

Recommended Practice for the Design of Offshore Facilities Against Fire and Blast Loading

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FOREWORD

This recommended practice is under jurisdiction of the API Subcommittee on Offshore Structures. This Recommended Practice for the Design of Offshore Structures against Fire and Blast Loading is based on sound engineering principles and many years of experience gained by the owners, operators, designers, fabricators, suppliers, and classification/certification agencies of offshore facilities. In no case is any specific recommendation included that could not be accomplished by presently available techniques and equipment. Consideration is given in all cases to the safety of personnel, compliance with existing regulations, and prevention of pollution.

This recommended practice has been developed with the help and extensive contributions from industry experts of different areas of expertise. This recommended practice covers both fixed and floating structures that are in use by the industry as offshore oil and gas production systems. These include systems supported by column-stabilized units (semi-submersible vessels), ship-shaped vessels, Tension Leg Platforms (TLP), deep draft caisson vessels (also known as SPARs), and other hull shapes.

This recommended practice provides an assessment process for the consideration of fire and blast in the design of offshore structures and includes guidance and examples for setting performance criteria. This document complements the contents of the Section 18 of API RP 2A, 21st Edition with more comprehensive guidance in design of both fixed and floating offshore structures against fire and blast loading. Guidance on the implementation of safety and environmental management practices and hazard identification, event definition and risk assessment can be found in API RP 75 [51] and the API RP 14 series [52, 53]. The interface with these documents is identified and emphasized throughout, as structural engineers need to work closely with facilities engineers experienced in performing hazard analysis as described in API RP 14J [52], and with the operator's safety management system as described in API RP 75 [51].

This recommended practice provides general guidelines for incorporating hazard analysis output into the structural response assessment in determining whether the structure or its components meet the specified performance criteria.

This recommended practice includes code provisions and associated commentary. The commentary provides design guidelines for the evaluation of structural response to fire and blast loads. Nominal blast load cases are provided for certain classes of facilities. Guidance is also provided for the calculation of fire loads. Discussion of alternative methods for the calculation of blast loads, in lieu of applicable nominal load cases, is included with reference to sources of detailed guidance. The commentary also includes examples of good practice for fire and blast design including guidelines for facilities layout and structural connection detailing.

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Recommended Practice for the Design of Offshore Facilities Against Fire and Blast Loading

0 Definitions

- **Blast Relief Panel:** Parts of a module wall, ceiling or roof, which are designed to increase the area of venting in an explosion by being opened or removed by the force of the explosion.
- **Blast Wall:** A structural barrier, which is designed expressly for the purpose of resisting blast loads.
- **Blow-down:** The rapid controlled or accidental depressurization of a vessel or piping network.
- **Cellulosic Fire:** A fire with a fuel source predominantly of cellulose (e.g. timber, paper, cotton). A fire involving these materials is relatively slow growing, although its intensity may ultimately reach or exceed that of a hydrocarbon fire.
- **Conduction:** The mode of heat transfer associated with solids. Each solid has a temperature dependent factor, which is a measure of the rate of conduction.
- **Convection:** Heat transfer associated with fluid movement around a heated body; warmer, less dense fluid rises and is replaced by cooler, denser fluid.
- **Ductility Ratio:** The ratio of the total deflection to the deflection at elastic limit. The deflection at elastic limit is the deflection at which strength behavior can be assumed to change from elastic to plastic.
- **Emergency Shutdown System:** A safety shutdown system comprising detection, signaling and logical control, valves and actuators, which can, in tandem with alarm and direct control mechanisms, enable the safe and effective shutdown of plant and machinery in a controlled manner.
- **Emmissivity:** A constant used to quantify the radiation emission characteristics of a flame. Emmissivity of a perfect black body is 1.
- **Fixed Platform:** A platform extending above and supported by the sea bed by means of piling, spread footings or other means with the intended purpose of remaining stationary over an extended period.
- **Heat Flux (heat density):** The rate of heat transfer per unit area normal to the direction of heat flow. A convenient unit is kW m^{-2} ($1 \text{ kW m}^{-2} = 317 \text{ Btu ft}^{-2} \text{ h}^{-1}$). It is a total of heat transmitted by radiation, conduction and convection.
- **Hydrocarbon Fire:** A fire fuelled by hydrocarbon compounds, having a high flame temperature achieved almost instantaneously after ignition. A hydrocarbon fire will spread rapidly, burn fiercely and produce a high heat flux.
- **Mass Burning Rate:** The mass-burning rate of a pool fire is the mass of fuel supplied to the flame per unit time, per unit area of the pool. Units are typically $\text{kg/m}^2/\text{sec}$.
- **Mitigation:** Mitigation actions are defined as modifications or operational procedures that reduce loads, increase capacities, or reduce exposure.
- **Nominal Value:** The value assigned to a basic variable determined on a non-statistical basis, typically from acquired experience or physical conditions [ISO 32].
- **Operator:** The person, firm, corporation or other organization employed by the owners to conduct operations.
- **PFP:** Passive Fire Protection
- **Prevention:** The action that is taken to reduce the probability of an event in order to reduce the overall risk that the event poses to the platform.

- **Safety Critical Element:** Any component part of structure, equipment, plant or system whose failure could cause a major accident.
- **Specific Heat:** The amount of heat, measured in Joules, required to raise the temperature of one kilogram of a substance by one degree C. Units are Joules/kg/°C.
- **Surface Emissive Power (SEP):** The heat radiated outwards from a flame per unit surface area of the flame. Units are kW/m².
- **Survival:** For purposes of fire and blast consideration, survival means demonstration that at least one escape route and the temporary refuge or safe mustering area are maintained for a sufficient period of time to allow platform evacuation and emergency response procedure, in accordance with the safety philosophy defined by the owner/operator of the platform.
- **Temporary Refuge (TR) or Safe Mustering Area:** An area of the platform that will enable the occupants to survive the defined fire or blast event. The area must also be safely accessible by personnel not in the immediate vicinity of the event and provide access to the primary escape route.
- **Unmanned Platform:** A platform upon which persons may be employed at any one time, but upon which no living accommodations or quarters are provided.
- **Utilization Ratio:** The ratio of actual stress to allowable stress.
- **AISC:** American Institute of Steel Construction
- **API:** American Petroleum Institute
- **ASCE:** American Society of Civil Engineers
- **ASTM:** American Society of Testing and Materials
- **AWS:** American Welding Society
- **ISO:** International Organization for Standardization
- **NFPA:** National Fire Protection Association
- **SFPE:** Society of Fire Protection Engineers
- **SCI:** Steel Construction Institute
- **SCE:** Safety Critical Element

1 General

This document provides guidelines and recommended practice for the satisfactory design of offshore structures against fire and blast loading. For guidelines and recommended practice and other requirements relating to planning, designing and constructing offshore structures relevant API recommended practices, such as API RP 2A, API RP 2FPS, etc., should be followed. The Section 18 of API RP 2A, 21st edition provided a brief overview of the issues associated with the design of fixed offshore structures against fire and blast loading. This document has no contradiction of the issues as identified in the Section 18 of API RP 2A, 21st edition, instead it expands on the details and includes various issues associated with floating structures previously not indicated.

The scope of this document is mainly directed to the new design of offshore structures against fire and blast, but is also widely recommended for use in verifying existing offshore structures against fire and blast loading if the operator so desires.

Fire and blast loading events can lead to partial or total collapse or sinking of an offshore platform resulting in loss of life and/or environmental pollution. Consideration shall be given in the design of the structure and in the layout and arrangement of the facilities and equipment to minimize the effects of these events. Implementing preventative measures has historically been, and will continue to be, the most effective approach in minimizing the possibility of occurrence of an event and the resulting consequences of the event. For procedures for identifying significant events and for assessment of the effects of these events

from a facility engineering standpoint, guidance for facility and equipment layouts can be found in API Recommended Practice 75, API Recommended Practice 14G, API Recommended Practice 14J, and other API 14 series documents.

The operator is responsible for the overall safety of the facility. The structural engineer needs to work closely with facility engineers experienced in performing hazard analyses as described in API Recommended Practice 14J, and with the operator's safety management system as described in API Recommended Practice 75.

The probability of an event occurring that leads to a partial or total platform collapse and the consequence resulting from such an event vary with platform type. In the U.S. Gulf of Mexico, consideration of preventive measures coupled with established infrastructure, open facilities and relatively benign environment have resulted in a good safety history. Detailed structural assessment should therefore not be necessary for Gulf of Mexico-type platforms designated as low risk. A screening process is described herein to screen from further consideration those platforms considered to be at tolerably low risk from fire and blast events, and therefore not requiring specific structural evaluation for fire and blast. As discussed above, however, all designs should include consideration of facilities and equipment layout to minimize the effects of fire and blast events and the adoption of good practice in regard to structural detailing to optimize performance in the event of the occurrence of a fire or blast event.

2 Risk Assessment

2.1 GENERAL

The risk assessment process consists of three levels, as follows:

- **Screening:** The first level is a simple risk based screening process that establishes a class of unmanned fixed structures as low risk facilities for which specific consideration of fire and blast loading is not required beyond the adoption of good practice.
- **Nominal Loads:** The second level of assessment relates to those classes of facilities for which, nominal load cases are provided and require an assessment of the facility to meet the performance criteria for the nominal load cases.
- **Event Based:** The third level of assessment consists of a series of evaluations of specific fire and blast events that could occur for the facility over its intended life and service function(s). The risk associated with each event is defined as the product of the probability of the event occurring and the consequences of the event should it occur. Three risk levels are defined i.e. low-risk, medium risk and higher risk.

The event-based assessment will likely require a formal hazard identification study for the definition of credible events and assessment of the associated risk. More detailed guidance on hazard identification study is available in the API RP 14 series and other sources [7,16,24].

2.2 SCREENING

The screening process described is intended to identify those facilities considered to be at low risk from fire and blast events and therefore not requiring detailed structural assessment. The risk matrix shown in Figure 2.4-1 may be useful to help identify low-risk facilities. For low-risk platforms, qualitative assessment of consequence of events and likelihood of events may be performed by close examination of the facilities of the platform.

Low-consequence platforms will be characterized by low equipment counts, limited to wellheads and manifold with few vessels and little associated pipe work, which would lead to low congestion and inventory. The consequence could also be low if the confinement is low with no more than two solid boundaries including solid decks. For low consequence facilities, the manning would be consistent with normally unattended facilities with low maintenance frequency.

Likelihood considerations tend to align closely with the consequence factors in that the low consequence installations will tend to be small and therefore less complex. Larger installations will have higher potential for leak and ignition sources and therefore a greater requirement for intervention and maintenance.

For low-likelihood events, installations and compartments will have a low equipment count. The low frequency of intervention will contribute to low likelihood of events from the standpoint of maintenance risk.

2.3 NOMINAL LOADS

Nominal loads for fires have been in use since the publication of the Interim Guidance Notes [24] in 1993, and have been updated and extended in more recent references [16]. For fires, these take the form of recommended radiation levels and flame temperatures for pool and jet fires in confined and open conditions. Jet fires may give rise to radiation levels up to 300 kW/m^2 in open conditions whereas in confined situations radiation levels may rise to 400 kW/m^2 where re-circulation of the flow occurs. Pool fires generally give rise to lower radiation levels of the order of $100\text{-}160 \text{ kW/m}^2$.

For blast considerations, the nominal loads are space averaged peak blast overpressures determined for specific platform types from a set of data. The details are provided in the section C6.3 of the Commentary. If available and considered suitable for use for the particular facility, these nominal loads may be used for the assessment of the platform. The sensitivity of the available data set will determine whether assessment using nominal load cases should be restricted to preliminary design only.

Nominal loads are intended for use at an early project phase where Safety input is most effective and detailed geometry of the layout, particularly small bore pipe work, is not known. They may be applied as static loads if this can be justified. Each element of the structure will respond according to its natural period and resistance. An alternative method presently under development [46], the response spectrum method takes into account variations in natural periods and allowable plastic deformations (ductilities). The method is briefly described in the section C6.3 of the Commentary.

2.4 EVENT BASED

Fire and blast events originate from the release of hydrocarbons. Causes of release may include dropped objects, ship impact, intervention, fatigue, corrosion, wear, vibration, extreme environmental conditions, imperfections and/or faulty equipment, exceedance of design conditions and human error [37]. Generic release scenarios based on historic evidence in the Gulf of Mexico [35] and the UK sector of the North Sea [36] can be found in the references cited. The event based assessment process is intended to be a series of evaluations of specific events that could occur for the selected platform over its intended service life and service function(s).

For facilities not considered as low-risk (see Section 2.2) and where nominal loads (see Section 2.3) are not considered applicable, the risk assessment process should identify the risk levels for each credible fire and blast event. A formal hazard identification study will usually be required for the definition of credible events and assessment of the associated risk. More detailed guidance on hazard identification is available in the API RP 14 series and other sources [7,16,24].

For each credible event, the need for consideration within the structural design of the facility should be determined using the flow chart shown in Figure 2.8-1.

Low Risk: Insignificant or minimal risk that can be tolerated because of low potential for escalation and no significant impact on either life safety or the environment. This level of risk need not be considered further for structural design purposes.

Medium Risk: The risk level requiring further study or risk assessment may be needed to better define the risk level, consequence and cost of mitigation. In some instances, medium risk may be deemed acceptable as low as reasonably practicable (ALARP) when the effort and/or cost of mitigation become disproportionate to the benefit.

Higher Risk: This risk level must be reduced by implementation of prevention and/or mitigation measures or through change(s) in layout and/or structural design. Alternatively, more rigorous assessment of probability and/or consequence of the event may be undertaken.

The risk matrix shown in Figure 2.4-1 is a 3 x 3 matrix that compares the probability of occurrence of a defined fire or blast event with the consequence of its occurrence.

Probability of Occurrence	High	Medium Risk	Higher Risk	Higher Risk
	Medium	Low Risk	Medium Risk	Higher Risk
	Low	Low Risk	Low Risk	Medium Risk
		Low	Medium	High
	Consequence of Occurrence			

Figure 2.4-1—Risk Matrix

2.5 PROBABILITY OF EVENT

The probability of occurrence of a fire or blast event is associated with the potential of the origin of the event. The type and presence of a hydrocarbon source can also be a factor in event initiation or event escalation. The significant events requiring consideration and their probability of occurrence levels (that is low, medium or high) are normally defined from a fire or blast process hazard analysis.

2.5.1 Factors Affecting Origin of Events

Factors affecting the origin of the fire or blast event can be as follows:

- **Storage:** The number and size of isolatable hazardous inventories is important.
- **Equipment type:** The complexity, amount, and type of equipment are important. Separation and measurement equipment, pump and compression equipment, fired equipment, generator equipment, safety equipment, and their piping and valves should be considered.
- **Risers and wells:** The location and number of risers and wells will affect the probability of certain events including blowouts and riser failure.
- **Product type:** Product type (that is, gas, condensate, light or heavy crude) should be considered.
- **Ignition sources:** The presence and location of exposed ignition sources should be considered in determining the probability of the event occurring.
- **Operations type:** The types of operations being conducted on the platform should be considered in evaluation of the probability of occurrence of an event. Operations can include drilling, production, re-supply, and personnel transfer.
- **Production operations:** Production operations are those activities that take place after the successful completion of the wells. They include separation, treating, measurement, storage, pressure boosting, transportation, operational monitoring, lifting and handling, modification of facilities and maintenance. Simultaneous operations include two or more activities.
- **Deck type:** The potential of a platform deck to confine a vapor cloud is important. Whether a platform deck configuration is open or closed should be considered when evaluating the probability of an event occurring. Most platforms in mild environments such as the U.S. Gulf of Mexico are open allowing natural ventilation. Platform decks in more severe climates, such as Alaska or the North Sea, are frequently enclosed, resulting in increased probability of containing and confining explosive vapor and high blast overpressures. Equipment generated turbulence on an open deck can also contribute to high blast overpressures.
- **Structure Location:** The proximity of adjacent platforms should be considered in the evaluation of the probability of certain events e.g. strong shock response or projectile impact.
- **Other factors:** Other factors such as the type and frequency of personnel training should be considered. The level of maintenance and the implementation of a fully functional safety management system will also affect the probability of occurrence of a fire or blast event.

2.5.2 Probability Level

The determination of the applicable level for the probability of the event should consider the following definitions:

- High Probability: The event is likely to occur during the life of the platform and has occurred more than once on similar platform in the past.
- Medium Probability: The event is not expected to occur during the life of the platform, and the platform does not meet the criteria of High Probability or Low Probability.
- Low Probability: The event is extremely unlikely to occur during the life of the platform and no such occurrence of the event is reported in similar platforms.

2.6 CONSEQUENCE OF EVENT

The degree to which negative consequences could result from platform partial or total structural failure is a judgment, which should be based on the potential risk to life safety, the environment and to the level of economic losses that could be sustained because of the failure. In addition to loss of platform and associated equipment, and damage to connecting pipelines, the loss of reserves should be considered if the site would be subsequently abandoned.

Removal costs include the salvage of the collapsed structure, reentering and plugging damaged wells, and cleanup of the sea floor at the site. If the site is not to be abandoned, restoration costs must be considered, such as replacing the structure and equipment, and reentering the wells. Other costs include repair, rerouting, or reconnecting pipelines to the new structure. In addition, the cost of mitigating pollution and/or environmental damage should be considered in those cases where the probability of release of hydrocarbon or sour gas remains high. When considering the cost of mitigating pollution and environmental damage, particular attention should be given to the hydrocarbon stored in the topside process inventory, possible leakage of damaged wells or pipelines, and the proximity of the platform to the shoreline or to environmentally sensitive areas such as coral reefs, estuaries, and wildlife refuge. The potential amount of liquid hydrocarbons or sour gas released from these sources should be considerably less than the available inventory from each source.

The consequence level for a defined fire or blast event should be assigned as low, medium or high as applicable for either life-safety (see section 2.6.1), environmental (see section 2.6.2), or other (see section 2.6.3) consequences.

2.6.1 Life Safety Consequences

The life safety of personnel in the direct vicinity of the event is an issue for operational safety procedure and control and not of structural design and is outside the scope of this document. In the selection of life safety consequence for structural design, therefore, the user should be considering life safety consequence of personnel away from the immediate vicinity of the event.

The determination for the applicable level for life safety consequence should be based on the following descriptions:

- High Consequence: Occurrence of the event may result in loss of life for personnel and/or health/safety implications to the general public.
- Medium Consequence: Occurrence of the event may result in serious injury for personnel with limited or no health/safety implications to the general public.
- Low Consequence: Occurrence of the event may result in minor injury to personnel or no health/safety implications to the general public.

2.6.2 Environmental Consequences

The determination for the applicable level for environmental consequence should be based on the following descriptions:

- High Consequence: Occurrence of the event may result in environmental contamination as a result of well flow of either oil or sour gas or from oil stored for intermittent shipment.
- Medium Consequence: Environmental contamination resulting from the occurrence of the event is limited to process inventory, which includes large capacity containment vessels.
- Low Consequence: Environmental contamination resulting from the occurrence of the event is limited to process inventory where the continued integrity of most of the vessels, piping and valves is anticipated post-event.

2.6.3 Other Consequences

Other consequences of failure include anticipated losses to the owner, other operators, and/or to the public interest. The determination for the applicable level for these consequences should be based on the following descriptions:

- High Consequence: Occurrence of the event will likely result in significant business disruption to other operators (e.g. the event will result in shut down of major oil transport lines) or in the non-recovery of significant hydrocarbon reserves (e.g. decommissioning of the platform without replacement following occurrence of the event).
- Medium Consequence: Occurrence of the event will likely result in minor business disruption to other operators (e.g. the event will result in shut down of low volume in-field flow lines).
- Low Consequence: Occurrence of the event will not likely impact other operators or be detrimental to the public interest.

2.7 PERFORMANCE CRITERIA

In the structural evaluation of a defined fire and/or blast event, the structure should be designed to meet specific performance criteria. These criteria should be selected to ensure that the consequence of the event is consistent with the risk level assigned in the risk assessment for that event. The operator is responsible for the overall safety of the platform and performance criteria should be established consistent with the operators overall safety management philosophy.

In the selection of performance criteria consideration may be given to a number of issues as follows:

- For structural evaluation of loads associated with low probability, fire and/or blast events (infrequent occurrences) performance criteria should ensure defined 'survival' of the platform.
- Any blast walls and/or firewalls should remain in-place without rupture or disconnection from their supports. Deformations of the wall should be limited to avoid escalation.
- Safety critical elements (SCEs) that are designed to mitigate the effects of a major accident, such as, those necessary for (a) the safe shut down of the installation, (b) personnel protection and escape, (c) fire protection, suppression and control, (d) communications, and (e) hydrocarbon containment including transport and storage; should remain intact.
- For platforms with the potential to be manned during the defined event, performance criteria should ensure defined 'survival' of the platform.

For structural evaluation of loads associated with medium or especially high probability fire and/or blast events (more frequently occurring) performance criteria may be modified to limit damage to the facility consistent with the consequence assigned in the risk assessment. For example, the platform may be designed to permit restarting of operations within a short time following appropriate integrity checks.

2.8 RISK ASSESSMENT PROCESS

The assessment process is illustrated in Figure 2.8-1 and comprises of a series of tasks to be performed by an integrated engineering team to identify facilities at significant risk from specific fire and/or blast events. The assessment tasks listed below should be read in conjunction with Figure 2.8-1 (Risk Assessment Process) and Figure 2.4-1 (Risk Matrix):

- Task A1: Determine whether the facility meets the definition of a low-risk facility as per the screening criteria, Section 2.2. If so, consideration of specific fire and blast loading in the design of the structure is not required.
- Task A2: Establish the performance criteria for the facility in accordance with Section 2.7. Performance criteria should comply with the overall safety and environmental management philosophy, guidance as provided in API RP 75, as well as relevant regulations and company standards.
- Task A3: Implement measures to reduce fire and blast risk in accordance with the guidelines for good design practice.
- Task A4: Establish whether nominal load cases for fire or blast loading are available for the facility. Nominal load cases are provided in the commentary for certain classes of facility for which a sufficient combination of analytical study and operational experience exists. If nominal load cases are not available for the facility, proceed to Task B1.
- Task A5: Evaluate the response of the critical structure and other key components to the nominal load cases. Critical structure and key components refer to elements of the facility that must survive for a specified duration of time following the occurrence of the event in order that the performance criteria for that event are met.
- Task A6: If the performance criteria set in Task A2 can be met for the nominal load cases the structural design for the event is complete for the facility.
- If it has been established from Tasks A1 to A5 that the facility does not meet the screening definition and that either nominal load cases are not available or structural evaluation indicates that the facility does not meet the performance criteria for the nominal load cases applied, it is necessary to consider fire and blast risk on an event-by-event basis.
- Task B1: Consideration of event-by-event fire and blast risk requires a formal hazard identification study for the definition of credible events (scenarios) and determination of their associated risk. Some guidance for the determination of the probability of events and their consequences is provided in section 2.5 and section 2.6 respectively. More detailed Guidance is available within the API RP 14 series and other sources [16,18].
- Task B2: Using the risk matrix, Figure 2.4-1, determine whether the level of risk associated with the event is low-risk, medium risk or higher-risk. If the risk is low, the assessment is complete for the defined event.
- Task B3: For events, where a higher-risk is identified, consideration may be given to modifying the design concept or adopting an alternative concept. This may be especially applicable during the early stages of a project. In this case, the assessment process is repeated from Task B1 for the modified or alternative concept. If ALARP is a part of performance criteria, the same would typically be assessed here.

The details of the assessment methods are given in the Commentary.

- Task B4: This task provides the choice for the engineering team to explore prevention and mitigation options to reduce the risk associated with the event.

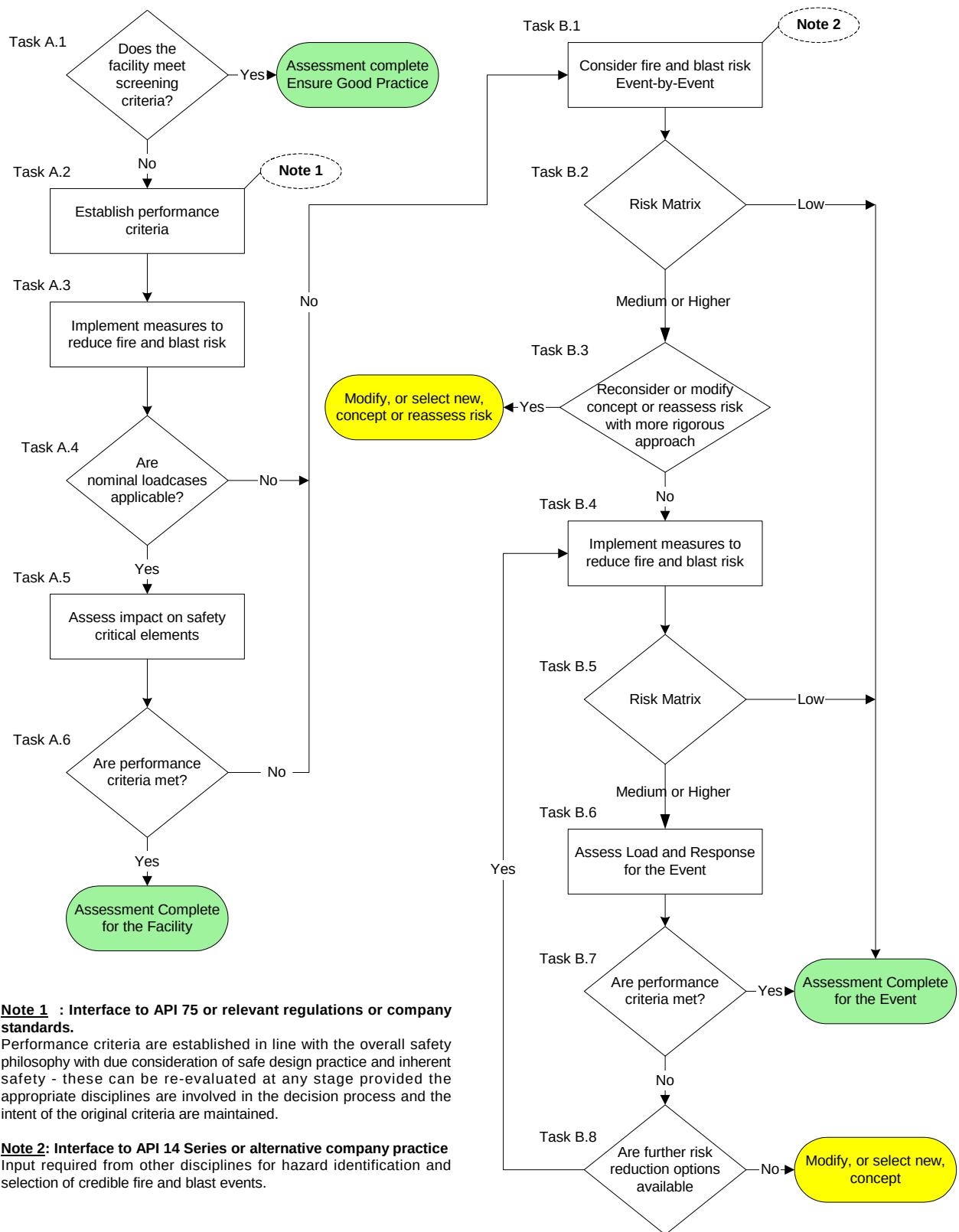


Figure 2.8-1—Risk Assessment Process

- Task B5: If the probability of the event or its consequence or both be reduced such that the risk, in accordance with risk matrix, Figure 2.4-1; becomes low-risk, the assessment is complete for that event.
- Task B6: This task involves the calculation of the fire or blast loads associated with the event and the evaluation of the ability of the critical structure and other key components required to meet the performance criteria set in Task A2.
- Task B7: If the performance criteria set in Task A2 can be met for the load cases for the specific event, the assessment is complete for the event.
- Task B8: In the case that the structural evaluation indicates that the performance criteria cannot be met, the engineering team must consider whether further risk reduction/mitigation options exist. If so, these should be implemented and the process reverts to Task B4. If no further risk reduction options are available, it will be necessary to modify the design concept or, adopt an alternative concept. In this case, the assessment process is repeated from Task A1 for the modified or alternative concept.

3 Fire as a Load Condition

If the risk assessment process described in Section 2 identifies that a significant risk of fire exists, fire should be considered as a load condition.

The treatment of fire as a load condition requires that the following be defined:

- The fire event or scenario, see section 2.4,
- Heat flow characteristics from the fire to the unprotected and protected steel members,
- Properties of steel at elevated temperatures, and where applicable
- Properties of fire protection systems (active and passive).

The fire scenario may be identified during process HAZOP (hazard and operational) analysis. The fire scenario establishes the fire type, location, geometry, and intensity. The fire type will distinguish between a hydrocarbon pool fire and a hydrocarbon jet fire. The fire's location and geometry defines the relative position of the heat source to the structural steel work, while the intensity (heat flux) defines the amount of heat emanating from the heat source.

Fire loading may be computed using the techniques presented in the Commentary.

4 Structural Response Assessment Against Fire

Structural assessment should ensure that the design meets appropriate performance criteria, as set forth in section 2.7. The structural response assessment against fire can be carried out using one, or a combination of, the following methods:

- a. Zone (or screening) method
- b. Strength level method
- c. Ductility level method

Each of the analysis methods is successively more complex, requiring different analysis tools with increasing complexity.

Should a structure fail to meet the performance criteria in screening analysis then a strength level analysis should be carried out. If the structure fails in strength level analysis then a ductility level analysis should be performed.

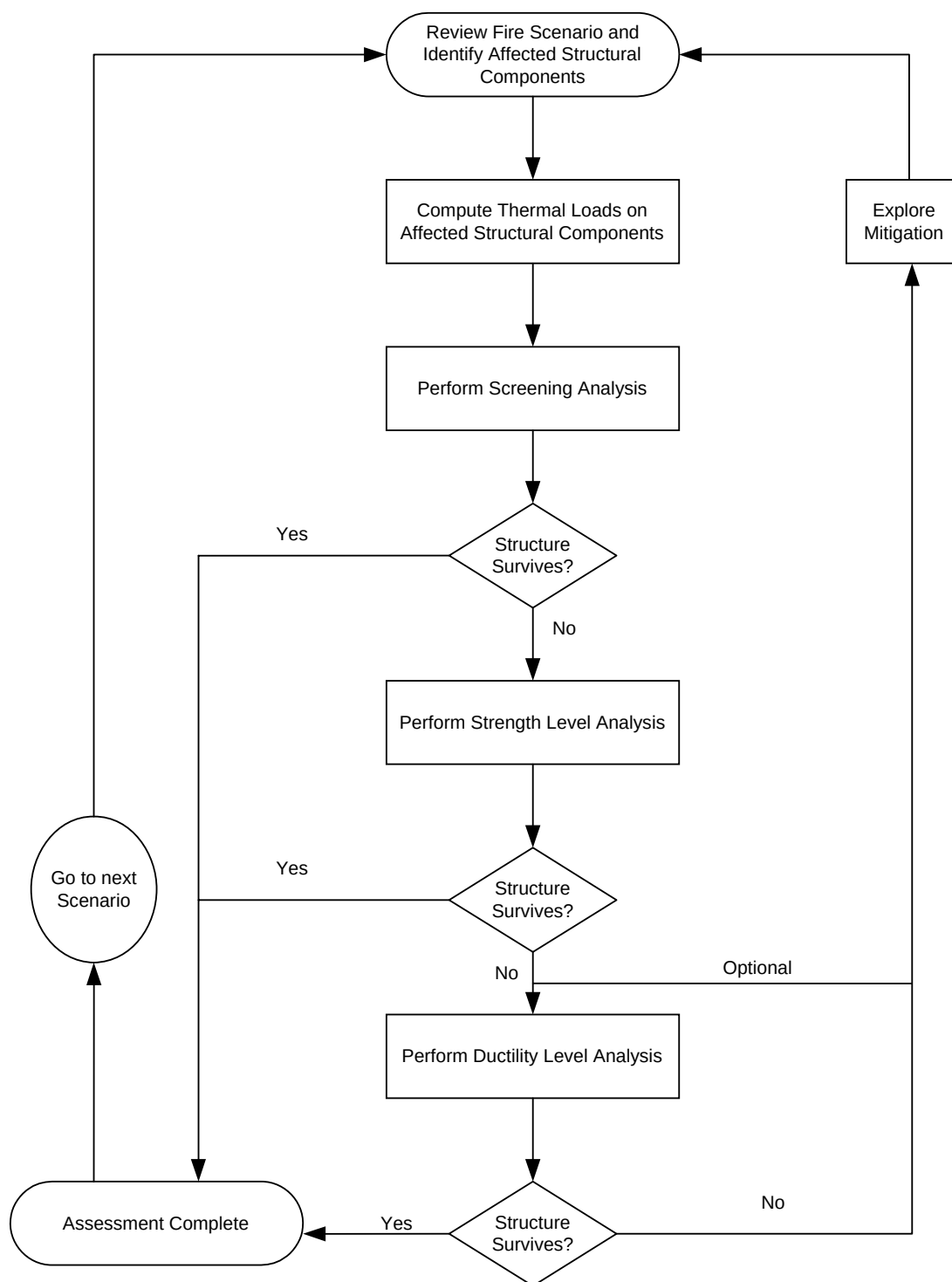


Figure 4-1—Process of Structural Assessment Against Fire

5 Fire Mitigation

Consideration of fire mitigation includes breaking the chain of events leading from the initial release to the full development of a fire scenario, reducing intensity and duration of fire, and provision of protection for structural members from fire.

5.1 GENERAL

While protection of structural members from fire remains the primary concern of the structural discipline, other means of fire mitigation may be considered by process and safety disciplines. These means of fire mitigation include, installation layout, process design, module layout, ventilation, cladding and decking details, drainage, vulnerability of equipment, pipe work and cabling, flame detection, fire detection, heat detection, smoke detection, gas detection, emergency shut down (ESD), de-pressurization, liquid inventory disposal, bunding drainage, and active fire suppression (deluge, halon, foam, CO₂ and sprinkler systems, etc.).

Generally, layout may be optimized to minimize flame length and complexity of flame paths. Escalation may be prevented by the introduction of barriers and by the use of separation by distance where possible.

Experiments described in [18] state that deluge system has a negligible benefit when dealing with natural gas and propane jet fires. More recent experiments (37) have shown that there is a small probability that jet fire may be extinguished by deluge leading to the possibility of an explosion, indeed jet fires may become unstable and self extinguish.

Pool fires are usually extinguished by deluge. Water curtains are effective against pool fires in reducing radiation levels on escape ways and limiting extent of the flame.

While active fire suppression may be most effective against pool fire, the effective protection of structural members from hydrocarbon jet fire may be possible by appropriate positioning of firewalls, and/or application of passive fire protection (PFP) to the affected structural members.

Additional information on control and mitigation of fire events in offshore installations may be obtained from ISO 13702 [34].

5.2 FIREWALLS

The ratings for firewalls were originally developed for cellulose fires rather than hydrocarbon fires, which are more severe. The type of fire is represented in a furnace test where the firewall is in contact with a furnace with a well-defined temperature-time relationship. The hydrocarbon fire curve has a higher rate of temperature rise and attains a higher peak temperature than a cellulose fire curve.

The following equation is used to generate hydrocarbon temperature-time curve for furnace testing of steel structures designed to resist a hydrocarbon fire [17]:

$$T := 1100 \left(1 - 0.325e^{-0.167 \cdot t} - 0.204e^{-1.417 \cdot t} \right) - 0.471e^{-15.833 \cdot t}$$

where

T is the furnace temperature in °C at time t, minutes

The following equation is used to generate cellulose temperature-time curve for furnace testing of steel structures designed to resist a cellulosic fire [17]:

$$T := 345 \log(8 \cdot t + 1) + T_c$$

where

T₀ is the initial furnace temperature in °C at the start of testing.

In the offshore industry, the three ratings used are as follows [5]:

- B Class – maintains stability and integrity for 30 minutes when exposed to a cellulose fire. The temperature rise of the cold face is limited to 140°C (284°F) for the period in minutes specified in

the rating, i.e., B15 rating has a 15-minute time-period during which temperature rise is below 140°C (284°F) for maintaining insulation performance [2].

- A Class – maintains stability and integrity for a period of 60 minutes when exposed to a cellulose fire. The temperature rise of the cold face is limited to 140°C (284°F) for the period specified in the rating.
- H Class – maintains stability and integrity for a period of 120 minutes when exposed to a hydrocarbon fire. The temperature rise of the cold face is limited to 140°C (284°F) for the period specified in the rating.

In these definitions for the ratings for A-Class and H-Class, maintaining stability and integrity means that the passage of smoke and flame is prevented and that the load bearing components of the fire boundary, preferably do not reach a temperature in excess of 400°C (752°F) [2].

Table 5.2-1 outlines the performance standards for firewalls according to their ratings and applies to a pool fire. The rating of firewalls against jet fires gives about half the endurance times of those given in Table 5.2-1.

The positioning of firewall and its rating are critical in determining its effectiveness in providing adequate protection of the structural components from a particular fire scenario for the duration of the fire.

Structural assessment of a firewall should be considered when designing the division to meet the desired performance standard or rating of the firewall.

The erosive and momentum effects of a jet fire must also be considered. See Commentary for details.

5.3 PASSIVE FIRE PROTECTION (PFP)

The determination of PFP requirement may be made after completion of appropriate level of structural analysis and after consideration of all possible fire mitigation measures.

The application of PFP on to the exposed surface of the steel work restricts the temperature rise in the protected steel structure for the defined duration of the fire scenario. The PFP thus limits the thermal stress levels in structural steel so that its load-bearing ability is not compromised.

Amongst available PFP materials and systems are mineral wool, ceramic fiber, concrete and vermiculite-based materials, phenolic syntactic foam, and epoxy intumescent materials. Intumescent materials are thin coatings, generally between 5mm to 15mm thick. When exposed to fire this material forms a thick char preventing heat transfer. These materials provide protection against hydrocarbon pool and jet fires, and retain their fire performance throughout the life of an application, subject to material characteristics, surface preparation and specified application.

Care should be taken to protect structural steel from corrosion under certain PFP materials.

The materials for the PFP must be tested and certified by competent authority. The application of PFP must conform to the manufacturer's specifications.

The thickness of the PFP would depend upon the performance standards.

The erosive and momentum effects of a jet fire must also be considered to prevent scaling of PFP materials.

Table 5.2-1—Performance Standard for Fire Walls by Rating (For Pool Fire)

Wall Rating	Stability and Integrity (Minutes)	Time for the Temperature to Rise to 140°C on Cold Face (Minutes)
H120	120	120
H60	120	60
H0	120	0
A60	60	60
A30	60	30
A15	60	15
A0	60	0
B15	30	15
B0	30	0

6 Blast as a Load Condition

If the risk assessment process described in Section 2 identifies that a significant risk of blast exists, blast should be considered as a load condition.

A blast scenario developed as a process HAZOP (hazard and operational) analysis establishes the make up and size of the vapor cloud, and the ignition source for the area being investigated.

The loading generated by a blast depends on many factors, such as the type and volume of hydrocarbon released; ignition source, type and location; the amount of congestion in a module; the amount of confinement; and the amount of venting available. Additional details on blast loading are presented in the Commentary.

Blast loading can be categorized in four components:

- Overpressure loads which result from increases in pressure due to expanding combustion products
- Drag loads which result from the flow of air, gases, and combustion products past an object.
- Shock loads have a very small duration compared to the whole blast.
- Global reaction loads, which result from differential pressure loading, have same time scale as the pressure variation.

6.1 BLAST OVERPRESSURE

There are no simple calculation methods for determining blast loads for offshore structures. A number of predictive approaches are currently being applied to generate blast overpressure from explosions in congested volumes. These are:

- Empirical Models based on the correlation of experimental data and the models' accuracy and applicability relating to the experimental database
- Phenomenological Models based on modeling the underlying physical processes, interpolating more accurately between data and extrapolating with more certainty to situations not addressed by experimental work
- Numerical Models which solve the underlying equations describing gas flow, turbulence and combustion processes

Numerical models following the principles of Computational Fluid Dynamics (CFD) have the potential for providing a higher predictive accuracy and a greater potential of addressing any blast scenario [24].

In addition, there is a reasonable experience base across industry from which ‘nominal overpressures’ have been established for certain classes of structures. Nominal overpressures and their application are discussed in the commentary Section C6.3. In lieu of the availability of applicable nominal overpressures, some level of blast simulation modeling, as described above, is recommended for computation of blast loading on offshore structures.

6.2 DRAG LOADS

If a body is subjected to a blast induced wind, then it will experience a directional loading due to the passing air/gas flow, known as the drag load. See commentary for further details.

6.3 SHOCK AND GLOBAL REACTION LOADS

The two major sources of loads from blasts are:

- Reaction loads from the expulsion of vented gases.
- Side loads due to the ignition of an external gas cloud, which has drifted to one side of the platform – the external blast.

A structure, which is subjected to a blast, may experience differential pressure loading. The duration of the loading is typically only a fraction of the blast. In this case, the relationship between the load experienced by the structure and the overpressure in the incident wave is much more complicated. If the pressure wave is normally incident on a closed wall then all the blast energy is reflected and the peak overpressure on the impacted surface is amplified. This results in a peak net directional loading greater than that of the incident wave.

When the blast wave propagates past or through openings in the structure, more complex interaction occurs giving rise to reflected and diffracted components. See commentary for additional details.

7 Structural Response Assessment Against Blast

Structural assessment should ensure that the design meets appropriate performance criteria, as set forth in Section 2.7.

7.1 DYNAMIC EFFECTS

When computing structural response against blast loading, the duration of the loading is important as it determines whether the loading is impulsive, dynamic or quasi-static. The duration of a typical hydrocarbon blast is often close to the fundamental natural period of the structural members, which would call for a dynamic analysis. The details of computing dynamic effects may be seen in the commentary.

7.2 STRUCTURAL ASSESSMENT FOR BLAST

The treatment of blast as a load condition can be addressed using one of the following methods:

- a. Screening check
- b. Strength level analysis which considers a more frequent design event where it is required that the structure does not deform plastically and that the SCEs remain operational
- c. Ductility level analysis which considers the extreme design event and utilizes reserve strengths of the structure

A screening check may be used as a conservative design basis or to assist in the identification of structural components for further response assessment to ensure compliance with performance criteria. The strength level analysis is a linear elastic analysis with modified code checks, which provides a less conservative basis for the design. If the strength level analysis fails to satisfy the performance criteria, a ductility level analysis may be performed. If the ductility level analysis fails to meet the performance criteria, then blast mitigation and/or structural modification should be considered.

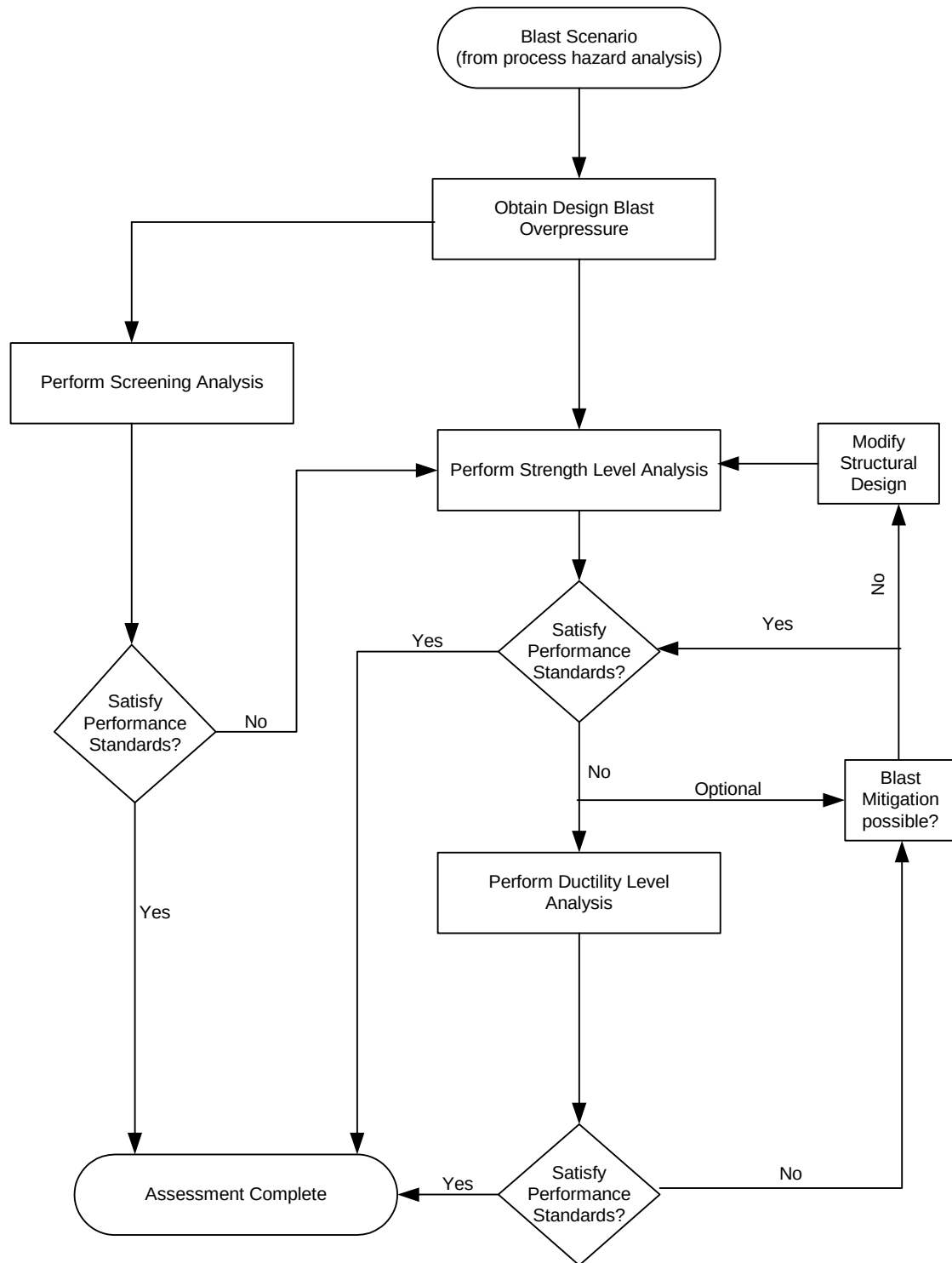


Figure 7-1—Process of Structural Assessment against Blast

At any stage of the process, mitigation measures may be considered. This may include measures for elimination of the initiating event, reduction of the severity of the event, and/or structural modification. If none of the mitigation options is feasible, structural modification/strengthening measures should be considered to satisfy the performance criteria. The assessment process is shown in Figure 7-1. The details of the assessment methods are given in the Commentary.

7.3 BLAST LOAD LEVELS

For higher consequence facilities operators may, optionally wish to consider two levels of explosion loading by analogy with earthquake assessment, i.e., the ductility level blast and the strength level blast.

The design level blast load is referred to as the Ductility Level Blast (DLB); defined as a low-probability high-consequence event, which must be investigated for at least retaining the integrity of the temporary refuge, safe muster areas and escape routes. The ductility level blast is the design level overpressure used to represent the extreme design event

A reduced blast load, sometimes referred to as a Strength Level Blast (SLB) by analogy to earthquake design, is defined as a higher-probability, lower-consequence event. Performance criteria associated with the SLB may include elastic response of the primary structure, with the safety critical elements remaining functional, and with an expected platform restart within a reasonable period.

The SLB load case may be desirable for the following reasons:

- a. The SLB may detect weaknesses in the structure at an early stage of the design improving the likelihood of meeting performance criteria for the DLB.
- b. The prediction of equipment and piping response in the elastic regime is better understood than the conditions that give rise to rupture. The SLB enables these checks to be made at a lower load level often resulting in good performance at the higher level.
- c. It is quicker to perform SLB load case. If performed correctly, the assessment will provide good assurance of adequacy of structure under DLB loads.
- d. The SLB load case provides a degree of additional asset protection.

Overpressures computed from the extreme design event are used as blast loading for ductility level analysis. If computations are not available for overpressures for frequent design events, then $1/3^{\text{rd}}$ of the blast loading from the extreme design event may be used for strength level analysis.

8 Blast Mitigation

8.1 MITIGATION OF THE CONSEQUENCES OF BLAST

Blast mitigation measures may include one or more of the following:

- a. Measures to reduce the probability of formation of a gas cloud,
- b. Upgrading the emergency shut down equipment,
- c. Introduction of blast relief panel to alleviate peak pressure,
- d. Modification to equipment layout,
- e. Provision of deluge
- f. Providing/strengthening blast walls, and
- g. Removal or isolation of ignition sources.

Mitigation measures should address the chain of events that occur in the lead up to a vapor cloud explosion incident such as, prevention or reduction in the size and concentration of a vapor cloud, measures to prevent ignition and/or combustion, followed by measures to alleviate blast severity and finally strengthening of the structure.

Additional information on control and mitigation of blast events on offshore installations may be obtained from ISO 13702 [34].