Monte Carlo Simulation on Ultimate Bending Capacity of Hybrid Composite Girder

モンテカル法に基づくハイブリッド合成桁の終局曲げ耐力に関する研究

XU YIFEI

Yamamoto Lab., EME, GSSIE
University of Tsukuba

INTRODUCTION

Specification-based Design for Bridge

Updated[1]

Performance-based Design for Bridge

Allowable Stress Design method (ASD)

Stress-based Design

$$f_{\mathrm{d}} > \sigma_{\max}$$

Design Strength — Maximum Stress

Limit State Design Method (LSD)

Capacity-based Design

Stress-based Design

$$R_{\mathrm{d}} > M_{\max}$$

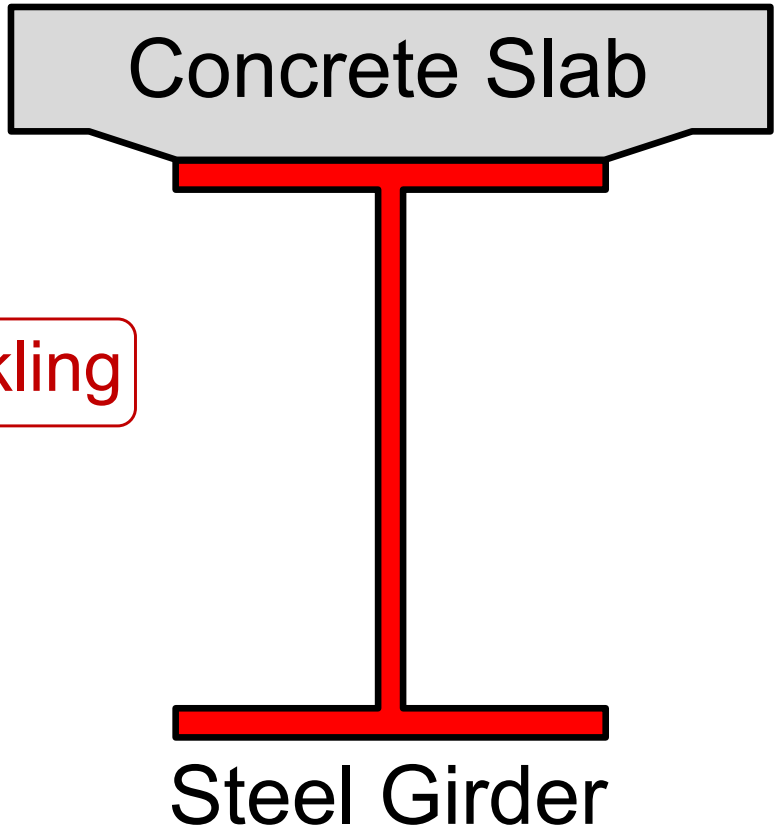
Design Capacity — Maximum Load

[1] Japan Road Association: Road Bridge Specifications, 2017. (in Japanese)

MERIT OF CAPACITY-BASED DESIGN

Ultimate Limit State =

Concrete Crushing or Steel Buckling



[2] Kyosuke Yamamoto, Hitotaka Kouno, Kuniyuki Sugiura, Yoshinobu Oshima and Tarou Tonegawa, Effect of material plastic properties on ultimate Bending Capacity of Hybrid Composite Girder, 62nd Annual Lecture of Civil Engineering Society, 2007. (in Japanese)

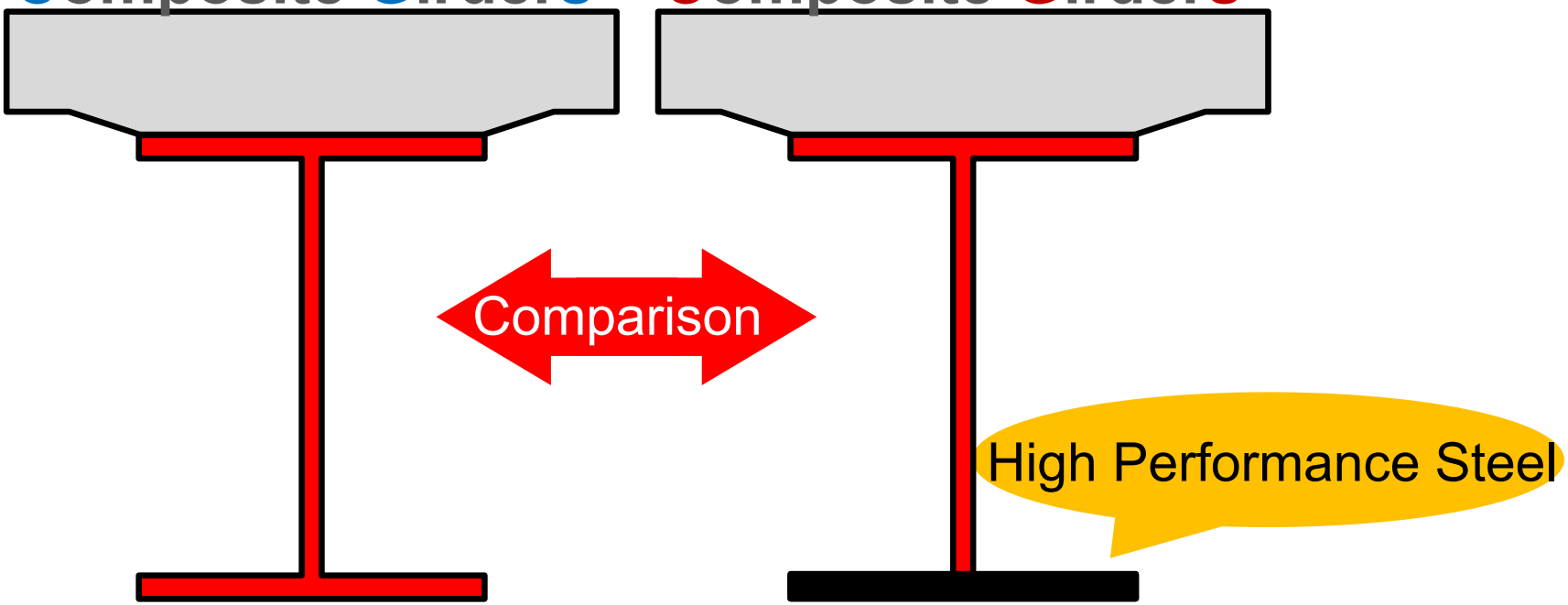
COMPOSITE GIRDER AMELIORITON

Normal

Composite Girders

Hybrid

Composite Girders



Steel Cost 20% decrease[3] 10% decrease

[3] Masutsugu Nagai, Takeshi Miyashita, Cuiping Liu, Naofumi Inaba and Atsushi Homma, Design and Application of Steel and Steel-Concrete Plate Girds Bridges with Hybrid Section, Journal of Japan Society of Civil Engineers A1, Vol68, No.1, pp.203-215, 2012. (in Japanese)

BENDING CAPACITY CALCULATE CRITERION

Full-Plastic Bending Moment Ultimate Bending Moment calculated by **Fiber Method** / **Finite Element Method**

M_p or M_b or M_f

Easier → **More Accurate**

$$M_d < M_u$$

The Design Value Of Ultimate Limit State

The true value of Ultimate Bending Moment

Factor of safety

$$M_d = \alpha M_P$$

- M_P: basic design method (easy)
- $M_d = \alpha M_P$: design load

→ evaluate M_u < or > M_d

< : Failure

> : Safety

Bending Capacity → evaluate M_u/M_P

PURPOSE

NCGs = Normal Composite Girders
HCGs = Hybrid Composite Girders

To verify the ultimate limit state
Compare the Reliability of NCGs and HCGs

▽

Failure Probability

▽

Ultimate Limit State = Concrete Crushing or Steel Buckling

▽ ▽

Fiber Method FEM

All Material Parameters are taken as Random Variables

NUMERICAL EXPERIMENT

M_u/M_p evaluate = Bending Capacity

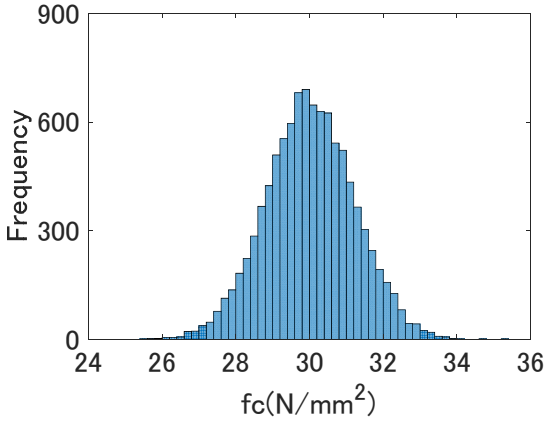
Ultimate Bending Moment

Full-Plastic Bending Moment

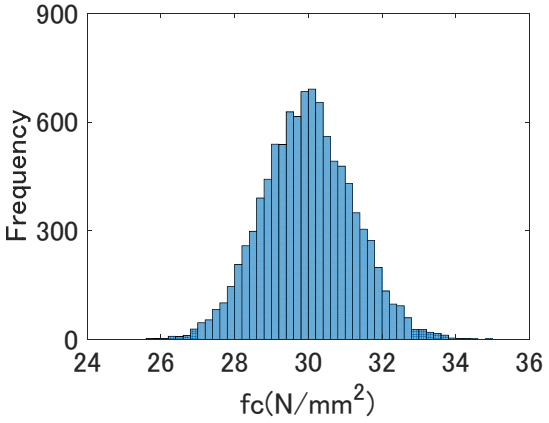
Random Variables

- Compression Strength f_c
- Young's Modulus E
- Yield Strength σ_y
- hardening strain ε_{st}
- Hardening Coefficient E_{st}
- Hardening Curvature ξ

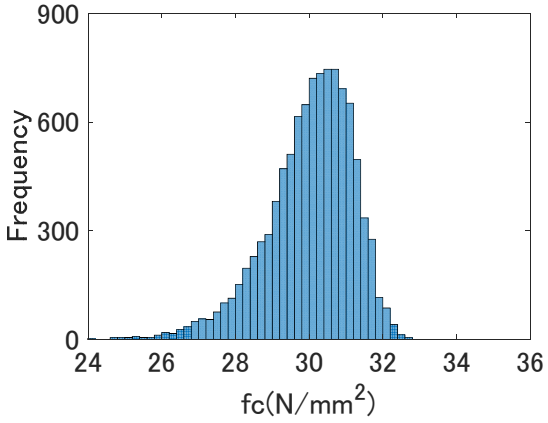
Normal Distribution



Log-normal Distribution



Weibull Distribution



$$f_c(\mu = 30N/mm^2, \sigma = 1.2)$$

CONTENT

- **Fiber method**
  - ① Concrete crushing ultimate state
  - ② Model setup
  - ③ Results and Discussion
- **FEM**
  - ① Steel buckling ultimate state
  - ② Model setup
  - ③ Results and Discussion

CONTENT

- **Fiber method**

① Concrete crushing ultimate state

② Model setup

③ Results and Discussion

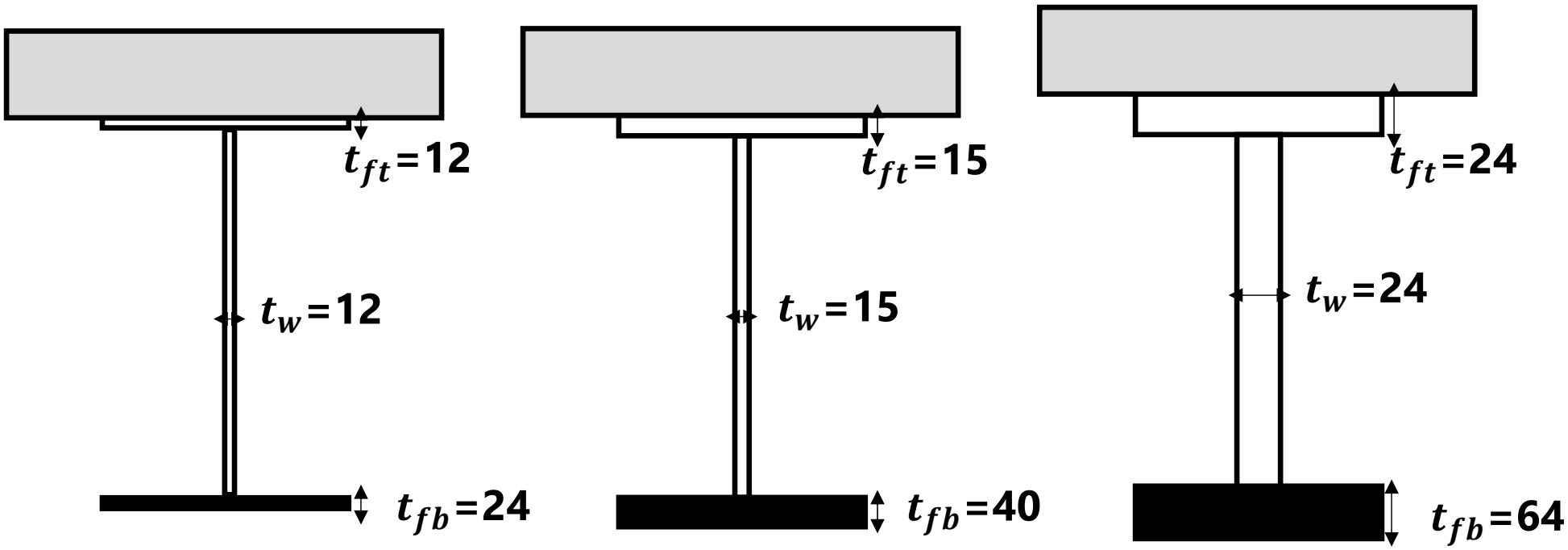
- **FEM**

① Steel buckling ultimate state

② Model setup

③ Results and Discussion

SIMULATION MODEL

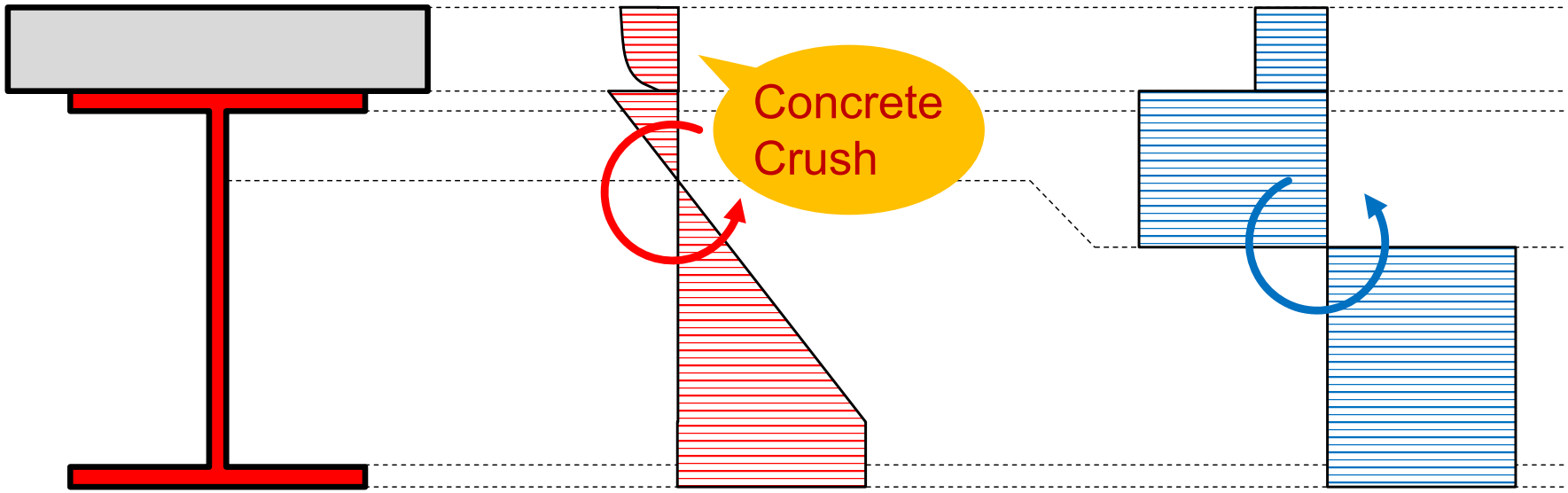


slender standard compact

FIBER METHOD

Basic design method

Ultimate Limit State　Design Index

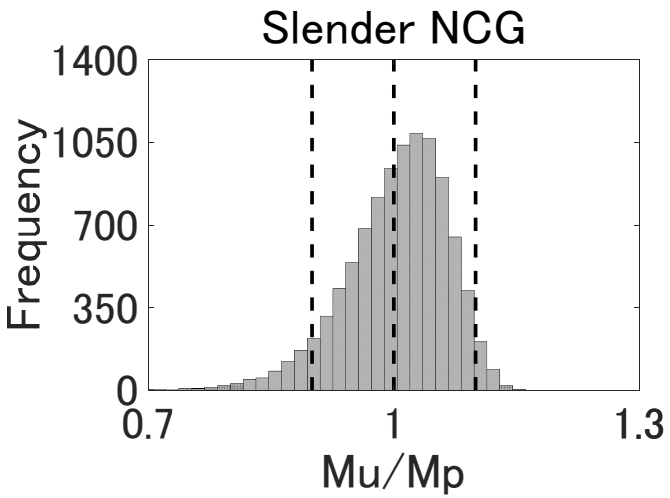


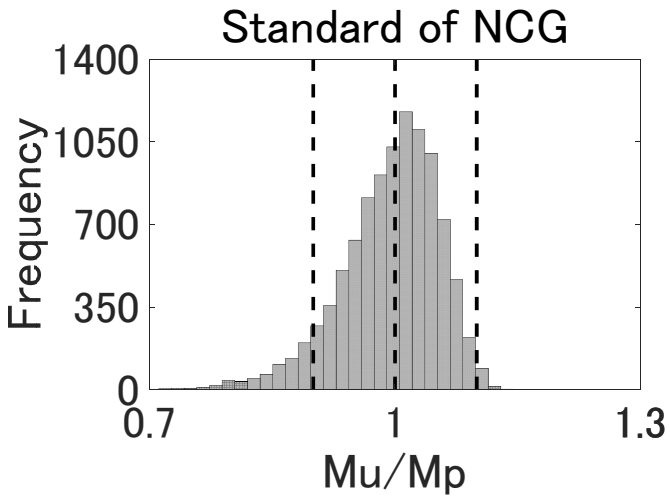
Ultimate Bending Moment : M_u

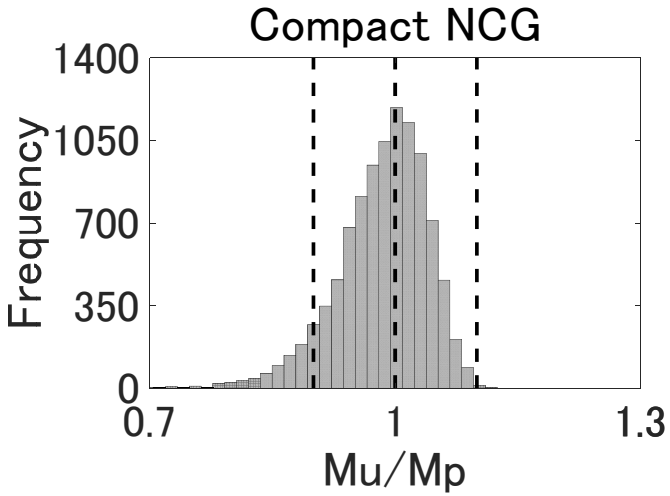
Full-Plastic Bending Moment : M_p

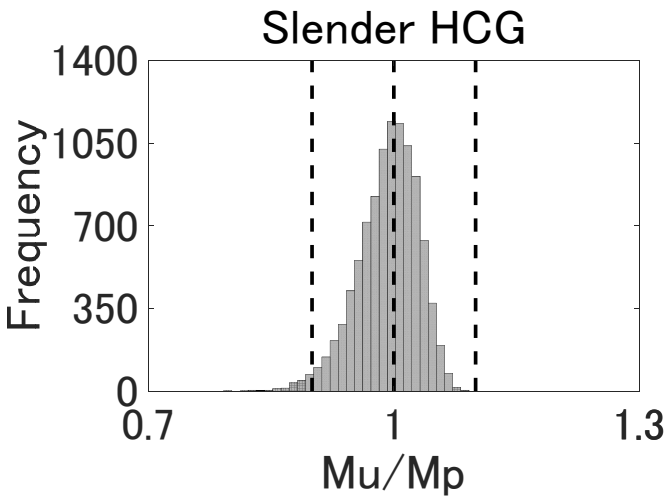
[4] Yukio Maeda, Yasuharu Kajikawa and Masao Ishiwata, Bending Behaviors and Maximum Load-Caring Capacity of Hybrid Composite Beams, Kawasaki Technical Report, Vol.10, No.1, pp.86-99, 1978. (in Japanese)

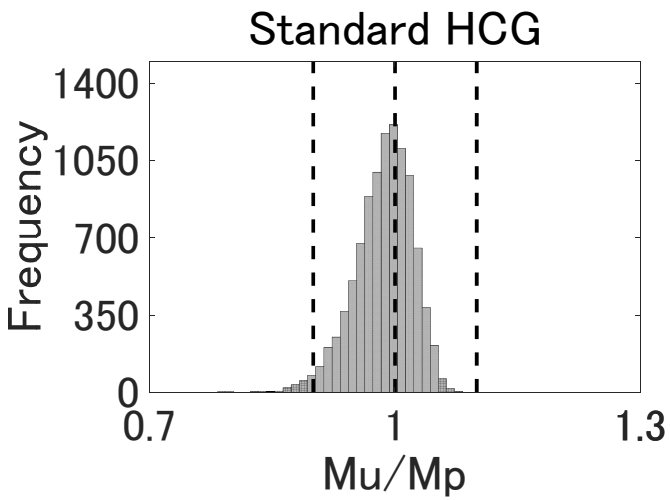
RESULT OF WEIBULL DIST.

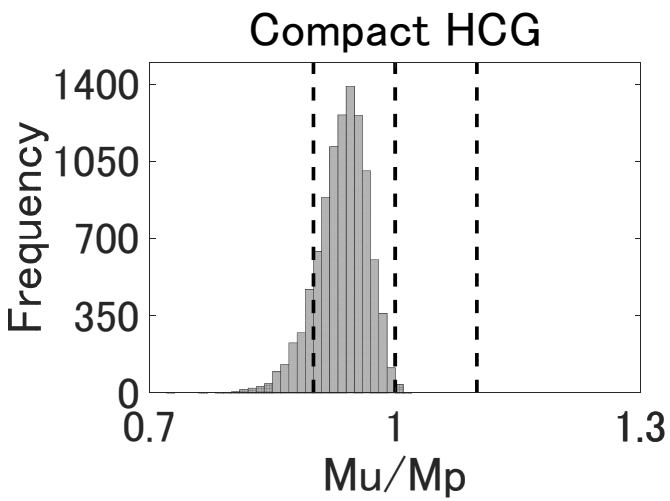








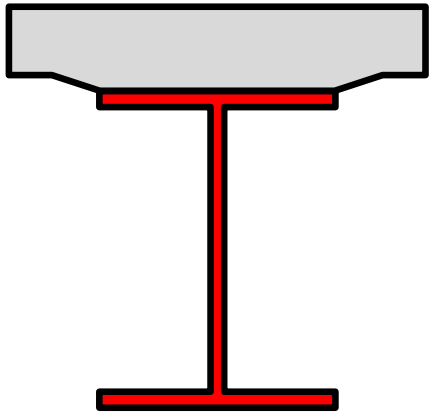


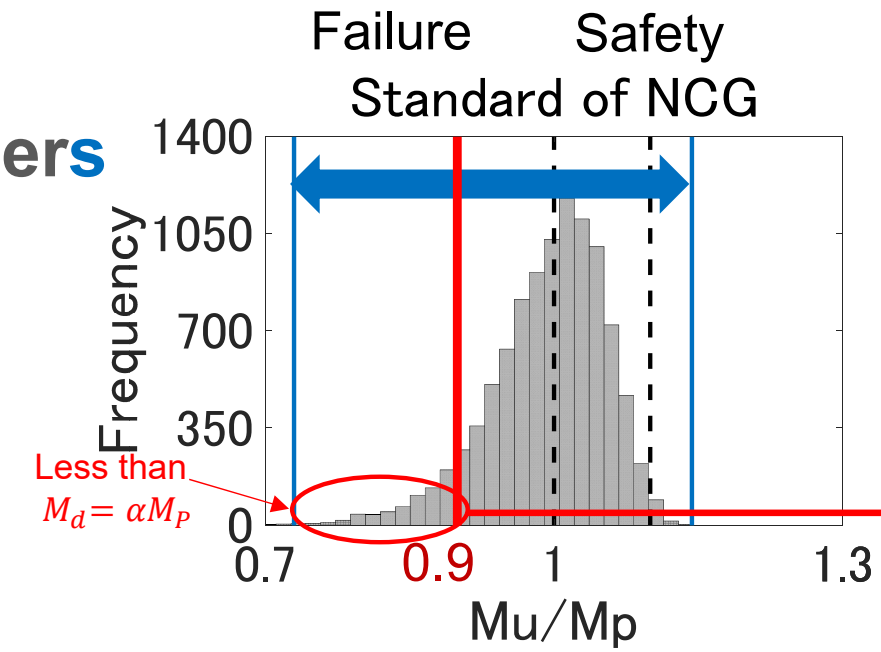


DISCUSSION OF HISTOGRAMS

Normal

Composite Girders





Larger quality variation

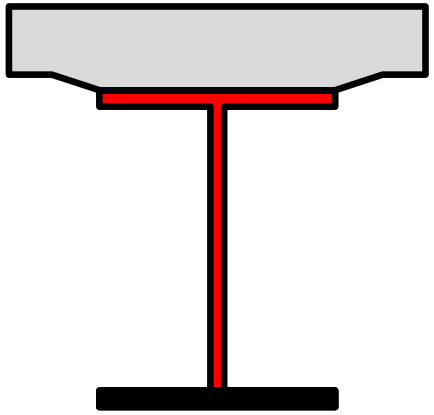
Large quality variation means a disperse data distribution and is more likely to have more abnormal samples.

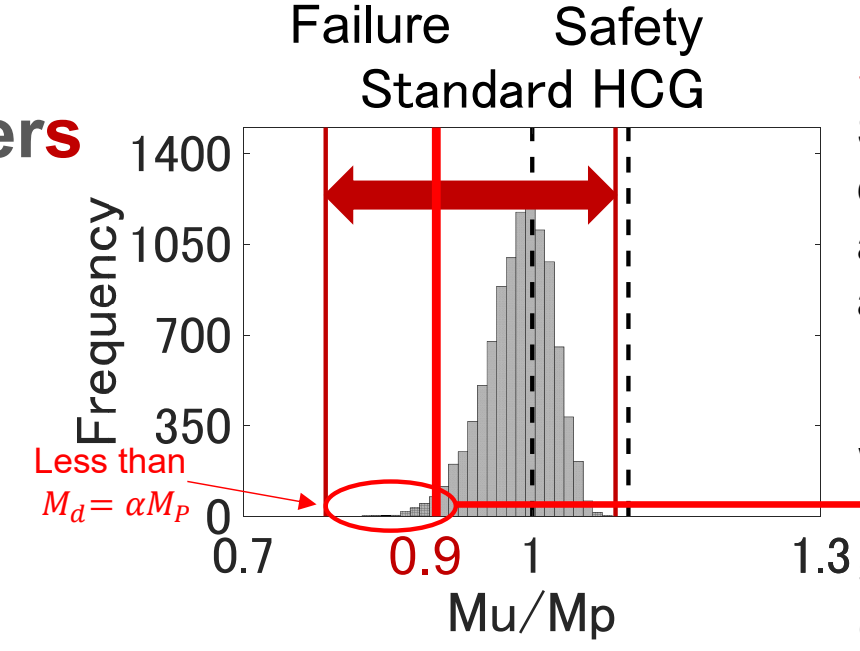
Higher Failure Probability

High failure probability means , with certain factor of safety, there are more unreliable samples and more failure cases, with means less reliable.

Hybrid

Composite Girders





Smaller quality variation

Small quality variation means a concentrate data distribution and is more likely to have fewer abnormal samples.

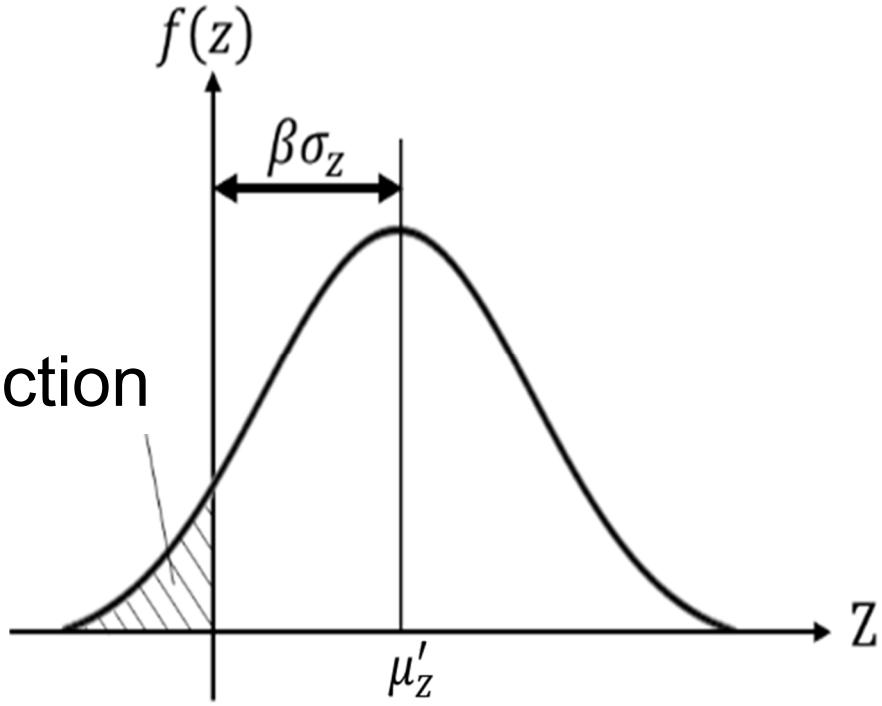
Lower Failure Probability

Low failure probability means , with certain factor of safety, there are fewer unreliable samples and fewer failure cases, with means more reliable.

RELIABILITY INDEX

$$\beta = \frac{\mu_Z - \alpha}{\sigma_Z} = \frac{\mu'_Z}{\sigma_Z}$$ [3]

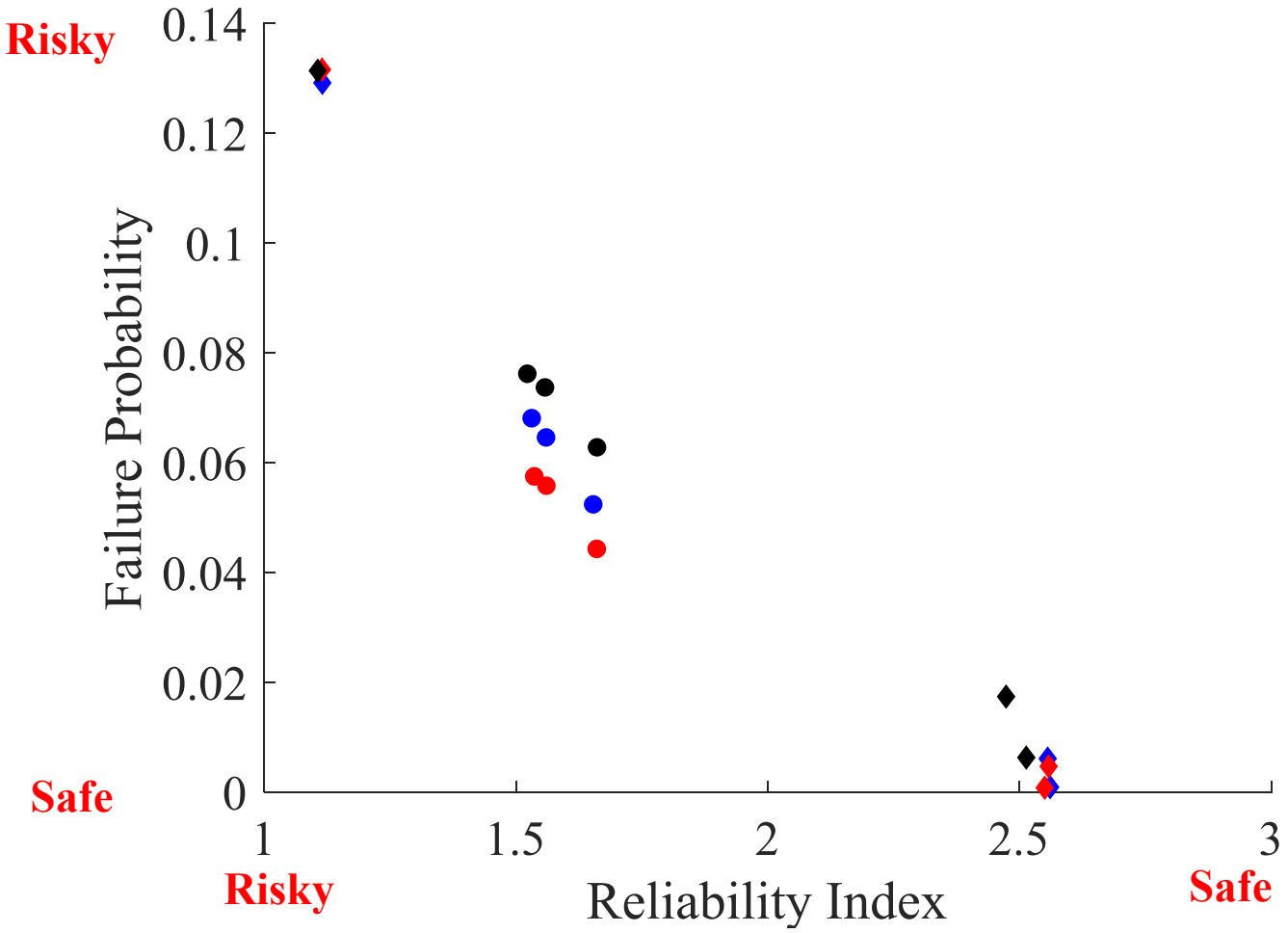
Destruction



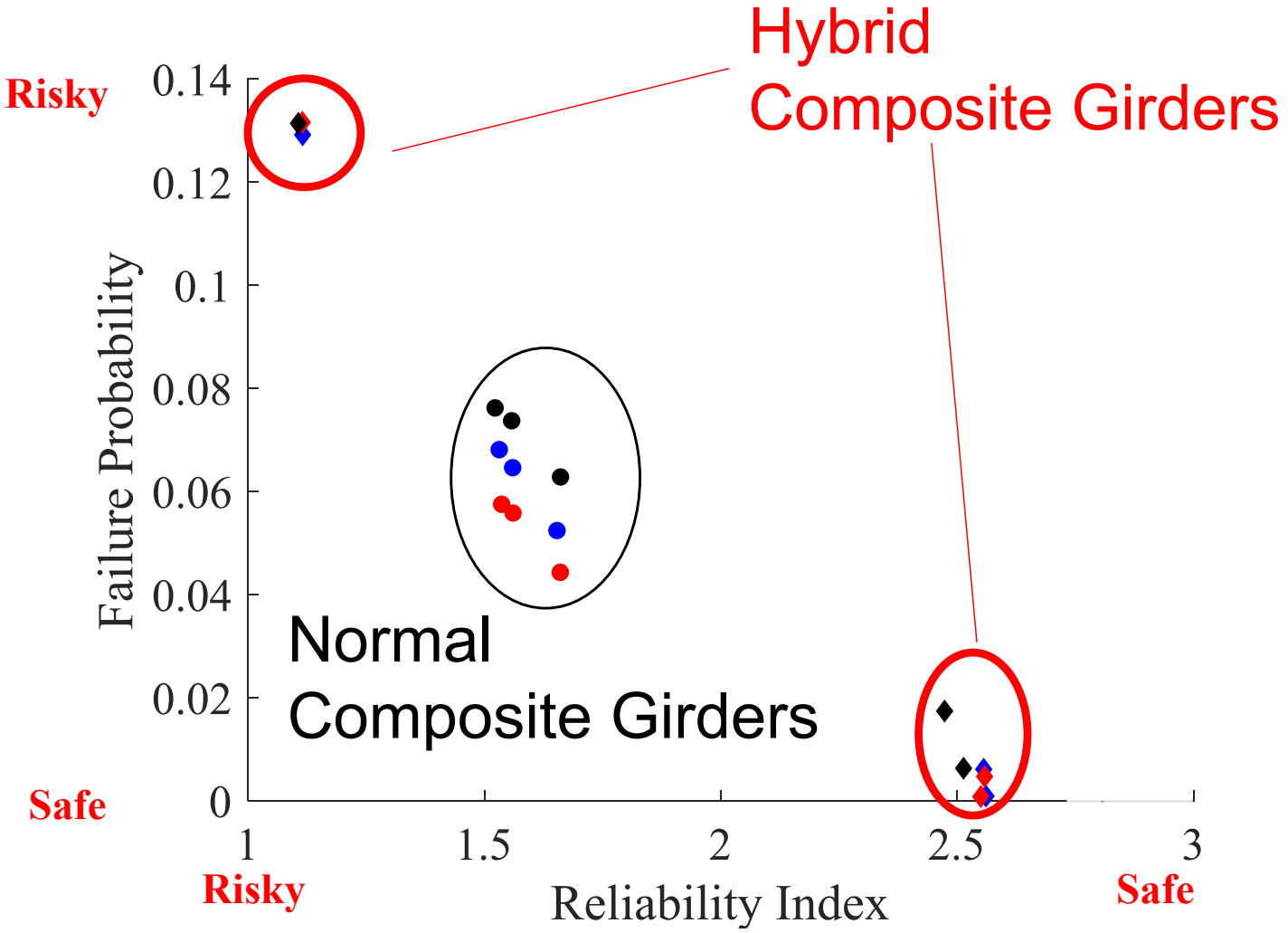
Design Load = αM_P

[3] Masatsugu Nagai, Takeshi Miyashita, Guiping Liu, Naofumi Inaba and Atsushi Homma, Design and applicabicability of steel and steel-concrete plate girder bridges with hybrid section, Vol.68, No.1, 203-215,2012. (in Japanese)

RESULT

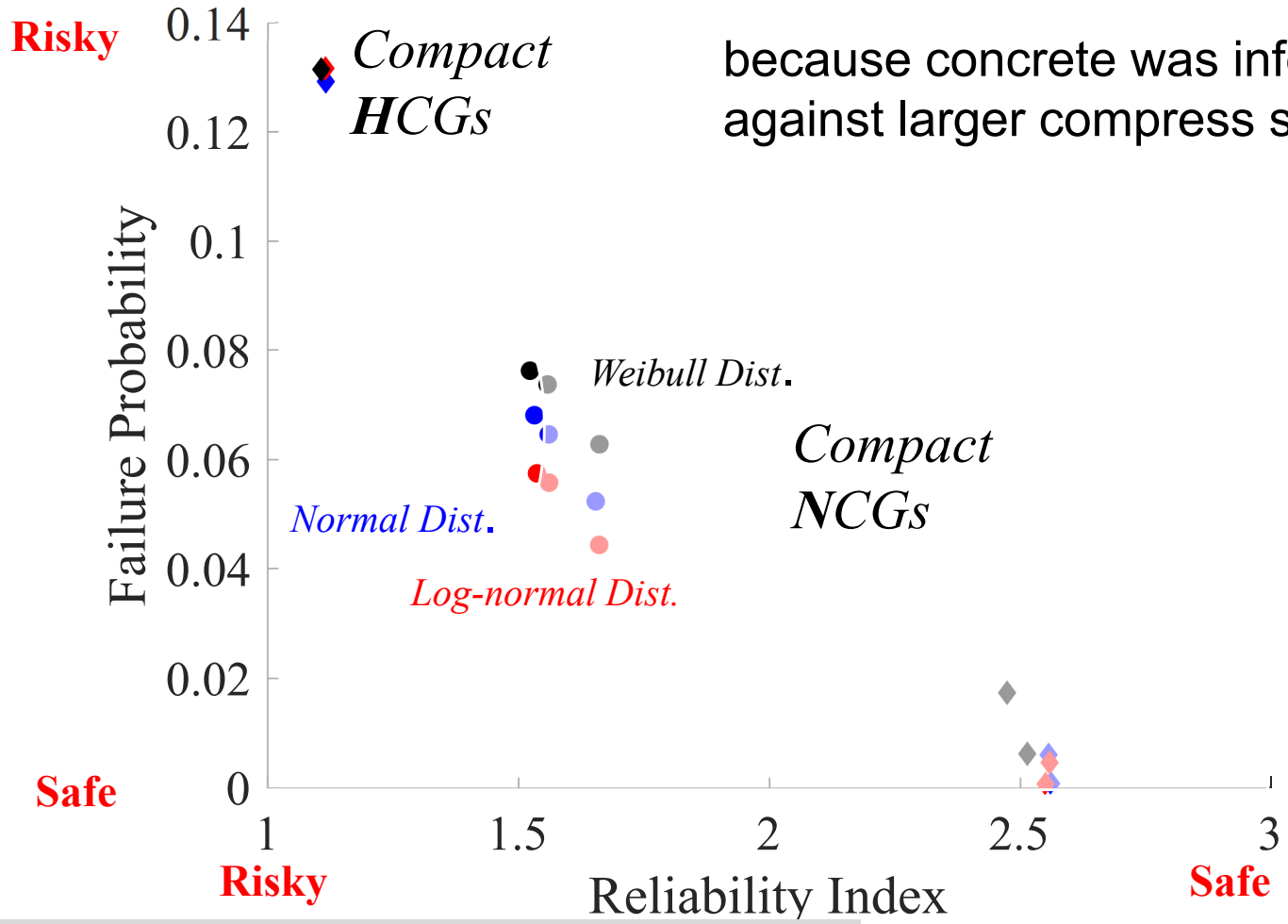

Risky
Safe
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Failure Probability
1
1.5
2
2.5
3
Risky
Reliability Index
Safe

RESULT


Hybrid
Composite Girders
Risky
Safe
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Failure Probability
Normal
Composite Girders
1
1.5
2
2.5
3
Risky
Safe
Reliability Index

RESULT

With same section dimensions, HCGs have lower Reliability than that of NCGs.

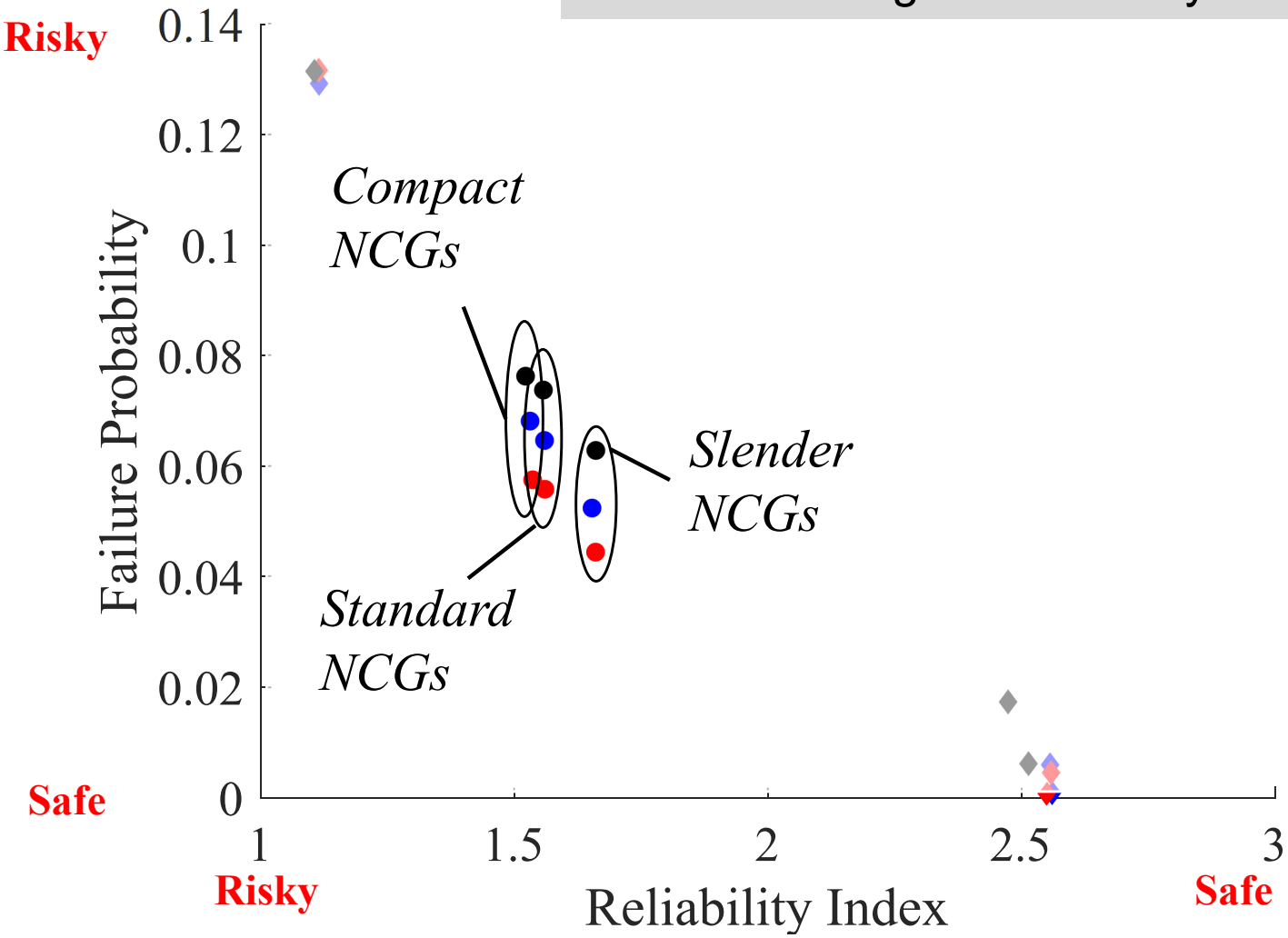


because concrete was inferred to resist against larger compress stress.

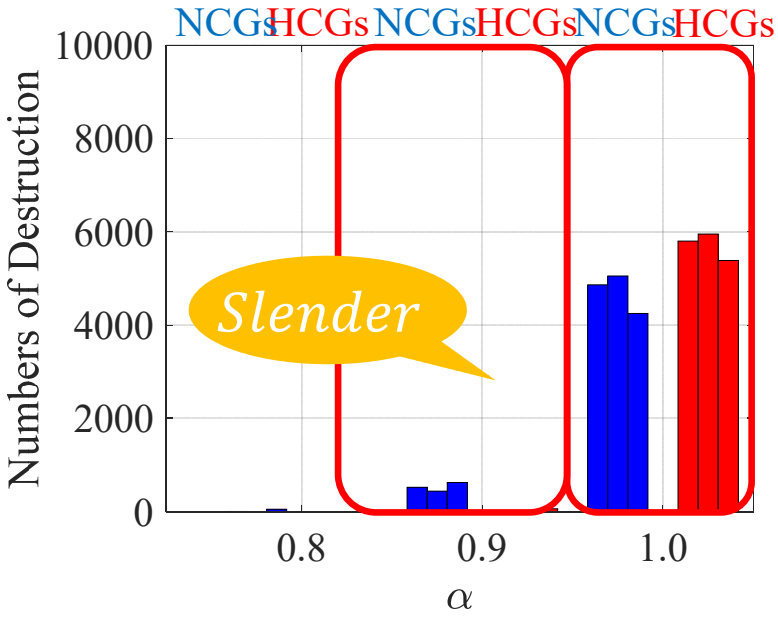
Failure Probability estimated from the assumption of **Weibull Dist.** is highest, which means better to use for safety

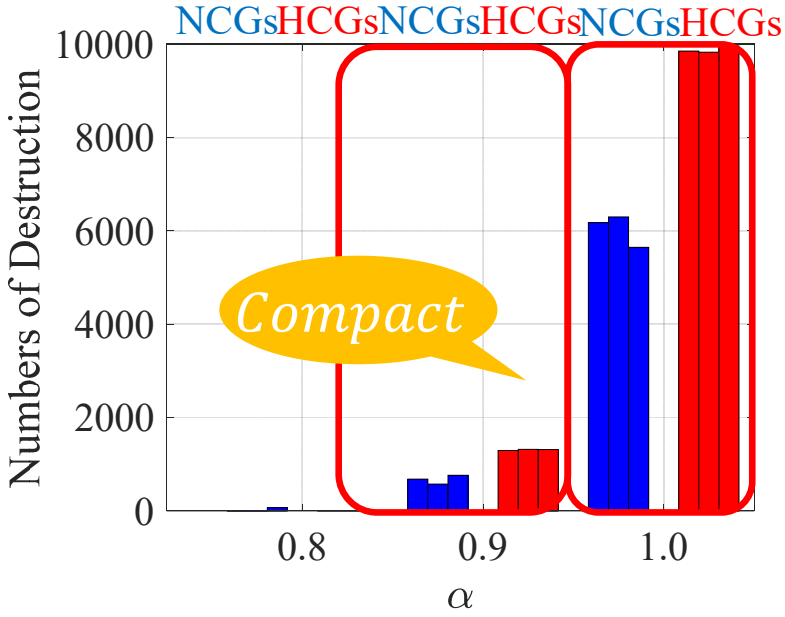
RESULT

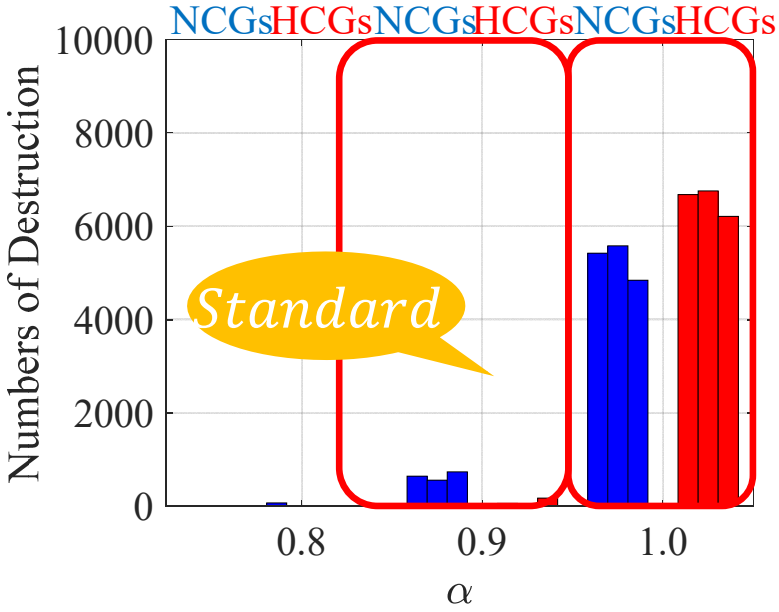
With same material properties, the slender model has a higher Reliability.



RESULT







- $\alpha = 0.9$ ➡
  Small design load
- $\alpha = 1.0$ ➡
  Large design load

CONTENT

- **Fiber method**

① Concrete crushing ultimate state

② Model setup

③ Results and Discussion

- **FEM**

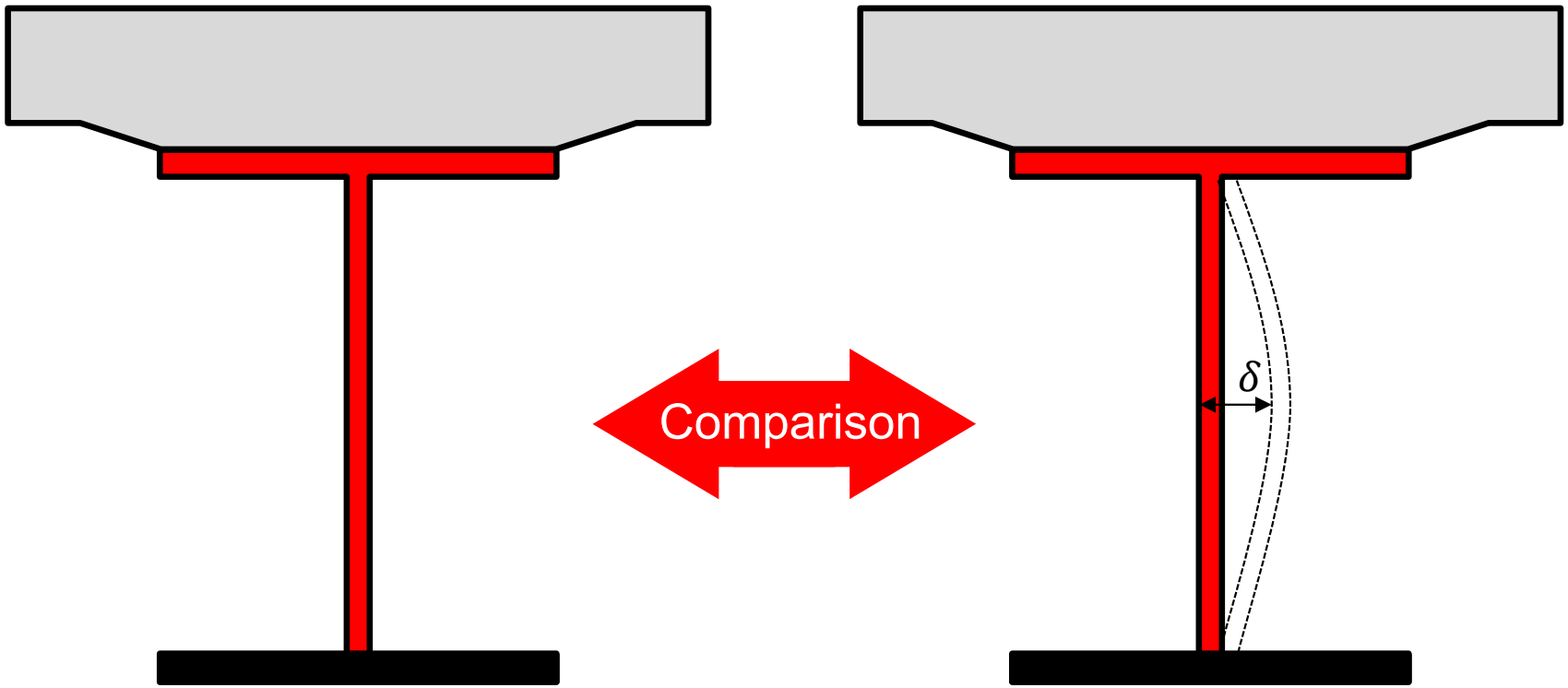
① Steel buckling ultimate state

② Model setup

③ Results and Discussion

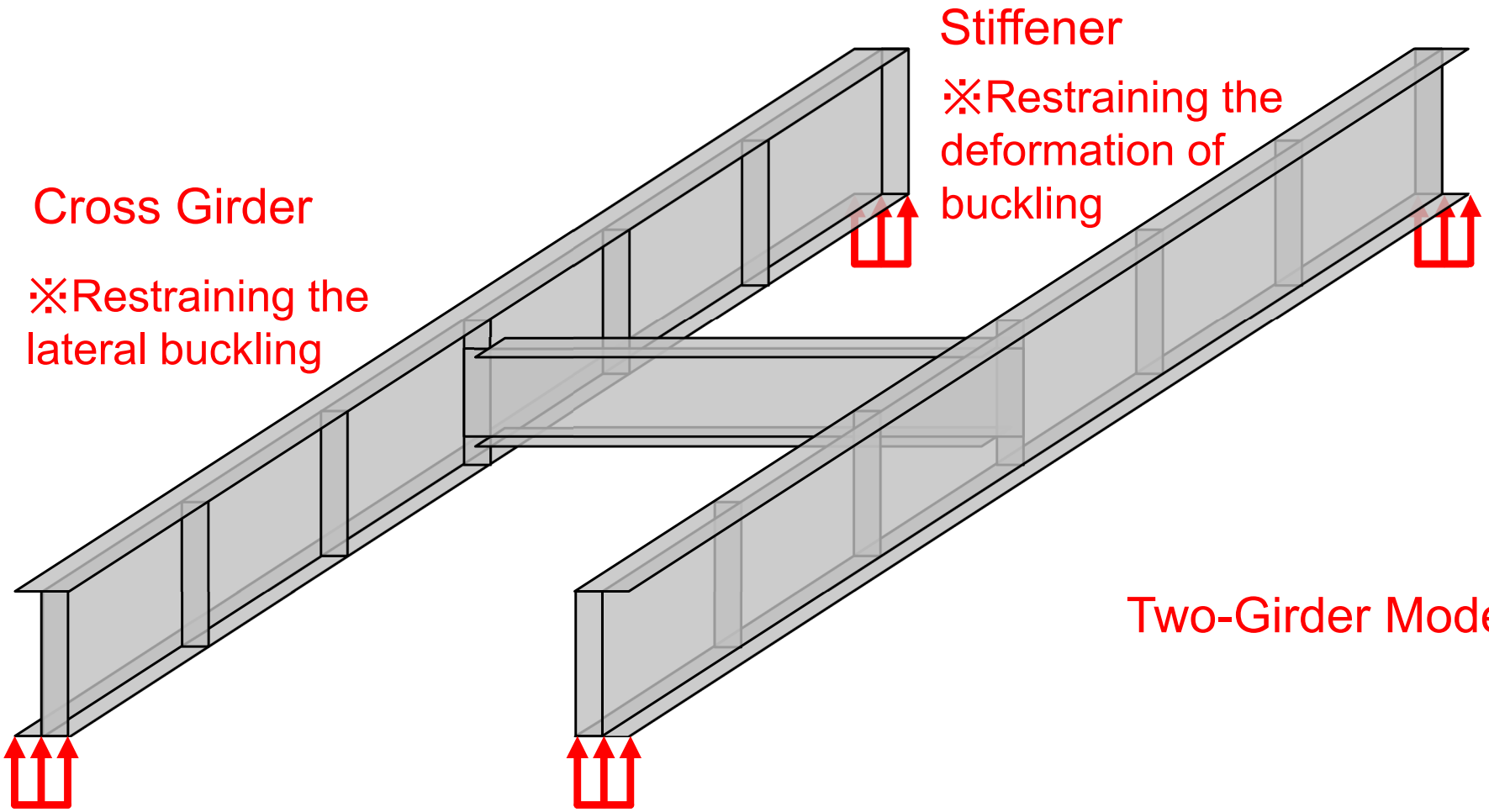
FINITE ELEMENT METHOD

Concrete Crushing → Steel Buckling



[4] Shun-Fa Hwang, GUU-Huann Liu, Buckling Behavior of Composite laminates with multiple delaminations under uniaxial compression, Composite Structures, 53 (2001) 235-243.

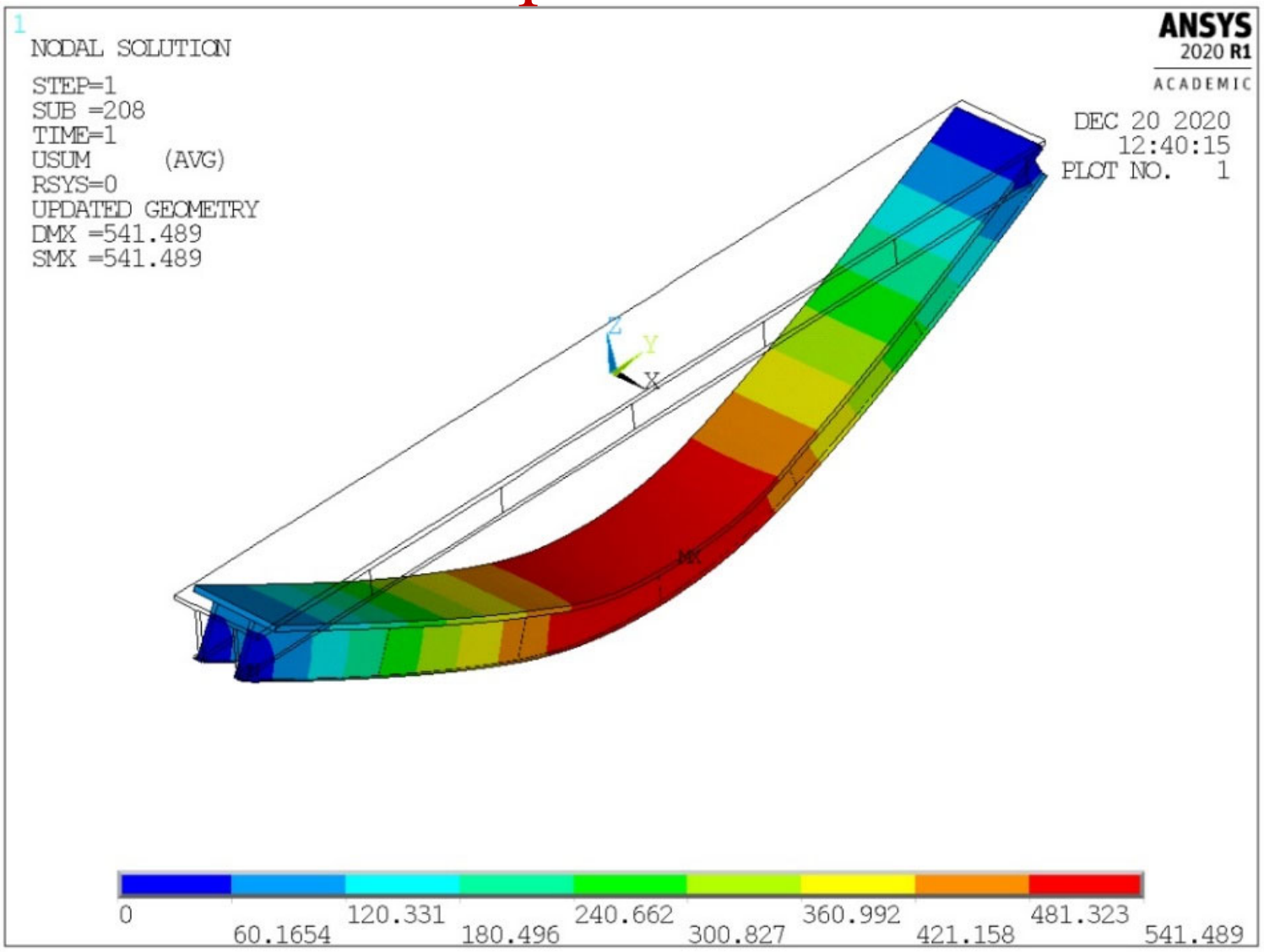
SIMULATION MODEL



RESULT

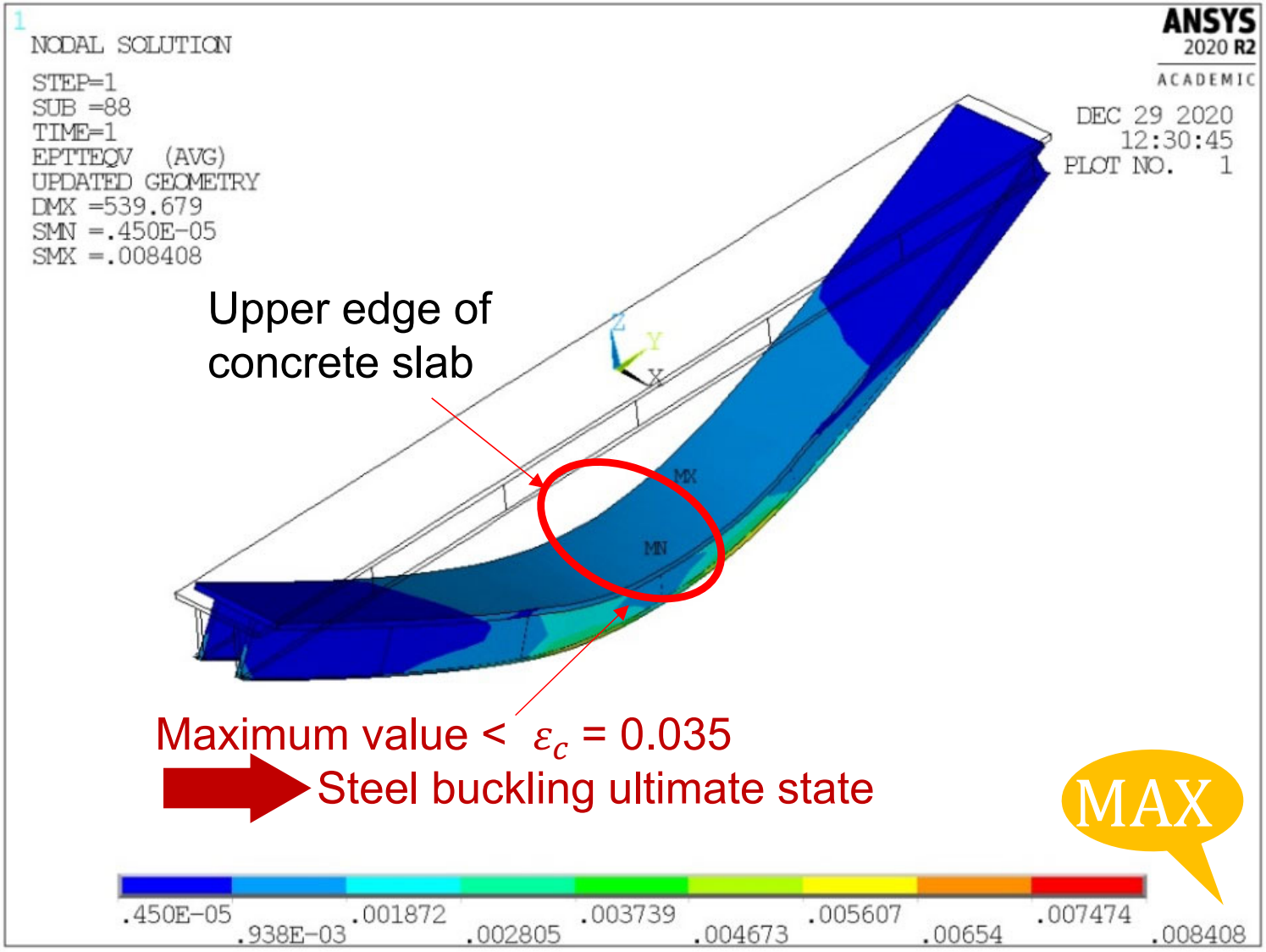
Displacement

10 times scale



RESULT

Total mechanical strain *10 times scale*



RESULT OF WEIBULL DIST.

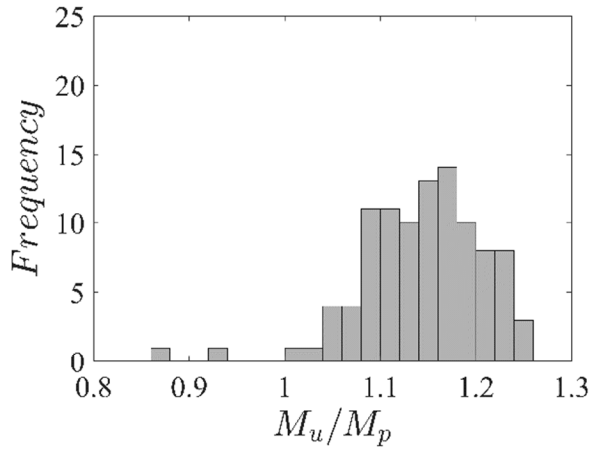
M_u/M_p

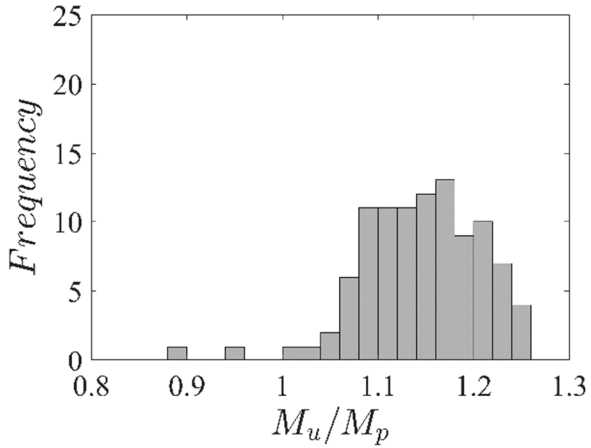
Slender

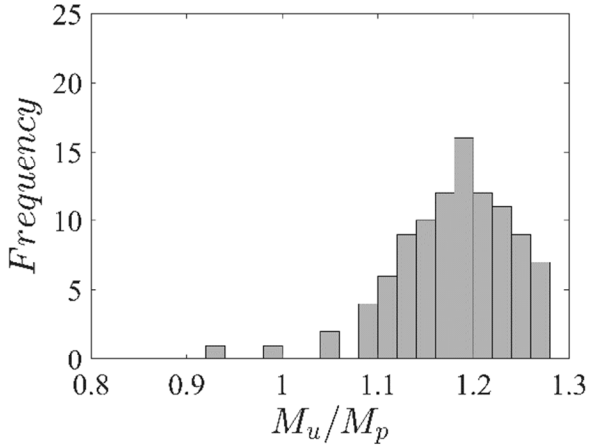
Standard

Compact

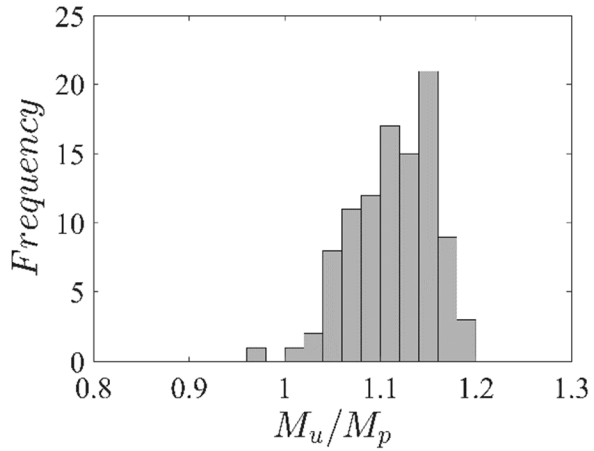
NCGs

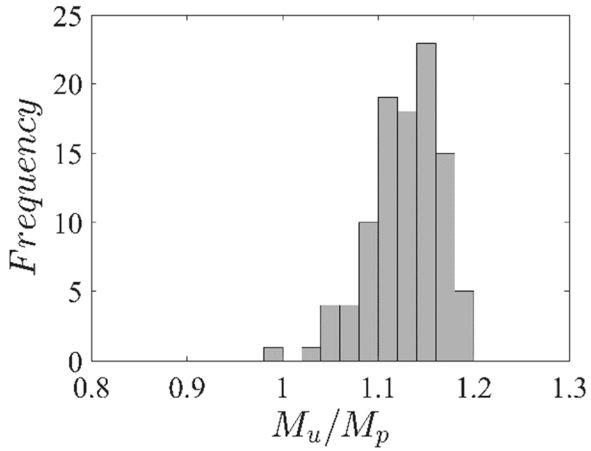


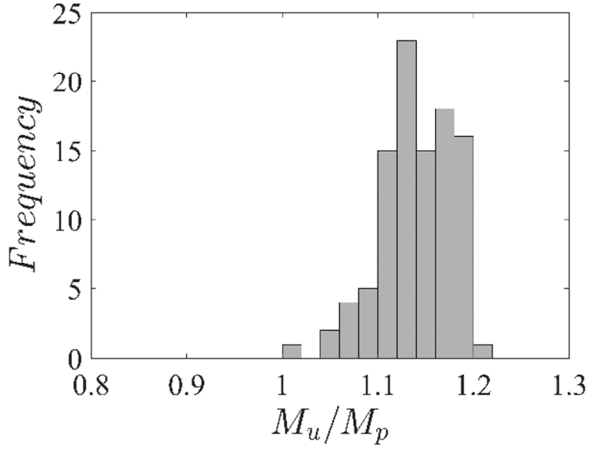




HCGs



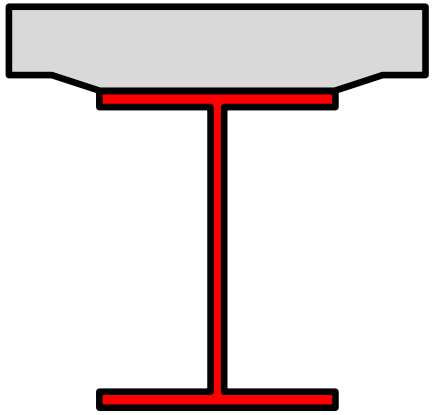


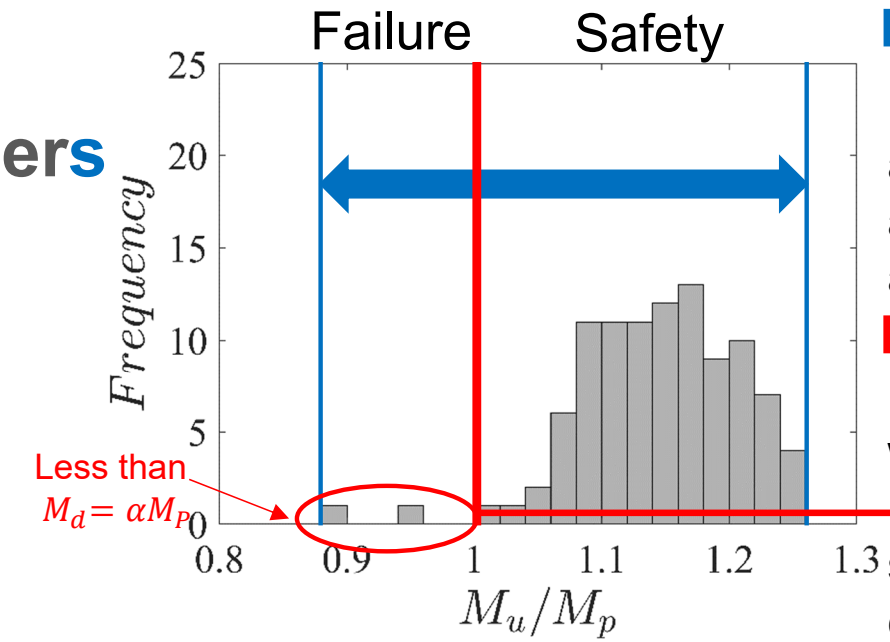


DISCUSSION OF HISTOGRAMS

Normal

Composite Girders





Larger quality variation

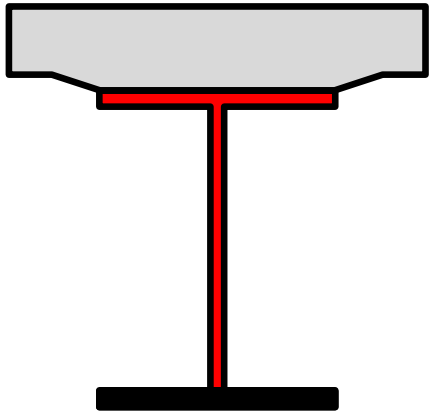
Large quality variation means a disperse data distribution and is more likely to have more abnormal samples.

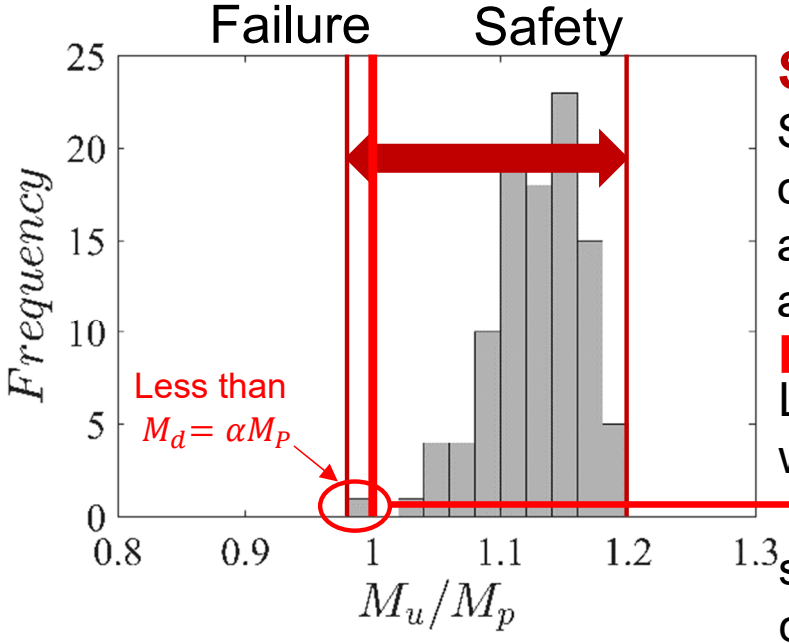
Higher Failure Probability

High failure probability means , with certain factor of safety, there are more unreliable samples and more failure cases, with means less reliable.

Hybrid

Composite Girders





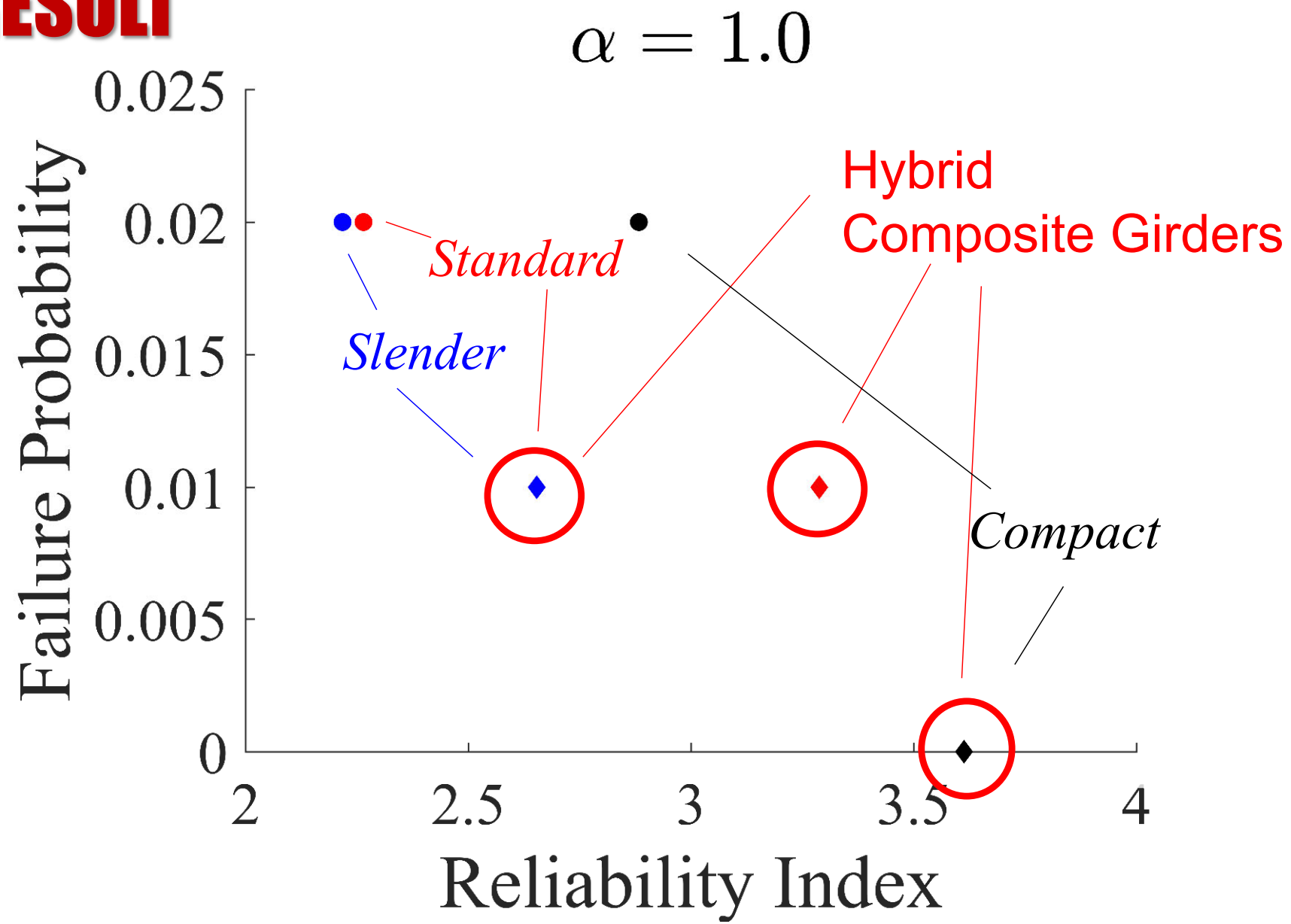
Smaller quality variation

Small quality variation means a concentrate data distribution and is more likely to have fewer abnormal samples.

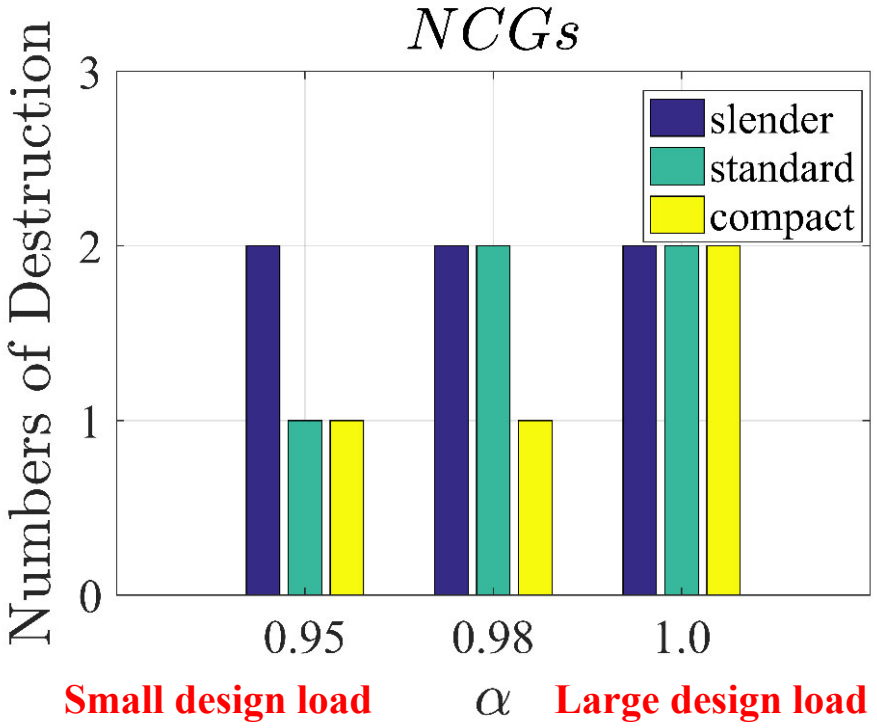
Lower Failure Probability

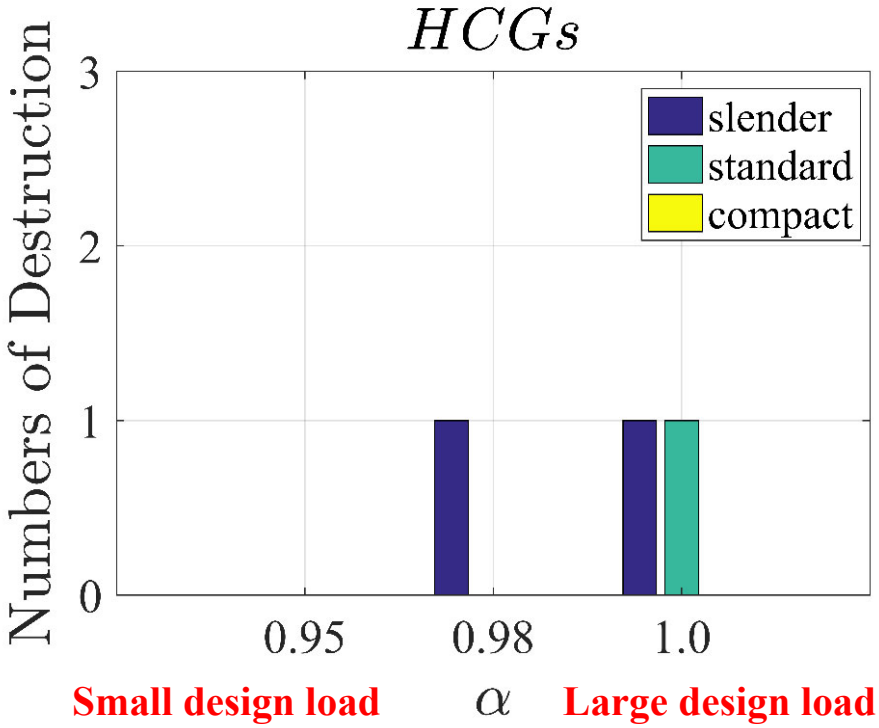
Low failure probability means , with certain factor of safety, there are fewer unreliable samples and fewer failure cases, with means more reliable.

RESULT


$\alpha = 1.0$
Failure Probability
0.025
0.02
0.015
0.01
0.005
0
2
2.5
3
3.5
4
Reliability Index
Standard
Slender
Hybrid
Composite Girders
Compact

RESULT


NCGs
Numbers of Destruction
3
2
1
0
slender
standard
compact
0.95
0.98
1.0
Small design load
α
Large design load


HCGs
Numbers of Destruction
3
2
1
0
slender
standard
compact
0.95
0.98
1.0
Small design load
α
Large design load

SUMMARIES

- Fiber Method: Concrete crushing ultimate state
- FEM: Steel buckling ultimate state

	Design load	*Section dimension*	*model*
Fiber	*Large*	*Slender*	*NCGs*
	Small	*Slender*	*HCGs*
FEM	*Large*	*Compact*	*HCGs*
	Small	*Compact*	*HCGs*

CONCLUSIONS

- From the results of Fiber method, slender section shows a better performance of bending capacity, and NCGs are proved to have a higher reliability with large design load. The reliability of HCGs is overvalued.
- From the results of FEM, compact section is inferred to have a better performance of resisting buckling. And the buckling resistance performance of HCGs are obvious. Thus, the compact HCGs are concluded to be most reliable structure.
- To synthesize the results of Fiber method and FEM, the results of Fiber method are not completely credible when the structure has a thin shell part, and the buckling calculation should be considered in the simulation. The advantages of HCG could be interpreted. The compact HCGs could be concluded to have a highest structural reliability among these situations and have a better performance to resist buckling.

FUTURE WORK

- It is possible to improve the parameters used in numerical simulation. Due to the different statistical data of references, materials and steel manufacturers, it is possible to further rationalize the results by using more realistic values.
- Due to the complexity and time-consuming of the FEM buckling analysis, only 100 variables are generated for simulation in this research. In the future work, we should try to simplify the calculation process and use more variables to make the results more reliable.
- For the structure with thin shell part, Fiber method is not enough for calculation. In order to make the result more reliable, buckling analysis of FEM should be added into calculation. To make fully use of performance of each material, a more appropriate section dimension could be found for the design of composite girder in the future work, which should satisfy that the structure achieves the failure of upper edge of concrete slab and buckling ultimate state simultaneously.