Subsea Equipment Pressure Ratings

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Subsea Equipment Pressure Ratings

1 Scope

The impact of operation in deep water on the pressure rating of equipment is a special concern. The objective of this document is to foster a better understanding of the effects of simultaneous internal and external pressures on the rated working pressure of equipment covered by the scope of API Specification 17D, Subsea Wellhead and Tree Equipment.

Additionally, it is intended to provide a high-level overview of issues that should be considered if a user elects to consider differential pressure in their design, especially in components with irregular geometry and with high stress concentrations. It is not intended to serve as a design specification. This document was prepared in response to a request from the API Subcommittee 17 (SC17).

2 Normative References

The following referenced documents are essential when considering the examples outlined in this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API 17TR12, *Consideration of External Pressure in the Design and Pressure Rating of Subsea Equipment*

ASME *Boiler and Pressure Vessel Code, Section VIII, Division 2* [1]*, "Rules for Construction of Pressure Vessels, Alternative Rules*, 2010 Edition

ASME *Boiler and Pressure Vessel Code, Section VIII, Division 3, Rules for Construction of Pressure Vessels, Alternative Rules for Construction of High Pressure Vessels*, 2010 Edition

3 Definitions and Nomenclature

3.1 Definitions

For the purposes of this document, the following definition applies.

3.1.1
rated working pressure
The maximum internal pressure a piece of equipment is designed to contain and/or control. [Source: API Spec 17D, API Spec 6A]

3.2 Nomenclature

A cross-sectional area of vessel wall

D_i inside diameter of vessel

D_o outside diameter of vessel

d diameter variable, such that $D_i < d \le D_o$

F external applied force

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1 ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

P_i internal pressure

P_o external pressure

S_a axial stress

S_h hoop stress

S_r radial stress

S_{VME} von Mises equivalent stress

4 Design Issues

During the design of any piece of equipment, all loads and conditions that may realistically occur must be considered, including accidental loads. A complete functional understanding of the system is needed to appropriately define design loads and operating conditions.

API 17D defines rated working pressure (RWP) as the maximum internal pressure that the equipment is designed to contain and/or control (see API 17D [2011], 3.1.42). This is an absolute pressure. The API specifications state that the effects of external load, such as external pressure, should be taken into account in the design, but the use of external pressure to increase the equipment RWP is not recommended.

The equipment design must be evaluated for fitness for service and shown to provide sufficient margins for all relevant failure modes in a consistent manner. As stated in API RP 17G, failure is an event causing an undesirable condition, e.g. loss of component or system function, or deterioration of functional capability to an extent that the safety of the unit, personnel or environment is significantly reduced (see API 17G [2006], Section 3.1.50). Failure of a pressure vessel is commonly described using the following forms:

— ductile failure (called plastic collapse in ASME *BPVC*);

— brittle failure resulting from use of brittle materials or from environmental cracking;

— fatigue failure resulting from cyclic loading;

— failure from service criteria (as defined by the manufacturer, such as elastic deflection resulting in binding of components).

Systems must be evaluated for additional potential failure modes such as:

— failure of sealing mechanisms

— failure of non-metallic sealing materials

— failure of closure bolting

Therefore, limits must be defined for materials and loads to provide protection against the appropriate types of failure. ASME BPVC Section VIII, Div. 2 and ASME BPVC Section VIII, Div. 3 require that the design of the vessel parts shall be limited to values that ensure an adequate safety margin against relevant failure modes under the stated conditions. Examples of loads and conditions or combination of conditions that must be considered during the equipment design phase include:

— internal pressure,

— external pressure,

- axial loads (tension and compression),
- bending loads,
- collapse and buckling loads,
- cyclic loads,
- temperature effects,
- corrosion/erosion/wear/galling,
- fluid compatibility.

It is essential that the designer be able to justify that the design has adequate margins to protect against failure due to any reasonable combination of possible events during the life cycle of the product. Safety margins are addressed in industry-specific codes, standards, and recommended practices. However, these documents are usually not intended to be used as a handbook and must be applied in conjunction with education, experience, and careful engineering judgment. API 1111 states the following: "Nothing in this RP should be considered as a fixed rule for application without regard to sound engineering judgment" (see API 1111 [1999], Section 1.5). API 17D further states that: "Users of this standard should be aware that additional or different requirements might better suit the demands of a particular service environment, the regulations of a jurisdictional authority or other scenarios not specifically addressed" (see API 17D [2011], Introduction).

5 Example Application

The following example of a closed-end cylinder is shown only to illustrate the effect of external pressure on the stresses of the cylinder. The example does not represent a complete design verification analysis of the vessel, but only one aspect of the design verification analysis.

Figure 1 represents a simple closed-end cylinder being acted on by both simultaneous internal pressure (P_i) and external pressure (P_o). There is an external longitudinal force (F) in addition to the pressure loads.

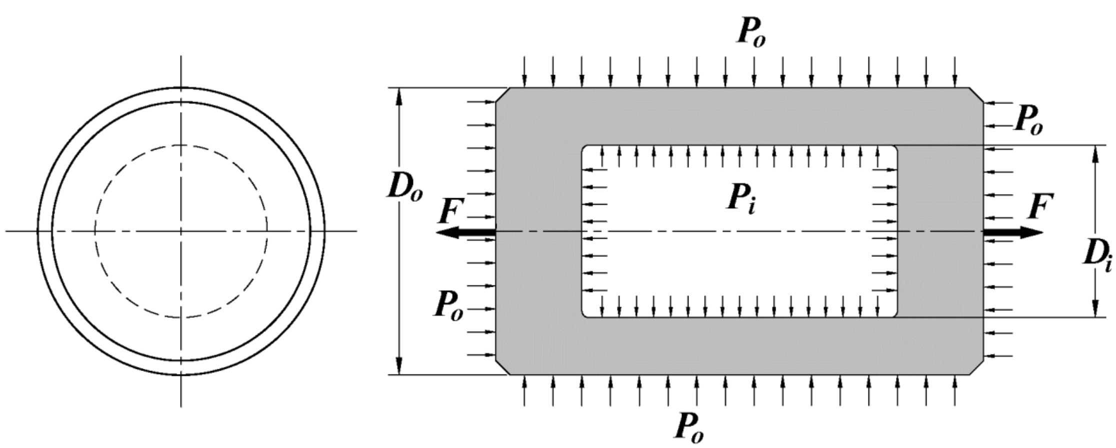

Figure 1—Example Vessel Under Pressure and Longitudinal Loading

Figure 2 presents a pair of free-body diagrams of forces that, with superposition, are equivalent to Figure 1. In Figure 2 are (1) a closed-end vessel with only internal pressure and an externally applied force plus (2) the effects of hydrostatic pressure acting both internally and externally on the vessel.

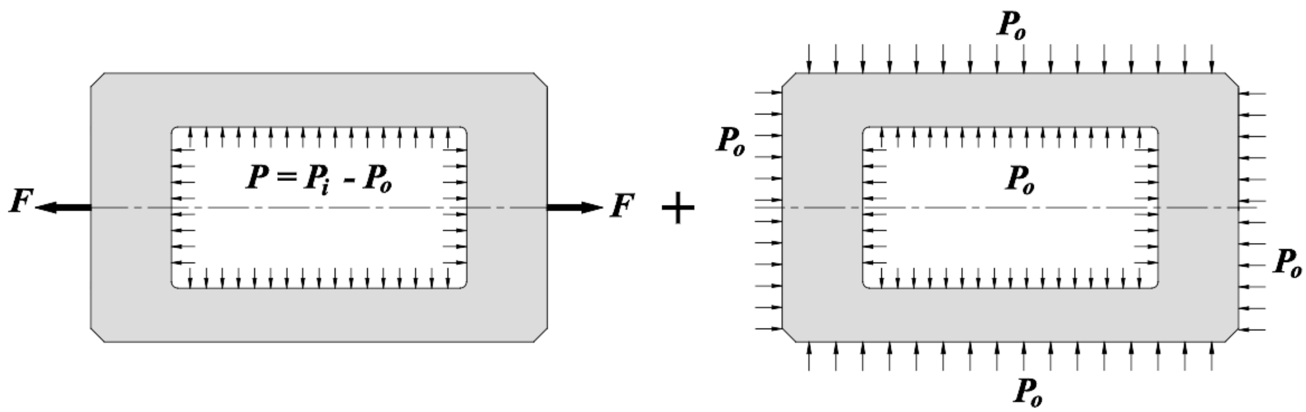

Figure 2—Loading on Example Vessel Broken into Two Components

Radial, hoop, and longitudinal stresses on the sides of the vessel can be determined using the Lame equations for an elastic cylinder without stress concentration areas.

Radial Stress: $$S_r = (P_i - P_o) \cdot \frac{D_i^2}{D_o^2 - D_i^2} \cdot \left(1 - \frac{D_o^2}{d^2}\right) - P_o \text{ for } D_i < d \le D_o$$

Hoop Stress: $$S_h = (P_i - P_o) \cdot \frac{D_i^2}{D_o^2 - D_i^2} \cdot \left(1 + \frac{D_o^2}{d^2}\right) - P_o \text{ for } D_i < d \le D_o$$

Longitudinal Stress: $$S_a = \frac{F}{A} + (P_i - P_o) \cdot \frac{D_i^2}{D_o^2 - D_i^2} - P_o$$

where the cross-sectional area, $A = \pi / 4 \cdot (D^2 o – D^2 i)$

The von Mises equivalent (VME) stress is defined as:

VME Stress: $$S_{VME} = \sqrt{\frac{1}{2} \cdot \left[(S_h - S_r)^2 + (S_r - S_a)^2 + (S_a - S_h)^2\right]}$$

which, after substituting in the stress definitions, reduces to

VME Stress: $$S_{VME} = \sqrt{3 \cdot \left[\left(P_i - P_o\right) \cdot \frac{D_i^2}{D_o^2 - D_i^2} \cdot \left(\frac{D_o}{d}\right)^2 \right]^2 + \left(\frac{F}{A}\right)^2} \ for\, D_i < d \le D_o$$

6 Discussion

Note that the VME stress calculation for the cylinder is a function of differential pressure, (P_i – P_o), and external force, F. Therefore, the failure criterion based on the VME stress is affected only by differential pressure and F. If the relative difference between P_i and P_o does not change, as is the case with an internally pressurized vessel evaluated at both atmospheric conditions and in deepwater, the VME stress does not change.

For a constant differential pressure, the VME stress is constant regardless of the level of the external pressure, P_o. However, the principal stresses are affected by P_o. The radial, hoop, and longitudinal stress all have P_o terms in addition to differential pressure terms. The principal stresses are important in analyzing failure from cyclic loading. Also note that the externally applied force is usually different for subsea equipment as compared to surface equipment because of different system requirements and loads. This is why the designer must fully understand the operating conditions and apply all appropriate loads in the design verification and validation processes.

To emphasize the point, while VME stress can be easily accounted for in a differential pressure design analysis for subsea equipment, full, meticulous consideration of the principal stresses and their effects must also be completed and resolved.

A single load cycle analysis of equipment is typically based upon the VME stress level and an adequate safety margin for the design. As shown, the VME stress is a function to the differential pressure across the pressure vessel. However, the life cycle analysis of the equipment, fatigue is based upon the principal stresses. In deepwater applications, the principal stresses are affected by the high hydrostatic external pressure and the differential pressure. Hence, the fatigue life of subsea equipment will be different from surface equipment even though the differential pressure remains constant.

In addition to the general stress conditions, localized stress concentration areas also need to be well understood in engineering design for deep water. These localized stress concentration areas may likely be loaded into the plastic stress region. Examples of localized stress concentration areas are fillets, welds, the root diameter of threads, areas of discontinuity, and the intersection of cross-bores. These regions, many of which are affected by hydrostatic pressures, are normally where fatigue failures initiate. The primary loading in these areas may be from either hoop, axial, or a combination of loads. In addition, due to potentially higher pressures, consideration should be given to crack face pressures during a fracture mechanics analysis. Consequently, the fatigue life of subsea equipment is likely to be impacted by hydrostatic pressure and that impact may be either beneficial or deleterious.

The evaluation of external pressure on equipment should follow the guidelines set forth by API 17TR12.

7 Conclusion

It is not appropriate to categorically state that the internal pressure capacity of a pressure vessel is defined by the differential pressure capacity. The simple example illustrated that while the VME stress is a function of differential pressure (and not the magnitude of P_i or P_o), failure criteria based on the individual stress components or the principal stress is a function of the magnitude of P_i and P_o. Proper analyses must be conducted with a thorough understanding of the system and operating requirements along with consideration of all appropriate failure modes.

The following items summarize this document.

— During the design of equipment, all loads and conditions that may realistically occur must be considered, including accidental loads. A system approach is often necessary to identify all applied loads to individual components, especially to understand the loads involved at the interface with adjacent components.

— Failure is an event causing an undesirable condition to an extent that the safety of the unit, personnel or environment is significantly reduced.

— Limits must be defined for materials and loads to provide protection against the appropriate types of failure.

— Limit load failure based upon VME stress is affected by differential pressure and external applied loads.

— Localized stress concentration areas, such as areas of discontinuity and areas of high mean and alternating stresses, are normally where fatigue failures occur.

— Principal stresses are important in analyzing failure from cyclic loading.

— Other system failures, such as non-metallic seals, may be the weak link in the system instead of the pressure vessel body.

Bibliography

[1] API RP 17G, *Recommended Practice for Completion/Workover Risers,* Second Edition (July 2006).

[2] API Recommended Practice 1111, *Design, Construction, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)*, Third Edition (July 1999).

[3] API Report, *Example Model Analysis in Accordance with API RP 6HP Methodology*, by Stress Engineering Services, August 2008.

[4] API Spec 17D, *Design and Operation of Subsea Production Systems – Subsea Wellhead and Tree Equipment*, Second Edition (May 2011).

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