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Ring Slice Method for Tank Expansion
PEMY White Paper

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Introduction

PEMY Consulting has produced a new method for determining the volume expansion across the vertical length of a tank, called the **"Ring Slice Method**"; the method proposed is more accurate over a wide range of tank diameters, can be applied simply on an Excel Spreadsheet, and is transparent for the purchaser of the standard to implement.

We arrived at this conclusion by comparing a variety of models against the results for finite element analysis (FEA). In this report we will summarize the results for volume expansion using different independent variable such as the tank diameter, specific gravity, fill height and more. The results for volume expansion are most reliably and simply determined using the Rings Slice Method at a 1-ft interval.

Description of the Models

To perform this analysis, we produced 3 separate models for comparison:

1. Finite Element Analysis (FEA) – this analysis is achieved in ANSYS by creating an axisymmetric tank model for various tank diameters. FEA is a modeling technique that determines the force each element exerts on the others and the results produced are the best possible. FEA is therefore an ideal model, and we will compare the results of the 2.2A and Ring Slice methods to determine which is more accurate. FEA is much costlier and time consuming than the other methods, and it would not be practical to perform FEA on every tank.

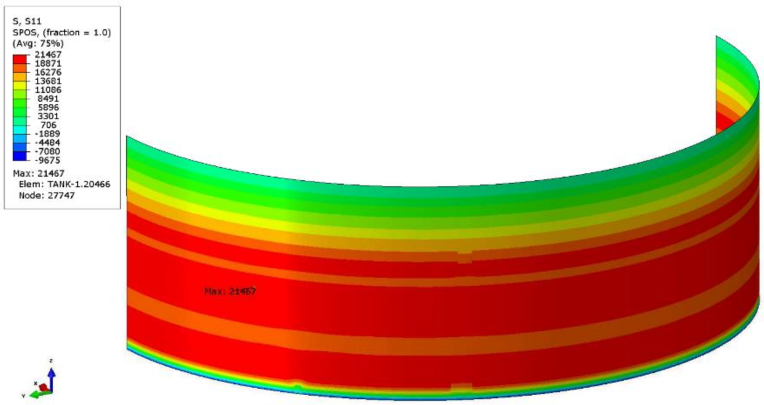
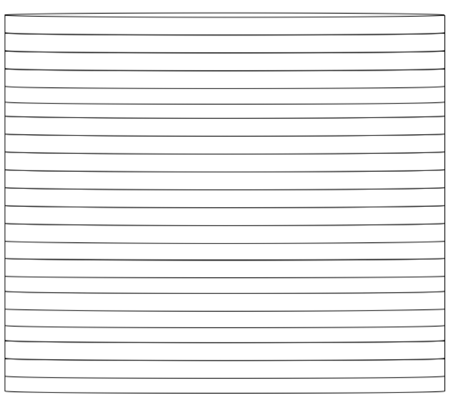


Figure 1 Example of FEA

2. Ring Slice Method (RSM) – this method is performed by theoretically slicing a tank shell every vertical foot, determining the pressure at those slices, and then calculating the radial expansion for that slice by assuming it behaves as a thin cylinder under internal pressure with no edge constraints. Because the Ring Slice Method is not iterative, it can be applied in an Excel spreadsheet so that change in specific gravity of the product or other variations can be adjusted without rerunning each calculation.

Ring Slice Method



$$R_{expansion} = \frac{pr^2}{Et}$$

Radial expansion is calculated for each 1-ft ring

Figure 2 Example of RSM

3. Ch 2.2A Method (2.2A) – the methods, equations and process that are utilized in API MPMS Ch 2.2A B.1.4-B.1.8 for radial expansion and volume calculations. The current standard in 2.2A were affirmed in 1995 and reaffirmed in 2012. As of December 18, 2018, 2.2A is being rewritten and balloted by CPMS (Committee on Petroleum Measurement Standards). Please consider that some statements, calculations, or other analysis may become incorrect or irrelevant due to future revisions.

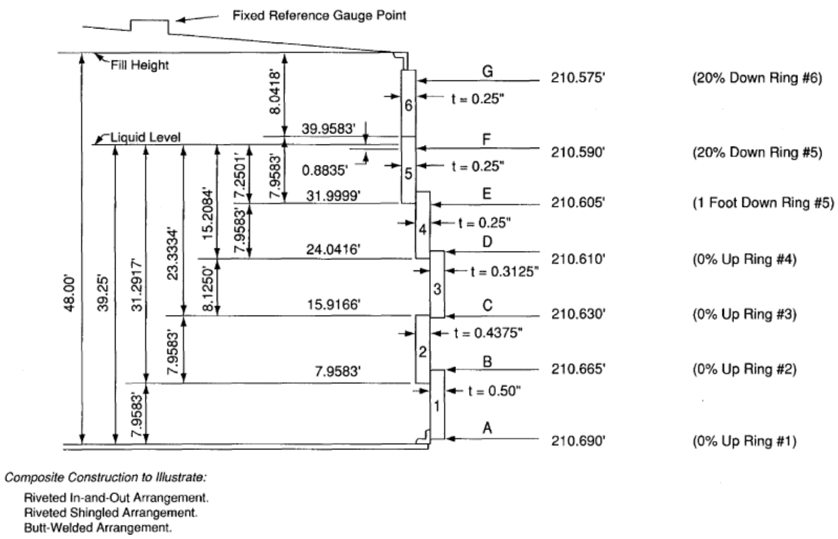


Figure 3 Example B-1 in MPMS 2.2A

Variables and Constants

Independent Variables:

1. Model
   - Finite Element Analysis
   - Ring Slice Method
   - 2.2A Method
2. Tank Diameter
   - Ranging from D = 50-ft to 300-ft in increments of 50-ft
3. Specific Gravity
   - Ranging from SG=1.0 to 0.5 in increments of 0.1

Dependent Variables

1. Radial Expansion ↔ Area Expansion ↔ Volume Expansion
   - We will compare the radial expansion and volume expansion between the models [Ring Slice Method and 2.2A Method] to determine which is closest to the FEA (ideal model).

Constants

1. Course Heights
   - Each course is 8-ft in length
2. Tank Height
   - Each tank is 48-ft tall and composed of 6 courses
3. Course Thicknesses
   - The thickness of each course for each diameter tank is determined by the 1-ft method in API 650 (5.6.3)

- The course thicknesses change with tank diameter but not when comparing specific gravities

4. Material Properties
   - Each model assumes the tank is composed of A36 steel and has a modulus of elasticity (E = 29,000,000 psi). The tank stresses within the elastic region and returns to initial conditions when the load is removed (tank emptied)
5. Assumptions
   - The bottom point of the tank is stiffened to the bottom plate and does not expand
   - The top of the tank contains no liquid, and is therefore not subjected to hydrostatic pressure

Comparing Models

To determine the best model, we must define a baseline for comparison; in this study we take the volumetric expansion results obtained through finite element analysis (FEA) to be the ideal baseline from which we will compare the Radial Slice Method and 2.2A Method. The results for tank expansions at varying diameters were obtained and are displayed in Figure 4. The percent difference in dV Total between FEA and the proposed methods (RSM & 2.2A) are displayed in Figure 5.

Figure 4 shows the trend of Volume Expansion [bbl] v Tank Diameter [ft]. The gray line indicates the results obtained through FEA, the ideal model. It is clear the orange line (Ring Slice dV Total) is closer to the gray line (FEA dV Total) for large diameter tanks but difficult to discern at diameters smaller than 250-ft.

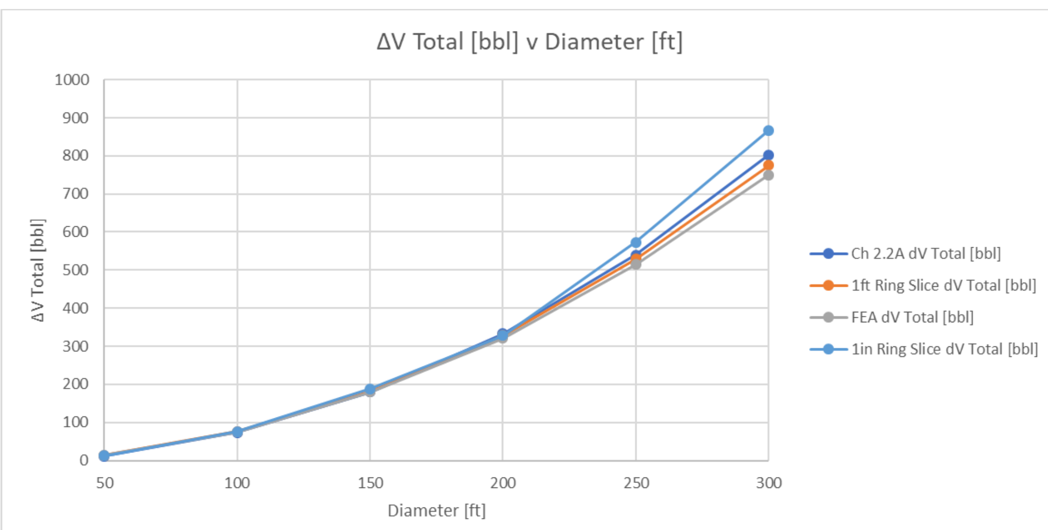


Figure 4 Total Volume Expansion for Varying Models of Diameters Ranging from 50-ft to 300-ft

It is more appropriate to consider a % Difference in Volume Expansion between the ideal model (FEA) and the proposed models (RSM & 2.2A); the results displayed in Figure 5 show that the Ring Slice Method has a smaller percent difference from the FEA over a wider variety of tank diameters. Tanks that are approximately 150-ft in diameter are more accurately modelled by the current 2.2A Method, but the

2.2A Method becomes considerably less accurate when tank diameters are small (< 100-ft) or large (> 200-ft).

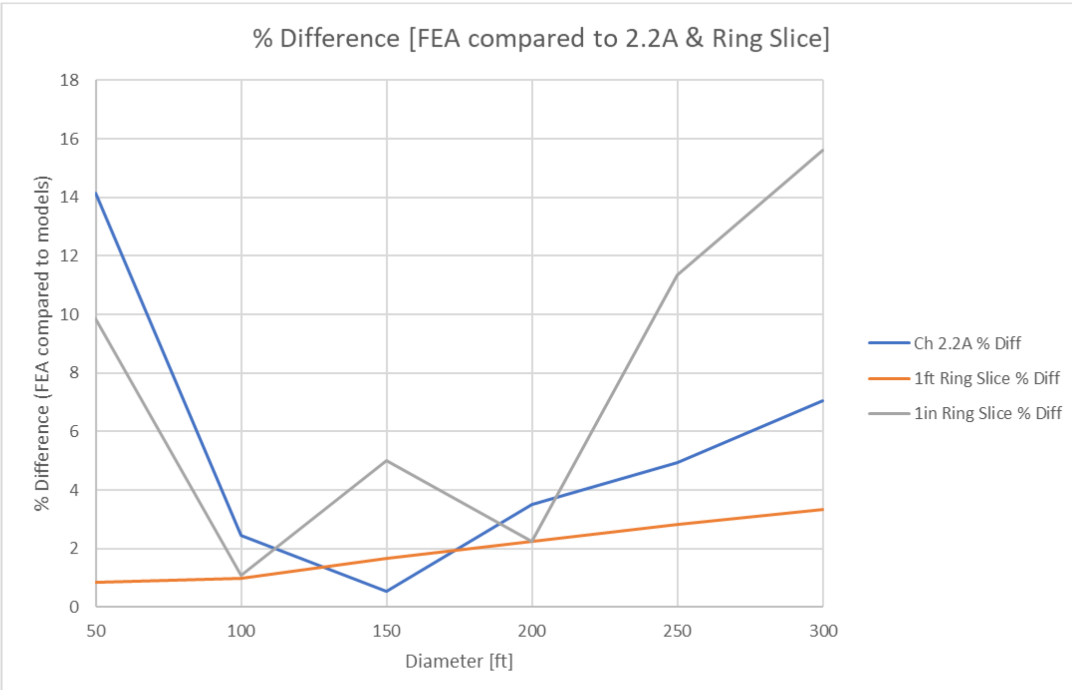


Figure 5 Percent Difference between FEA (ideal model) and Proposed Models (RSM & 2.2A)

Further, the precision is improved when using the Ring Slice Method; the RSM % Difference from FEA never exceeded 3.5% in total Volume Expansion.

Figure 6 shows the FEA results for radial expansion across tank diameters varying from 50-ft to 300-ft. The shell course thicknesses are determined using the 1-ft method in API 650 12th edition. Because the shell thickness changes every 8-ft, the pattern is generally wavy, and the maximum radial deformation occurs on or near the bottom course. The 50-ft diameter tank appears linear above the maximum radial expansion (approximately 0.25”); this is because the design course thickness is ¼” for each course, and the radial expansion of a thin cylinder under pressure increases linearly with pressure.

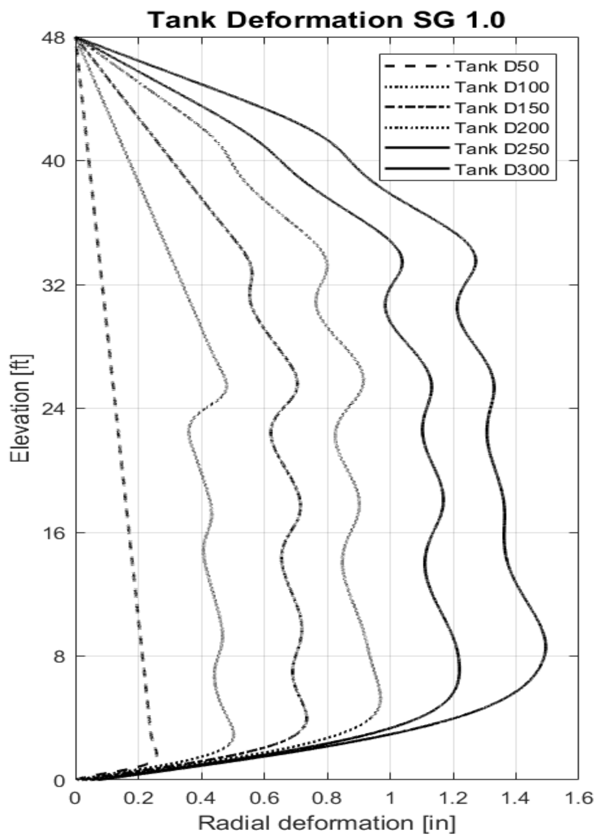


Figure 6 FEA Radial Expansion for Varying Tank Diameters (SG=1.0)

The radial expansion for varying diameter tanks using the Ring Slice Method are shown in Figure 7. Notice the maximum values and overall trend are extremely close between the FEA (Figure 6) and the RSM (Figure 7) models. The Ring Slice Method is a simplified model that assumes no edge constraints, so changes in expansion between courses are distinct.

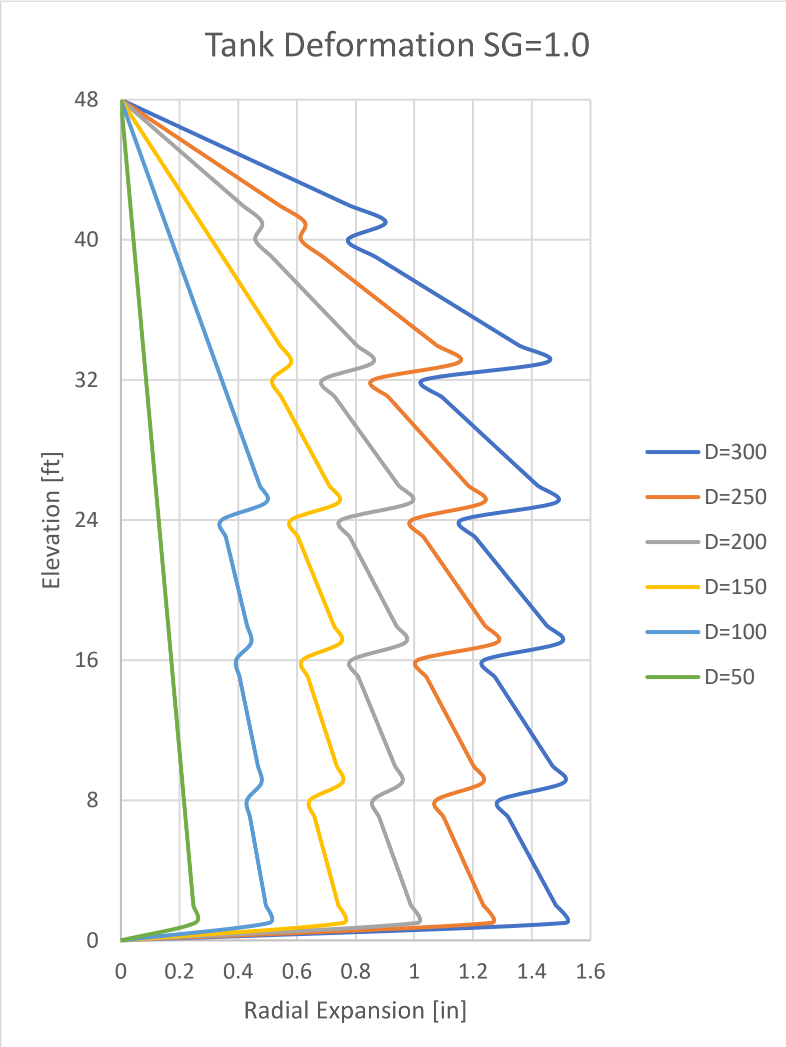


Figure 7 Ring Slice Method Radial Expansion for Varying Tank Diameters (SG=1.0)

Change in Fill Level

The current 2.2A method performs poorly when applied across a variety of fill heights and tank diameters, see Figure 8-Figure 10. The dashed gray line represented the percent difference between the total volume expansion predicted by the current 2.2A model and FEA; The blue line represents the percent difference between the total volume expansion predicted by the 1-ft RSM and FEA. The blue line is generally lower than the dashed gray line, meaning that the 1-ft RSM is more accurately modelling the volume expansion results determined by FEA than the current 2.2A method.

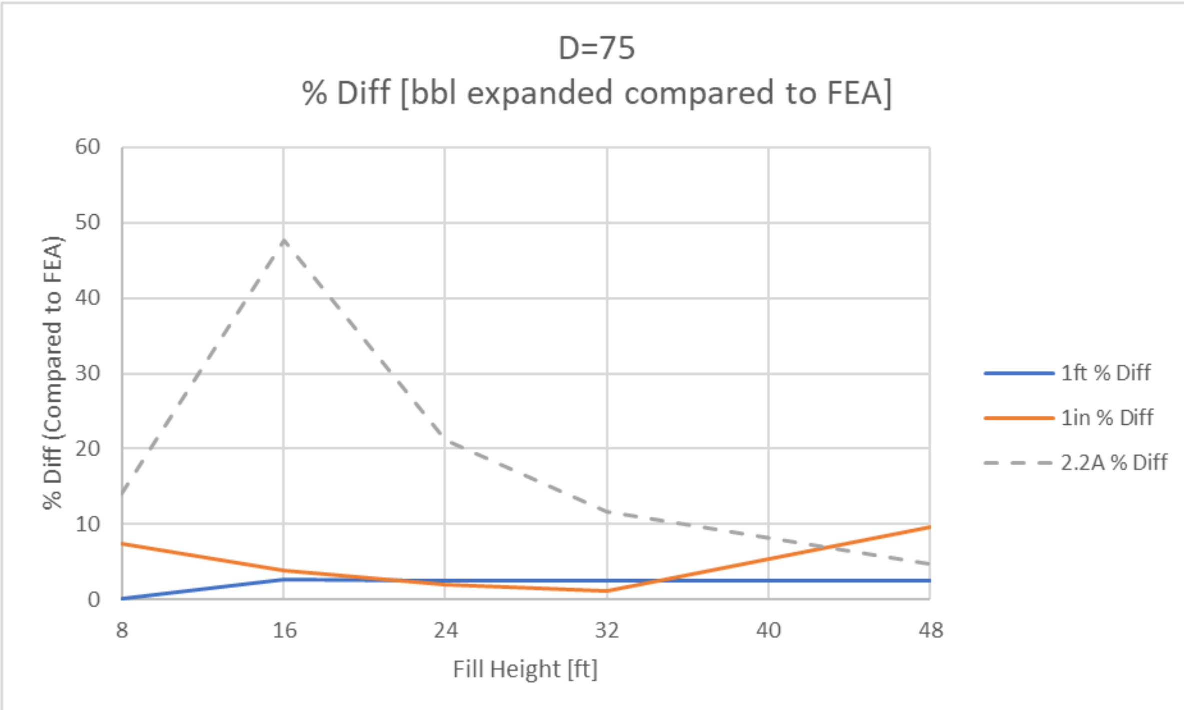


Figure 8 Volume Expansion at Various Fill Height (D=75)

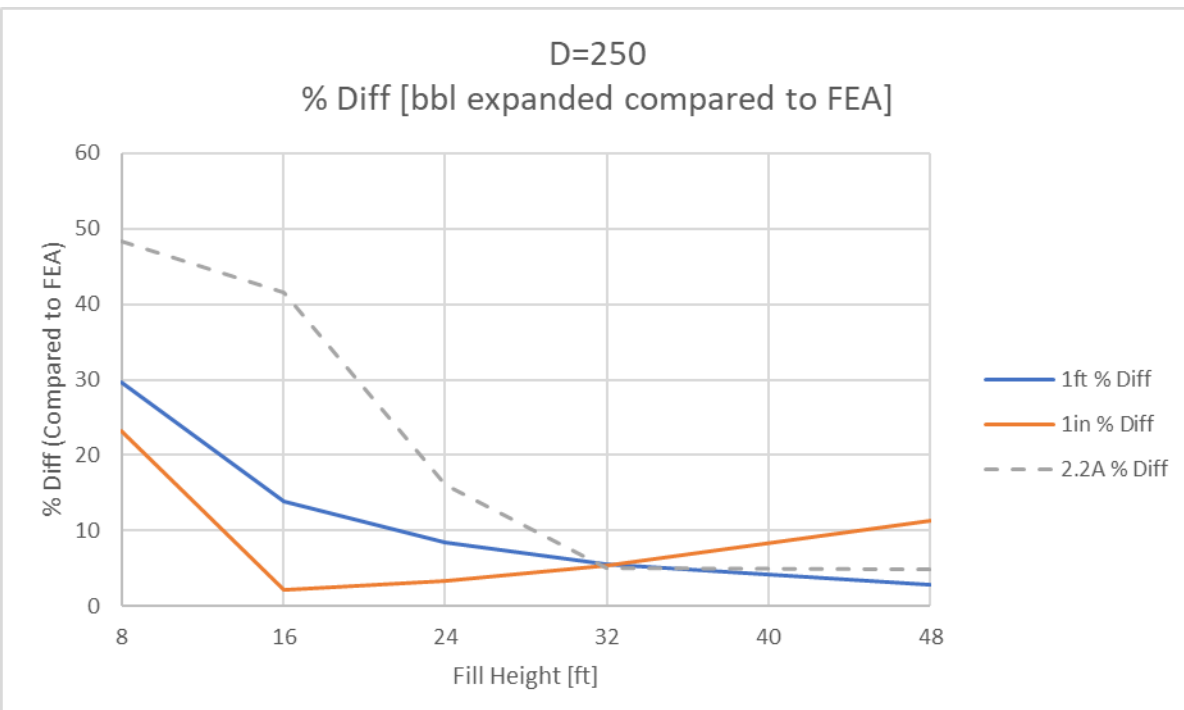


Figure 9 Volume Expansion at Various Fill Height (D=250)

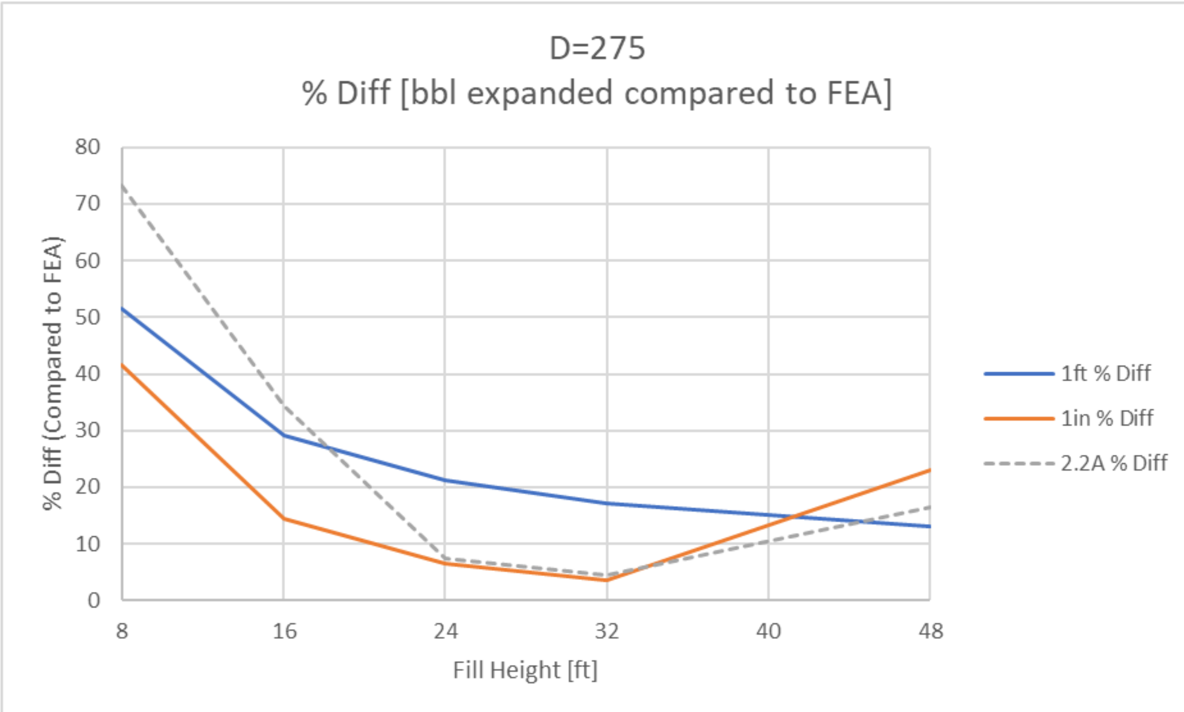


Figure 10 Volume Expansion at Various Fill Height (D=275)

Change in Specific Gravity

The API Committee on Petroleum Measurement Standards requested PEMY Consulting to investigate the effect of change in specific gravity of product liquid on radial expansion of the shell, currently presented in Table A-5 of MPMS 2.2A. This led us to vary the specific gravity within several diameter tanks and observe the resulting increase in volume. We used the Ring Slice Method to see if the results were within the ranges available in Table A-5 of 2.2A, see Figure 11.

Table A-5—Product Specific Gravity Variations

Variation in Specific Gravity %	Approximate Variation in Volume %[a]
10	0.008–0.015
20	0.015–0.030
30	0.030–0.040
40	0.040–0.050
50	0.050–0.065

[a]Actual variation in hydrostatic head correction volume could be higher than specified, depending on tank plate thickness.

Figure 11 MPMS 2.2A Table A-5

The results obtained when changing specific gravity using the RSM is within the range available in Table A-5, except for the 50-ft diameter tank. The range offered in Table A-5 is a good approximation but does not allow the user to consider tank diameter. A modern adoption of 2.2A could offer an equation to determine the variation in tank volume with respect to specific gravity or a table for determining the volume variation of various tank diameters.

Figure 12 Volume Expansion for Change in SG (Diameters 50-ft to 300-ft)

Conclusions

The RSM performs more reliably than the current tank strapping method suggested in 2.2A across a variety of tank diameters, specific gravities, and fill heights. The RSM method is generally simpler to apply than the current method, because the RSM is a noniterative calculation. The current 2.2A strapping method performed better than the RSM in only one case, a tank with 150-ft diameter. Because the RSM is simpler to apply and more accurate across a variety of tank geometries and conditions, PEMY Consulting proposes that the method be considered by the COPM.