— topsides primary steel that provides direct support and stability of the LQ or TR (individual members or joints in a topside are not CS);

— temporary refuge;

— helideck and helideck support structure;

— bridges and bridge support structure;

— TEMPSC (totally enclosed motor propelled survival craft) davits and support structure;

— muster area walkways and support structure.

A.9.4.3 Major environmental event

Examples of CS whose loss can result in a major environmental event include:

— conductors;

— conductor centralizers;

— conductor guide framing.

A.9.4.4 Major accident prevention or mitigation

Examples of CS that are intended to prevent or limit the effect of a major accident, directly or by loss of a prevention or mitigation barrier:

Direct escalation:

— risers or pipelines, riser clamps, riser guides and emergency shutdown valve supports;

— hydrocarbon pipework supports;

— process equipment tie-downs.

Escalation due to loss of a mitigation barrier:

— riser and conductor protection frames;

— fire wall and fire wall supports;

— blast wall and blast wall supports;

— fire pump enclosures;

— fire pump caissons and supports or guides;

— dropped object protection.

A.9.4.5 Personnel safety

Examples of CS whose loss can result in one or more fatalities include:

— walkways (including their supporting structure), handrails and stair treads;

— drilling rigs (and masts), substructure, tie-downs and skid beams;

— communication towers and support structure;

— crane pedestals and support structure;

— exhaust stack support structure;

— runway beams and their connections.

A.9.4.6 Financial loss

Examples of CS whose loss can result in significant financial loss to the operator:

— flare boom and support structure;

— caissons and supports (other than fire pump caisson);

— primary topside structure (other than that providing direct TR support).

A.9.5 Risk

A.9.5.1 General

In developing an inspection strategy for a fleet of platforms, one approach is to categorize the platforms based on the risk posed to the operator by each platform.

In a qualitative approach the determination of the likelihood of exceeding a limit state is based upon information on structural configuration to determine its "baseline" susceptibility (e.g. tripod, versus 4 leg, versus 8 leg), as well as its present condition, based on inspection that can influence the baseline likelihood (e.g. damaged members). As an example, and although deck level is the most important parameter for metocean hazards, a 1960's vintage 6 leg, K-braced platform has a higher likelihood of exceedance than a 1980's vintage 8 leg, X-braced platform. The newer platform is designed to better standards, (e.g. incorporating joint cans), and has an inherently more redundant structural configuration since it has 8 legs and is X-braced.

A.9.5.2 Consequence

A.9.5.2.1 General

Consequence is governed by the most critical of the life-safety consequence, environmental consequence or financial consequence categories.

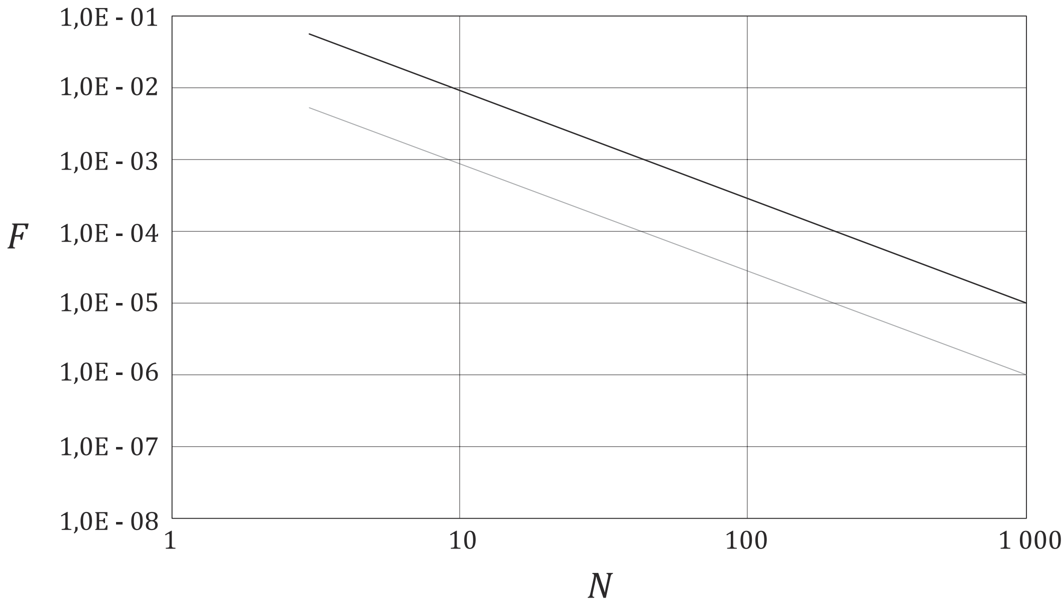
Life-safety consequence in ISO 19900 and in this document is not a function of the number of potential fatalities. However, the operator or regional regulator can require an F-N approach where life-safety consequence is a function of the number of potential fatalities.

Financial consequence should account for the anticipated losses to the operator, other operators, and industry. Financial consequence should include possible repair costs, lost production revenues, and clean-up costs. A driver for the financial categorization can be the possible damage to society (e.g. the situation where a community/state/country will suffer significant financial losses because of the interruption of production). Financial consequence categorization assumes that the operator determines the financial loss category to suit its tolerance of risk, with the agreement of the regulator where applicable.

A.9.5.2.2 F-N Curve

An *F-N* curve (see Figure A.2) specifies the intolerable cumulative probability of fatalities (F) as a function of the number of fatalities (N). The *F-N* curve for fatalities due to non-structural hazards is summed with the *F-N* curve for hazards for fatalities from a hazardous event, and then compared against the operator's and/or regulator's *F-N* requirements.

The intolerable F, F_{int}, is specified as $F_{int} \times N^m$ = constant, where, if risk aversion is included, m is greater than 1,0 (typically m = 1,5) as illustrated in Figure A.2 from CCPS[13]. If a platform collapses in an abnormal storm, then the number of fatalities (N) is likely to equal the PoB as rescue of personnel in the water would be unlikely.



Key

———— (thick line)	boundary of intolerable societal risk for workers
———— (thin line)	boundary of intolerable societal risk for public
N	fatalities
F	cumulative frequency of *N* or more fatalities (1/yr)

Figure A.2 — Life-safety F-N curve (including risk aversion)

A.9.5.2.3 Life-safety risk

Life-safety risk can be measured by the individual risk and the group (or societal) risk. Individual risk per annum (IRPA) includes hazards that offshore personnel can be exposed to, and includes a summation of the operational risks (e.g. helicopter transfers and hydrocarbon blast and fire risks) along with the structural failure risks in determining the tolerable risk.

In some regions, operators and regulators have a structural integrity strategy to unman specific platforms on forecast of the sea state exceeding a predetermined magnitude. In these situations, the operator demonstrates that the annual life-safety risk while the platform is manned is smaller than the limit state criteria.

Risk per annum can be measured by temporary refuge impairment frequency (TRIF) and includes hazards that personnel can be exposed to in the TR (or LQ), including smoke and gas ingress, heat stress and submergence of the TR (or LQ) by global or local collapse of the platform.

In the US Gulf of Mexico, platforms are unmanned (evacuated) for full-population hurricanes and the operator demonstrates that the minimum life-safety limit state is achieved for the winter storm and sudden hurricane metocean hazards.

Scenarios that can result in fatalities are:

— fatalities from loss of TR (or LQ) integrity by sudden platform collapse (topsides, substructure or foundations) during a hazardous event;

— fatalities from loss of TR (or LQ) integrity by platform collapse (topsides, substructure or foundations) because of sustaining severe damage during a hazardous event followed by progressive component failures during the same hazardous event;

— fatalities from loss of TR (or LQ) integrity by sliding or toppling because of local topside collapse during a hazardous event;

— fatalities from loss of TR (or LQ) integrity due to escalation of a hydrocarbon release because of structural failure of risers, pipework or conductors or their supports from the substructure, underdeck or topsides;

— fatalities from escalation due to loss of protective barrier for fire and/or blast;

— fatalities from escalation due to loss of protective barriers for vessel collision or dropped/swinging objects;

— fatalities due to loss of supports for evacuation, escape and rescue.

A.9.5.2.4 Regulators

Presently, regional regulators can require different limit state verification criteria for life-safety. However, all are consistent in recommending that risk reduction measures should be assessed. For example:

a) US regulator, using API RP 2SIM[11] for metocean hazards, specifies the required minimum return period of the action, RP_A, having an annual probability of exceedance of $1/RP_A$, that causes collapse of the platform based on mean values of resistance parameters.

b) US regulator, using API RP 2EQ[10] for seismic hazards, specifies the required minimum return period to collapse of the platform, RP_c. The calculation of RP_c accounts for the uncertainty in the resistance parameters by convolution of the hazard curve with the slope of the fragility curve. If $E_{2\,500}$ is the action having an annual probability of exceedance of 1 in 2 500 years, then the minimum required capacity is $C_c \times E_{2\,500}$ based on mean values of resistance parameters.

c) Norwegian regulator, using NORSOK N-006[40], specifies the required minimum return period of the action, RP_A, having an annual probability of exceedance of $1/RP_A$, that causes collapse of the platform based on characteristic values of resistance parameters.

   If the platform does not collapse, but sustains damage, when resisting the action with return period RP_A, then a further performance level is required to demonstrate that the platform does not collapse during the remainder of the hazardous event in which the action with return period RP_A occurred. This includes demonstration that the damaged platform does not collapse in the 2nd, 3rd etc., largest actions during the remainder of the hazardous event (e.g. metocean or seismic event) and includes the requirement that further damage from component failures during the 2nd, 3rd etc., largest actions and due to low-cycle fatigue in the remainder of the hazardous event is accounted for. The minimum capacity requirement of $C_c \times E_{RP}$ based on mean values of resistance parameters is approximately equal to the capacity requirement of E_{RP} based on characteristic values of resistance parameters. NORSOK N-006[40] methodology is therefore compatible with the ISO 19901-2 and API RP 2EQ[10] methodology.

d) Norwegian regulator, using NORSOK N-006[40], requires that shutdown and unmanning procedure is determined in a way that verifies that the structural reliability of the facility with personnel on-board is not less than for manned platforms (NORSOK N-006[40]) and is assumed to give a life-safety limit state objective in accordance with the ALS requirement of NORSOK N-001[38].

e) UK regulator requires the life-safety risks for individuals and groups on the platform to be less than 1/1 000 per annum.

   IRPA (see UK HSE[47]) is an individual’s probability of fatality per annum and accounts for the sum of the probability of fatality due to the following hazards:

   — collapse of the platform or local structural collapse leading to toppling of the TR (or LQ) while the individual is on the platform;

   — hydrocarbon explosion while the individual is on the platform;

   — helicopter travel by the individual to and from the platform while individual is performing his role on the platform (occupational risk).

TRIF (temporary refuge impairment frequency, see UK HSE[49]) is the probability of fatality per annum of the group of individuals on the platform and accounts for the sum of the probability of fatalities due to the following hazards:

— collapse of the platform leading to submergence of the TR (or LQ) or local structural collapse leading to toppling and submergence of the TR (or LQ);

— smoke or gas ingress to the TR (or LQ);

— heat stress to personnel in the TR (or LQ);

— crushing due to collision with the TR (or LQ) from vessels, dropped objects or toppling of the drilling derrick or flare tower.

A.9.5.3 Likelihood

Perceived likelihood accounts for:

a) characteristics of actions or action combinations;

b) vulnerability to accidental loading (e.g. proximity to shipping lanes);

c) present structural condition;

d) degradation mechanisms;

e) service history;

f) reserve strength;

g) structural redundancy and alternative load paths;

h) fatigue sensitivity.

Structural configuration is a function of the ability of a structure to sustain component damage without loss of system structural capacity. Tolerance to damage is a parameter in developing a SIM inspection/monitoring strategy and the associated SIM programs.

An X or XH type of framing configuration typically provides robustness to component damage when subjected to abnormal actions through many alternate paths to transmit loading to the foundation. In the absence of accidental actions, this configuration can often allow the operator more flexibility in developing and implementing an inspection program due to the significant tolerability to component damage and/or overload.

Conversely, a D or K framing pattern does not provide alternate load paths and is less ductile when subjected to abnormal actions. As such, this framing does not provide as much flexibility in developing and implementing an inspection program.

A.9.5.4 Risk presentation

Typical matrices for the life-safety consequence and environmental/financial consequence are provided in Figure A.3 and Figure A.4, respectively. In these figures, the consequence category and likelihood category are arranged such that the highest risk ranking is toward the upper right-hand corner. The operator can adopt more detailed risk assessment techniques or more complex matrices to further subdivide the consequence category and/or likelihood. Risk categories are typically assigned to the boxes on the risk matrix as illustrated in Figure A.3 and Figure A.4.

Risk matrices and consequence categories in Figure A.3 and Figure A.4 provide a useful basis for presenting risk. However, the risk determination should be supplemented with additional evaluation, if the risk level is:

— too coarse;

— too general to address:

  — specific concerns;

  — aspects of performance;

  — individual components.

Risk matrices can be presented as symmetrical or asymmetrical (i.e. the consequence of loss of structure or structural components is given a higher weighting than the likelihood category).

Consequence of failure	Manned	Risk level 3	Risk level 2	Risk level 1
	Unmanned	N / A	N / A	N / A
		Low	Medium	High
		Likelihood of failure		

Figure A.3 — Example life-safety risk matrix

Consequence of failure	High	Risk level 3	Risk level 2	Risk level 1
	Low	Risk level 4	Risk level 3	Risk level 2
		Low $\leq 10^{-3}$	Medium $> 10^{-3}$ and $\leq 10^{-2}$	High $> 10^{-2}$
		Likelihood of failure		

Figure A.4 — Example environmental pollution risk matrix

A.9.6 Demonstrating fitness-for-service

A.9.6.1 General

Limit states to limit life-safety risk and environmental pollution risk are independent of remaining service life (i.e. these risks are measured as risk per annum). Financial risk can be measured per annum or over the remaining total service life.

In engineering practice, it is widely recognized that although an existing structure does not always meet present-day design standards, the structure can still be adequate or serviceable. Examples of this do not only include fixed offshore structures, but also buildings, bridges, dams, and onshore processing plants.

ISO 19900 recognizes that the partial factor design approach inherent to limit states design has not been developed for each aspect of offshore structures and consequently other methods can be used. ISO 19900 states that a reliability-based approach can be used for the following:

— determination of partial action factors and resistance factors in the process identified as calibration;

— for design, provided the consistency of SRA with acceptable design practice has been demonstrated.

A.9.6.2 Linear-elastic analysis

Linear-analysis methods (or design level methods) that check the component ULS may be used to demonstrate fitness-for-service.

Recommendations on performing linear-elastic analysis for the possible hazardous events are provided in companion design standards (e.g. ISO 19902, ISO 19901-2, ISO 19906) that provide calibrated action and resistance factors. In lieu of calibrating for different action return periods these standards may be used to demonstrate that the platform is fit-for-service.

For structures that are likely to have decks inundated with waves, ISO 19902 ALS linear-elastic analysis approach may be used to demonstrate that a structure achieves fitness-for-service. However, to investigate the potential for structural collapse induced by a metocean hazardous event with wave-in-deck, nonlinear analysis methods should be used.

A.9.6.3 Nonlinear analysis

Static or dynamic nonlinear analysis methods may be used to demonstrate that a structure is fit-for-service. A nonlinear analysis may use representative values or mean values for resistance.

If mean values are used, the variability of a parameter's value about its mean value should be included.

To verify that the collapse prevention limit state has been met, nonlinear analysis methods should use either of the analysis options provided in Table A.3. Two nonlinear analysis options are provided which differentiate between using representative or mean resistance parameters. Either analysis option, when used, will implicitly demonstrate that the structure is fit-for-service against the collapse prevention limit state. The provision of two nonlinear analysis options allows for situations where information on the actual resistance parameters (e.g. yield strength from mill certificates) is available. However, the use of mean parameters without an adjustment of the characteristic RP load will invalidate the analysis recipe.

Table A.3 — Nonlinear analysis recipe for collapse prevention performance level conformance

Analysis recipe		Conformance
Resistance	**Action**	
Representative	Characteristic action at RP in ISO 19902	Structure does not exceed the limit state at or before the applied action.
Mean	Characteristic action at RP in ISO 19902 increased by a correction factor (Cc) that accounts for the uncertainties in using mean resistance parameters[a,b]	

[a] Seismic nonlinear analyses performed in accordance with the recommendations in ISO 19901-2 include a correction factor.

[b] A 1,15 correction factor can be used for a nonlinear analysis of a metocean event in lieu of establishing a more representative value. Guidance on deriving a correction factor for analyses of metocean events is provided in Reference [35].

A.9.7 Assessment

A.9.7.1 General

A fitness-for-service assessment determines the design action effect combination and design resistance of a structure or structural component, and verifies this against the required limit state.

An assessment may consist of comparing the platform response to an actual proof or extreme/abnormal action against the limit state. However, this is typically only possible when financial risk governs (e.g. evacuated, low consequence platforms in the US Gulf of Mexico) and the return period for the collapse performance level is of the order of 100 years. Platforms with a return period requirement of several thousands of years for the collapse performance level are unlikely to have experienced the required proof load since their installation.

There are numerous methods that have evolved that can be used for performing DLM and USM assessments that are simple to use. However, care should be taken when using such methods, including prior testing and verification of the method to confirm the approach and the applicability of the method to the assessment case.

A.9.7.2 Assessment motive

No guidance is offered.

A.9.7.3 Assessment initiators

A.9.7.3.1 General

No guidance is offered.

A.9.7.3.2 Changes in condition

Evaluation should periodically review the condition of the structural components to determine if the structural capacity has reduced below that used to demonstrate that the structure is fit-for-service. The evaluation should review the condition used in the design or most recent assessment against the new condition.

Evaluation should account for credible degradation and deterioration mechanisms. The mechanisms should be divided into the following categories:

— time dependent where the deterioration can be observed and measured through inspection (e.g. corrosion);

— non-time dependent where deterioration develops quickly after an unknown incubation period and inspection is ineffective (e.g. mechanical damage).

An assessment of the structure or structural component strength against the limit states should be performed if the evaluation indicates that the condition of the structure has resulted in a reduction of the structural capacity. The assessment should be made for the present degraded condition and the anticipated additional degradation by the planned end of total service life.

A.9.7.3.3 Changes in action

Evaluation should periodically review the actions (metocean, gravitational, seismic, etc.) used to demonstrate that the structure is fit-for-service. The evaluation should review the actions used in the design or most recent assessment against the estimated new actions.

An assessment of the structure or structural component strength should be performed if the evaluation indicates that the actions on the structure have increased. An increase in action could occur from the addition of conductors not accounted for in design or the findings from an underwater inspection that indicate that the marine growth exceeds the thicknesses assumed in design.

One of the most notable factors leading to changes in actions is the potential addition of wave-in-deck actions due to subsidence or revised metocean conditions. Other changes in action can include adding a new appurtenance that attracts increased metocean action or a brownfield modification that adds additional equipment and/or structure to the topsides.

Many historical platform failures in the US Gulf of Mexico have been attributed to waves impacting the cellar deck, resulting in a large step-wise increase in loading. In several of these cases, this conclusion is based on hurricane wave and storm surge hindcast results, which indicate conditions at the platform location that include estimated wave crest elevations being higher than the underside (bottom elevation) of the cellar deck main beams.

Inadequate cellar deck height can result from one or more of the following circumstances:

— cellar deck elevation set to only clear a lower design wave height;

— platform installed in deeper water than its original design specified;

— subsidence of the seabed formations.

In some cases, the cellar deck elevation can be greater than the crest elevation for the E_{RP} action, but the sub-cellar deck, such as a scaffold or sump deck, can be impacted by waves causing the E_{RP} action. The sub-cellar deck typically has a small profile and the anticipated wave loading is not expected to be sufficient to cause collapse. However, the assessment should account for the hydrodynamic loads on these decks and associated equipment, for either a DLM assessment or a USM assessment.

A.9.7.3.4 Changes in criteria

Evaluation should periodically review the design/assessment structural or soil data criteria used to demonstrate that the risks are tolerable. Design/assessment criteria can change as industry knowledge and capability to improve the accuracy of hazard curves increases.

Evaluation should review the following criteria used in the design or most recent assessment against the new criteria, as a minimum:

— metocean;

— seismic;

— ice;

— collision;

— geotechnical.

An assessment of the structure or structural component strength level should be performed if the evaluation indicates that the new assessment criterion is more onerous.

A.9.7.3.5 Changes in consequence

Evaluation should periodically review the consequence. If the evaluation indicates that the consequence of exceeding a limit state is more restrictive than that used in the design or most recent assessment, an assessment of the structure or structural component strength should be performed.

Evaluation should, as a minimum, review the following consequence:

— addition of accommodation facilities;

— addition of facilities (e.g. additional pipelines, additional wells, or an increase in topside hydrocarbon inventory capacity).

A.9.7.3.6 Changes in use

If there are plans to change a platform's use, an evaluation should be performed to demonstrate that the risks are tolerable. For L3 structures that are unmanned and that have a low environmental consequence, the change-of-use suitability should be based on an evaluation of the financial risk.

An assessment of the structure or structural component strength against the limit states should be performed.

Examples of platform change-in-use include the addition of a pipeline crossing to an existing platform, the use of an existing platform as a tie-back for a deepwater facility, and the conversion of an existing platform into a receiving terminal for liquid natural gas or other non-exploration and production activity. In these cases, the use of the structure has changed since the platform can now have a different function, expected life and consequence.

For example, fatigue should be re-evaluated since the structure now has a longer-term use under perhaps different actions compared to its original design.

A.9.8 Mitigation measures

A.9.8.1 General

Mitigation can help extend the life of a structure or improve its chances of survival in an abnormal or accidental event if employed early. Mitigation typically involves reducing actions on the structure such as removing unused risers, plugged and abandoned conductors, appurtenances such as boat landings and barge bumpers and increase deck height elevation (deck inundation reduction) or increasing the structure's strength.

Consequence mitigation and likelihood reduction can be addressed at any stage of the assessment process.

Mitigation can include active programs to minimize consequence, such as plugging and abandoning unused wells, removing inactive process equipment, relocating critical equipment., or modifications or operational procedures that reduce actions, increase capacities.

Mitigation measures can include:

— change to operational procedures (e.g. supply vessel operating procedures);

— unmanning criteria;

— inspection of other components, or similar structures;

— more detailed or frequent inspection of defects or damage;

— remedial grinding of crack-like indications;

— repair of identified damage or defects;

— loading reductions (e.g. marine growth removal);

— strengthening.

A.9.8.2 Consequence reduction

A.9.8.2.1 Life-safety

If the structural integrity strategy includes unmanning on a forecast, then the influence of uncertainty in weather forecasting is accounted for in setting the wave height threshold that initiates unmanning. The wave height threshold that initiates unmanning is determined by accounting for the financial costs of shutdown, demanning, re-manning and re-starting in addition to the requirement of meeting at least the minimum life-safety limit state.

A.9.8.2.2 Environmental

When a platform is known to have storage for oil that can be released during a hazardous event, the operator should demonstrate that the CS supporting oil containing pipes (e.g. risers supported from the underdeck or substructure, emergency shutdown valves supported from the underdeck, pipework supported from the deck or conductors) achieve the relevant environmental limit state.

Rupture of oil containing pipes can be caused by the action from the hazardous event being applied directly to the pipe or can be due to large deformations of their supports or due to platform collapse.

A.9.8.2.3 Abnormal storm preparedness

Examples of abnormal storm preparedness are:

a) Evacuation planning, including priority evacuation of platforms that are at greater risk of failure and those that are furthest from shore. Initial evacuation of non-essential personnel should begin early.

b) Evacuation planning for extreme storms that occur with short notice can include evacuation to a more robust platform.

c) Development of advance plans for accessing the structure post storm, if normal access and safety systems are not available due to damage.

d) Establishing of evaluation guidelines and procedures for the eventual safe re-boarding of a damaged structure in terms of whom, how, and when.

e) Identification of critical members and joints for structural integrity for post storm inspections.

A.9.8.3 Likelihood reduction

A.9.8.3.1 General

Strengthening of the jacket structure can be an effective means of reducing the likelihood of damage. Strengthening scheme should be designed to increase the system capacity to the level required to demonstrated that the risks are tolerable. Alternatively, it may be possible to modify the structure to reduce the action effects.

A.9.8.3.2 Increased inspection and/or monitoring

Revisions or additions to the inspection and monitoring plan to detect anomalies may be used to reduce the risk. More frequent inspection of an area known to have damage or where damage is more likely to occur will identify damage, enabling mitigation to be implemented before loss occurs. Similarly, an increased level of inspection may be used (e.g. CVI instead of GVI or NDE instead of CVI) to provide a better level of clarity on the true condition of a CS and detection of anomalies.

Monitoring may be used to help maintain a level of understanding about the condition of a CS between inspections. Monitoring can identify anomalous conditions that could increase the likelihood of damage such that a response (e.g. additional inspection, repair) can be implemented.

A.9.8.3.3 Strengthening, modification and/or repair (SMR) techniques

A.9.8.3.3.1 General

Design practices for SMR should take account of applicable specifications, industry standards, statutory and regulatory requirements.

A selection of SMR techniques available for likelihood reduction is provided in Figure A.5.

The assessment methods (see Clause 12) should determine whether strengthening or repair is required to demonstrate that the risks are tolerable. If the structure requires strengthening and/or repair, the assessment model should be used to develop strengthening options. Once a decision has been made in favour of SMR, an appraisal should be performed of available SMR techniques.

Selecting and designing an SMR technique should account for:

a) safety of diving, diving support, construction and operations personnel;

b) potential for use of diverless techniques;

c) difficulty of fabrication, handling, and installation;