

ISO 19906 Update - An International Standard for Arctic Offshore Structures

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ABSTRACT

In 2014, the International Standards Organisation (ISO) approved the proposal to update ISO 19906, the International Standard for design of Arctic Offshore Structures.

The revision is being developed by an ISO working group (WG8) led by Canada, within ISO Subcommittee TC67/SC7 for offshore structures. WG8 had been established in 2002 with the remit to develop a new standard, now ISO 19906. The first edition (ISO 19906:2010) has been adopted by all “arctic” and many other countries, replacing existing national documents.

Planning for the revision started in 2013. New knowledge gained from front-end engineering design for development projects, joint industry research projects, and activities such as Barents 2020, suggested that ISO 19906 needed to be updated to maintain currency and relevance. The technical work was initiated in 2014, with a review of issues to be addressed and the re-manning of Technical Panels with international experts to address them. A first working draft (WD1) of the revision was completed in October 2016. Publication of the approved second edition is currently scheduled for December 2018.

This paper includes an overview of current status and experiences. It presents the organisation and timeline for the revision work, and a summary of the changes drafted. It also presents some key interfaces, with the others of the ISO 19900 series of International Standards for offshore structures, and with the new ISO Subcommittee TC67/SC8 for arctic operations.

KEY WORDS: Arctic offshore structures; Design; ISO 19906.

INTRODUCTION

Working Group 8 (WG8), within committee ISO/TC67/SC7 Offshore Structures, was responsible for the first edition of International Standard ISO 19906. It was published December 2010, as described in Spring et al, 2011.

After some years of experience in use, and with advances in technical knowledge, the need for an update was recognised. In 2013, a revision to ISO 19906:2010 was proposed and a “new work item proposal” was initiated in February 2014 by WG8, led by Canada.

ISO 19906 SCOPE AND OBJECTIVES

ISO 19906 provides requirements, recommendations, and guidance, for design of offshore structures in the physical environment of arctic and cold regions. It relies on other ISO standards in the 19900 series for common structure types, general requirements, and non-arctic specific requirements. It was written with the assistance of over 150 of the world's leading experts in Arctic and structural design, with particular focus on ice features, ice-structure interaction, ice engineering, ice management, and structural reliability appropriate for arctic and cold regions.

“Arctic and cold regions” is deemed to include both the Arctic and other locations characterized by low ambient temperatures and the presence or possibility of sea ice, icebergs, icing conditions, persistent snow cover, and/or permafrost.

The objective of ISO 19906 is to ensure that complete structures, including substructures, topsides structures, floating production vessel hulls, foundations and mooring systems in arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value. Value includes value to the owner, to the industry and to society in general.

ISO 19906 provides design principles applicable to all phases of the life of the structure, including the successive stages of construction (i.e. fabrication, transportation, and installation), service in-place, and decommissioning.

NATIONAL ADOPTIONS OF ISO 19906:2010

ISO 19906:2010 has been widely adopted, including in all countries with arctic interests, replacing pre-existing national standards and industry technical design documents.

Canada

Canada replaced their offshore structures standard (CSA S471-04) dealing with arctic structures with ISO 19906:2010 and ISO 19900, without deviation. Canada has also adopted the entire ISO 19900 series of standards dealing with offshore structures.

Europe

ISO 19906:2010 was “parallel processed” by the European Committee for Standardization (CEN) under the ISO-CEN Vienna Agreement, resulting in EN ISO 19906:2010 being published at the same time. All CEN Members, the national standards bodies of the European Union and European Economic Area countries, adopted it nationally within the following six months. Significantly for arctic and cold regions, these countries include Denmark and Greenland, Finland, France, Germany, Netherlands, Norway, Sweden, and the United Kingdom.

Russia

A final draft of the Russian version of ISO 19906:2010 was adopted as GOST R ISO 19906 by the responsible national committee. Documentation was sent to the Federal Agency on Technical Regulating and Metrology (Rosstandart) that is responsible for official publishing of Russian standards. The effort to validate the translation and editing continues.

United States

ISO 19906:2010 was adopted in the USA as “ANSI/API RP2N, Third Edition, April 2015 (ISO 19906:2010 modified)”. It replaced the previous edition of API RP2N, after an API ballot which resulted in a few minor modifications to ISO 19906:2010. The modifications are being incorporated in the current update work for the second edition of ISO 19906.

Others

ISO 19906:2010 has been adopted or otherwise accepted in many other countries with arctic and cold regions interests, such as China, Japan, Korea, and Singapore.

The European committee responsible for the Structural Eurocodes, the standards for civil and structural engineering practice, has recognized ISO 19906 as providing the definitive provisions for ice actions and arctic offshore structures.

In its design requirements for offshore wind turbines, the International Standard published by the International Electrotechnical Commission (IEC) invokes ISO 19906 for ice actions on turbine supports, for regions such as the Baltic Sea.

EXPERIENCES IN USE

ISO 19906:2010 is used worldwide for arctic design issues such as characterizing ice scenarios and ice actions. Use has ranged from concept development, front-end and detailed engineering design, and completion of projects now in service. ISO 19906 also includes earlier project experiences subsequently incorporated in the content.

Use for Different Regions and Structure Types

Regions in which industry has gained experience for, or has subsequently used, ISO 19906:2010 include the Beaufort Sea, Chukchi Sea, offshore Newfoundland and Labrador, Greenland (East and West offshore), Barents Sea, Pechora Sea, Kara Sea, Ob Bay, offshore Sakhalin Island, and the Caspian Sea.

Some examples of specific use or influence are illustrated in Figures 1 to 5.



Figure 1. Man-made islands: Northstar Island, Alaskan Beaufort Sea. (left, courtesy BP); Kashagan field, Caspian Sea, Kazakhstan (right)



Figure 2. Concrete GBS: Prirazlomnaya, Pechora Sea, Russia (courtesy of GazProm)



Figure 3. Concrete multi-legged GBS: Lunskoya-A, Sakhalin (courtesy of GazProm)



Figure 4. Floating platform: SeaRose FPSO, Grand Banks, Canada (courtesy of Harland and Wolff HI Ltd and Husky Energy)

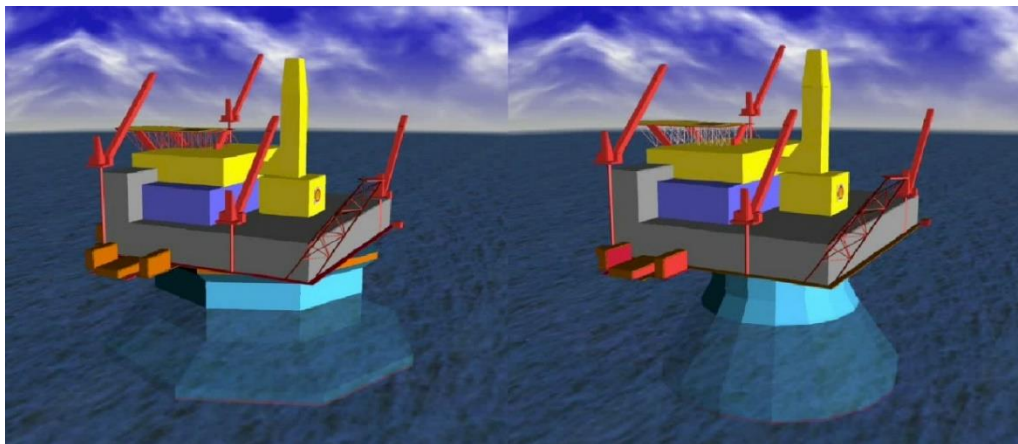


Figure 5. GBS concepts, Beaufort Sea, Alaska (from Lovcraft and Eicken, 2011)
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Hebron, Jeanne d’Arc Basin, Canada

The ISO 19906 standard was used for the specification of iceberg actions on the GBS soon to be installed at the Hebron site in the Jeanne d’Arc Basin 350 km southeast of St. John’s, Newfoundland in a water depth of 93 m. The conceptual design is illustrated in Figure 6.

Because iceberg interactions are infrequent at this site, the design of the concrete supporting structure is driven primarily by the abnormal-level iceberg event specified at an annual probability of 10^{-4} (Widianto et al, 2013). Ice pressures were based on a random relationship as presented in ISO 19906:2010, Annex A.8, and capped at a fixed value at large contact areas.



Figure 6. Hebron platform concept, Jeanne d’Arc Basin, Canada (from Widianto et al., 2013)

NEED FOR REVISION AND UPDATE

Issues Deferred from Development of First Edition

During development of the first edition, the focus was on writing provisions that had consensus. If there was more than one approach in common use which could not be reconciled, provisions were written for both approaches with some guidance on applicability.

This gave rise to some unresolved issues when there was insufficient agreement on approaches developed at that time, for example specific provisions for ensuring the reliability of different types of floating structures incorporating operational measures.

And there were a number of unresolved issues related to ice actions as a result of the final review of ISO 19906:2010 which were reported by the relevant Technical Panel.

The final ballot for publication resulted in approximately 120 technical comments which would have required technical revisions to the content. None were considered sufficiently compelling

as to require immediate revisions and a second ballot, so these had been archived for the next edition.

Industry Feedback on ISO 19906:2010

After publication, there has been feedback from experts and from industry users, which identified the need to do the following:

- Include other advances in knowledge, from industry activity (see below), and from articles in technical journals and conference proceedings.
- Include further new knowledge on ice actions.
- Clarify some key terms and ensure their consistent use.
- Incorporate issues arising from the API ballot for US adoption of ISO 19906:2010.
- Align with more recent publication of ISO standards in the 19900 series.
- Correct a few editorial errors.

Advances in Knowledge – Barents 2020

In anticipation of imminent developments in the Barents Sea, authorities and industry in Russia and in Norway cooperated on the development of joint offshore standards and guidelines under the Barents 2020 project.

A working group “Design of stationary floating units against ice loads in the Barents Sea” addressed gaps in ISO 19906:2010. In 2012 it published a supplementary guidance document with a number of practical recommendations for updating ISO 19906 related to stationary floating structures and ice management operations. See Moslet et al, 2012.

Other working groups developed technical bases for standards on arctic operations which were later taken forward into ISO and prompted the creation of ISO/TC67/SC8, see below.

Advances in Knowledge – Industry Research Projects

In the 2009-2014 timeframe, several industry research projects contributed advances in knowledge that are being included in the updating of ISO 19906. Some detailed reports are not in the public domain, but key issues can be acknowledged. The projects included:

- IceStruct JIP, a joint industry project managed by DnV, was to produce a document on “Ice Effects on Arctic Offshore Structures”, with the intent to supplement ISO 19906 by addressing selected gaps (DnV, 2009). Gaps identified were designer-friendly methods and examples for determining actions and action effects, particularly with respect to floating structures, and to the overall approach to “reliability”.
- Ice-Induced Vibrations JIP, a joint industry project was to develop an engineering approach to understanding and assessing ice-induced vibrations for a wide range of structures and ice conditions (Dr. techn. Olav Olsen, 2010). One objective was to provide new content for “dynamic ice actions” in ISO 19906.
- Models for level ice loading on sloping structures and multi-year ridge loading on conical structures were developed as part of a recent research project. These algorithms, presented in Croasdale et al., 2016, supplement those presented in ISO 19906:2010 and

provide for a better characterization of the progressive ice failure process against these types of structures.

ORGANISATION AND RESPONSIBILITIES

ISO/TC67 and its Arctic Committees

Technical Committee TC67 is responsible for International Standards for oil and gas industry materials and equipment. Its two subcommittees of interest for arctic standards are.

- Subcommittee SC7 “Offshore structures”: responsible for the ISO 19900 series for design of offshore structures of all types and in all regions worldwide.
- Subcommittee SC8 “Arctic operations”: for ISO Standards for arctic operations.

SC7 Offshore Structures Committee

SC7, under the leadership of the United Kingdom, was created in 1990. The current organisation of WGs is shown in Figure 7. The flags indicate the country of the WG Convenor who provides leadership. SC7/WG8 is responsible for ISO 19906, Arctic offshore structures.

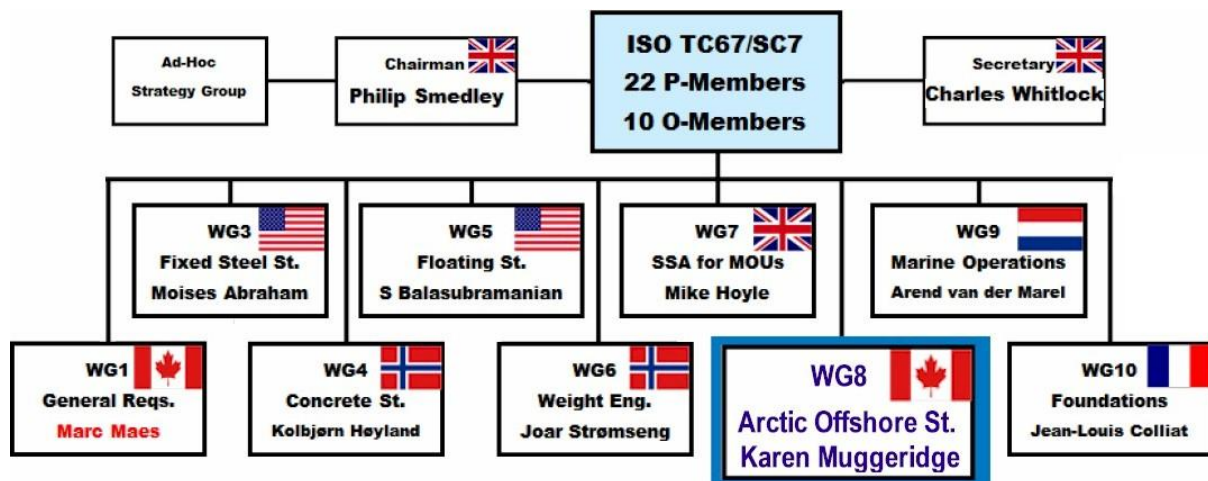


Figure 7. Organisation of ISO/TC67/SC7 Offshore structures

ISO 19900 Series of International Standards

ISO 19906 is one of the ISO 19900 series of International Standards for offshore structures. The full references are provided in ISO 19900 and in ISO 19906. The series is interdependent, and the relationships are illustrated in Figure 8.

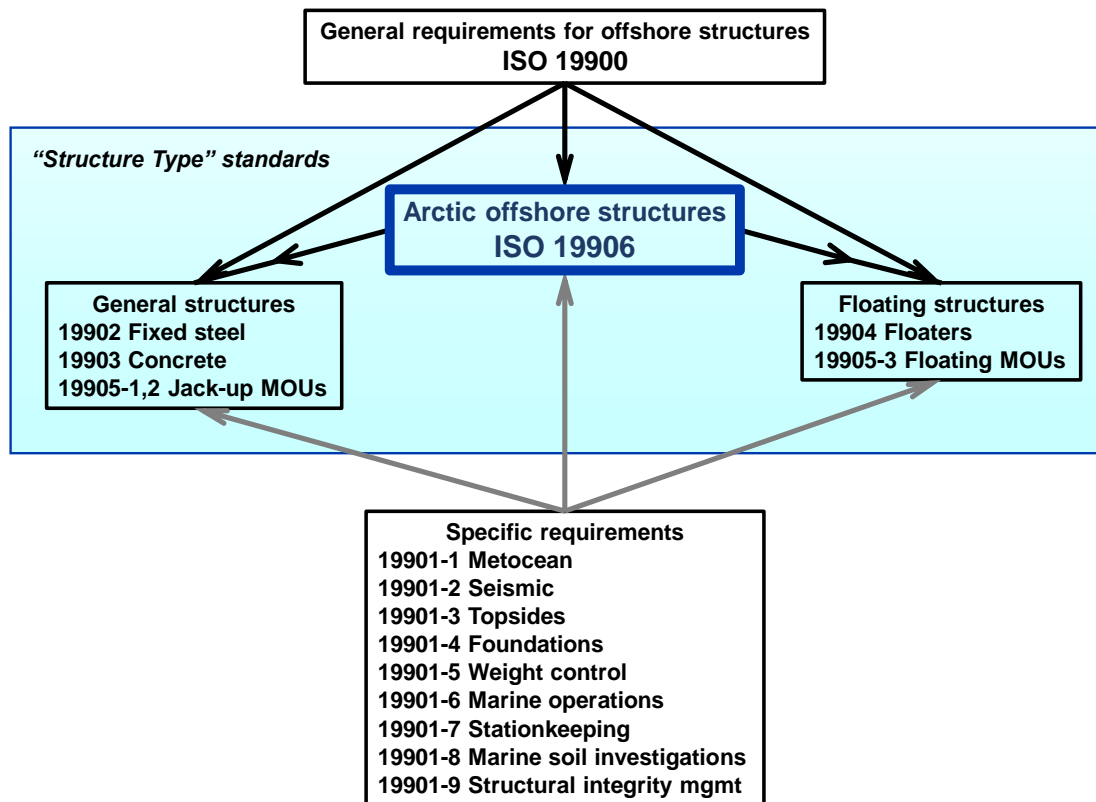


Figure 8. Relationships of ISO 19900 series of Documents for Offshore Structures

General requirements (ISO 19900) and specific requirements (the ISO 19901 series) provide generic input and support to ISO 19906. ISO 19906 adds provisions and guidance necessary for arctic and cold regions. ISO 19906 directs the user to the standard for the relevant “structure type” for generic provisions, without duplicating their content.

WG8 Arctic Offshore Structures Working Group

WG8 is comprised of experts nominated by national bodies as country representatives. The revision of 19906:2010 was initiated by Dan Masterson in 2012. Following Dan’s retirement, Karen Muggeridge was selected to lead WG8 and her role as Convenor was approved in June 2014. A meeting of WG8 was held in Hamburg, Germany, in June 2014 to commence the work of revising and updating ISO 19906:2010.

After analysis of the work required, technical panels of recognised experts were organised to focus on the areas requiring significant revisions. TP0 covered minor updates to issues not otherwise covered. Table 1 shows the TPs and their leaders.

Table 1. Organisation of WG8 Technical Panels for revision of ISO 19906

Technical Panel (TP)	TP Leader	Country
TP0 Coordination/Editing/General	Karen Muggeridge	Canada
TP1 Physical Environment	Anne Barker	Canada
TP2a Reliability and Limit States	Adel Younan	USA







TP2b Ice Actions and Ice Engineering	Robert Frederking	Canada
TP4 Man-made Islands and Foundations	Ken Been	Canada
TP7 Floating Structures and Ice Management	Costas Makrygiannis	Norway

SC8 Arctic Operations Committee

SC8 was created in 2011 under the leadership of the Russian Federation, as recommended by the Barents 2020 project. Its scope includes onshore and offshore operations in arctic and other locations with low ambient temperatures and the presence of ice, snow and/or permafrost.

SC8 is organised with six WGs, each responsible for one new document, see Table 2. Leadership (Convenorship) is indicated by the national flags.

Table 2. ISO/TC67/SC8 Arctic operations: organization and documents

Working group	Title	ISO number	ISO Title: Arctic operations -
SC8/WG1 	Working environment	35101	Working environment
SC8/WG2 	Escape, evacuation and rescue	35102	Escape, evacuation and rescue from offshore installations
SC8/WG3 	Environmental monitoring	35103	Environmental monitoring
SC8/WG4 	Ice management	35104	Ice management
SC8/WG5 	Arctic materials	35105	Material requirements for arctic operations
SC8/WG6 	Physical environment for arctic operations	35106	Metocean, ice and seabed data

There is a close liaison between the WG8 Technical Panels and the SC8 Working Groups. As SC8 developed their documents, relevant content from ISO 19906:2010 was included such that this content could be removed from ISO 19906 and the SC8 document referenced instead.

The work of an original seventh SC8/WG, on man-made islands and land extensions, was transferred to SC7/WG8 and is now incorporated in the revision of ISO 19906, clause 10.

INTERFACES

Interfaces with Other 1990-Series Documents

Interdependencies of the ISO 19900 series were illustrated in Figure 8. Although all these standards have been published, the timelines for revisions are not synchronised due to the different scopes, resources and experts available, and industry needs.

ISO 19900:2013, however, is currently being updated, with publication planned in 2019. A look ahead to some possible changes in ISO 19900 is given in Thomas, 2017. However it is possible that the current update of ISO 19906 will be completed before changes to ISO 19900 are confirmed and can be incorporated.

Interfaces with New Documents from SC8 Arctic Operations

Three of the arctic operations standards have significant interfaces of content with ISO 19906. As of January 2017, they were all at the DIS stage, undergoing ISO member country review.

The new ISO 35102 (Escape, Evacuation, and Rescue) (EER) will incorporate most of the provisions of ISO 19906:2010, clause 18. The revised clause 18 retains only those EER issues that influence the overall design of the offshore structure.

The new ISO 35104 (ice management) will replace some of the previous provisions of ISO 19906:2010, clause 17. The revised clause 17 focuses on the ice management requirements for structural reliability, without any details as to how this is accomplished. ISO 35104 will contain many new provisions on planning and executing ice management for the protection of offshore platforms and for other offshore operations.

The new ISO 35106 (metocean, ice and seabed data requirements) will address collection, analysis, presentation and archival of data for the physical environment for arctic and cold regions operations and design. Its scope includes water depths, winds, waves, currents, air and water temperature, and atmospheric parameters related to visibility. It will also include provisions for data on sea ice, icebergs, and seabed parameters such as ice gouges, strudel scours and permafrost.

KEY AREAS BEING REVISED AND UPDATED

Summary

Significant changes have been made to targeted clauses in this revision to ISO 19906:2010. The changes will be published for public review and comment, as an ISO Draft International Standard (DIS), later in 2017.

The extent of key updates to the clauses is summarized in Table 3.

Table 3. Revisions and updates for ISO 19906 second edition

Subject	Clause	Issues
Terms and definitions	3	Arising from Barents 2020, definitions for “ice event” and “stationary floating structure” have been introduced. Definitions for “broken ice” and “ice management” have been improved.
General	5	Recommendation to consider implementing an ice alert system
Physical environment	6	Thermal ice growth equations have been modified to allow for use in estimating ice thickness.
		Text on temperature specification has been added to distinguish measures used for material and equipment specification, and for ice properties specification.
		Align with and reference ISO 35106.
Regional information	Annex B	Regional data for the physical environment for Western Greenland was combined with that of Baffin Bay. A new section with data for (North) Eastern Greenland was added.
Reliability	7	Alignment with ISO 19900:2013, especially clarifying and referencing descriptions of hazards, exposure levels, and design situations.
		Terminology with respect to ice events and ice actions.

Events and actions	8	Terminology with respect to events and actions, ice scenarios, and design situations.
Ice actions	8	Global ice pressures, low aspect sea ice interactions, probabilistic analysis.
		Local ice pressures, update with recent work reflecting pressures associated with EL and AL actions.
		More clarity on ice-induced vibrations.
		Revisions to ice properties.
		New algorithm to handle multi-year (MY) ridges.
Foundations	9	Alignment with revised foundation and geotechnical standards ISO 19901-4 and ISO 19901-8.
Manmade islands	10	New provisions added, including text on “coastal engineering” and “construction”, in liaison with ISO/TC67/SC8.
		Experience of islands in the Caspian Sea incorporated.
		Revisions for better alignment with the clauses on foundations (clause 9) and reliability (clause 7).
Floating structures	13	Complete revamp of philosophy, emphasizing operational procedures under an ice alert system (activity specific operating guideline).
		Specific requirements have been added to ensure that reliability requirements for abnormal and extreme design situations can be met by means of operational procedures.
		Guidance on the development of ice operating envelopes.
Subsea structures	14	Alignment of permafrost and ice gouge content with ISO 35106, as well as transfer of content to that standard.
Other ice engineering topics	16	Technical revisions in relation to physical modelling; additional guidance on scaling and limitations of model results.
Ice management	17	Significant transfer of content to new ISO 35104.
		Narrowed the focus in 19906 to requirements for ice management systems for structure design aspects.
EER	18	Narrowed the focus in 19906 to structure design aspects and moved previous content to new ISO 35102.

PROCESS AND TIMELINE FOR ISO 19906 SECOND EDITION

The Technical Panels were confirmed and started work in 2015, with the target to address all issues assigned and deliver responses and proposed text to the Technical Editor by June 2016. Milestones completed during 2016 and further milestones to achieve the target publication date of December 2018 are detailed in Table 4.

Table 4. ISO 19906 Timeline for second edition

Date	Milestone
June 2016	Technical Panels completed technical work.
July – September 2016	Technical Editor merged contributions of TPs to provide first full Working Draft (WD1).
October 2016	TP0 and TP Leaders completed review of WD1.
November 2016	Technical Editor compiled Working Draft 2 (WD2).

December – January 2017	WG8 Country Representatives and all Technical Panels review WD2, and submit comments using the ISO standard form.
February - March 2017	Technical Editor compiles Working Draft 3 (WD3).
Late March, 2017	WD3 and the register of resolved WD2 comments distributed for final review by WG8 and TP0.
Early April, 2017	Make final revisions if any, and prepare Working Draft 4 (WD4) as “ready for DIS”.
Mid-April, 2017	Provide WD4 to ISO/TC67/SC7 Secretariat (via IOGP Standard Solution Project Manager and ISO/TC67 Secretariat).
April - May 2017	SC7 Secretariat review. ISO Central Secretariat prepares DIS.
May – July 2017	National standards bodies have two months to translate ISO/DIS 19906 to their national language, if desired.
July – October 2017	Formal twelve-week DIS ballot, supervised by ISO CS. Comments received are sent to the ISO/TC67/SC7 Secretariat.
November 2017 – February 2018	Convenor (with TP0) allocates comments to Technical Panels to resolve. Technical Editor to prepare the full comments register (table of comments and responses), and the “ready for FDIS” version.
March 2018	WG8 review and approval of “ready for FDIS”, and comments register with all DIS comments and responses.
April 2018	Convenor sends ISO/FDIS 19906 to ISO/TC 67/SC7 Secretariat, who checks the document and forwards to ISO CS.
May – September 2018	ISO CS perform final editing and formatting, followed by distribution to ISO Members for formal eight-week FDIS vote.
October – November 2018	WG8 final review and approval of editorial corrections. Convenor submits document for publication via ISO/TC67/SC7 Secretariat to ISO CS.
December 2018	Publication of second edition of ISO 19906.

CONCLUDING REMARKS

International Standard ISO 19906 specifies requirements and provides recommendations and guidance for offshore structures in arctic and cold regions. The objective is to ensure that these structures provide a level of reliability with respect to personnel safety, environmental protection and asset value, similar to that for offshore platforms in other regions of the world.

ISO 19906:2010 has been widely adopted and recognized as the definitive document for assessment of ice scenarios and ice actions, for design of structures in ice environments and for further developing the science and engineering of ice-structure interaction.

The intent of the revision was to update ISO 19906:2010 with new knowledge accepted by industry and the Arctic engineering community. See Table 5, the work is focused on specific clauses identified from feedback and advances in knowledge, filling gaps in the first edition, and updating the interfaces with other ISO standards.

Table 5. ISO 19906 contents, and clauses being revised or updated

Clause	Clause Title	Clause	Clause Title
1	Scope	10	Man-made islands
2	Normative references	11	Fixed steel structures
3	Terms and definitions	12	Fixed concrete structures
4	Symbols and abbreviated terms	13	Floating structures
5	General requirements and	14	Subsea production systems
6	Physical environmental	15	Topsides
7	Reliability and limit states design	16	Other ice engineering topics
8	Events and actions	17	Ice management
9	Foundation design	18	Escape, evacuation and rescue

Legend	White rows: Minor revisions, mostly editorial
	Yellow rows: Some technical revisions and updates
	Orange rows: Significant technical revisions and updates

Details of key technical issues considered during the revision of 19906 and the rationale for the updates will be provided in a suite of technical papers planned to be published in 2018 or 2019, to support the publication of ISO 19906 second edition.

ISO 19906 second edition is expected to be published in December 2018.

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REFERENCES

Canadian standard CSA S471-04, 2004. *General requirements, design criteria, the environment, and loads*, February 2004. ISBN 1-55397-525-1. Canadian Standards Association.

Croasdale K., Brown T., Fuglem M., Li G., Spring, W., J. Thijssen J., 2016. Improved Equations for the Actions of Thick Level Ice on Sloping Platforms. OTC27385. *Arctic Technology Conference, St John's, NL, Canada*.

DnV, 2009. Project Summary proposal: ICESTRUCT JIP: *Ice effects on Arctic Offshore Structures*, 1-Oct-2009. Det norske Veritas.

Dr. techn. Olav Olsen, 2010. Project Proposal for JIP KO11179: *Ice Induced Vibrations*, Rev.06, 20-Jul-2010. Dr. techn. Olav Olsen.

ISO 19900, 2013, *Petroleum and natural gas industries – General requirements for offshore structures*, International Organization for Standardization.

POAC17-063

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

Lovecraft, A.L and H. Eicken, 2011: *North by 2020*. University of Alaska Press, 736 pp.

Moslet, P.O., Eide, L.I., Mansurov, M., Onishchenko, D., Liferov, P., Gürtner, A., Thomas, G.A.N., 2012. Barents 2020 - Working group 02 - Design of floating structures in ice. OTC 23709. *Arctic Technology Conference, Houston, Texas. December 2012*.

Spring, W., McKenna, R.F., Thomas, G.A.N., Blanchet, D., 2011. ISO 19906: An International Standard for Arctic Offshore Structures. *Proceedings of the 21st International Conference on Port and Ocean Engineering under Arctic Conditions (POAC11-K3), Montreal, Canada*.

Thomas, G.A.N., 2017. Design Situations and Limit States in the Design of Arctic Offshore Structures. *Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, Busan, Korea*.

Widianto, Khalifa, J., Younan, A., Karlsson, T., Stuckey, P., Gjørven, A., 2013. Design of Hebron Gravity Based Structure for Iceberg Impact. *Proceedings of the Twenty-third (2013) ISOPE International Ocean and Polar Engineering Conference, Anchorage, Alaska, USA*.