLOADS OUTLINED IN SLIDE 9 SHOULD BE RESPONSIBLY CONSIDERED

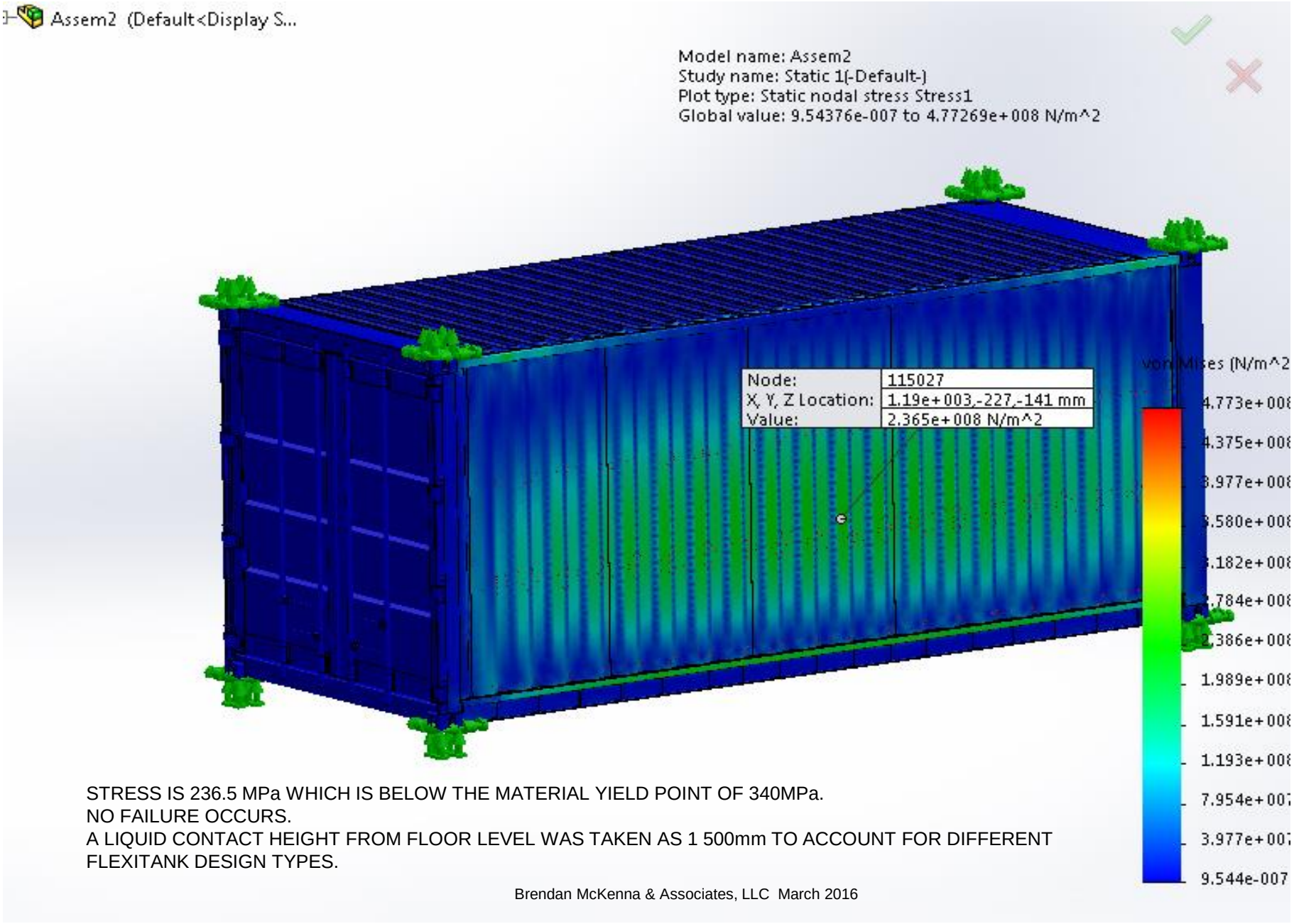
- THE FLEXITANK INDUSTRY SHOULD BE ENCOURAGED TO LOOK AT MORE VALID AND RELIABLE TEST METHODOLOGIES TO ADDRESS A WIDER RANGE OF OPERATIONAL ENVIRONMENTS WITH A VIEW TO IMPROVING PUBLIC SAFETY

- MODELING AS OUTLINED IN THIS STUDY IS AN ACCURATE AND RELIABLE APPROACH IN DETERMINING PARAMETERS FOR LIVE TESTING

- PLEASE CONTACT US FOR ANY QUESTIONS:

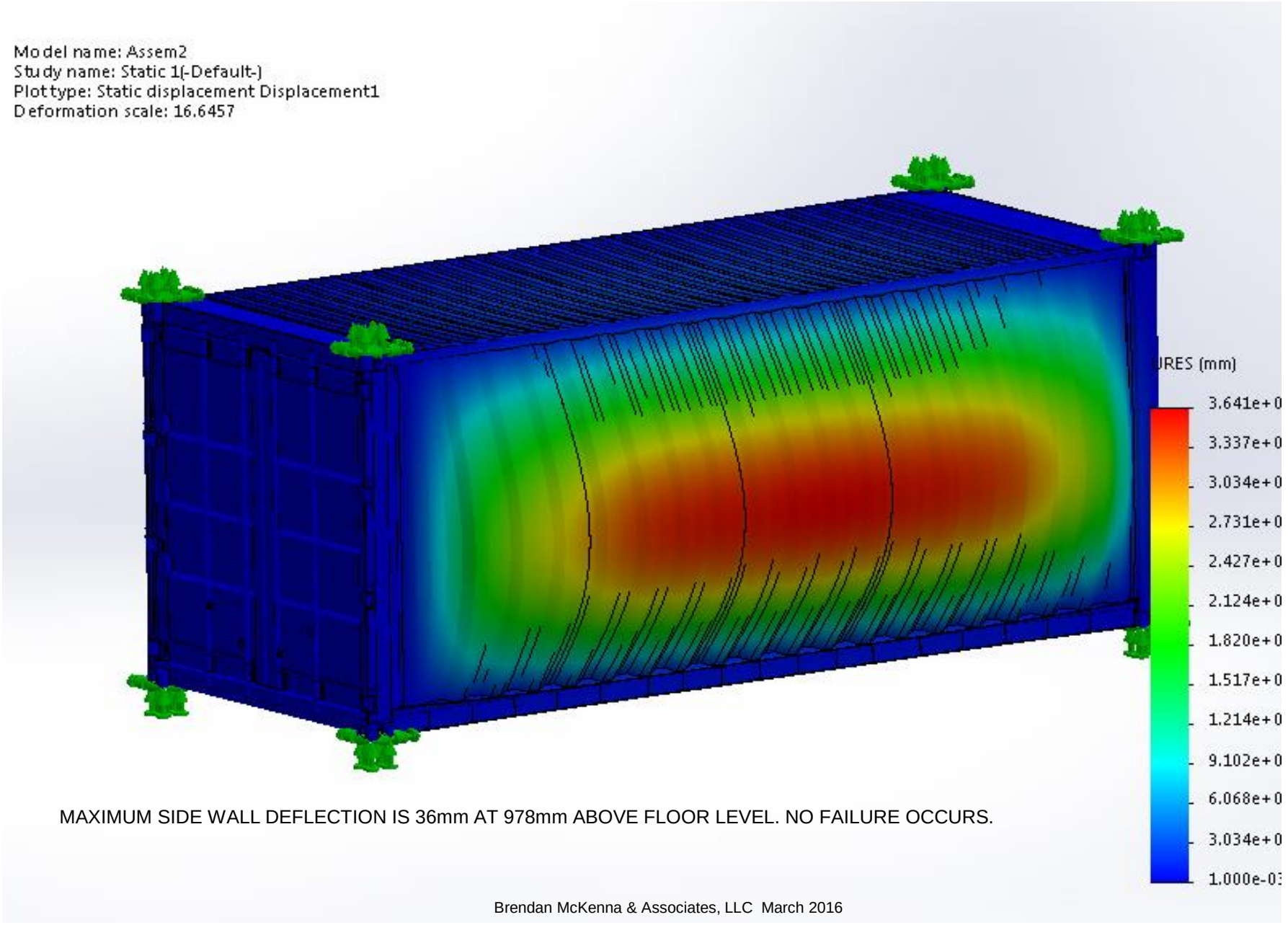
Brendan P. McKenna – USA on +1 832 707 6947; brendanmckenna@comcast.net
Martin Clive-Smith – UK on +44 1926 863 140; martin@clive-smith.com

STATIC STRESS PLOT 24 000 LITERS WATER IN FLEXITANK NO FlexiBin S3



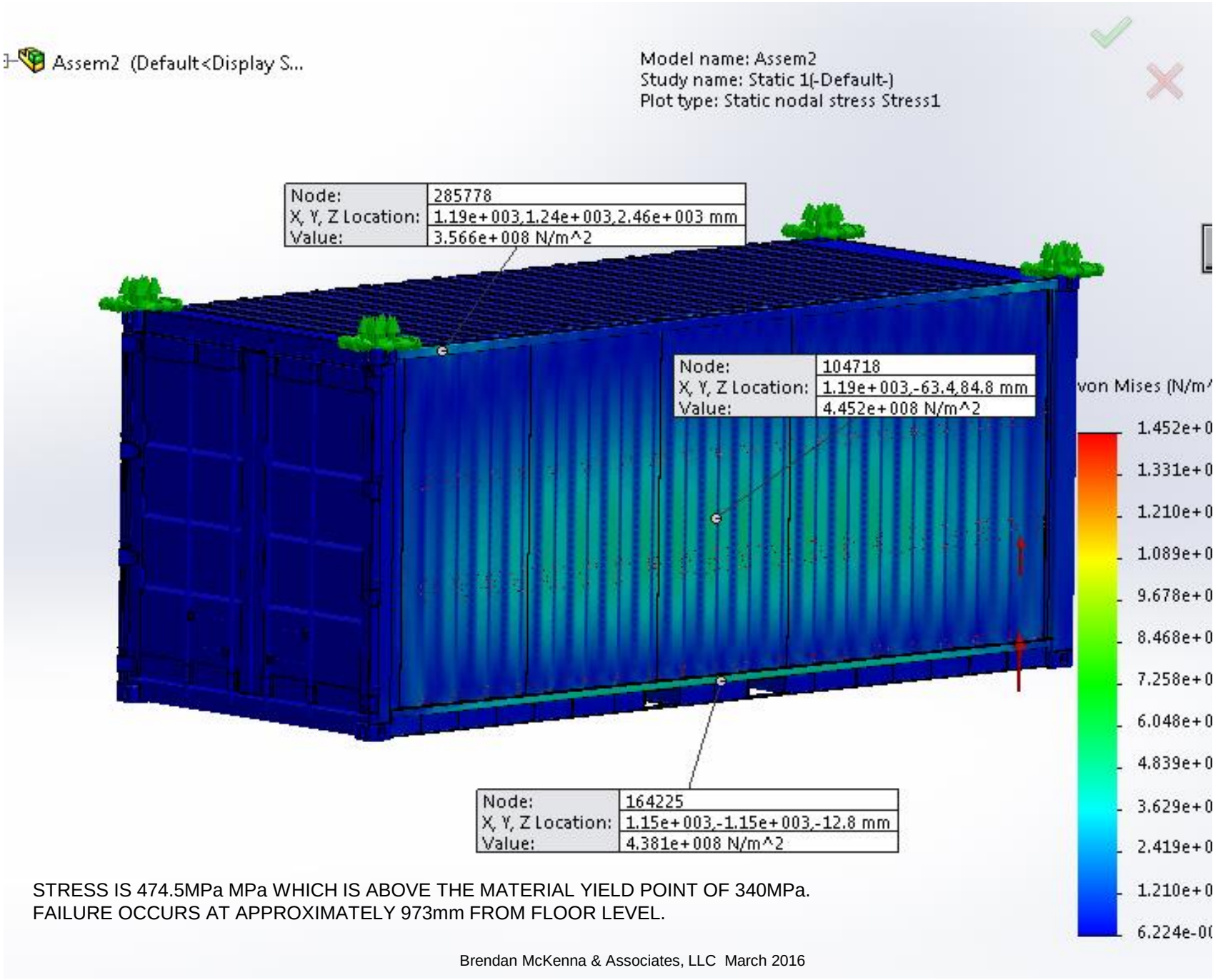
STRESS IS 236.5 MPa WHICH IS BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.
A LIQUID CONTACT HEIGHT FROM FLOOR LEVEL WAS TAKEN AS 1 500mm TO ACCOUNT FOR DIFFERENT FLEXITANK DESIGN TYPES.

24 000 LITERS STATIC LOAD MAX DEFORMATION NO FlexiBin S3



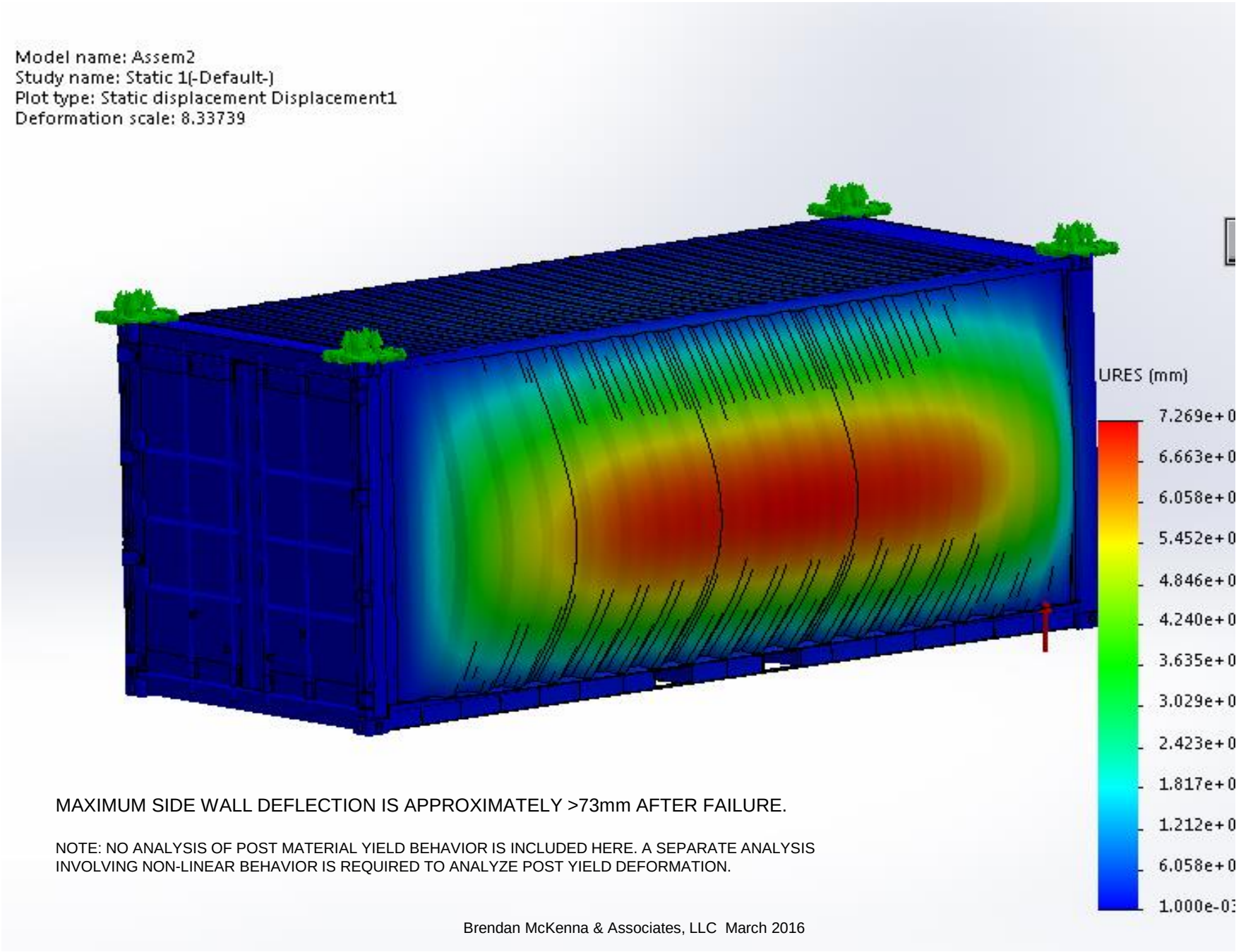
MAXIMUM SIDE WALL DEFLECTION IS 36mm AT 978mm ABOVE FLOOR LEVEL. NO FAILURE OCCURS.

24 000 LITERS AT 2g VERTICAL LIFT NO FlexiBin S3



STRESS IS 474.5MPa MPa WHICH IS ABOVE THE MATERIAL YIELD POINT OF 340MPa.
FAILURE OCCURS AT APPROXIMATELY 973mm FROM FLOOR LEVEL.

24 000 LITERS AT 2g VERTICAL LIFT NO FlexiBin S3

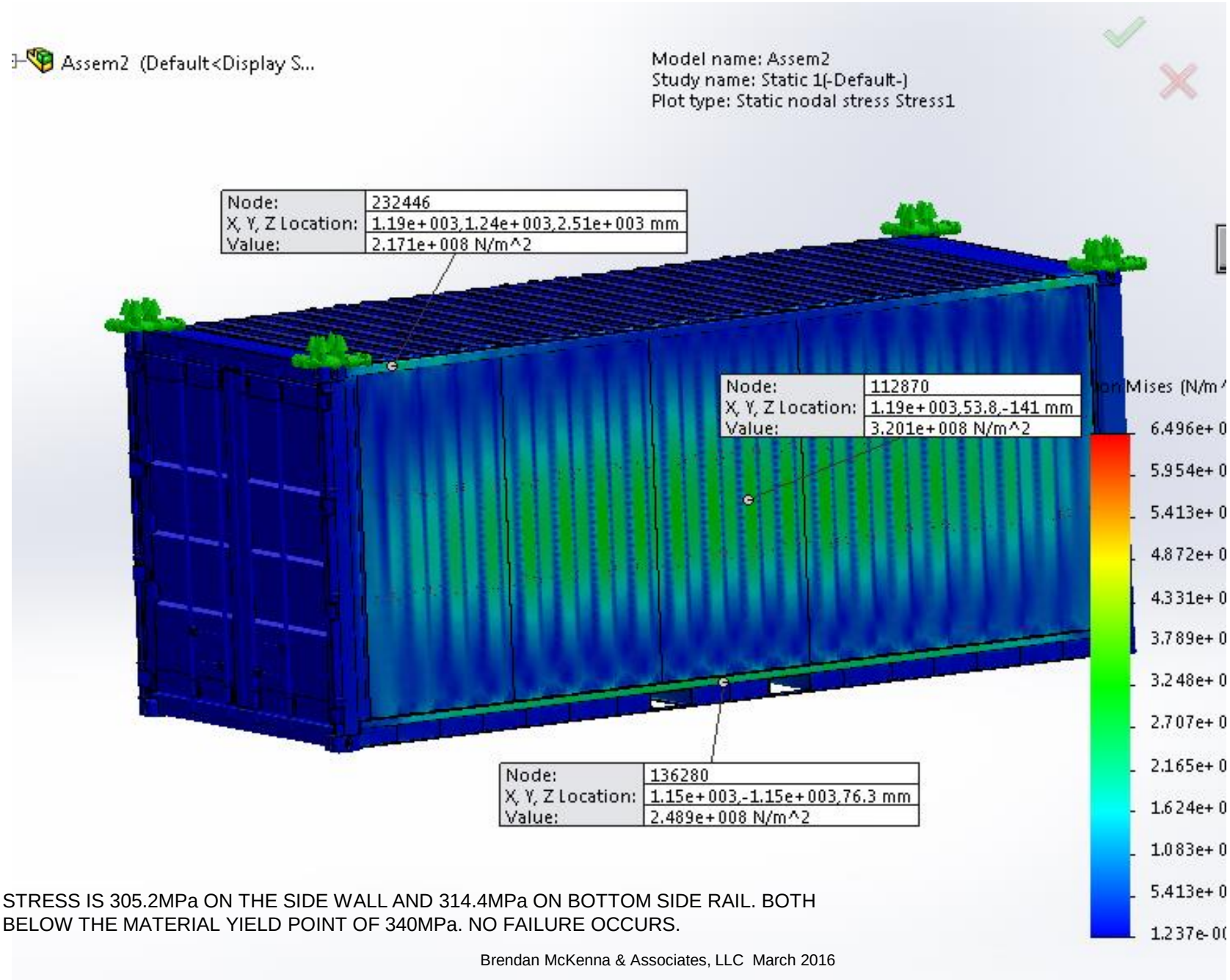


MAXIMUM SIDE WALL DEFLECTION IS APPROXIMATELY >73mm AFTER FAILURE.

NOTE: NO ANALYSIS OF POST MATERIAL YIELD BEHAVIOR IS INCLUDED HERE. A SEPARATE ANALYSIS INVOLVING NON-LINEAR BEHAVIOR IS REQUIRED TO ANALYZE POST YIELD DEFORMATION.

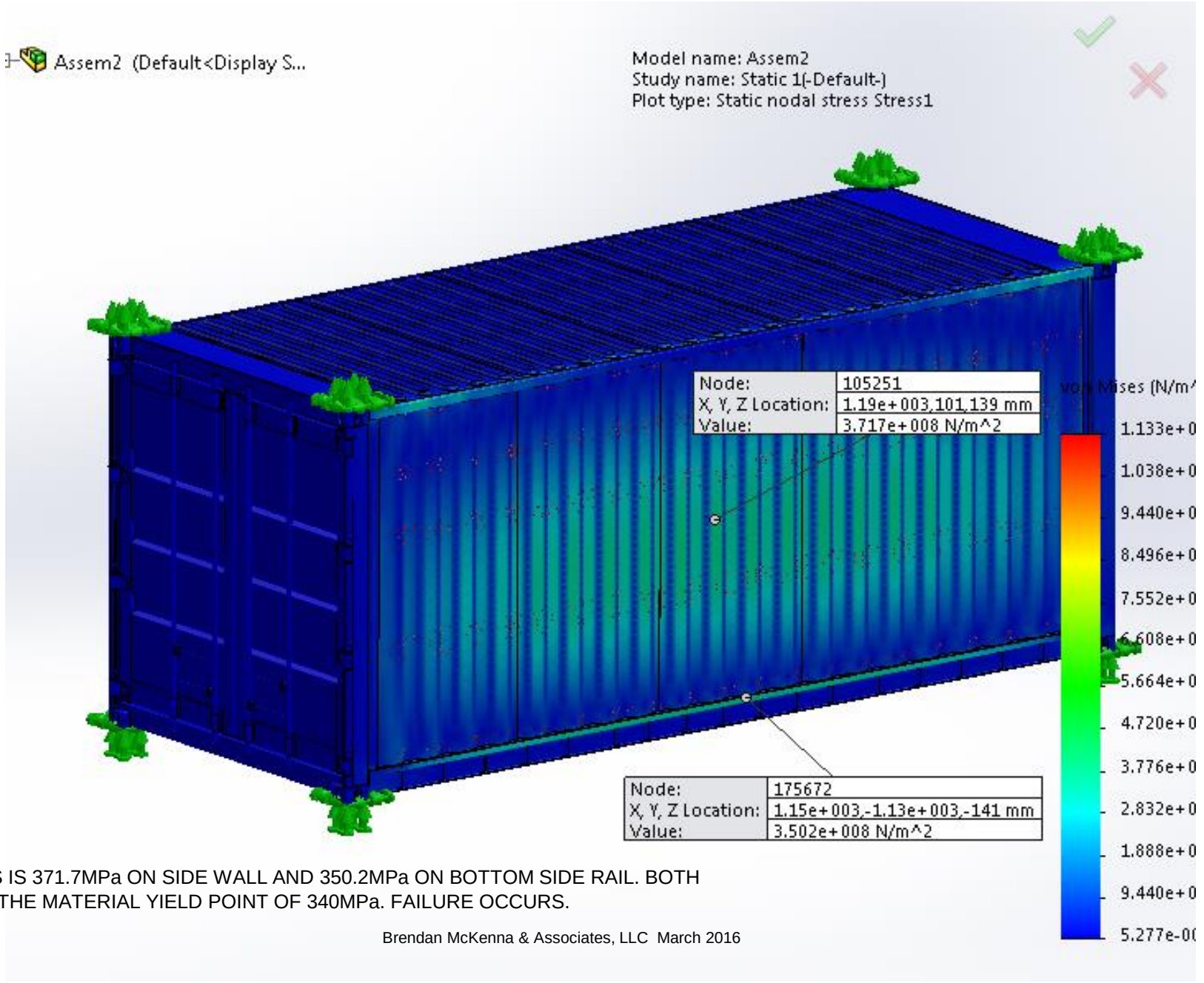
TYPICAL FAILURE PATTERNS SUCH AS THESE CAN COMPROMISE THE STRUCTURAL INTEGRITY OF THE SHIPPING CONTAINER AND CAN CAUSE DAMAGE TO PROPERTY AND PUT LIVES AT RISK

26 000 2g VERTICAL LIFT WITH FlexiBin S3



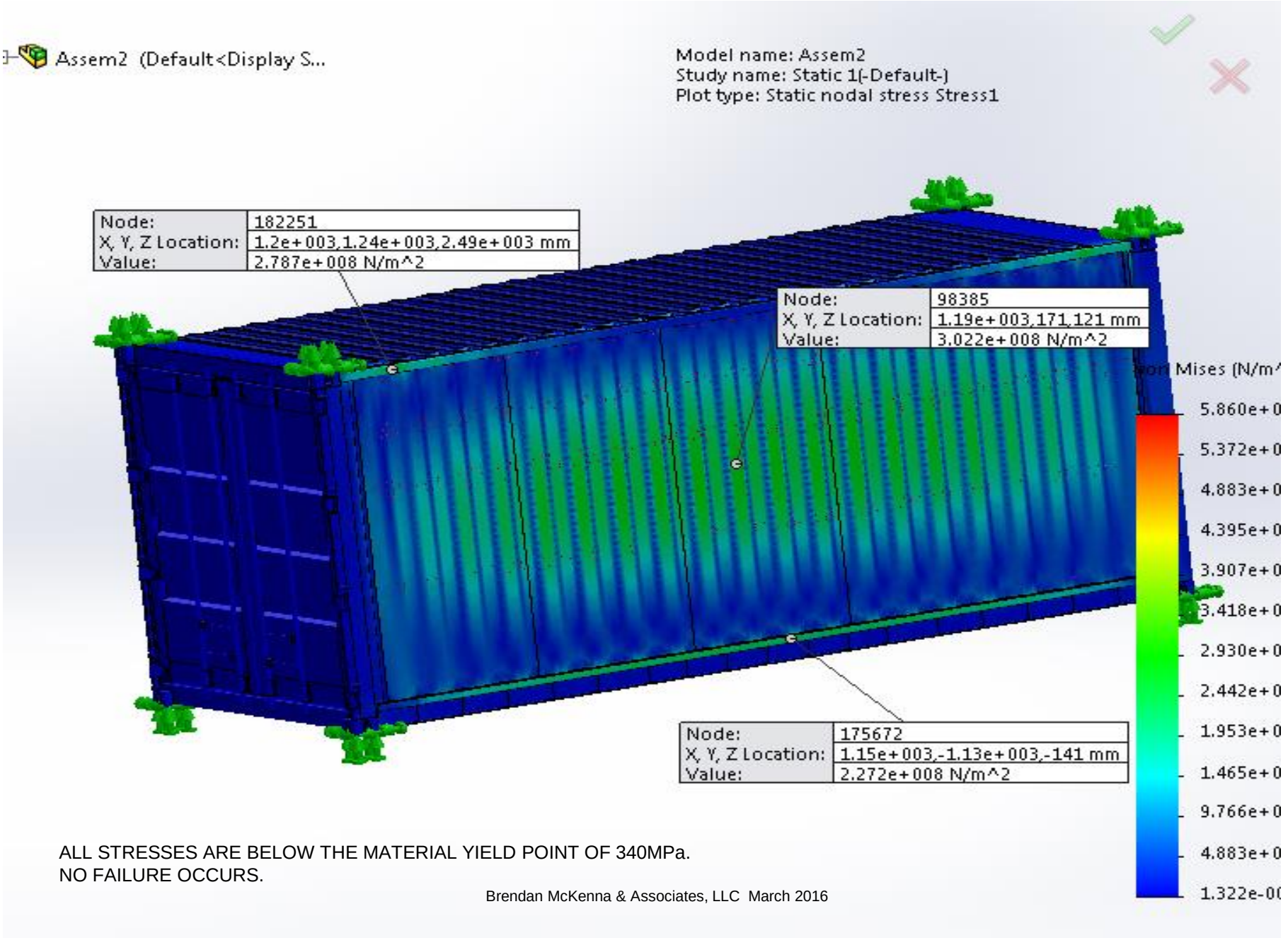
STRESS IS 305.2MPa ON THE SIDE WALL AND 314.4MPa ON BOTTOM SIDE RAIL. BOTH BELOW THE MATERIAL YIELD POINT OF 340MPa. NO FAILURE OCCURS.

24 000 LITERS AT 30^0 ROLL ANGLE STATIC NO FlexiBin S3



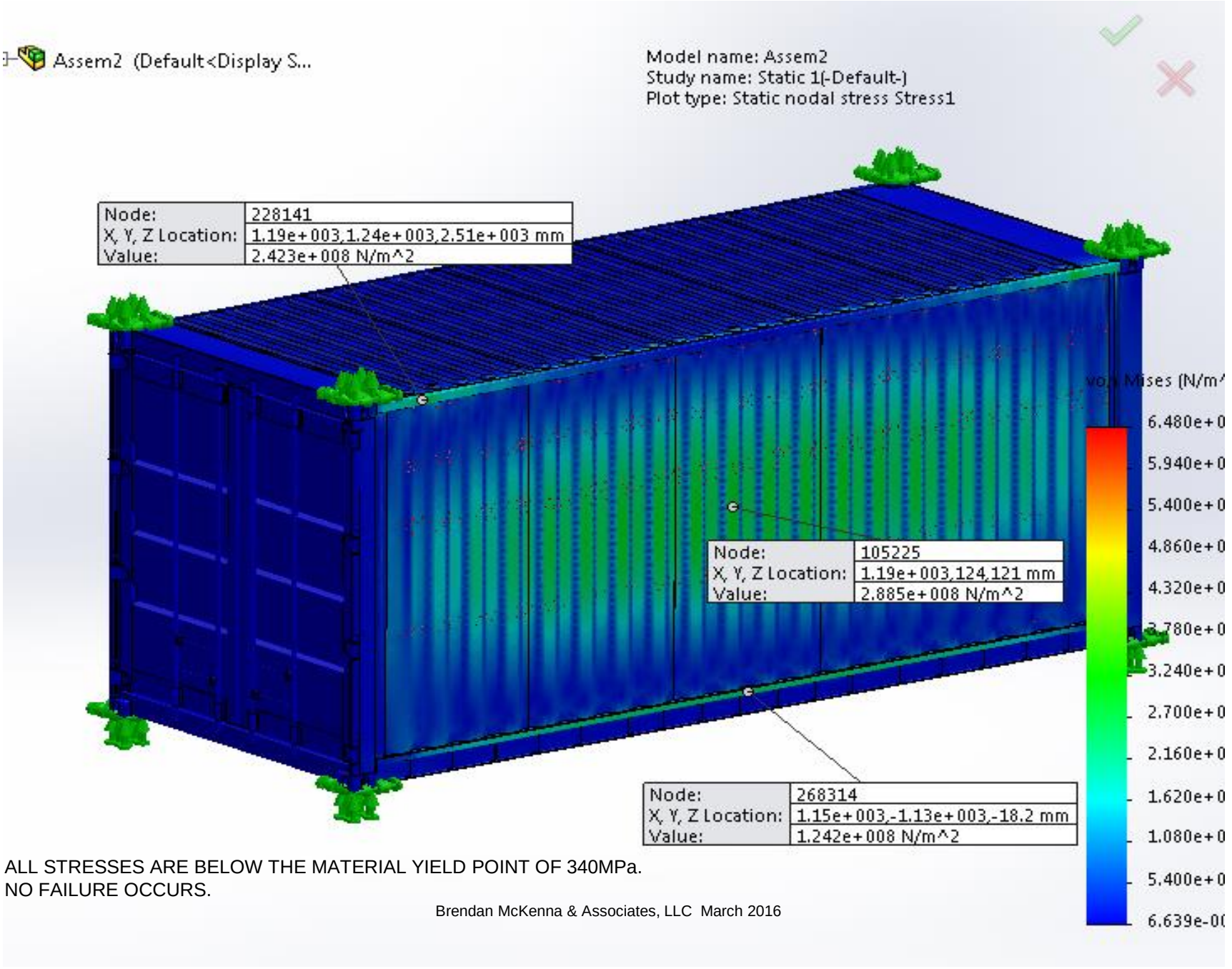
STRESS IS 371.7MPa ON SIDE WALL AND 350.2MPa ON BOTTOM SIDE RAIL. BOTH ABOVE THE MATERIAL YIELD POINT OF 340MPa. FAILURE OCCURS.

24 000 LITERS 30^0 ROLL ANGLE AND 6s ROLL PERIOD AND HEAVE DYNAMIC WITH FlexiBin S3



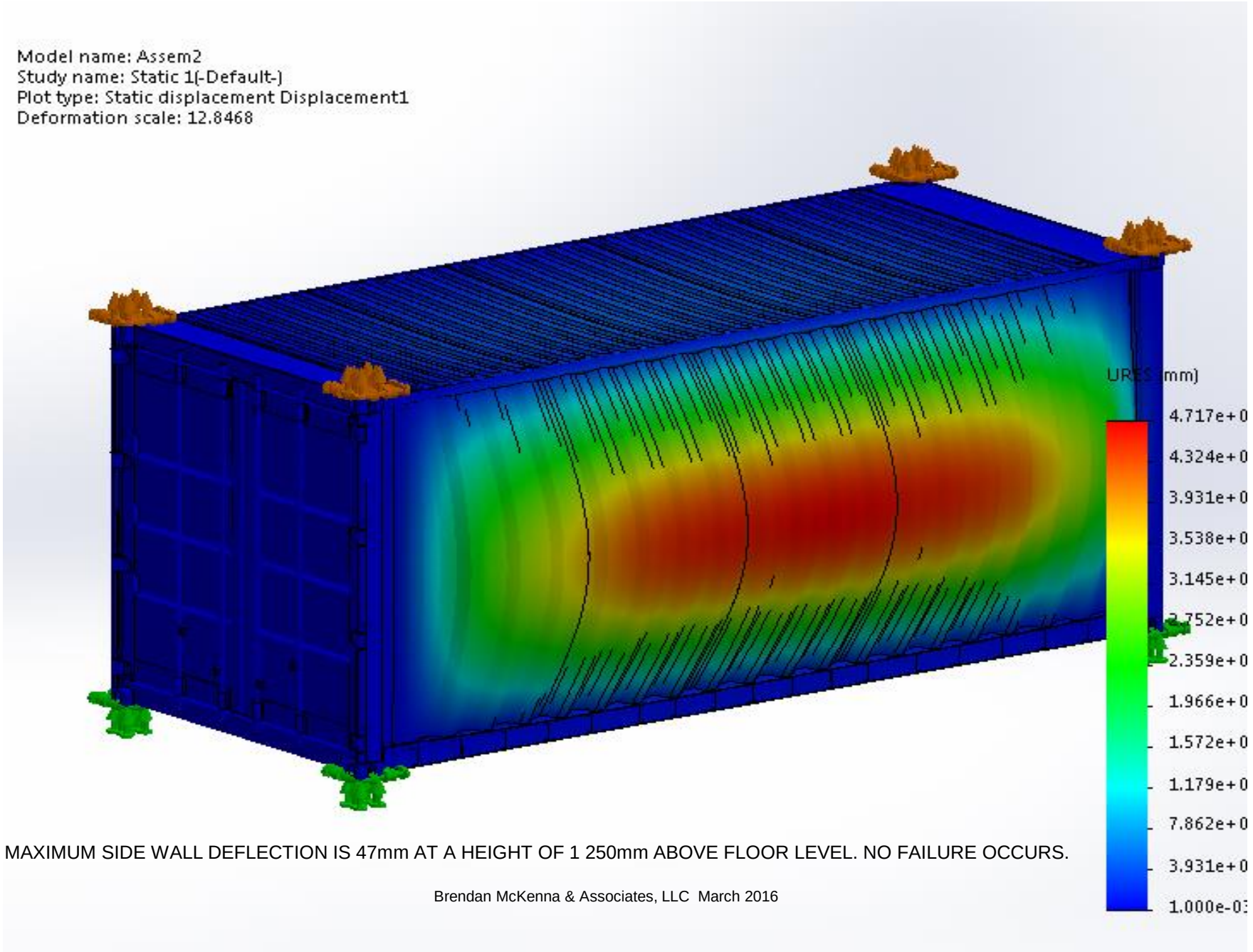
ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

26 000 LITERS AT 30^0 ROLL ANGLE STATIC WITH FlexiBin S3



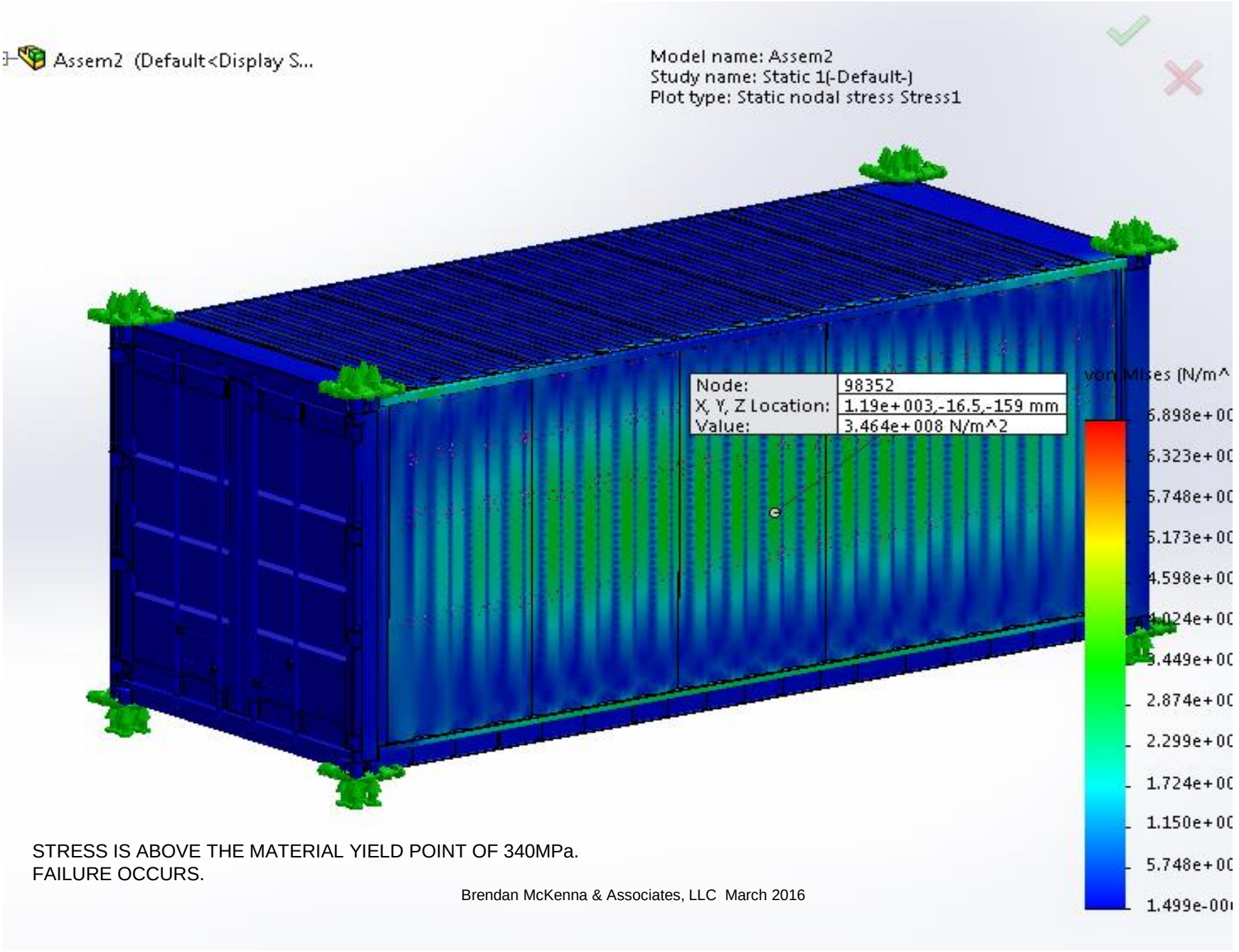
ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

26 000 LITERS 30^0 ROLL ANGLE STATIC WITH FlexiBin S3



MAXIMUM SIDE WALL DEFLECTION IS 47mm AT A HEIGHT OF 1 250mm ABOVE FLOOR LEVEL. NO FAILURE OCCURS.

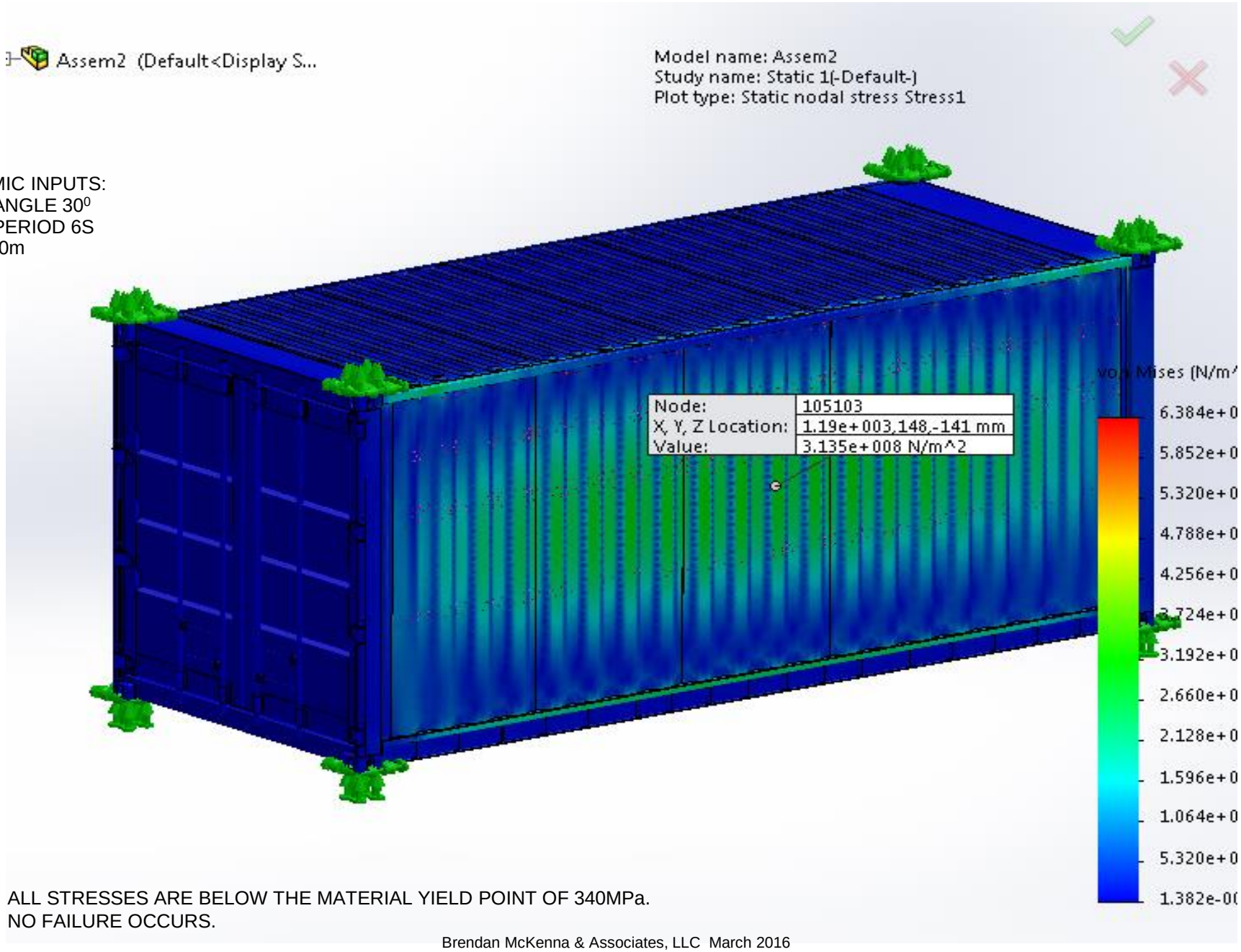
26 000 LITERS 30^0 ROLL ANGLE AND 6s ROLL PERIOD AND HEAVE DYNAMIC WITH FlexiBin S3



STRESS IS ABOVE THE MATERIAL YIELD POINT OF 340MPa.
FAILURE OCCURS.

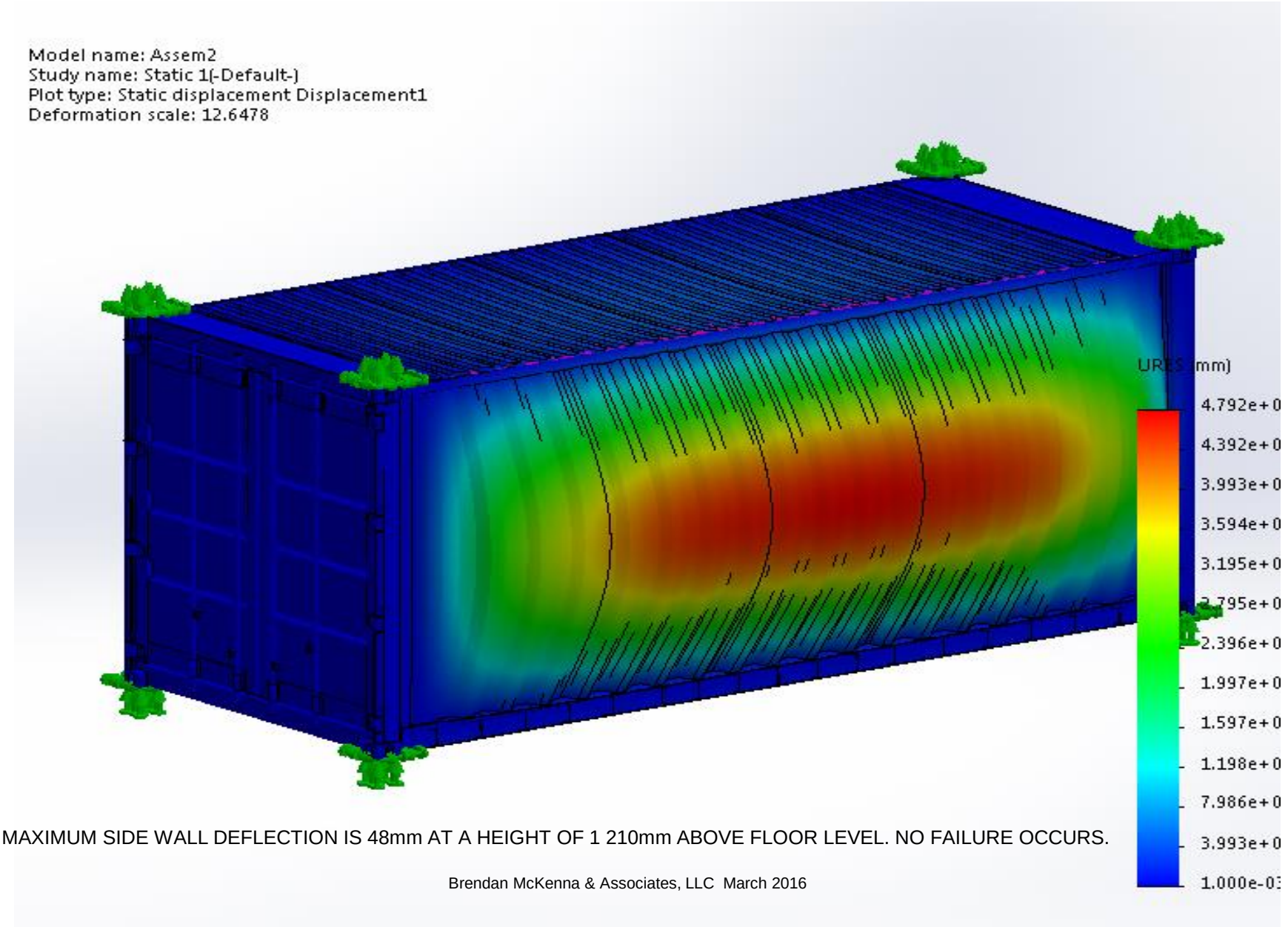
25 000 LITERS 30^0 ROLL ANGLE AND 6s ROLL PERIOD AND HEAVE DYNAMIC WITH FlexiBin S3

DYNAMIC INPUTS:
ROLL ANGLE 30^0
ROLL PERIOD 6S
Rct = 10m



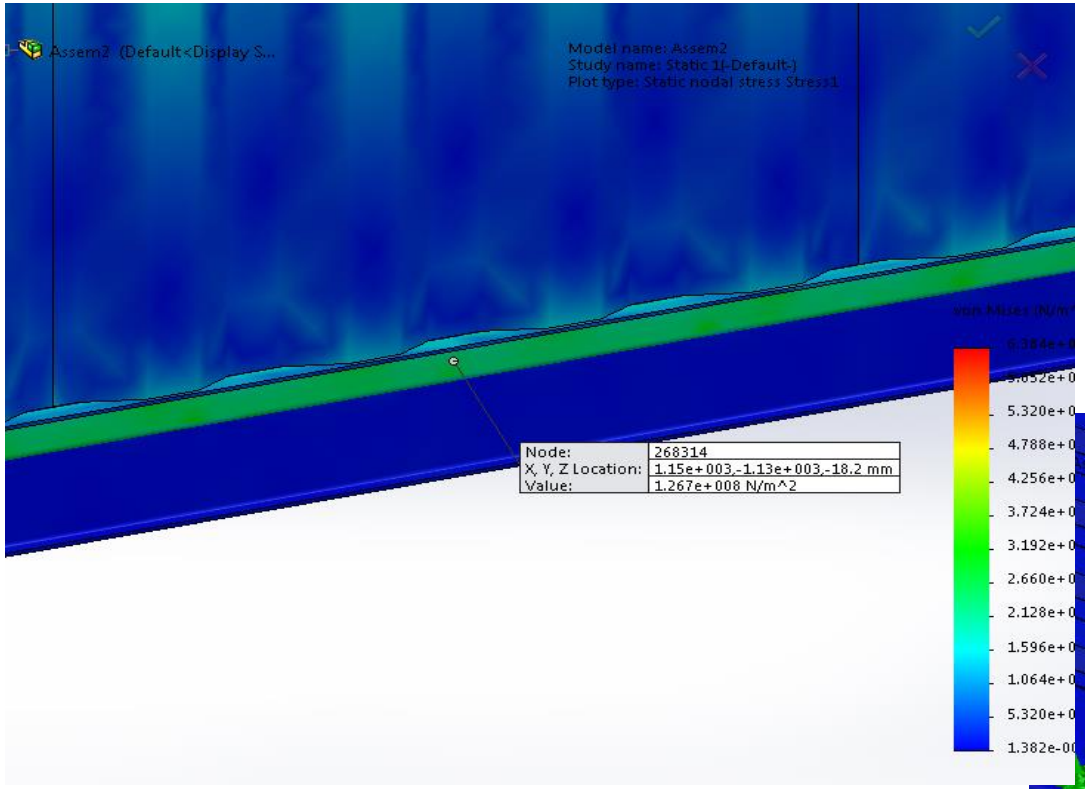
ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

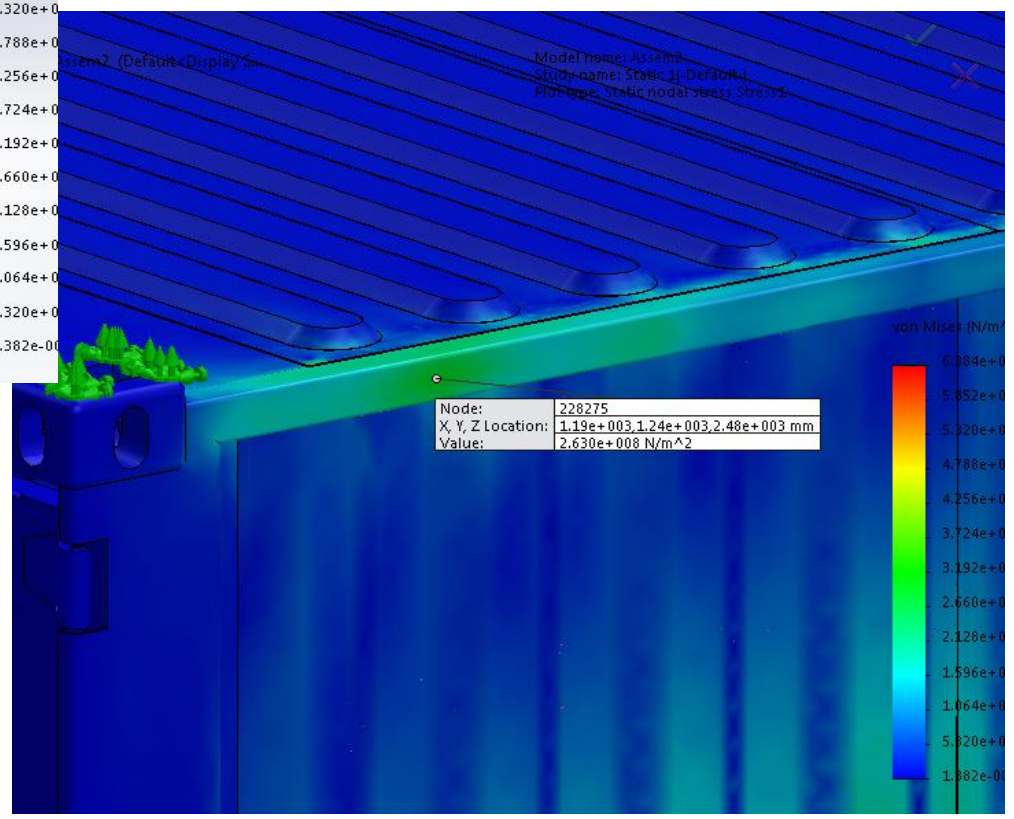
25 000 LITERS 30^0 ROLL ANGLE PERIOD 6s AND HEAVE DYNAMIC WITH FlexiBin S3



MAXIMUM SIDE WALL DEFLECTION IS 48mm AT A HEIGHT OF 1 210mm ABOVE FLOOR LEVEL. NO FAILURE OCCURS.

25 000 LITERS 30^0 ROLL ANGLE AND 6s ROLL PERIOD AND HEAVE DYNAMIC WITH FlexiBin S3





BOTTOM AND TOP SIDE RAIL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa. NO FAILURE OCCURS.

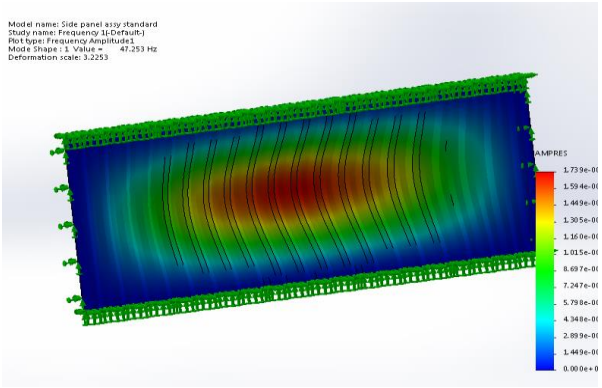
EFFECT OF LIQUID SLOSHING …

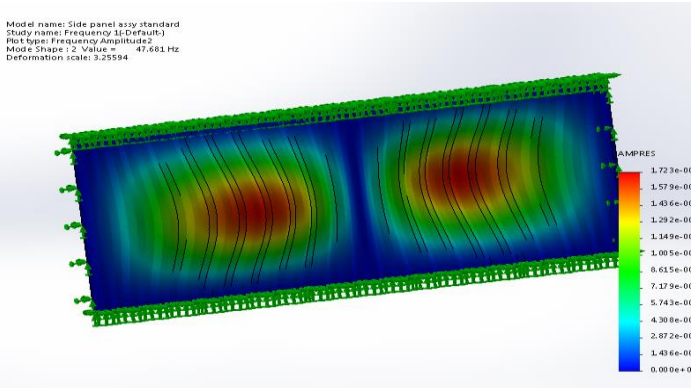
THE NATURAL PERIOD OF SLOSHING WATER TRANSVERSELY IN THE CONTAINER IS 0.5747Hz. SIMILARLY, LONGITUDINAL SLOSHING HAS A NATURAL FREQUENCY OF 0.328Hz.

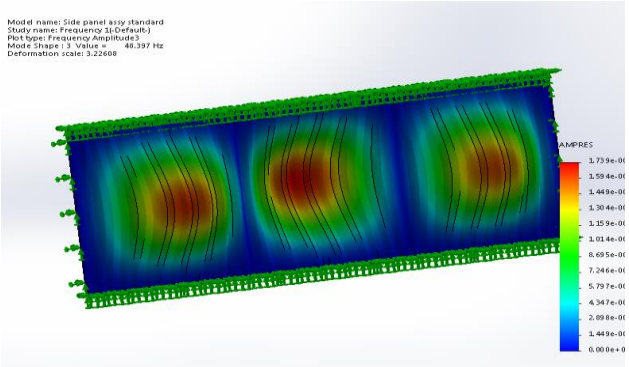
THE TYPICAL CONTAINER SIDE WALL (NO DAMAGE) HAS 5 MODAL NATURAL FREQUENCIES RANGING FROM 47 TO 51Hz. SEE SLIDES 25 AND 26.

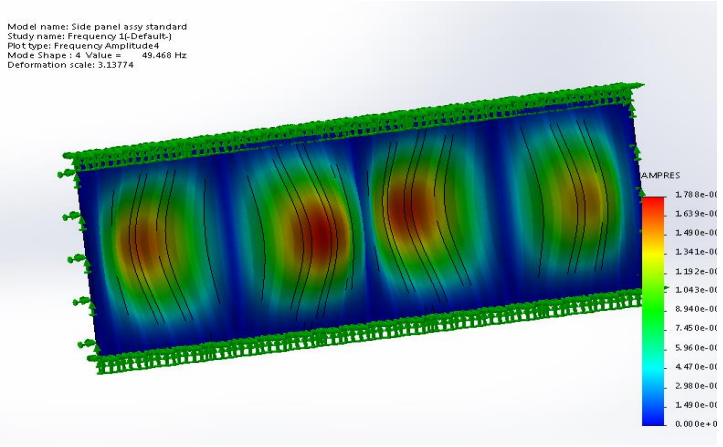
THE CALCULATED FREQUENCY RATIOS ARE SUFFICIENTLY HIGH FOR US TO IGNORE SLOSHING AS A SIGNIFICANT SOURCE OF LOAD ACCELERATION AMPLIFICATION.

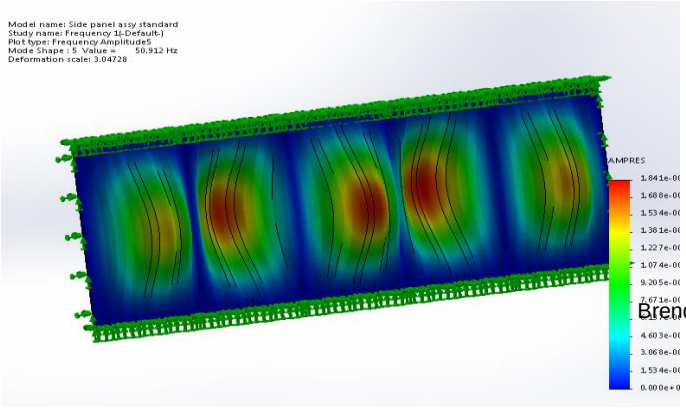
PLOTS OF MODAL FREQUENCIES OF STANDARD 20' CONTAINER SIDE WALL







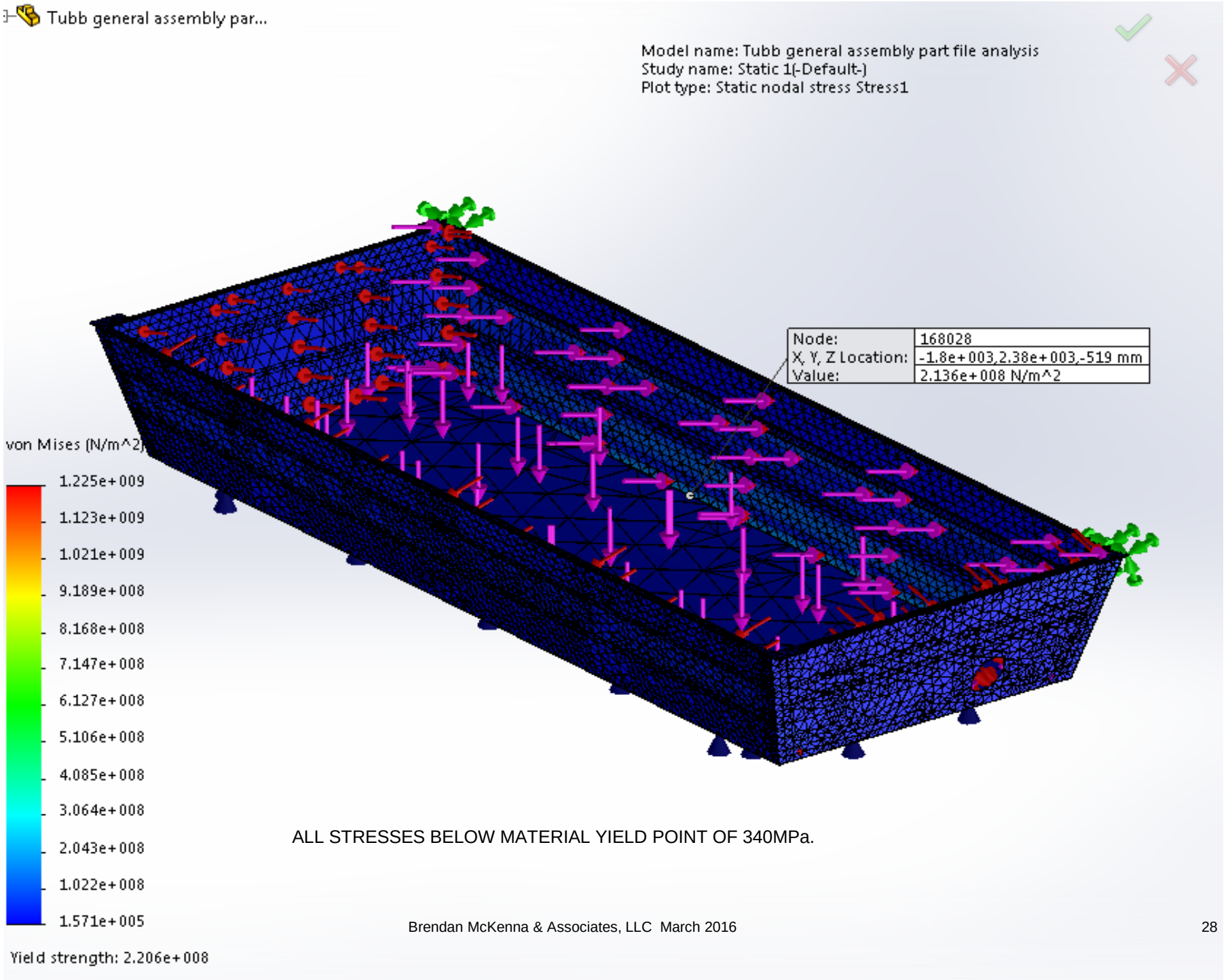




LIST OF MODAL FREQUENCIES

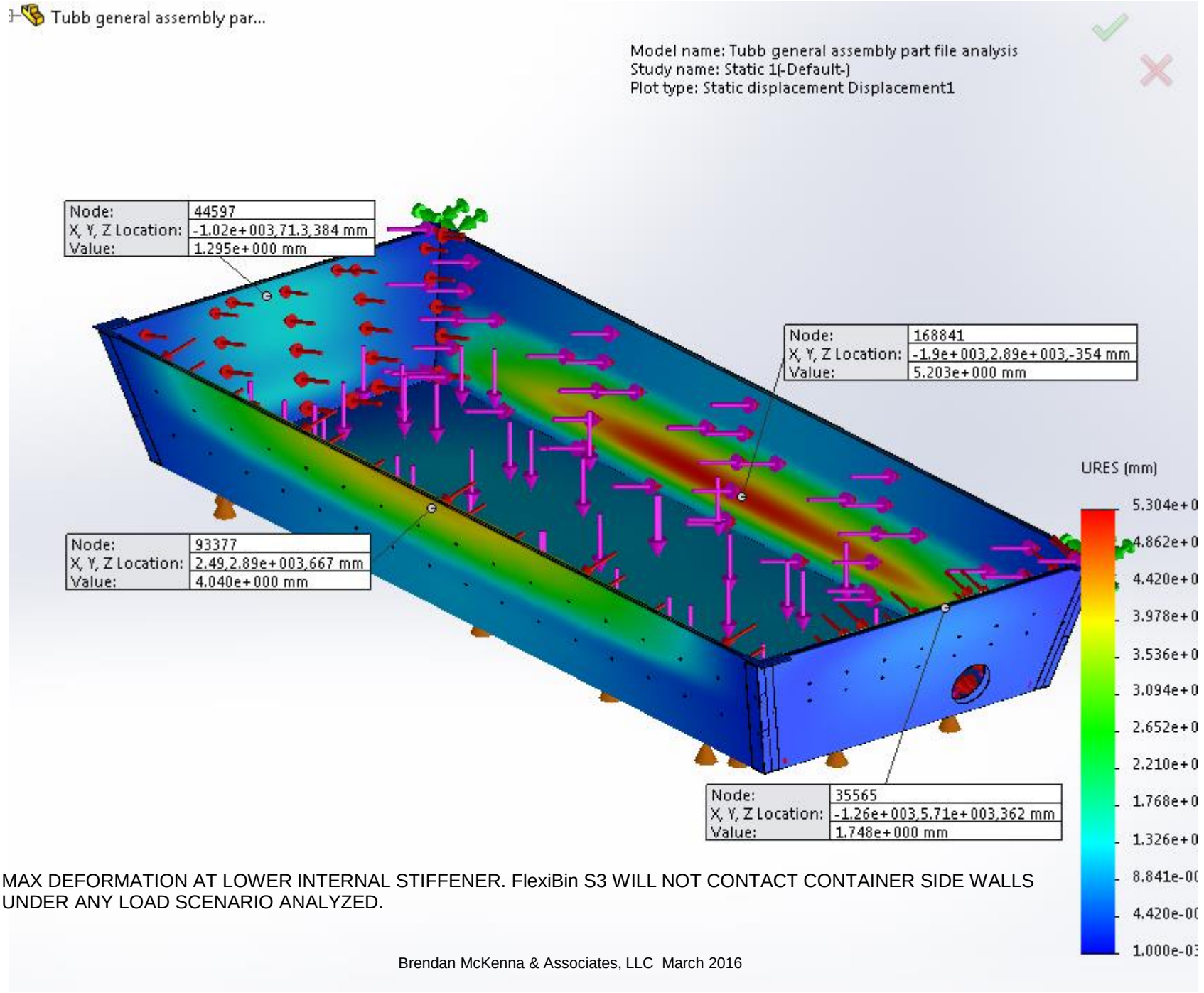
22:59	Saturday	February 20	2016
Study name: Frequency 1			
Mode No.	Frequency(Rad/sec)	Frequency(Hertz)	Period(Seconds)
1	296.9	47.253	0.021163
2	299.59	47.681	0.020973
3	304.09	48.397	0.020662
4	310.81	49.468	0.020215
5	319.89	50.912	0.019642

FlexiBin S3 STRESS PLOT STATIC 30^0 ROLL 26 000 LITERS IN FLEXITANK



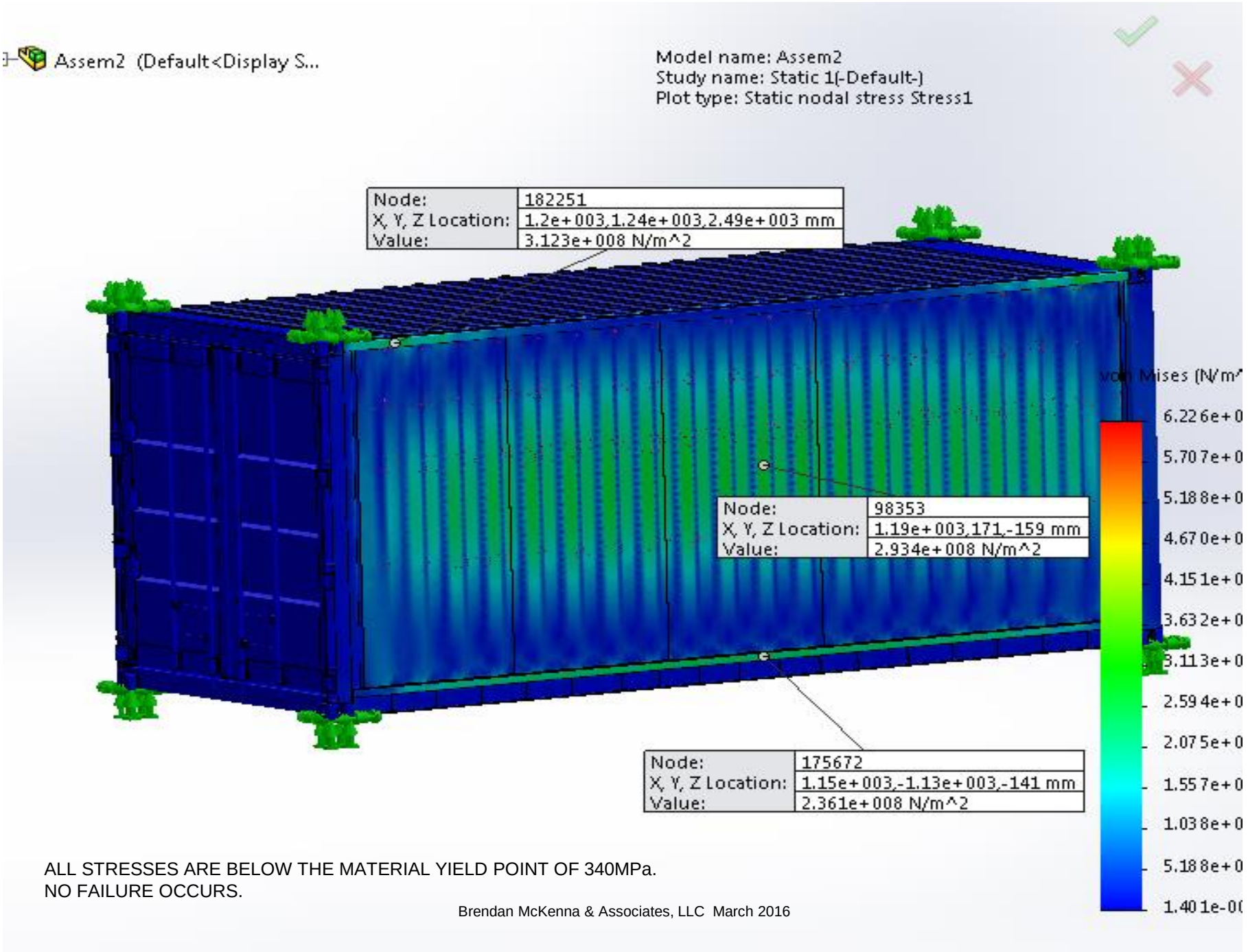
ALL STRESSES BELOW MATERIAL YIELD POINT OF 340MPa.

FlexiBin S3 MAX DEFORMATION 6 mm AT 30^0 STATIC ROLL 26 00 LITERS IN FLEXITANK



MAX DEFORMATION AT LOWER INTERNAL STIFFENER. FlexiBin S3 WILL NOT CONTACT CONTAINER SIDE WALLS UNDER ANY LOAD SCENARIO ANALYZED.

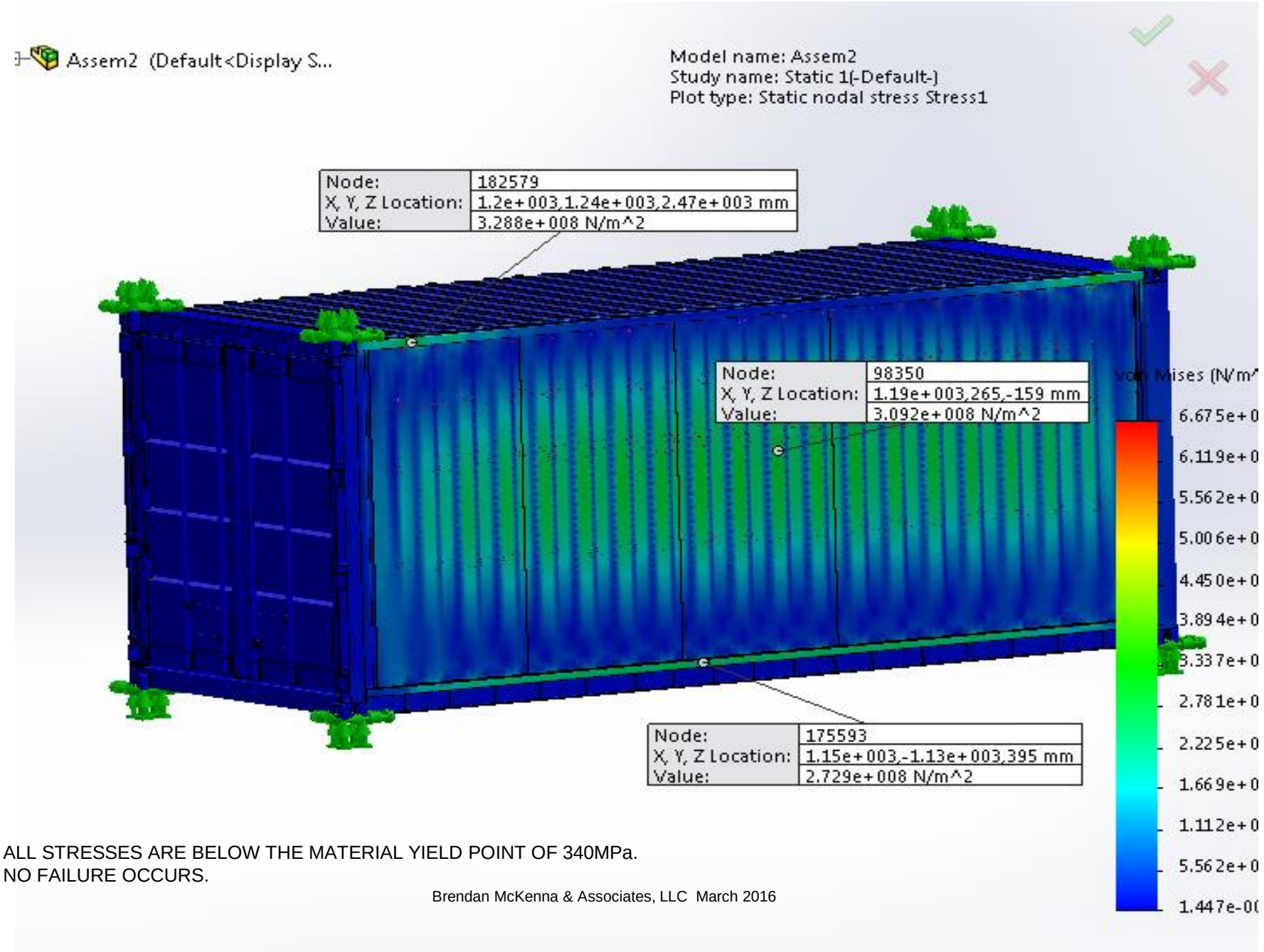
26 000 LITERS WITH FlexiBin S3 DYNAMIC ROLL AND HEAVE 30^0 ALL 2mm THICK PANEL



ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

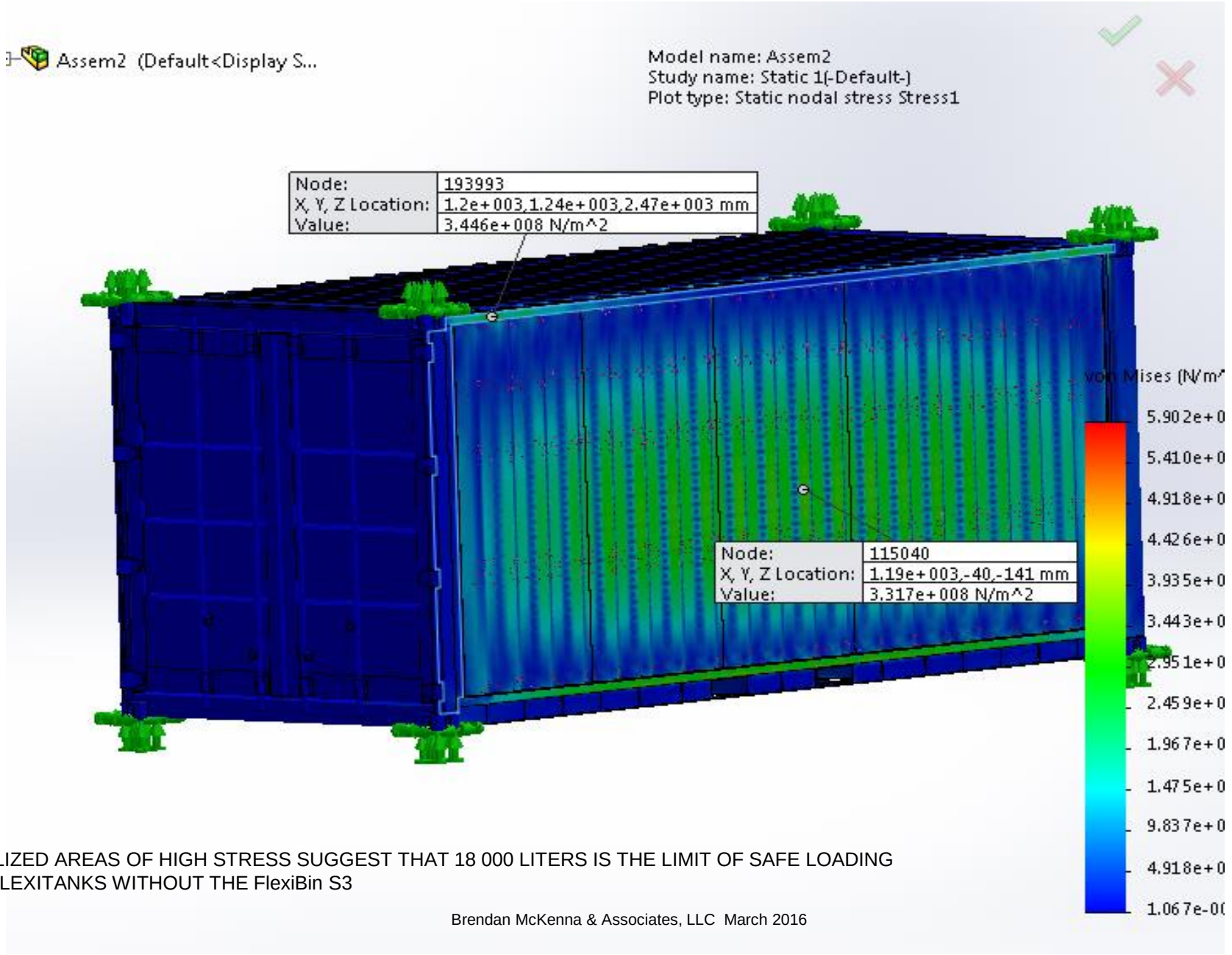
Brendan McKenna & Associates, LLC March 2016

27 000 LITERS WITH FlexiBin S3 DYNAMIC ROLL AND HEAVE 30^0 ALL 2mm THICK PANEL



ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

18 000 LITERS AT 30^0 DYNAMIC ROLL AND HEAVE WITHOUT FlexiBin S3



LOCALIZED AREAS OF HIGH STRESS SUGGEST THAT 18 000 LITERS IS THE LIMIT OF SAFE LOADING FOR FLEXITANKS WITHOUT THE FlexiBin S3

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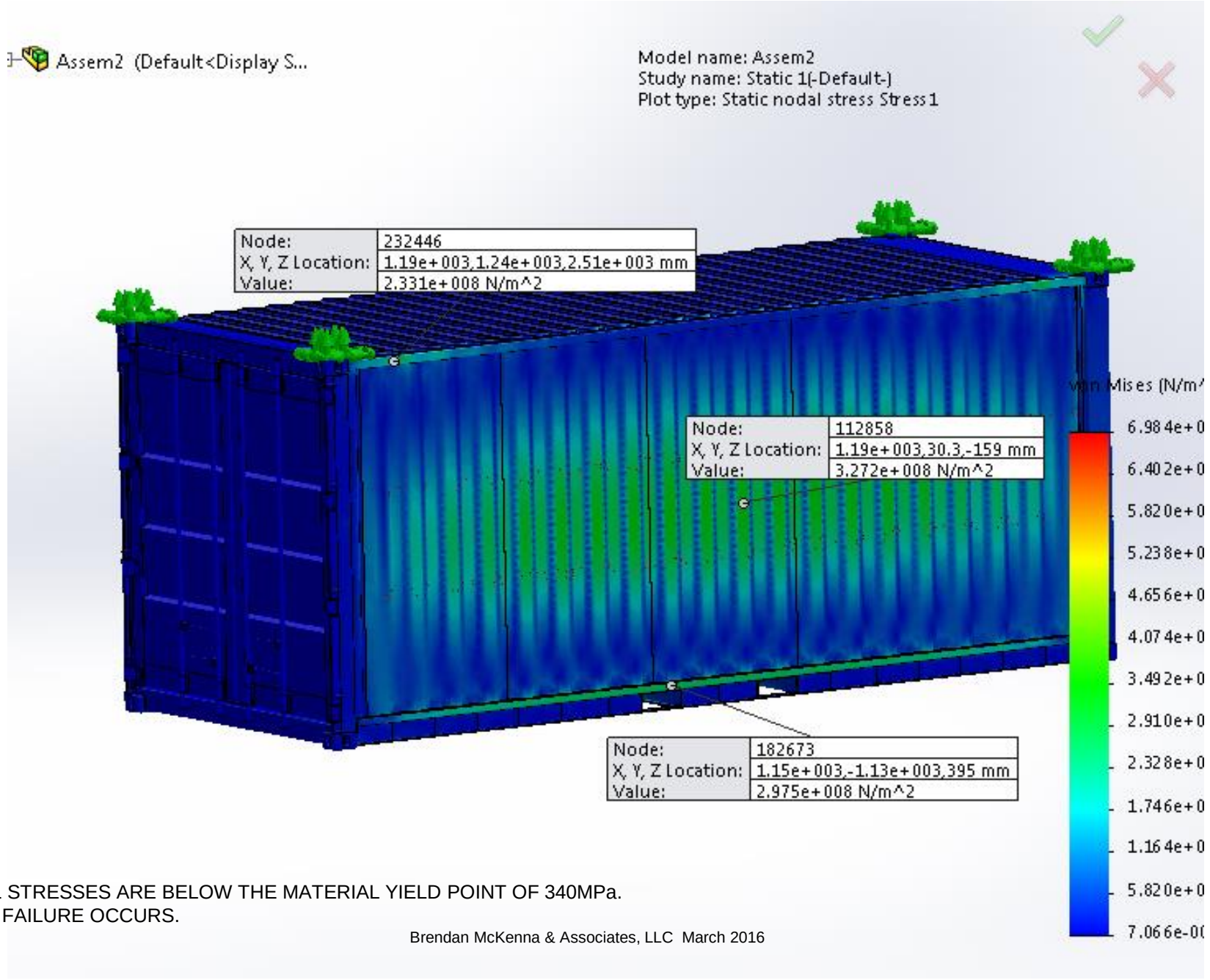
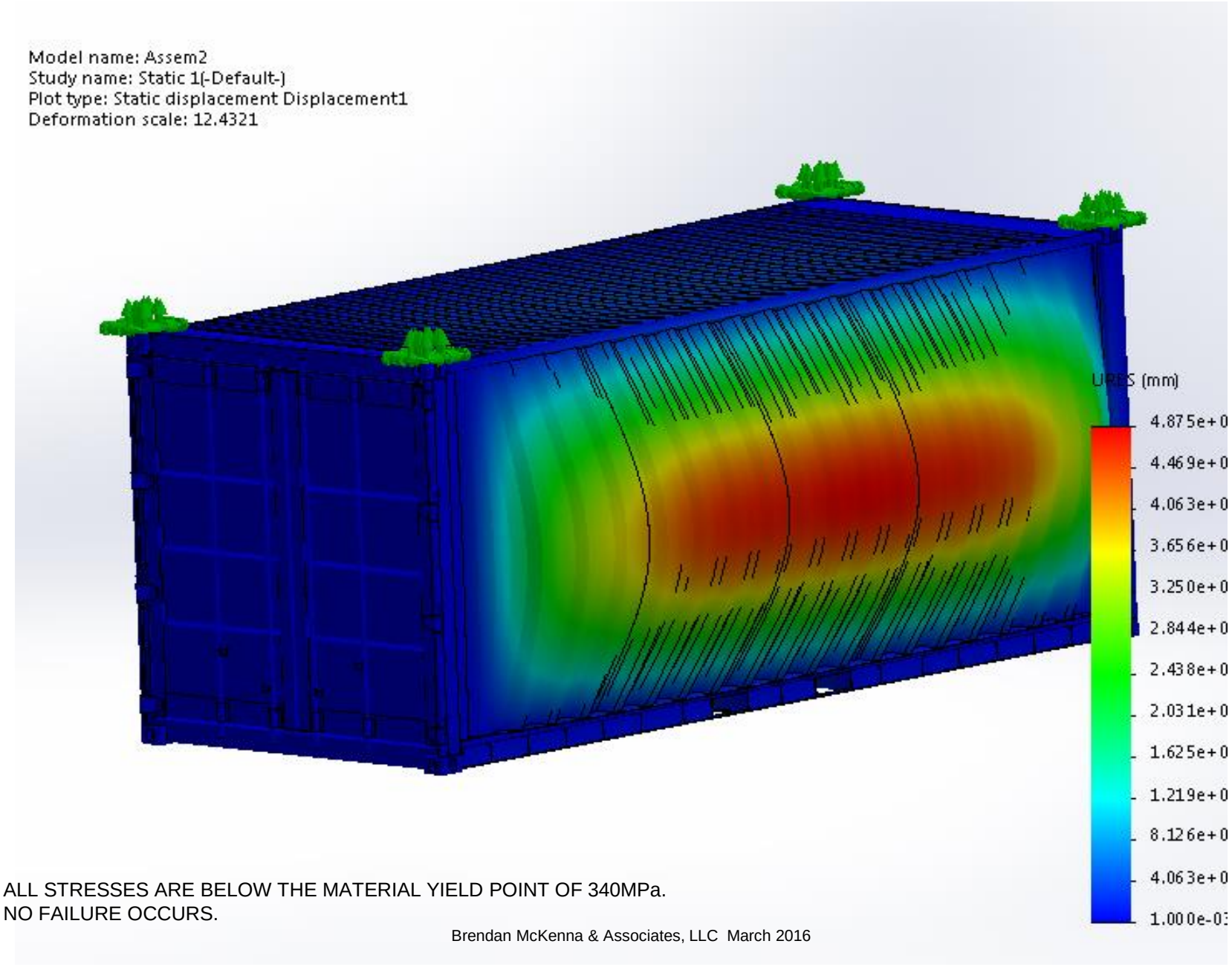
26 700 LITERS WITH FlexiBin S3 2g VERTICAL LIFT



ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

Brendan McKenna & Associates, LLC March 2016

26 700 LITERS WITH FlexiBin S3 2g VERTICAL LIFT MAX DEFLECTION 49mm AT 1105mm FROM FLOOR LEVEL



ALL STRESSES ARE BELOW THE MATERIAL YIELD POINT OF 340MPa.
NO FAILURE OCCURS.

Brendan McKenna & Associates, LLC March 2016