

# Outlook for Safety Level of New Ship Design and Construction

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## Provisional Long-Term Work Plan for the SLA –summary-

1. **Determination** of the **current safety level to develop Tier I goals**
2. **Consideration** of the **work on FSA**, in particular concerning **risk acceptance criteria**.
3. **Reconsideration** of the GBS **tier structure**
4. **Reexamination of Tier II functional requirements by** using SLA
5. **Examination of risk models**
6. **Development of goal-based standard guidelines**
7. **Consideration of the Tier III verification process**

# SLA issues from view point of structural design and construction

Quantitative (Probabilistic) Assessment method for structural failure

↔ **Structural Reliability Assessment (SRA)**

- **Design Method** ↔ **Limit State Design**

e.g.

- ▣ **DNV**: Structural Reliability Methods (Classification Note)
- ▣ **Architectural Institute of JAPAN**: Recommendations for Limit State Design of Buildings
- ▣ **ISO 2394**: General Principles on reliability for structures etc.

- **Rule calibration (verification)**

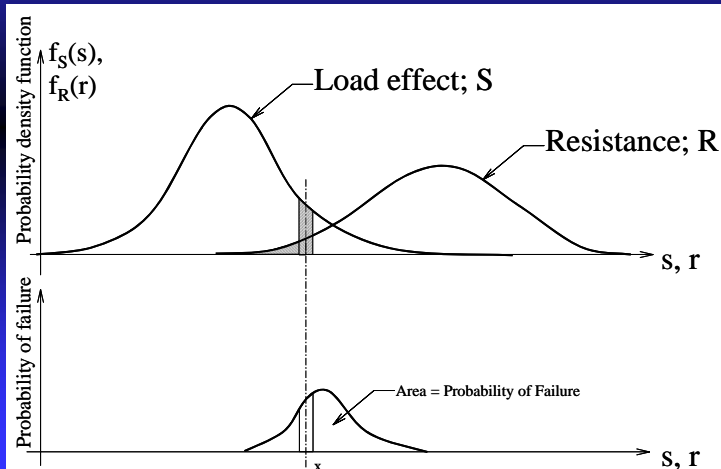
e.g.

- ▣ Background Document of **CSR** for Oil Tankers
- ▣ Reliability based structural design and code development (**ISSC 2006**) etc.

## Structural Reliability Assessment (SRA)

Probability of Failure ;  $P_f$

$$P_f = \int_0^{\infty} f_S(S) \cdot F_R(S) dS$$



# Structural Reliability Assessment (SRA)

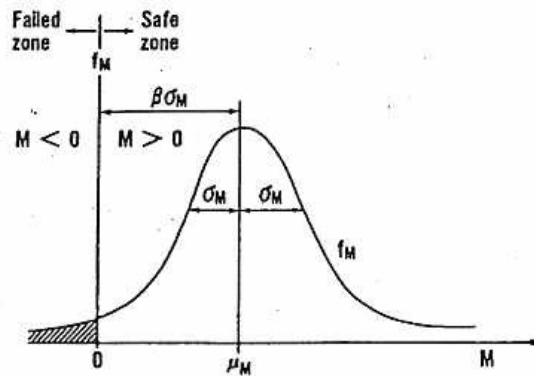
Reliability index ;  $\beta$

$$\beta = \frac{\mu_M}{\sigma_M} \quad \text{First Order Second Moment Method}$$

Where

**M**: Limit State Function (M=R-S)

$\mu_M$  : mean of M     $\sigma_M$  : standard deviation of M



## Limit State Design

Limit State Design requires appropriate degrees of reliability of structures or structural elements not to exceed limit states provided in the design rule.

$$\begin{aligned} \text{Allowable Probability of failure } P_{fa} &\geq \text{Designed Probability of failure } P_f \\ \text{or} \\ \text{Allowable reliability index } \beta_a &\leq \text{Designed reliability index } \beta \end{aligned}$$

Evaluation criteria  
Target Safety Level

How to set ?

# Target Safety Level

## Assumed Approach to set Target Safety Level

- 1 Based on **accident statistics data**  
↔ Statistical total data against failure seem unclear.
- 2 Based on existing **rules calibration**  
↔ It sometimes seems unclear if existing rules requirement are optimum level or not.
- 3) Based on **comparison** with risk assessment for **another disasters**  
↔ Hazard for failure differs from each design.
- 4 Based on **cost-benefit assessment** averting a fatality  
↔ Linkage between fatality and structural failure is very complicated.

# Target Safety Level

Probability of failure ;  $P_f$   
Reliability index :  $\beta$

**notional** values,  
**index** rather than probabilistic expectation

Approach based on the existing **rule calibration**

↔ **Current safety level** for the rule

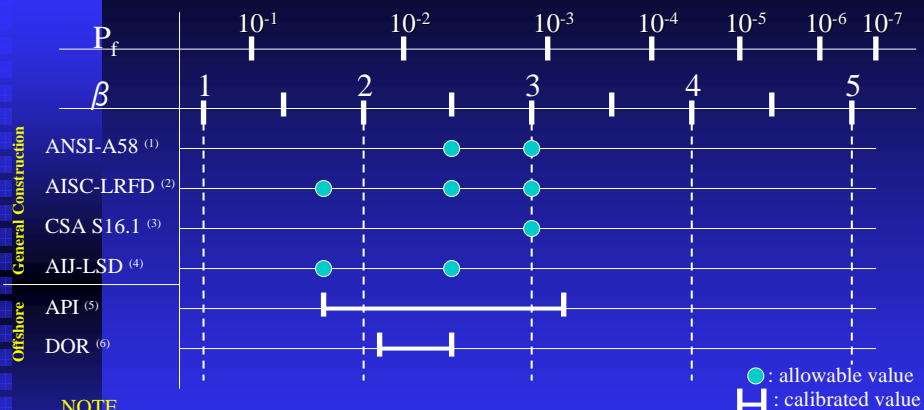
Standardized or agreed manner, including probabilistic model, to calculate Probability of failure or Reliability index,  
is deemed necessary

## Target Safety Level -Example (1) -

Failure development	Failure consequences		
	Not serious	Serious	Very serious
Ductile failure with reserve strength capacity	$P=10^{-3}$ $\beta=3.09$	$P=10^{-4}$ $\beta=3.71$	$P=10^{-5}$ $\beta=4.26$
Ductile failure with no reserve capacity	$P=10^{-4}$ $\beta=3.71$	$P=10^{-5}$ $\beta=4.26$	$P=10^{-6}$ $\beta=4.75$
Brittle behaviour in terms of fracture or instability	$P=10^{-5}$ $\beta=4.26$	$P=10^{-6}$ $\beta=4.75$	$P=10^{-7}$ $\beta=5.20$

Source: MSC79/INF.5 submitted by Denmark, Iceland, Norway and the Faroe Islands

## Target Safety Level -Example (2) -



**NOTE**

- (1) Probability Based Load Criteria (American National Standard A58; USA)
- (2) The AISC Load and Resistance Factor Design Criteria (USA)
- (3) Limit State Design of Steel Structures (Canada)
- (4) Recommendations for Limit State Design of Buildings (Architectural Institute of JAPAN)
- (5) Designing and Constructing Fixed Offshore Platforms (American Petroleum Institute; USA)
- (6) Regulations for Permanent Offshore Steel Construction (Danish)

Source: Text (Japanese) "Reliability Design Method of structure by Masaru HOSHIYA et al."

## Target Safety Level -Example (3-1) -

**CIRIA**<sup>(1)</sup> (COnstruction I ndustry R esearch and I nformation A ssociation)

$$P_{fa} = \frac{10^{-4}}{n_r} K_s \cdot T$$

Where

$P_{fa}$  : Allowable Probability of failure during survive life

$T$  : Service life of construction [year]

$K_s$  : Social criterion factor

$n_r$  : Averaged number of victim due to construction failure

**Allen**<sup>(2)</sup>

$$P_{fa} = \frac{T \cdot A \cdot 10^{-5}}{W \sqrt{n}}$$

Where

$P_{fa}$  : Allowable Probability of failure during survive life

$T$  : Service life of construction [year]

$A$  : Activity factor

$W$  : Warning factor

$n$  : Maximum number of victim due to construction failure

Source (1) : CIRIA Report 63, 1977

Source (2) : 3<sup>rd</sup> International Conference on Structural Safety and Reliability, 1981

## Target Safety Level -Example (3-2) -

**Guidelines on Reliability Design of Offshore Structure**<sup>(3)</sup>

$$\beta = -0.4 \cdot \log T + 0.53 \cdot (\log N + \log W) + \beta_0$$

Where

$\beta$  : Allowable reliability index during survive life

$T$  : Service life of construction [year]

$N$  : Damage influence factor

$W$  : Warning factor

$\beta_0$  : Criterion factor

Source (3) : The Society of Naval Architectures of Japan, 1993

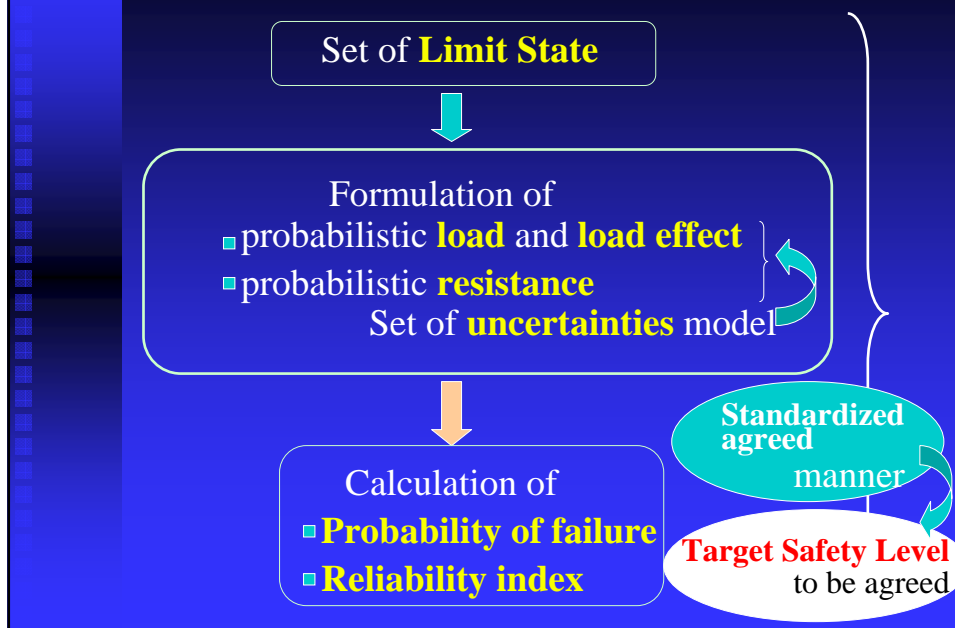
## Target Safety Level -Example (4) -

### ISO 2394

#### 8.3 Specified degrees of required reliability

- Specified **maximum acceptable failure probabilities** should depend on the **consequence** and the **nature of failure**, the **economic loss**, the **social inconvenience**, and the **amount of expense** and **effort** required to reduce the probability of failure.
- Specified degrees of **required reliability** should **be calibrated** against **well-established cases** that are known from **past experience** to have adequate reliability.
- When dealing with **time-dependent structural properties**, the effect of the **inspection** and **repair** procedures on the probability of failure should be taken into account.
- Specified **failure probabilities** should always be considered in relation to the **adopted calculation** and **probabilistic models** and the **method of assessment** of the degree of reliability.

## Calculation of probability of failure



## Limit State

### ISO 2394

- Ultimate Limit State
- Serviceability Limit State

General construction

### IACS (Draft Tier II — Safety Level Approach MSC 82/5/5)

- Ultimate Limit State
- Fatigue Limit State
- Serviceability Limit State
- Accidental Limit State

Ship

### ISSC 2006 “Reliability based structural design and code development”

- Ultimate Limit State
- Fatigue Limit State

Calculation of failure probability

## Limit State Function

### ISSC 2006 “Reliability based structural design and code development”

#### • Ultimate Limit State

$$g(\cdot) = R - \sum_i S_i$$

Where

$R$  : ultimate load carrying capacity

$S_i$  : load effect due to the  $i^{\text{th}}$  load

#### • Fatigue Limit State

##### ■ Crack initiation

$$g(\cdot) = D_{\text{lim}} - D_d$$

Miner's Rule

Where

$D_{\text{lim}}$  : fatigue damage at failure (1.0 ; Miner Rule)

$D_d$  : cumulative damage (period,  $t$  with  $N_T$  cycles)

##### ■ Crack propagation

$$g(\cdot) = a_f - a$$

Paris' Law

Where

$a_f$  : crack size at failure

$a$  : crack size as a function of the number of cycles,  $N$

## Formulation of statistical model

### Set of uncertainty model (1)

#### ● Type of uncertainty

- **Probabilistic uncertainty** → Environmental condition, material properties, etc.
- **Statistical uncertainty** → lack of data, lack of measurement accuracy  
Data Standardization etc. ↑
- **Model uncertainty** → Modeling (e.g. calculation method, etc.)  
Model Standardization etc.
- **Human element uncertainty** → Human error

## Formulation of statistical model

### Set of uncertainty model (2)

#### ★ Related to **Load Model**

Environmental condition  
(Sea State etc.)

Calculation of ship motion, pressure, Load etc.

Combination of Loads

#### ★ Related to **Resistance Model**

Material properties

Size, shape of structure

Calculation of strength

# Probabilistic Model for load (load effect)

Sea-States Data

Table  
Probability of sea-states in the North Atlantic described as occurrence per 100,000 observations

Hs/Tz	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	SUM
0.5	00	00	13	133.7	565.6	1169.0	634.2	1563	369	56	07	01	00	00	00	00	00	00	3060
1.5	00	00	00	26.3	996.0	4876.0	7738.0	8697	2375.7	703.5	1607	30.5	5.1	0.8	0.1	0.0	0.0	0.0	22675
2.5	00	00	00	2.2	197.5	2198.8	6238.0	7480.5	4860.4	2066.0	6445	100.2	33.7	6.3	1.1	0.2	0.0	0.0	23810
3.5	00	00	00	0.2	34.9	696.5	3285	6750	9091	2850	1141	337.7	84.3	18.2	3.5	0.6	0.1	0.0	19428
4.5	00	00	00	0.0	6.0	191.1	1344.3	3285	387.5	295.5	175.2	455.1	191.9	31.9	6.9	1.3	0.2	0.0	13269
5.5	00	00	00	0.0	1.0	61.0	488.4	932.9	2372.7	2108.3	1120.0	463.6	165.9	41.0	9.7	2.1	0.4	0.1	8338
6.5	00	00	00	0.0	0.2	12.6	167.0	6903	1277.9	1266.6	629.9	385.8	101.8	42.2	10.9	2.5	0.5	0.1	4456
7.5	00	00	00	0.0	0.0	0.0	3.0	52.1	2701	594.4	703.2	524.9	257.7	111.7	36.7	10.2	2.5	0.5	2586
8.5	00	00	00	0.0	0.0	0.0	0.7	15.4	97.9	259.9	368.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	1309
9.5	00	00	00	0.0	0.0	0.0	0.2	4.3	33.2	101.9	169.9	152.2	98.2	48.3	18.7	6.1	1.7	0.4	626
10.5	00	00	00	0.0	0.0	0.0	0.0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4.0	1.2	0.3	285
11.5	00	00	00	0.0	0.0	0.0	0.0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	124
12.5	00	00	00	0.0	0.0	0.0	0.0	0.1	1.0	4.4	9.9	12.8	11.0	6.8	3.3	1.3	0.4	0.1	51
13.5	00	00	00	0.0	0.0	0.0	0.0	0.0	0.3	1.4	3.5	5.0	4.6	3.1	1.6	0.7	0.2	0.1	21
14.5	00	00	00	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0.0	8
15.5	00	00	00	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0.0	3
16.5	00	00	00	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.0	1
SUM:	0	0	1	16	201	920	1822	2469	2880	1268	624	249	87	247	66	16	3	1	10000

Source: IACS Rec. No.34 "Standard Wave Data"

# Probabilistic Model for load

## Calculation method of wave induced response

Method	Hydrodynamic model	Structural loads
Full-3D, nonlinear, time-domain analysis	<ul style="list-style-type: none"> <li>3D-non-linear pressure distribution</li> <li>Inertia forces</li> </ul>	Long-term pressure and acceleration time series
3D-linear analysis (frequency domain)	<ul style="list-style-type: none"> <li>3D linear pressure distribution</li> <li>Inertia forces</li> </ul>	Set of short term spectra for pressure and acceleration
2D time domain analysis	<ul style="list-style-type: none"> <li>2D/2.5D hydrodynamic model</li> <li>Strip theory</li> </ul>	Long-term force and acceleration time series
2D linear analysis (frequency domain)	<ul style="list-style-type: none"> <li>2D linear strip theory/frequency domain</li> </ul>	Sectional force (pressure)

Source: ISSC 2006 "Reliability based structural design and code development"

## Uncertainty model

Material properties (e.g. yield stress)

Source	Material	Bias (%)	COV (%)	comments
ISSC (1985)	MS + HTS Plate	32	5.6	Japanese mill data
	Rolled Angles	31	3.3	
Baker (1972)	MS Plate	10.6	4.8	COV reduces with incr.thick.
	HTS Plate	10.1	4.9	
Flint (1980)	HTS Plate	15.6	6.7	Limited sample size
Fjeld (1978)	MS	5	5	DNV reported experience

Source : Frieze, P.A. : Lessons learnt from Reliability Analysis Studies of Offshore Platforms (OMAE'86)

## Uncertainty model

- **IACS** Shipbuilding and Repair Quality Standard

- Materials
- Cutting
- Fabrication and fairness
- Alignment
- Welding

- **Japan Shipbuilding Quality Standard (JSQS) (1999)**

by The Society of Naval Architects of Japan

**e.g. Gas cutting**

Item	Standard range	Tolerance limits
General members	± 3.5 (mm)	± 5.0 (mm)
<b>compared with correct sizes</b>	± 2.5* (mm)	± 4.0* (mm)

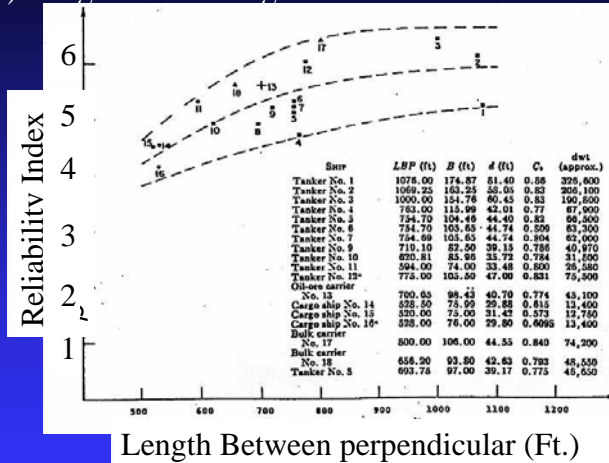
etc.

\* For the depth of floor and girder of double bottom

- **ISO 15401** Ships and marine technology- Bulk carriers  
- Construction quality of hull structure

## Calibration of safety level

e.g.) Longitudinal strength



Source: Mansour, A.E. : Probabilistic Design Concepts in Ship Structural Safety and reliability (1972)

Other Reference: Mansour, A.E. : Development of Reliability Based Classification Rules for Tankers (2002)

## The issue to be solved in Structural Reliability Assessment

- Set of **Limit State** in the IMO-GBS work
  - ★ Ultimate Limit State
  - ★ Fatigue Limit State
  - ⋮
- Set of **Structural Risk Model** in the IMO-GBS work
  - ★ Probabilistic model for **load or load effect**
  - ★ Probabilistic model for **resistance**
- Consistency between Target Safety level of Tier I and **Target Probability of Failure**

Cooperative work

## **Work plan in the NMRI**

- **Examination of Structural Risk Model, including which limit state should or can be organized in the IMO work.**
- **Examination of current structural safety level in order to set target structural safety level, which is consistent with goal of Tier I.**
- **Examination of related draft instrument based on the above consideration.**