Estimating Load Condition Having Caused Structure Failure and an Optimal Design Taking Account of the Estimated Result

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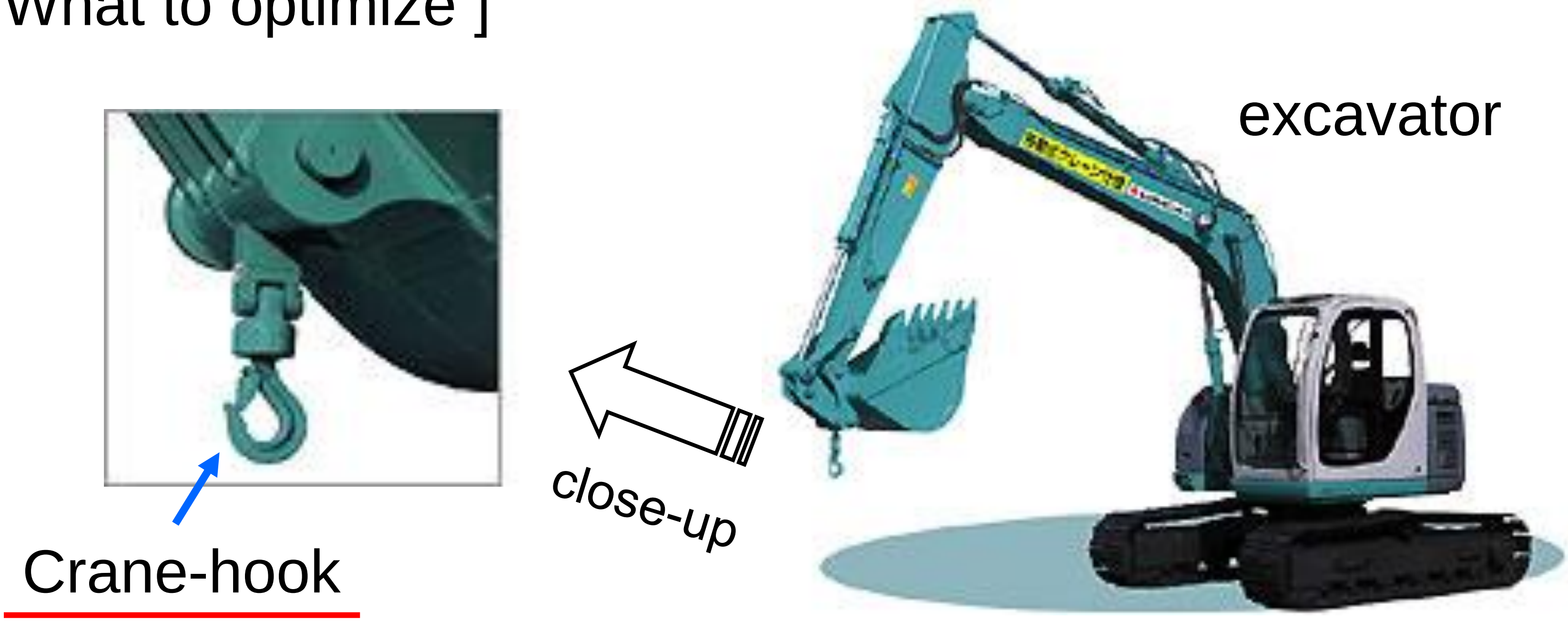
Introduction

[What to optimize]



Excavators having a crane-hook can do both **digging** and **suspension** work.

Background

Contrary to its convenience, crane-hook is damaged during some kind of suspension works.

typical crane-hook

failed sample

It is necessary to take effective steps.

however

Real conditions are **unclear**…

Policy

☆ Improvement of performance

(A) Identification of applied load condition

(B) Shape design of crane-hook

- load applied point, direction, magnitude
- probability distribution of critical load

- light weight
- strength to critical load condition

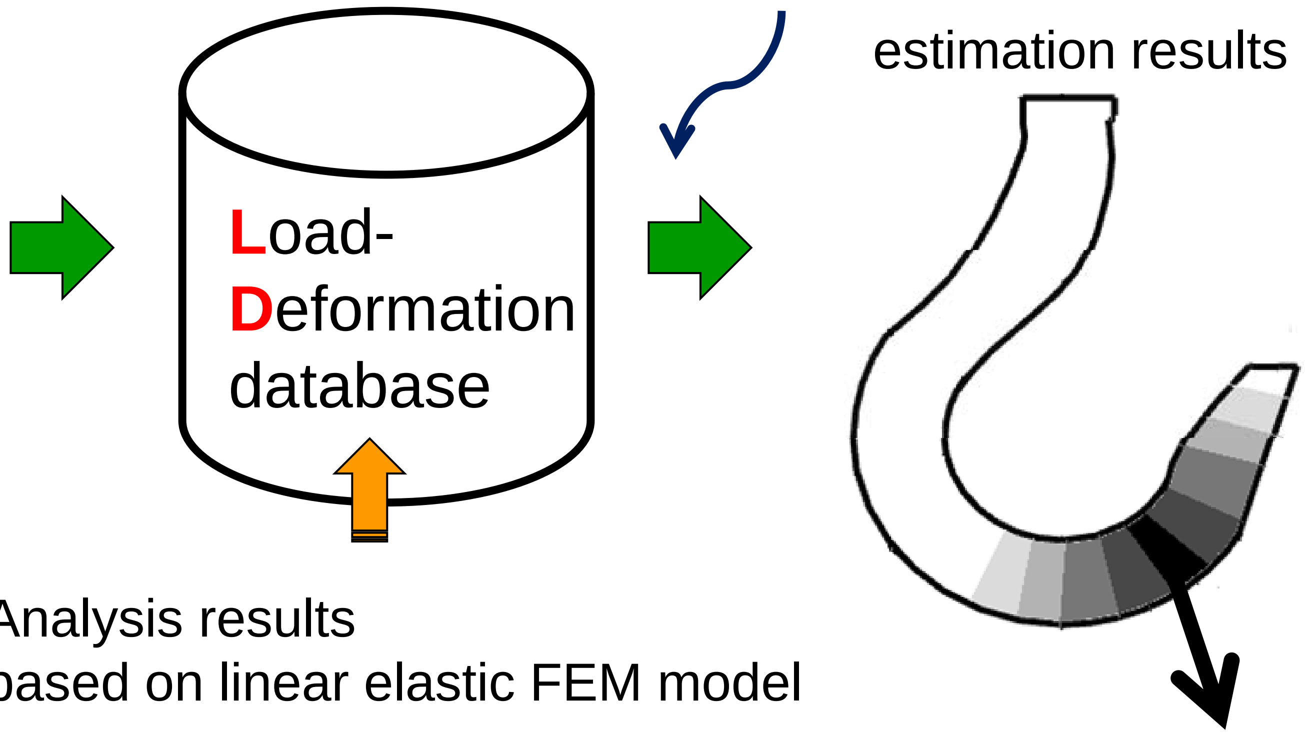
Previous Study

Our previous work (REC2010)

failed sample

Bayesian theory

estimation results



Analysis results
based on linear elastic FEM model

Current Study

- Introduction of elasto-plastic analysis

identification of load applied point / load direction } previous work

+ **load magnitude** new!

- Support for multi peak distribution model

Estimation result is obtained based on

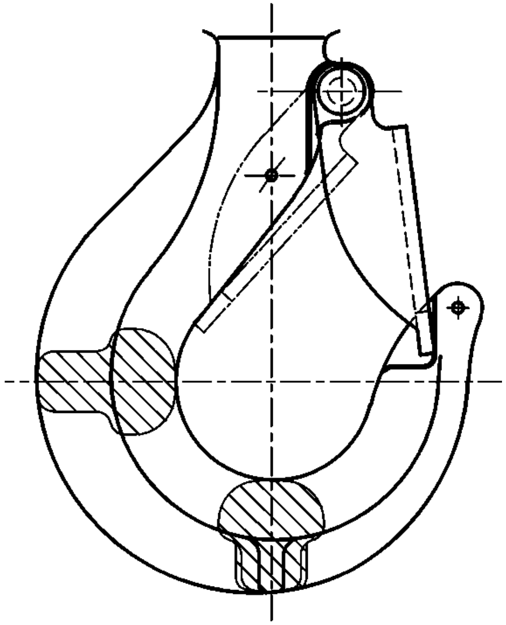
single peak probability distribution function (modify)

→ multi peak probability distribution function

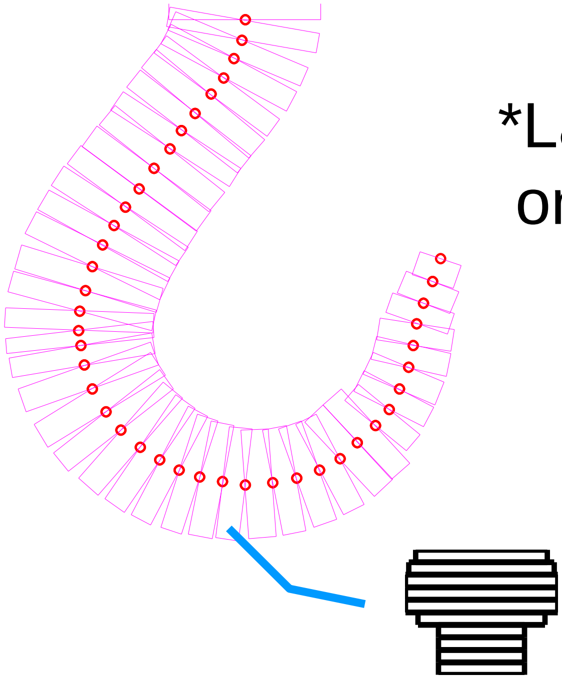
← **EM algorithm**

Crane-Hook Model

design drawing



adopted FEM model



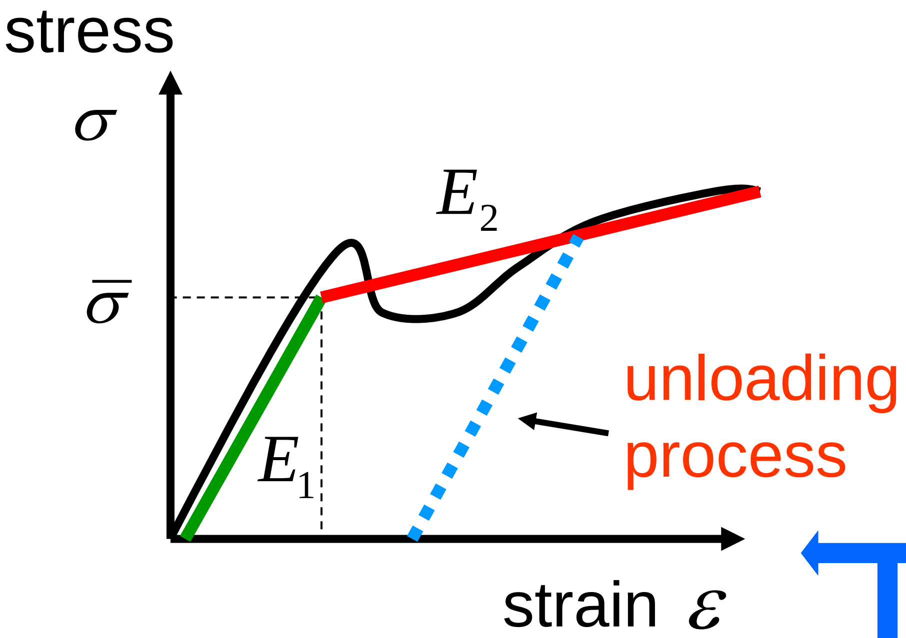
*Latch part is omitted.

cross-sectional shape

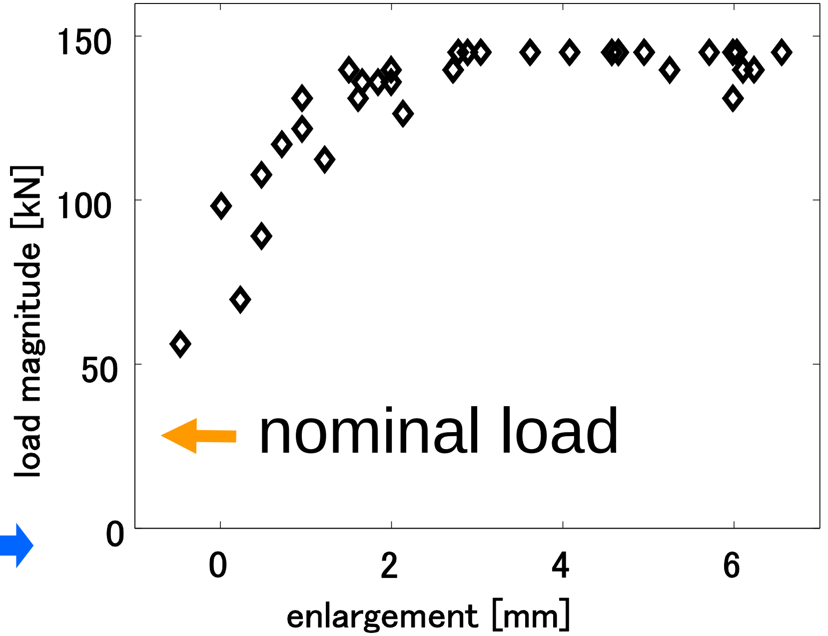
- FEM model is constructed by N_e beam elements.
- Each element is constructed by N_d layers.

Stress-Strain Relationship

adopted bi-linear model



experimental result

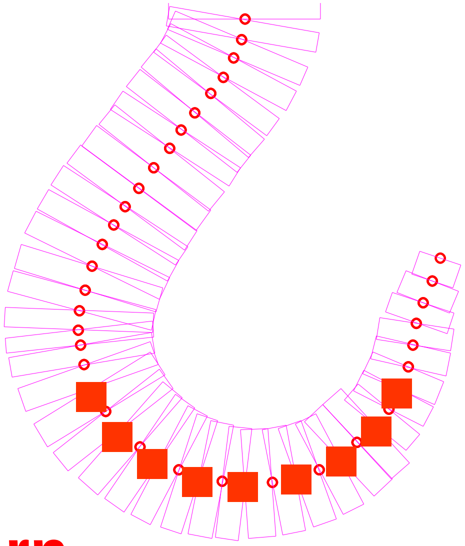


yield stress	Young's modulus	tangent modulus
$\bar{\sigma}^* = 200$ [MPa]	$E_1^* = 260$ [GPa]	$E_2^* = 1$ [GPa]

Load Condition

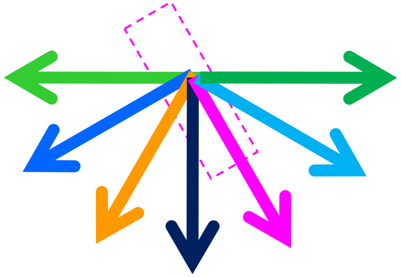
applied load condition on FEM model

(1) load applied point



9 pattern

(2) load direction



7 pattern

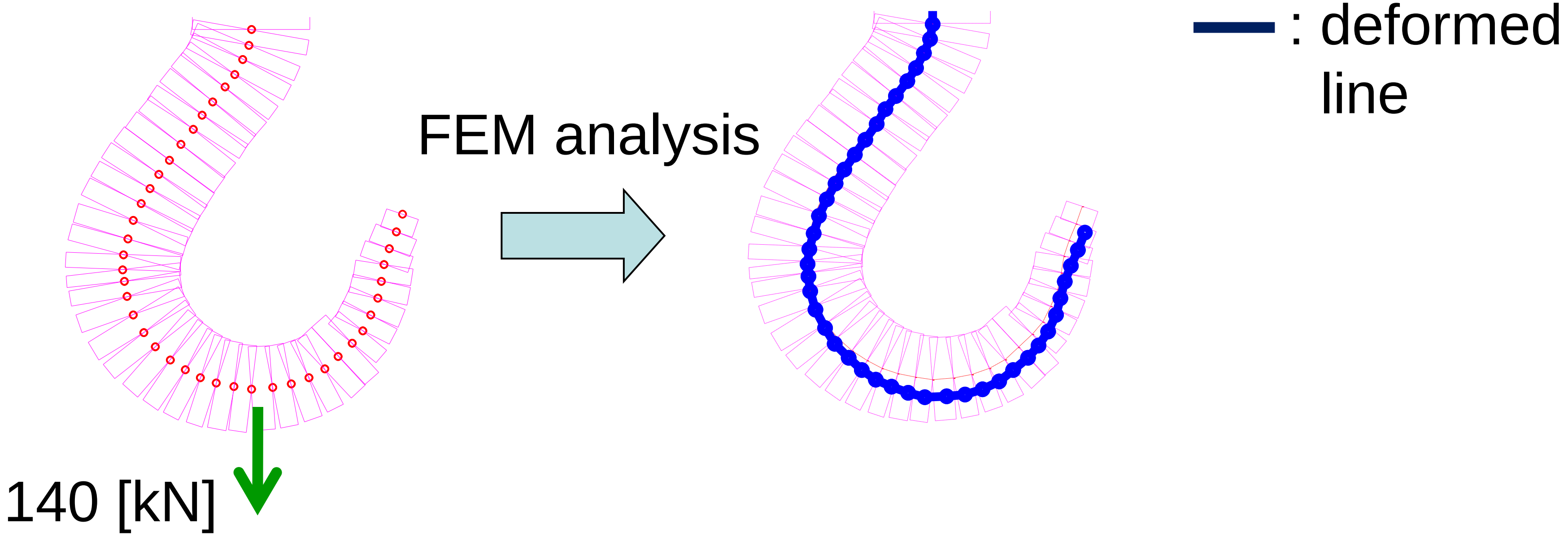
(3) load magnitude

20kN, **40**kN, **60**kN, **80**kN
100kN, **120**kN, **140**kN

7 pattern

all combination: **441 pattern**

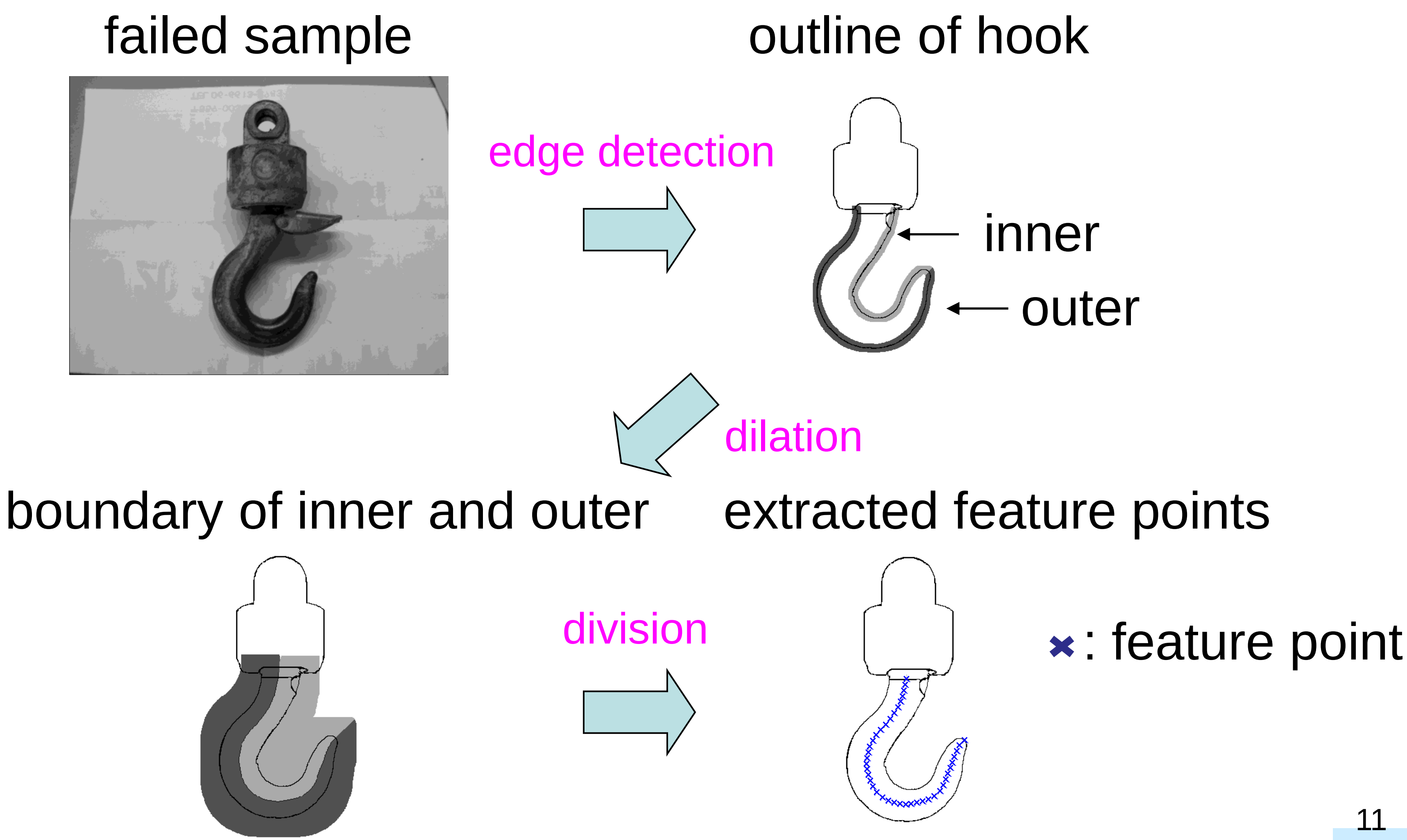
Construction of Database



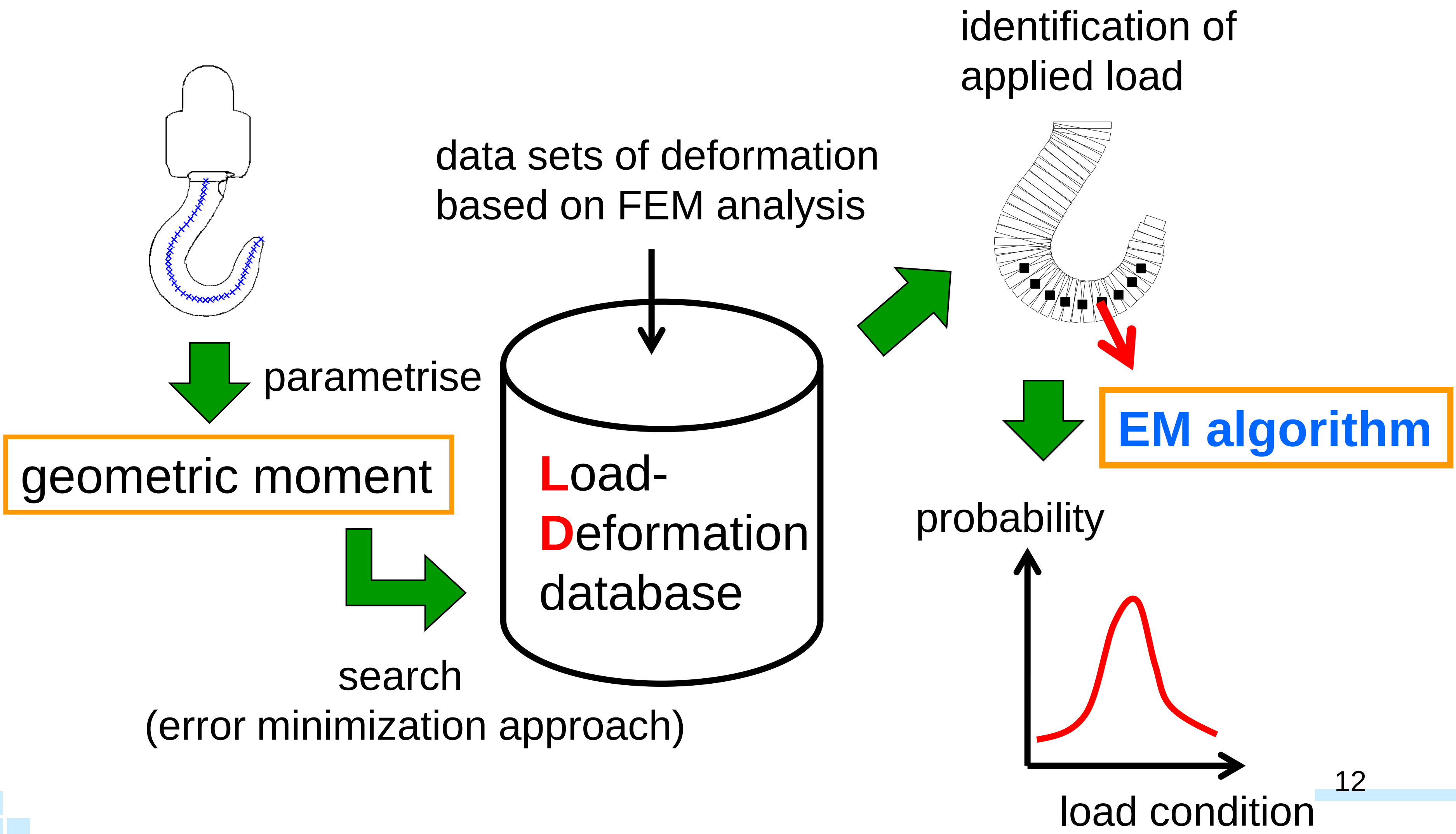
identification number
load condition, geometric moment

Load-**D**eformation database

Feature Extraction



Estimation Process



EM Algorithm

EM (Expectation Maximization)

- iterative optimization method to estimate unknown parameters
- maximize posterior probability

$\boldsymbol{\Theta}$: some unknown parameters

$\boldsymbol{G}$: some "hidden" nuisance variables

χ : given measurement data

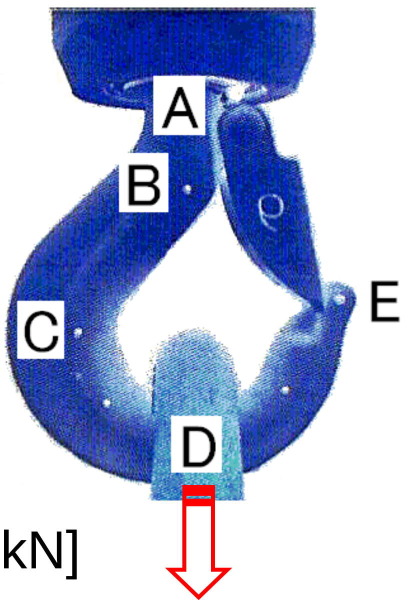
search for a maximum of $P(\boldsymbol{\Theta}, \boldsymbol{G} \mid \chi)$

1. **step E**: calculate $P(\boldsymbol{\Theta}^{\text{old}}, \boldsymbol{G} \mid \chi)$
2. **step M**:

$$\boldsymbol{\Theta}^{\text{new}} = \arg\max_{\Theta} \sum_{\boldsymbol{G}} P(\boldsymbol{\Theta}^{\text{old}}, \boldsymbol{G} \mid \chi) \ln P(\boldsymbol{\Theta}, \boldsymbol{G} \mid \chi)$$

Applicability Test

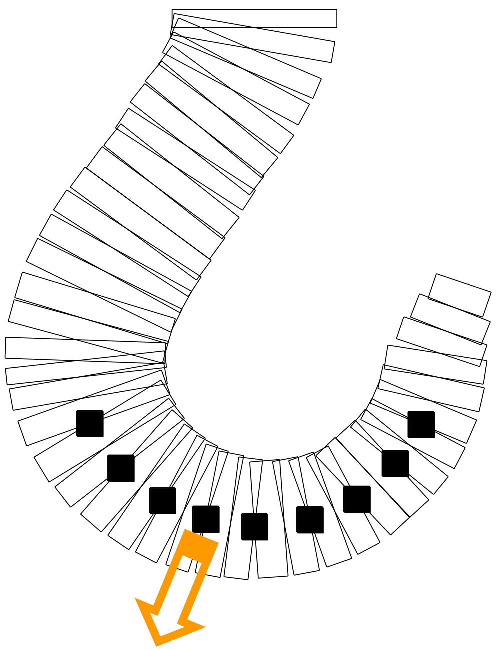
- load identification using stretch experiment image



140 [kN]

downward load is applied around ‘D’

estimation result



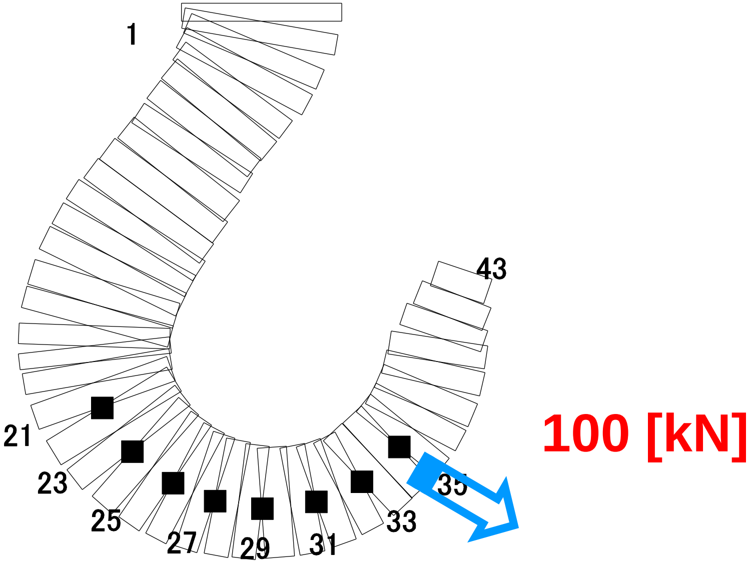
100 [kN]

- estimated load magnitude is smaller than actual load
- the estimation method has uncertainty to this level

Sample Result

failed hook

identification result

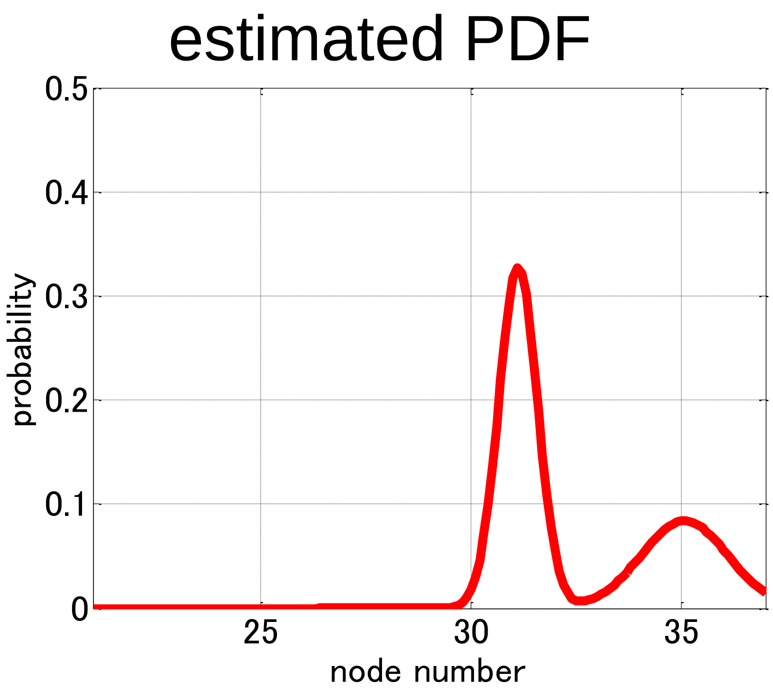


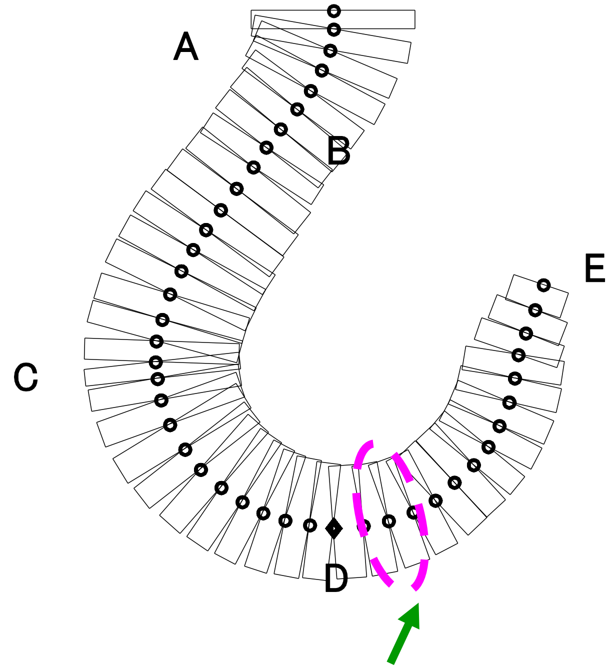
- load applied position shifts rightward from lower center
- load magnitude is 3 times greater than nominal load
- load direction shifts rightward

Estimation Result (1/2)

We apply the method to 12 failed samples.

☆ **load applied point**

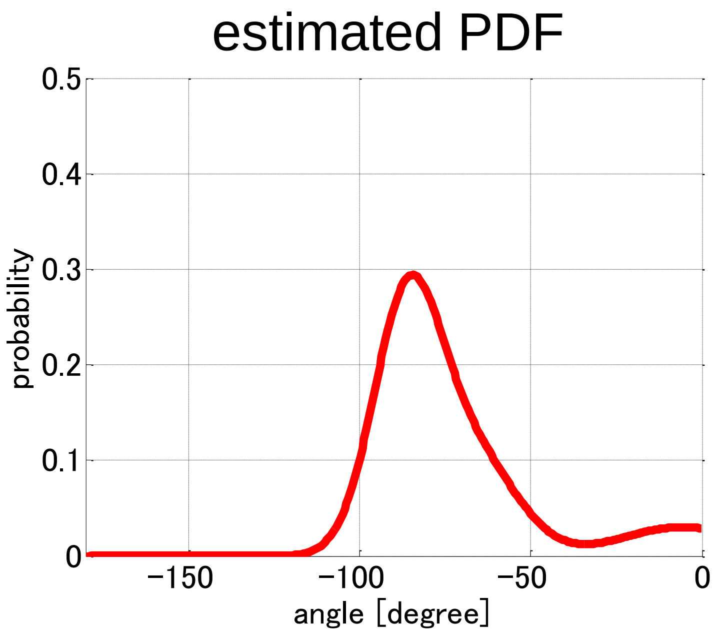


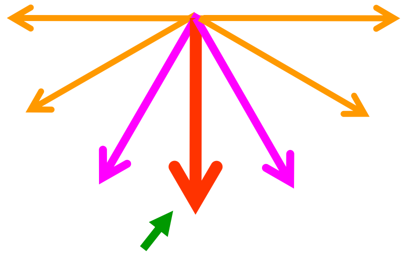


most probable area

Estimation Result (2/2)

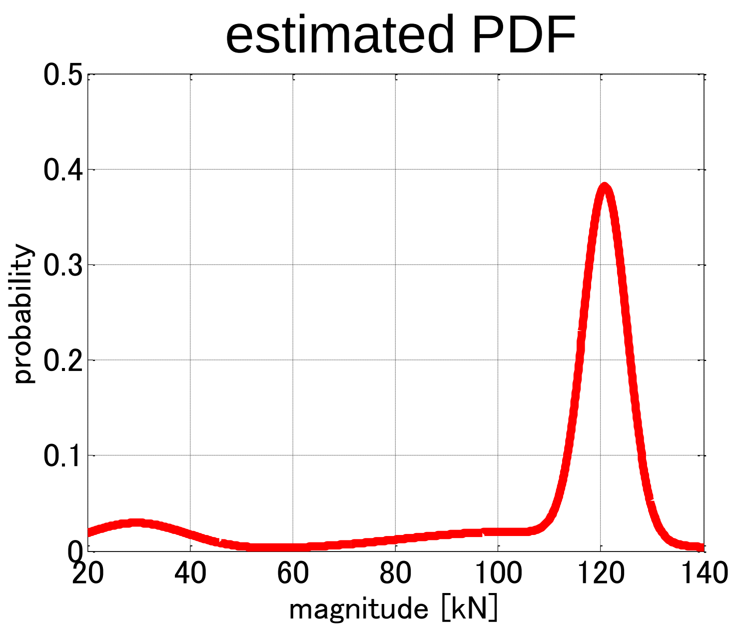
☆ load direction





most probable direction

☆ load magnitude



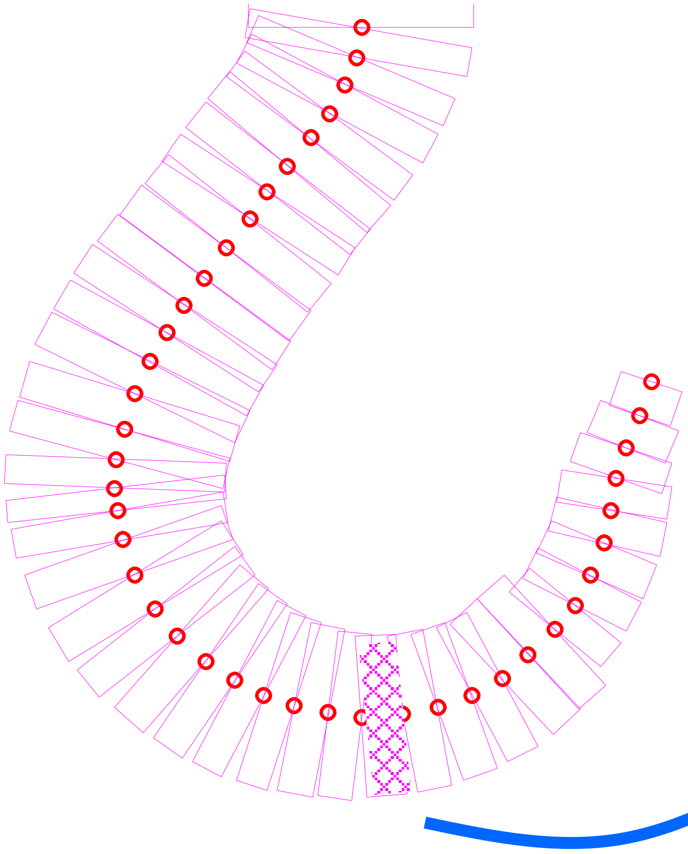
peak is at **120 [kN]**

(nominal load is 29 [kN])

FEM model

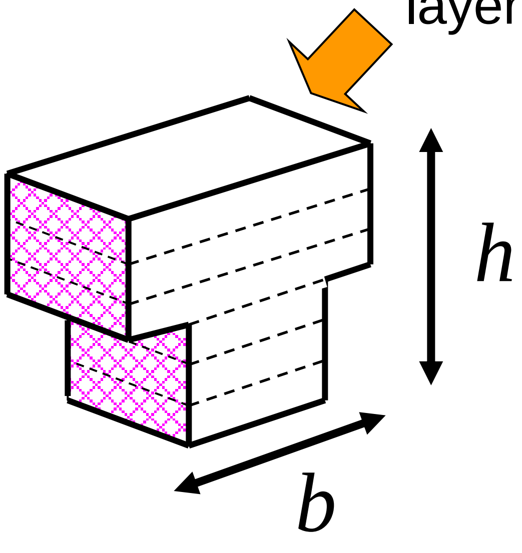
- Shape design of crane-hook

same model as used in load estimation



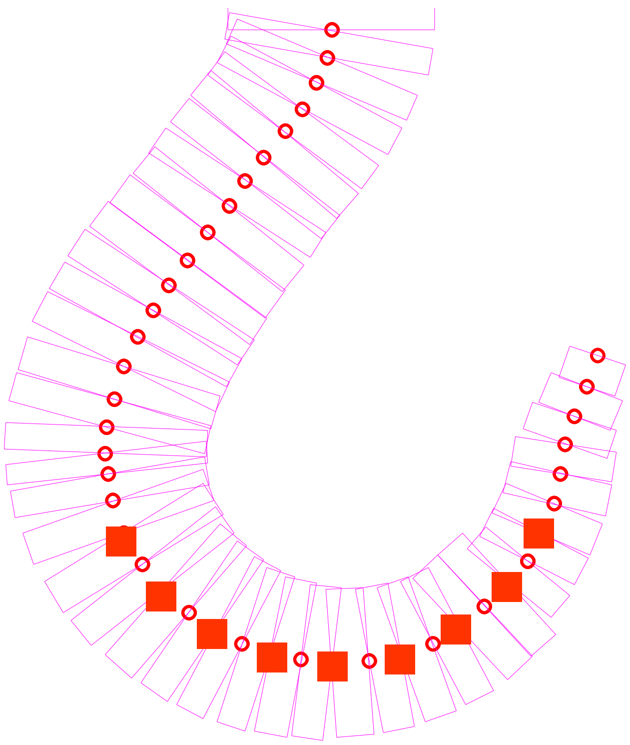
design variables

height h
width b



Objective Function

design objective: **light weight**, **high stiffness**



■ : possible load applied points

criterion (1)

structural weight

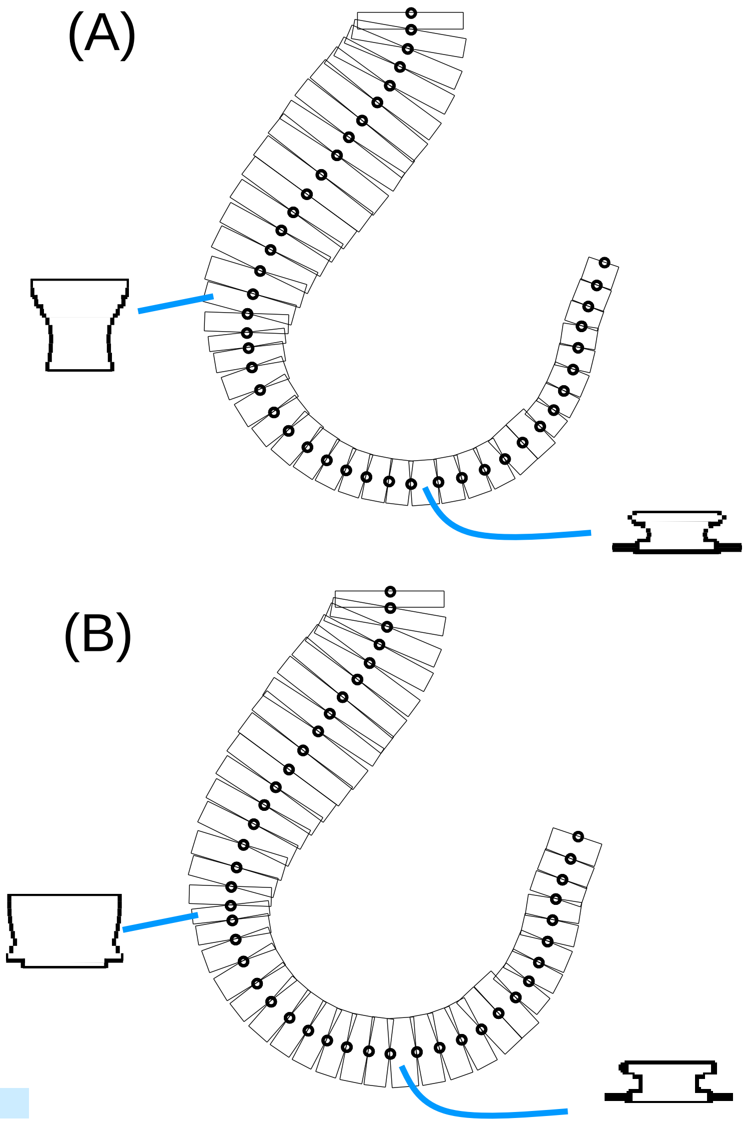
criterion (2)

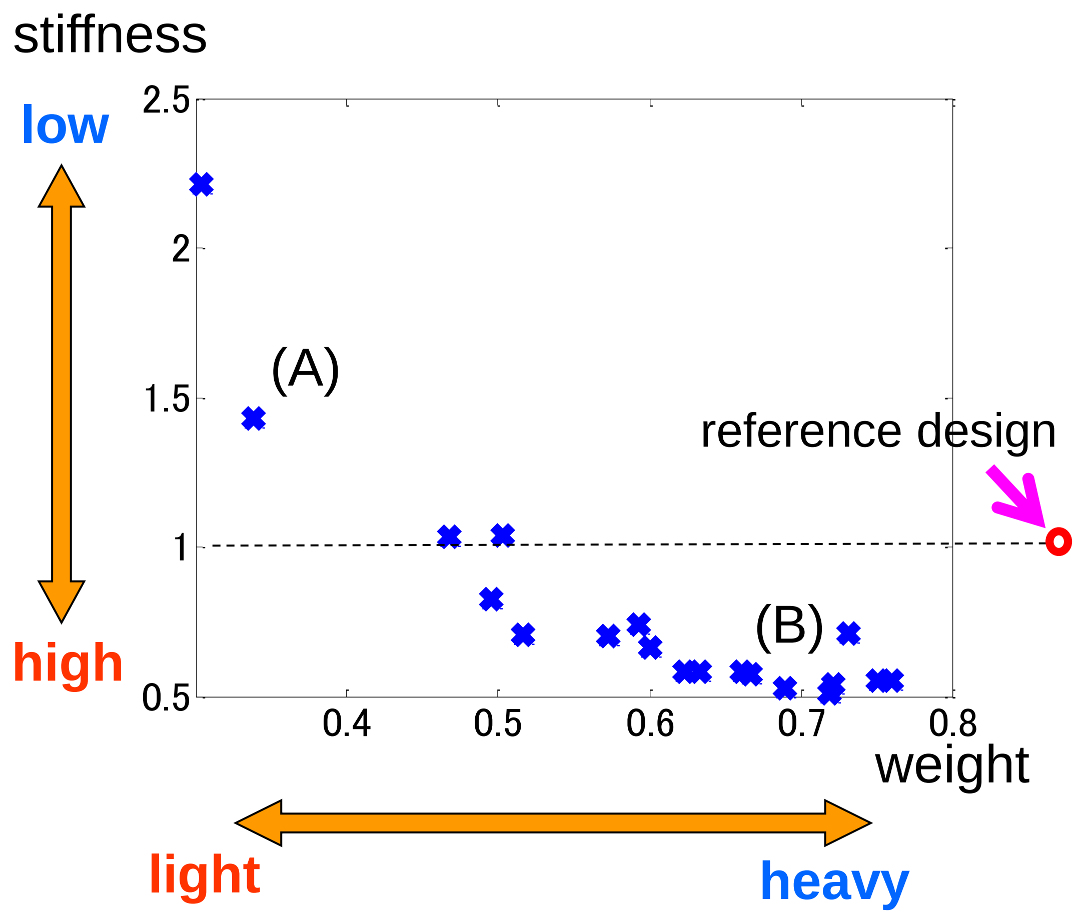
structural stiffness

ratio between load and displacement

(load vector is specified by estimation result of load applied point)

Obtained Designs

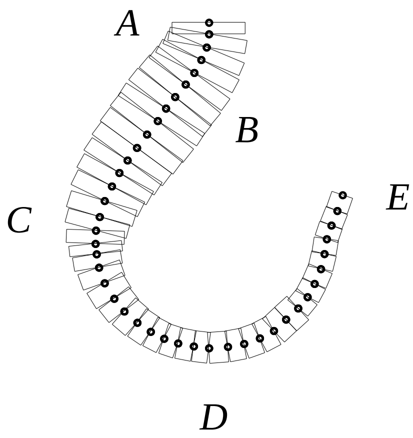




Features of Obtained Design

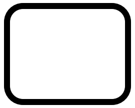
hook shape

- hook shape becomes thinner toward the tip point “E” from the lowest center point “D”
- thickness of region around the point “B” is greater than any other region



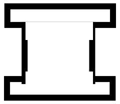
cross-sectional shape

- cross-sectional shape of the point “C” is rectangular



- at the point “D”, center part is thinner than both end side (upper and lower)

I-shape



Conclusion

☆ load estimation

implement elasto-plastic analysis
for construction of Load-Deformation database

- load position lies between lower center and tip-end
- load magnitude is four times larger than nominal load
- load direction is downward

☆ shape design

formulate multi-objective optimization problem
taking account of estimation results

- obtained hook shapes have a tapered shape
- cross-sectional shapes do not have “a T-shape” but have “a rectangular” or “an I-shape”

Questions are welcome.

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EM Algorithm

probability density function (PDF)

mixtured Gaussian model

$$P(\chi) = \sum_{k=1}^{K} \pi_k N(\chi \mid \boldsymbol{\mu}_k, \boldsymbol{V}_k), \quad N(\chi \mid \boldsymbol{\mu}, \boldsymbol{V}) = \frac{1}{(2\pi)^{D/2} |\boldsymbol{V}|^{1/2}} \exp\{-\frac{(\chi - \boldsymbol{\mu})^T \boldsymbol{V}^{-1} (\chi - \boldsymbol{\mu})}{2}\},$$

☆ EM algorithm

π_k : mixture weight

$\boldsymbol{\mu}$: mean

$\boldsymbol{V}$: variance

Step1

$$\gamma(z_{nk}) = \frac{\pi_k N(\chi_n \mid \boldsymbol{\mu}_k, \boldsymbol{V}_k)}{\sum_{j=1}^{K} \pi_j N(\chi_n \mid \boldsymbol{\mu}_j, \boldsymbol{V}_j)}$$

Step2

$$\boldsymbol{\mu}_k^{\text{new}} = \frac{1}{N_k} \sum_{n=1}^{N} \gamma(z_{nk}) \chi_n$$

$$\boldsymbol{V}_k^{\text{new}} = \frac{1}{N_k} \sum_{n=1}^{N} \gamma(z_{nk}) (\chi_n - \boldsymbol{\mu}_k^{\text{new}})(\chi_n - \boldsymbol{\mu}_k^{\text{new}})^T$$

$$\pi_k^{\text{new}} = \frac{N_k}{N}$$