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# Determination of localized stresses in the shell above anchor bolt chairs attachments of anchored storage tanks

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ABSTRACT

Anchor bolt chairs are attachments widely used to control the overturning stability of storage tanks subjected to external and internal forces. This paper discusses three different procedures based on mathematical equations, stress linearization and stress extrapolation to determine the localized stresses occurring in the shell above the chairs due to wind load. Several finite element models were built to study the effect of four different parameters such as the tank height, the tank diameter, the shell thickness and the anchor chair height. The results of the three methods are compared in terms of the localized stresses obtained from each one as well as in terms of the utilization ratio of the shell material.


## 1. Introduction

The design of aboveground storage tanks requires to guarantee the overturning stability due to wind pressures, seismic loads and internal pressures. When the stability cannot be satisfied, some anchor attachments shall be provided to the tanks to meet the requirements. The API 650 [1] recommends that the anchorage shall be done through stiffened chair-type assemblies or anchor rings and refers to two different procedures to design the attachments: the AISI Steel Plate Engineering Data, Volume 2, Part 5, “Anchor Bolt Chairs” [2] and the second one is the ASME Boiler and Pressure Vessel Code Section VIII Division 2, Part 5 [3].

The anchor bolt chairs are structural elements that support and distribute the uplift forces occurring in the base of the tank. This paper addresses the analysis of the localized stresses produced above the anchor bolt chairs due to wind loads using the AISI formulation [2], the ASME linearization method [3] and the extrapolation method presented by Niemi et al. [4]. A typical storage tank with anchorage as well as an anchor bolt chair detail are shown in Fig. 1 and Fig. 2, respectively.

The use of anchor bolt chair attachments on storage tanks with overturning stability problems has been a common practice in the oil and gas industry. The design of such chairs is generally done by using the AISI Steel Plate Engineering Data procedure [2]. This procedure computes local stresses in the shell above the anchor chair using mathematical expressions based on elastic thin shell theory. Additionally, the API 650 [1] recommends the ASME Section VIII Division 2, Part 5 [3] to evaluate localized stresses that may be produced by external loads such as wind load and seismic load as well as internal pressure acting on an anchored storage tanks. This method requires the development of computational models using finite elements to determine the stresses. Although the AISI and the ASME procedures are accepted by the API 650, it could not be found any study that relates both criteria.

Local stresses in pressure vessels have been extensively studied in the past. The AISI formulation is based on a work presented by Bijlaard [5] who published significant literature regarding the local stresses in cylindrical and spherical vessels in 1950s based on shell theory. Moreover, the methods to determine the localized stresses in welded joints or pressure vessels have been compared for different problems by many authors. The International Institute of Welding (IIW) presented a work done by Niemi et al. [4] which explained the basis of the extrapolation method. Muscat et al. [6] compared the linearization method, the extrapolation method and the nodal force (Dong's) method [7] using a T-shaped welded plate model. It was concluded that the linearization and extrapolation procedures were mesh sensitive while the Dong's method was mesh insensitive for this problem. Doerk et al. [8] concluded for four different types of weld problems that the nodal method could be mesh insensitive for 2D problems whereas it can show some scatter in 3D problems. Additionally, Doerk et al. recommended

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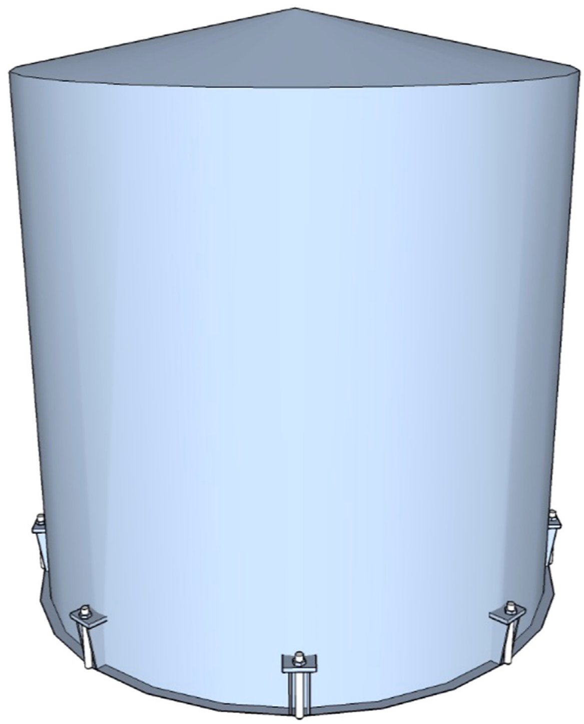

**Fig. 1.** Typical storage tank with anchor bolt chairs.

that "The analyst should always be aware of the limitations set by the finite element model as well as by the evaluation method of the structural hot-spot stress".

In conclusion, this study provides relevant information that relates the different methods to analyze the localized stresses occurring in the shell of storage tanks just above of the anchor bolt chairs due to wind loads. Additionally, the linearization and extrapolation method analysis presented in this paper were based on previous works to compare the results of the localized stresses in 3D finite elements models using shell elements.

## 2. Methods for determination of localized stresses

### 2.1. AISI formulation

The American Iron and Steel Institute (AISI) [2] presented this method as an alternative to design the anchor bolt chairs of storage tanks. It explains that the chairs not only support the tank but also distribute the loads to the shell. Moreover, the AISI specifies formulas to determine localized stresses occurring in the shell above the chairs as well as in the top plate of the chair.

The formulae (2.1) and (2.2) are used to calculate the localized stresses above the top of chair.

$$S = \frac{Pe}{t^2}\left[\frac{1.32Z}{\frac{1.43ah^2}{Rt} + \left(4ah^2\right)^{0.333}} + \frac{0.031}{\sqrt{Rt}}\right] \tag{2.1}$$

$$Z = \frac{1.0}{\frac{0.177am}{\sqrt{Rt}}\left(\frac{m}{t}\right)^2 + 1.0} \tag{2.2}$$

Where $P$ is design load in kips, $e$ is the anchor bolt eccentricity in inches, $t$ is the shell thickness in inches, $a$ is the top plate width in inches, $h$ is the chair height in inches, $R$ is the nominal shell radius in inches, $m$ is the base plate thickness and $Z$ is a reduction factor. Eqs. (2.1) and (2.2) are unit dependent and they work in U.S Customary units. A typical chair detail is given in Fig. 2.

This procedure recommends an allowable stress of 2 ksi (172 MPa). This allowable stress is essentially 5/6th of 30 ksi (207 MPa) yield stress ($F_y$) of a common carbon steel plate specification ASTM A283 Grade C at the era when AISI method was first introduced in 1971. In the current API 650 this allowable stress is modified based on the shell plate yield stress and nature of loading. For example, for wind load the allowable stress is 5/6 $F_y$ while for design pressure, it is 2/3 $F_y$.

The AISI Eqs. (2.1) and (2.2) are approximations to the Bijlaard's work based on thin shell theory [5]. Bijlaard expressed the governing equations of the displacements of a cylindrical shell under radial loads in terms of an eight-order ordinary differential equation of radial displacements. This differential equation is similar to

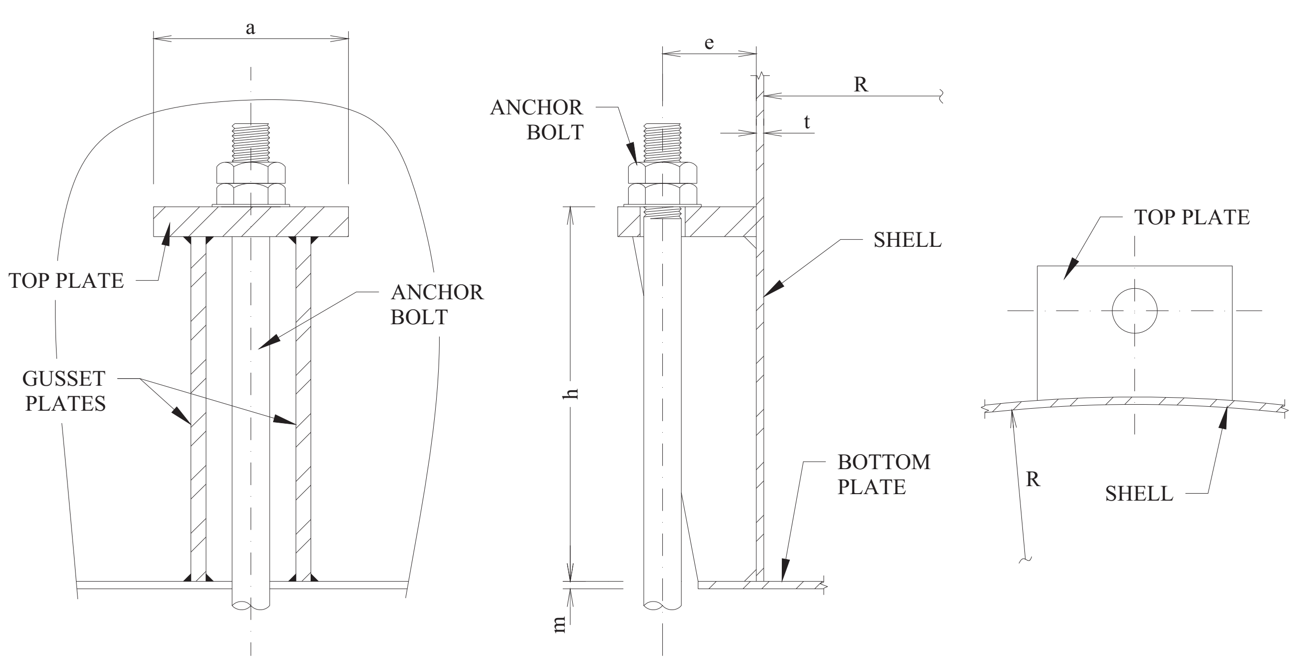


**Fig. 2.** Anchor bolt chair detail.