余寿命予測の未来： Society 5.0/SDGsへの展開 2019-1-24 前川宏一

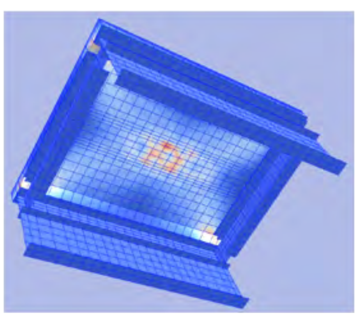
既設橋梁コンクリート床版の余寿命推定から次の展開へ

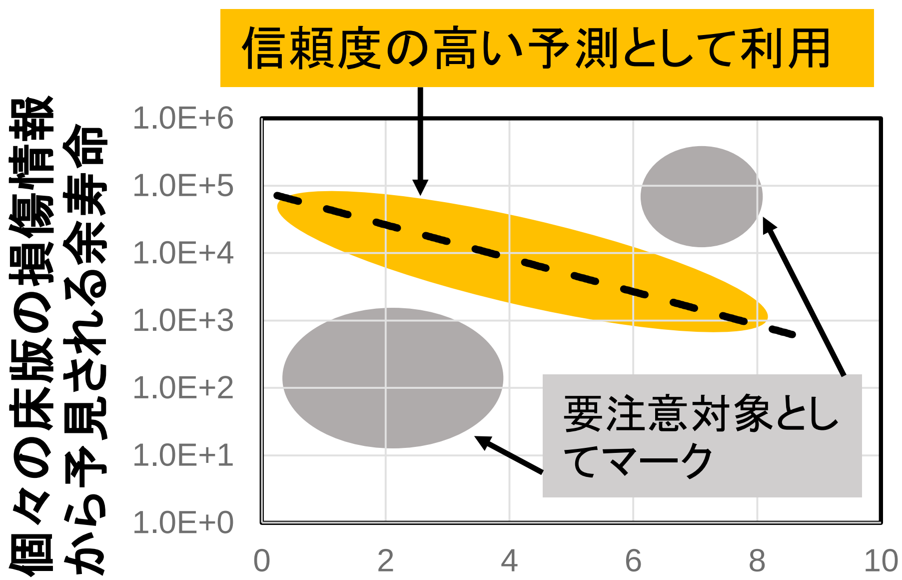
構造工学・材料工学
計算力学・物質科学
物理化学・統計力学
Multi-scale Modeling
ー総動員ー
ミクロ的視点

実験室内と実環境/社会での知見に基づく相互検証

新補修補強技術の評価
過去の延長にはない未来予測

膨大な維持管理情報(ビッグデータ)から統計的手法により寿命推定 & リスク評価
ー生存解析ー
マクロ的視点





膨大な管理データから予見されるハザードスコア(余寿命)

生存解析：過去の経験の総合（統計）知　ハザードの評価

膨大なデータに立脚

生存解析

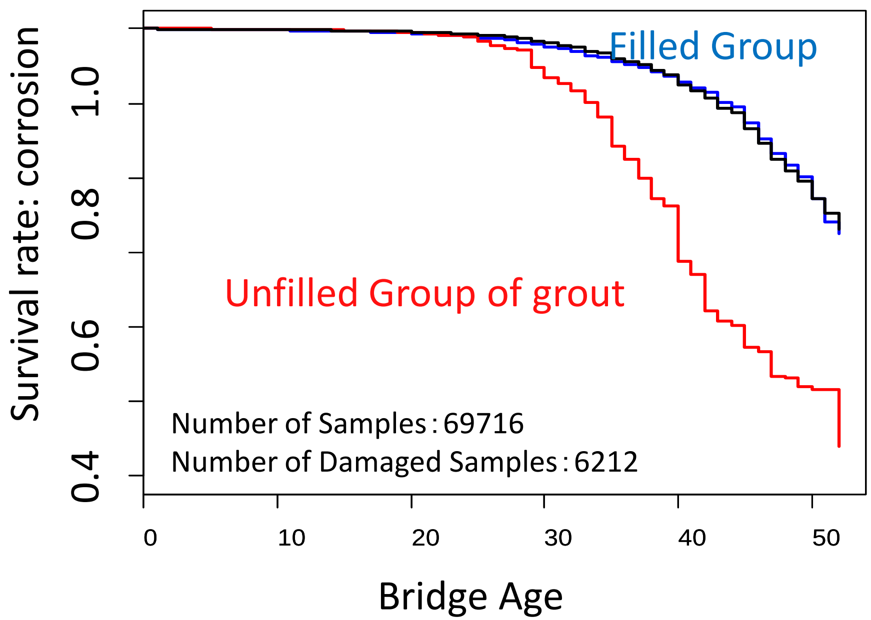
1. **Kaplan–Meier survival curves**

ex. Used to estimate the survival rate of patient

2. **Cox proportional hazard model**

ex. Used for quantitative analysis of the medical risk

Frigid, Cold temperate, Temperate, Semi-tropical zones



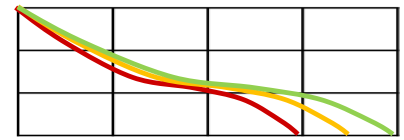
Yamazaki and Ishida: The application of survival analysis on the degradation of concrete bridges in Tohoku region, SSMS 2015, Journal of JSCE(2016)

Degradation

Structure　Environment

Degradation types

Difference of Degradation



All Samples：82016　Damaged Samples：16246

Event = Efflorescence under the slab

Variable	coefficient	Hazard rate
Numerical variables (standardized)		
Normal Traffic	-0.247	0.781
Heavy Traffic	-0.328	0.720
Span Length	0.186	1.204
Slab Thickness	0.340	0.721 (1.405)
Deicing Salt	0.189	1.208
Winter Temperature	0.030	0.970(1.031)
Spring rain	0.518	1.679
Summer rain	-0.750	0.472
Autumn rain	-0.380	0.684
Winter rain	0.501	1.651
Distance from sea shore		
Very Close		1.000
Close	-3.884	0.021
Far (no risk)	-3.487	0.031
Crossing situation		
River		1.000
Road/ Railroad	0.271	1.312
Unknown	-0.325	0.722

維持管理ビッグデータによるリスク評価：未来は過去の延長上として

Cox regression analysis and risk factors

ハザードスコアを利用した維持管理支援手法

$$h(t,\boldsymbol{x},\boldsymbol{\beta}) = h_0(t)\underline{\exp(\boldsymbol{x\beta})}$$

1 plotting of hazard scores

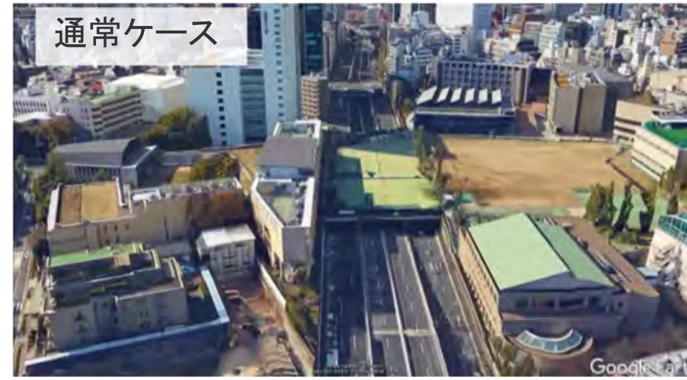
● high risk ● low risk

- GIS information, Google earth, risk score overlay
- 熊野町JCT⇔板橋JCT（traffic/structure）
- areas to be highly controlled are clarified

2 repair/strengthening plans

Route 3

2001 fib AAYE awardee



Impact of strengthening

増厚ケース

- Priority of repair and strengthening can be clarified, and the strategic maintenance is made possible.

Yamazaki and Ishida (2015): APPLICATION OF SURVIVAL ANALYSIS TO DETERIORATED CONCRETE BRIDGES IN EAST JAPAN, Journal of Japan Society of Civil Engineers, Ser. F4 (Construction and Management), 71(4).

検査情報＋構造詳細データ → ミクロ的視点からの推定

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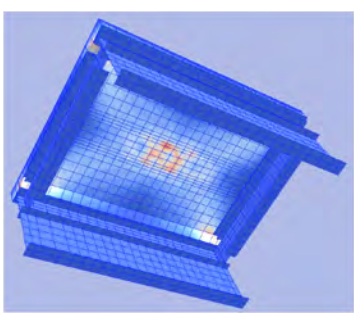
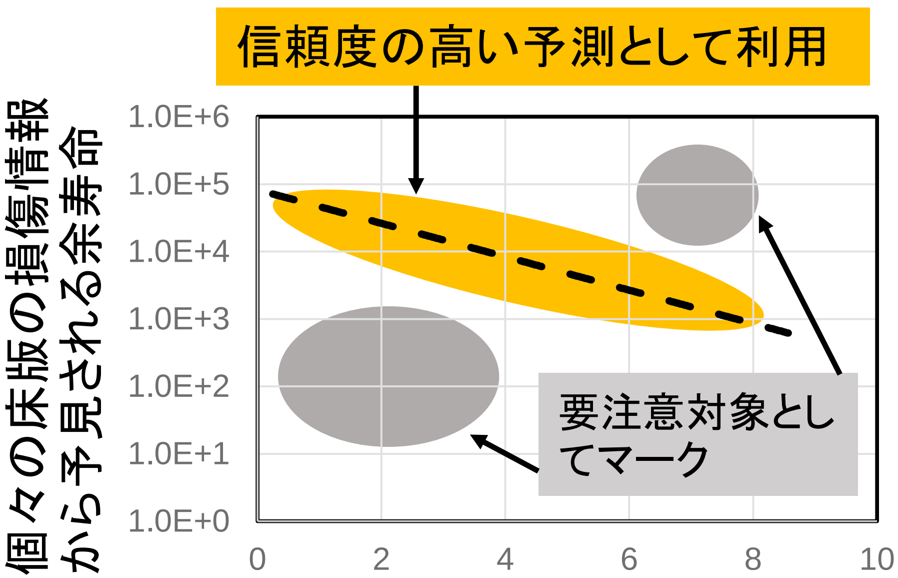
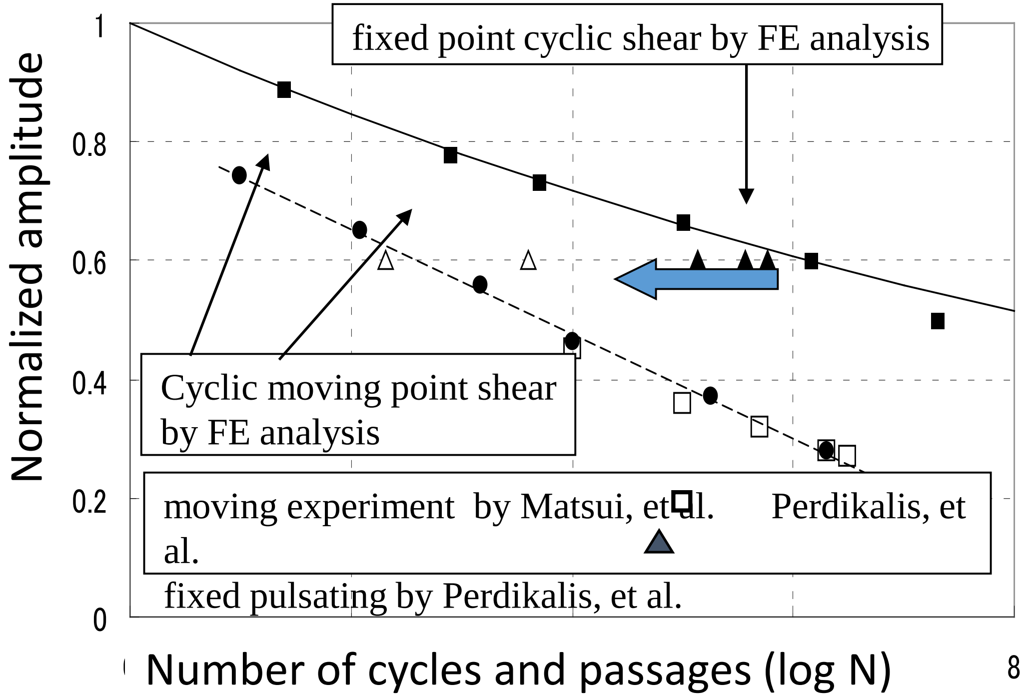
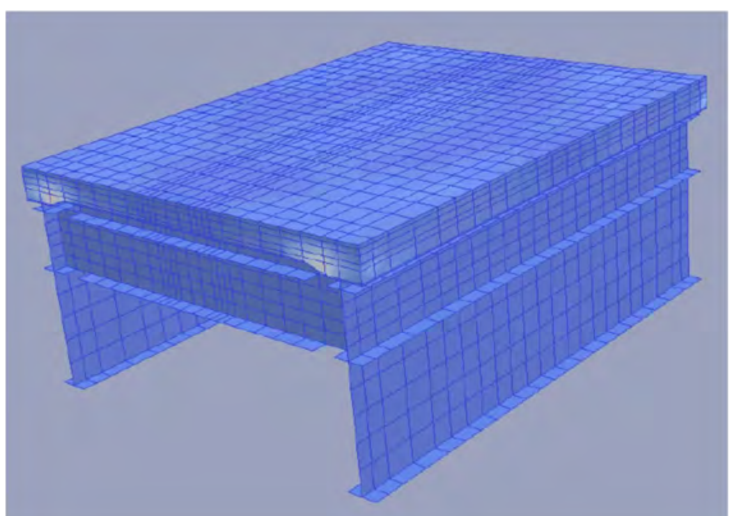


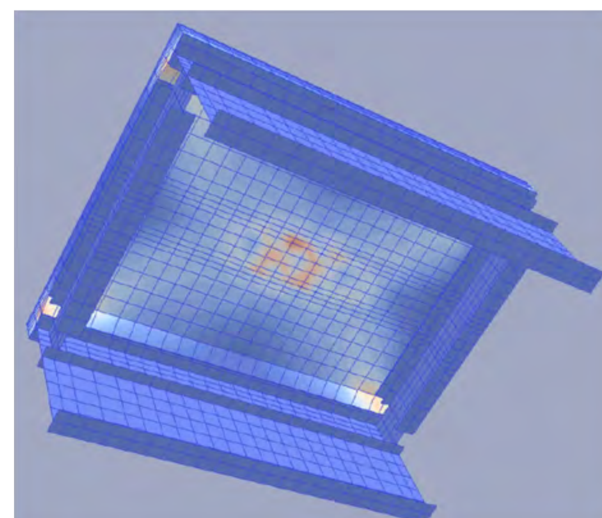


膨大な管理データから予見されるハザード(余寿命)

ミクロ数値解析：サイバー空間に建設されRC床版の挙動



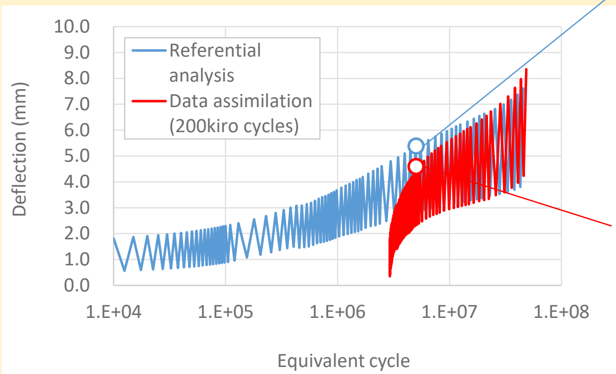




データ同化(≠逆解析)が成立する理由:進化の過程の全てを再現

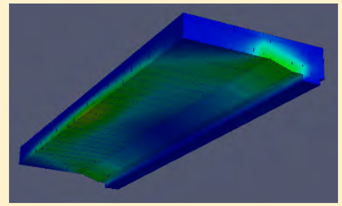
Multi-scale simulation platform used

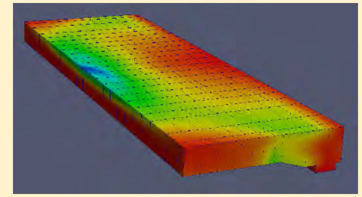
Fatigue life simulation of RC bridge decks



Center deflection

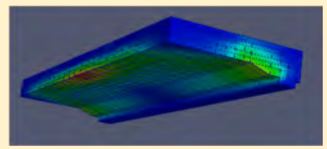
通常の解析

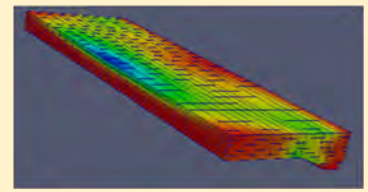




Mostly assimilated!

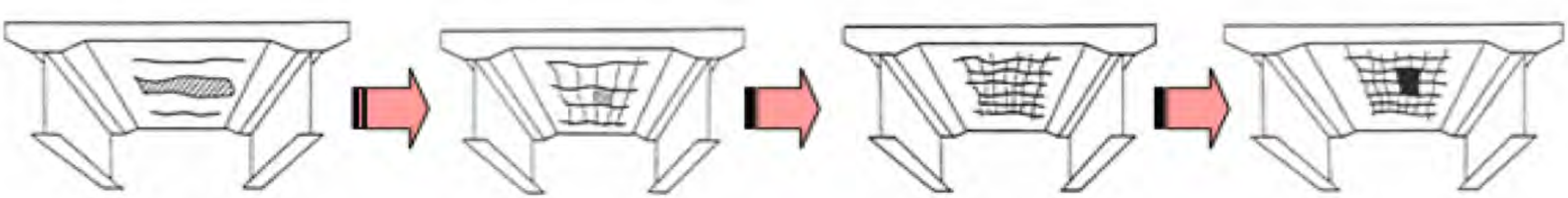
Start from damaged states





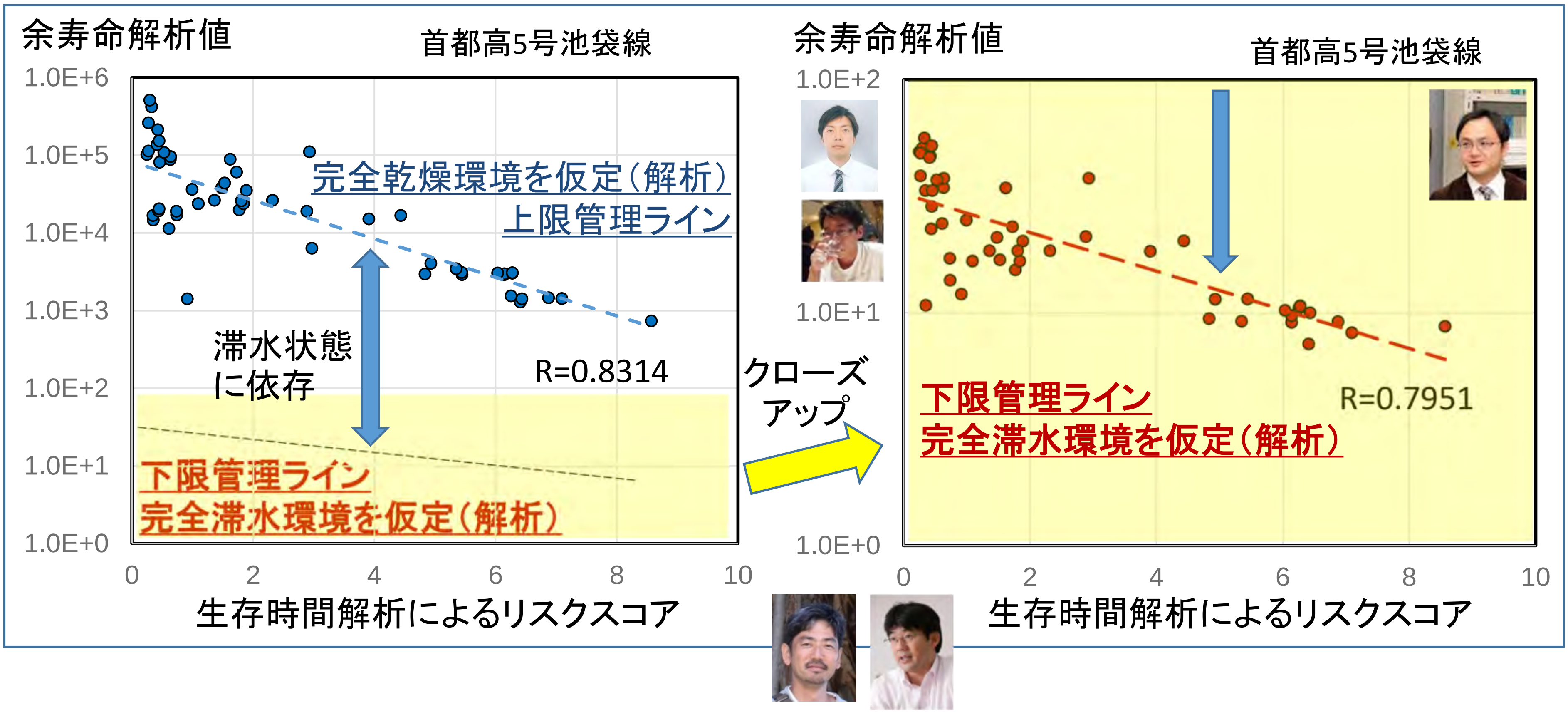
From any cases of damages

データ同化



破壊に至る過程に現れる全現象を辿りながら最後を看取る **Data同化が可能に**

ミクロとマクロの視点で寿命推定値の信頼性を確保



膨大な経験知と科学的知見が整合するデータ→予測の信頼性は高

整合ラインから乖離している床版＝危険(学べる)対象として注視

ミクロ解析による、新たな補修補強技術提案の信頼性評価が可能に

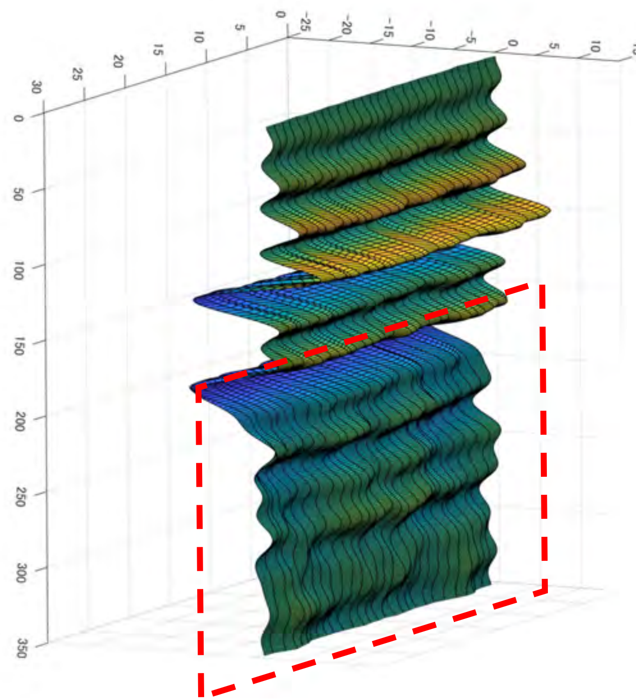
水により強く反応する電磁波レーダーで水＋損傷を検知

0.16 million bridges (more than 15m)

First, pavement stripped and deck surfaces inspected

Percussion by inspectors
Tough works!

Necessary to stop traffic → huge social cost and time

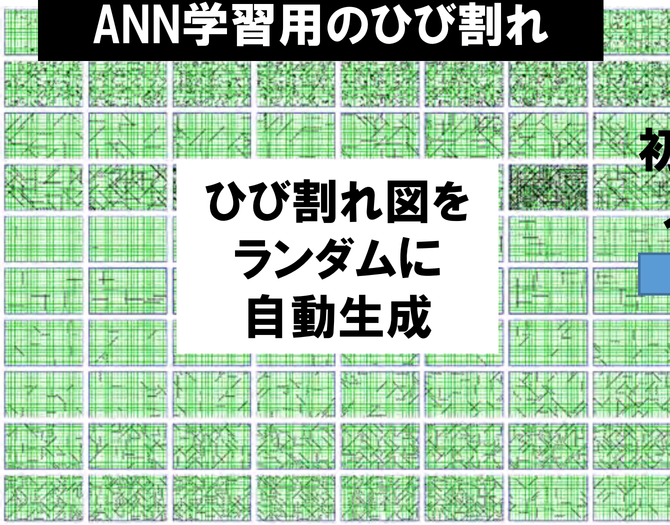


Dr. Mizutani, AP, IIS-UT

数万ケースの実験をサイバー空間で実施→ANNで高速余寿命評価実現

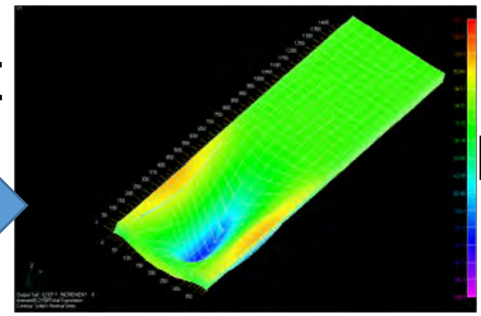
Fathalla, E., Tanaka, Y., Maekawa, K. (2018). Remaining fatigue life assessment of in-service road bridge decks based upon artificial neural networks, Engineering Structures

ANN学習用のひび割れ

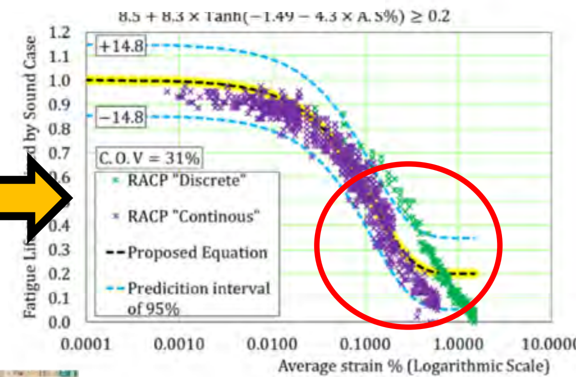


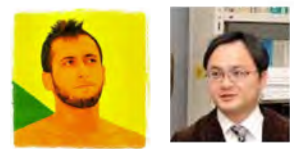
初期値入力

マルチスケール解析



疲労寿命を計算

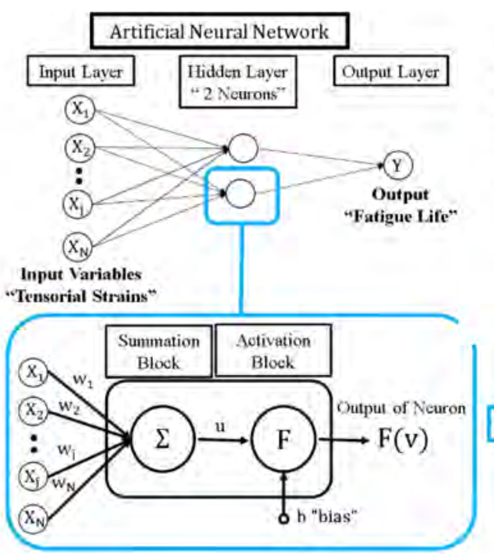




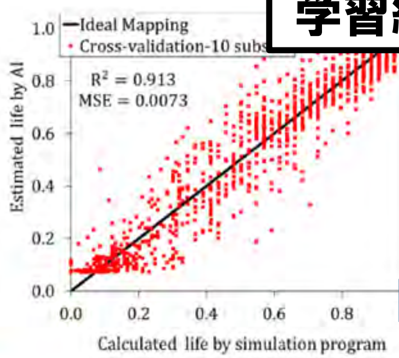
1000個の計算結果

機械学習

ANNモデルを構築

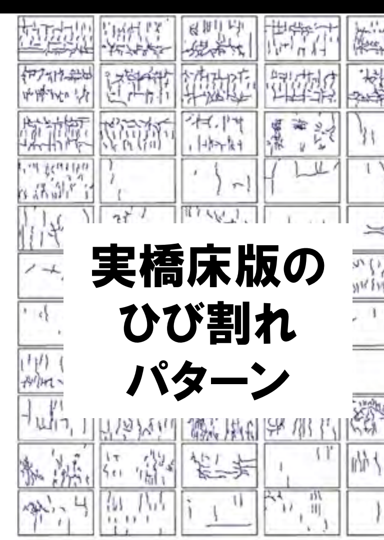


学習結果

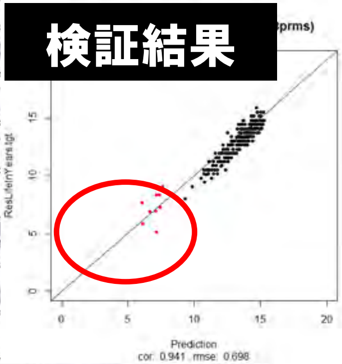


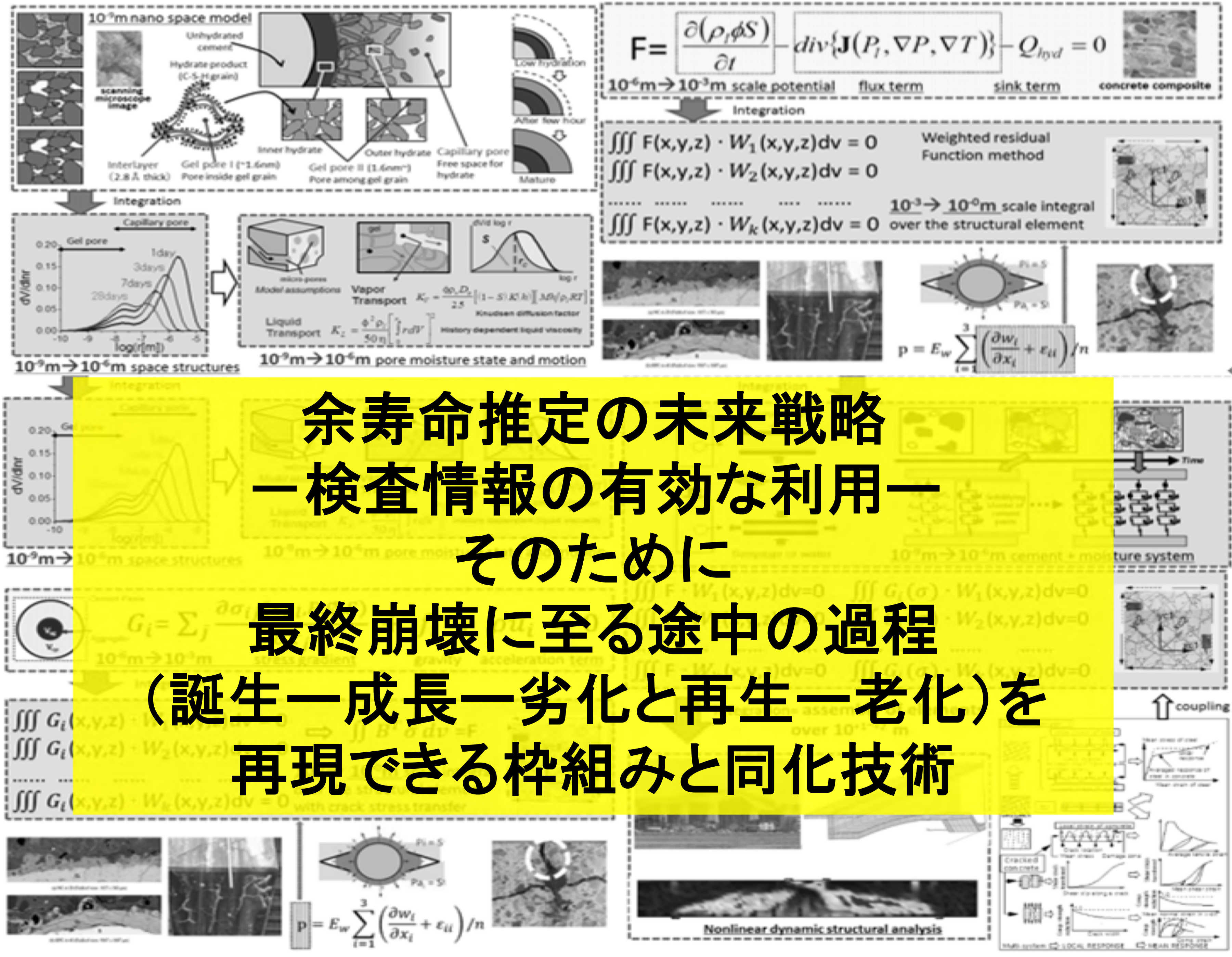
検証

検証用のひび割れ



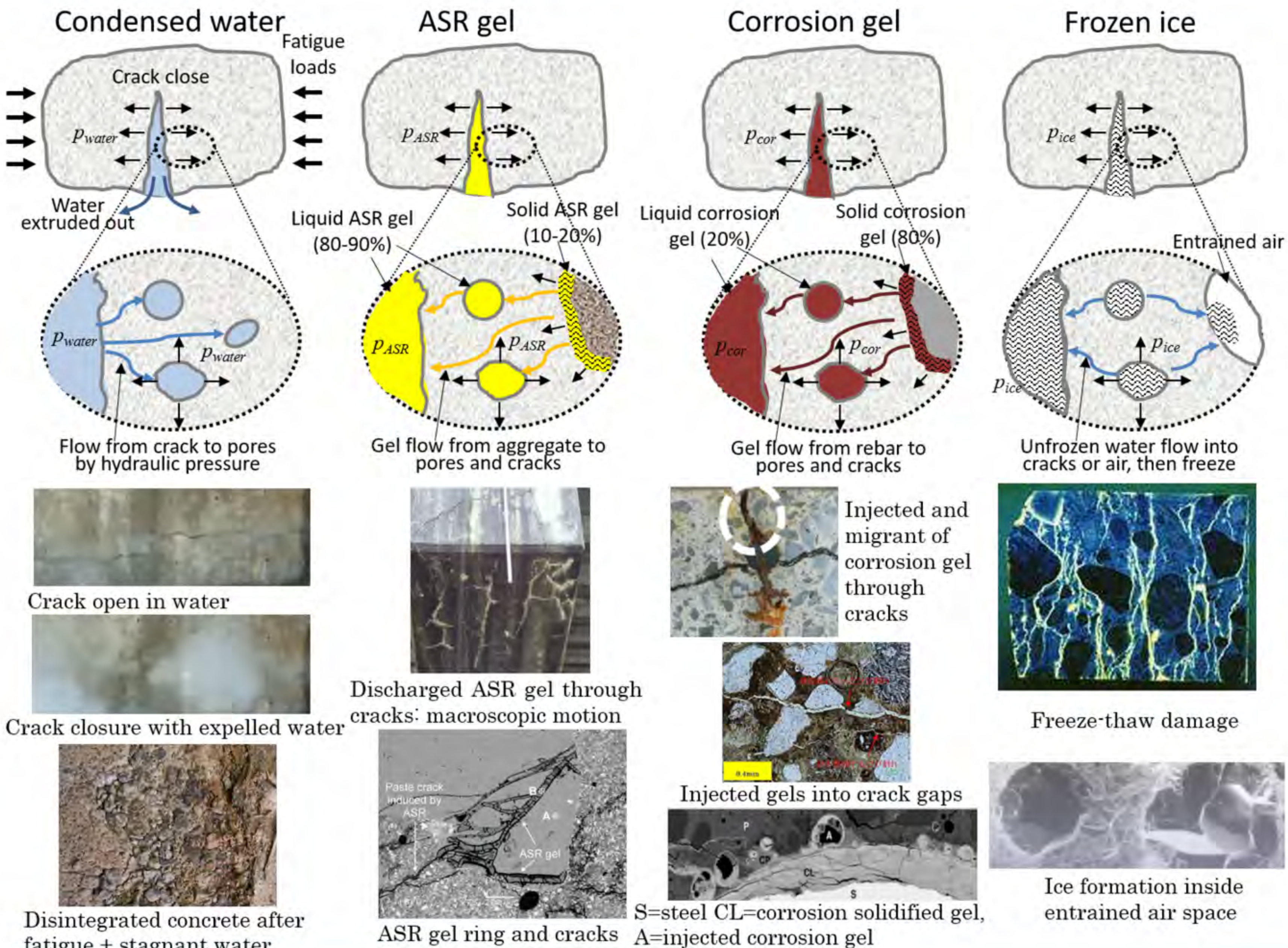
検証結果





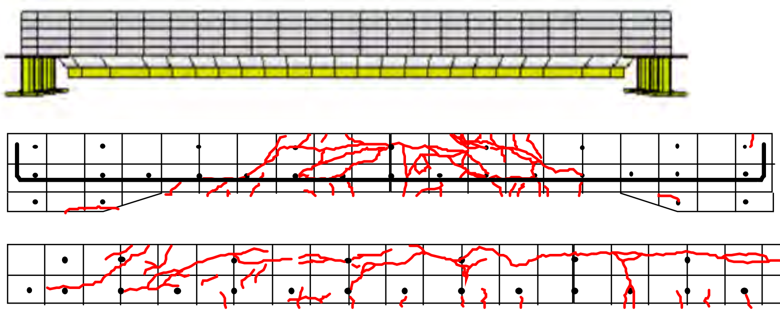
余寿命推定の未来戦略
ー検査情報の有効な利用ー
そのために
最終崩壊に至る途中の過程
（誕生ー成長ー劣化と再生ー老化）を
再現できる枠組みと同化技術

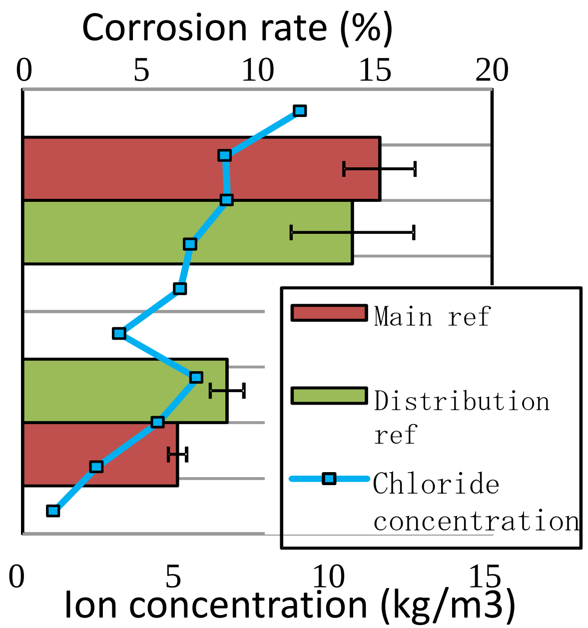
疲労+腐食+ASR+凍結を総合化：任意自然環境に対応

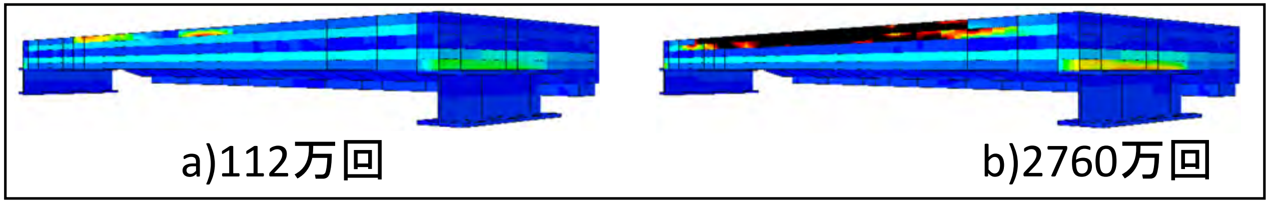


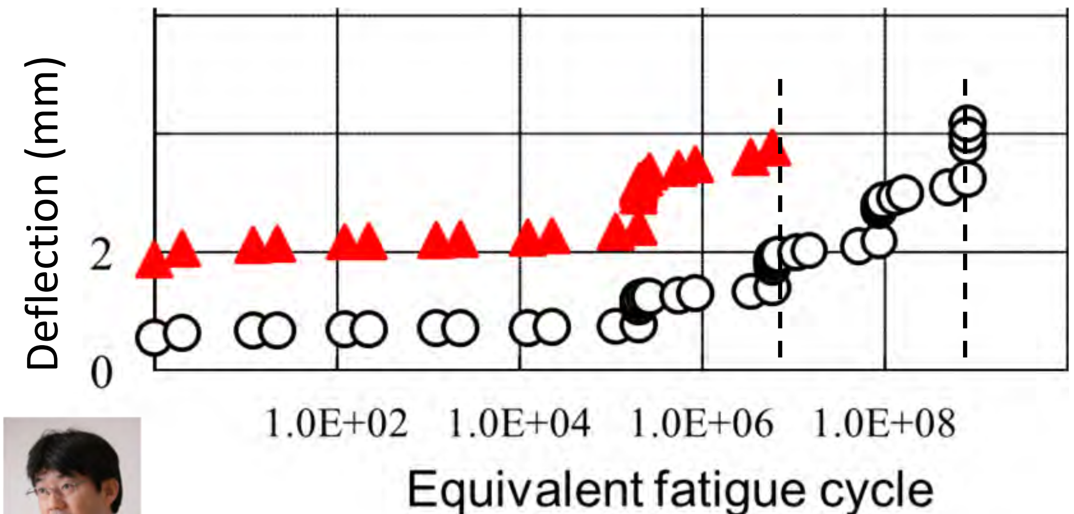
腐食ひび割れと滞留水と寿命

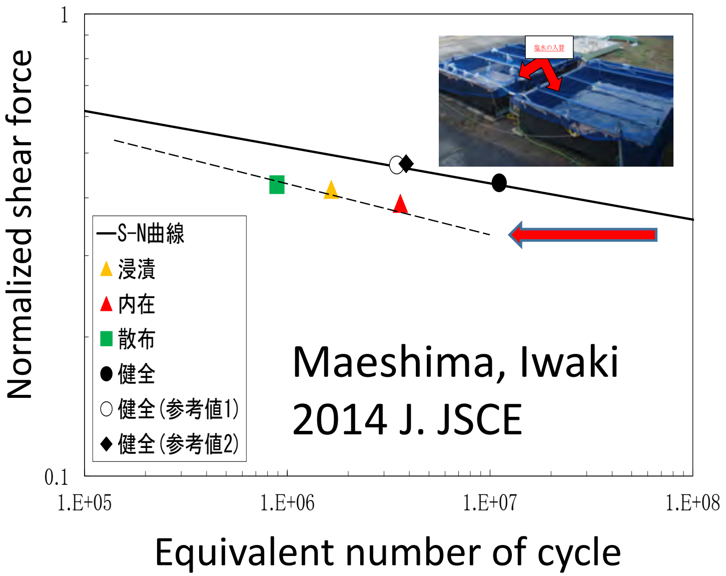
By Prof. I. Iwaki et al. (2016). Journal of JSCE







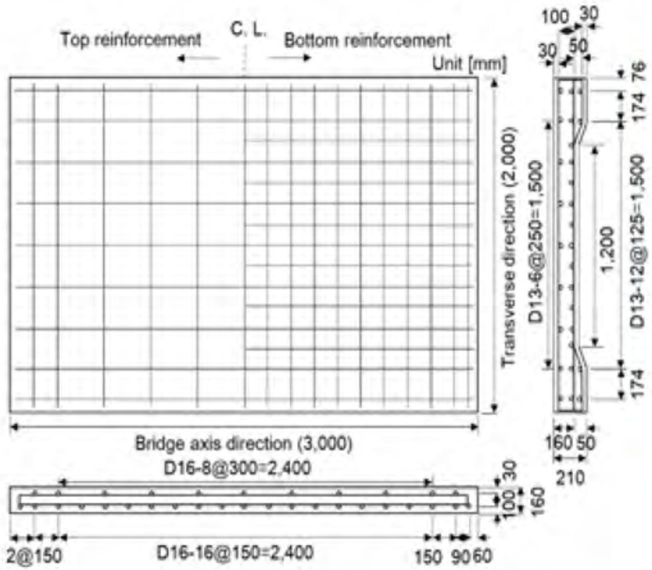


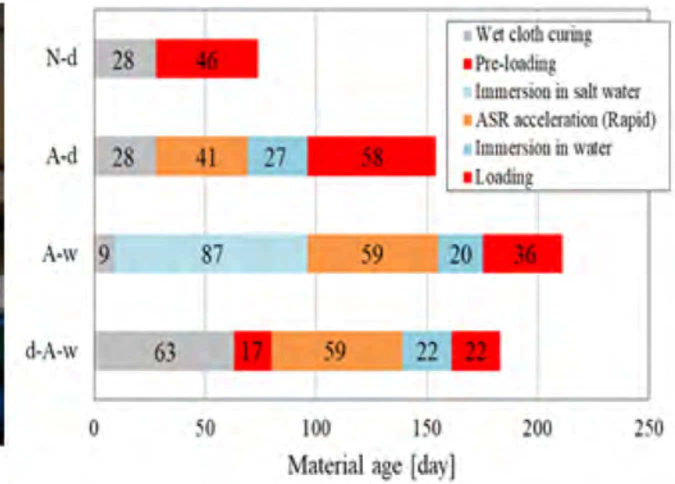


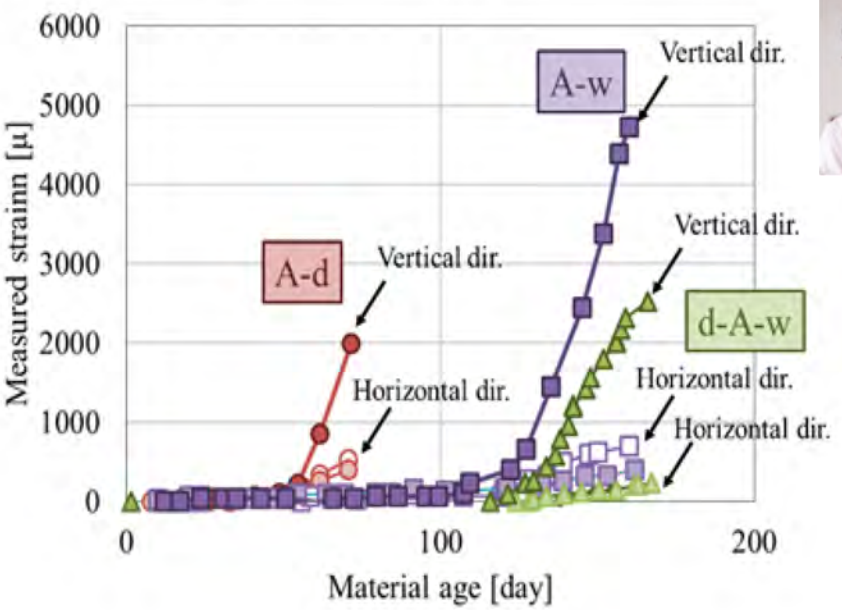
Maeshima, Iwaki
2014 J. JSCE

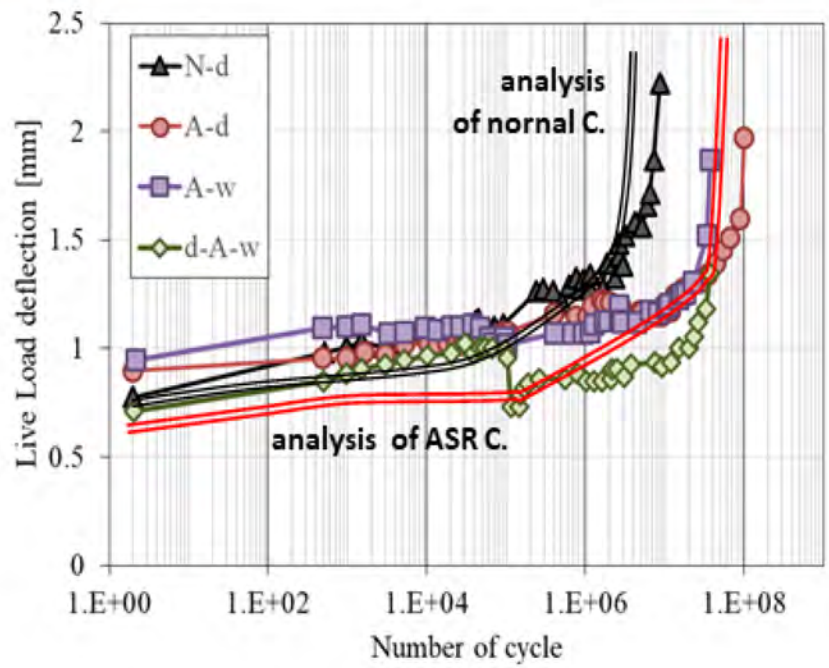
ASR損傷と滞留水と寿命：厚さ方向でも同化

Maeshima et.al (2016). Journal of JSCE



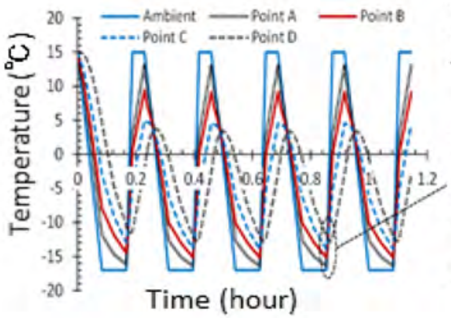


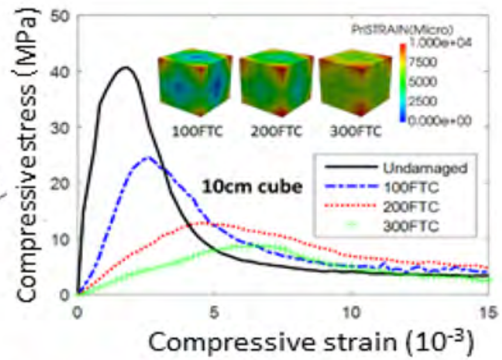


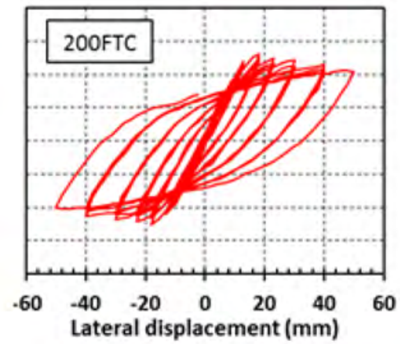


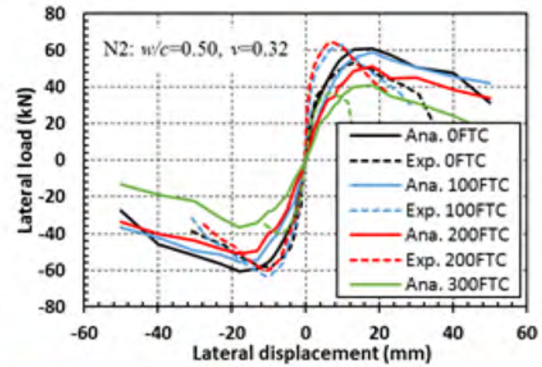
シリカゲル、腐食ゲル、氷晶、液状水がメソスケールで関与する構造問題

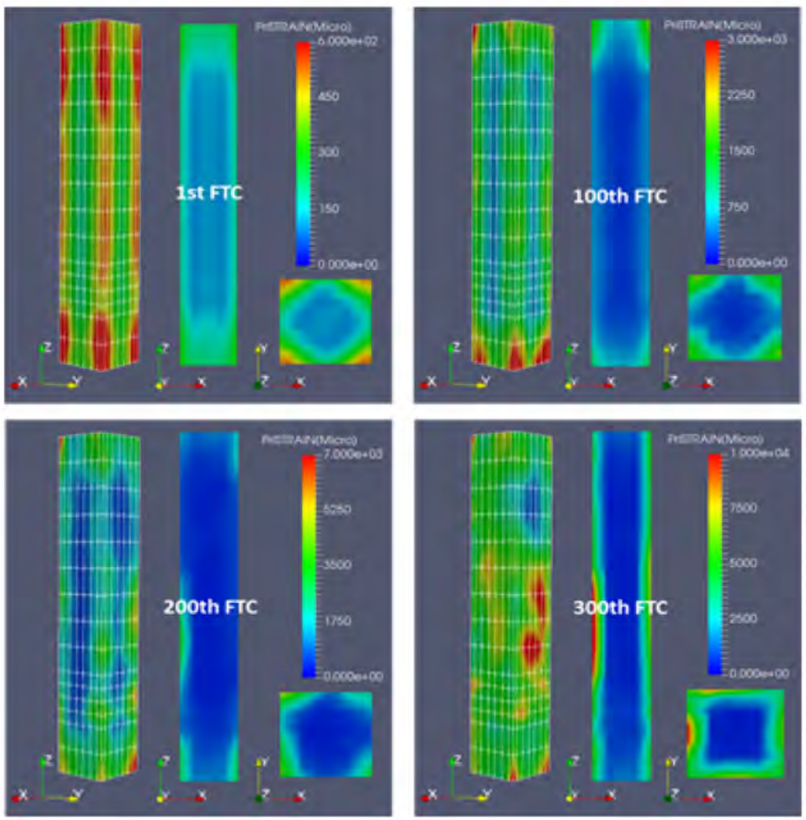
Gong, F. and Maekawa, K. (2018). Multi-scale simulation of freeze-thaw damage to RC column and its restoring force characteristics, Engineering Structures

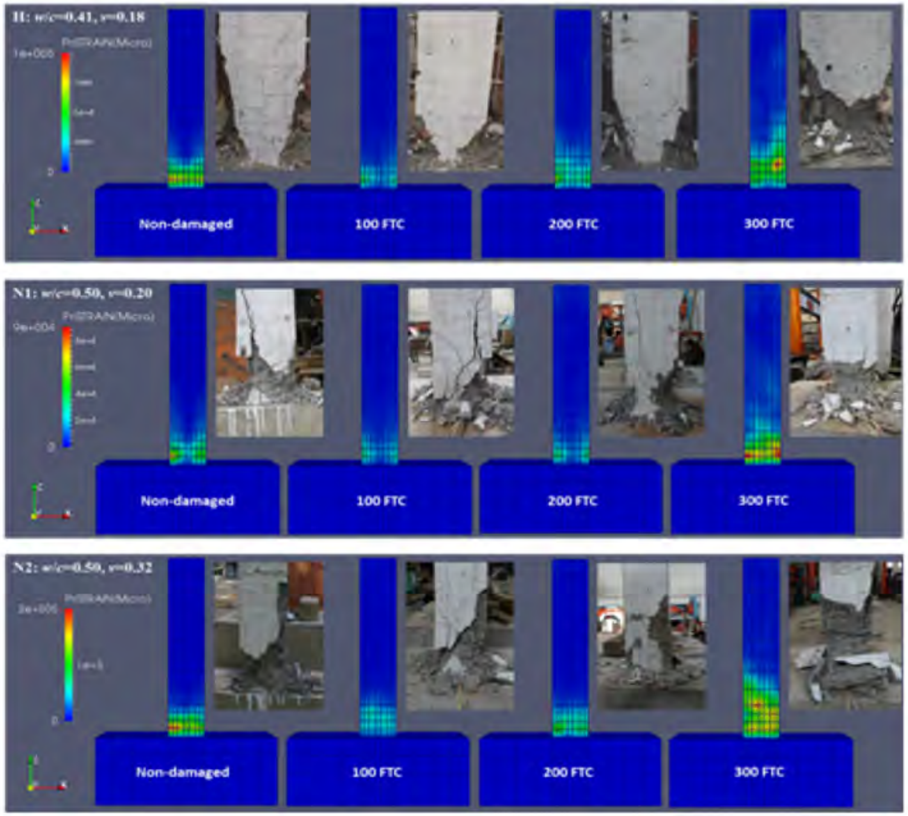






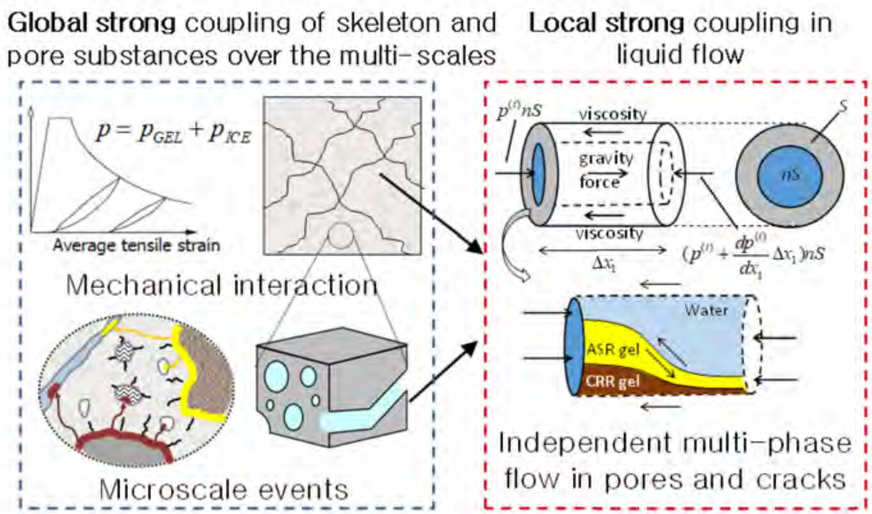


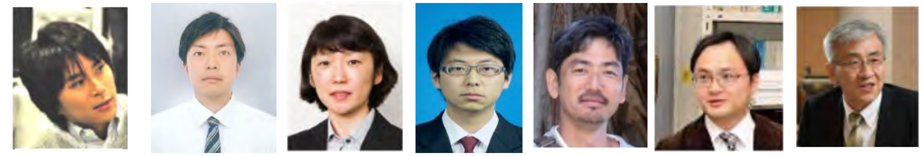


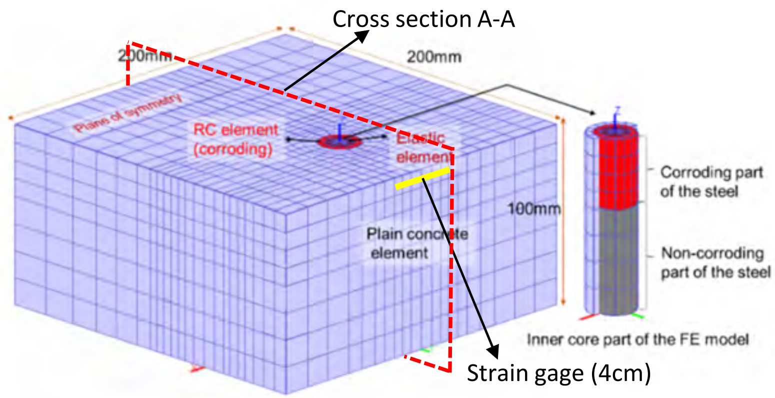


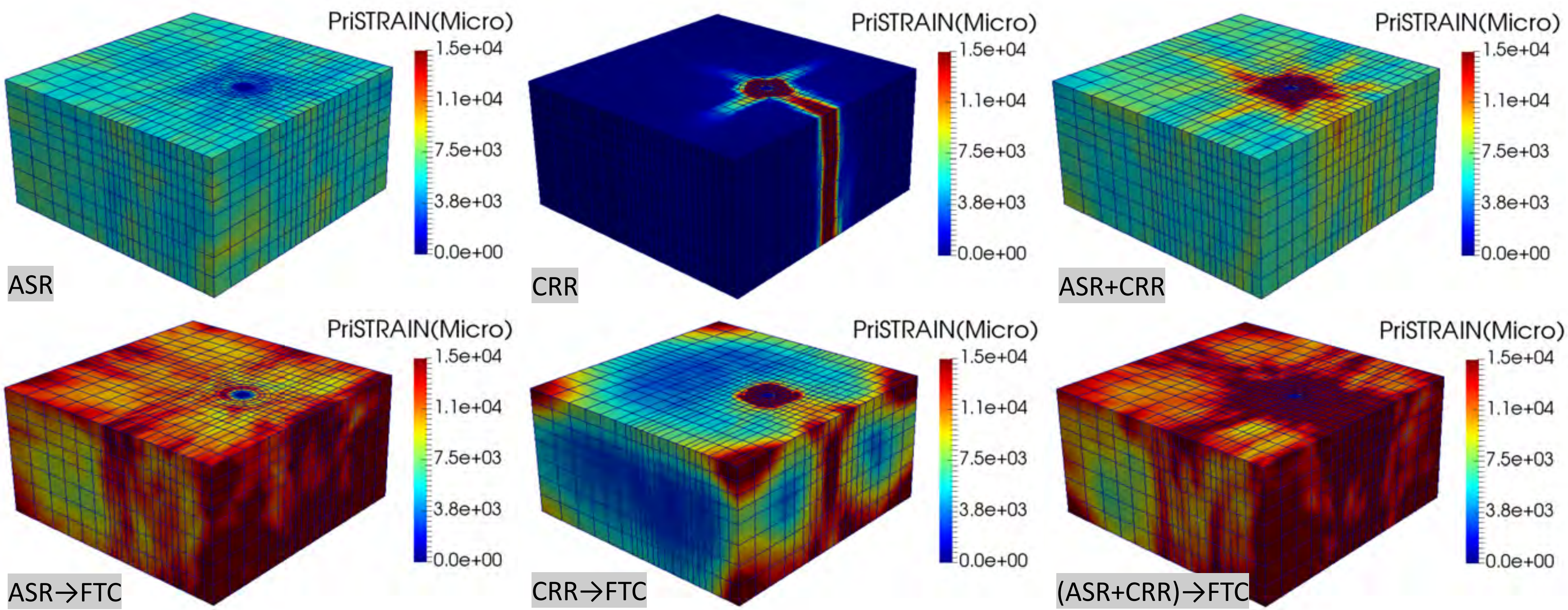
シリカゲル、腐食ゲル、氷晶、液状水がメソスケールで関与する構造問題

Global deformation coupled with local flow:

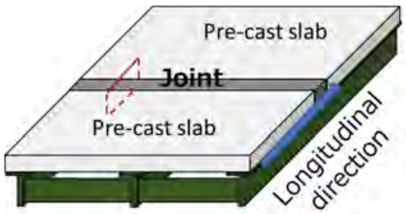








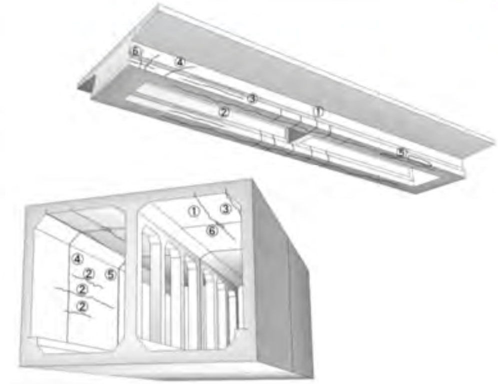
場所打ち床版→ プレキャスト、桁、地下構造、地盤と舗装、電磁場 etc 展開

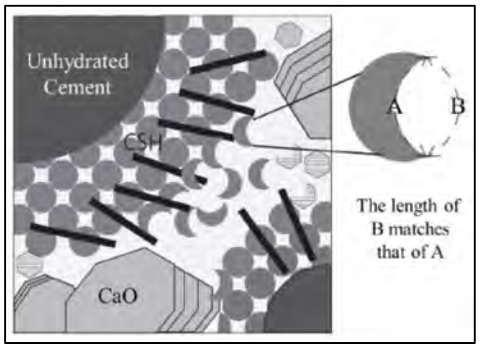


ACF2018 by Sogawa et al.

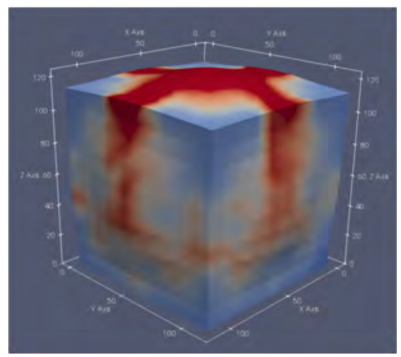
道路構造ジャーナル
https://www.kozobutsu-hozen-journal.net/walks/detail.php?id=34&page=2

JSCE標準示方書2018

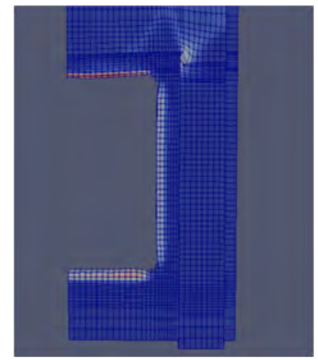




Decomposed CSH + vapor

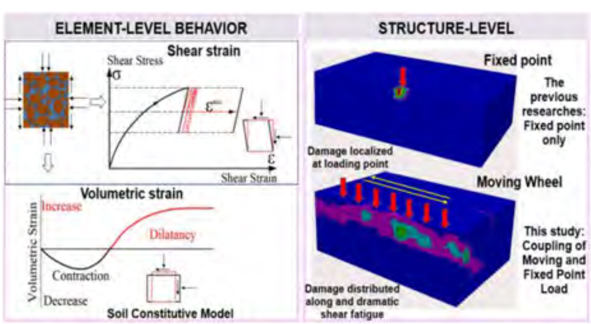


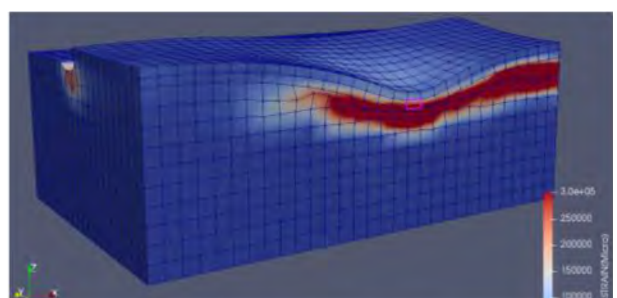
Meso-scale with cracks

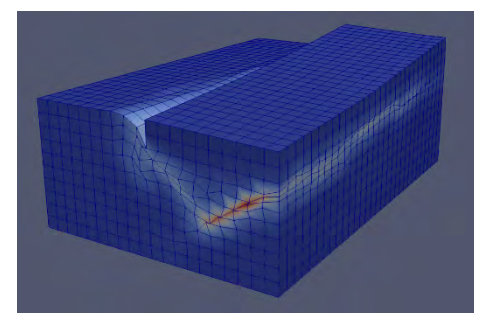


Structural

耐火性能評価：硬化体ー複合材料ー構造システム（ACF2018. by Iwama, Ishibashi et al.）







地盤ー舗装システムの余寿命推定と更新計画 (ACF2018 by Hung et al.)