LOTE for Naval Vessels – Procedure and Experience

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Synopsis

It is well known that navies today are facing increasing challenges to fulfil their more and more complex duties with aging fleets. This implies the need for system up-grades and for keeping the existing fleet longer in service than designed or planned for, especially considering very long lead times for newbuilding programs. In summary this puts additional pressure on limited budgets and resources and drive the demand for alternative solutions. To extend the original design lifetime of the existing vessels and investigate the potential to utilize their actual capabilities beyond the original design limitations is one of the most practical approaches to overcome this situation and fulfil the needs of future duties and commitments. For doing this in a safe and reliable way, DNV GL has developed a flexible, inclusive Life of Type Extension (LOTE) approach, as part of DNV GL's Naval Technical Assurance Services. This is building on the in-service experience of platform systems from hundreds of naval vessels and support of new-build programs over a long period worldwide. Through a unique combination of numerical simulations and a tailored Navy CAP survey, the actual condition and the remaining service life can be determined. Furthermore, it is possible to investigate the effects of maintenance systems and modifications on the remaining life with respect to fatigue and corrosion as the focused degradation mechanisms. Due to the intensive involvement of DNV GL during the design phase of many combatants and the close cooperation between the building yards and DNV GL in this respect the application of the DNV GL LOTE approach for naval vessels is a perfect match. The consideration and consequent re-use of calculation models and calculation results from the design phase, whenever possible, offers both a consistent and seamless technical basis for the subsequent LOTE calculations and assessments as well as a most efficient approach from commercial point of view. Using the example and experience from a practical LOTE application for a typical surface combatant the thorough capabilities and benefits of the approach are shown. The general findings and results of this example are representative for a typical LOTE application and confirmed by several different projects. Furthermore, the key learnings as well as areas potentially subjected to future development will be named.

Keywords: Technical Assurance; Life of Type Extension; LOTE; Navy CAP Survey;

1. Introduction

Navies today are facing increasing challenges for their aging fleets. Rapidly changing and commonly extended duties often imply the need for system up-grades and put pressure on limited budgets and resources - not to mention very long lead-times for new-build programs. Proving the platform's capability to fulfil the extended duties in a safe and reliable way and to assess its readiness for up-grades becomes a key task. The application of a life of type extension (LOTE) procedure provides one of the best solutions to overcome this situation.

Within the umbrella of DNV GL's naval technical assurance regime and the systematic generation of a naval experience database a flexible inclusive LOTE approach has been developed (Doerk, 2017). Due to the long-term partnership between many shipyards, designers and DNV GL and the consequential unique experience with these designs covering the new-building (design) as well as the operational phase this builds a perfect match. A robust initial design or platform is key to realize the whole capabilities of a LOTE approach in an efficient way i.e. with low efforts and costs.

While the basic elements of the LOTE approach are the same for nearly all practical applications the details and especially the level of the analyses and investigations differ significantly from project to project and need to be adjusted to the needs of each individual project.

2. Initial situation

The basic objective of any Life of Type Extension (LOTE) activity is to ensure a safe and reliable operation of a vessel beyond the originally planned lifetime or beyond the designed degradation limits. Often this goes along with a system up-grade and from time to time an additional change of the operational duties or the operational area. In practical application LOTE activities are commonly limited to hull structural and machinery aspects i.e. on platform related issues, with a clear focus on the former.

Normally, the hull structure of naval ships undergoes regular inspections in prescribed intervals and with defined scope. Structural degradation is determined, documented and necessary repairs carried out. For damages, as buckles and cracks, the need for repair is straightforward but when it comes to corrosion, it is less clear, whether and to what extent the corroded structure must be replaced. In contrast to merchant ships, for naval ships in most cases no explicit corrosion margins are given in the ship files from the design phase. In consequence often the rolling tolerances are taken as maximum tolerable diminution margins leading in practice to an expensive 'repair-to-new' approach. However, the practical experience confirms that for many structural members of a ships' hull their structural capacity is not fully utilized i.e. that there are significant diminution margins available.

The determination of these available implicit corrosion margins is a key element of the LOTE approach as it allows to apply much more flexible maintenance and repair scheme based on practical working margins but without touching the required safety and reliability levels. Once the condition and implicit corrosion margins of the hull structure have been determined within a LOTE assessment, the necessary extent of steel replacement can be decided in a rational and traceable way.

When it comes to the quantification of the actual lifetime consumption of machinery and equipment, the situation is different to the hull structure. Their condition mainly depends on the operating hours, maintenance levels and service intervals prescribed by the manufacturers. Need for repair or replacement can be determined in a straightforward way, either when the component shows signs of pending failure (condition monitoring) or when routine replacement intervals are exceeded.

3. LOTE procedure

The goals and boundaries of LOTE-related navy projects are as different as the affected vessels and strategies of the concerned naval authorities. Therefore, the here discussed LOTE procedure offers a levelled and flexible approach which can or has to be customized to the individual requirements respectively.

Normally, LOTE assessments are carried out in connection with hull surveys in the later stage of the planned ship operational lifetime or when an upgrade of capabilities is required. At this point it must be decided whether the vessel is going to be replaced or should be kept longer in operation than planned. A clear definition of the LOTE objectives is of ultimate importance in that respect. Particularly, it must be addressed whether a maximum lifetime or a minimum effort for up-grade and maintenance measures is aimed at

3.1. Scope

As illustrated in Figure 1, a LOTE assessment is based on a combination of two key activities: an advanced desktop study, defining the design baseline, and an on-board survey, providing the actual condition of the hull structure.

The results of the desktop study are summarized in two documents: a list of the minimum required thicknesses of the structural members and a summary of the so-called 'areas of attention', listing the expected lifetime of structural details which are considered vulnerable to fatigue cracking.

Complementary, the results of the hull condition survey are summarized in a list of actual measured thicknesses and a survey report including a rating of the structural condition of the areas of attention.

In the LOTE assessment the measured thicknesses are finally compared against the minimum required thicknesses and the observed condition of the areas of attention set in relation to their expected fatigue lifetime.

On that basis it is derived to what extent structural repairs are required to operate the platform longer than planned or at which time structural degradation might become critical if no significant repairs or maintenance measures are carried out, respectively.

 https://doi.org/10.24868/issn.2515-818X.2020.036

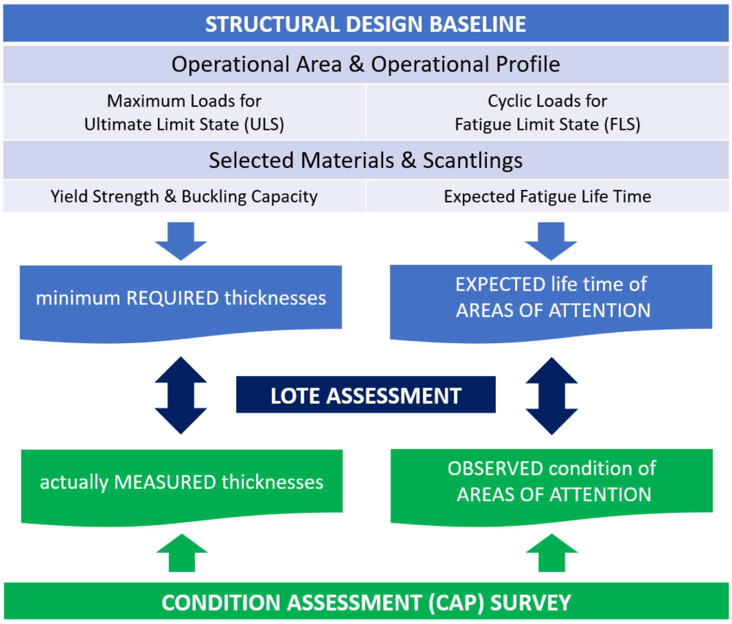

Figure 1: Key elements of DNV GL LOTE approach

3.2. *Design Baseline*

Each naval vessel is designed according to a defined set of structural requirements so that it can be expected to be saved from damage and failure over its entire design lifetime. These requirements are normally laid down by the respective naval authority, either based on an own and self-maintained rule set, international standards or referring to the naval rules of a classification society, as given by (DNV GL, 2015) for instance.

Ship structures might get damaged due to environmental, accidental, or operational loads. Failure modes can be permanent deflection, rupture or buckling or cracking under the action of cyclic loads. The former failure modes are commonly referred to as Ultimate Limit States (ULS) and the latter as Fatigue Limit State (FLS), but both to be addressed by the standards or rules applied for the structural design.

A common key difference between the design of naval and merchant vessels is the consideration of corrosion margins. Historically many naval vessels have been designed according to the standards of naval authorities e.g. the German BV1040 (BV 1040-1, 2007) without any consideration of corrosion margins. In these cases, often only the very small rolling tolerances (plus tolerances), typically between 0.2 and 0.3 mm can be utilized for this purpose i.e. when corrosion is observed although they are not intended for this.

Ship structures including naval vessels suffer from two main degradation mechanisms: corrosion and structural fatigue. For both mechanisms the design baseline must be known to assess the actual hull condition in relation to the condition at newbuilding stage. Furthermore, conversions and up-grade measures which are typical and relevant for navy vessels should be considered as they can have an important impact on the structural capabilities and utilization over time.

3.2.1. Degradation by corrosion

With respect to corrosion, two different phenomena must be considered. On the one hand, general corrosion - resulting in a laminar thickness diminution – and on the other hand local corrosion as pitting and grooving - leading to localized thickness reductions.

In class rules e.g. (DNV GL, 2019) degradation by general corrosion is commonly considered by standard corrosion margins, t_c as a simple add on to the required scantlings. The corrosion margins define in a generic way the permissible reduction of the as-built thickness, $t_{a.b}$, until the respective plate or stiffener must be replaced or reinforced. Hence, the renewal thickness, t_{ren}, is represented by the difference of $t_{a.b}$ and t_c. If, in a class survey, the measured plate thickness, t_{meas}, is found to be smaller than the renewal thickness, the plating must be renewed.

In this context it is important to mention that the special thin plate design of naval vessels requires adjusted corrosion margins which are lower compared to the standard margins of merchant vessels. In addition to the use of the standard corrosion margins for naval vessels the DNV GL Navy Rules (DNV GL, 2015) allows the application of individual corrosion margins– a vital feature of any LOTE approach.

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In addition to the global impact of corrosion, the local effects of corrosion must be considered within a LOTE procedure. These must be differentiated into the local effects of general corrosion, i.e. if a plate or girder subjected to general corrosion can still withstand local loads e.g. tank pressures and local corrosion types like pitting and grooving.

3.2.2. While the local impact of general corrosion is assessed by means of a prescriptive net thickness-based rule check, for local corrosion types a different approach should be used. DNVGL's LOTE procedure builds on a transformation of the well-established approach and acceptance limits for merchant vessels to the special conditions of navy vessels.

3.2.2. Degradation by structural fatigue

Fatigue as the degradation caused by cyclic loads is always directly linked to a structural detail and its actual stress concentration, fabrication quality and post weld treatment. The baseline with respect to fatigue, is given by the lifetime of the most fatigue sensitive structural details. For single hull navy ships large openings and the transitions between the superstructure and the hull are typically subjected to a high fatigue utilization. The structural details required for fatigue strength assessment are determined with consideration of probability of fatigue cracking and consequence of failure.

3.3. Design loads

The calculation of appropriate design loads – ULS loads for corrosion and the required minimum thickness list and FLS for fatigue – is the initial step of any baseline determination. Methods ranging from first principal CFD methods e.g. according to the design wave approach (Rörup, et al., 2008) to simple Rule formulas - can be applied.

To account for coinciding load situations, rule sets usually rely on explicitly combinations of design loads. The design wave approach however does not specify the related design wave a priory. Instead, it analyzes wave-induced hydrodynamic pressures and finds those wave situations that lead to critical loads. Fully balanced wave load cases considering a realistic phasing of the different load components and unlike the traditional rule formula-based design, the direct wave load analysis accounts for physically rational loads experienced by the ship.

When it comes to the local loads e.g. tank pressures, green water etc. it is recommended to apply simplified loads from appropriate Rules and applicable guidelines.

3.4. Basic and advanced procedure

In general, the level and extent of the investigations to be carried out within a LOTE procedure depends on various factors and conditions. The level and quality of available data and information, the schedule, the budget and of course the goal to be reached must be named in this respect. Generally, it is to be distinguished between two possible approaches, the basic approach and the advanced procedure.

The basic procedure utilises for both global and local loads the prescriptive rule loads in connection with standard corrosion margins.

In practice often the advanced approach is chosen where the global hull girder loads (ULS and FLS) are calculated by means of direct wave load analyses tailored to the vessel type to be investigated, while a Rule-based approach is applied for local loads like sea pressures, tank pressures and green water. In any case, possible impacts of conversions and/or up-grades and changes in the operational profile, must be investigated and considered.

Whether a high-level simulation based, or a simplified prescriptive solution is to be applied is not a simple black and white decision. More sophisticated and advanced solutions will not in all cases automatically lead to better or beneficial results.

3.5. Determination of structural utilization

The determination of the structural utilization is a prerequisite for the generation of a list of minimum tolerable thicknesses the so-called minimum thickness list. This minimum thickness list is the vital information indispensable for any advanced corrosion assessment.

3.5.1. ULS failure modes

As discussed before, failure modes under ULS loads can be permanent deflection due to exceedance of the material's yield strength, rupture if tensile strength is exceeded or buckling in case of exceedance of the stability limits. All these failure modes must be considered in determining the strength limits of the structure or the minimum thicknesses, respectively.

To account for the consequences of the maximum expected environmental and operational loads, the stresses under these loads are computed and subsequently compared with the permissible stresses or loads respectively.

The main difference of a ULS assessment during initial design or for a LOTE assessment, is the hull structural condition to be considered. The former is dependent on the design approach based on gross or net thicknesses while the latter i.e. the LOTE ULS assessment, considers dedicated diminution scenarios Here the impact of general corrosion beyond the standard tolerance limits of relevant rules (DNV GL, 2015) and standards is investigated.

The derivation of reasonable diminution scenarios with practical relevance requires long term experience from a large base of ships and navy vessels in operation. Typically, two diminution scenarios are evaluated within a LOTE assessment.

Figure 2 shows two common global corrosion scenarios reflecting typical but conservative degradation conditions which are very close to what is observed on board.

In the first scenario, only the tank plates (in the double bottom) are assumed to be degraded down to net scantling. This scenario reflects, in a conservative way the experience from navy ships in operation.

The second scenario typically to be investigated is that all plates are affected by corrosion down to the maximum corrosion margin of tc = 1.0 mm for tank plates and tc = 0.5 mm for all other plates (DNV GL, 2015). This worst-case scenario reveals important information on the sensitivity of the design against global corrosion.

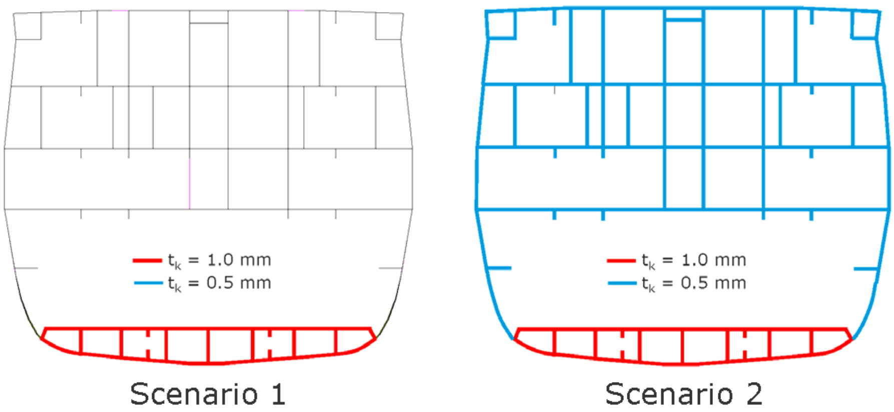


Figure 2: Typical global corrosion scenarios applied for LOTE assessment

The minimum thickness lists derived from the further ULS assessment of these global corrosion scenarios commonly show the biggest potential compared to the standard corrosion allowances of the Rules with a clear focus on the bottom area (tank top or inner bottom plate as well as bottom shell).

Independently from the scenario investigated for the ULS assessment a realistic distribution of the global stresses is essential for the quality of the results. It is strongly recommended to utilize a 3D global strength analysis as key additional input for the ULS assessment. The complex superstructure arrangements and large deck openings characteristic for navy vessels can be identified as key drivers in this respect. As illustrated in Figure 3 by red colour, also a first indication of areas of attention prone to fatigue damage can be obtained in this way.

 https://doi.org/10.24868/issn.2515-818X.2020.036

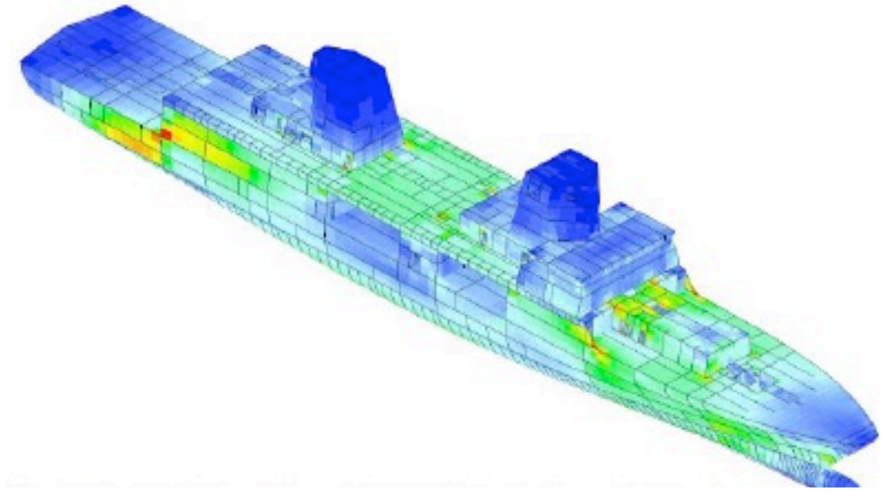


Figure 3: Distribution of principal stresses for a frigate type navy vessel computed by a combination of direct wave load analysis and 3D finite element analysis

3.5.2. FLS failure modes

As mentioned, fatigue is related to certain structural details showing high stress concentration and / or material notches. Due to the nature of the structural design of navy vessels, simplified 2D cross section based approaches are not recommended, as the accuracy and quality of the results cannot be expected to fulfil the requirements of a LOTE procedure.

Supported by experience with navy vessels, the structural details most relevant for the fatigue strength of the investigated vessel can be located and assessed within a global strength analysis. So called local fatigue approaches, e.g. as described in (Radaj, et al., 2006), must be applied to achieve the required quality and accuracy of the results. Figure 4 shows the global FE model and the related fine mesh sub-model of a superstructure - hull transition – a typical fatigue sensitive structural detail of navy vessels.

Commonly for the 20 – 30 structural details most relevant with respect to fatigue, the expected lifetime is calculated. Influences of the operational profile as well as of up-grades and modifications are to be considered.

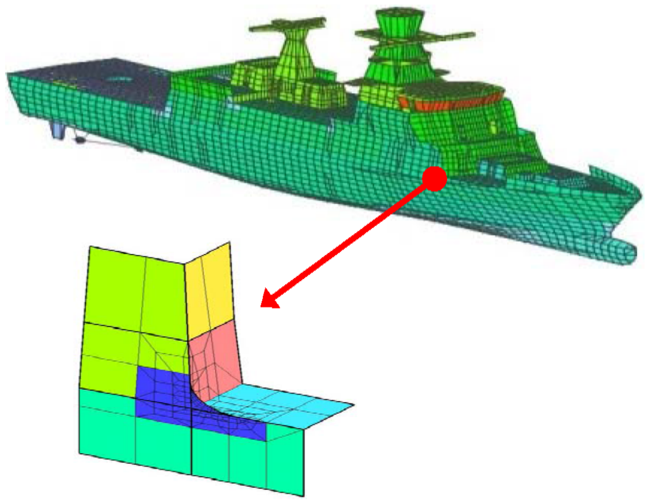


Figure4: Global FE model and fine mesh sub-model of a superstructure – hull transition as a typical fatigue sensitive structural detail of navy vessels

3.6. Condition survey

Within this step the results of the baseline determination are reconciled with the information on the actual condition of the vessel. This applies for both the hull structure as well as the machinery. Based on the outcome of the survey recommendations are for immediate repair measures and which repairs should be planned for the next docking.

 https://doi.org/10.24868/issn.2515-818X.2020.036

3.6.1. Hull structure

A dedicated Navy CAP (Condition Assessment Program) survey is applied for the determination of the actual hull condition of the vessel. Based on the well-established CAP procedure for tankers the Navy CAP survey is adjusted to the special conditions of military environment and navy vessels. Key principles of the rating systematic are kept but the scope and the acceptance limits are modified for application to navy vessels.

As a result, the entire hull structure is assigned with a rating ranging from CAP1 to CAP4.

The thickness measurement results obtained from the survey are to be systematically documented. In Figure 5 a generic example of a minimum thickness list is shown. In this example the results of the baseline determination are compared with the actual condition. The recommendations for repair are automatically indicated by the software for each specific plate field.

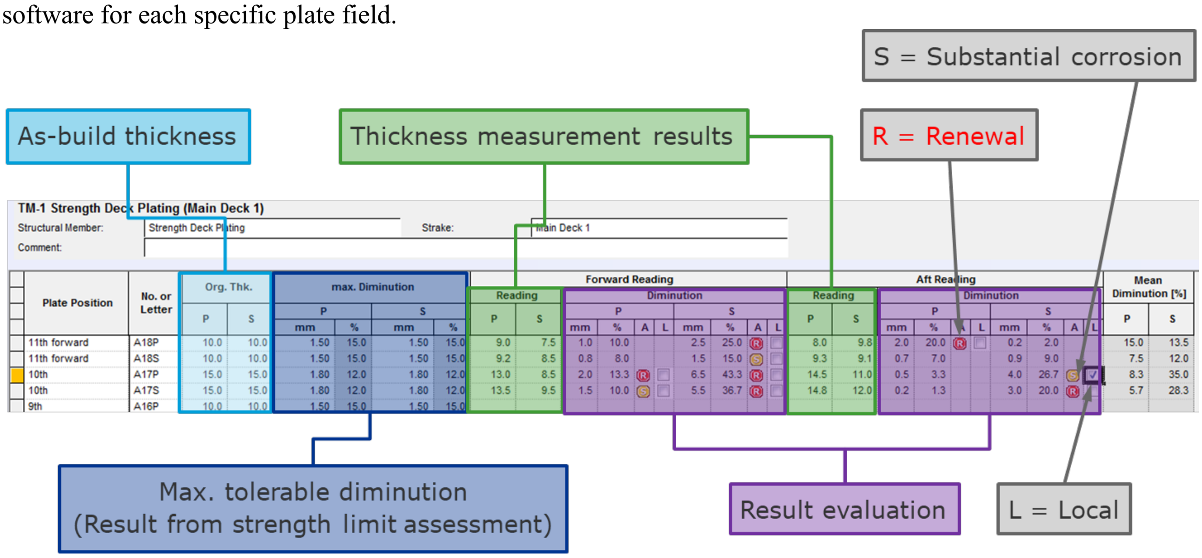


Figure 5 Example of Minimum thickness list

3.6.2. Machinery & Equipment

As for the hull structure, a dedicated navy CAP (Machinery) procedure is considered for the determination of the actual condition of machinery components.

DNV GL conducts targeted risk-based survey procedure for machinery and systems based on a digitized database regularly updated where all the feedback and findings from surveys and inspections are compiled, assessed and prepared to form a reliable basis for the survey scheme. Beside the machinery components itself, special topics such as the aging of cables and related efforts for exchange, must be considered when a maintenance strategy is to be developed which is a frequent consequence of such investigations.

3.7. LOTE assessment

The final step within a LOTE procedure, is benchmarking the available lifetime against the desired extended lifetime. While lifetime is a direct result of a fatigue assessment, things are more challenging for corrosion assessment. Especially a reliable prediction of the corrosion is still a subject of research and the results show very large variances (Paik & Melchers, 2008). So, for practical application, this is solved by applying an empirical and experienced based CAP survey and classification systematics.

The situation for machinery is not as well defined as for the hull structure meaning that a quantitative prediction of the to-be-expected lifetime is extremely difficult. An intelligent combination of CAP machinery survey results and condition monitoring including a smart data analysis, offer the greatest potential to improve the situation in future. So currently the experienced based but well proven CAP machinery approach is applied to evaluate the condition of machinery components.

Basically, two different situations need to be considered from the condition evaluation – the aspired lifetime (extension) is reached without any additional measures (Situation A) or not (Situation B). While for the former, no further action needs to be taken, for the latter reasonable countermeasures must be developed and verified to reach the (lifetime extension) goal. **Error! Reference source not found.**6 illustrates these basic situations schematically.

Of course, the situation is often not that simple if different degradation mechanisms and disciplines show divergent results.

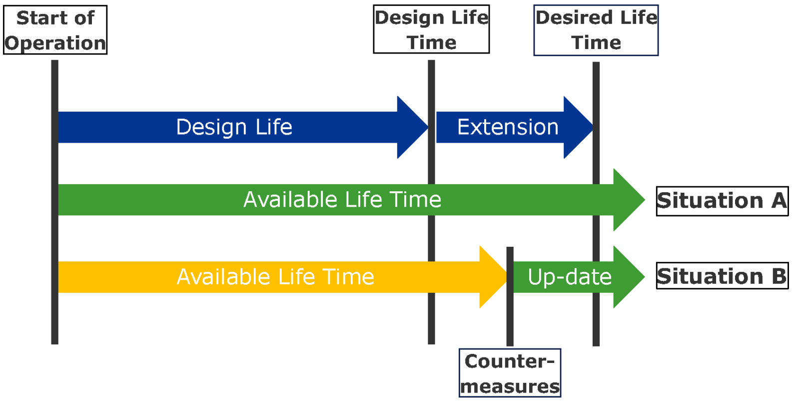


Figure 6: Basic LOTE situations – schematic illustration

4. Experience from practical application

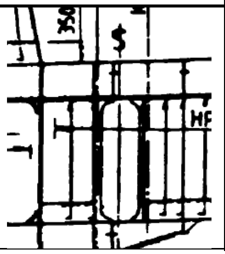
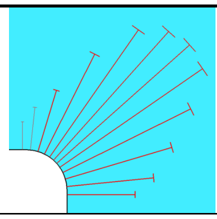
The here described LOTE procedure has proven its practical applicability and benefits from several projects on different naval surface combats. This covers both simple basic approaches and sophisticated advanced solutions. Eventually the simplicity of the core results in terms of minimum required thickness lists and remaining fatigue lifetimes is very well received and fitting into the maritime practice.

Especially the combination of global strength analysis and prescriptive Rules under the umbrella of the DNV GL naval technical assurance regime confirmed the anticipated perfect match showing that both parts of the Rule framework i.e. direct simulation procedures and prescriptive requirements are well aligned.

The consideration and consequent re-use of calculation models and calculation results from the design phase does not only offer a consistent and seamless technical basis for the LOTE calculations and assessments but has also proven to ensure a most efficient approach from commercial point of view due to considerably reduced efforts needed. However, this depends on the quality and the approach that was applied during the initial design phase. This is called “aging of procedures” and describes the continuous development of the state of practice of calculation and assessment procedures respectively. Its potential effects on a LOTE assessment are described more in detail by means of the subsequent example of a fatigue assessment.

The procedures reflecting the state of the art of fatigue assessment have been fundamentally changed and improved during the last 15 or 20 years. While in the 90’ of the last century a simple generic stress concentration factor (SCF) based fatigue assessment for a very limited number of structural details was performed today a direct fatigue assessment (Radaj, et al., 2006) by means of sub-model or direct refinement technique is applied for a large number of relevant structural details. A typical comparison of both approaches is presented in Table 2 for a typical fatigue sensitive structural detail of a naval vessel (door opening in a longitudinal bulkhead). The SCF based solution from initial design is scaled to 100 % utilization i.e. a utilization factor of USF = 1.0 (see Table 2).

Table 2: Comparison of the fatigue assessment applying SCF as well as sub-model technique (Doerk, 2017)

Detail	SCF approach		Sub-model approach	
	SCF	USF	Notch stress	USF
	$SCF_{\square n} = 4.2$	**1.0**		**1.4**
	$SCF_{\square} = 7.0$			

Significant differences compared to the initial calculations performed during the design phase may result just from applying current state-of-the-art approaches within LOTE assessment – a 40% increased utilization for the actual example. It must be emphasized in this respect that the direction of the deviation is varying i.e. that increased as well as decreased utilizations have been observed when comparing sub-model results against SCF results. For practical application, it is essential to be aware of this and define (agree) a way forward already in the early phase of each particular LOTE project.

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When it comes to the strength part of the LOTE assessment i.e. the determination of the minimum required scantlings and the related available corrosion margins commonly significant margins beyond the standard corrosion margins of DNV GL navy Rules (DNV GL, 2015) are unveiled. These can be used to form a reliable basis for a subsequent condition-based life-cycle management regime. Consequent application and utilization of these margins has already shown significant beneficial effects on both schedule as well as costs of different maintenance and repair programs. This is mainly due to the increased flexibility when repair measures must be taken offered by the individual corrosion margins and related acceptance limits.

5. Conclusions

DNV GL's systematic procedure offers a sound and flexible basis to deal with LOTE of naval vessels tailored to the individual project and its objectives. The procedure is sound and well proven by its already successful application to several projects worldwide. Basically, it can be applied in the design or new-building phase of a project as well as during the mid-term or late ship in operation phase. Irrespective of when it is applied, forming the basis for planned maintenance and repair schemes, it offers clear benefits in terms reduced out of service time and costs savings.

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