Consideration of External Pressure in the Design and Pressure Rating of Subsea Equipment

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Introduction

For pressure-containing equipment, as defined by API 6A and API 17D, where external pressure is constant and acting on the outside of the component, it is reasonable to include the external pressure effects when designing and rating the equipment. Examples would be piping, valve body, bonnet, and similar items, which are always wetted by the seawater or fluid, resulting in an external pressure equal to ambient seawater pressure at the installed water depth.

For pressure-controlling equipment (see API 6A and API 17D), external pressure (or in some case, backpressure) may not always be present downstream of the pressure-controlling element (closure mechanism), or the backpressure pressure magnitude may fluctuate. Example of this scenario is a closed valve or choke where downstream pressure of the closure mechanism may not always be equal to external ambient seawater pressure (e.g. a subsea flowline is blown-down to low pressure during a system shut-in to avoid hydrate formation in the flowline as its contents cool down).

Another example of external pressure assessment is equipment containing one-atmosphere pressure (or 14.7 psia) voids such as spaces between dual seals where the inner seal does not benefit from the external pressure effects. Pressure in trapped spaces between closed valves can decline significantly due to thermal effects when a hot system is shut-in and begins to cool down.

In certain cases where dual barriers are designed into the equipment (i.e. dual packings on valve stems, connector gaskets with primary and secondary seals, penetrators with internal and external seals, etc.), the effects of external ambient seawater pressure may not be present behind the primary seal during subsea operation, nor present during shop testing operations. If the pressure equipment is designed with consideration of external pressure due to ambient seawater pressure at depth, it may not be possible nor practical to perform FAT pressure test of the primary seal (inboard) for the dual barrier sealing arrangement to the maximum pressure that it will see in operation at depth without overstressing the pressure equipment since external pressure in the shop is only one-atmosphere. It is a proper quality assurance practice to test all seals to at least the differential pressure they will see in service, or higher. If such testing cannot be conducted, the manufacturer and equipment purchaser/end-user should address the associated risk of the utilizing external pressure in the design with dual barrier sealing configuration, and the potential risk of a seal defect not being detected during the FAT.

As illustrated above, the evaluation of pressure-controlling equipment and equipment containing trapped one-atmosphere void spaces can be more complicated than for pressure-containing equipment with consideration of external pressure. In all cases, a full system analysis is necessary, along with HAZID/HAZOP and FMEA/FMECA studies to ensure that external pressure conditions during all potential operating modes and scenarios are properly identified and evaluated. Additionally, equipment with trapped voids or dual barrier seals configuration may not have the beneficial effects of external pressure and this must be taken into consideration when assessing pressure ratings.

Consideration of External Pressure in the Design and Pressure Rating of Subsea Equipment

1 Scope

This technical report addresses issues related to the effects of external pressure acting on API Subcommittee 17 (SC17, Subcommittee on Subsea Production Equipment) subsea equipment installed in deepwater for containing or controlling wellbore fluids. External pressure at deepwater can significantly reduce the differential pressure acting on the wall of subsea equipment, and therefore, this can improve its internal pressure containment capability. External pressure is typically ambient seawater pressure, but in some cases, external pressure may be due to the hydrostatic head of drilling mud, completion fluids, or other fluids contained within risers or other conduits that connect the subsea equipment to surface facilities.

There is a need for guidelines on the application of external pressure during the design, validation and operation of subsea equipment. Guidelines are also needed to calculate and/or determine a modification to the working pressure limits at the installed water depth, using the selected equipment API rated working pressure (RWP).

API Technical Report 17TR12 (hereafter API 17TR12) provides guidance for subsea equipment designers/ manufacturers to properly account for external pressure (or in some cases, differential pressure) when designing and validating subsea equipment. Additionally, this technical report provides guidance to equipment purchaser/end-user to appropriately select rated equipment for their subsea systems with consideration to the effects of external pressure in addition to internal pressure, including differential pressure across a closure mechanism, and other applied mechanical or structural loads under all potential operating scenarios and functionality criteria.

NOTE API Technical Report 17TR4 (hereafter API 17TR4) provides additional information on the effects of external pressure on stresses generated within subsea equipment for the equipment designer.

API 17TR12 applies specifically to API SC17 equipment. API 17TR12 is to be used as a supplement to the equipment's applicable API product specification (e.g. API 6A, API 17D, API 17G), depending on its specific application, associated regulations, and project requirements. Other API product specifications may elect to adopt this technical report, subject to their component hardware, application-related design constraints and acceptance criteria. Specific subsea recommended practices, standards, and/or specifications may elect to adopt this technical report, also subject to their component hardware and application-related design constraints.

For this technical report, the term "equipment" also applies to the terms "part", "component", "sub-component" or "device" within a subsea system.

2 Normative References

The following referenced documents are indispensable for the application of 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 Specification 6A, *Specification for Wellhead and Christmas-Tree Equipment*, Twentieth Edition, October 2010

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*, Second Edition, May 2011

API Recommended Practice 17G, *Recommended Practice for Completion/Workover Risers*, Second Edition, July 2006

3 Terms, Definitions, Acronyms, and Symbols

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1
design validation
Process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.1.2
design verification (assessment)
Process of examining the result of a given design or development activity to determine conformity with specified requirements.

3.1.3
depth adjusted working pressure
The maximum internal pressure a piece of equipment can contain and/or control with consideration of the equivalent external pressure at a specified water depth (measured in “psia”, absolute pressure).

3.1.4
differential working pressure
The difference between the upstream and downstream pressures on a pressure-controlling element that defines the working pressure for the pressure-controlling equipment (measured in “psid”, differential pressure).

3.1.5
manufacturer (equipment)
Individual or organization that is normally responsible for the design and manufacture of the equipment.

3.1.6
operator
Individual or organization that normally uses the equipment (also referred to as “end-user”).

3.1.7
pressure
The ratio of force to the area over which that force is distributed (i.e. pound-force applied to an area (in.^{2}), measured in “psi”, etc.):

1) *absolute pressure*: the internal pressure that the equipment is designed to contain and/or control or zero-referenced against a perfect vacuum, measured in “psia”;

2) *differential pressure*: the difference in pressure between any two points (p1 and p2), measured in “psid”;

3) *gauge pressure*: measured relative to the ambient pressure (e.g. atmospheric for surface application, hydrostatic for subsea application), measured in “psig”.

3.1.8
pressure-containing equipment
Part whose failure to function as intended results in a release of wellbore fluid to the environment.

EXAMPLE Subsea tree valve body, bonnet, stem.

3.1.9
pressure-controlling element
The closure mechanism contained within pressure-controlling equipment.

EXAMPLE Valve gate, choke, tubing hanger.

3.1.10
pressure-controlling equipment
Part intended to control or regulate the movement of pressurized fluids.

EXAMPLE Valve-bore sealing mechanism, choke trim, and hanger/packoff.

3.1.11
rated working pressure
The maximum internal pressure a piece of equipment is designed to contain and/or control.

NOTE For the purposes of this technical report, rated working pressure is defined as the absolute internal pressure minus 14.7 psia (see API 6A or API 17D).

3.1.12
specified water depth
In situ or installation water depth for the subsea equipment as related to depth adjusted working pressure and differential working pressure.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

ASME	American Society of Mechanical Engineers
BPVC	*Boiler and Pressure Vessel Code*
BSEE	Bureau of Safety and Environmental Enforcement
DAWP	depth adjusted working pressure
DWP	differential working pressure
FAT	factory acceptance testing
FEA	finite element analysis
FMEA	failure modes and effects analysis
FMECA	failure modes, effects and criticality analysis
FTA	fault-tree analysis
HAZID	hazard identification
HAZOP	hazard and operability
psi	pounds per square inch
psia	pounds per square inch, absolute pressure
psid	pounds per square inch, differential pressure
psig	pounds per square inch, gage pressure
RWP	rated working pressure (as defined in API 6A, API 17D, API 17G)

SC17	API Subcommittee 17 (Subcommittee on Subsea Production Equipment)
SIT	system integration testing
SWD	specified water depth
VME	von Mises equivalent stress
WSIP	well shut-in pressure

3.3 Symbols

For the purposes of this document, the following symbols apply.

$\sigma 1$	principal stress in the 1-direction
$\sigma 2$	principal stress in the 2-direction
$\sigma 3$	principal stress in the 3-direction
Di	inside diameter
Do	outside diameter
Pi	internal pressure
Po	external pressure
$Po(x)$	external pressure at (x) water depth
R	outside radius
S	design allowable stress
S_Y	yield strength (or YS)
t	wall thickness

4 Rating and Design Considerations

4.1 General

In the context of this technical report, there are several considerations that need to be discussed in order to provide background information as related to the consideration of external pressure in the design of subsea equipment.

4.2 Definition of "Rated Working Pressure"

There can be differing definitions for the term "rated working pressure" (RWP) when evaluating the effects of internal and external pressures in the design of subsea equipment. This technical report provides clarification of rated working pressure for subsea equipment which is subjected to external hydrostatic pressure from the in situ environment.

Relative to API 6A, API 16A and API 17D oilfield equipment, the term "rated working pressure" is currently defined as "the maximum internal pressure that the equipment is designed to contain and/or control" and usually interpreted as absolute internal pressure minus 14.7 psia. This has been commonly simplified to the "absolute internal pressure" of the fluid contained within the equipment, measured in "psia" (psi absolute). However, wording between API 6A and API 17D are inconsistent.

Confusion can arise when the terms "absolute" and "gage" or "gauge" pressure are used in subsea applications. Gauge pressure is the pressure relative to the local atmospheric or ambient hydrostatic pressure. At sea level, the absolute pressure in air is 14.7 psia, and the gage pressure is 0 psig. These terms could also be adopted for subsea, but the equipment designer needs to then be careful with the nomenclature and application. Piezo-electric digital pressure transducers provide an absolute pressure reading. Analog pressure gages are typically compensated, and therefore, provides a pressure reading relative to local hydrostatic pressure.

For subsea pipelines in the oil and gas industry, the term “pressure” is intended to mean the “differential pressure” acting on the pressure-containing equipment (absolute internal pressure minus absolute external pressure), measured in units of “psi” (see API 1111 and BSEE NTL No. 2009-G28).

It is important that guidelines, industry standards or RPs, and design documents be explicit wherever practical about definitions of the word “pressure”. Wherever “pressure” is described, the location needs to be defined and whether the pressure is internal pressure, external pressure, or differential pressure. API 1111 is consistent in this terminology, and is based on use of differential pressure. However, it is recognized that some regulations at present do not use the term “differential” pressure but pipeline design codes do.

For subsea hydraulic control systems and related components, rated working pressure (RWP) is typically considered to be the “differential pressure” (gauge pressure) produced by the hydraulic power unit (HPU) pumps on the surface. It should be noted that the “absolute internal pressure” of the hydraulic fluid acting on actuators, operators and other control system components located on the seabed can be significantly higher than the surface gauge pressure (due to hydrostatic head of the control fluid in deepwater) but these components typically have the same “RWP” as the surface HPU

NOTE Hydraulic controls equipment is outside the scope of this document, unless they contain or control well bore fluids.

As described above, there are different definitions of “pressure rating”, “working pressure” and “RWP” between various types of equipment used within the same subsea system. For applications in deepwater, external pressure can result in a significant reduction in the differential pressure for a given absolute internal pressure. Ignoring the benefits of external pressure can result in larger and difficult to produce equipment designs and potential overly conservative validation requirements. Inconsistency between “RWP” terminologies can also complicate equipment selection decision-making process.

Stresses within a pressure vessel are primarily driven by the differential pressure acting on the vessel wall (internal pressure minus external pressure). However, in some cases, stresses can also be affected by the absolute pressure and not simply by the differential pressure (for example, equipment containing trapped void spaces). While the presence of external pressure may reduce stresses due to the effects of internal pressure, it may not be on a “one-for-one” basis.

Therefore, when selecting equipment, the designer cannot simply subtract the external pressure from the internal pressure to determine the required “RWP” for API 6A or API 17D equipment. For example, a connector on a subsea manifold located in 10,000 feet of seawater and operating at a pressure of 14,000 psia would have differential pressure acting on the connector of 9500 psid. The analysis methodology outlined in this report could be used to validate a planned RWP of 10,000 psia.

It should be noted that the external pressure is likely to vary if the equipment is moved to a different subsea field location or different water depth, therefore, the engineering analysis described herein may need to be re-performed for the specific location where the equipment is deployed (particularly relevant to running tools, completion riser systems, BOPs, capping stacks, etc.), and may include re-validation testing.

Equipment designed with consideration of external pressure can, in some cases, be more efficient in weight and cost-effective when the effects of external pressure are accurately taken into account in the equipment design and validation process.

In order to accomplish this goal, it is necessary to establish consistent definitions for “rated working pressure” which should be agreed and adopted within the oil and gas industry.

4.3 Design Issues

4.3.1 General

For deepwater applications, external pressure becomes a significant factor and should be taken into consideration when designing subsea equipment. To perform a proper design analysis of equipment, applicable loads should be considered in the analysis.

Loads and conditions, or combinations of conditions, which should be considered in the design phase are defined in API 17TR4 as well as governing API product specifications (e.g. API 6A, API 17D, API 17G). This should include the load created from the external ambient seawater pressure. Although identified in current API specifications (e.g. API 17D, 17G), the use of external pressure in subsea equipment design has not been consistently applied in the past.

Most surface oilfield wellhead equipment or pressure vessels were typically designed and rated, assuming that one-atmosphere of pressure would be acting on the outside of the vessel. In contrast, subsea pipelines are typically designed using "differential pressure" [internal/inside pressure minus external/outside ambient seawater pressure [or ($Pi - Po$)], a practice which is simple and straight forward for cylindrical shaped, thin-wall pressure vessels or pipelines. This common design practice for flowlines can be justified by engineering physics and past experience for shallow water depth, and is allowed for subsea flowlines by the applicable US regulatory agencies. However, for pressure equipment with complicated geometric shapes (typically associated with subsea equipment), thick-wall vessels ("$R/t \leq 4$" or "$Do/Di \geq 1.25$"), and/or equipment subjected to complex load combinations (i.e. pressure, thermal, bending, tension, torsional etc., as applicable), the use of simple differential pressure calculation, e.g. ($Pi - Po$), may not give accurate results.

There is usually no practical impact on the design or in the operation of surface equipment (land or offshore platform topsides applications) based on varying "RWP" interpretations, whether it be as absolute internal pressure or differential pressure, since the external atmospheric pressure is one-atmosphere (or 14.7 psia), and it is insignificant compared to the internal pressure inside the equipment (from several hundred to several thousand psia). For such applications, the absolute pressure is essentially equal to the differential pressure, and thus it makes little difference which pressure, "absolute" or "differential," is used to perform stress analyses.

Similarly, for subsea equipment in relatively shallow water depths (i.e. within a few hundred feet, etc.); external pressure has a minimal effect on the resultant stresses where the rated working pressures are typically 5000 psia and above. For such cases, the absolute pressure contained within the equipment is reasonably close to the differential pressure acting across the pressure-containing equipment. Therefore, in the past, designing subsea equipment without taking credit for external pressure was the standard practice. As subsea operations have moved into deepwater applications, the effects of external ambient seawater pressure are much more significant and can be applied to advantage when designing, validating (as they are required to be currently in many API specifications) and rating subsea equipment.

4.3.2 Example Application

For a well with shut-in tubing head pressure of 10,000 psia, located in 10,000 ft of water (where the external pressure is approximately 4500 psia) the differential pressure acting on the pressure-containing equipment would be 5500 psid. If the equipment designer takes the approach of not considering the beneficial effects of the external pressure at depth, the resulting equipment is based on an absolute pressure of 10,000 psia rather than a potential differential pressure of 5500 psid. The specified equipment may be thicker-wall and heavier than equipment designed with proper consideration of the external pressure.

Thick-wall sections can result in some undesirable effects, such as difficulties during forging, heat treatment and fabrication, as well as inconsistent through-wall metallurgical properties. In addition, there are impacts on handling and installation operations due to component weight. In some cases, the weight of the equipment is at the limit of the installation vessel's lifting capacity; therefore, design processes that can be applied to control and/or manage the equipment's weight can be an important factor.

4.4 Considerations for API 17TR12

This technical report proposes the following terminologies:

1) "depth adjusted working pressure" (DAWP), measured in absolute pressure (psia);

2) "differential working pressure" (DWP), measured in "psid";

3) "specified water depth" (SWD), measured in "ft", associated with DAWP and DWP.

The design verification procedures for these terminologies are provided in Section 5.

Additional considerations to system-level analysis, markings, documentation control, quality assurance and quality control should be thoroughly addressed for equipment designed with consideration of external pressure.

API 17TR12 task group strongly advocates the cooperation between the equipment manufacturer and the equipment purchaser/end-user/operator to address design verification, document control, validation testing for equipment design with consideration of external pressure.

In cases where the equipment designed with consideration of external pressure will be moved and re-used in a different water depth, the equipment manufacturer and the equipment end-user/operator shall confirm the design verification and conduct additional validation testing (if necessary).

Where API product specifications exist with specific consideration of external pressure for equipment designs, the procedures of those governing API product specifications shall be followed. It is necessary that users of this technical report be aware of regulations from jurisdictional authority that may impose additional or different requirements to the consideration of external pressure or differential pressure in equipment designs.

5 Procedures for Consideration of External Pressure in Subsea Equipment Designs

5.1 General

For proper design assessment of subsea equipment, all loads should be considered. The governing API product specifications (e.g. API 6A, API 17D, API 17G) and/or API design guidelines (e.g. API 1PER15K-1, API 17TR8), typically specify the loads, conditions and/or the applicable combinations thereof that should be considered in the equipment design and are identified below, but not be limited to:

— internal pressure;

— external pressure (ambient hydrostatic pressure);

— axial loads (tension or compression);

— pressure loads due to thermal expansion/contraction of fluids;

— bending loads/torsional loads;

— collapse and buckling loads;

— cyclic loads;

— thermal loads;

— corrosion/erosion/wear/galling;

— fluid compatibility;

— pressure-end loads.

With reference to "external pressure" or "ambient hydrostatic pressure", it should be noted that this has not been consistently specified across the API product specifications associated with subsea equipment. External pressure is specified as a loading condition in API 17D and API 17G, however, it is not referenced in other API specifications associated with this technical report, e.g. API 6A does not specify external pressure in the design loads.

If the subsea equipment designs are properly evaluated and validated using the proposed design assessment procedures as provided in this technical report, the effect of external pressure on effective working pressure capacity can and should be considered.

For consideration of external pressure in subsea equipment design, Figure 1, provides the procedures that require the equipment designer to:

1) Identify the equipment's functional requirements including operational procedures.

2) Derive the equipment category through appropriate hazard assessment or risk identification, and based on a system-level approach. The equipment categories are:

   a) pressure-containing;

   b) pressure-controlling;

   c) subsea equipment with trapped voids, whether pressure-containing or pressure-controlling.

3) Perform applicable design analyses based on the equipment category.

Material properties and material quality, as required for specific product forms, are to be in compliance with the governing API product specifications.

5.2 Functional Specifications

The equipment purchaser/end-user should provide a complete functional specification as the basis of for selecting the appropriate API RWP for the equipment. The following information should be specified in the equipment's functional specifications, as related to consideration of external pressure, in conjunction with the typical parameters (see API 1PER15K-1).

1) Well shut-in pressure and temperature (bottom hole and at wellhead during flowing conditions) over the life of the well. For well shut-in pressure and temperature greater than 15,000 psia and/or 350 °F, respectively, design verification and design validation in accordance with API 17TR8 shall apply, in conjunction with this technical report for consideration of external pressure design (see API 17TR8 for definitions of high-pressure high-temperature conditions).

2) Specific water depth where the equipment is to be installed.

3) Operational pressure cases or operating procedures.

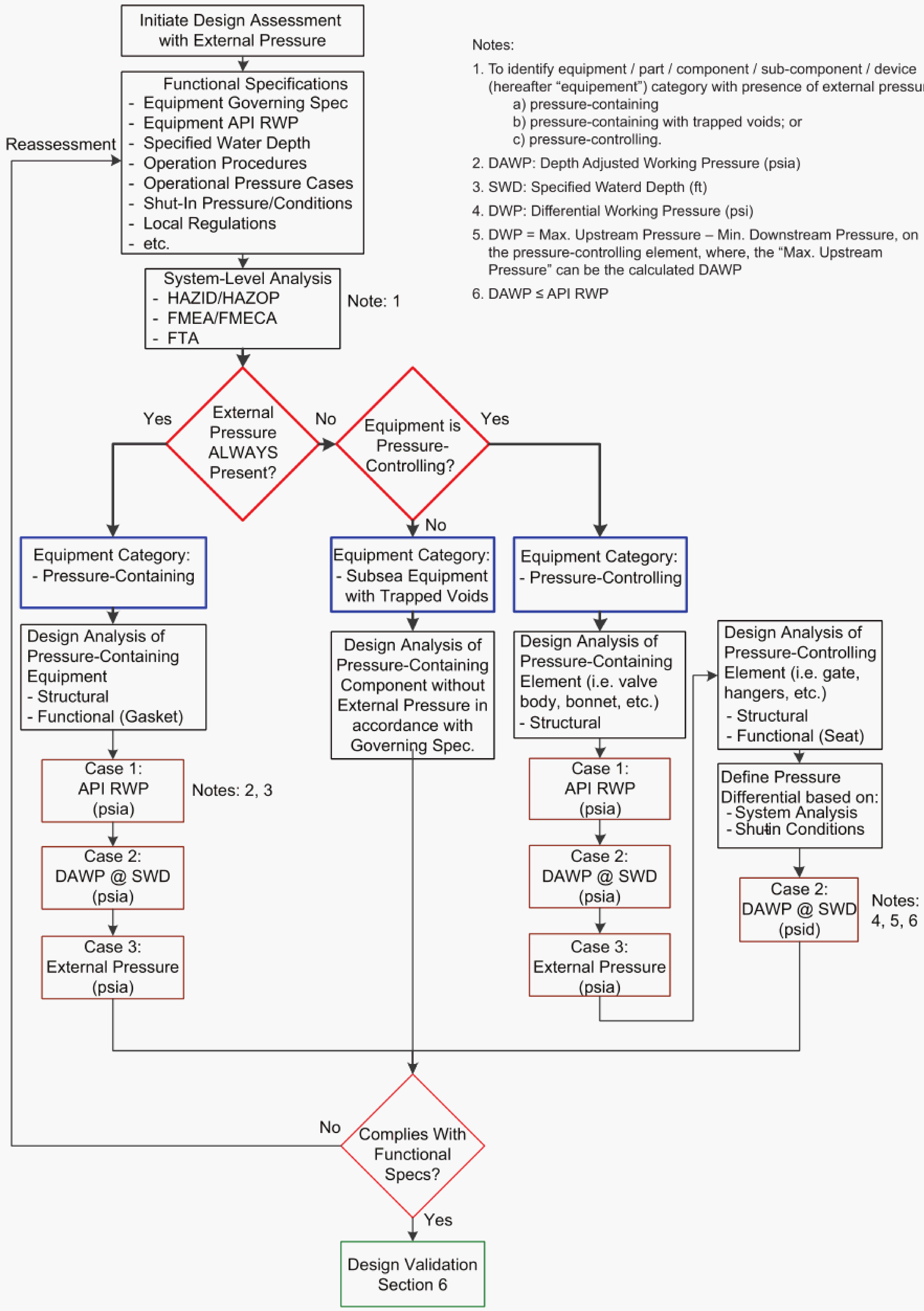
4) Environmental and/or metocean conditions (external load effects).

5) Cyclic loading/life-cycle requirements (i.e. pressure cycles, temperature cycles, external loads, etc.).

6) Corrosion, corrosion/erosion requirements.

7) Applicable industry standards and/or regulatory requirements.

NOTE Guidance on developing a functional specification is provided in API 1PER15K-1 and ISO 13879.



Notes:

1. To identify equipment / part / component / sub-component / device (hereafter "equipement") category with presence of external pressure:
   a) pressure-containing
   b) pressure-containing with trapped voids; or
   c) pressure-controlling.
2. DAWP: Depth Adjusted Working Pressure (psia)
3. SWD: Specified Waterd Depth (ft)
4. DWP: Differential Working Pressure (psi)
5. DWP = Max. Upstream Pressure – Min. Downstream Pressure, on the pressure-controlling element, where, the "Max. Upstream Pressure" can be the calculated DAWP
6. DAWP ≤ API RWP

Figure 1—External Pressure Design Assessment Flowchart

5.3 System-Level Analysis

5.3.1 General

A thorough understanding of the complete system/subsystem and associated equipment's operational and/or functional characteristics is required for the appropriate consideration of external pressure in design of subsea equipment. This can be assessed through the various hazard identifications/risk assessment tools described below, in order to appropriately evaluate and assign the subsea equipment into one of the following categories.

1) *Pressure-Containing*: Pressure-containing equipment should have constant exposure to external pressure.

   Examples of pressure-containing equipment would be subsea tree valve body, bonnet, flow loops, drill-through equipment bodies, etc.

2) *Pressure-Controlling*: The design assessment of pressure-controlling equipment requires 1) identification of the loads for the pressure-containing element, and 2) identification of loads on the pressure-controlling element or closure mechanism. While assessing the loads and associated failure modes for pressure-containing elements can be straightforward, analyzing the pressure-controlling elements requires the identification of the upstream and downstream loads acting the closure mechanism. This process requires thorough analysis of the equipment operational scenarios and potential hazards associated with these operations, since backpressure downstream of the closure mechanism may not be consistent, sufficient or present in all cases.

   Examples of pressure-controlling element are valve gate, choke trim, tubing hanger, etc.

3) *Subsea Equipment with Trapped Voids*: The effects of external pressure may not be applicable for subsea equipment (pressure-containing or pressure-controlling) "trapped void" spaces (internal cavities where one-atmosphere pressure could be trapped and sealed off during assembly of the equipment). These are cavities that would not be flooded and pressure compensated at depth. Trapped void spaces could be present in between dual seals, behind diaphragms in pressure sensors, empty spaces within electrical penetrators, etc. Trapped void evaluation should be performed to assess the effects of all possible combinations of pressure differential. The effects of trapped volume fluid can have an increase and decrease in pressure due to thermal expansion/contraction of the fluids.

Some common techniques for hazard identifications and/or risk assessments relevant to appropriate application of external pressure are provided below. The basis for hazard identifications and/or risk assessments should be derived from functional specifications, operating procedures and other applicable documents (i.e. equipment technical specifications, schematic diagrams/drawings, etc.). API 17N provides guidance on these hazard identifications and/or risk assessment procedures.

5.3.2 Hazard Identification (HAZID)

HAZID is a general term used to describe an exercise whose goal is to identify hazards and associated events that have the potential to result in an undesirable consequence. The HAZID technique can be applied to all or part of a system or it can be applied to analyze operational procedures. Typically, the system being evaluated is divided into manageable parts and a brainstorming session (often with the use of checklists) identifies potential hazards associated with each part of the system. This process is usually performed with a team experienced in the design and operation of the system, and the hazards that are considered significant are prioritized for further evaluation.

5.3.3 Hazard and Operability (HAZOP)

HAZOP analysis technique uses specific or special guidewords to prompt an experienced group of individuals to identify potential hazards or operability concerns relating to pieces of equipment or systems. Guidewords describing potential deviations from design intent are created by applying a predefined set of adjectives (i.e. high, low, no, etc.) to a pre-defined set of process parameters (i.e. flow, pressure, temperature, etc.). The group brainstorms potential consequences of these deviations and if a legitimate concern is identified, they ensure that appropriate safeguards are in place to help prevent the deviation from occurring. This type of analysis is generally used on a system level and generates primarily qualitative results, although some simple quantification is possible. The HAZOP analysis can also be used to review procedures and sequential operations.

5.3.4 Failure Modes and Effects Analysis (FMEA)

FMEA technique; 1) identifies all potential failure modes of the component or system, 2) considers how the failure mode of each system component can result in system performance problems, and 3) assures that appropriate safeguards against such problems are in place. This technique is applicable to any well-defined system, but the primary use is for reviews of mechanical systems. FMEA generates qualitative descriptions of potential performance problems [i.e. failure modes, root causes, effects, safeguards (through appropriate designs, procedures, etc.)].

5.3.5 Failure Mode, Effects and Criticality Analysis (FMECA)

FMECA assists in mitigating any identified risks where modifications to the design are feasible options. The FMECA analysis should be performed by the equipment purchaser/end-user and manufacturer. FMECA is performed to identify all possible failure modes, resulting hazards affecting the component/sub-system/system, and the component's criticality to a complete sub-system or system. FMECA is an extension of an FMEA process where a criticality assessment, "C", is identified or assigned to the component.

5.3.6 Fault-Tree Analysis (FTA)

FTA is a deductive analysis that graphically models how logical relationships among equipment failures, human errors and external events can combine to cause specific problem of interest. This type of analysis can provide; 1) qualitative descriptions of potential problems or combinations of events causing specific problems of interest and 2) quantitative estimates of failure frequencies/likelihoods and the relative importance of various failure sequences or contributing events. This methodology can also be applied to many types of applications, but is most effectively used to analyze system failures caused by relatively complex combinations of events.

5.4 Design Assessment Procedures

5.4.1 General

For reasons discussed in Section 4, it is recognized that the equipment designer should not simply subtract external pressure from the internal absolute pressure when making equipment "RWP" selection. The results of the hazard identification analysis can further assist the equipment designer in identifying the appropriate loading conditions, load cases or combination(s) thereof required for design assessment.

In consideration of external pressure for subsea equipment design, it is recommended that a comprehensive finite element analysis (FEA) is performed, with the additional consideration of 5.5, for all load cases specified for each respective equipment category identified below in consideration of external and/or differential pressure (associated with closure mechanism) of subsea equipment.

For API 17TR12, the following rated working pressure terminologies are determined or calculated by the design assessment procedures specified in the sections below.

1) Depth adjusted working pressure (DAWP): the maximum internal pressure the equipment can contain with consideration of the equivalent external pressure, $Po(x)$ at a specified water depth (SWD), measured in "psia".

2) Differential working pressure (DWP): the difference between the upstream and downstream pressures across the pressure-controlling element (closure mechanism) that can define the rated working pressure for the pressure-controlling equipment, measured in "psid".

Examples of external pressure application on subsea equipment are provided in Annex A and Annex B.

5.4.2 Pressure-Containing Equipment

5.4.2.1 General

For consideration of external pressure on pressure-containing equipment with a selected API RWP, the equipment designer should perform FEA to determine stresses and deflections for the load cases with the analysis procedures at the specified water depth, as provided below, and the analyses results are to be in compliance with the applicable API product specification.

For equipment that may be subjected to pressure-end loads, thermal loads, mechanical or structural loads (i.e. external bending, tension, compression, etc.), these loads should be combined and analyzed, as applicable, with the pressure load cases listed below. For subsea equipment that may undergo cyclic operations (i.e. pressure [internal and external], temperature, external loads, etc.) fatigue assessment should be considered—commensurate with its functional specifications.

The equipment designers/manufacturers should clearly document the defined/specified water depth and allowable load cases for operation of the equipment, consistent with the results of the design analyses.

Examples of external pressure application on subsea equipment are provided in Annex A and Annex B.

5.4.2.2 Load Cases

1) Case 1: Rated Working Pressure (RWP), "psia"

The objective is to establish a base load case, where the design assessment is with an applied internal pressure, RWP, with no atmospheric external pressure considered. This is the existing procedures in API product specifications (e.g. API 6A, API 17D, API 17G).

a) See API RWP and hydrostatic test pressure definitions and requirements in applicable API product specifications.

b) Apply internal pressure as the equipment's API RWP, with no external pressure and confirm resultant stresses/ deflections are within the allowables defined in the appropriate API product specification for the equipment.

c) Apply the required hydrostatic test pressure in accordance with the governing API product specifications, with no external pressure, and confirm stresses/deflections are within the allowables defined in the appropriate API product specification for the equipment.

NOTE In accordance with API definition or convention, RWP is the absolute internal pressure (measured in "psia") of the fluid contained by the equipment.

2) Case 2: Depth Adjusted Working Pressure (DAWP), "psia" @ Specified Water Depth (SWD), "ft"

The objective is to determine or calculate the equipment DAWP @ SWD, where the design assessment is performed with an applied internal pressure and an external pressure equal to the ambient seawater pressure at the specified water depth (SWD), or $Po(x)$. This case simulates the effects of external pressure on the equipment using the applicable seawater gradient, typically 0.45 psi/ft of water depth (other regional seawater density should be used, as applicable).

a) Manufacturer or equipment purchaser/end-user to define the SWD for the equipment (measured in "ft").

b) Calculate an equivalent external pressure, $Po(x)$, measured in "psia", for the SWD (using typical seawater gradient of 0.45 psi/ft of water depth or other appropriate regional seawater density) and apply as an external pressure to FEA model accordingly.

c) Initiate analysis by applying an internal pressure equal to depth adjusted working pressure (DAWP), where DAWP is a function of the specified water depth, DAWP = API RWP + $f(Po(x))$, in sequence and/or manner as agreed upon by the equipment manufacturer and equipment purchaser/end-user. Verify that stresses/deflections are within the design allowables defined in the applicable API production specification for the equipment. Localized stress concentration regions should be evaluated for static stress and considered for fatigue.

d) Adjust the applied internal pressure, as necessary, for compliance with the applicable design stress allowables from the governing API product specification.

e) The resultant internal pressure is considered to be the equipment DAWP @ SWD, and is an absolute pressure, measured in "psia".

The use of DAWP method may result in higher internal pressures than the equipment was initially rated or designed for. When applicable, the increase of the pressure-end load and its effect in the system should be carefully evaluated.

3) Case 3: External Pressure, "psia"

The objective is to verify protection against buckling, hydrostatic collapse, reverse pressure on seal, etc., as applicable. The design assessment is performed with an applied external pressure, $Po(x)$, for the specified water depth (SWD) and with no internal pressure.

a) Apply the external pressure, $Po(x)$, with no internal pressure.

b) Confirm that the stresses/deflections are within the allowables defined in the appropriate API product specification for the equipment, including verification for protection against buckling, hydrostatic collapse, etc.

For cases where internal pressure is not lower than the external pressure from ambient seawater (i.e. certain BOP annular preventer pressure-controlling component, etc.), then Case 3 analysis may be omitted, but this should be justified, through appropriate hazard identification, and documented in the product design and validation records.

5.4.3 Pressure-Controlling Equipment

5.4.3.1 General

Design assessment of pressure-controlling equipment requires the analyses of both the pressure-containing element and the pressure-controlling element (or closure mechanism). The pressure-containing element would further consist of upstream and downstream sides or cavities, separated by the closure mechanism.

For equipment that may be subjected to pressure-end loads, thermal loads, mechanical or structural loads (i.e. external bending, tension, compression, etc.), these loads should be combined and analyzed, as applicable, with the pressure load cases listed below. For subsea equipment that may undergo cyclic operations (i.e. pressure (internal and external), temperature, external loads, etc.) should be subjected to fatigue assessment should be considered—commensurate with its functional specification requirements.

Examples of external pressure application on subsea equipment are provided in Annex A and Annex B.

5.4.3.2 Load Cases for Pressure-Containing Element

1) Case 1: Rated Working Pressure (RWP), "psia"

See Case 1 of 5.4.2.2-1), including acceptance criteria.

2) Case 2: Depth Adjusted Working Pressure (DAWP), "psia" @ Specified Water Depth (SWD), "ft"

See Case 2 of 5.4.2.2-2), including acceptance criteria.

3) Case 3: External Pressure, "psia"

See Case 3 of 5.4.2.2-3), including acceptance criteria.

5.4.3.3 Load Case for Pressure-Controlling Element

The pressure-controlling element can be exposed to a differential pressure between the upstream and downstream sides of the closure mechanism, and the worst-case loading should be derived from the system-level analysis and/or operational procedures (i.e. no pressure downstream of the pressure-controlling element, etc.). A detailed HAZID/HAZOP between the equipment purchaser/end-user and equipment manufacturer should be performed to fully cover the functional requirements and understand the effects of external or differential pressure on the pressure-controlling element. Consequently, the design assessment of the pressure-controlling element with consideration of external and differential pressure on the pressure controlling-element (or in this scenario, backpressure on the downstream side) should be performed as follows.

1) Case 2a: Differential Working Pressure (DWP), "psid" @ Specified Water Depth (SWD), "ft"

The objective is to determine or calculate the DWP across the pressure-controlling element (closure mechanism) with consideration of external pressure on the pressure-containing element upstream and downstream sides.

a) Apply the equivalent external pressure, $Po(x)$ for the SWD, on the pressure-containing element.

b) Apply an upstream pressure on the closure mechanism, including the pressure-containing element cavity. This upstream pressure can be the calculated DAWP @ SWD (see Case 2) or as derived from the system-level analysis, equipment's functional specifications, and/or operational procedures at SWD.

c) Apply a minimum downstream pressure (worst-case loading) on the closure mechanism, including the pressure-containing element cavity. This minimum downstream pressure should be derived from the system-level analysis, equipment's functional specifications, and/or operational procedures at SWD.

d) The difference between the upstream and downstream pressures is defined as the differential working pressure or DWP @ SWD, measured in "psid".

e) The resultant stresses (i.e. bending, shear, torsional, etc.) and deflections on the pressure-controlling element, including surrounding support structure and seats due to the DWP @ SWD shall not exceed the numeric value of the API RWP marked on the equipment, or DWP $\leq$ API RWP

f) The resultant stresses and/or deflections on the pressure-containing element - upstream and downstream sides, shall comply with its respective acceptance criteria. See 5.4.3.2-2).

NOTE Application of DAWP may result in operating loads on pressure-controlling equipment, such as valve drivetrain/actuator components, higher than the original design basis. Pressure-controlling equipment should be evaluated to verify the design to the relevant API product specification requirements under DAWP functional load conditions.

5.4.4 Subsea Equipment with Trapped Voids

The effects of external pressure should not be applied to subsea equipment (pressure-containing/pressure-controlling) where trapped voids are present. For such elements of the design, the equipment should be designed, analyzed and validated (as applicable) with the "maximum absolute pressure rating" applied as differential pressure acting against any components with trapped void spaces (i.e. dual stem packings having a void space between packings, pressure-temperature sensor diaphragms, electrical penetrators, barrier fluids, annulus in gas lift operations, etc.).

5.4.5 Metallic Seals

The metal sealing performance is typically evaluated by analysis of the contact loads (contact stresses and/or line loads) and comparison of the results to acceptable contact loads thresholds determined based on metal seal validation by physical laboratory testing and/or field proven performance. In the design analysis, the seal element and mating component deflections are also evaluated as they may impact the magnitude of the contact loads.

If the HAZID/HAZOP determines that external/differential pressure may be used in the seal design, FEA should be performed to evaluate the metal seal design under these conditions. The contact loads (contact stresses and/or line loads) should be determined under these conditions and compared to the acceptable contact load threshold that is used for seal design for rated working pressure (with no external/differential pressure). Some of the metal seal designs can be sensitive to the changes in pressures, deflections, and geometric tolerances and assumptions made on pressure-containing components should not be applied without proper analysis evaluation.

If DWP rating is used for metal seals, FEA should be used to evaluate all applicable upstream and downstream pressures and their combinations, as applicable. Aspects of the seal performance and functionality including the primary and secondary metal seals, and redundant non-metallic seals, should be considered, as applicable. The presence of a secondary seal will typically isolate the primary seal from the benefits of external ambient pressure, and this should be accounted for in the seal design/analysis and verification program.

5.5 Additional Consideration for Design Assessment

5.5.1 General

For the analysis of subsea equipment in accordance with the external pressure design assessment flow chart, this technical report provides the following additional provisions to be applied for the design analysis.

5.5.2 Finite Element Analysis Methodology

The selection of the FEA methodology; e.g. linear-elastic, limit-load, or elastic-plastic, is at the discretion of the equipment designer and should be utilized consistent with the requirements of the applicable API specifications or standards.

The analytical method traditionally used in current API product specifications (e.g. API 6A, API 17D) is based upon the design practices of ASME *BPVC* Div. 2, 2004 Edition Appendix 4, applying linear-elastic analysis with design margin defined based on the material's yield strength. These existing industry practices have resulted in successful, field proven equipment. However, higher design pressures and design temperatures, and external loads would result in higher stresses and strains on the pressure-containing or pressure-controlling equipment and would require the use of thick-wall components. This may require consideration of additional assessment and/or the use of advanced FEA methodology of elastic-plastic analysis, as provided in ASME *BPVC* Div. 2 (2007 Edition or later) or ASME *BPVC* Div. 3, utilizing the material's true-stress true-strain properties including other applicable properties for accurate analysis.

When using FEA, it is efficient to perform the additional load cases with consideration of external pressure. Comparison of the FEA results, with and without external pressure identify if the equipment is sensitive to the presence of external pressure.

The analysis procedures referenced in Case 1 through Case 3 may vary from one design entity to another, however, the design verification objectives as stated in Case 1 through Case 3 shall be satisfied for consideration of external pressure in designs of subsea equipment.

5.5.3 Selection of FEA Methodology

In accordance with the ASME *BPVC* guidelines, it is recommended that the equipment designer utilizes the elastic-plastic FEA methodology for thick-wall equipment, where “$R/t \leq 4$” or “$Do/Di \geq 1.25$”, as specified in ASME *BPVC* Div. 2 (2007 Edition or later) or ASME *BPVC* Div. 3.

The traditional application of linear-elastic analysis (API 6X or ASME *BPVC* Div. 2, 2004 Edition) may result in non-conservative designs from the stress classification procedures (see the ASME Hopper diagram) to demonstrate structural integrity for thick-wall pressure-containing components (“$R/t \leq 4$” or “$Do/Di \geq 1.25$”), especially around gross structural discontinuities, such as corners, edges or notches. This is also due to variation in the stress distribution within the wall thickness from variation or inconsistent through-wall material properties in thick-wall component. Therefore, linear-elastic analysis may be used for the design analysis, with the additional verification as specified in 5.5.5. These additional design verifications are also applicable to elastic-plastic FEA.

5.5.4 von Mises Equivalent (VME) Stress

The calculated stress components derived from the FEA should be combined using the triaxial von Mises equivalent (VME) stress theory. The triaxial VME stress failure theory is considered a more accurate predictor for the onset of yielding (stress states) in ductile materials. The methods of applying VME stress criteria are defined in API 6X or ASME *BPVC* Section VIII, Div. 2/Div. 3.

5.5.5 Additional Design Verification

In addition to the design verification for typical failure modes such as global plastic collapse and fatigue in accordance with the procedures specified in 5.4.2 and 5.4.3, and the respective API product specifications, it is recommended that the equipment designer also verify the following with respect to external pressure.

1) *Principal stresses*: The application of internal pressure with external pressure has effects on the principal stresses ($\sigma 1/\sigma 2/\sigma 3$) and this is a key element to be examined and considered while evaluating the equipment design including in the fatigue regime.

2) *Local strain limit*: Localized stress concentration areas (i.e. notches, fillets, weld, areas of gross structural discontinuities, etc.) are typical locations for high-stress risers (peak stress/strain) which may cause local plastic strain and potential initiation sites for fatigue and may be affected by external hydrostatic pressure.

   The linear-elastic analysis criteria to verify local strain limit (or protection against local failure due to excess strain) at peak stress locations or the triaxial-stress verification are defined in ASME *BPVC* Div. 2 Paragraph 5.3.2. This calculation is verification of the combined principal stresses which is expected to be at highest magnitude on the inside diameter of the equipment; $(\sigma 1+\sigma 2+\sigma 3) \leq 4S$, where is $S = 2/3S_Y$.

   Equivalent methods for verification of protection against local failure due to excess strain (local strain limit) are available for elastic-plastic analysis and they are provided in the applicable sections of ASME *BPVC* Section VIII, Div. 2 or ASME *BPVC* Section VIII, Div. 3.

3) *Ratcheting effects*: Ratcheting is the progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress or both.

   The linear-elastic ratcheting analysis using the FEA results as defined in ASME *BPVC* Section VIII Div. 2 Article 5.5.6 can be applied. This calculation allows the primary plus secondary plus peak stresses to be extracted from post-processing of linear-elastic analysis including thermal stresses to be evaluated for a worst-case load cycle. If the equipment designer is utilizing external pressure to offset higher internal pressures, these are straightforward verifications which can be performed at the same time the von Mises stress is evaluated.

Equivalent methods for verification of protection against ratcheting effects are available for elastic-plastic analysis and they are provided in the applicable sections of ASME *BPVC* Section VIII, Div. 2 or ASME *BPVC* Section VIII, Div. 3.

5.6 Documentation

5.6.1 General

When the equipment is shown to meet API 17D, API 17G, or API 17TR8 design requirements with consideration of external pressure, including fatigue assessment, as applicable, then it is proposed that the equipment be documented by the following.

5.6.2 Nameplate Markings

API RWP nameplate marking, in accordance with the applicable API product specification (e.g. API 17D), is typically indicated as:

— Rated Working Pressure (RWP)

NOTES:

a) RWP, measured in "psia";

b) Manufacturer hydrotest pressure during FAT are defined in the applicable API product specifications.

— Example of API RWP marking:

API RWP = 15,000 psia

5.6.3 Documentation of DAWP @ SWD

It is proposed that the new terminology, depth adjusted working pressure (DAWP) at specified water depth (SWD), should not be marked on the equipment for proper control and management of subsea equipment designed with consideration of external pressure.

The "DAWP @ SWD" should be provided by the equipment manufacturer to the equipment purchaser/end-user through appropriate documentation, i.e. tabular and/or graphical forms, certificate of compliance, etc. Annex A is provided as an analysis example for pressure-containing equipment, and it illustrates two (2) methods by which the equipment manufacturer can convey the DAWP @ SWD.

Example of equipment manufacturer's documentation of DAWP @ SWD, resulting from the design analysis procedures of 5.4.2:

API RWP = 15,000 psia

DAWP @ SWD = 17,993 psia @ 7000 ft

NOTE "17,993 psia @ 7000 ft" is from the analysis example for DAWP @ SWD in Annex A.

5.6.4 Documentation Management

The equipment end-user may elect to relocate equipment to a different installation with different water depth(s). In that case, additional verification and confirmation with the equipment manufacturer should be performed for the revised water depth (see 5.7). A critical element to this provision is the appropriate documentation management for equipment that are associated with external pressure design/rating.

The equipment end-user quality management system should provide detailed procedures in document management and control to ensure that the equipment's documentation is appropriately verified for its intended service.

NOTE Guidance on document controls through quality management systems is provided in API 75 and API Q1.

5.7 Verification of External Pressure at Different Water Depth

Equipment purchaser/end-user may elect to use the subsea equipment at a water depth less than the specified water depth (SWD) where there will be a reduction in the external pressure ($Po(x)$). In such cases, equipment end-user should revise the depth adjusted working pressure (DAWP) by the revised water depth in accordance with the information provided by the equipment manufacturer (see Annex A).

Using internal pressure equal to the DAWP in water depth less than the SWD results in higher differential pressure across the pressure-containing boundary (for simplicity: internal pressure minus external pressure), producing stresses and/or deflections exceeding the limits for which the equipment has been designed/calculated and qualified.

Equipment purchaser/end-user can only use the DAWP when the water depth is equal to or greater than the SWD. Equipment purchaser/end-user should ensure that for their particular application, the differential pressure acting on the equipment does not exceed the numeric value of the API RWP marked on the equipment and should be confirmed by the equipment manufacturer.

An example scenario is provided to demonstrate this verification, based on the example problem of Annex A:

Example: Pressure-containing equipment with the following markings and external pressure documentation is currently used on a well with WSIP = 17,600 psia.

1) Markings: API RWP = 15,000 psia

2) External Pressure Documentation: DAWP @ SWD = 17,993 psia @ 7000 ft, see Annex A

NOTE The DAWP of 17,993 psia (maximum pressure containment capability) is greater than the WSIP of 17,600 psia (or DAWP > WSIP).

Relocation: Could this equipment be relocated and used in 5000 ft of water depth with the similar WSIP of 17,600 psia?

Assessment: The equipment manufacturer has provided a table of DAWP at various water depth, see Annex A. Review of the table shows that the DAWP for the equipment at 5000 ft (SWD) is 17,138 psia.

Answer: No, the equipment cannot be used at the water depth of 5000 ft because the revised DAWP of 17,138 psia is less than the WSIP of 17,600 psia (or DAWP < WSIP).

6 Design Validation

6.1 General

In general, validation is performed in accordance with the governing API product specifications. Validation of subsea equipment with external pressure should consider the following provisions.

6.2 Validation Testing

Where feasible and practical, the pressure-containing component should be qualified by testing under the worst-case stress condition (Case 1/Case 2/Case 3, whichever load case produces the highest stress levels). Case 2 validation testing can be conducted within a hyperbaric chamber, to simulate the effects of the maximum external pressure, where the size of the equipment is compatible with dimensions of the available chamber or the effects of external pressure on specific equipment or components may be simulated with appropriately configured test fixtures.

For large equipment that cannot fit within available hyperbaric chambers, comprehensive FEA validation can be used to validate the stresses and deflections of the structural housings, and fixture tests (simulating the loading effects of both internal and external pressure) can be used to validate components and subcomponents (i.e. stems, seals, penetrators, sensors, gauges, etc.).

For components that are subjected to high cycle fatigue/wear testing as part of their validation, those components should be exposed to the worst-case hydrostatic test pressure and FAT pressure condition before starting the cycle testing program. Any tests conducted in fixtures should accurately simulate the field operating pressure and deflection conditions (at maximum design water depth) during the cycle test program, if feasible.

Large equipment that cannot be tested in a hyperbaric chamber, or tested using fixtures to simulate the effects of external pressure, may be qualified by FEA methods, providing that the FEA methods and results are appropriately validated (see 6.3).

The acceptance criteria for consideration of external or differential pressure test should be in accordance with the requirements of the applicable API product specifications.

6.3 Validation of Finite Element Analysis

Validation of FEA results should be performed with respect to loads, boundary conditions, material properties, etc. It should also include FEA model meshing sensitivity verification.

For the validation process, prescribe as completely and accurately as possible the equipment geometry, as well as the initial and boundary conditions of the FEA, and all of the other model input parameters. All of the applied loads, multiple response features, and changes in the boundary conditions should be measured; and uncertainties in the measurements should be reported. Load sequencing should be consistently followed with the FEA process.

The accuracy assessment of FEA can be based on an established validation metric, comparing the validation testing to the FEA results. The recommended accuracy values between the FEA results and validation testing should be within 5 % to 10 %, typically dependent on the measured responses and locations of measurements, etc.

Mesh sensitivity analysis should be performed to validate the FEA analysis and ensure that the mesh density variations do not affect the stress distribution (within 5 % variance) through the component thickness.

Additional guidance for validation of FEA is provided in ASME *V&V* 10-2006, *Guide for Verification and Validation in Computational Solid Mechanics*.

6.4 Validation Testing of Seals

6.4.1 Metallic Seals

For the qualification of metal seals, current API standards requires extensive pressure and temperature cycle testing, (for example, see API 6A, Annex F).

Validation testing is not required for DWP rating of a single seal, but may be done when practical for selected cases that encompass the pressure ranges considered and can be based on prior agreement between the equipment manufacturer and the equipment purchaser/end-user. The presence of a secondary seal typically isolates the primary metallic seal from the benefits of external ambient pressure, and this should be accounted for in the seal design/ analysis and verification program.

6.4.2 Non-Metallic Seals

Non-metallic seals may be subjected to compression effects and/or stress relaxation at higher external pressures. Validation should be conducted to verify long term exposure to high pressures do not degrade the sealing capacity due to compression set or stress relaxation. These tests can be conducted in full scale test fixtures or by obtaining the defining properties from material testing as input into FEA for sealability analysis. Higher hydrostatic pressures can result in higher loads and increased operating forces for components such as actuators. This change in loading should be validated through component or fixture testing.

7 Factory Acceptance Testing

FAT testing should continue to follow the established API 6A, API 17D, and API 17G practices for hydrostatic testing, with API RWP. It is not required to simulate external pressure equivalent to the ambient seawater pressure at SWD rating during FAT testing if all other aspects of the equipment design, evaluation and validation testing have followed the guidelines in this technical report.

8 Conclusion

For pressure-containing equipment, there is a valid case for equipment designers to optimize the designs with consideration of the effects of external pressure due to ambient hydrostatic seawater where the equipment is always exposed to external pressure. While the presence of external pressure may reduce stresses due to the effects of internal pressure, it may not be on a “one-for-one” basis.

For pressure-controlling equipment, the designer should analyze the pressure-containing and pressure-controlling elements, both with appropriate application of the upstream and downstream pressures on the closure mechanism, including the pressure-containing cavities, and with consideration of external pressure. There may be challenges to the consideration of external pressure or differential pressure on pressure-controlling equipment, as the downstream pressure on the closure mechanism may not always be present or negligible to maintain the equipment structural integrity (i.e. downstream pressure is vented on purpose to prevent hydrate formation during a shut-in period, downstream pressure could be lost unintentionally due to a leak or other unplanned event, etc.).

In cases where pressure-controlling equipment is designed utilizing external pressure to reduce the pressure differential across the closure mechanism, the methods of determining the downstream pressure, along with the operating procedures and safeguards required to ensure the downstream pressure is always present, shall be clearly documented by both the equipment designer and the equipment purchaser/end-user.

External pressure evaluation requires thorough attention to all loads acting on the equipment during all phases of the equipment’s life (i.e. FAT, SIT, normal operations, abnormal conditions, emergency, survival, etc.). Rigorous hazard identifications and/or risk assessment studies (i.e. HAZID, HAZOP, FMEA, FMECA, FTA, etc.) are required for equipment design with consideration for external pressure, especially when pressure-controlling equipment is designed using backpressure or external pressure to reduce the effective differential pressure across the pressure-controlling element or closure mechanism.

It is critical that the equipment designer has a thorough understanding of the functionality of the equipment, subsystems and/or systems in order to appropriately apply external pressure to the designs. The proposed design and validation guidelines described in this technical report should ensure that the equipment designers address the issues identified in API 17TR4 and that their design results meet the requirements as specified in API 17D, API 17G, or API 17TR8, as applicable.

The evaluation of external pressure effects should be for a specified water depth and the equipment purchaser/end-user should assess the “fitness for purpose” or “fit for intended service” of any equipment that is moved to a different subsea location or reused in conditions that are different from those considered in the original external pressure evaluation (see 5.7).

The technical issues addressed in this technical report apply only to the “pressure” aspects of subsea equipment designs. Equipment designers should also address all other applicable loads which will, or could, act on the equipment during installation and operation (i.e. external tension or compression loads, bending loads, thermal effects, and/or combinations thereof, etc.).

Examples provided in this technical report illustrate that different portions within an assembly/system can have different pressure ratings when external hydrostatic pressure is considered. The equipment designer should take into consideration the potential variations in the pressure ratings when determining the DAWP for an assembly/system or subsystem.

An opportunity exists to optimize the size/weight of subsea equipment for deep and ultra-deepwater applications by including the effects of external pressure in the design and validation process. In addition, by optimizing the equipment wall thickness with consideration of external pressure, this should produce higher quality products, by avoiding material fabrication and heat treating problems typically associated with thick-wall sections.

Annex A
(informative)

Analysis Example for Pressure-Containing Equipment

A.1 General

As an example, an equipment manufacturer evaluated their 10 ksi and 15 ksi API RWP pressure-containing equipment for consideration of external pressure in order to determine the equipment's DAWPs at various SWDs (2000 ft to 10,000 ft, in 1000 ft increments). The assessments were performed in accordance with the design analysis procedures specified in 5.4.2. The manufacturer has determined for this specific equipment that the external pressure is 95 % efficient (on average) in offsetting the internal pressure:

$$\text{DAWP} = \text{API RWP} + 0.95(Po(x)) \tag{A.1}$$

The following examples reflect two (2) methods by which the equipment manufacturer can convey the DAWP @ SWD for pressure-containing equipment at various water depths.

A.2 Example of Manufacturer's Tabular Form for DAWP @ SWD for Pressure-Containing Equipment

From the results of the design analysis of 5.4.2, the equipment manufacturer presented their results in a tabular form as shown in Table A.1.

A.3 Example of Manufacturer's Certified Capacity Chart of DAWP @ SWDs for Pressure-Containing Equipment

Further to A.2, the equipment manufacturer can also present the calculated DAWP @ SWD by way of a manufacturer's certified capacity chart for 10 ksi API RWP pressure-containing equipment (see Figure A.1).

Table A.1—DAWP at Specified Water Depth

API RWP (psia)	**SWD** (ft)	**External Pressure (@ 0.45 psi/ft)** (psia)	**Depth Adjusted Working Pressure (DAWP)** (psia)
10000	2000	900	10855
	3000	1350	11283
	4000	1800	11710
	5000	2250	12138
	6000	2700	12565
	7000	3150	12993
	8000	3600	13420
	9000	4050	13848
	10000	4500	14275

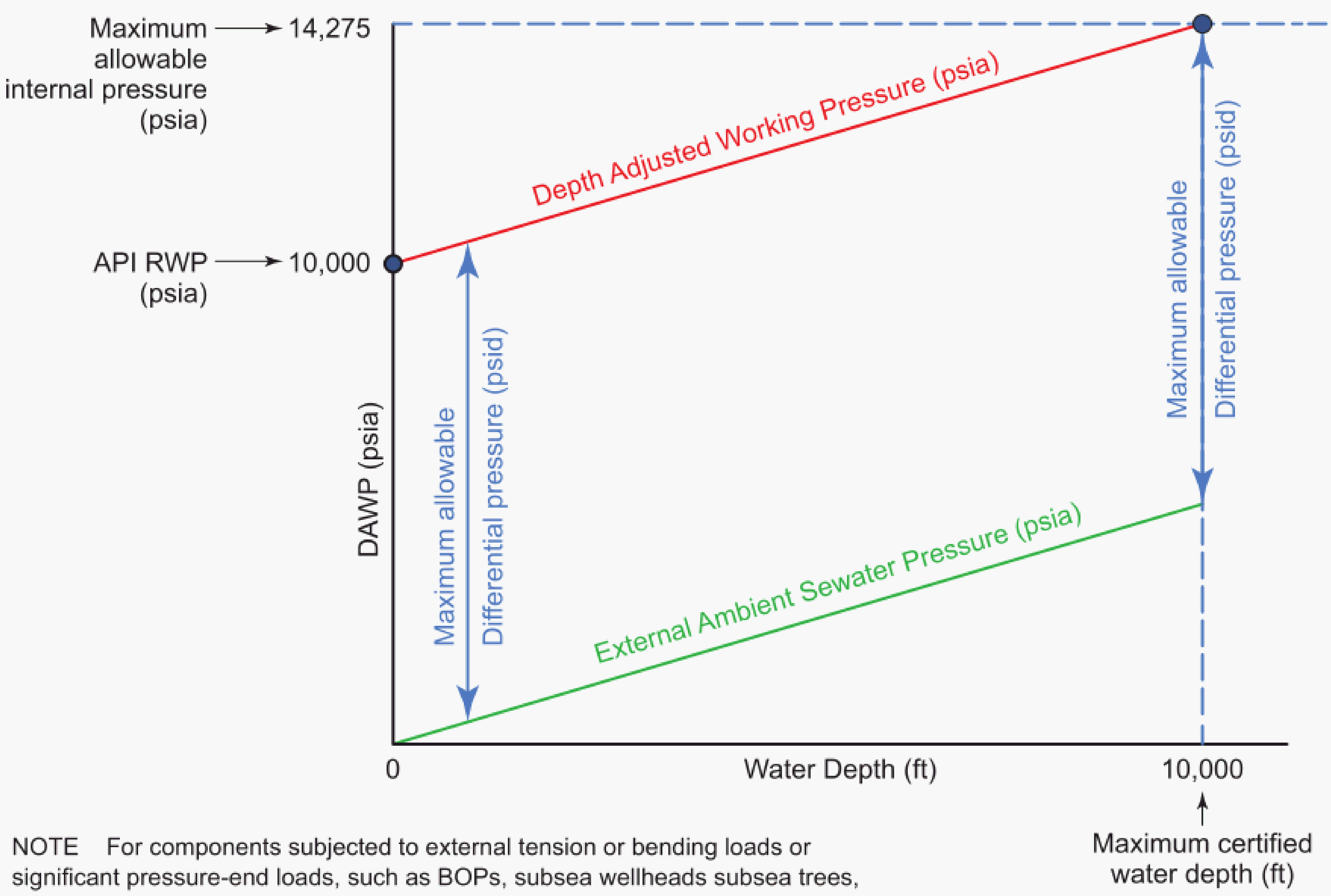
Table A.1—DAWP at Specified Water Depth (Continued)

API RWP (psia)	**SWD** (ft)	**External Pressure (@ 0.45 psi/ft)** (psia)	**Depth Adjusted Working Pressure (DAWP)** (psia)
15000	2000	900	15855
	3000	1350	16283
	4000	1800	16710
	5000	2250	17138
	6000	2700	17565
	7000	3150	17993
	8000	3600	18420
	9000	4050	18848
	10000	4500	19275

NOTE 1 Consultation with equipment manufacturer is necessary for water depths in between referenced SWDs.

NOTE 2 Equipment manufacturer and equipment purchaser/end-user to confirm equipment is appropriately assessed for consideration of external pressure (e.g. "pressure-containing", "pressure-controlling", and "pressure-containing with trapped voids").

NOTE 3 Equipment designer should apply the appropriate seawater salinity, as this may vary in different regions.



NOTE For components subjected to external tension or bending loads or significant pressure-end loads, such as BOPs, subsea wellheads subsea trees, and riser equipment, a family of curves similar to above may be required to illustrate DAWP variations caused by these loads.

Figure A.1—Depth Adjusted Working Pressure (DAWP) for "XX-YYY Product Name"

Annex B
(informative)

Analysis Example for Pressure-Controlling Equipment

B.1 General

As an example, an equipment manufacturer evaluated their 15 ksi API RWP pressure-controlling equipment for consideration of external pressure for service with the following parameters derived from the equipment functional specifications:

1) API 6A, *15 ksi RWP Gate Valve (Pressure-Controlling Equipment)*

2) Well Shut-In Pressure (WSIP) = 16,450 psia

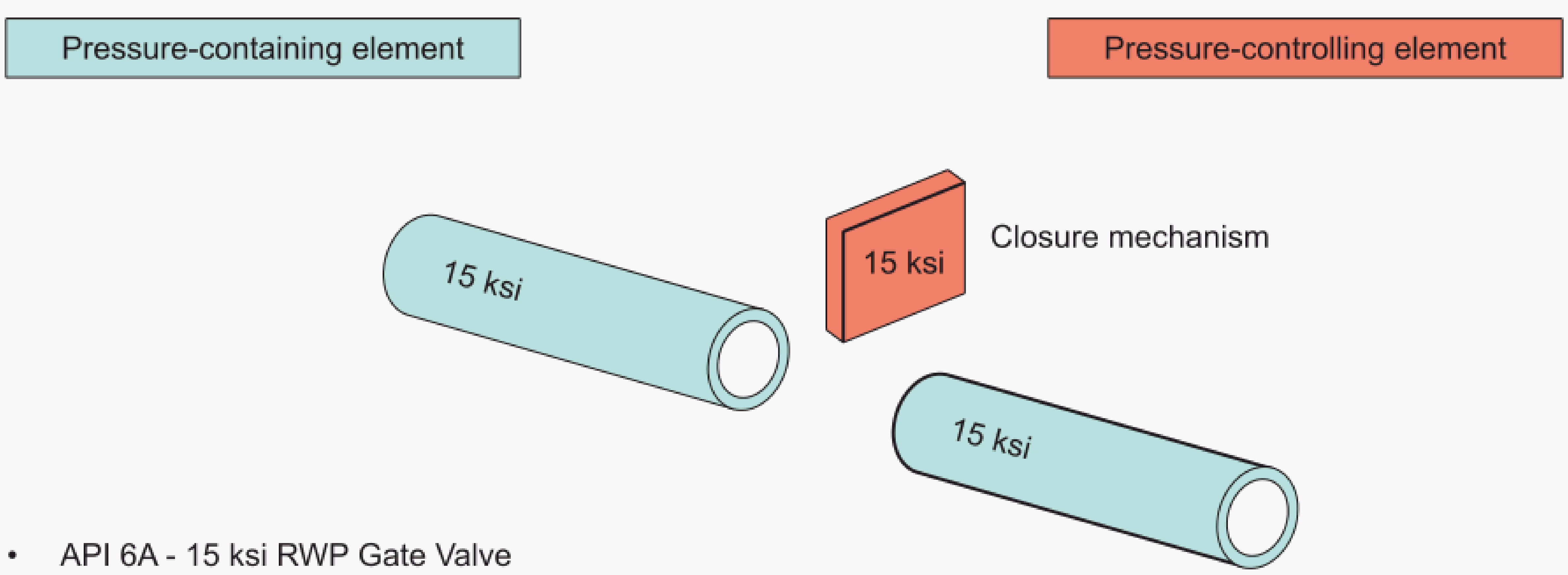
3) Specified Water Depth (SWD) = 7500 ft

4) Seawater Density=0.45 psi/ft

The assessments were performed in accordance with the design analysis procedures specified in 5.4.3, where the pressure-containing element and pressure-controlling element (closure mechanism) were analyzed appropriately. The manufacturer has determined for this specific equipment that the external pressure is 92 % efficient (on average) in offsetting the internal pressure

The following are pictorial depictions of the design analysis procedures of 5.4.3.

B.2 Design Assessment of Gate Valve with Consideration of External Pressure



- API 6A - 15 ksi RWP Gate Valve
  - Pressure-containing element = Valve body
  - Pressure-controlling element = Closure mechanism
- Gate valve to be installed on a subsea well with:
  - Well shut-in pressure = 16,450 psi (WSIP)
  - Specified water depth (SWD) = 7500 ft @ 0.45 psi/ft
- External loads to be applied after verification of structural integrity of pressure loads (internal and external)

Figure B.1—15 ksi API RWP—Gate Valve Pressure-Controlling Equipment

B.3 Case 1: API RWP (Pressure-Containing Element)

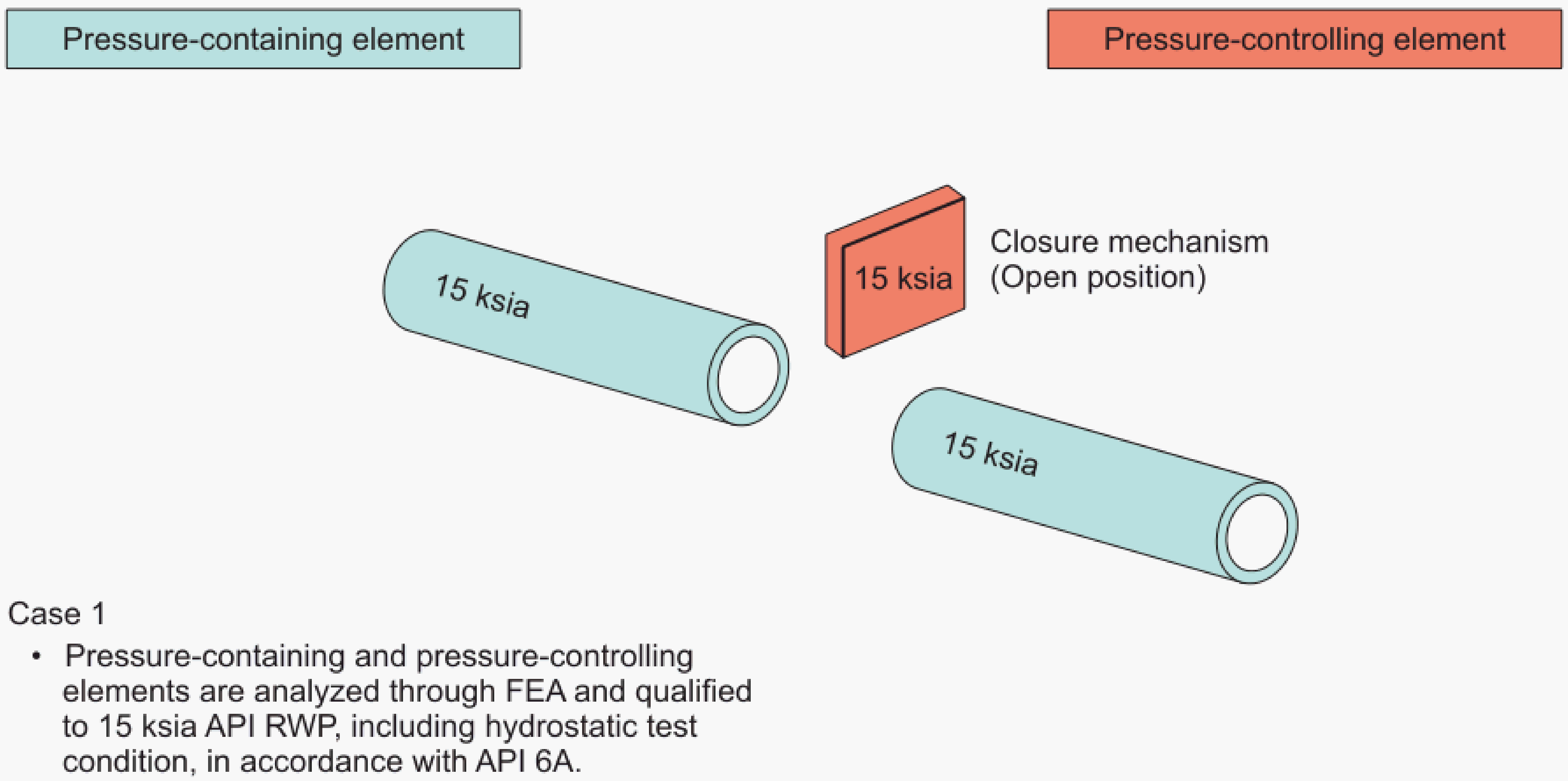


Figure B.2—15 ksi API RWP—Gate Valve, Case 1: API RWP

B.4 Case 2: DAWP @ SWD (Pressure-Containing Element)

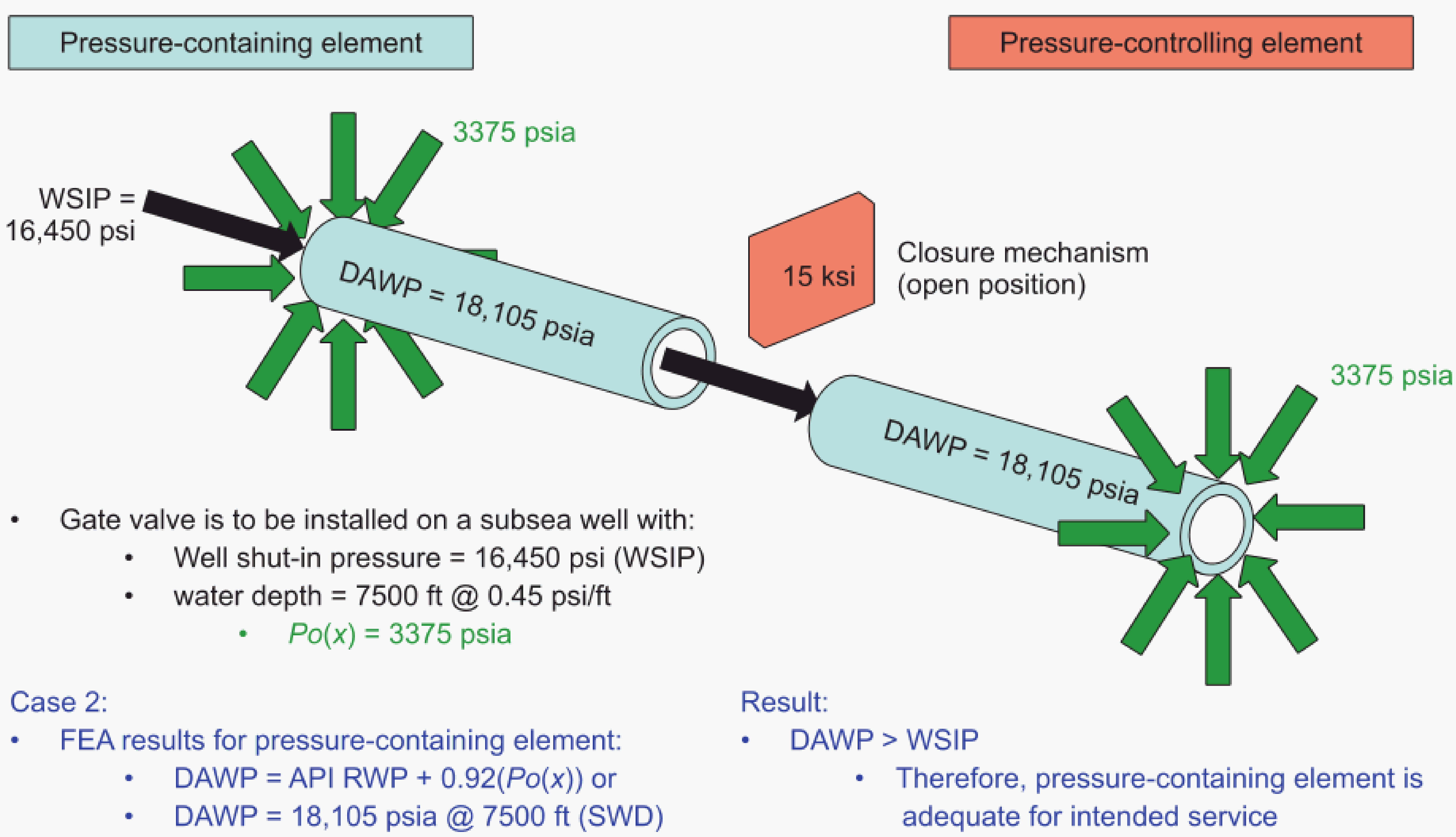


Figure B.3—15 ksi API RWP—Gate Valve, Case 2: DAWP @ SWD

B.5 Case 3: External Pressure (Pressure-Containing Element)

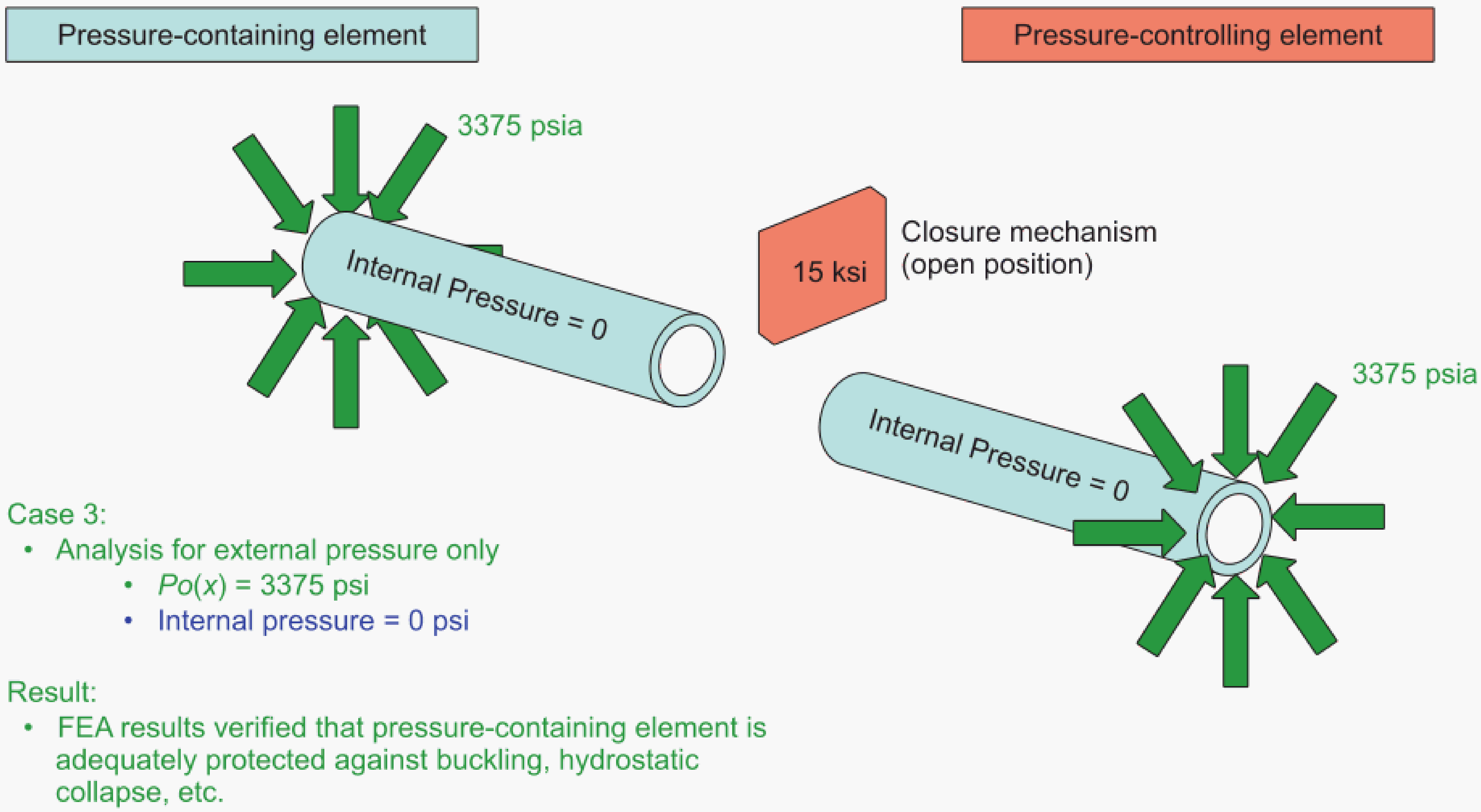


Figure B.4—15 ksi API RWP—Gate Valve, Case 3: External Pressure

B.6 Case 2a: DWP @ SWD (Pressure-Controlling Element)

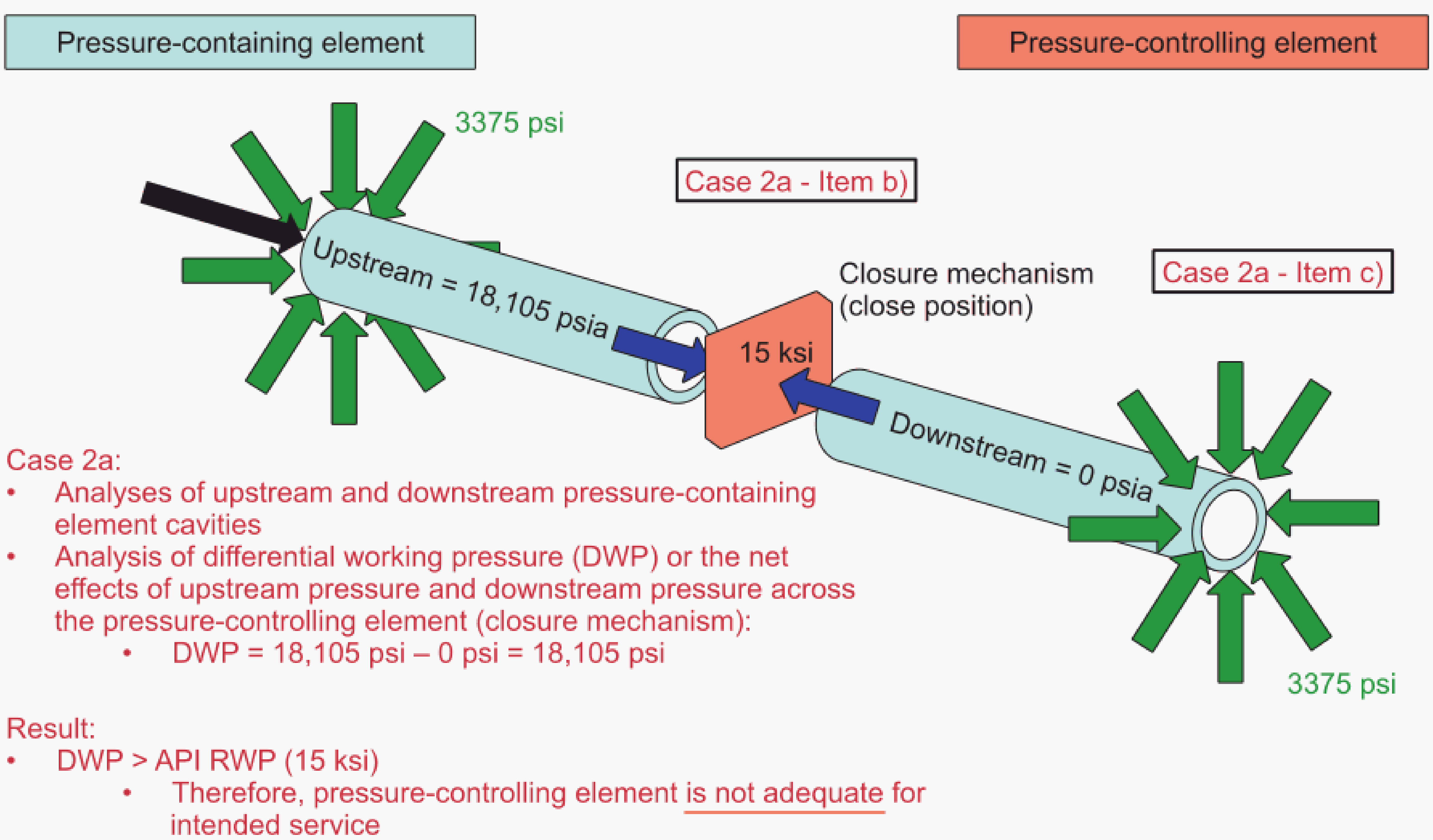


Figure B.5—15 ksi API RWP—Gate Valve, Case 2a: DWP @ SWD

B.7 Verification Summary

	Case 1	Case 2	Case 2a	Case 3
Pressure-Containing Element	√	√	NA	√
Pressure-Controlling Element	NA	NA	X	NA

Requirements:

- The FEA results (stresses and/or deflections) from each load case shall comply with its respective acceptance criteria

Conclusions:

- API 6A, 15 ksi RWP Gate Valve is not adequate for the intended service as specified in the equipment functional specifications due to the design analysis results of Case 2a
- Greater than 15 ksi API RWP equipment required or means to provide sufficient downstream pressure on the closure mechanism of Case 2a

Figure B.6—15 ksi API RWP—Gate Valve, Pressure-controlling Equipment, Load Case Verification Summary

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