2017 U.S.-CANADA NORTHERN OIL AND GAS RESEARCH FORUM

IMPLEMENTING THE ISO 19906 NOMRATIVE

Andrew T. Metzger
Associate Professor
University of Alaska Anchorage

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- DISCLAIMER
- The results shown here-in are provided to illustrate the concept of reliability in the context of the ISO 19906 normative. They are theoretical and should not be used in practice without prior verification as to their suitability for any particular application.

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- ISO 19906
- “Petroleum and natural gas industries – Arctic offshore structures”
- US version: “API RP 2N – Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions”

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- Purpose – to provide a *consensus standard* to guide and/ or regulate offshore constructed facilities in the arctic

- Scope – "…provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures…related to…petroleum and natural gas industries…in the artic and other cold regions"

- Applicability
  - Man-made islands
  - Fixed structures – steel and concrete
  - Floating structures
  - Subsea production systems

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- Philosophy – *reliability-based design*
  - The structure and it's components are proportioned such that the *probability of failure is at or below a determinable threshold of failure*, for a specified period of time
  - $R = 1 - P_f$
- Implementation of the philosophy – *Limit-State Design*
  - Limit State – the condition of a system where it no longer fulfills its design criteria
    - Design criteria = requirements of the system

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- Limit States – general
  - SLS – serviceability limit state
    - limit beyond which system is no longer functional
    - System is intact and has additional capacity
    - *E.g., magnitude of ice forces beyond which deflections of the structure are excessive and production systems cannot function properly. Structure is intact; operations shut down*
    - Example: “a 1/10 chance of being exceeded”; $R = 90\%$; $P_f = 10\%$

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- Limit States – general
  - ULS – Ultimate Limit State
    - Maximum capacity of the system
    - Beyond this limit material will “yield”; permanently deform
    - Without additional “inelastic” capacity, system will fail catastrophically
    - Additional capacity from secondary mechanisms that develop within the system.
    - Example: “a 1/100 chance of being exceeded”; R = 99%; $P_f = 1\%$

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- Limit States – general
  - ALS – Abnormal Limit State; ELS – Extreme Limit State
    - Design a system for extraordinary events
      - Earthquakes
      - Vessel impact, etc.
      - Severe ice feature
    - Typically used where secondary hazards results if the system exceeds ULS
      - Building collapse – life safety
      - Hazardous material release – environmental safety
    - Example: "a 1/10,000 chance of being exceeded"; R = 99.99%; P_f=0.01%
  - **ALS relies on additional, capacity (e.g., non-linear) of the structure after ULS is achieved**

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Intact + Functional

Intact
non-functional

damaged
additional
capacity

collapse

magnitude
of action

0

SLS

ULS

ALS

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IMPLEMENTATION

- Reliability and Probability of Failure
  - Uncertainty is inherent to engineering design
    - Uncertainty of external actions (e.g., forces from sea ice) on the structure
      - Variability of ice characteristics, etc.
      - Impact velocity?
    - Uncertainty of material properties (of the construction)
      - Variability on steel strength/ concrete strength, etc.
      - Variability in QA/QC, etc.

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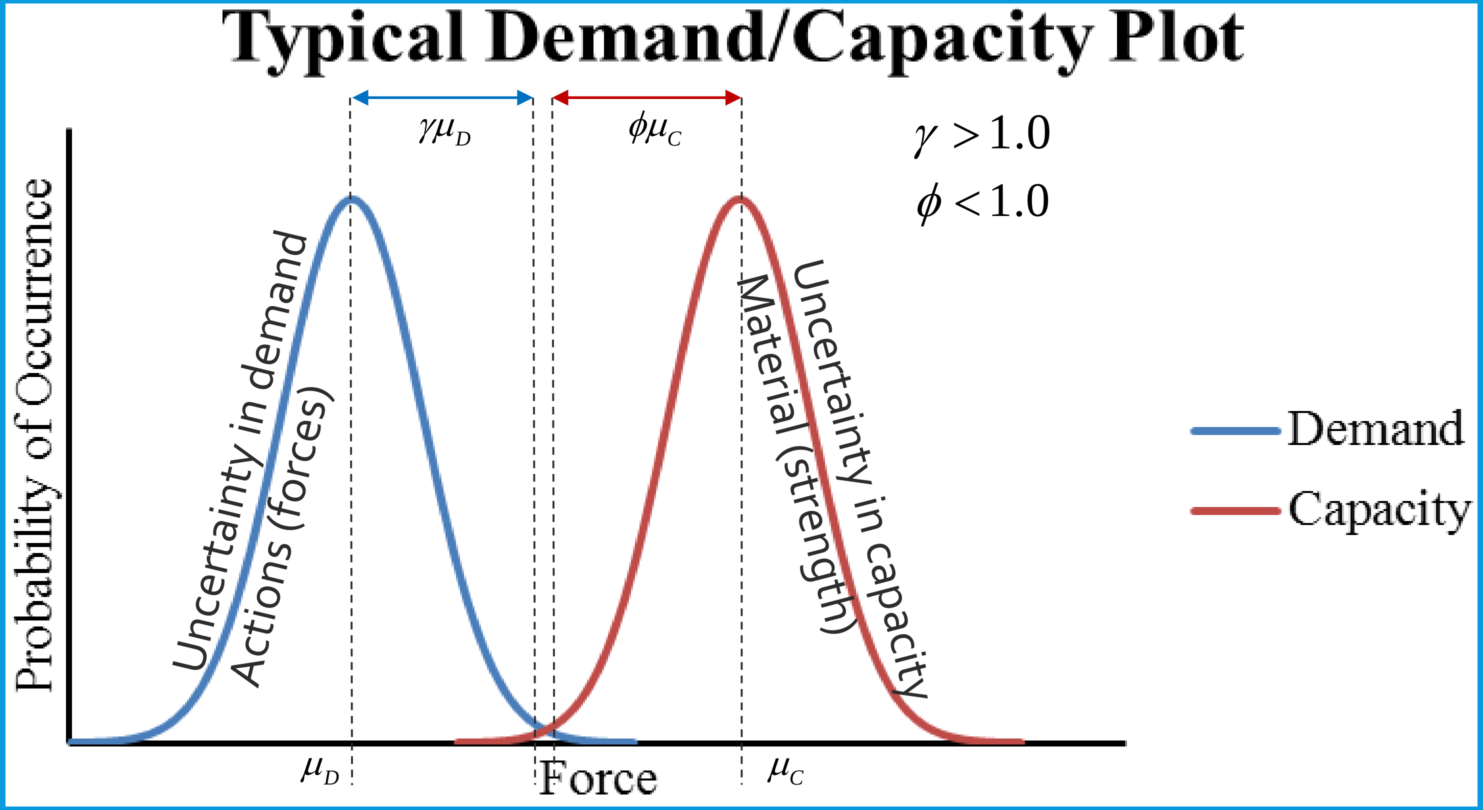
IMPLEMENTATION

- Reliability and Probability of Failure
  - Uncertainty must be accounted for to determine reliability/ probability of failure
  - Proportion the structure so that the uncertainty in actions (forces) and the uncertainty ion material property (strength) are accounted for.
  - Ensure that:

$$\gamma\mu_D < \phi\mu_C$$



Typical Demand/Capacity Plot

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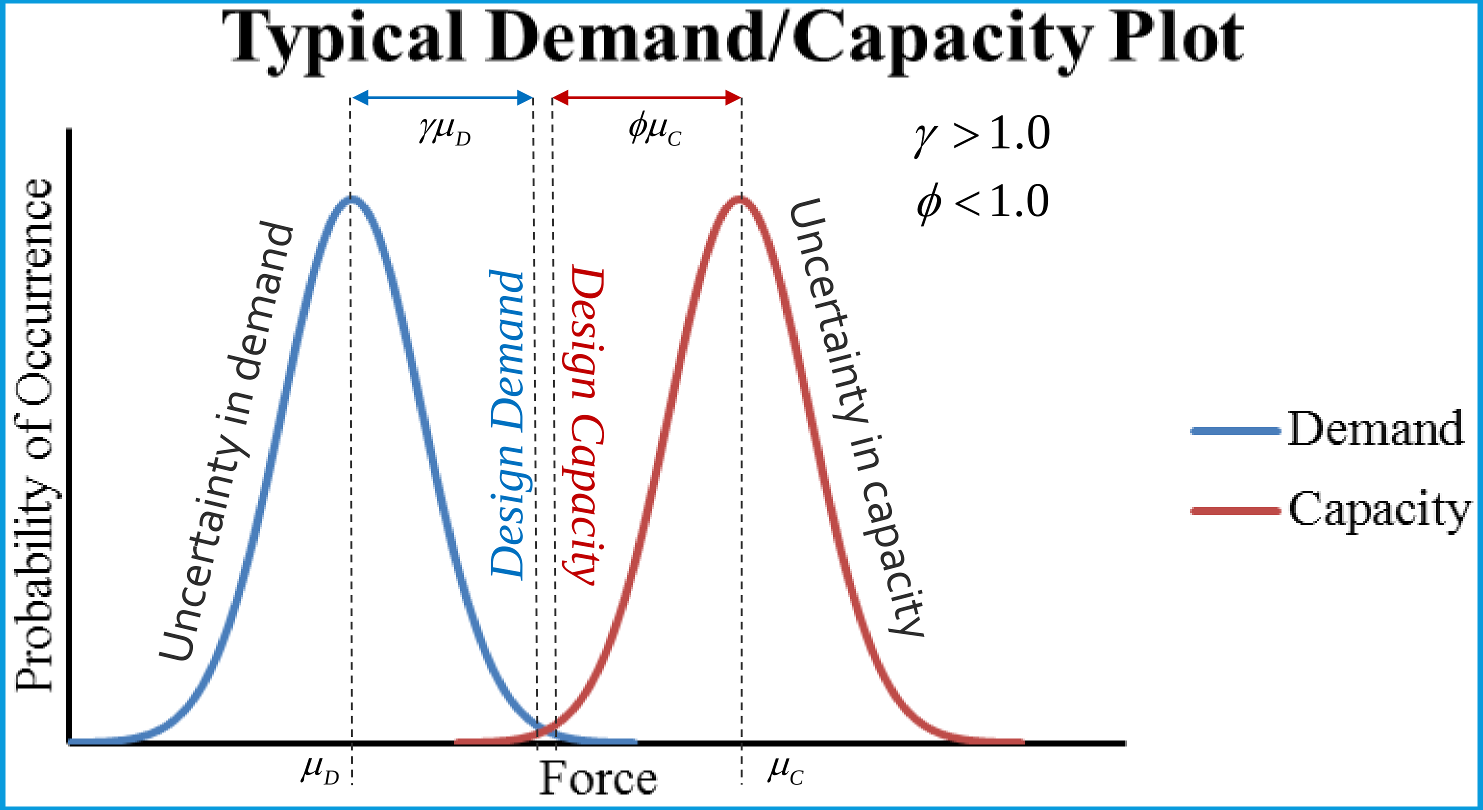
IMPLEMENTATION

- Reliability and Probability of Failure
  - Ensure that: $\gamma\mu_D < \phi\mu_C$

$\gamma\mu_D$ Probability that *Design Demand* will be exceeded (a small probability)

Probability that *Design Capacity* will not be met with construction provided (also a small probability) $\phi\mu_C$



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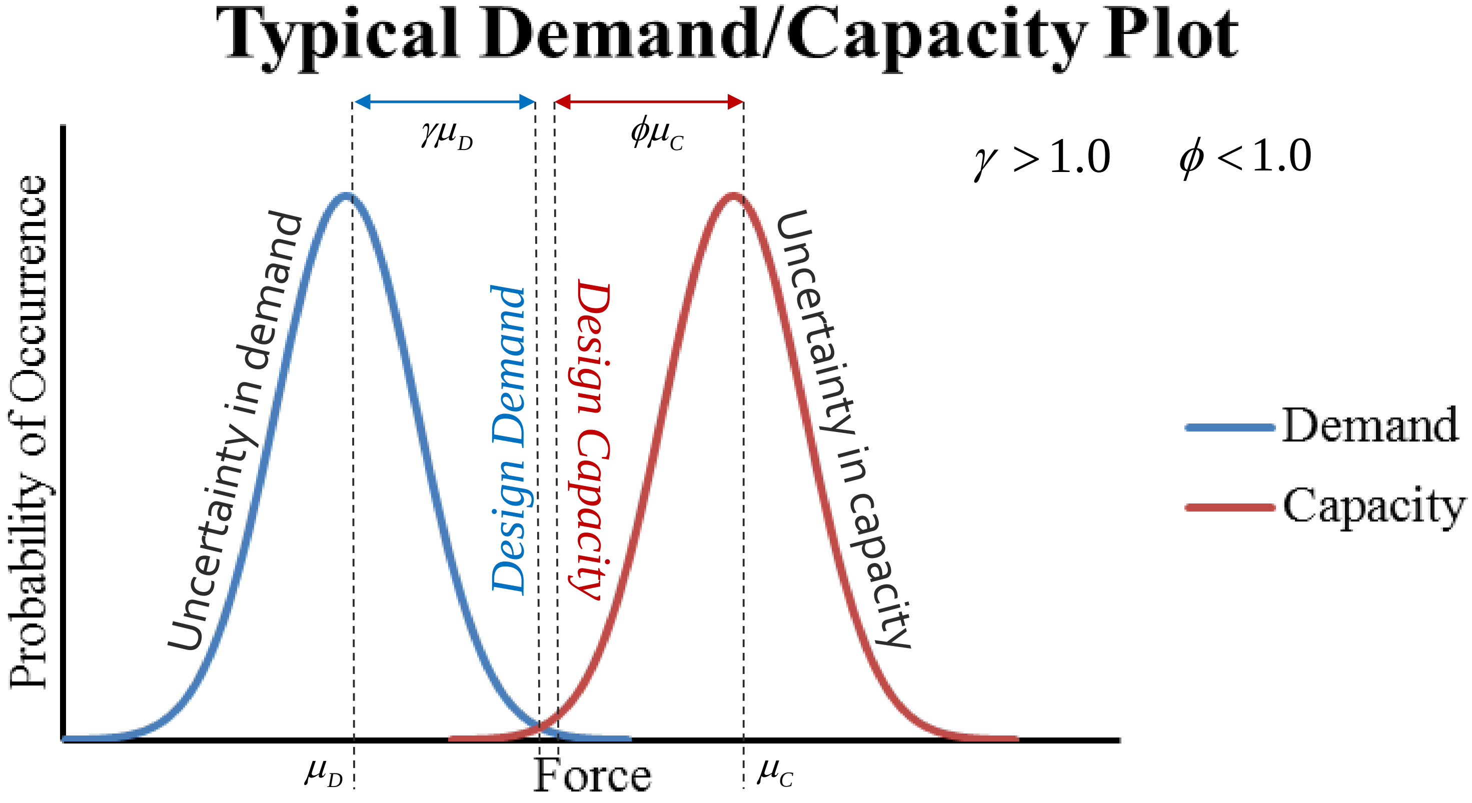
IMPLEMENTATION

- Reliability and Probability of Failure
  - Uncertainty in demand governed by ISO 19906, for example
  - Uncertainty in Capacity governed by *material standards*
    - *E,g,*
      - *ISO 19902 –Fixed steel offshore structures*
      - *ISO 19903–Fixed concrete offshore structures*
    - Each material standard has it's own consensus group, etc.



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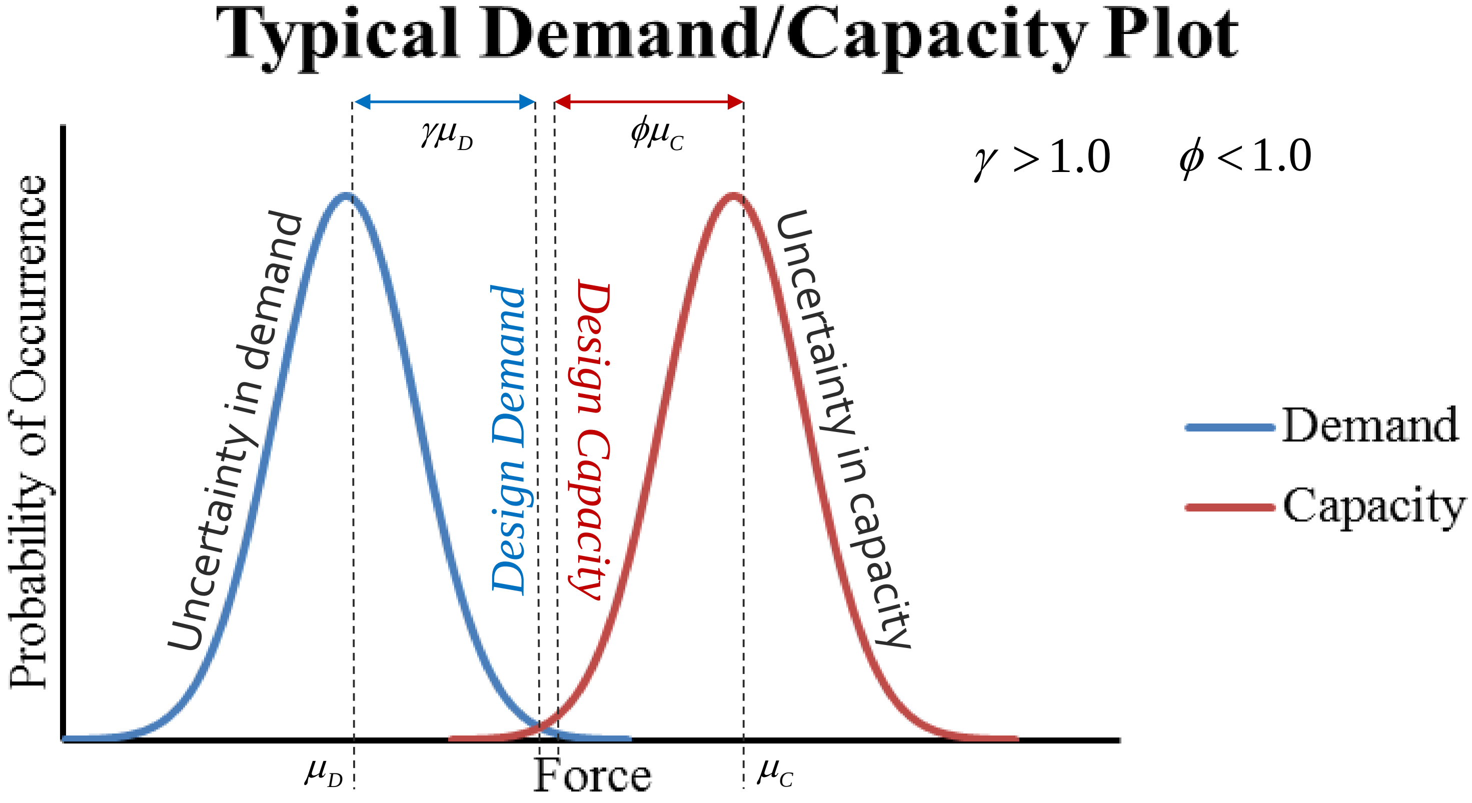
IMPLEMENTATION

- Reliability and Probability of Failure
  - Standard governing design demands and material standards, governing design capacity are typically calibrated to one another
  - The two documents are meant to work together to achieve a desired reliability of the constructed facility


Typical Demand/Capacity Plot

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IMPLEMENTATION

- Example:

$\gamma\mu_D$ If the Design Demand is chosen so there is a 2% probability of exceedance…

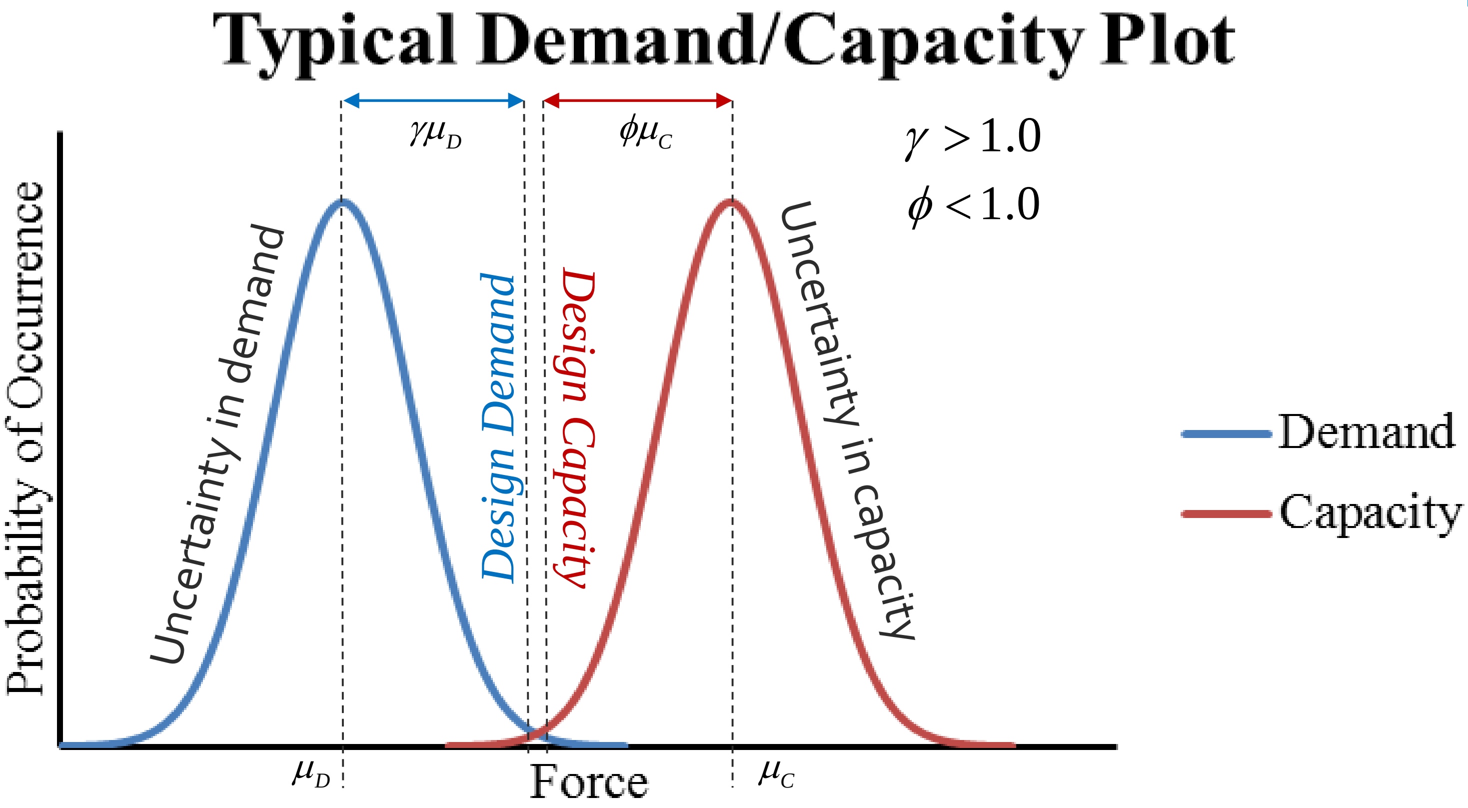
…and the Design Capacity is chosen so there is a 2% probability the construction provided will be inadequate; i.e., less than the specified Design capacity $\phi\mu_C$

The overall reliability is:

R = 1-[(0.02)(0.02)] = 99.96%

P_f = 0.04%

….or, a 1/2500 chance the system will fail



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- Example: in terms of limit states presented above

Assume there is a 2% probability the construction provided will be inadequate; i.e., less than the specified Design capacity

The overall reliability is:

R_{SLS} = 1-[(0.02)(0.1)] = 99.80%; P_f = 0.2%; 1/500 chance the system will fail

R_{ULS} = 1-[(0.02)(0.01)] = 99.98%; P_f = 0.02%; 1/5000 chance the system will fail

R_{ALS} = 1-[(0.02)(0.0001)] = 99.9998%; P_f = 0.0002%; 1/500,000 chance the system will fail

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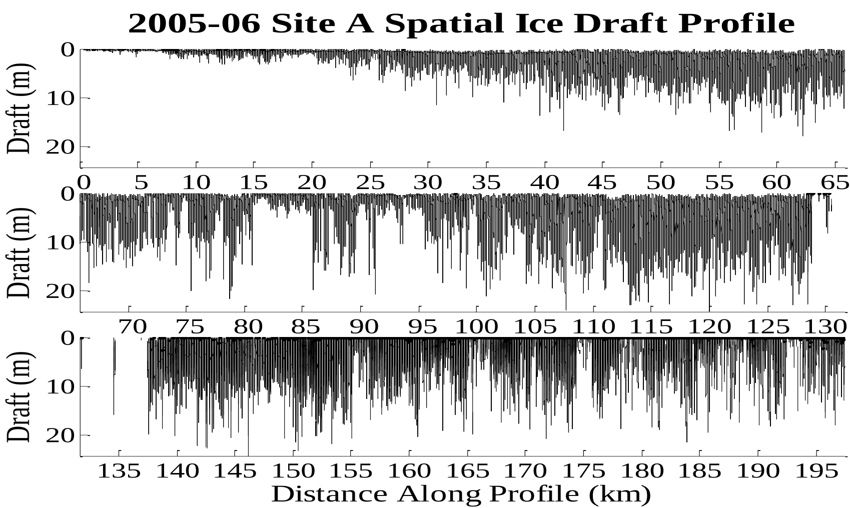
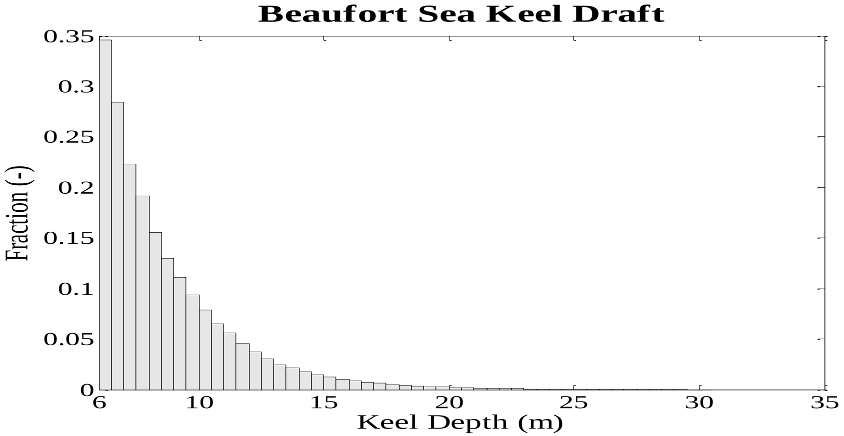
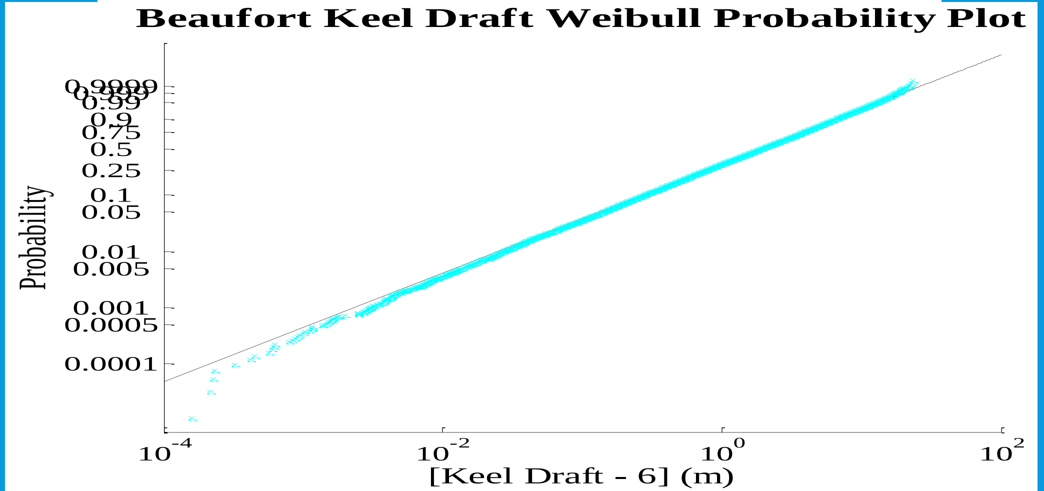
IMPLEMENTATION – EXAMPLE:

DESIGN KEEL DEPTH

- During exploration activities in the Chukchi and Beaufort lease areas; several seasons of under ice measurements were obtained.
- Pressure ridge keel features were isolated from the records
- The data was compared to a number of Probability Density Functions
- A goodness-of-fit-test for the Weibull Distribution passed the test







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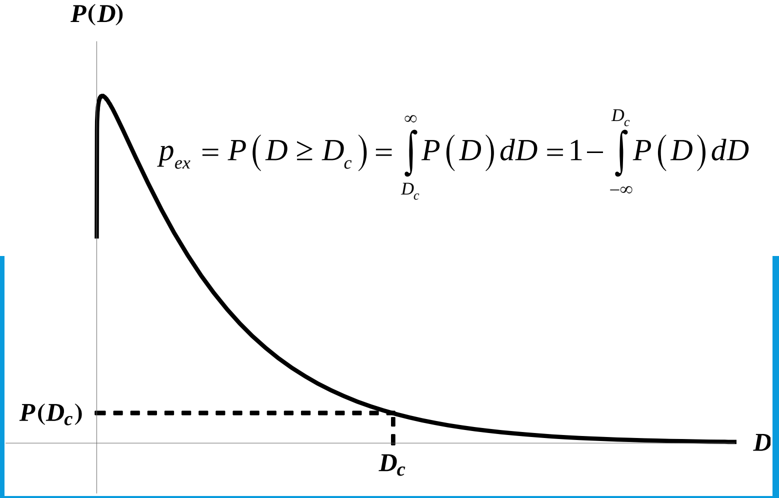
IMPLEMENTATION – EXAMPLE:

DESIGN KEEL DEPTH

- Limit-State keel features were extrapolated from the p.d.f.s using Probability Theory
- Limit-State features were used to calculate limit-state forces using ISO 19906 provisions



$$p_{ex} = P\left(D \geq D_c\right) = \int_{D_c}^{\infty} P\left(D\right) dD = 1 - \int_{-\infty}^{D_c} P\left(D\right) dD$$

Probability of exceedance after the passage of n keels

$$p_{ex} = 1 - P\left(0|n\right)^{\frac{1}{n}}$$

Cumulative Probability associated with Reliability – probability of non-exceedance (using Weibull c.d.f.)

$$C\left(D\right) = \begin{cases} 0 & D \leq \mu \\ 1 - e^{-\left(\frac{D-\mu}{\beta}\right)^{\alpha}} & D > \mu \end{cases}$$

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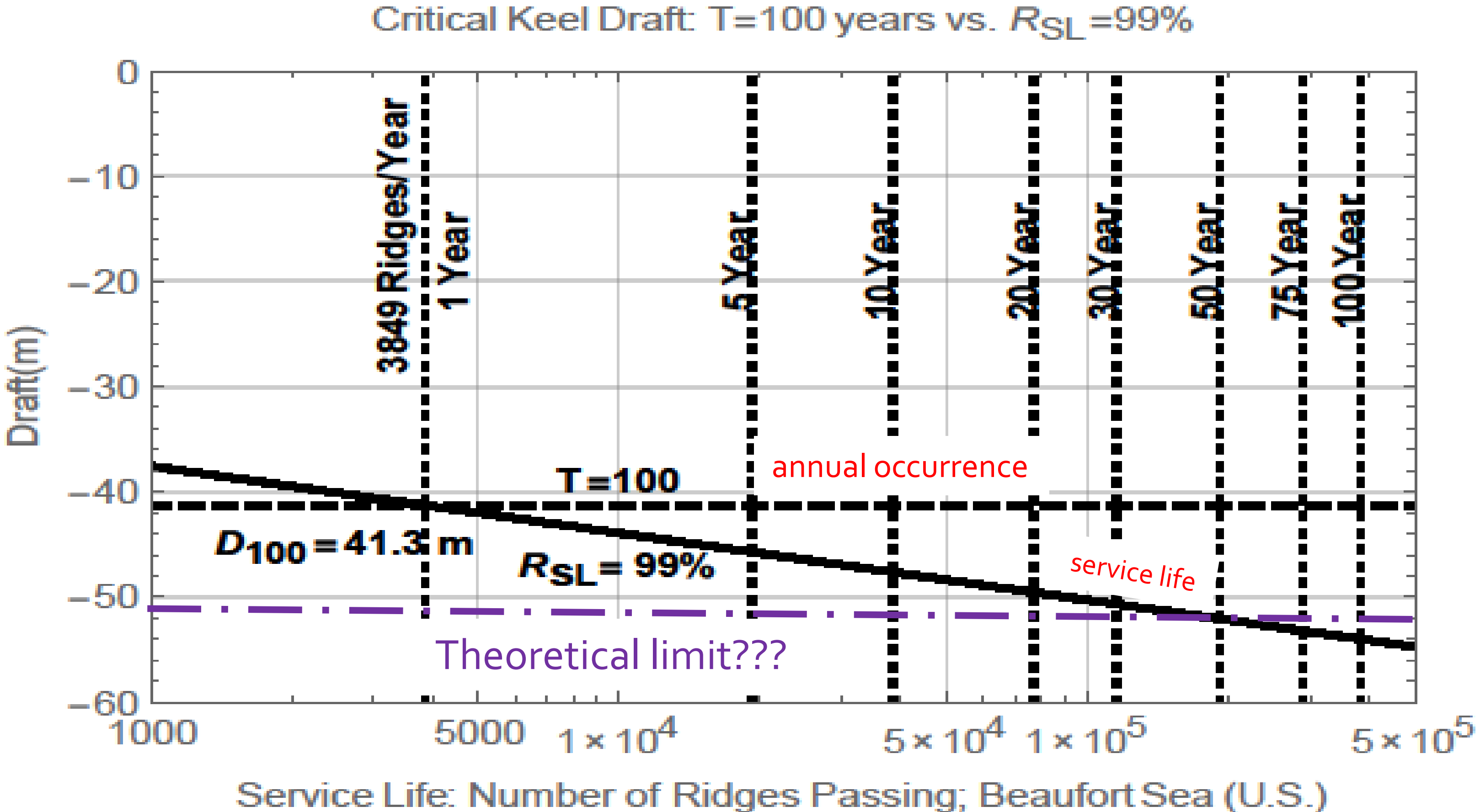
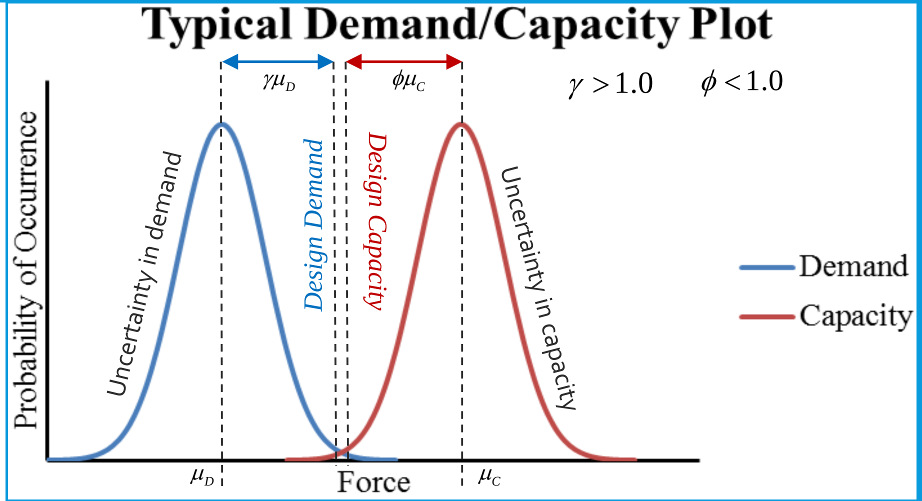
IMPLEMENTATION – EXAMPLE:

DESIGN KEEL DEPTH

- Results were used to construct reference for keel depth versus design life





Values represent keel depth corresponding to *Design Demand*

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IMPLEMENTATION – EXAMPLE: *ICE SCOUR*

DESIGN GOUGE DEPTH

- Using the probabilistic description of keel depth from the previous example….
- ….coupled with the results from [C-CORE 2008] that provides a distribution for gouge depth…
- …a probabilistic presentation of gouge depth was derived using probability theory

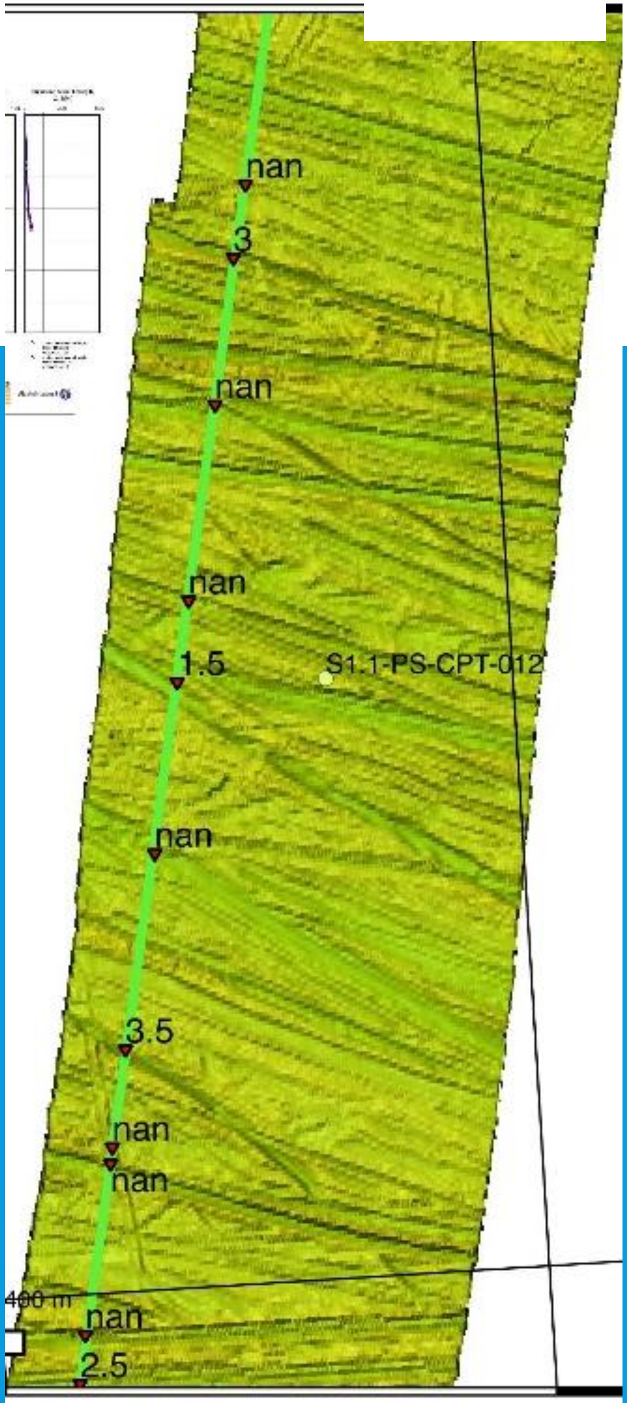

Image of sea floor from
Multi-beam data

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IMPLEMENTATION – EXAMPLE: *ICE SCOUR*

DESIGN GOUGE DEPTH

Probability of a particular keel depth:

Three-parameter Weibull p.d.f.

$$P(D) = \frac{\alpha}{\beta}\left(\frac{D-\mu}{\beta}\right)^{\alpha-1} e^{-\left(\frac{D-\mu}{\beta}\right)^{\alpha}}$$

Probability of a particular gouge depth:

Exponential Distribution [C-CORE 2008]

$$P(B) = \lambda e^{-\lambda(B-B_0)}$$

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IMPLEMENTATION – EXAMPLE: *ICE SCOUR*

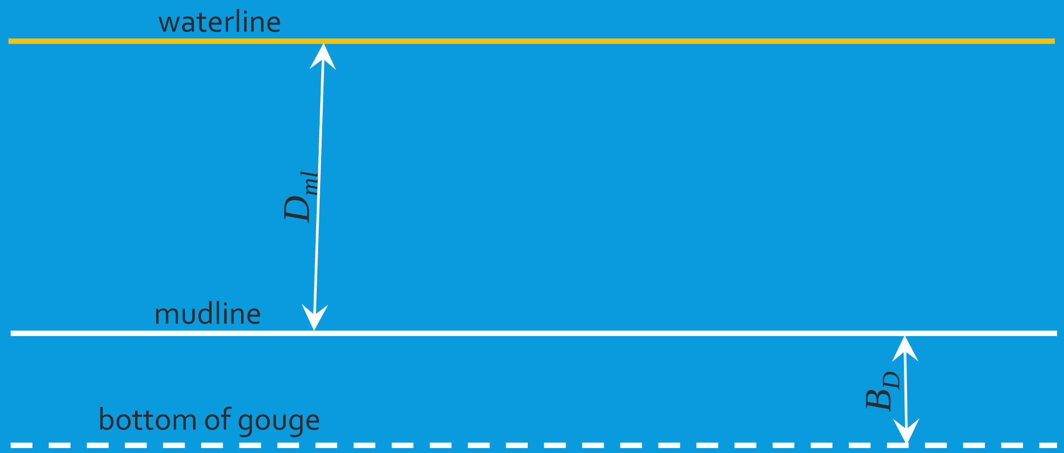
DESIGN GOUGE DEPTH

Probability that a keel will exceed a specified gouge depth:

$$P\left(D \geq B_D\right) = P\left(D \geq D_{ml}\right) \cdot P\left(B \geq B_D\right)$$

Subsisting p.d.f.s and solving for design gouge depth:

$$B_D = -\frac{\ln\left[\dfrac{1-\left(P_{ex}\right)^{\frac{1}{n}}}{\int_{D_{ml}}^{\infty} P\left(D\right) dD}\right]}{\lambda} + B_0$$



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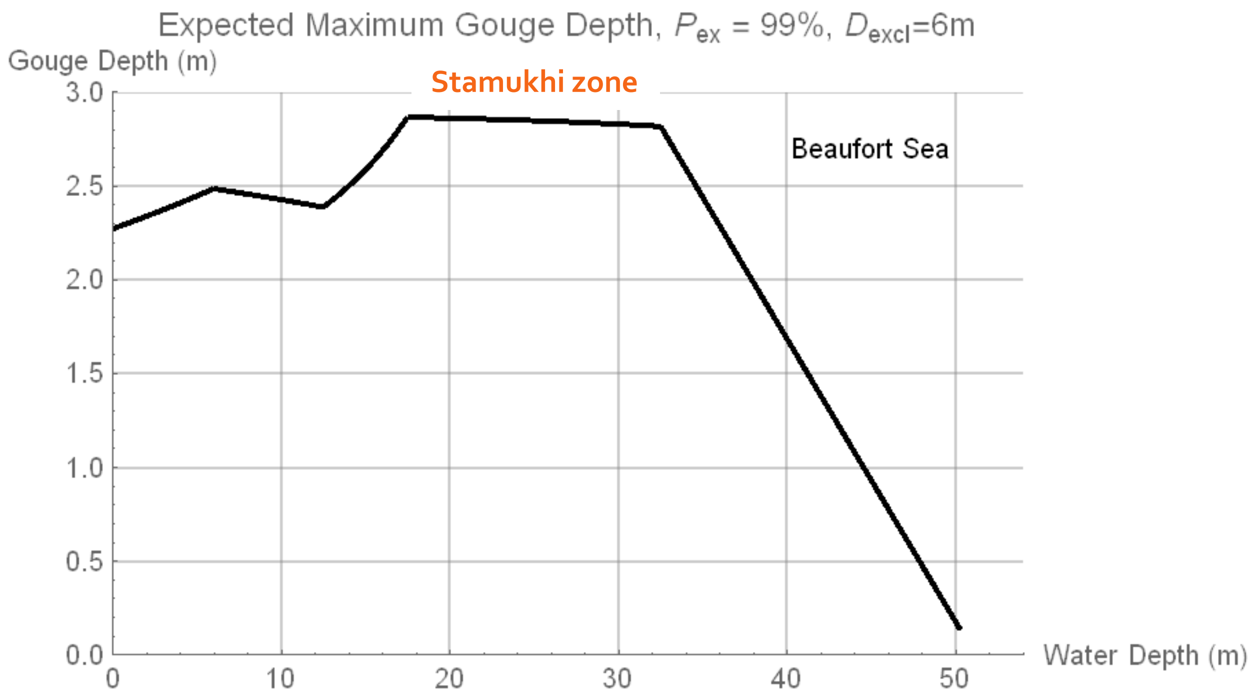
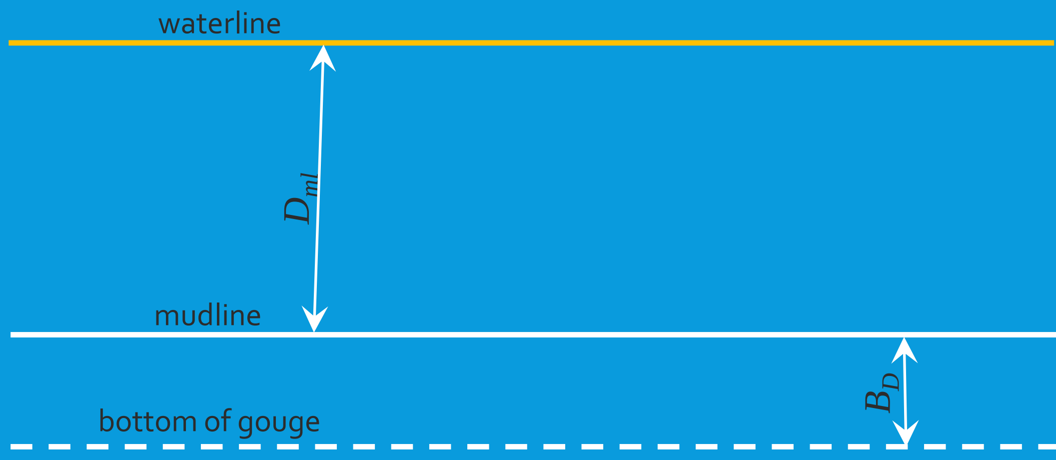
IMPLEMENTATION – EXAMPLE: *ICE SCOUR*

DESIGN GOUGE DEPTH

Result: design gouge depth versus water depth

R = 99%; $P_f = 1\%$





- Results showed agreement with measurements for water depth 15m and deeper.
- There is a lack of data for shallower depths due to seasonal shoaling.
    - This likely impacted results for values for water depth <15m.

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- Concluding Remarks
- Philosophy of the ISO 19906 is sound
  - The same philosophy is in wide-spread use for other types of facilities where public safety and welfare are paramount
  - Sound theoretical basis

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- Concluding Remarks

- Implementation of the philosophy

  - REQUIRES A ROBUST DESCRIPTION OF THE UNCERTAINTIES OF DESIGN
    - Material strength; construction QA/QC – relatively easy to ascertain

    - Uncertainties of actions – external demands
    - Relatively expensive to determine
    - Often difficult to determine
    - PROJECTS SHOULD BE PRO-ACTIVE IN THEIR DETERMINATION
      - PUT FORTH EFFORT BEFORE THE PLANNING STAGE
      - 2 TO 3 YEARS OF SITE-SPECIFIC DATA
        - METEROLOGICAL
        - OCEANOGRPAHIC
        - SEA ICE

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  - Final report: **TAP-716-Reliability-Based Sea-Ice Parameters for Design of Offshore Structures**