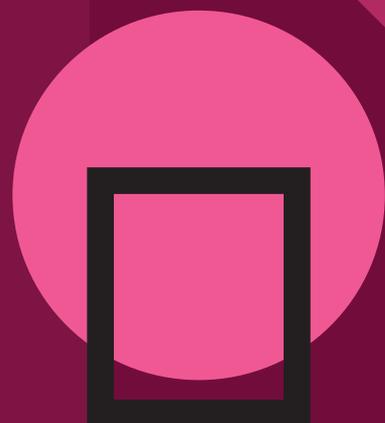


MIDAS
CONSTRUCTION
TECHNICAL
DOCUMENT
COLLECTION

地盤変形・トンネル分野 9



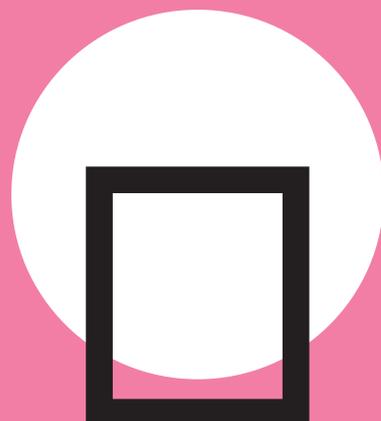
MIDAS CONSTRUCTION TECHNICAL DOCUMENT COLLECTION

地盤変形・トンネル分野

9.

琉球諸島における
土木工学問題に対する数値
解析の役割とその適用

琉球大学 藍檀 オメル 教授



琉球諸島における土木工学問題に対する 数値解析の役割とその適用

藍檀 オメル

琉球大学 工学部 環境建設工学科

基礎式

質量保存則 $\frac{\partial \rho}{\partial t} = -\nabla \cdot \mathbf{q} \pm Q$

浸透流

拡散問題

2D・3D一般的に厳密解を得ることが大変難しいため、近似解と呼ばれる数値解析が不可欠である。

運動量保存則 $\rho \frac{d\mathbf{v}}{dt} = -\nabla \cdot \boldsymbol{\sigma} + \mathbf{b}$

エネルギー保存則 $\rho c \frac{\partial T}{\partial t} = -\nabla \cdot \mathbf{q}_h + \boldsymbol{\sigma} \cdot \dot{\boldsymbol{\varepsilon}} + Q_h$

数値解析法

有限差分法(FDM)、有限要素法(FEM)、境界要素法(BEM)

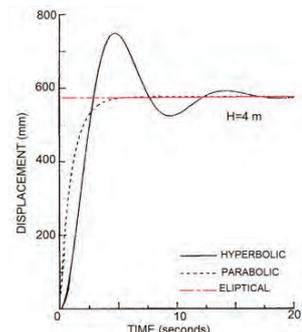
離散化された形(大円型、放物型、双曲型)

構成則:線形、非線形

双曲型 $[\mathbf{M}]\{\ddot{\phi}\} + [\mathbf{C}]\{\dot{\phi}\} + [\mathbf{K}]\{\phi\} = \{\mathbf{F}\}$

放物型 $[\mathbf{C}]\{\dot{\phi}\} + [\mathbf{K}]\{\phi\} = \{\mathbf{F}\}$

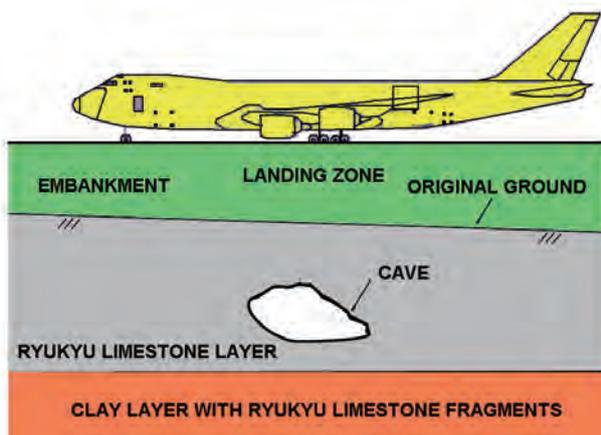
大円型 $[\mathbf{K}]\{\phi\} = \{\mathbf{F}\}$



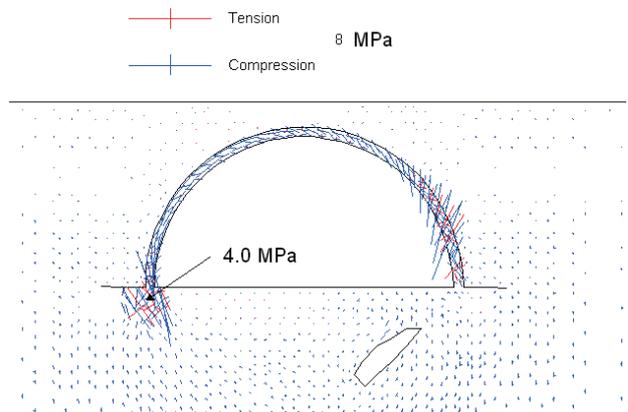
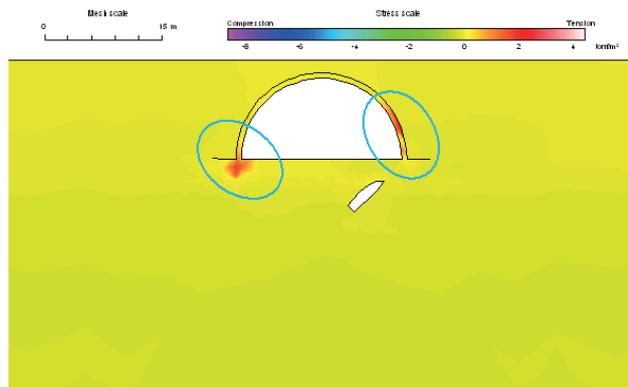
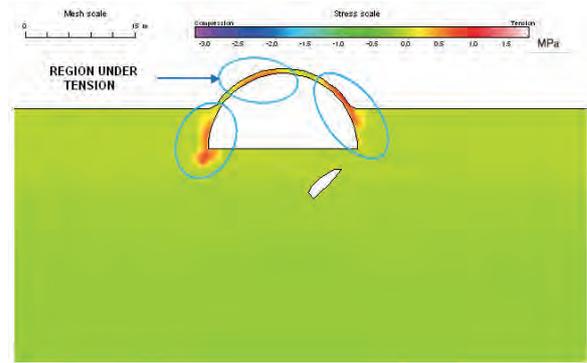
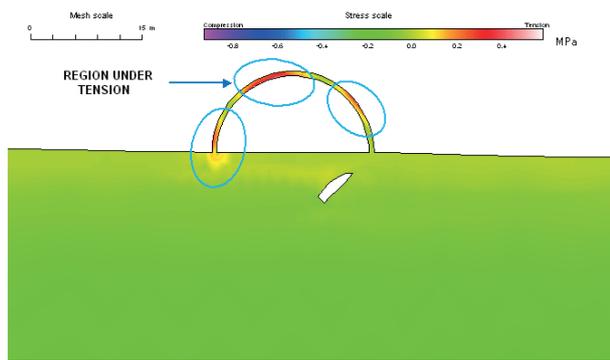
適用例

- 1) 新石垣空港・鍾乳洞問題
- 2) 具志川城址・鍾乳洞問題
- 3) 姫ゆり塔・鍾乳洞問題
- 4) 運転トンネルの補強
- 5) 地下墓に対する橋脚の杭工事の影響の検討
- 6) 掘りこみ港(南大東島)
- 7) 琉球石灰岩の海食岸の不安定性
- 8) 島尻層群における地すべり問題
- 9) 石造文化材におけるアーチの安定性問題
- 10) 島尻層群上の中城城址の長期挙動
- 11) 島尻層群内空洞の短期・長期挙動
- 12) 用水発電所周辺の岩盤の浸透・熱応答
- 13) 液状化
- 14) 普天間基地の変換後の再開発の際に空洞対策問題
- 15) 構造物の非破壊健全性評価法

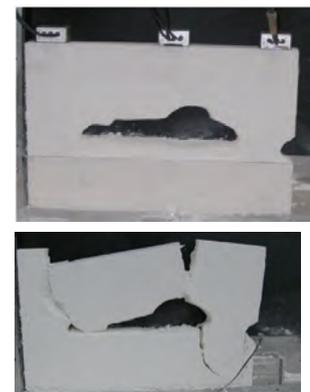
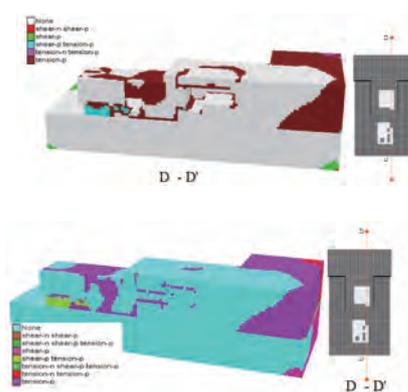
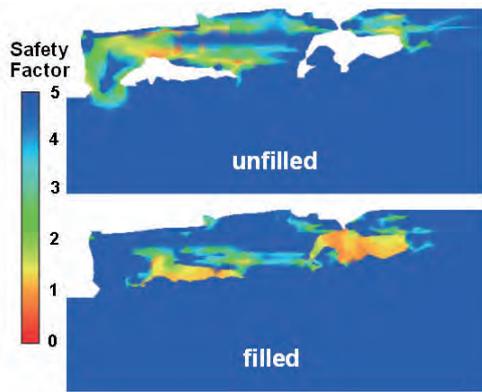
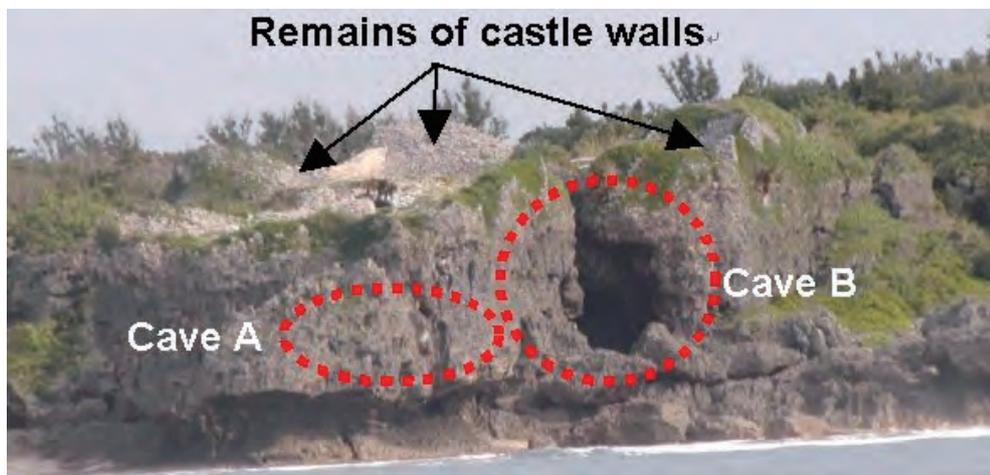
新石垣空港における鍾乳洞とその対策



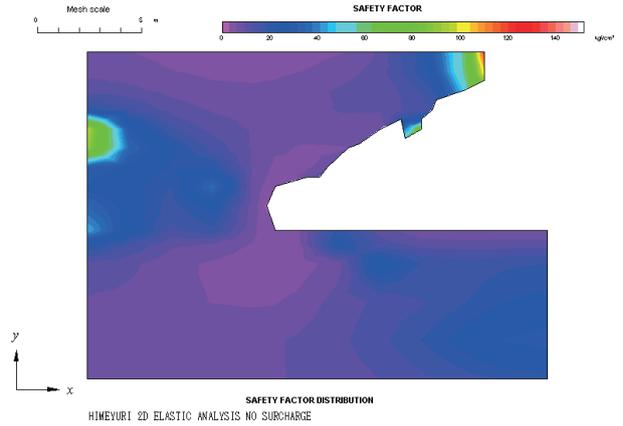
盛土の建設に伴う空洞対策工の応力分布



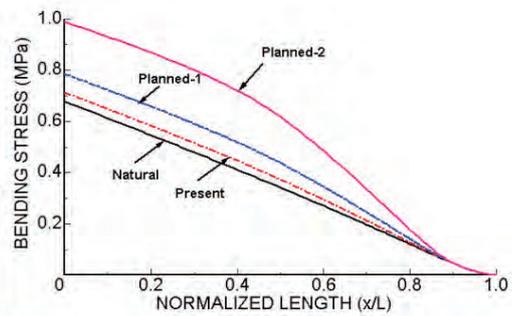
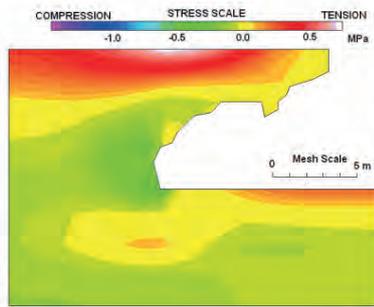
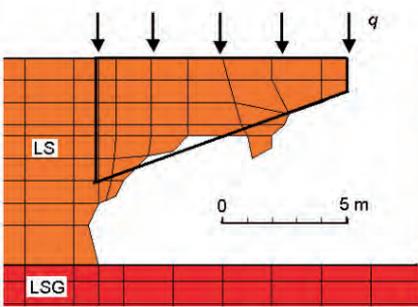
具志川城址基礎岩盤内における鍾乳洞問題の解析



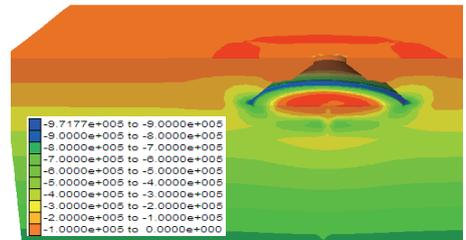
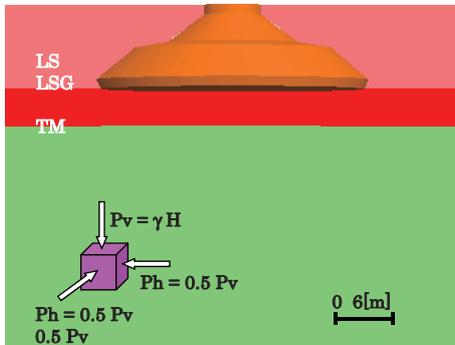
姫ゆり塔



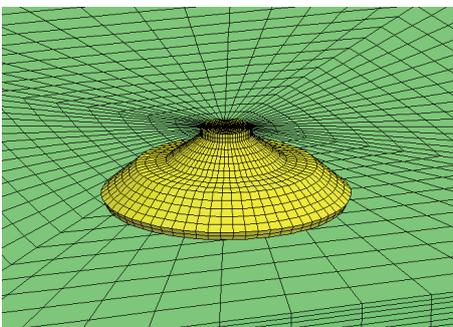
2D



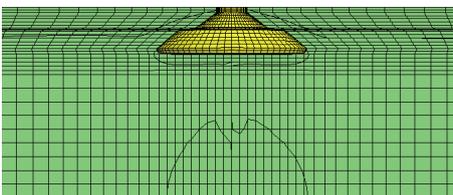
3D-FDM-弾性解 側圧係数 (0.5)



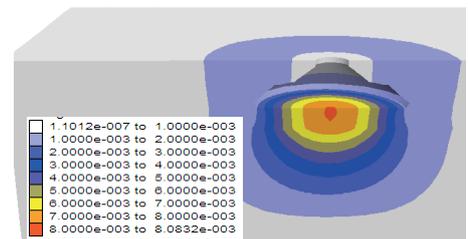
最大主応力 (Pa)



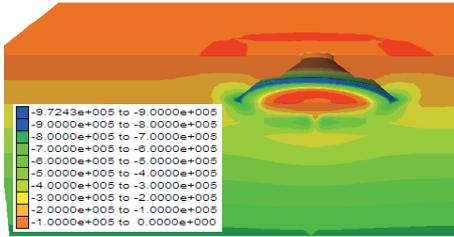
最小主応力 (Pa)



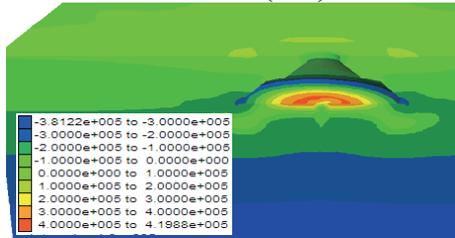
変位 (m)



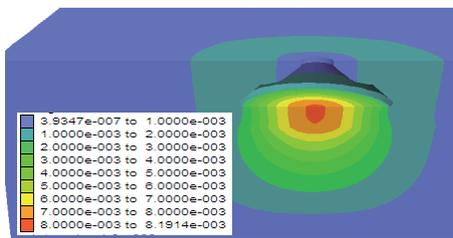
3D-FDM-弾塑性解



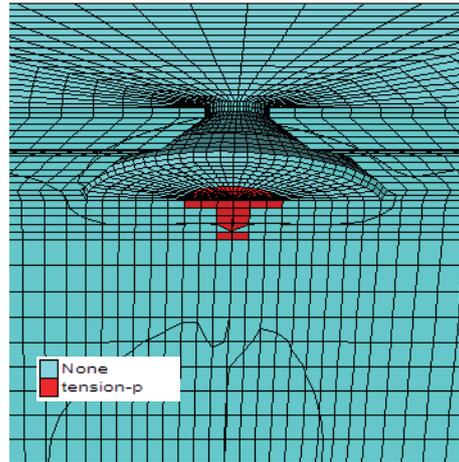
最大主応力 (Pa)



最小主応力 (Pa)



変位 (m)

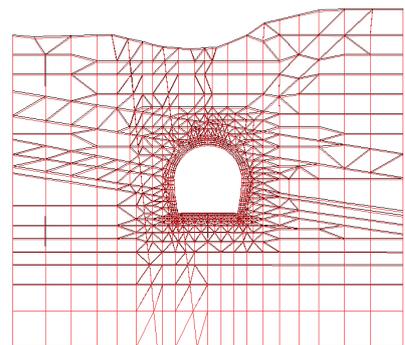
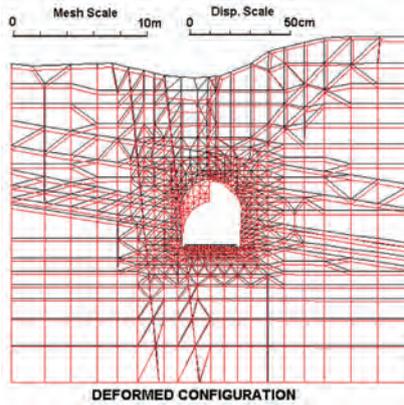
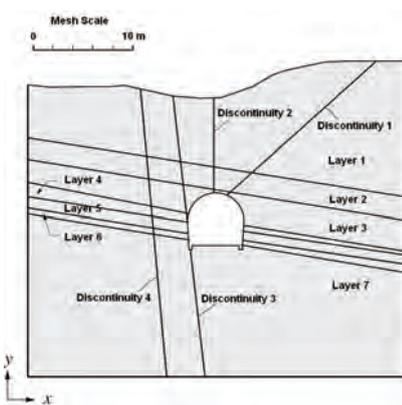


空洞周辺の塑性域

スボリのトンネルに対する対策(運転トンネル)



2D-DFEM

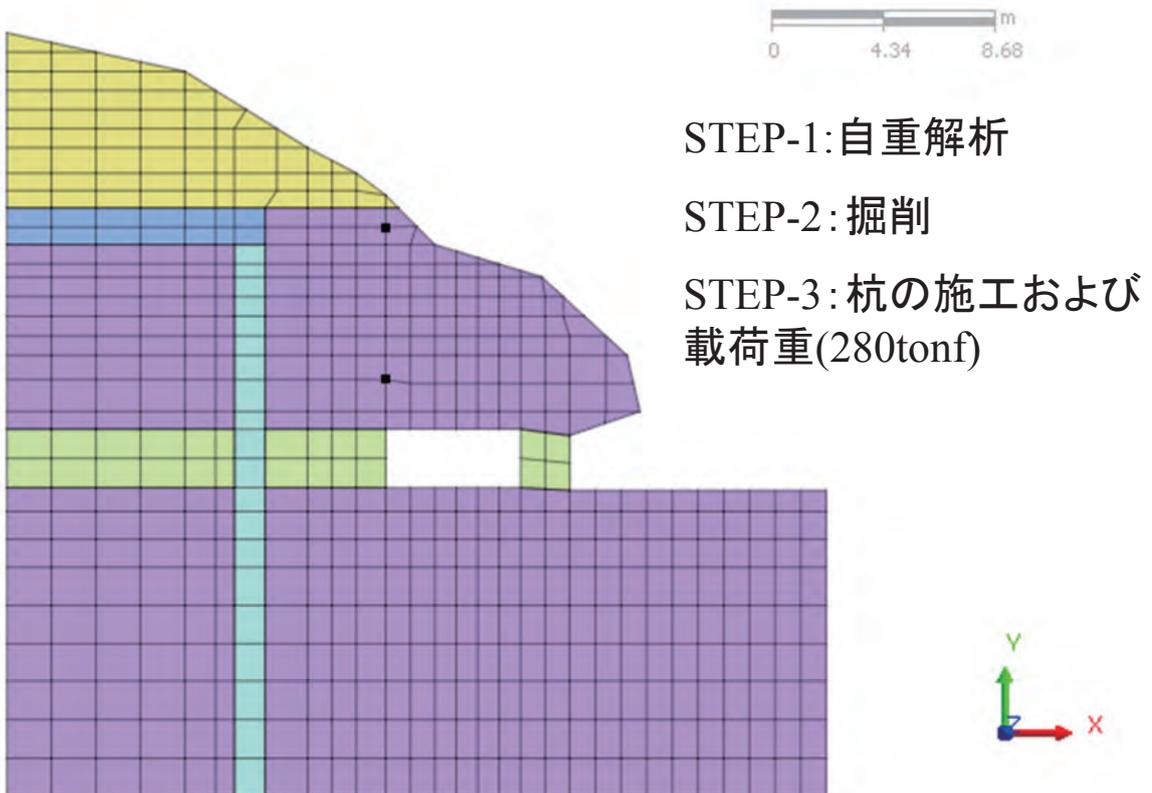


地下墓に対する橋脚の杭工事の影響の検討



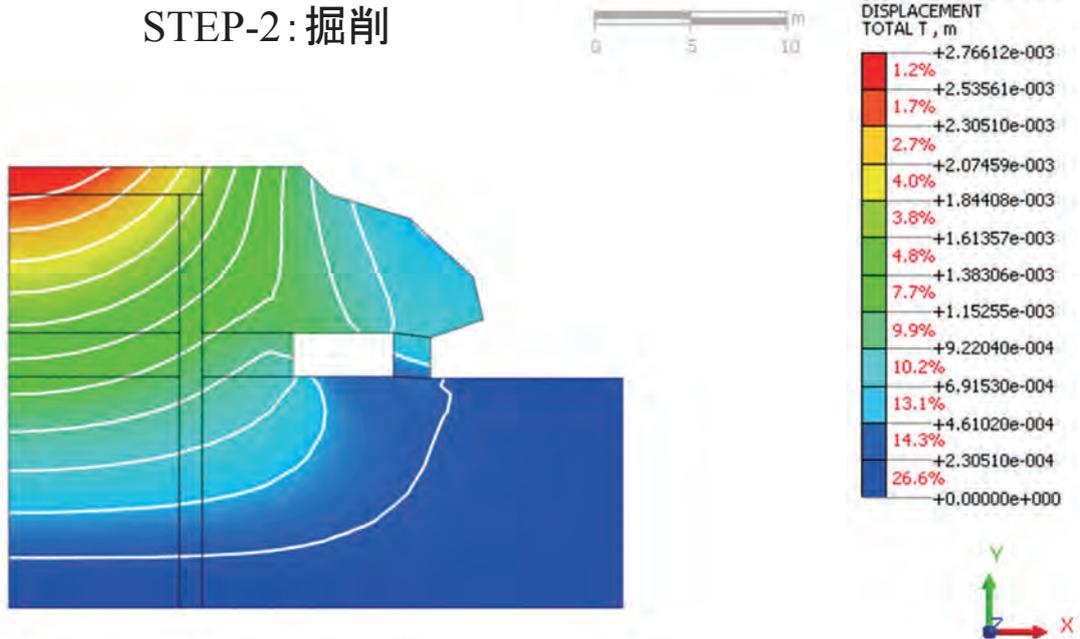
RMQR=68-79

有限要素法による解析—MIDAS—GTS



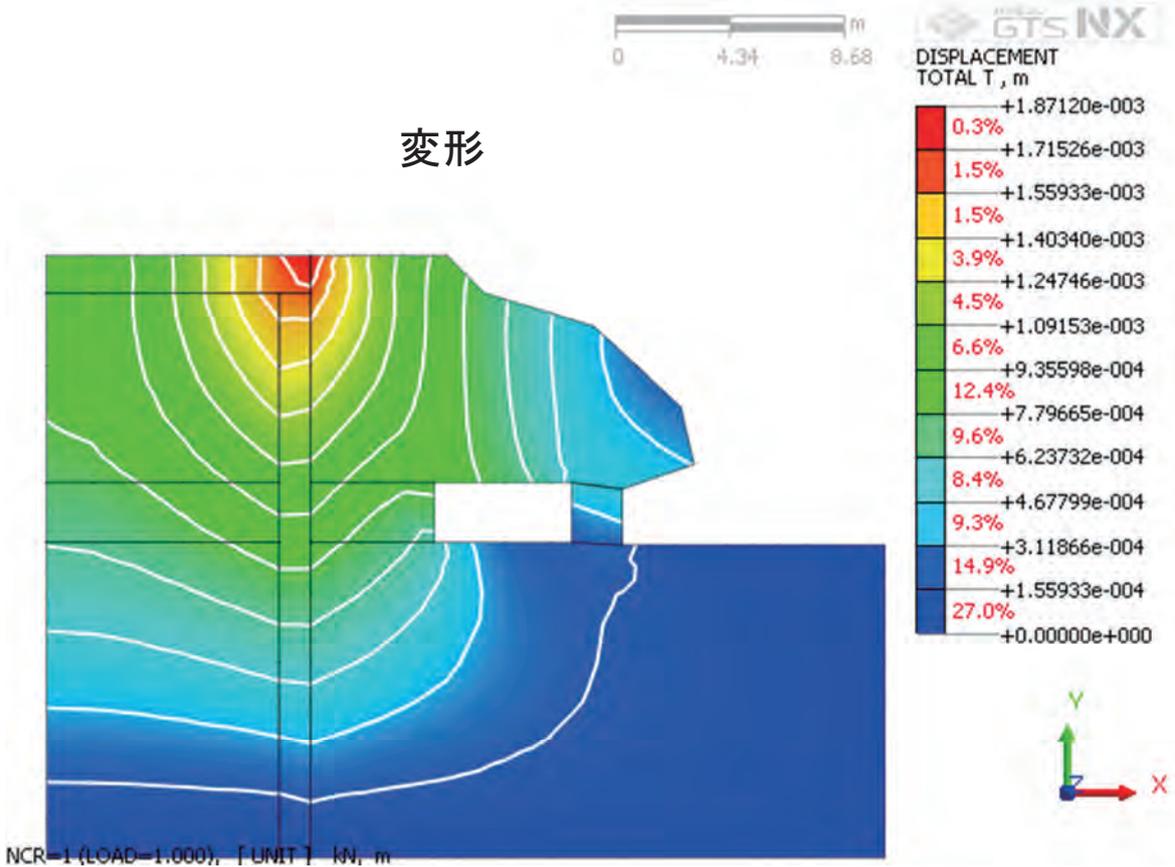
掘削による変形

STEP-2: 掘削

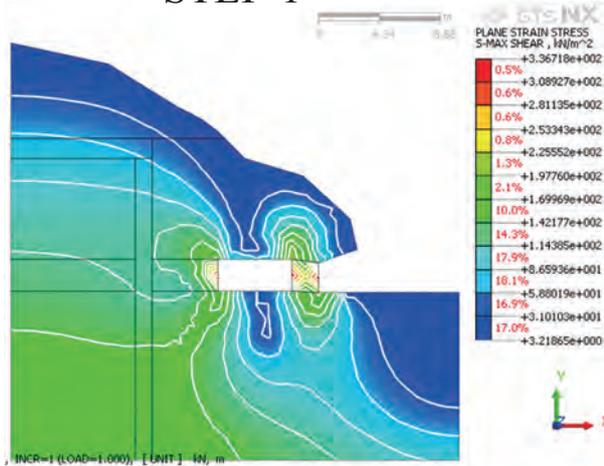


[DATA] CASE1, kussaku, INCR=1 (LOAD=1.000), [UNIT] kN, m

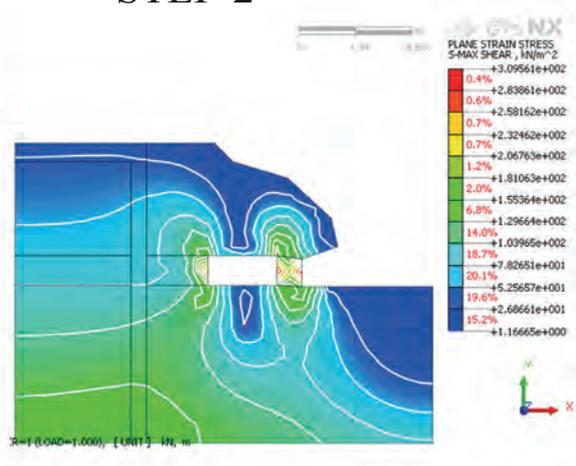
STEP-3: 杭の施工および上部構造物の荷重(280tonf)



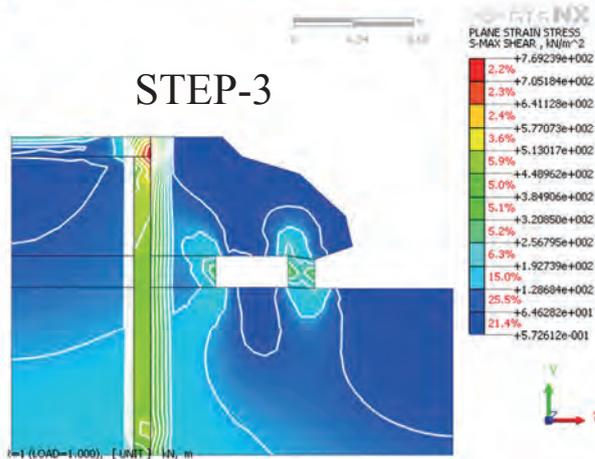
STEP-1



STEP-2



STEP-3

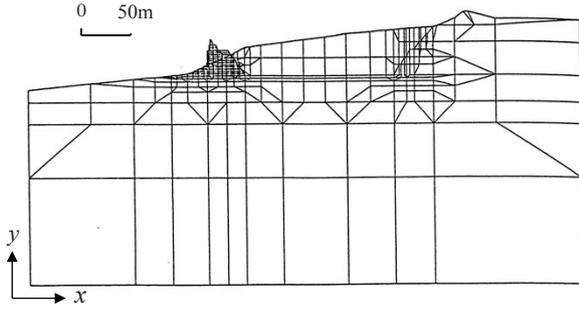


最大せん断応力分布

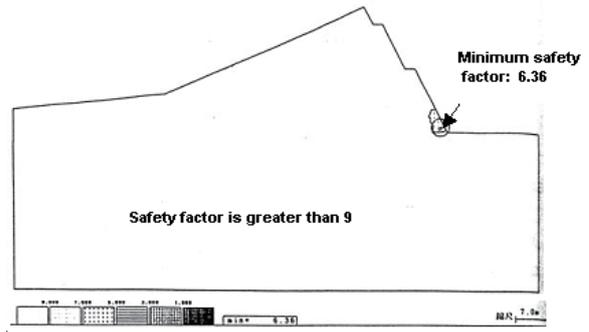
南大東島港プロジェクト



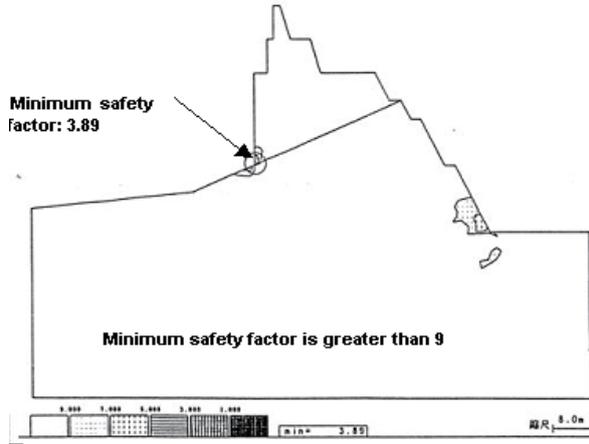
From Tokashiki, 2010



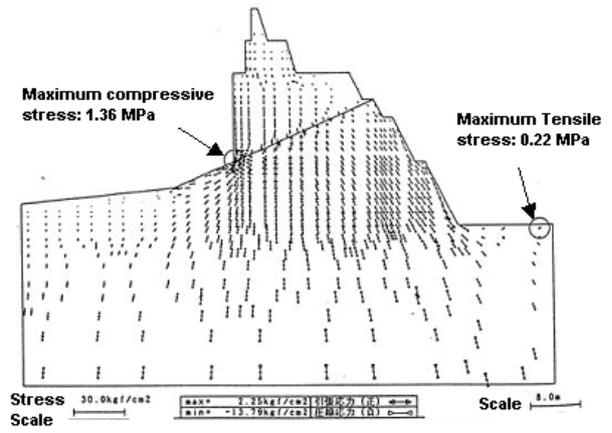
CASE-1: Aida Eq., Sea level $\pm 0.0m$ Before Paraphet Installation



CASE-5: Aida Eq., sea level $\pm 0.0m$ After Paraphet Installation



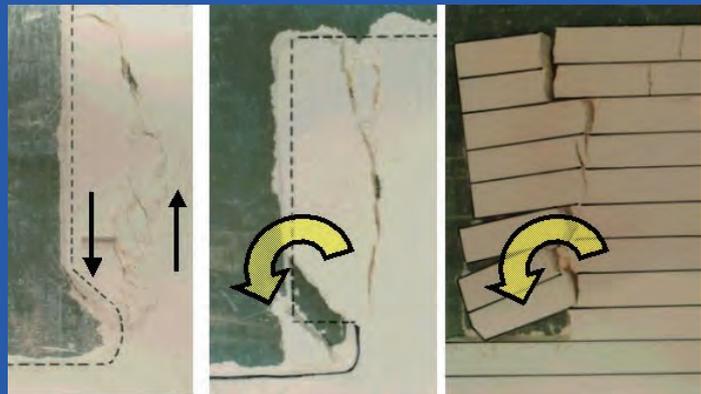
CASE-5: Aida Eq., sea level $\pm 0.0m$ After Paraphet Installation



琉球諸島における海食岸の崩壊様式と関連の問題



キャン岬海岸



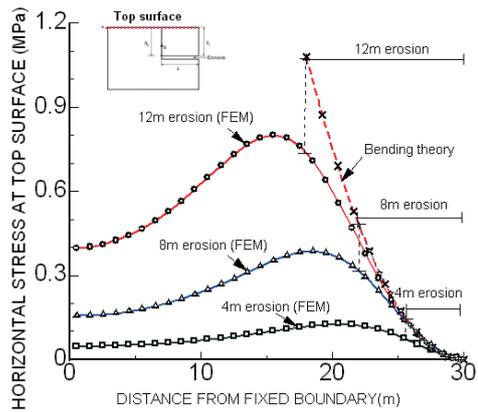
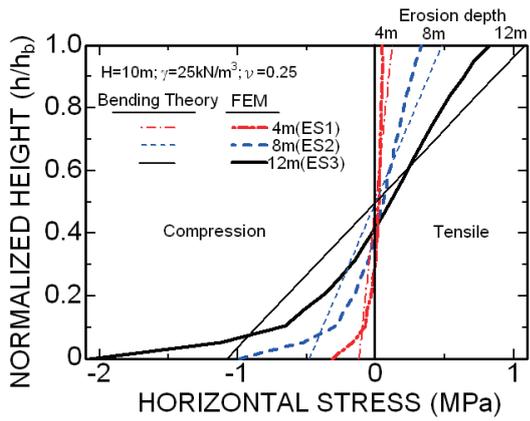
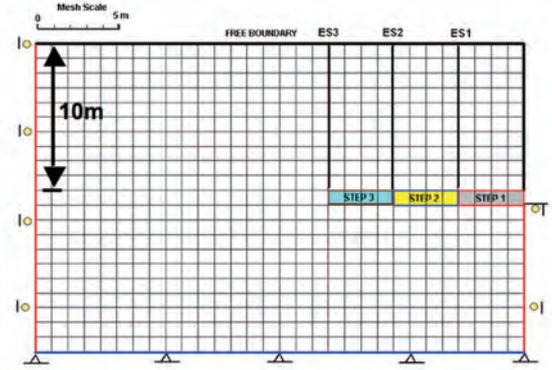
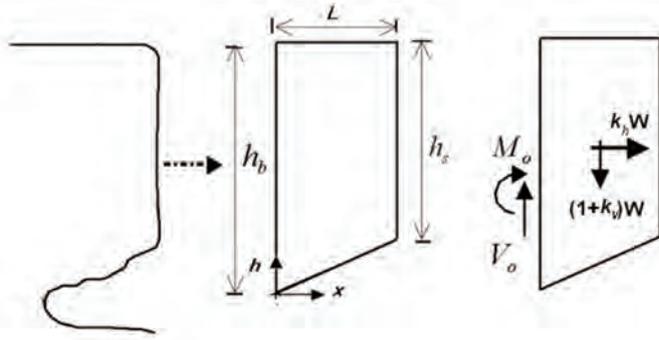
Aydan et al., 1985



Route 331 in 南城市

Tokashiki & Aydan, 2010

2D-FEM-弾性解



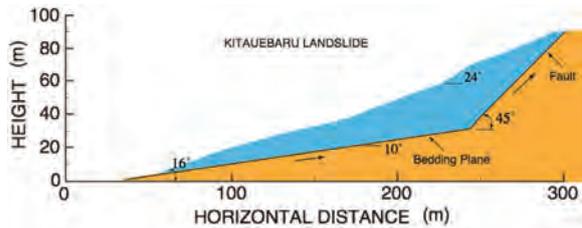
Tokashiki & Aydan, 2010

琉球諸島における地盤工学問題

島尻層泥岩斜面の崩壊事例



中城村北上原斜面崩壊(2006年)



予想すべり面

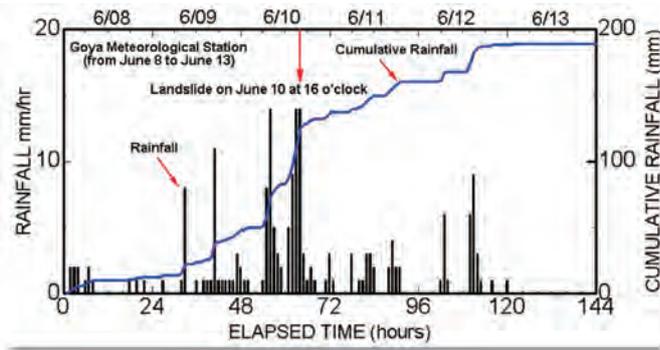


岩塊のすべりをもたらした層理面

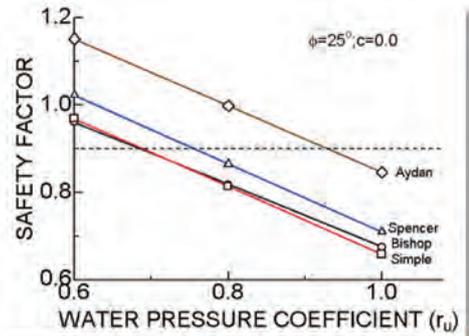
Tokashiki & Aydan, 2010

琉球諸島における地盤工学問題

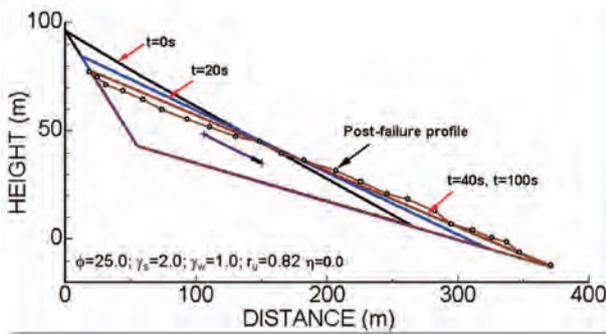
島尻層泥岩斜面の崩壊事例



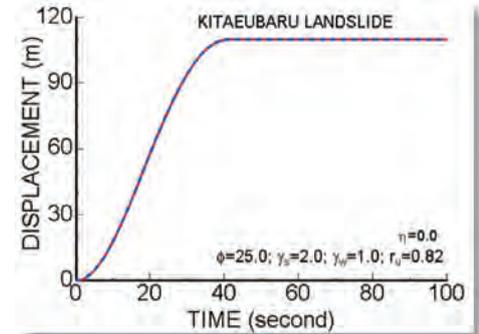
集中豪雨記録(2006年6月8日~13日)



斜面安全率



斜面崩壊後移動状況



崩壊岩塊移動距離

石積構造物の安定性と修復



首里城



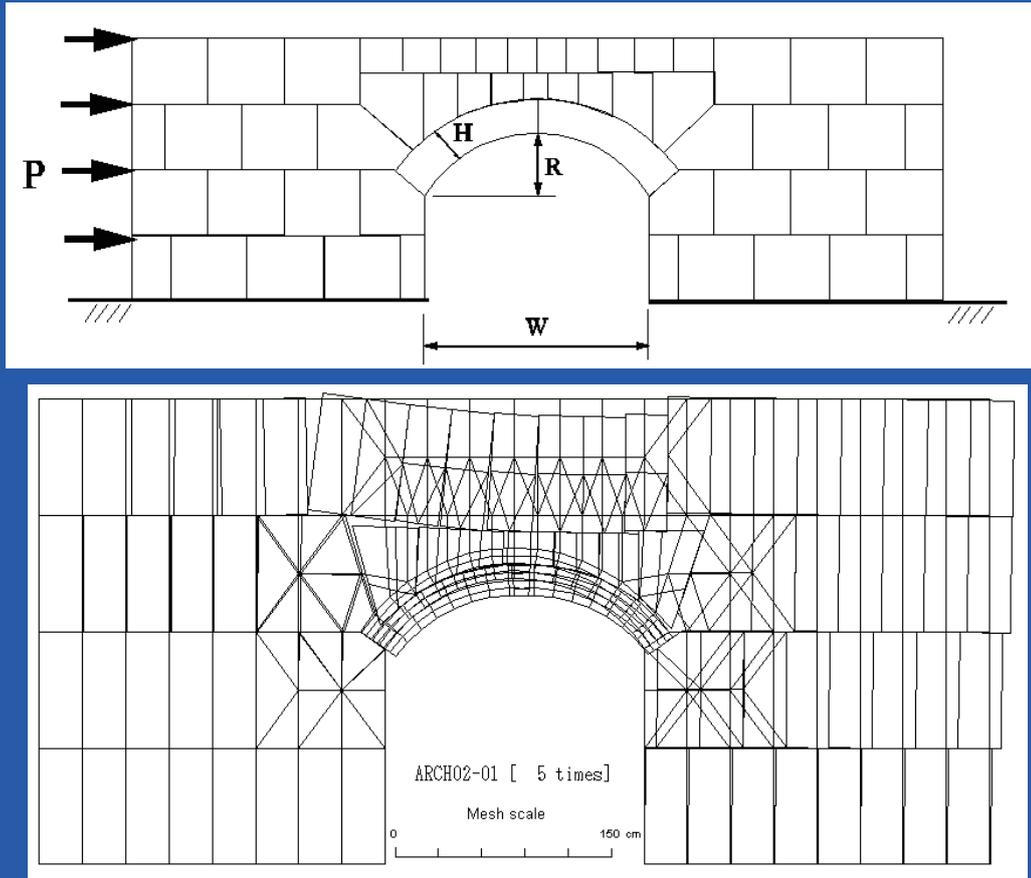
伊江殿内石橋



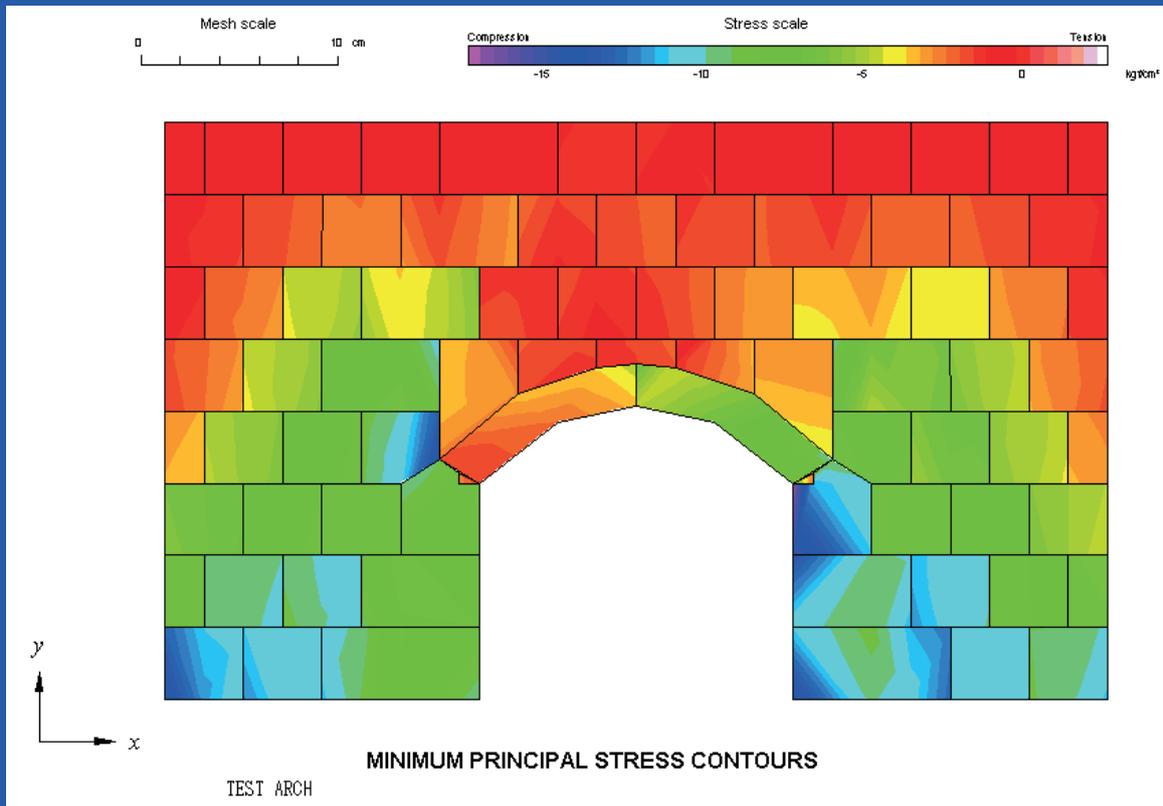
浦添ようどれ



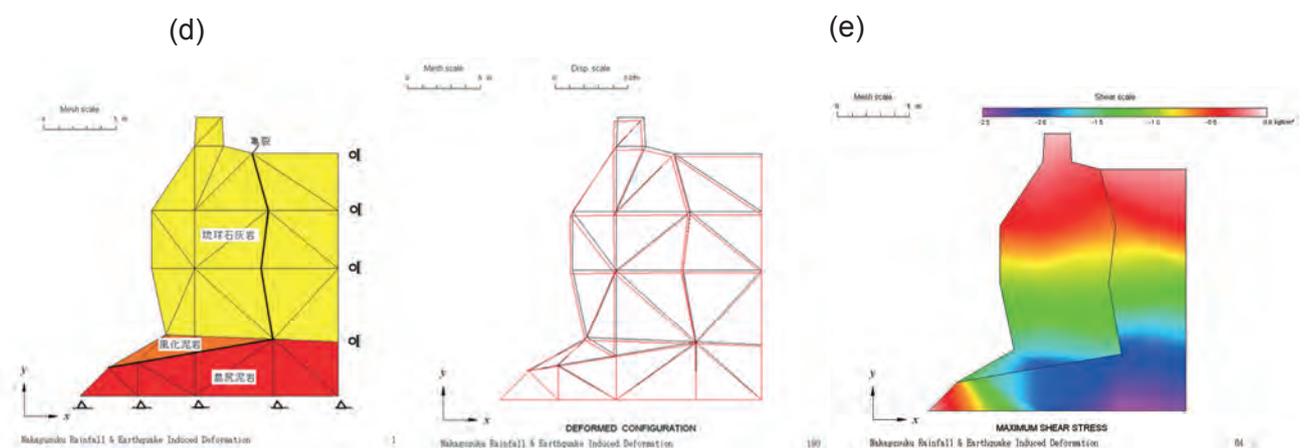
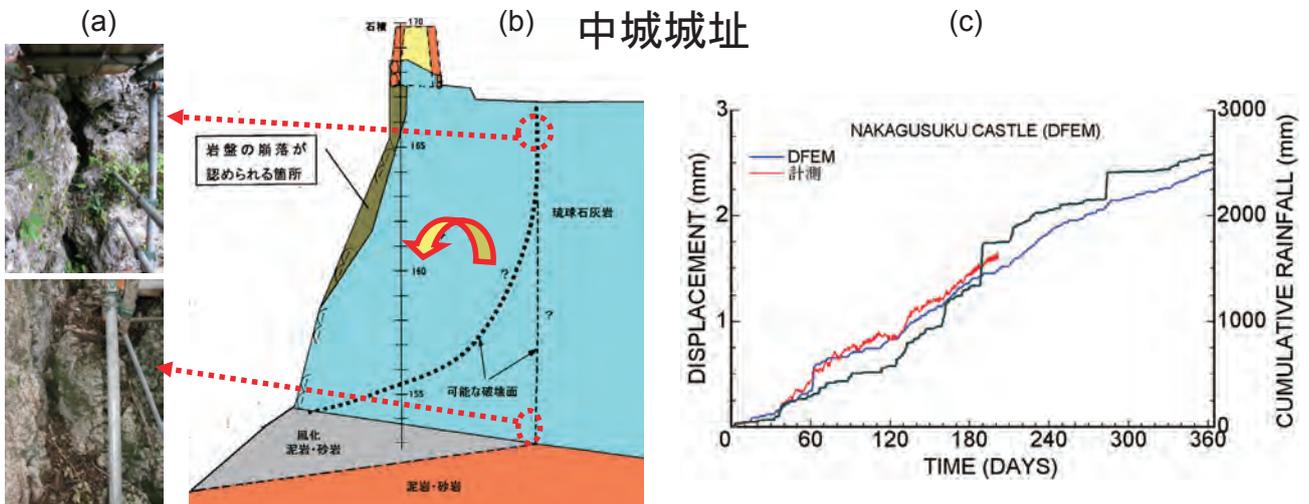
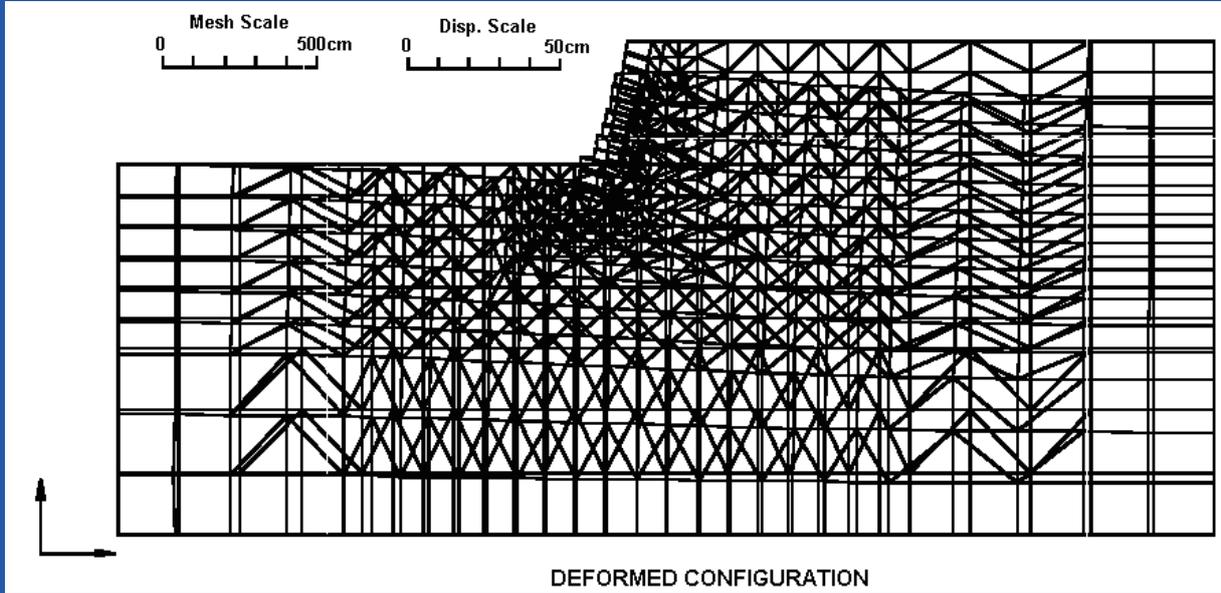
DFEMを用いてアーチ門の安定性解析



個別有限要素法(DFEM)に対するアーチ門の解析



個別有限要素法(DFEM)による石積み擁壁の安定性解析



島尻層群内空洞の短期・長期挙動－1



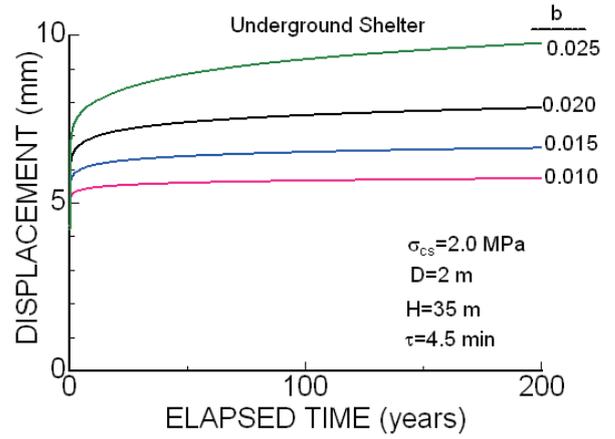
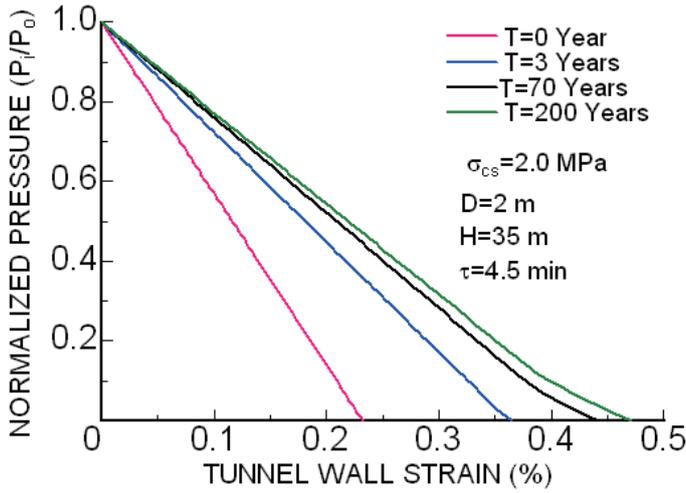
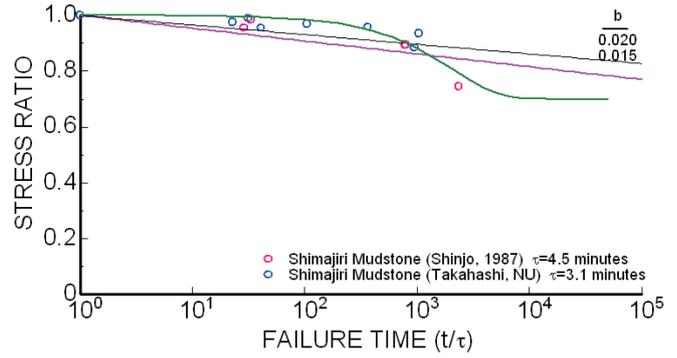
島尻層群内空洞の短期・長期挙動－2



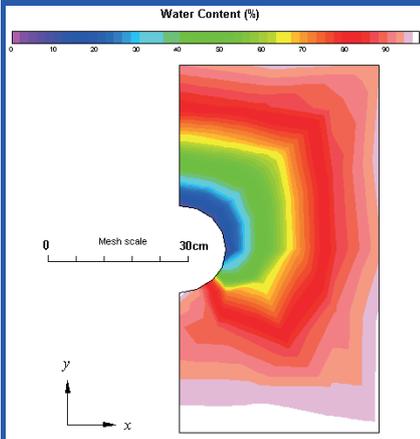
島尻層群内空洞の短期・長期挙動－3

長期的安定性の検討

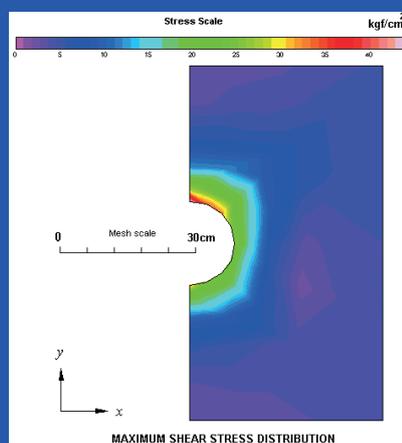
$$\frac{\sigma_c(t)}{\sigma_{co}} = 1 - b \ln(t/\tau)$$



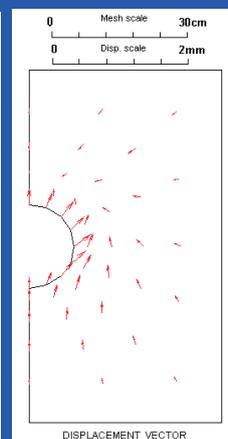
水分量の変化により空洞の安定性問題 (Aydan 2006)



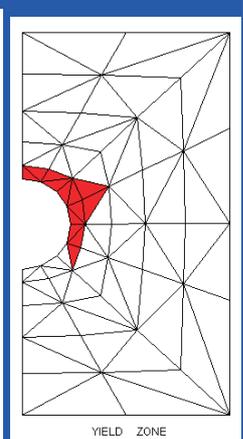
水分量の分布



最大せん断応力

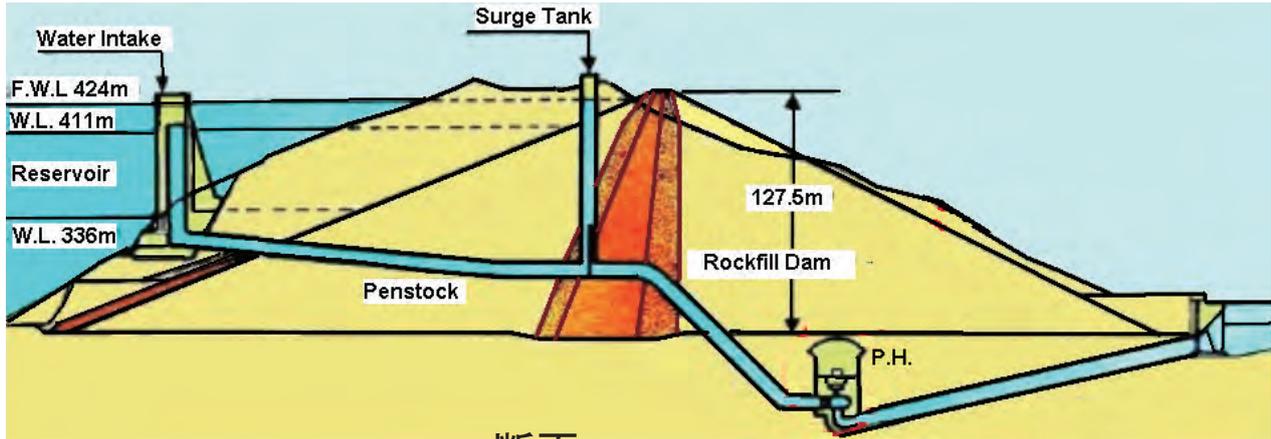


変位

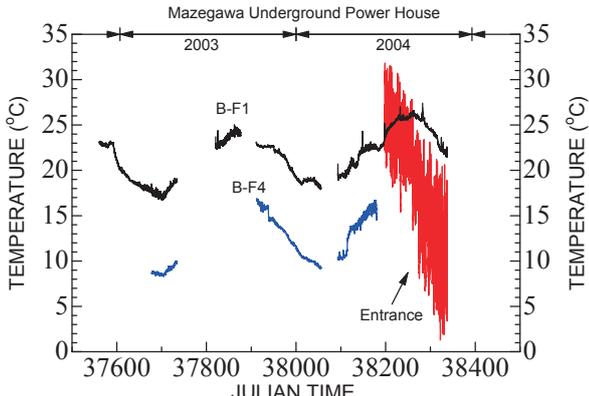


塑性域

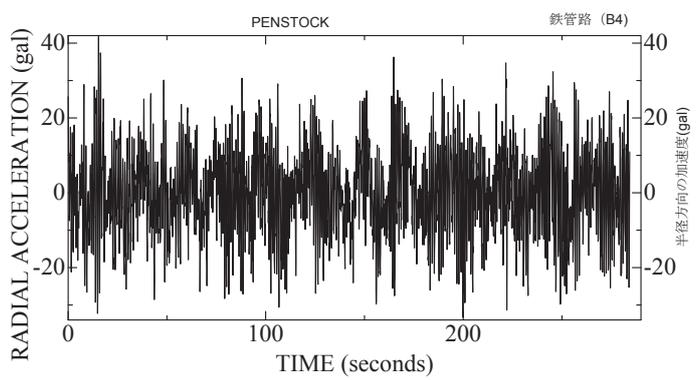
温度・浸透・振動が揚水発電所周辺の岩盤に当てる影響



断面

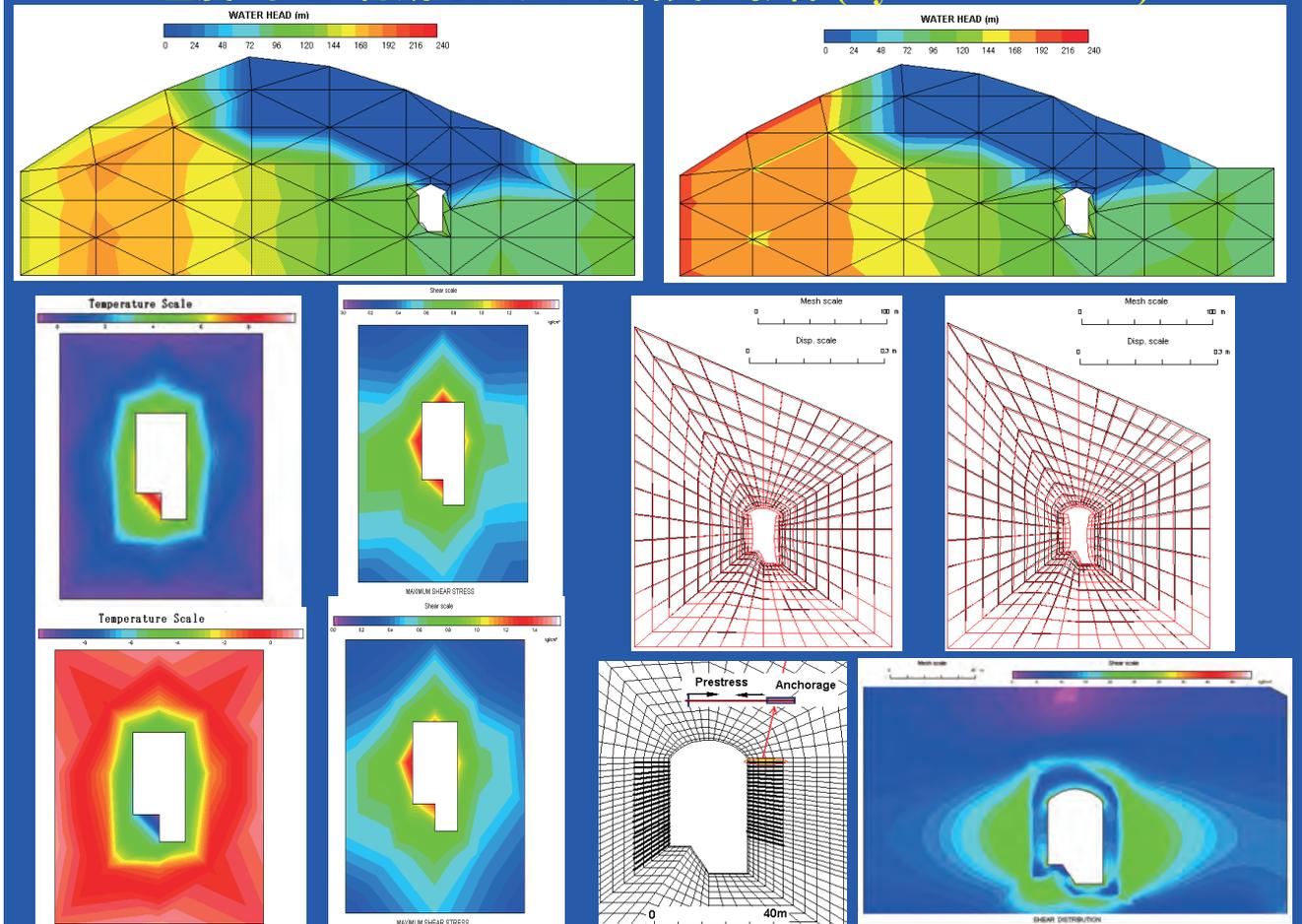


温度変化

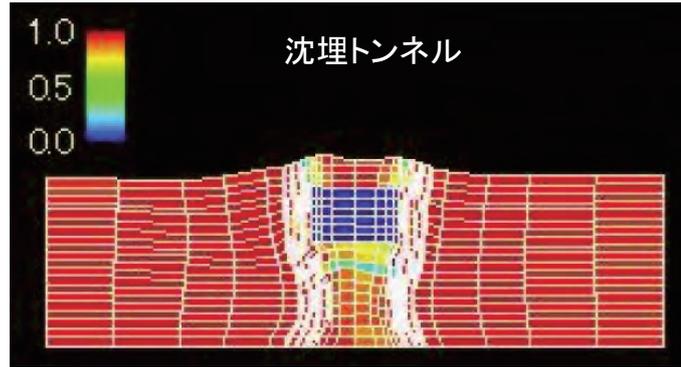


水車による振動

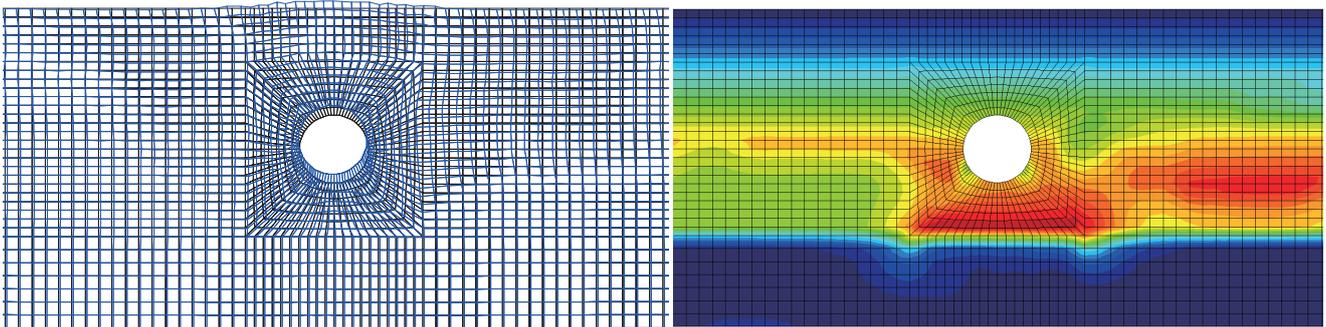
温度・水圧・初期応力および腐食の影響 (Aydan et al. 2012)



地盤の液状化



シールドトンネル



ユーロアジアトンネル(トルコ)

■ 今後の課題

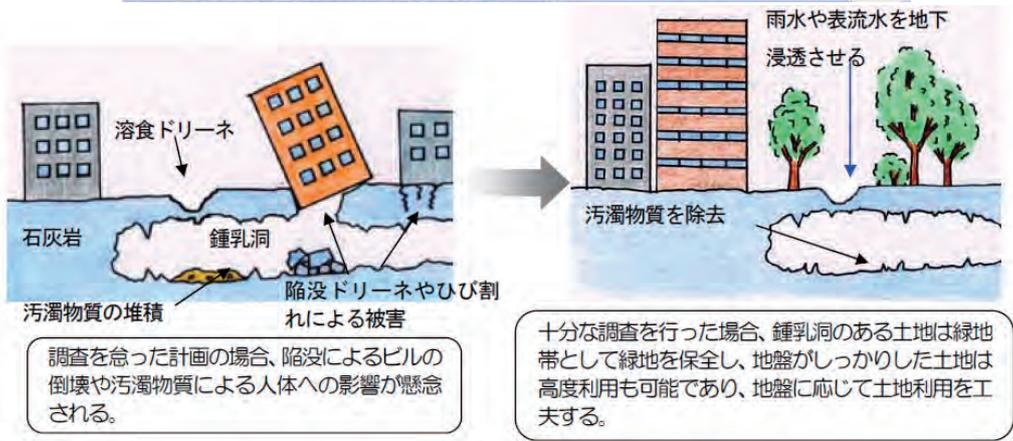
琉球石灰岩城の普天間基地の変換後の再開発の際に空洞対策は大きな課題になる。空洞調査と陥没による基礎破壊などを防ぐため空洞充てん対策が必要である。



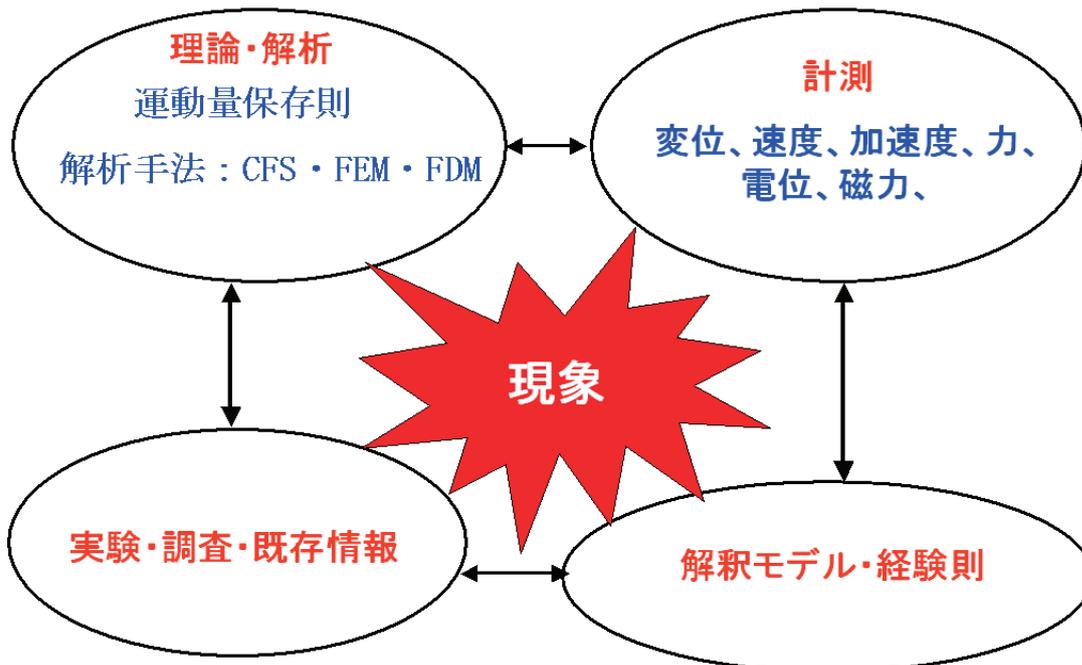
普天間基地



普天満宮内の鍾乳洞



構造物の非破壊健全性評価法



単価がやすい;信頼できる;設置・設定が簡単;自然環境に強い

従来の試験方法(リフトオフ試験)



一部の箇所
試験体の破断

非破壊的な試験方法があれば、単価が安く、数多くの
の場所で利用が可能に！

基礎式の有限要素法における定式化
弱形式化

$$\int \delta u_b \rho \frac{\partial^2 u_b}{\partial t^2} dx = \int \delta u_b \frac{\partial \sigma}{\partial x} dx + \int \delta u_b \frac{2}{r_b} \tau_b dx$$

$$\delta u_b \frac{\partial \sigma}{\partial x} = \frac{\partial}{\partial x} (\delta u_b \sigma) - \frac{\partial \delta u_b}{\partial x} \sigma$$

$$\int \delta u_b \rho \frac{\partial^2 u_b}{\partial t^2} dx + \int \frac{\partial \delta u_b}{\partial x} \sigma dx - \int \delta u_b \frac{2}{r_b} \tau_b dx = \int \delta u_b \sigma_n \Big|_{x=a}^{x=b}$$

離散化

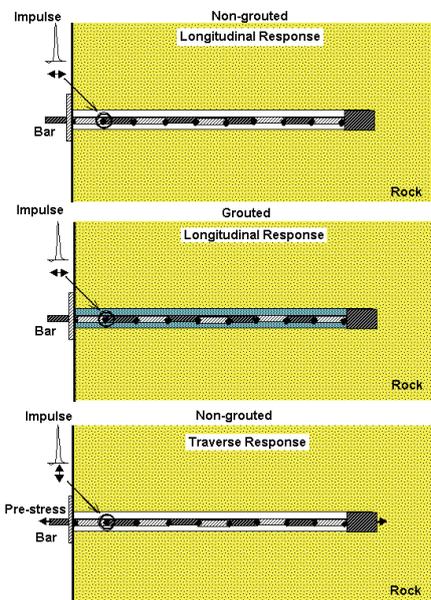
$$u_b = [N] \{U_b\} \quad a_b = \frac{\partial^2 u_b}{\partial t^2} = [N] \{\ddot{u}_b\}$$

$$\epsilon_b \frac{\partial u_b}{\partial x} = \frac{\partial}{\partial x} ([N(x)] \{u_b\}) = [B] \{u_b\}$$

$$[M_e] \{\ddot{u}_b\} + [C_e] \{\dot{u}_b\} + [K_e] \{u_b\} = \{f_e\}$$

$$[M_e] = \int \rho [N]^T [N] dx \quad [C_e] = \int \eta [B]^T [B] dx$$

$$[K_e] = \int E [B]^T [B] dx - \int \frac{2Kg}{r_b} [N]^T [N] dx$$

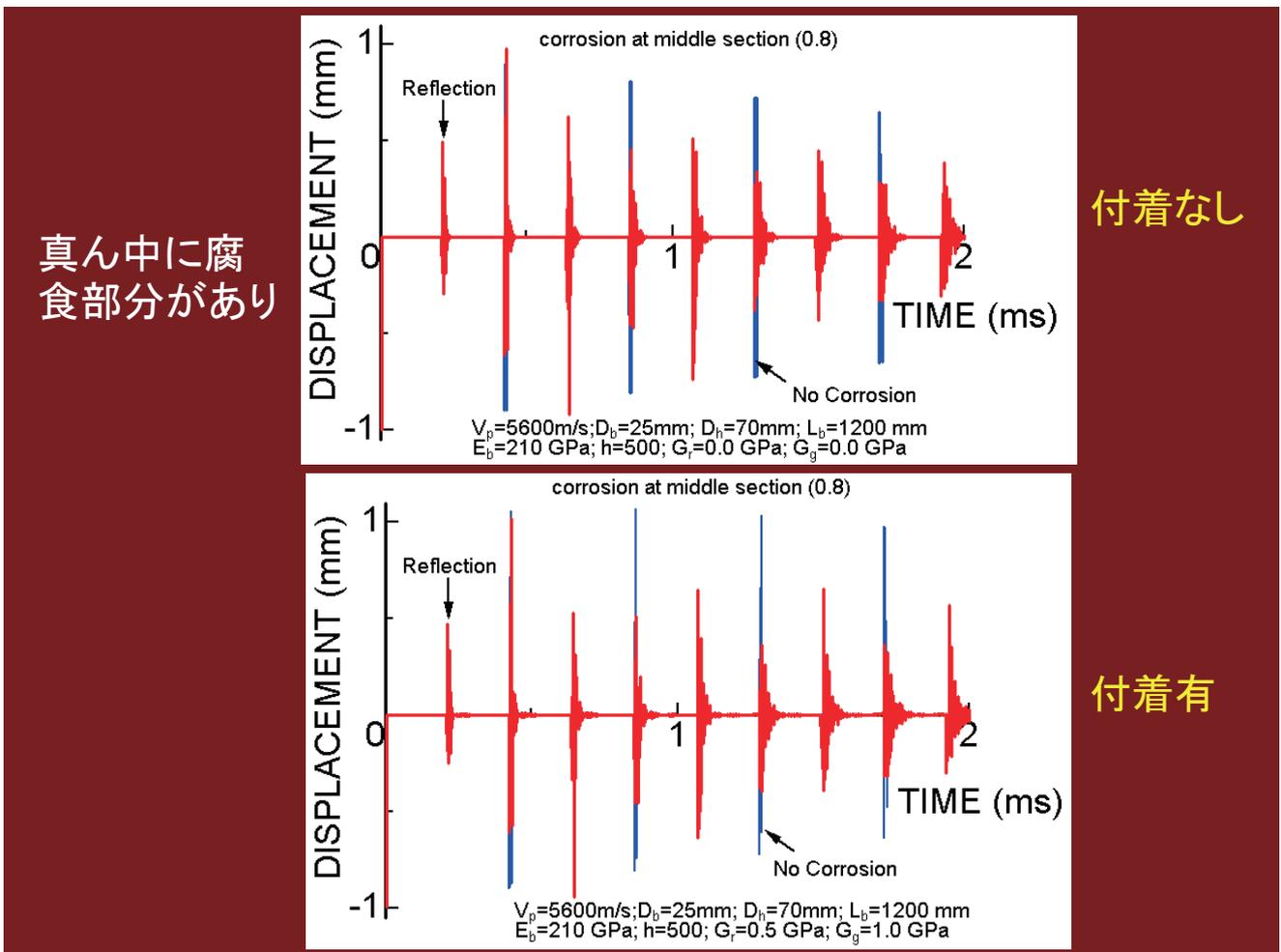
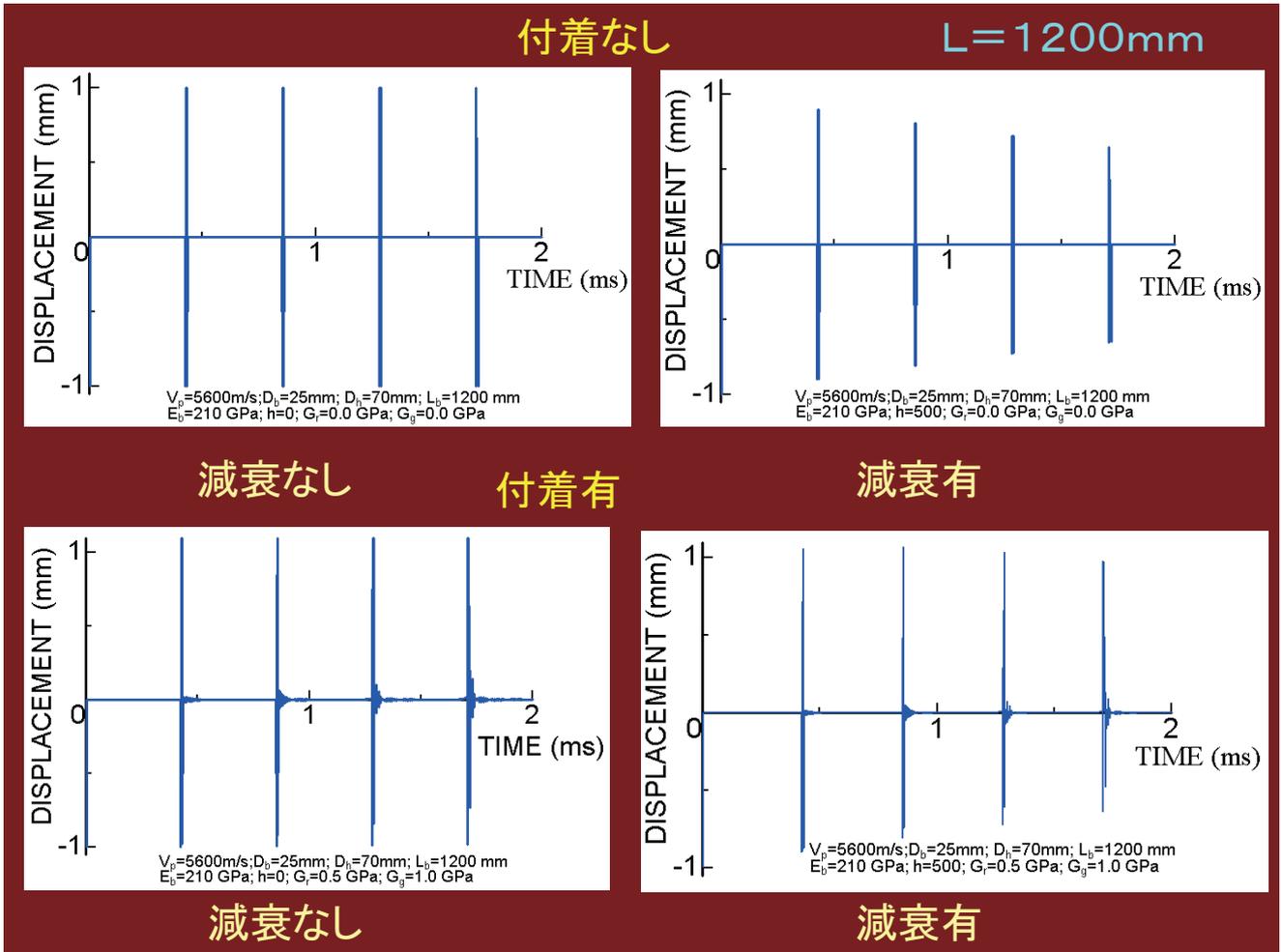


長軸直行直行方向の定式化

$$[M_e] \{\ddot{v}_b\} + [T_e] \{v_b\} = \{t_e\}$$

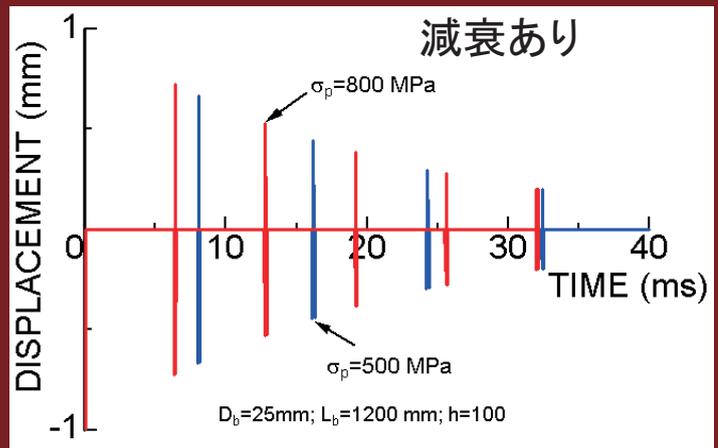
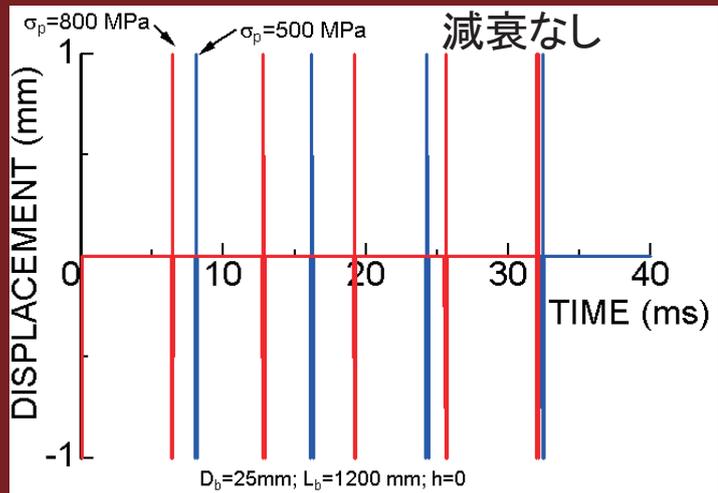
$$[M_e] = \int \rho [N]^T [N] dx$$

$$[T_e] = \int \frac{T}{A} [B]^T [B] dx$$

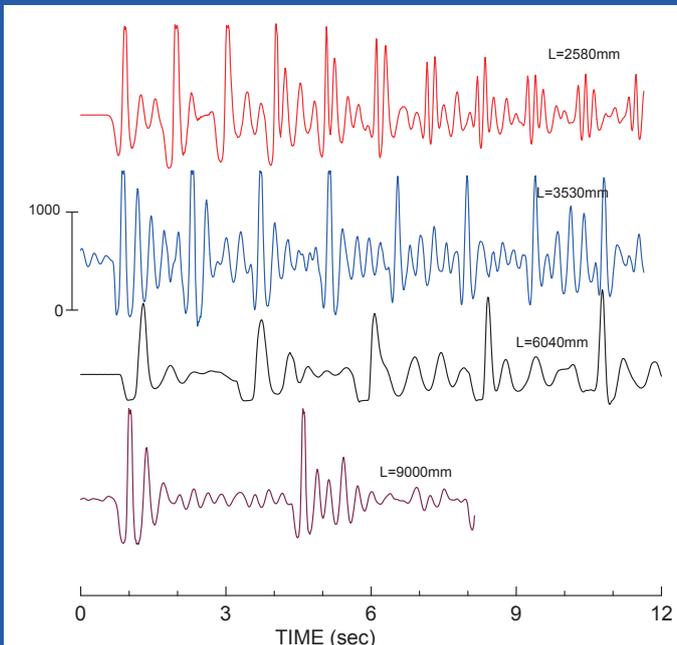
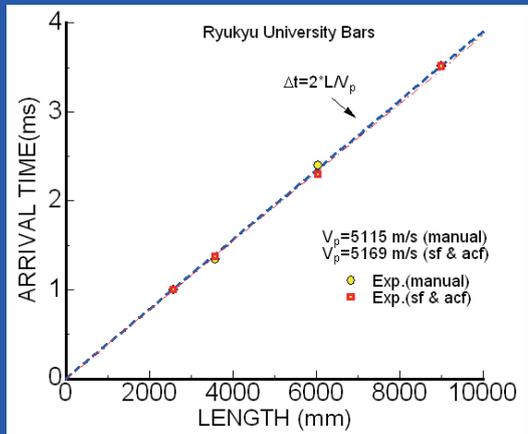
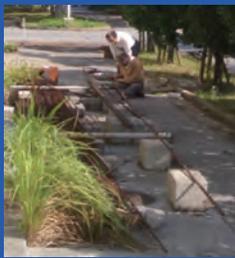


真ん中に腐食部分があり

導入力の影響



マニュアル的読み取り手法とSF-ACF法



$$\Delta t = \frac{2}{V_p} L \quad \text{縦波速度 : 5115m/s}$$

鉄筋棒の縦波速度 : 5500-5900 m/s)

$$\alpha = 1 - \left(\frac{v_p^*}{v_p^o} \right)^2$$

腐食断面率 : 14-25%

2019 Rock Dynamics Summit

A Specialized Symposium of ISRM

3-4-5 April, 2019
Okinawa, JAPAN

Organized by
JSCE-Rock Dynamics Committee of Japan
Japanese Rock Mechanics Society

To be held in **Bankoku Shinryokan** where 2000 Kyushu-Okinawa G-8 Summit was hosted

地盤変形・トンネル分野

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