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Low temperatures: terms and their application in ISO 19906

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ABSTRACT

In Arctic offshore activities, low air and water temperatures can lead to a wide range of adverse effects. When designing offshore structures and planning operations in arctic and cold regions, it is essential to ensure that materials and equipment, such as structural steel, mechanical equipment, liquids, and personal protective equipment including clothing, are fit for purpose.

In developing the 2019 edition of ISO 19906 “Arctic Offshore Structures”, one of the objectives has been to clarify provisions and definitions related to low temperatures. This is done by specifying three categories of low temperatures and by considering the corresponding temperatures at individual positions within three low temperature zones. The three categories are developed by improving the earlier definition and application of “Lowest Anticipated Service Temperature” (LAST), by explicitly applying the extreme-level (EL) low temperature for safety-critical equipment and materials, and by introducing a new parameter “Lowest Operational Service Temperature “(LOST) for equipment not required to operate in extremes. These definitions are explained in the paper and use of them is discussed.

When considering low temperature zones and individual positions within zones, the importance of selecting appropriate averaging intervals and elevations prior to estimation of extreme air temperatures is demonstrated.

The paper summarize typical applications where low air temperatures and low water temperatures can be of concerns and explains differences between various types of design temperatures used in the maritime and offshore industries. This includes design temperatures for materials and how local temperatures are used to specify material test temperatures.

KEY WORDS: LAST; LOST; Temperatures; Material testing; Temperature zones.

INTRODUCTION

Low air and water temperatures are a feature of arctic offshore activities. Materials and equipment, such as structural steel, mechanical equipment, liquids, and personal protective equipment, need to be fit for purpose down to the lowest temperature at which they are required to perform their function.

Material properties can change when the material is exposed to varying ambient temperatures. Steels can become brittle in low temperatures and unable to provide the required strength when exposed to design actions. Due to this, standards such as ISO 19902, ISO/TS 35105, API RP2A, EN 10225-1, and DNVGL-OS-C101 recommend or specify test temperatures for materials which are somewhat colder than the lowest temperatures to which the steel is expected to be exposed in service.

For equipment, it is essential that safety-critical equipment such as fire systems are available for operation at extreme-level low temperatures. Other equipment could be designed to less stringent temperatures, for example if operation can be suspended for a short period if the temperature falls below a level specified by the designer/operator.

This paper first highlights the content in key existing documents. A review of how low temperatures are addressed in existing codes and standards for offshore and arctic structures, and in some key maritime codes, reveals inconsistency and a lack of clarity.

The 2019 edition of the International Standard ISO 19906, see Muggeridge et.al., 2019, strives to address issues of extreme-level (EL) minimum temperatures, steel material test temperatures, and winterisation, with coherent provisions evolved from existing documents.

TEMPERATURE DEFINITIONS IN OTHER STANDARDS

API Standards - Origins of Lowest Anticipated Service Temperature (LAST)

LAST was first introduced into API RP2A *Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms* in the 1980s for steel specification and testing. It has not been modified since that time and persists unchanged in the 22nd (2014) edition.

API RP2A asserts, as information, that Class A steels, suitable for use at sub-freezing temperatures and for critical applications, can meet impact test requirements down to -40^{o}C, and may warrant testing at up to 30^{o}C below the “lowest anticipated service temperature”, depending on the specification. The acronym LAST is introduced only for recommending test temperatures related to LAST for underwater joints. With focus on service in the Gulf of Mexico, test temperatures would not be as low as -40^{o}C.

Unambiguous guidance for the interpretation of the terms “minimum” and “anticipated” are not found in the API standards. Furthermore, guidance on how to estimate LAST statistically is not included.

API RP2N *Structures and pipelines in arctic conditions* (the second edition, 1995, is the earliest edition available to the authors) adopted identical text to API RP2A. There were no additional recommendations specifically for low temperatures.

API RP2N, however, recognised that offshore structures in an ice environment could have “minimum ambient service temperatures” which could be classified into three different low temperature zones, where a LAST should be established for each:

1. The Submerged Zone
2. The Above Water Zone
3. The Enclosed Zone

ISO 19900 series (Petroleum and natural gas industries - Offshore structures)

The standards comprising the ISO 19900 series of International Standards on offshore structures is elaborated in Muggeridge et.al., 2019. ISO 19900 provides general requirements for all offshore structures. LAST (as an acronym) does not appear in ISO 19900, neither in the 2013 edition nor in the 2019 edition

ISO 19901-1 (2015 edition) addresses metocean including "air temperature" and "sea temperature at specified depths" in general terms. Recommendations for design temperatures such as LAST or similar does not appear in ISO 19901-1. There is no guidance on measurement in air such as elevations and durations, and no guidance on extremes, service temperatures, or LAST. The Regional Annexes give some information on regional air and sea temperatures, but not consistently.

LAST is not used in those of the ISO 19900 series of standards for concrete structures and floating structures, although the words "service temperature" and "lowest anticipated …. temperature" are used just once in each standard respectively.

ISO 19902 addresses fixed steel offshore structures, with a scope similar to that of API RP2A. ISO 19902 first introduced LAST to the ISO series of standards for offshore structures, for steel material testing. LAST is however not "defined" but adopted from API RP2A. LAST is set out in 19.2.2.4 of the normative text of the 2007 edition as follows:

> "The steel performance characteristics are affected by the lowest anticipated service temperature (LAST). The LAST value to be used in the material selection shall be in accordance with applicable regulatory requirements in the region of application.
>
> "The LAST value establishes the temperature for [Charpy impact test] toughness, which shall be taken as the LAST minus the temperature margins shown [up to 30^{o}C below LAST]".

Tables provided in regional annexes for ISO 19902 set out LAST for some but not all offshore areas worldwide. The tabulated values distinguish between LAST in air and LAST in water.

ISO 19906:2010 (Arctic Offshore Structures)

LAST was defined in the 2010 edition of ISO 19906 as an hourly-average extreme-level (i.e. 10^{-2} annual probability/100-year return period) temperature. Several clauses in ISO 19906:2010 refer to use of LAST in relation to applications such as material selection and winterisation of topsides. Some clauses in ISO 19906:2010 do however refer also to EL temperatures (corresponding to 10^{-2} annual probability) instead of LAST and there is a lack of clarity related to the interpretation of "anticipated".

Furthermore, the industry has questioned the need for requiring full functionality for all equipment and systems down to EL low temperatures. For some types of equipment, it may not be critical to continue operations during the coldest atmospheric events. With respect to actions it has been argued that it's unlikely (hence overly conservative) to consider EL temperatures simultaneously with ice actions or other environmental actions. Another argument raised against the use of LAST in 19906 is that the cooling process of equipment and of enclosed areas may be slow and that the exposure time needs to be accounted for hence using a 1-hour average temperature will be conservative for some types of equipment (or fluids).

ISO/TS 35105 (Material requirements for Arctic operations)

ISO/TS (Technical Specification) 35105 published in 2018 is intended for structural materials used in regions where LAST in air is less than -10°C. It clarifies that the standard is intended to be applicable for regions with temperatures down to -60°C and that such cold anticipated service temperatures can require material testing in temperatures down to -90°C if the provisions of ISO 19902 are followed. However, the authors of ISO 19902 were not considering such low temperatures when specifying testing at 30°C below LAST.

For the definition of LAST, a reference to ISO 19906 is provided. It is stated that defining LAST at Extreme Level (EL=100 year return period) is considered reasonable to ensure that an acceptable probability of failure (10^{-4} per year) is achieved.

EN 10225-1:2019 Weldable structural steels for fixed offshore structures

Annex F of European standard EN 10225-1 addresses steels for offshore structures in arctic areas. It covers "LAST temperature areas" down to -40°C but limits the Charpy test temperature to -60°C, which is the same as required for a LAST of -30°C.

CAN/CSA S473-1992 Steel structures (withdrawn)

Canadian standard CSA S473 is planned to be replaced by ISO 19902. In part, it is already replaced by CAN/CSA-ISO 19906, the national adoption of ISO 19906:2010 According to experts involved in development of the 1992 edition, a lot of effort was directed at the requirements for toughness for steel structures. These requirements were not fully transferred into ISO 19902:2007 and ISO 19906:2010.

Requirements for test temperatures were defined with a toughness design temperature, *T*, as a basis. *T* was defined as "the minimum temperature to which a structural element is subject, established on the basis of an annual probability of exceedance of 0.5". This annual probability corresponds to a return period close to 2 years. The rational for this probability level is not provided. Furthermore, whether *T* is to be considered as an instantaneous temperature or an average temperature over some period (e.g. 24 h) is not clarified.

NORSOK standards: N003 and N004

NORSOK N003 (Action and Action effects) specifies that structures shall be designed for the most extreme temperature differences they may be exposed to. The ambient sea or air temperature shall be calculated as an extreme value with annual probability of being exceeded of 10^{-2}. The rational for this probability level is not provided and there is no guidance on which averaging interval to use for temperature.

NORSOK N004 (Design of steel structures) invokes the NORSOK material data sheets (M120) for assurance of toughness and weldability for structures with an operating temperature down to -14°C. This is the principle standard for installations on the Norwegian shelf. The logic behind the limit at -14°C is not explained but a likely explanation is that -14°C relates to LAST at the coldest geographical location in the Norwegian Sea. When field developments were started in this region during the nineties, operators and authorities realised that air temperatures could be colder than -10°C (which typically had been adopted as minimum design temperature in the Gulf of Mexico and in the North Sea up to 62°N). Instead of developing new requirements for material testing for projects in the Norwegian Sea, it was assumed that the practice used to the south of 62°N could be applied also in regions were air temperatures may be slightly colder than -10°C. Due to this, the NORSOK standards M120 (Material data sheets for structural steel) and M101 (Structural steel fabrication) specified that they were applicable for structures with minimum design temperatures down to -14°C. The limit -14°C is therefore not related to any fundamental change in material properties. There is no guidance in any of the NORSOK standards on how to address steel for structures in colder regions.

DNVGL documents OS-C101 and OS-A201

OS-C101 (Design of offshore steel structures) introduced the following two temperature definitions:

1. ***Design temperature (t_d)*** **–** reference temperature for where a unit can be transported, installed and operated. The design temperature shall be lower or equal to the lowest mean daily air temperature (*LMDAT*) in air for the relevant areas.
2. ***Service temperature*** **–** reference temperature on various structural parts of the unit used as a criterion for the selection of steel grades.

DNVGL documents generally require that structures are designed with a service temperature not higher than the design temperature unless adequate supporting data can be presented.

LMDAT corresponds to the average air temperature at the coldest day during a year and is usually 15°C to 25°C degrees warmer than the extreme low air temperatures in Arctic regions.

OS-A201 (Winterization) introduced a reference extreme low air temperature (t_w) or winterization temperature. This is a temperature parameter which a ship/installation owner specifies as a basis for selection of winterization measures. There is a guidance note recommending end users to select the winterisation temperature in accordance with the LAST definition as provided in ISO 19906. Further, OS-A201 specifies that the winterization temperature cannot be less than t_d-15°C where t_d is the design temperature from OS-C101.

In this way, OS-A201 introduces the concept of a winterization temperature different from LAST and specifically for winterization, which has been further developed in ISO 19906:2019 to identify the three types of low temperature.

IMPORTANCE OF AVERAGING INTERVAL

Maritime standards generally refer to 24-hourly air temperatures in relation to material selection while ISO 19906:2010 specified that LAST shall be based on hourly ambient temperature. The following facts need to be accounted for when specifying low temperatures for design and assessment of material or systems/equipment adequacy:

1. Instantaneous temperatures are different from e.g. daily average temperatures;
2. The number of events per time unit affects the estimation of extreme values;
3. The duration of low temperature exposure will decide how quickly materials and equipment cool down.

Regarding temperature fluctuations and averaging period

Figure 1 shows an extract of a hindcast data set for the Johan Castberg location in the Barents Sea. The data are initially represented with 1-hourly sampling where each data point is considered to represent an average of the air temperature at the location over a period of 1 hour. By averaging 24 temperature values every day, a time series for daily average temperatures is established and plotted on top of the hourly data.

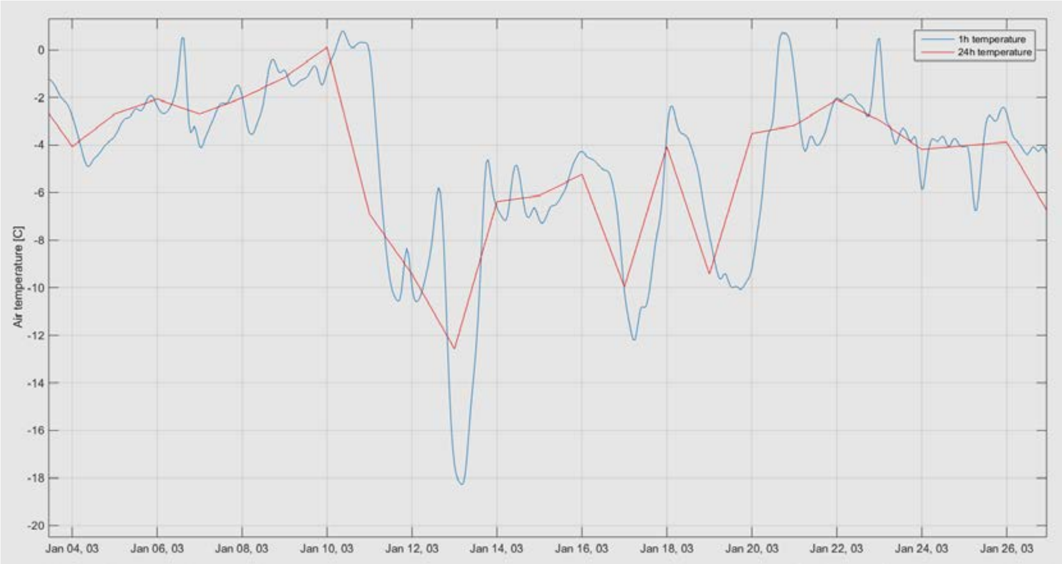

Figure 1. Time series plot of 1-hourly air temperature data vs daily average temperatures at the Johan Castberg field in the Barents Sea.

The hourly air temperatures can sometimes be significantly lower than the lowest daily average temperature. If one consider e.g. a gas detector qualified to function down to -16°C this will be satisfactory for use at Johan Castberg if one consider only the daily average values but it could stop operating for an hour or more due to the lower instantaneous temperature.

Regarding estimation of EL minimum temperatures

There are various acknowledged methodologies to estimate extreme-level values from a data set. If an annual extreme value (AEV) type of analysis is used, the duration of individual low temperature events is not important because events over one full year are considered. If a Peak Over Threshold (POT) approach is used, a high data sampling frequency is likely to break up the “storm events” and generate more peaks than if a lower frequency is used. This will not necessarily influence EL estimates since the peak distribution also is changed. If the Initial Distribution Method (IDM) is used however, all data values are independent and the number of events per year will simply be a function of the duration of each data point. Since the IDM methodology is commonly used (due to its simplicity) it can be used to illustrate how the duration of the input data can affect the extreme-level (EL) estimates:

If we are considering one hour temperature data, the number of events within a 100-year period will be 100•365•24. The probability of not exceeding the EL value will be:

$$P_{EL-1h} = 1 - \frac{1}{100 \cdot 365 \cdot 24} \approx 0.9999989 \quad (1)$$

If we are considering daily average temperatures, the number of events within a 100-year period will be 100•365. The probability of not exceeding the EL value will be:

$$P_{EL\_24h} = 1 - \frac{1}{100 \cdot 365} \approx 0.9999726 \quad (2)$$

Figure 2 shows a probability plot based on daily average values sampled every third hour. A statistical distribution is fitted to the data. By using the probabilities for not exceeding a parameter value with duration 1 h versus 24 h we can see that the EL estimates will differ by about 5°C even when based on the same data set.

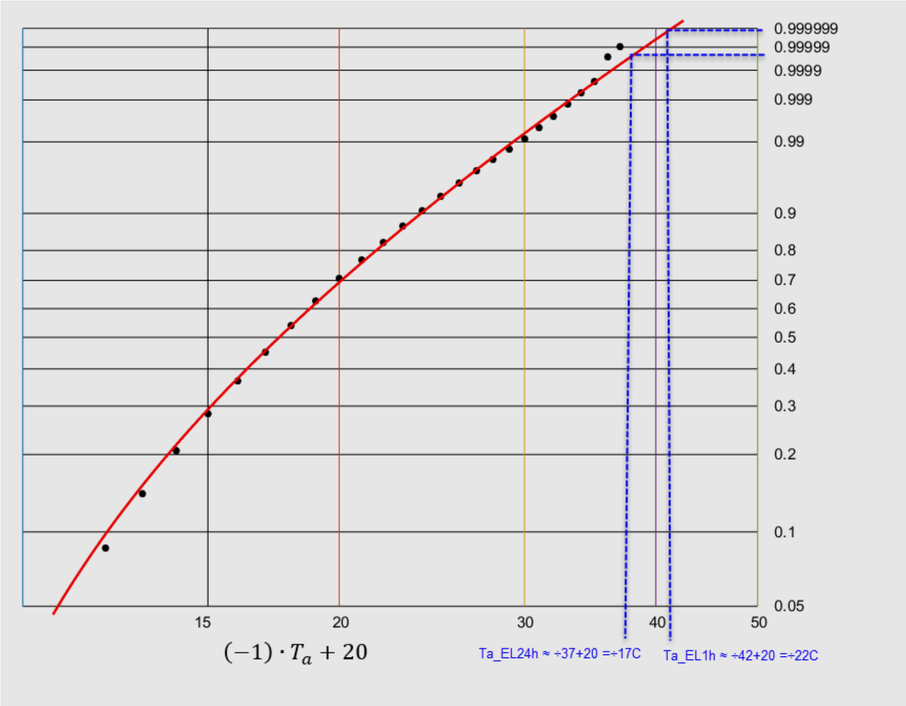

Figure 2. Illustration – effect of averaging interval when extrapolating to EL

DISCUSSIONS RELATED TO SELECTION OF PROBABILITY LEVEL FOR LAST

Impact on design verification

The objective of design verification is to ensure that in each design situation the structure and its components have adequate structural reliability. Both action effects (calculated from actions/loads) and resistance are stochastic parameters, and can be represented as illustrated in Figure 3. Design verification is achieved by ensuring that the probability of action effects being larger than resistance (black area in Figure 3) is sufficiently low and achieves a target for structural reliability.

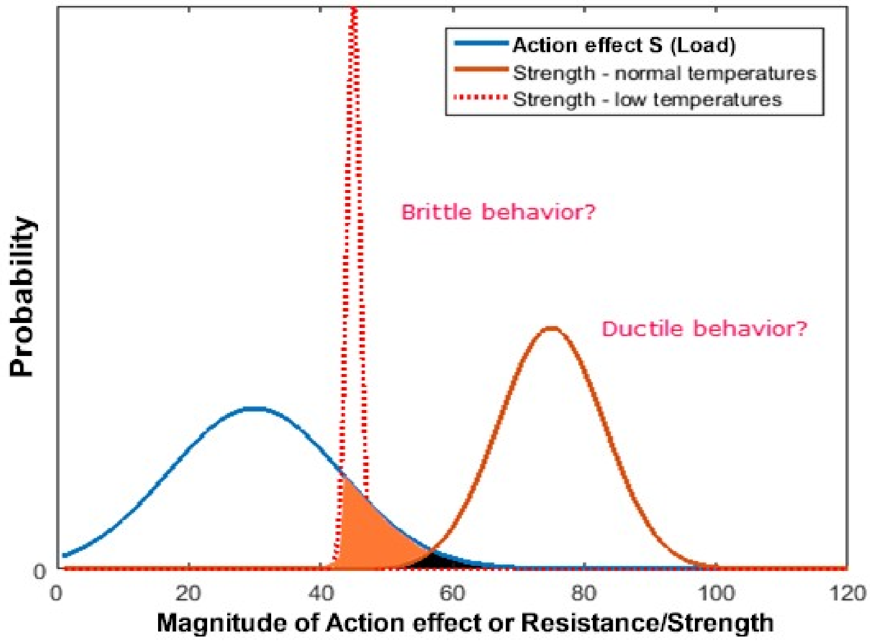

Figure 3 Illustration of basic principles in structural reliability

If the material/structure is exposed to ambient temperatures significantly lower than those for which the material is qualified, there is a possibility that the material properties become different and weaker than at “normal” temperatures. Figure 3 illustrates how the resistance probability distribution could change if low temperatures cause brittle rather than ductile behavior. The additional probability of action effects being larger than resistance is illustrated by the red area in Figure 3.

Action-Temperature combinations

By considering simultaneous data for actions (*A*) and temperatures (*T*), correlations between these two parameters can be studied. Figure 4 shows a scatter plot based on wind and air temperatures from a randomly selected hindcast data set in the Northern Barents Sea. For simplicity it has been assumed that the winds represent a deterministic action. The unit MN is used in the figure for illustrative purposes. A contour line (red line) identifying combinations of *A* and *T* that correspond to a 10^{-2} annual probability of exceedance level (100 year return period) is shown.

It can be seen that the air temperature associated with the EL-action (-2°C, which is the joint probability or “companion” air temperature at this location for the EL action of 29.3 MN on this structure) is much warmer than the EL-temperature (-38°C. If the companion temperature is used as “design temperature” many lower T values can be seen to occur with relatively high *A* values.

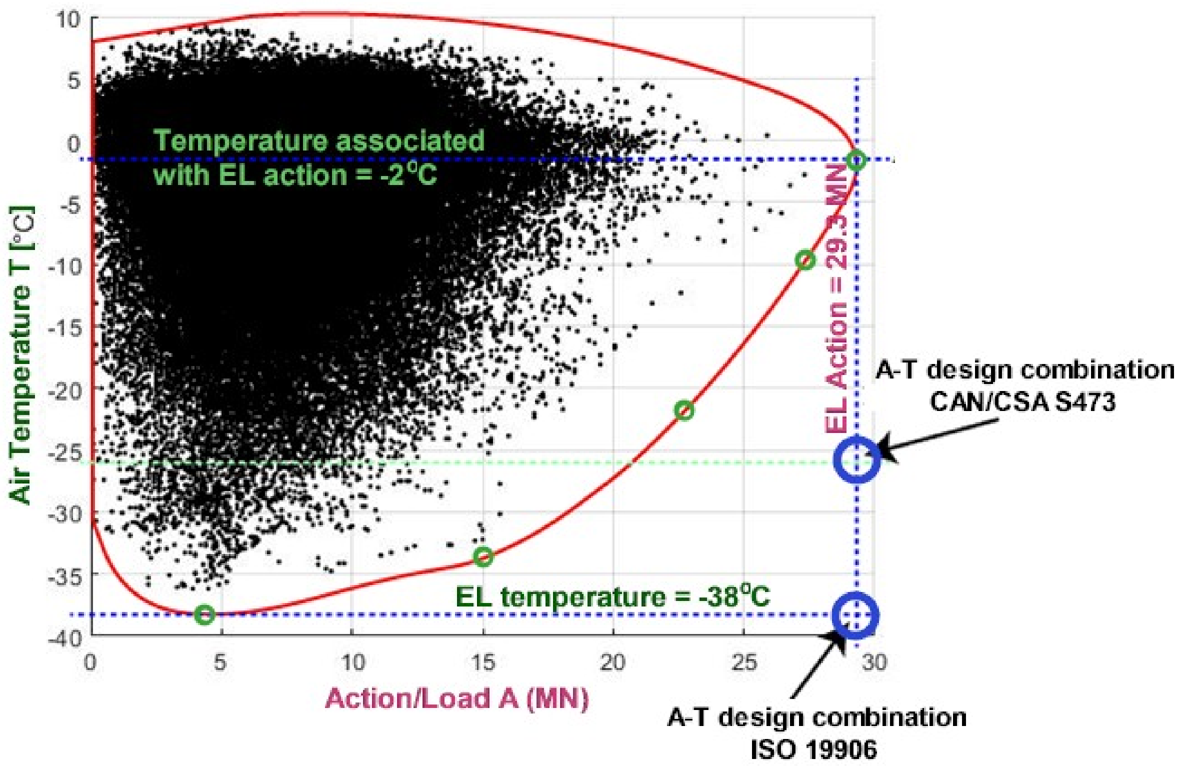

Figure 4. Scatter plot of 30 years of 3-hourly data of action vs temperature combinations.

With reference to Figure 4, a contour line corresponding to annual probability of exceedance 10^{-2} is shown as red line. Green circles illustrate that following a contour line approach robustness for various A-T combinations along the contour line should be evaluated and confirmed as acceptable. Following a contour line approach, sufficient A-T combinations along the joint probability contour should therefore (in theory) be evaluated and robust design should therefore be ensured for all combinations

Figure 4 shows further that using the approach recommended in ISO 19906 (both 2010 and 2019 versions), design is based on an *A*-*T* combination with annual probability far less than 10^{-2}. For comparison, the CAN/CSA S473 toughness test design temperature was set by the ambient temperature being exceeded (in a negative sense) with annual probability of 0.5 which corresponds to a LAST of about -26°C in the data set selected for illustration. As with ISO 19906, S473 would also result in an *A*-*T* design combination with annual probability far less than 10^{-2}

Designers could theoretically avoid unrealistic *A*-*T* design combinations if they knew at which ambient temperatures the transformation from ductile to brittle behavior would take place and exactly how much the probability distribution for resistance would change (ref. Figure 3). If the combination of updated material strength vs temperature causing transition from ductile to brittle was found to be outside the contour line, the material under consideration would have been considered satisfactory for purpose. For several reasons, not discussed further here, such an approach is not considered realistic.

To eliminate the possibility of adverse consequences arising from *A*-*T* combinations occurring with an annual probability greater than 10^{-2}, the only practical solution appears to be to require that there is no degradation, and original material properties persist, when the material is exposed to a LAST based on EL minimum temperature. This is the *A*-*T* design combination point for ISO 19906 illustrated in Figure 4. This would require a test temperature of -68°C for most of the steel ductility tests if testing at 30 °C below LAST is specified. See below for further discussion of material testing.

UPDATED TEMPERATURE DEFINITIONS IN ISO19906:2019

Based on the information and discussions presented above it was concluded that three low temperature categories and furthermore three low temperature zones be established in ISO 19906. The intention behind identifying three categories of low temperature is to ensure that appropriate temperature parameters are used for relevant applications.

The intention behind the low temperature zones is to ensure that the low temperatures relevant to integrity of structural materials, to the operation of systems and equipment, and for other purposes can be differentiated to take due account of locations and conditions of use.

With respect to duration, ISO 19906:2019 requires that temperatures used as EL-minimum temperatures and as LAST are based on 3-hourly average values. This contrasts with maritime codes such as DNVGL-OS-C101 and the IMO Polar Code which refer to 24-hour average temperatures.

The low temperature categories specified in ISO 19906:2019 are explained below:

Extreme-level (EL) minimum temperatures

These temperatures are calculated for positions in and around the structure, using the available meteorological and oceanographic data. They are the low temperatures with an annual probability of exceedance of 10^{-2} (100 year return period) in the various zones. They apply for ensuring adequately-reliable operation of safety critical equipment.

Excursions beyond the EL minimum temperature are considered abnormal and would be considered in a risk management plan in the unlikely event they were to occur.

Lowest Anticipated Service Temperature (LAST)

These temperatures apply for structural materials, in particular for determining test temperature for steel. In Arctic and cold regions, and pending further data and research, LAST shall be determined as the EL minimum temperature, except that LAST shall not be warmer than -10°C for positions in air or exposed to sea ice.

The limit of -10°C ensures that LAST for arctic and cold regions is not warmer than LAST for other regions such as the North Sea where applicable regulatory requirements as invoked by ISO 19902 mandate a LAST of -10°C.

Lowest Operational Service Temperature (LOST)

These temperatures are specified by the owner for winterization of non-structural, non-critical systems, equipment and materials. For systems and equipment where safety is not an issue, the owner would typically determine the reliability and availability necessary for the optimum return on investment.

Low Temperature Zones

Three low temperature zones are specified in ISO 19906:2019, as follows:

a) ***In air (exposed).*** The low temperatures shall be determined from the ambient atmospheric air temperature at the location of the structure. The same value normally applies for the entire zone, but it can be specified to vary with height above sea level.
b) ***In water and below the seabed.*** The low temperatures shall be determined from the ambient water temperature profile and from shallow geotechnical investigation. Temperatures lower than the water temperature should be considered for positions near the water surface and exposed to the sea ice. The possibility of permafrost below the seabed should be considered.
c) ***Enclosed***. The low temperatures for enclosed or internal structures which are permanently heated may be higher than the in-air zone if risk assessment of heating systems and consequences of failure periods demonstrates adequate reliability of continued safe operation or standby. Localised cryogenic storage or other cooling conditions shall be taken into account.

ISO 19906:2019 advises that air temperatures for enclosed zones should be estimated based on atmospheric air temperature and the effect of enclosure and heating, with due consideration of risk of heating failure, and of heat flux and cool-down times before restart of heating. Such zones can be fully enclosed or partially enclosed.

APPLICATIONS IN ISO 19906:2019

Material Testing

ISO/TS 35105 specifies that varying temperatures will affect the elastic, plastic and fracture properties of steel, and requires material tests related to LAST as follows:

- Crack Tip Opening Displacement (CTOD) for materials that undergo plastic deformation prior to failure. CTOD shall be performed at LAST.
- Charpy impact test / Charpy V-notch (CVN) test which is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. A test temperature of 30°C below LAST is specified.
- Charpy transition curve shall be established based on tests in temperatures from +20°C to -80°C with 20°C intervals and with 3 tests at each temperature.

In addition, for safety critical connections, crack arrest toughness should be demonstrated at a low temperature depending on the method, on LAST and on material thickness. For LAST of -40^{o}C, ISO/TS 35105 postulates a crack arrest test temperature of -107^{o}C.

There is uncertainty as to whether test temperatures much below -60^{o}C are practical and are providing reliable results. For a LAST of -60^{o}C (noting that the EL minimum temperatures in some arctic regions can be less than this), the calculation of test temperatures to ISO 19902 and ISO/TS 35105 require actual test temperatures of -90^{o}C; and as low as -125^{o}C or less for crack arrest toughness tests.

ISO 19906:2019 addresses the low temperature testing and the very low temperature issues as follows:

> Temperatures for testing of steel shall be based on LAST but when calculating test temperatures based on ISO 19902 for structures in arctic and cold regions, the LAST shall not be taken as warmer than -10^{o}C (as explained above). The Norwegian limit of -14^{o}C, seemingly adopted in ISO 19902, is deemed not relevant globally.
>
> If a test temperature based on ISO 19902 is calculated to be colder than −60^{o}C, special consideration should be given to material thickness and to service conditions such as structural redundancy and joint probability of low temperature and internal stresses, in order to establish an appropriate test temperature. In such cases, the test temperature should not be warmer than -60^{o}C.

In this way, ISO 19906:2019 provides for the possibility of materials research and technology development which could provide a better basis for setting very low test temperatures.

Systems and equipment

ISO 19906:2019 requires that critical systems, equipment, and materials shall function at temperatures down to the EL minimum temperature at their position. Safety-critical equipment shall be documented to function as intended down to EL minimum temperature.

Other systems and equipment shall function to the LOST specified by the owner.

CONCLUSIONS

A review of how existing codes and standards address low temperature issues has indicated a wide range of terms and their application. ISO 19906:2019 strives to consolidate these into a coherent approach for practical application.

Three categories of low temperatures are identified:

- EL minimum temperatures (from data);
- LAST – Lowest Anticipated Service Temperature (but not greater than -10^{o}C);
- LOST – Lowest Operational Service Temperature (for general winterisation).

Three types of low temperature zone are defined in and around the structure. These zones are: in air (exposed), in water (and below the seabed), and enclosed (fully or partially).

Appropriate minimum service temperatures can therefore be determined for selection and testing of materials, and for specification of systems and equipment.

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REFERENCES

API Recommended Practice 2A-WSD, Twenty-second edition, 2014. Planning, Designing, and Constructing Fixed Offshore Platforms – Working Stress Design. *American Petroleum Institute.*

API RP2N, Second edition, 1995. Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Structures in Ice Environments. *American Petroleum Institute.*

CAN/CSA S473.1-1992 (R2001). *Steel structures.* CSA Group.

DNVGL-OS-A201. *Winterization.* DNV GL AS.

DNVGL-OS-C101. *Design of offshore steel structures.* DNV GL AS.

EN 10225-1:2019. *Weldable structural steels for fixed offshore structures - Technical delivery conditions - Part 1: Plates*. European Committee for Standardization (CEN-ECISS).

ISO 19900:2019. *Petroleum and natural gas industries — General requirements for offshore structures*, International Organization for Standardization.

ISO 19901-1:2015. *Petroleum and natural gas industries – Specific requirements for offshore structures – Metocean design and operating considerations.* International Organization for Standardization.

ISO 19902:2007. *Petroleum and natural gas industries – Fixed steel offshore structures.* International Organization for Standardization.

ISO 19906:2010. *Petroleum and natural gas industries – Arctic offshore structures.* International Organization for Standardization.

ISO 19906:2019. *Petroleum and natural gas industries – Arctic offshore structures.* International Organization for Standardization.

ISO/TS 35105:2018. *Petroleum and natural gas industries – Arctic operations – Material requirements for Arctic operations.* International Organization for Standardization.

Muggeridge, K., McKenna, R.F., Thomas, G.A.N., 2019. *ISO 19906:2019- an International Standard for Arctic Offshore Structures.* Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions, Delft, The Netherlands

NORSOK M101, 2011. *Structural steel fabrication*. Standards Norway

NORSOK M120, 2008. *Material data sheets for structural steel*. Standards Norway

NORSOK N003, 2017. *Action and Action effects.* Standards Norway.

NORSOK N004, 2013. *Design of steel structures.* Standards Norway