

CHAPTER 9: TANK SETTLEMENT

Tank settlement is one of the topics of the Body Of Knowledge for the API 653 exam. It is a very important subject for us tank inspectors, although is also one of the vaguest topics for a new inspector. In fact, the word "settlement" is mentioned more than 250 times in the API 653 standard. As an inspector, you should be able to determine the type and extent of tank settlement, and decide if it can affect tank integrity. In the API 653 exam, maybe 2 questions will show up about this subject. And as complex as it may look in the API 653 standards, the limitations imposed by the BOK make it a really easy topic.

SETTLEMENT IN NEW CONSTRUCTION

In new tanks, the API 650 standard doesn't necessarily asks for a settlement measurement to be done during hydrostatic tests. If there is no settlement expected (for example, a tank over a giant rock), it might not need settlement measurements, but that's a decision that is entirely up to the owner.



FIGURE 22 A NEW TANK THAT PROBABLY WOULD NOT NEED SETTLEMENT MEASURED

In normal conditions, there will always be settlement. Anyway, you should design and construct foundations to limit settlement, as impossible it is to eliminate it.

For the sake of information, you should know how settlement measurements are made. During hydrostatic testing for new and old tanks, at least 6 sets of measurements shall be made.

1. When the tank is empty before hydrostatic testing
2. When the tank is 1/4 full
3. When the tank is 1/2 full
4. When the tank is 3/4 full
5. 24 hours after it is filled
6. With the tank empty again.

Shell elevation measurements shall be made at equally-spaced intervals around the tank circumference not exceeding 10 m (32 ft.)

SETTLEMENT OF IN-SERVICE TANKS

During operations, shell settlement measurements should be taken at a planned frequency, based on an assessment of soil settlement predictions. Bottom settlement monitoring is to be made during internal inspections, respecting the intervals given for inspections in API 653 4.4.6. Identify and evaluate any tank bottom settlement is one of the 3 key objectives of internal inspections, because it plays such an important role on many tank failures and floating-roof problems.

Settlement can be caused by the following:

1. Lack of support under the base circumference affecting the cylindrical shell and the tank bottom. Parts or the concrete ring may be lost.
2. Non homogeneous geometry or compressibility of the soil deposit (voids or crevices below the bottom plate)
3. Non uniform distribution of the load applied to the foundation. Differential pressure during emptying and filling cycles
4. Uniform stress acting over a limited area of the soil stratum

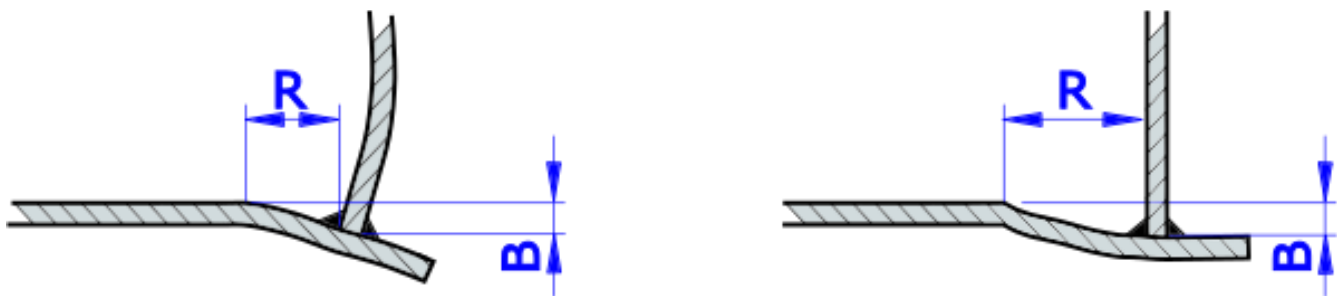
5. Wrongly constructed foundations (deficient reinforcement of the concrete, bad quality cement, etc.)
6. Liquefaction phenomenon around the foundation generated by earthquakes. Consider the following excerpt:

WHAT YOU SHOULD STUDY FOR YOUR EXAM

Various forms of settlements could take place in tanks. The BOK considers 3 types of settlement and their evaluation.

1. Edge settlement

Edge settlement occurs when the tank shell settles sharply around the periphery, resulting in deformation of the bottom plate near the shell-to-bottom corner weld, or the depth of the depressed area of the bottom plate. You can see a diagram for edge settlement below.



EDGE SETTLEMENT

B is B_e if welds are parallel or B_{ew} if welds are perpendicular

FIGURE 23 EDGE SETTLEMENT

Edge settlement affects bottom parallel and perpendicular welds in different manners. It affects weld seams that are "parallel" to the shell in a more critical manner than the ones that run "perpendicular".

How to evaluate edge settlement?

STEP 1. Annex B of API 653 separates Edge Settlement evaluations in two separate scenarios:

1. If edge settlement is in an area with a LAP welded seam than runs parallel $\pm 20^\circ$ to the shell, B turns into B_{ew}
2. If edge settlement is in an area with a LAP welded seam than runs perpendicular $\pm 20^\circ$ to the shell,, or a BUTT weld, or an area WITH NO WELDS, B turns into B_e

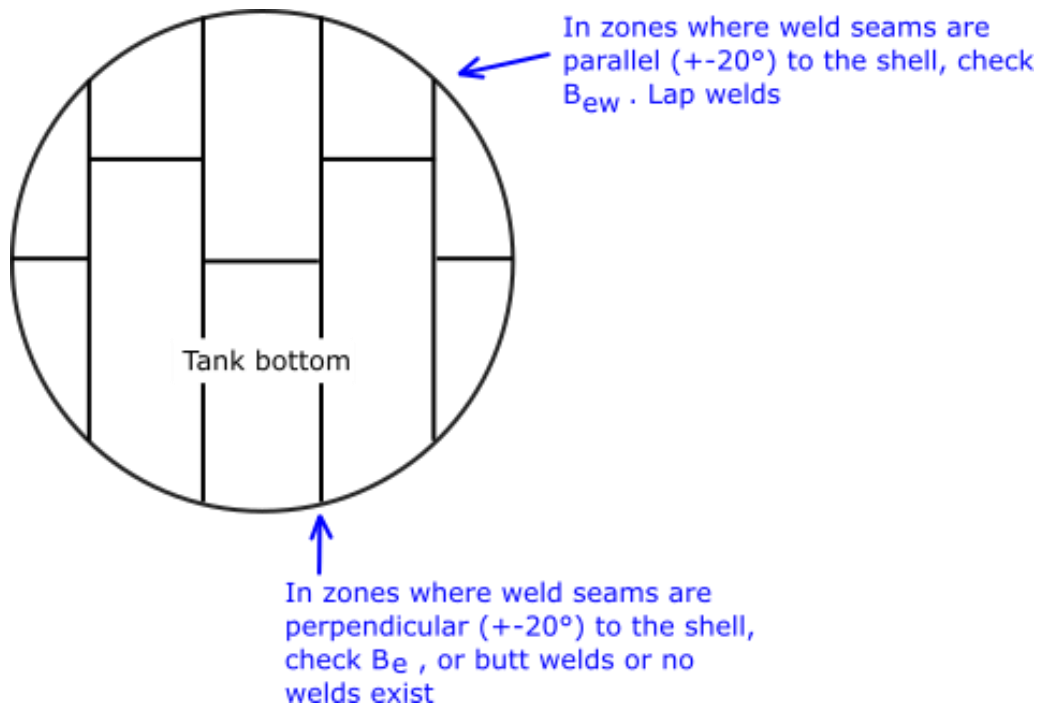


FIGURE 24 EDGE SETTLEMENT EVALUATION

STEP 2. With the value of R , B and the tank diameter, you can check the maximum allowable vertical settlement in figures B-11 of API 653 for B_{ew} or B-12 for B_e . A sample of that diagram you can see next.

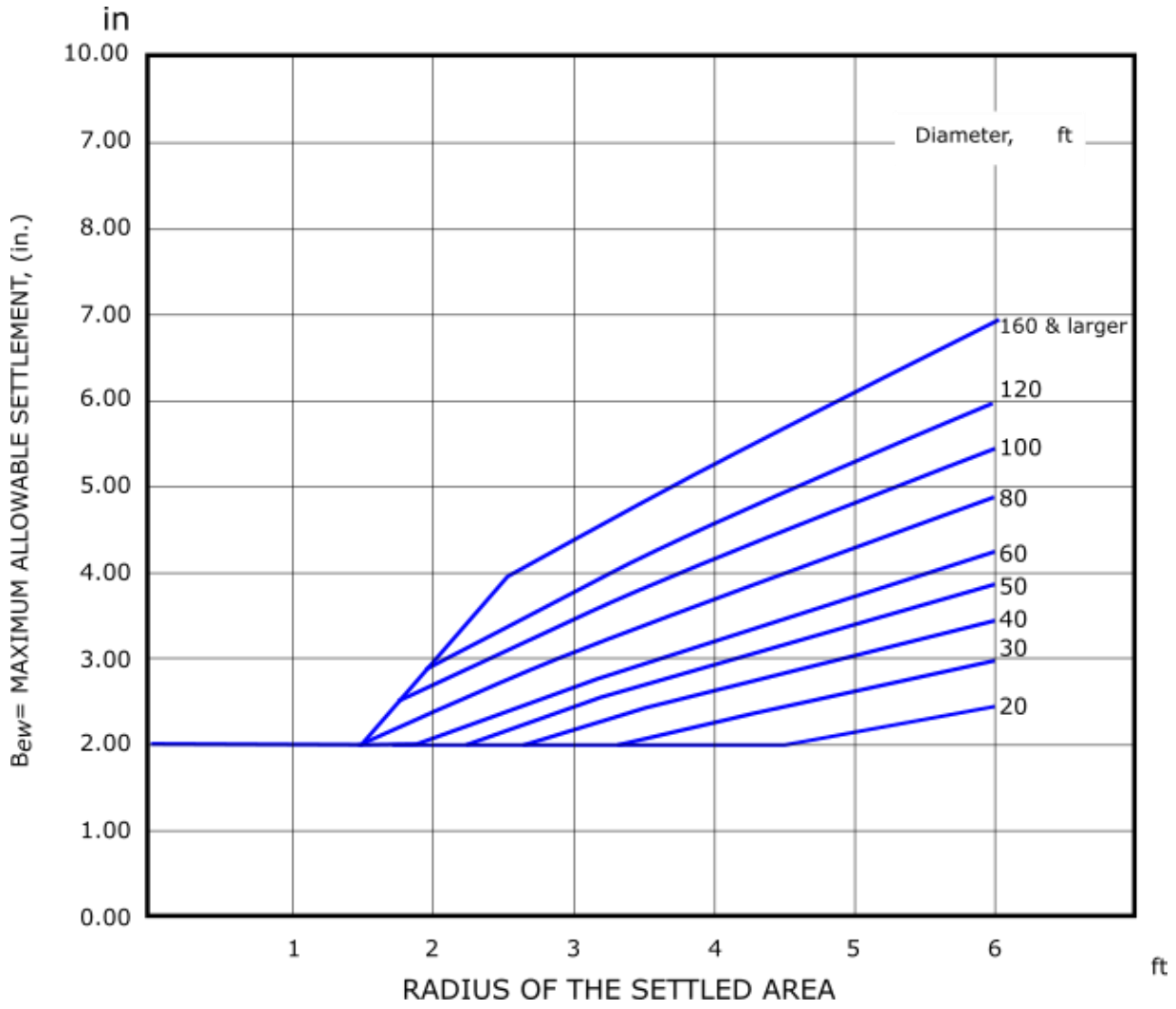


FIGURE 25 FIGURE B.11: MAXIMUM ALLOWABLE SETTLEMENT B_{ew}

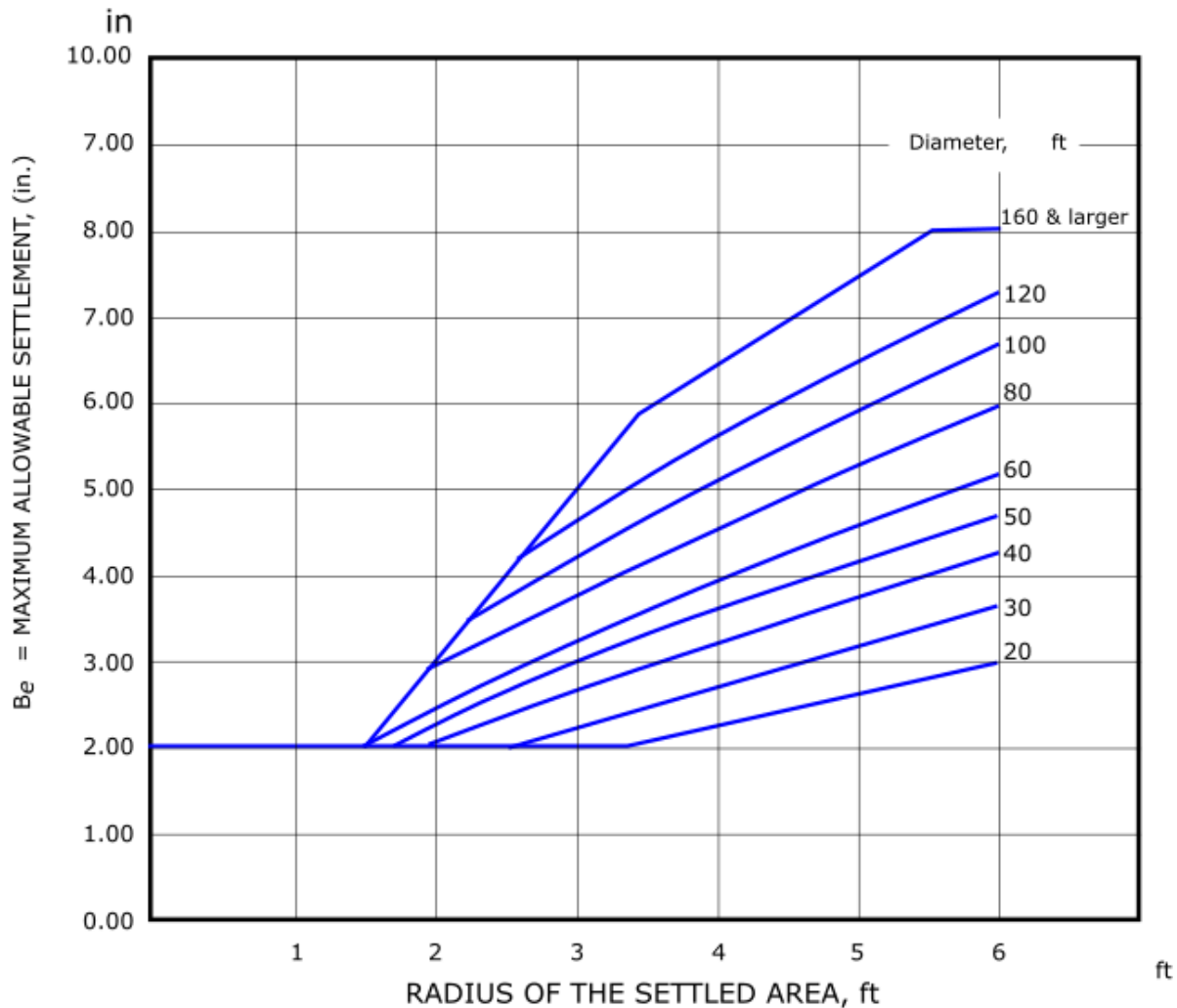


FIGURE 26 FIGURE B.12: MAXIMUM ALLOWABLE SETTLEMENT B_{eE}

See API 653 B-11 and B-12 for the whole details.

Welds in tanks with settlement greater than or equal 75 % of B_{ew} or B_e , and larger than 2 in., are to be inspected with magnetic particle or liquid penetrant method. Additionally, weld seams should be inspected visually and if they show strains bigger than 2%, they should be repaired. Any plate exceeding acceptable plastic strains (typically 2 % to 3 %) should be replaced.

2. Bottom settlement near the tank shell

This kind of settlement can be present in the bottom or in the annular ring zone, if there is one. It occurs when the bottom deforms showing a depression or a

convexity in relation with a flat plane bottom. That deformation is caused by stresses in the bottom plate that have to be evaluated.

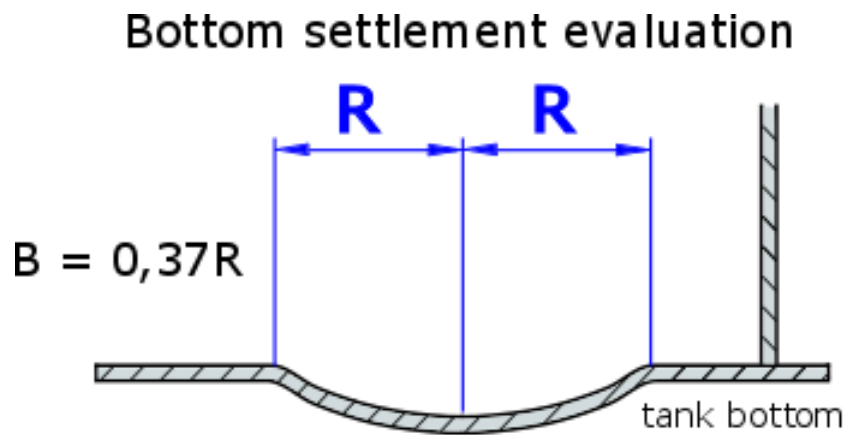


FIGURE 27 BOTTOM SETTLEMENT NEAR THE TANK SHELL

How to evaluate bulges in tank bottoms?

STEP 1. As per API 653 B3.3, measure the bulge or depression in its entire length. The half of that measure is radius R of the bulge.

STEP 2. The maximum dimension for bulges or depressions is given by the following equation:

$$B = 0.37R$$

Where

B is the maximum height of bulge or depth of local depression, in inches;

R is the radius of an inscribed circle in the bulged area or local depression, in feet.

3. Localized bottom settlement remote from the tank shell.

Localized bottom settlement remote from tank shell are depressions (or bulges) that occur in a random manner, remote from the shell. The same equation (B3.3) used for bottom settlement near the tank shell can be used for the evaluation of this kind of settlement, granted the bottom has single-pass welded joints.

RECOMMENDATIONS TO IMPROVE TANK RELIABILITY IN CASE OF SETTLEMENT

1. Leave plenty of free space under any nozzle, to prevent contact with the floor if there is settlement.
2. Settlement occurs to every tank, and it can be different in practice from the measured settlement during and after hydrostatic testing.
3. If there is uniform settled expected (If foundations weren't well built), you can use flexible joints or maritime hoses that can absorb those misalignments.
4. Edge settlement often can be predicted in advance, with sufficient accuracy from soil tests. Anyway, piping (especially buried piping) should be designed with adequate consideration to prevent problems caused by such settlement

If you want to become a certified API 653 inspector, this is what the body of knowledge for the 2015 API 653 certification exam asks from you

The inspector should be able to calculate the number of survey points for determining tank settlement.

At least one question on this matter will show up in the exam. And it is such an easy thing...

DETERMINING THE NUMBER OF POINTS FOR SETTLEMENT MEASUREMENT

In a tank, the number of settlement points around the periphery for external settlement measurement is given by the following formula

$$\text{Eq. 25. } N = \frac{D}{10}$$

where:

N is the minimum required number of settlement measurement points.

D is the tank diameter, in feet (ft).

And the following rules should apply:

- 1) The maximum spacing between settlement measurement points shall be 32 ft.
- 2) No less than eight measurement points

Before any hydrostatic test, elevation measurements should be taken inside the tank, as stated in 7.3.6.8 of API 650

Internal bottom elevation measurements shall be made before and after hydrostatic testing. Measurements shall be made at maximum intervals of 3 m (10 ft) measured on diametrical lines across the tank. The diametrical lines shall be spaced at equal angles, with a maximum separation measured at the tank circumference of 10 m (32 ft). A minimum of four diametrical lines shall be used.

There is not much to say about this issue, apart that just having a look at Figure 1 for easiness.

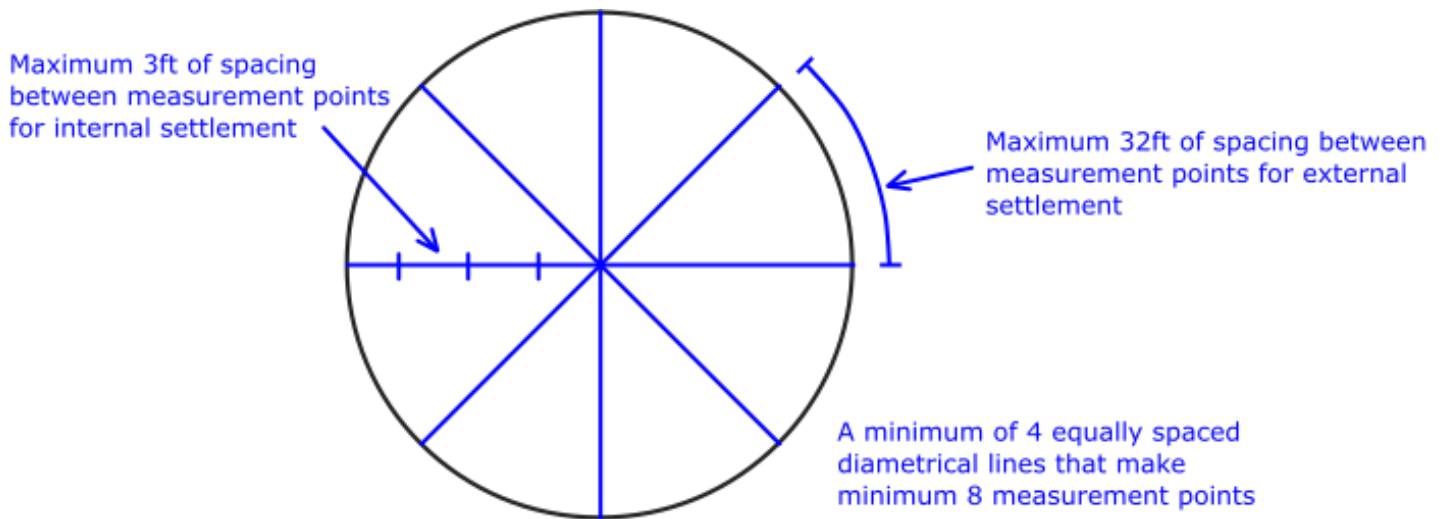


FIGURE 28 MEASUREMENTS OF BOTTOM SETTLEMENT (INTERNAL AND EXTERNAL)

Settlement measurement stations are to be used during hydrostatic test and operation of the tank; settlement measurements should be taken at a planned frequency, based on an assessment of soil settlement predictions (See Annex B of API 653)

Of utmost importance is the maximum allowable differential settlement between 2 consecutive stations that may have several consequences: (a) Out-of plane displacements are induced in the shell in the form of buckling under a displacement-controlled mechanism; (b) High stresses develop at the base of the shell and in the region of the settlement; and (c) High stresses develop in the tank bottom.

Uniform and Rigid body tilting of a tank are too complicated to appear in the exam. Further explanation of tank settlement is found in Annex B, API 653.

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