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Optimization via RAMDO considering Uncertainties for Marine Applications

Hyun-Seok Kim

Alternative Fuels and Power System Research Division,
Korea Research Institute of Ships and Ocean Engineering (KRISO)

(Previously) Offshore Platform Research Division at KRISO

선박해양플랜트연구소

KRISO 선박해양플랜트연구소 KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING

0. Introduction

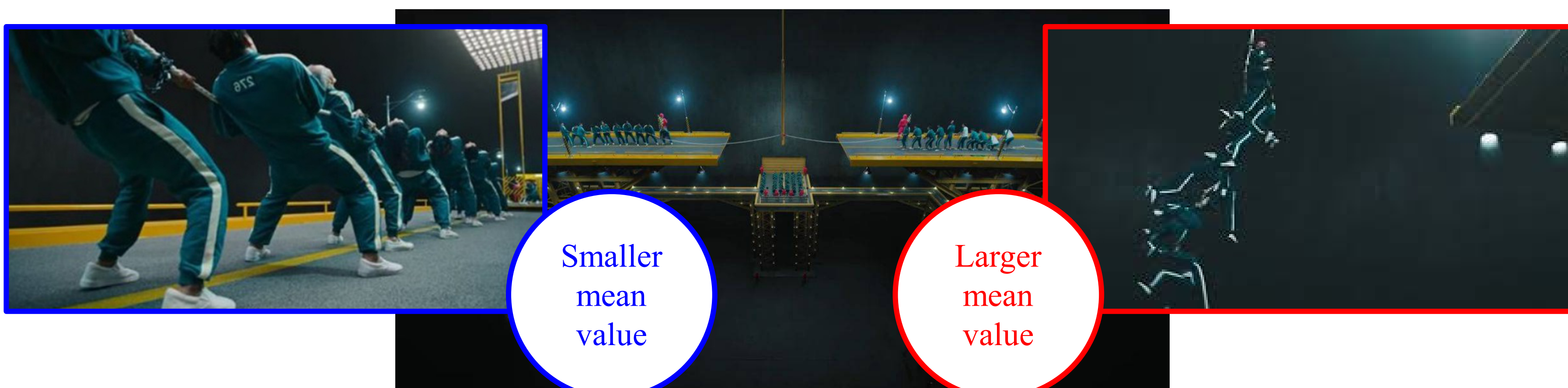
❑ What is uncertainty?

- Uncertainties in material properties

Same material

Different results due to different material properties

- Uncertainties in loads



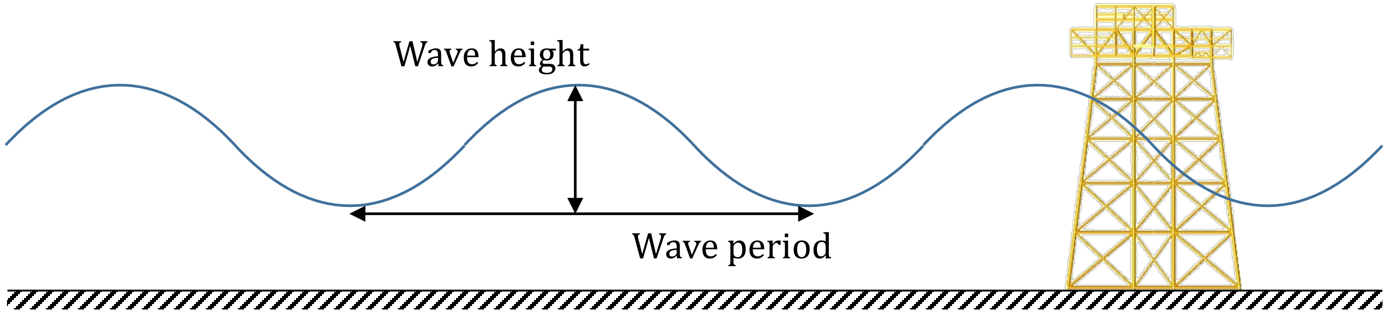
Due to distributions(=tactics), loads with smaller mean value can affect more

0. Introduction

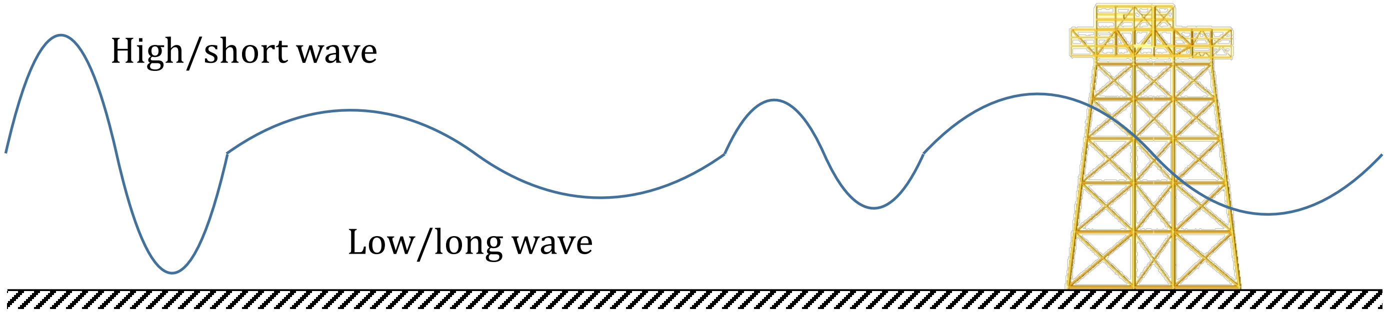
❑ How to consider uncertainties – Statistical approach

- Designing an offshore platform – How can we consider the waves?

Assumption: sinusoidal wave



Reality: Variability → What wave should we consider as design criteria?



- In practice, we define a deterministic design wave with certain return period (i.e., 100 years).
- What if a larger wave occur? When will it occur? → Uncertainty, Probability

0. Introduction

❑ Contents of this presentation

- How offshore platform is designed and evaluated in practice.
- How to consider uncertainties for designing an offshore platform.
- Optimization of an offshore platform considering uncertainties.

❑ Target offshore platform

- Installation site: the North Sea.
- Water depth: 130m
- Topside weight: ~20,000ton
- Supporting structure: ~13,200ton

Figure 1. Target installation site (By Halava)

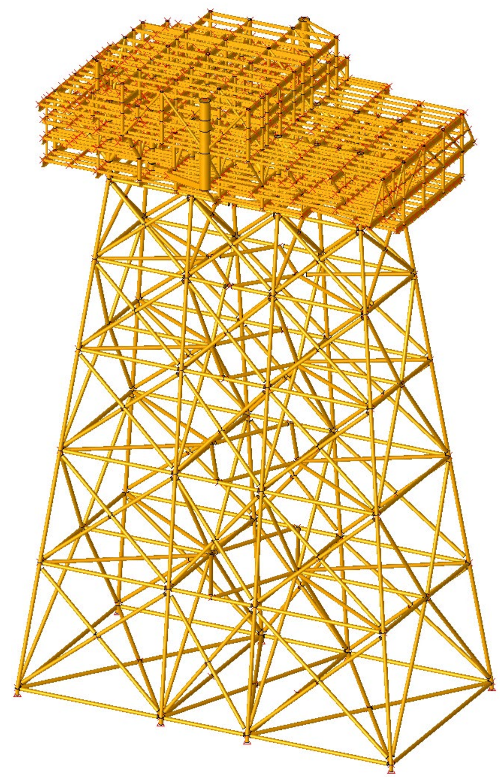


Figure 2. KRISO developed fixed-type offshore platform

1. Designing and Evaluating an Offshore Platform

❑ Design

- Designing offshore platform is followed by rules and codes of classification society.
- Environmental conditions are defined with certain return period based on observed data of the installation site.

❑ Structural safety evaluation

- Structural safety is evaluated for various load cases which are the combination of self weight, environmental(direction), and operational loads.
- Unity check value: ratio of acting stress and allowable stress.

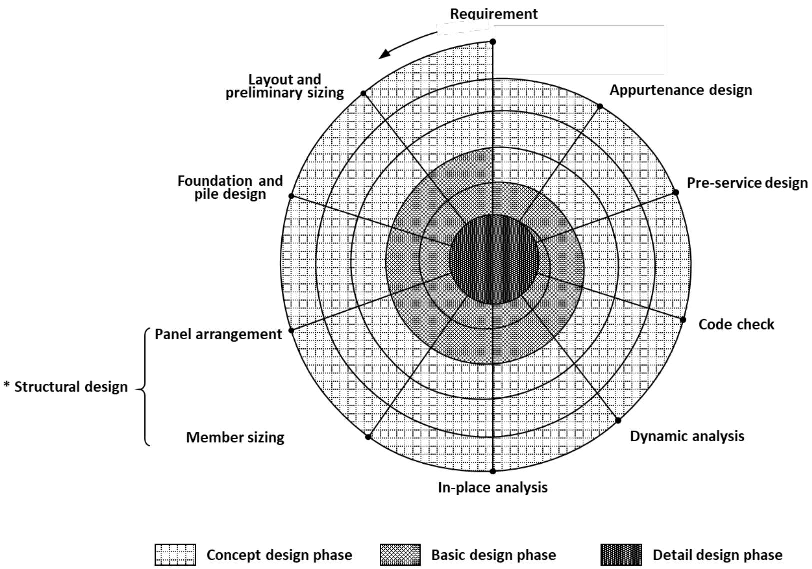


Figure 3. Design spiral

Table. 1 Environmental conditions considered for the design

Environmental conditions	Value
Wave height (100 years return period)	15.00 (m)
Wave period (100 years return period)	15.50 (sec)
Wind speed (100 years return period)	40.50 (m/s)
Current speed (at surface)	2.007 (m/s)

Table. 2 Structural safety evaluation result

	Criteria	Load Case
North Sea (Tp 15.5 sec)	**0.4148 (Safe, <1.0)**	LMU

2. Uncertainties on the Offshore Platform

❑ Uncertainties from environmental conditions

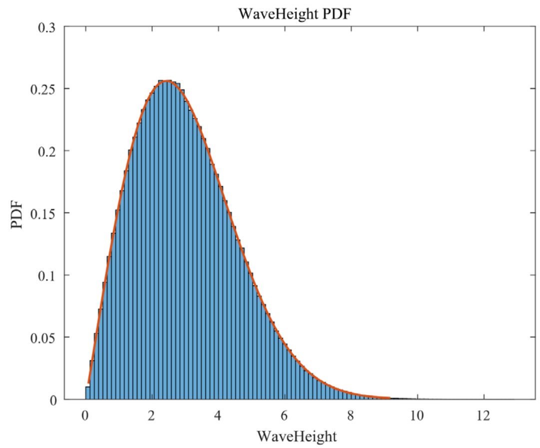
- Variability exist in environmental conditions such as winds, waves, and currents.
- We utilized references to determine the statistical characteristics of environmental conditions such as distribution type, distribution parameters, mean, and STD.
- Compared to the rules and standards, return periods are from 0 to infinite years.

Table 3. Statistical characteristics of environmental variables

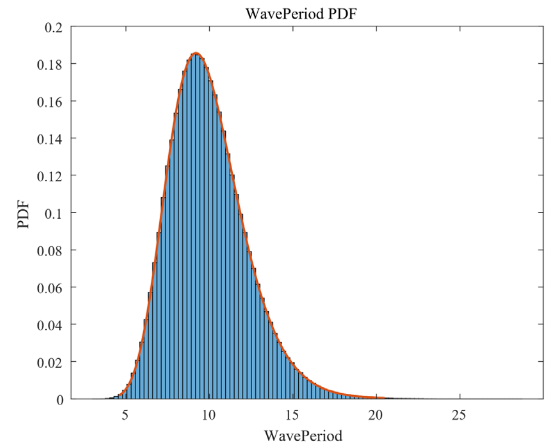
Name	Distribution Type	Distribution Parameters	Mean	STD
Marginal distribution of wind speed, f_{U_w}, [m/s]	Weibull	Shape = 1.708, Scale = 8.426	7.5197	4.5290
Conditional distribution of significant wave height given wave speed, $f_{H_s\|U_w}$, [m]	Weibull	Shape = 2.0 + 0.135u_w, Scale = 1.8 + 0.100$u_w^{1.322}$	3.0014	1.5451
Conditional distribution of Peak period given wave height and wind speed, $f_{T_p\|H_s,U_w}$, [sec]	Lognormal	$\mu_{T_p} = (4.883 + 2.68h_s^{0.529}) \left[1 - 0.19\left(\frac{u_w - (1.764 + 3.426h_s^{0.78})}{1.764 + 3.426h_s^{0.78}}\right)\right]$, $\sigma_{T_p} = (-1.7 \cdot 10^{-3} + 0.259e^{-0.113h_s})$	9.9360	2.2929
Marginal distribution of current speed, f_{V_c}, [m/s]	Weibull	$\mu_{V_c} = 0.137$, $\sigma_{V_c} = 0.01$	0.1370	0.0100

2. Uncertainties on the Offshore Platform

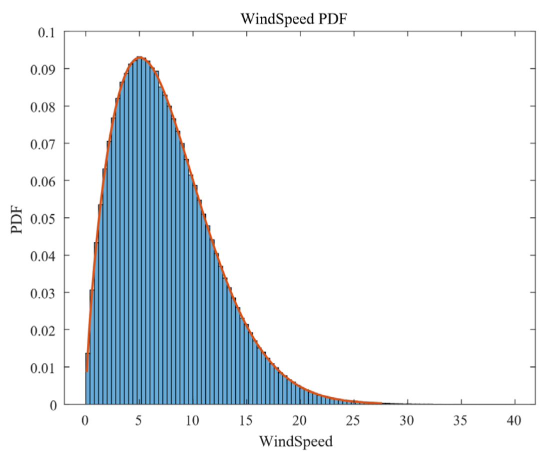
❑ Uncertainties from environmental conditions



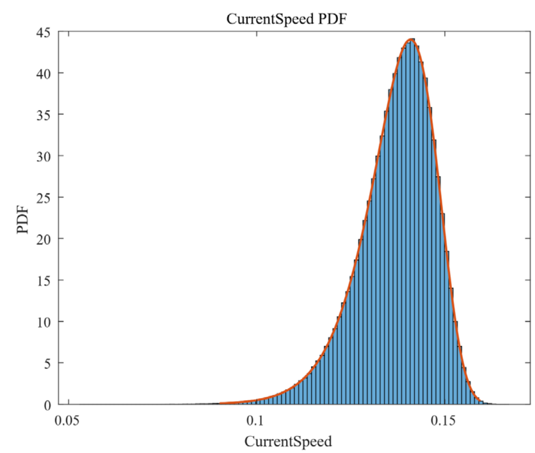
(a) PDF of Weibull distribution for wave height



(b) PDF of Log normal distribution for wave period



(c) PDF of Weibull distribution for wind speed



(d) PDF of Weibull distribution for current speed (surface)

Figure 4. PDF of environmental conditions

2. Uncertainties on the Offshore Platform

❑ Uncertainties from material properties and manufacturing

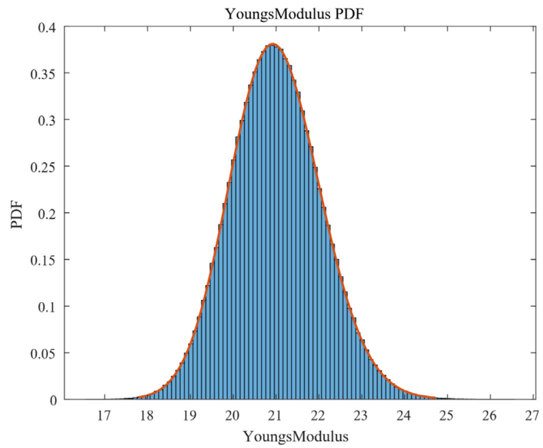
- Variability also exists in material properties and manufacturing.
- Based on experimental data, the statistical characteristics are defined.

Table 4. Statistical characteristics of material properties

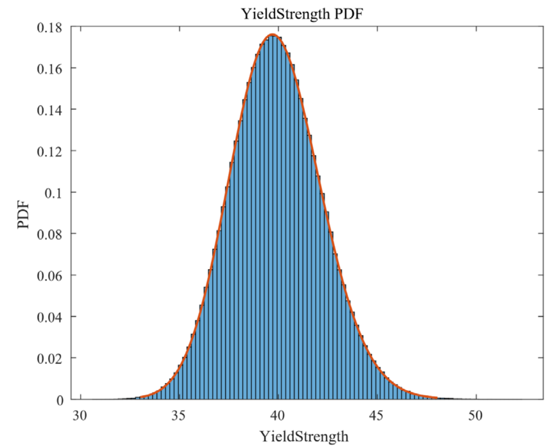
Name	Distribution Type	Nominal Design used in Analysis	Mean	STD
Elastic Modulus, $[kN/cm^2]$	Log normal	20.50	21.00	1.05
Yield Strength, $[kN/cm^2]$	Log normal	35.50	39.888	2.2736

Table 5. Statistical characteristics of manufacturing tolerance

Name	Coefficient of Variation (CoV)	Note
Thickness of members	5%	Applied as side constraints compared to the t/D ratio and slenderness ratio



(a) PDF of Log normal distribution for elastic modulus



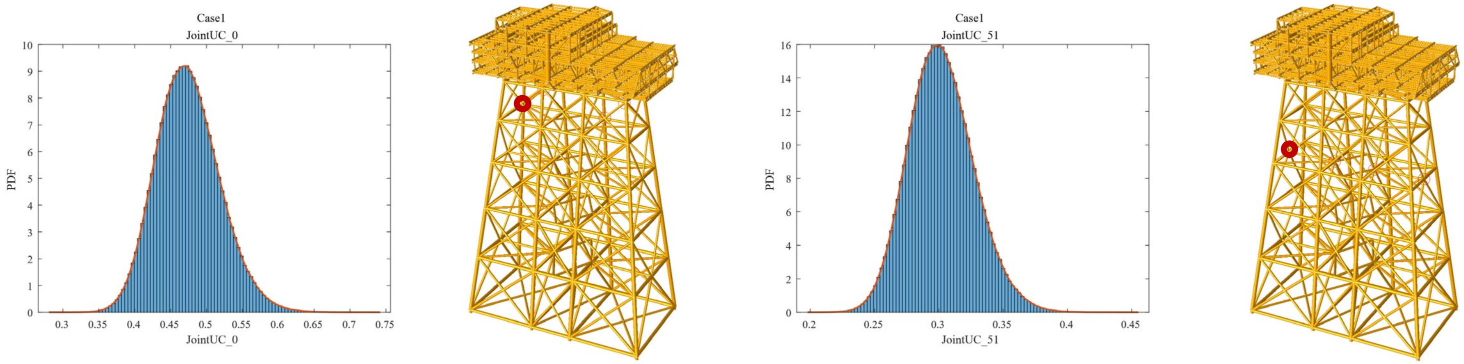
(a) PDF of Log normal distribution for yield strength

Figure 5. PDF of material properties

3. Structural Safety considering Uncertainties

❑ Uncertainty quantification and reliability analysis of the initial design

- UQ: how the outputs are affected by the uncertainties.
- RA: what are the probability of failure (violation of criteria) due to uncertainties.
- Analysis solver: FEM based offshore platform analysis code
- UQ and RA: RAMDO by RAMDO Solutions



Joint0 unity check, Re = 100%   Joint51 unity check, Re = 100%

Figure 6. Uncertainty quantification and reliability analysis results for the initial offshore platform design

- The initial design turned out to be too conservative → cost efficiency
- Target reliability: 99.865%

Table 6. Reliability analysis result at initial design

Reliability of joint stress unity check values								
Location	Joint51	Joint52	Joint53	Joint54	Joint0	Joint1	Joint2	Joint3
Reliability (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

4. Optimization of the Offshore Platform

- Efficient optimization considering uncertainties
  - We want make the offshore platform cost efficient and safe considering uncertainties → Reliability-Based Design Optimization.
  - RAMDO offers efficient optimization method considering uncertainties.

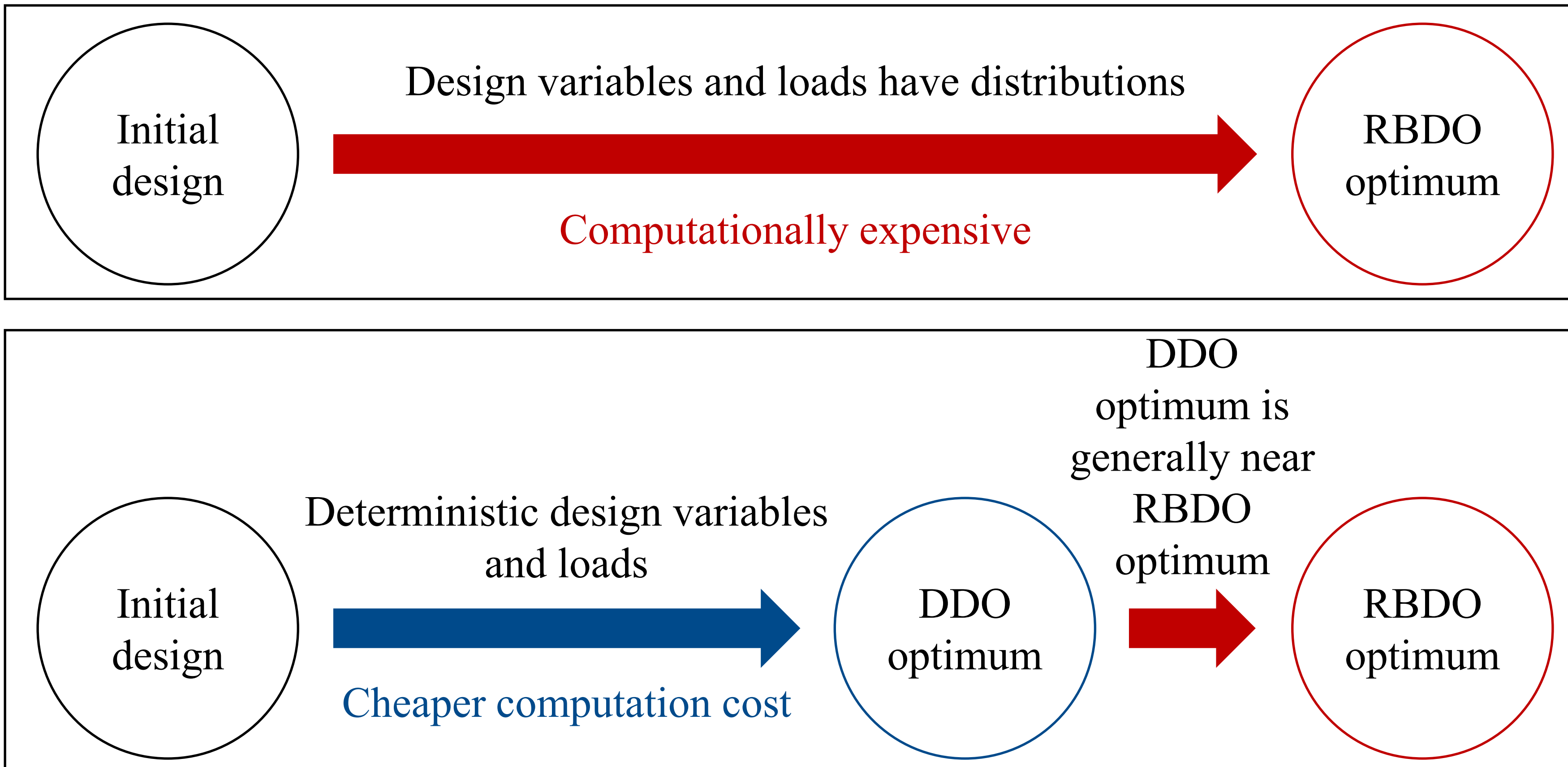


Figure 7. Efficient RBDO method via RAMDO

4. Optimization of the Offshore Platform

❑ Deterministic Design Optimization (DDO)

- Design variables and loads are deterministic.
- Objective function is to minimize the weight of the structure.
- 74 design variables, and total 91(initial 83, 8 added) constraints are defined.

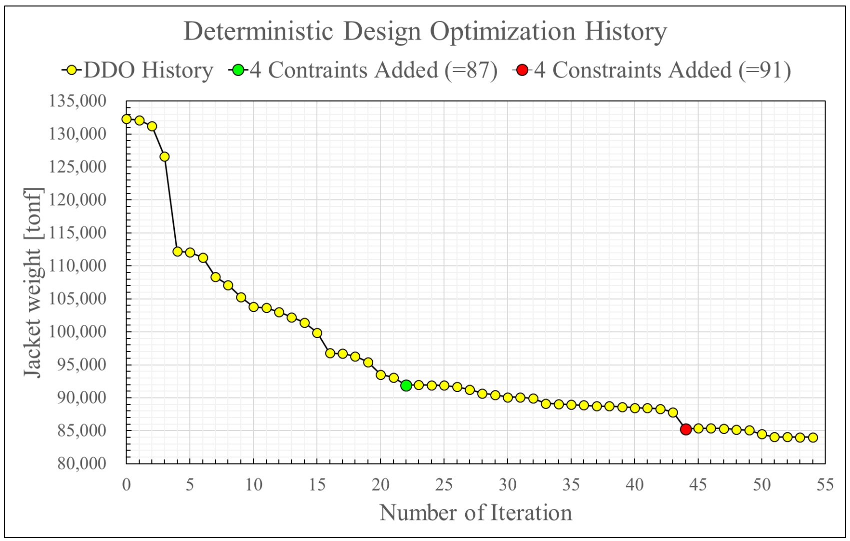


Figure 8. DDO history

Table 7. DDO results

	(a) Initial	(b) DDO Optimum	(c) (b)/(a) (%)
Objective function	132,311	84,011	63.49

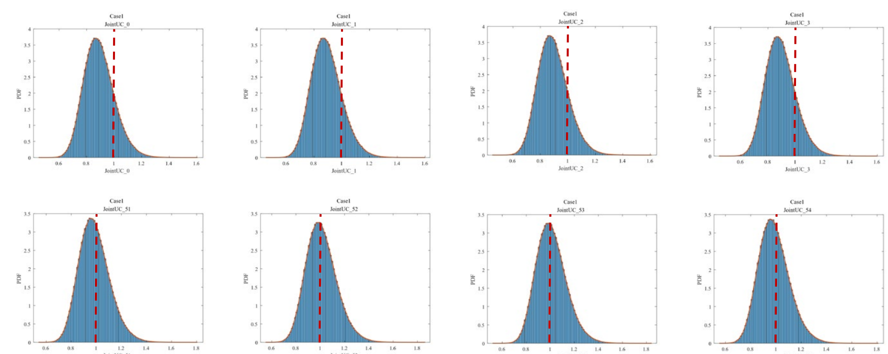


Figure 9. Uncertainty quantification at DDO optimum

Table 8. Reliability at DDO optimum (only ones below target reliability are tabulated)

Constraint	Joint #51 UC	Joint #52 UC	Joint #53 UC	Joint #54 UC	Joint #0 UC	Joint #1 UC	Joint #2 UC	Joint #3 UC
DDO optimum	57.491%	49.669%	49.670%	57.388%	83.788%	83.758%	83.461%	83.439%

4. Optimization of the Offshore Platform

❑ Reliability-Based Design Optimization (RBDO)

- Design variables and loads have distributions.
- Objective function is to minimize the weight of the structure.
- 37 design variables, and 8 constraints are defined. (Target Re = 99.865%)

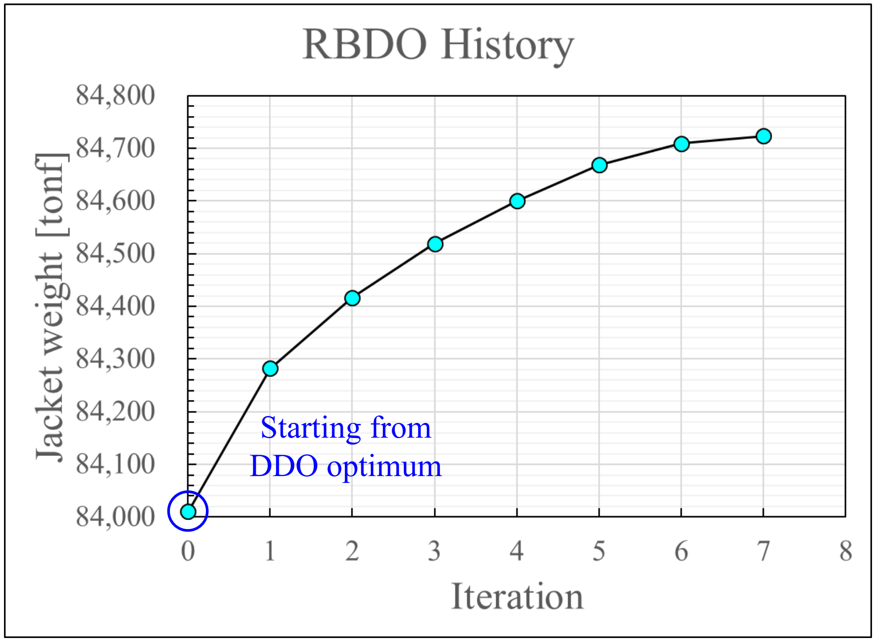


Figure 10. RBDO history

Table 9. RBDO results

	(a) Initial	(b) RBDO Optimum	(c) (b)/(a) (%)
Objective function	84,011	84,723	64.03

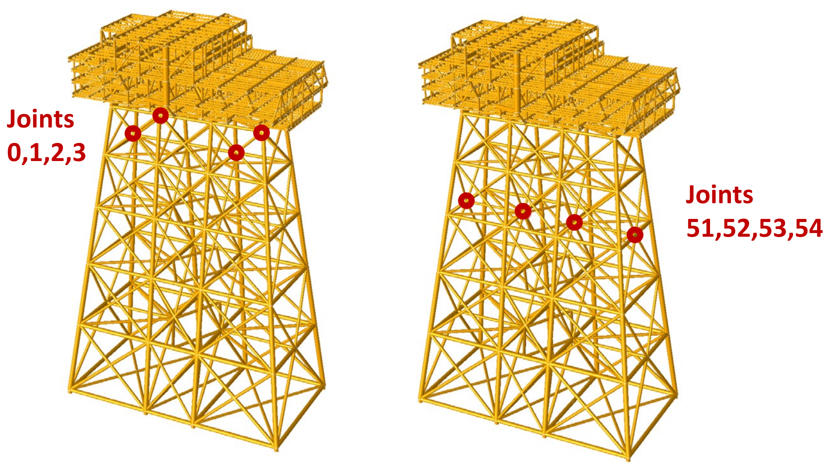


Figure 11. Location of the joints

Table 10. Reliability at RBDO optimum

Constraint	Joint #51 UC	Joint #52 UC	Joint #53 UC	Joint #54 UC	Joint #0 UC	Joint #1 UC	Joint #2 UC	Joint #3 UC
DDO optimum	57.491%	49.669%	49.670%	57.388%	83.788%	83.758%	83.461%	83.439%
RBDO optimum	99.922%	99.865%	99.865%	99.919%	99.871%	99.873%	99.865%	99.866%

5. Optimization via RAMDO – Based on Our Experience

❑ Pros

- RAMDO can be integrated with any SWs as simulation solver.
- Compared to other optimization tools, RAMDO provides accurate and reliable design optimum → optimum is obtained from sampling point.
- Easy customization to user specific problem → interactive and professional staffs.
- Validation and Verification: can validate your simulation model with test data[1)].

[1)] Moon, M-Y., et al, “Uncertainty Quantification and Statistical Model Validation for an Offshore Jacket Structure Panel Given Limited Test Data and Simulation Model,” *Structural and Multidisciplinary Optimization*, **61**, 2020.

❑ Cons

- When considering uncertainties, input information is expensive.
- Computational cost for RBDO is expensive → reduce the dimension of problem.

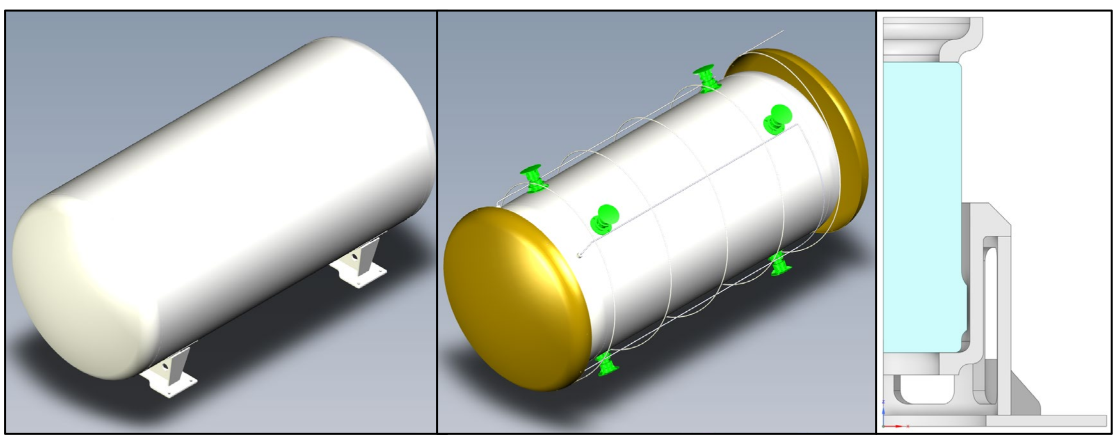


Figure. Design optimization of LH_2 storage tank support structures via RAMDO

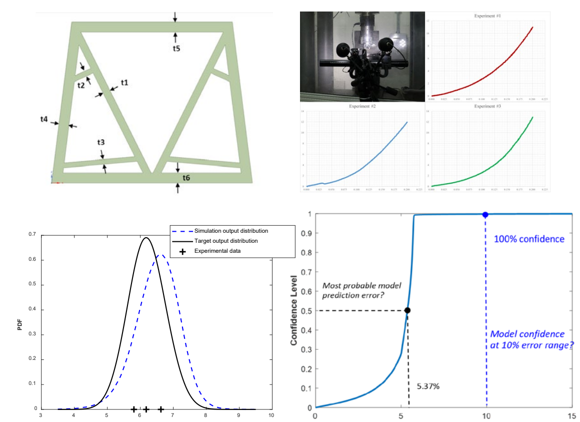


Figure. Statistical model validation via RAMDO[1)]

Conclusions

- Optimization of offshore platform considering uncertainties
  - Uncertainties from environmental loads, material properties, and manufacturing tolerance are considered.
  - When uncertainties are considered, structural safety is evaluated and is compared with the conventional rule based approach.
  - To enhance the structural safety(=reliability), and to reduce the weight of the structure, an efficient RBDO is carried out utilizing RAMDO.

- RAMDO as optimization tool
  - Compared to other optimization tools, RAMDO provides accurate and reliable solutions.
  - It can be integrated with any SWs as simulation solver.
  - For computational efficiency, reducing the dimension of problem is essential.

Thank You

Korea Research Institute of Ships & Ocean Engineering

Contact: **Hyun-Seok Kim**
hskim85@kriso.re.kr

For RAMDO related questions,

Contact: **Nicholas Gaul**
nicholas-gaul@ramdosolutions.com