reluis

SETTIMANA NAZIONALE DELLA PROTEZIONE CIVILE

PROMOSSA DA

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

SEISMIC BEHAVIOUR OF RETAINING STRUCTURES: FROM FUNDAMENTALS TO PERFORMANCE-BASED DESIGN

Giulia VIGGIANI University of Cambridge

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SEISMIC BEHAVIOUR OF **YIELDING** RETAINING STRUCTURES: FROM FUNDAMENTALS TO PERFORMANCE-BASED DESIGN

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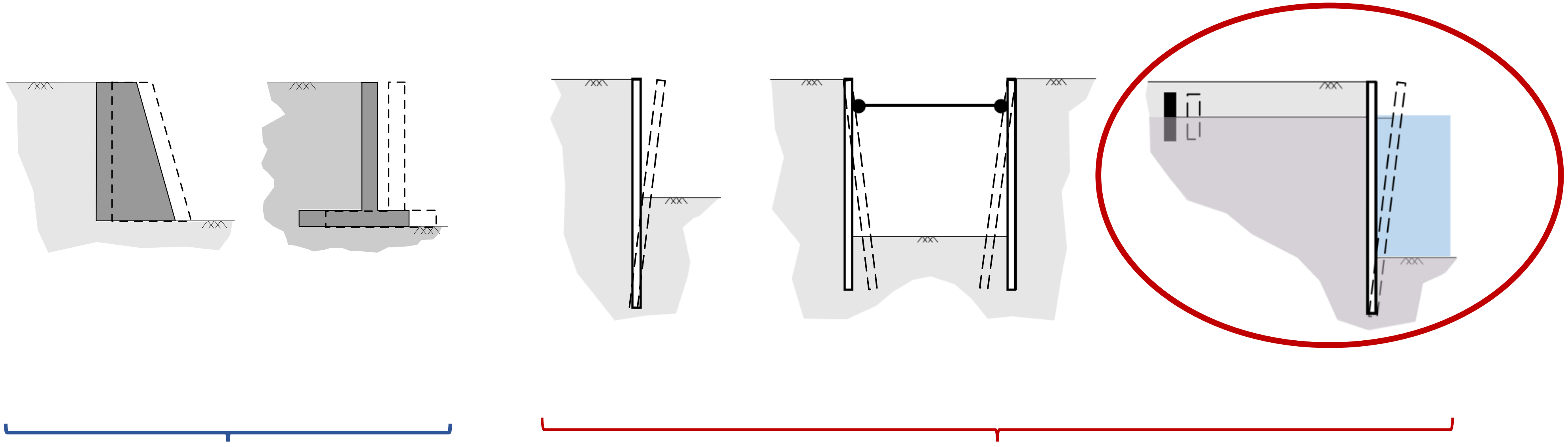
YIELDING (DUCTILE) RETAINING STRUCTURES

tied-back anchored steel sheet pile (ASSP) walls

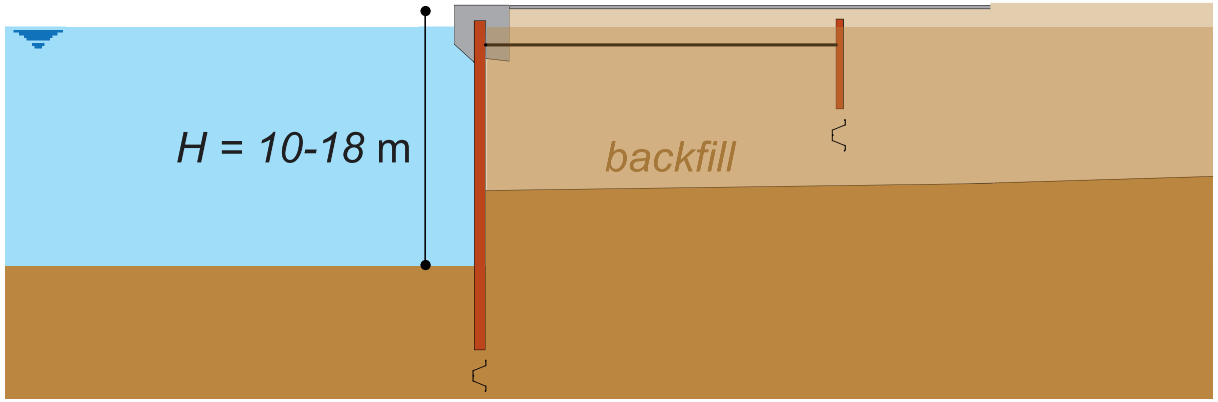


gravity/semi-gravity walls

embedded (flexible) walls

(instantaneous) mobilisation of strength $\not\Rightarrow$ collapse

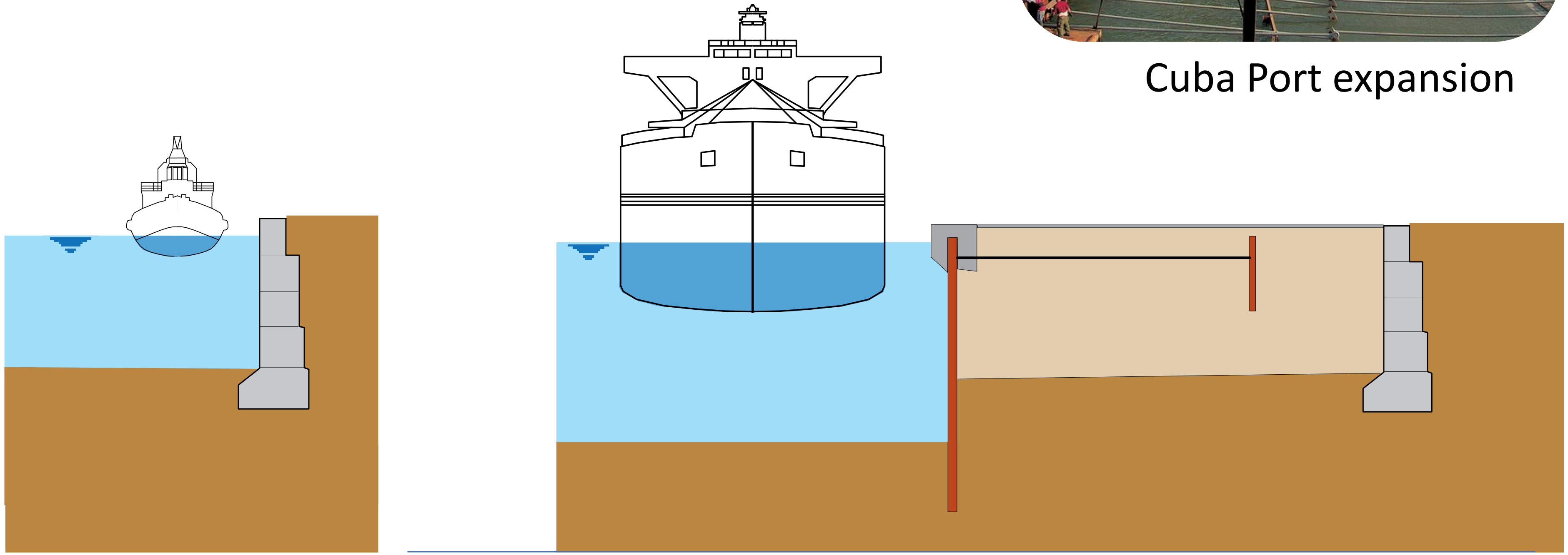
QUAY WALLS



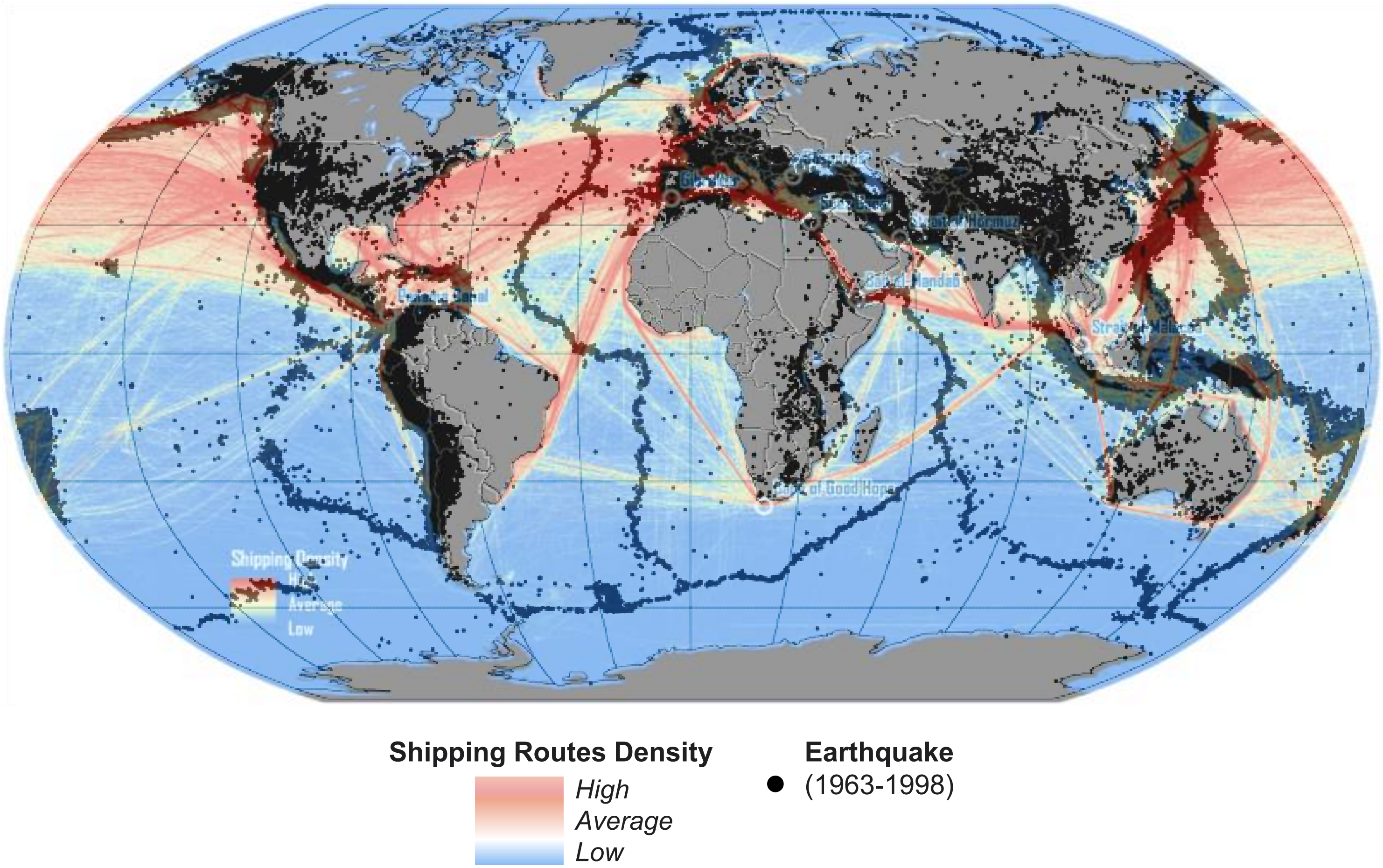
QUAY WALLS

increased vessel size and draft

Cuba Port expansion



SEISMIC VULNERABILITY



OBSERVED DAMAGE

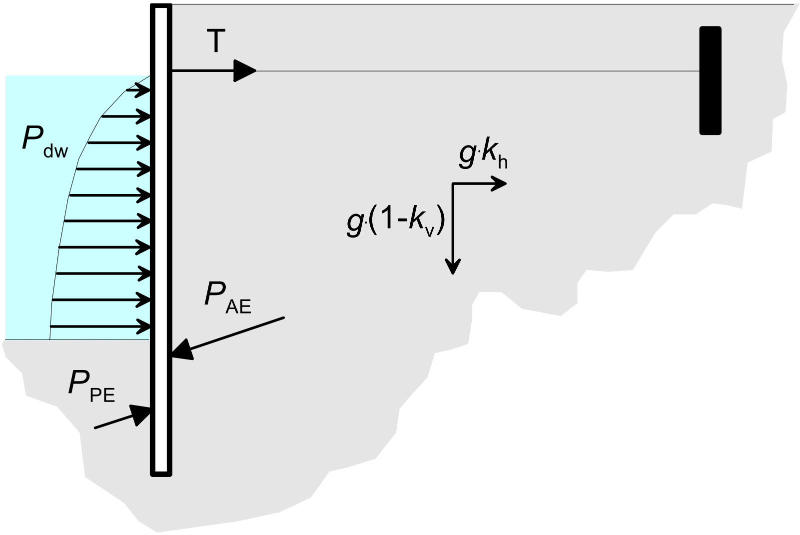

Hyogo-ken Nanbu earthquake (1995)


Tohoku earthquake (2011)


Hokkaido-Nansei-Oki earthquake (1993)


Tohoku earthquake (2011)

CONVENTIONAL SEISMIC DESIGN



simplified analysis

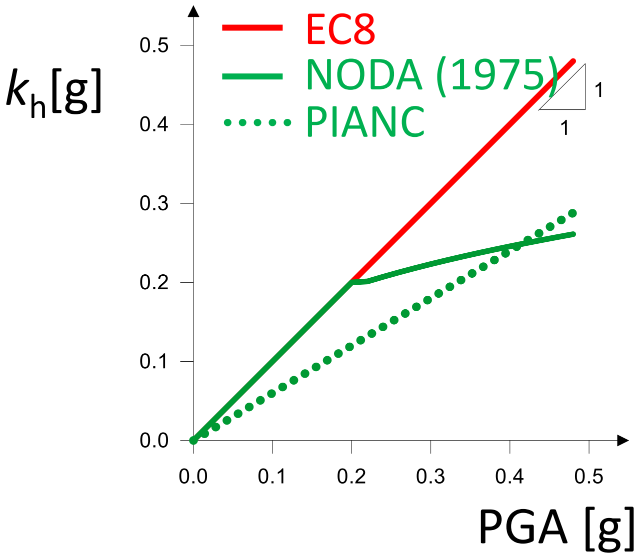
pseudo-static approach

equivalent seismic coefficient ∝PGA

limit conditions (active/passive) in the soil

pseudostatic forces ($k_{h,v}$ constant in time and space) equivalent to dynamic inertia forces:

$$F_h = k_h g \cdot m = k_h W$$
$$F_v = k_v g \cdot m = k_v W$$



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simplified analyses

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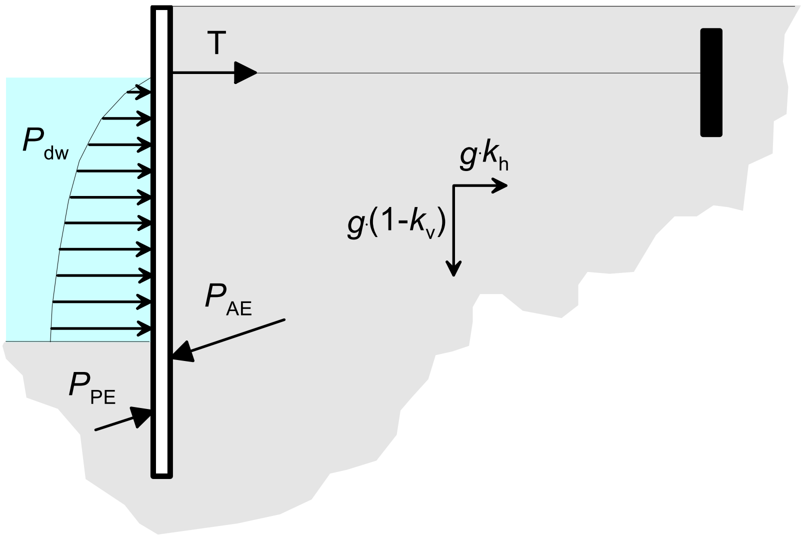
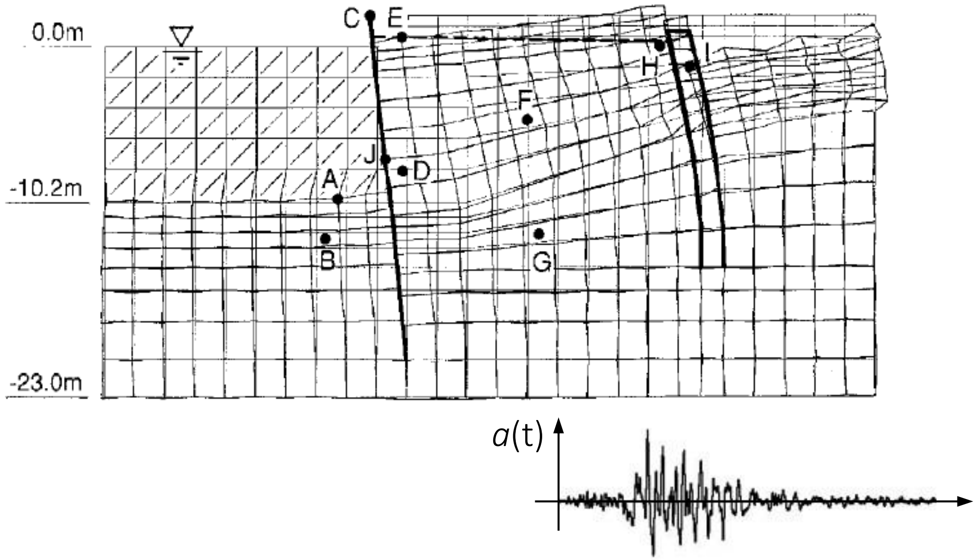


advanced numerical analyses

FEM/FDM

time domain

advanced constitutive models



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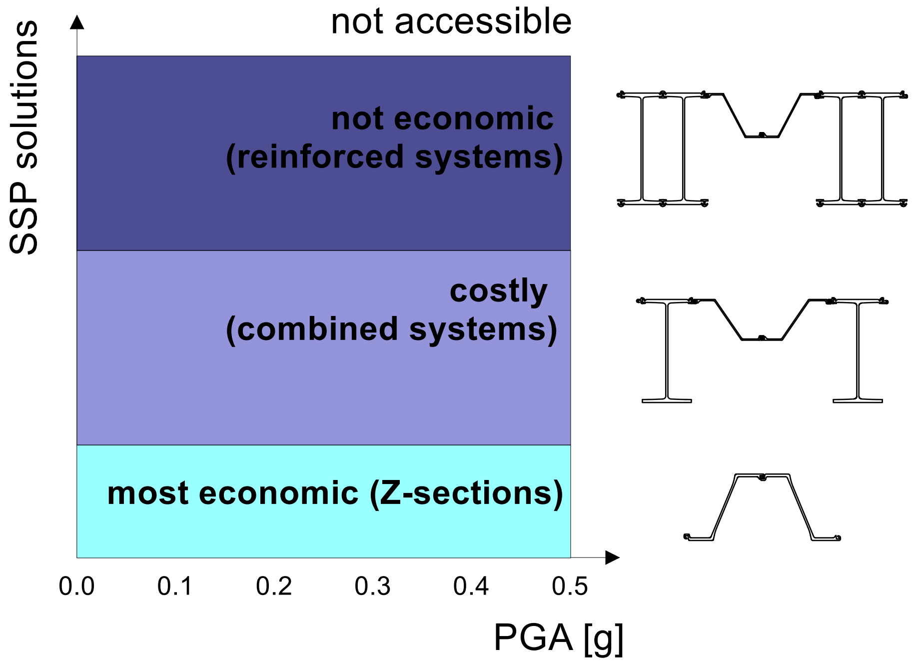

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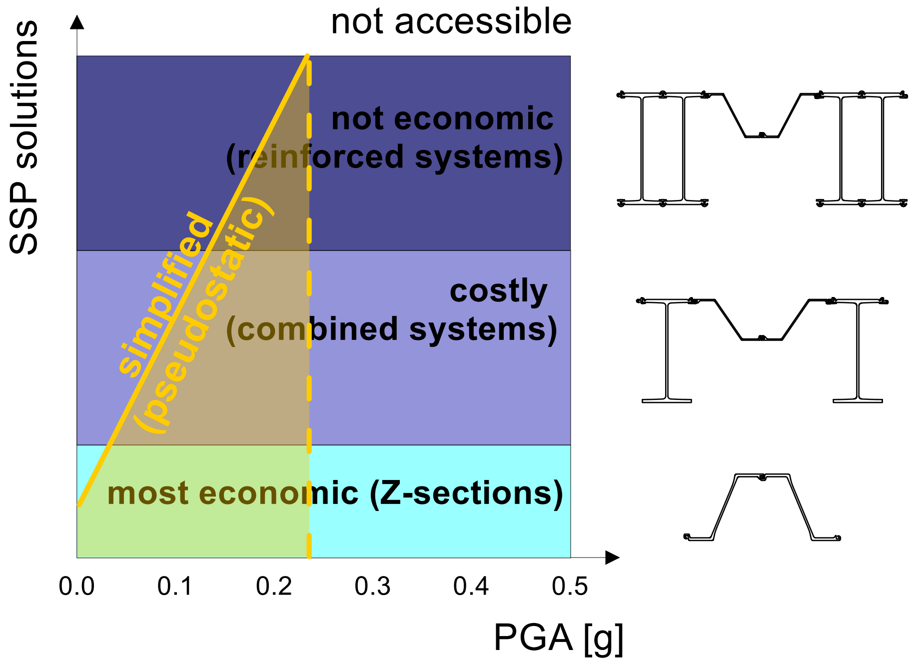

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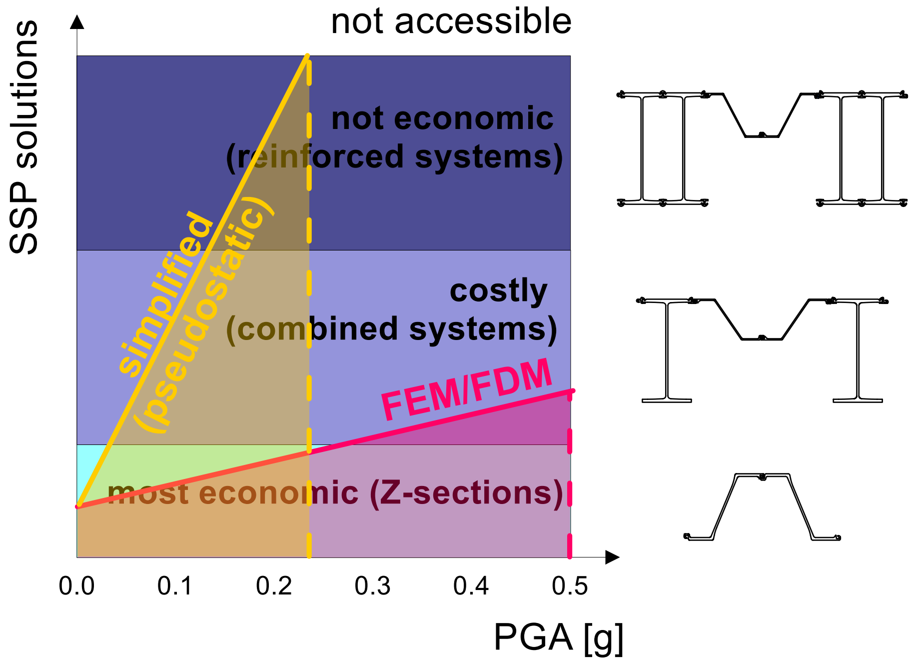


alternative (PBD) approach

PERFORMANCE BASED SEISMIC DESIGN

demand ≤ capacity

LIMIT STATE	REQUIREMENT
serviceability (SLS) frequent/weak earthquakes	limit deformations stiffness/strength
ultimate (ULS) rare/strong earthquakes	avoid brittle failure ductility/strength

strength
(seismic capacity)

performance
(seismic demand)

permanent displacement
(geotechnical design)

capacity/demand ratio structural elements
(structural design)

PERFORMANCE BASED SEISMIC DESIGN

displacement based approach

$$\boxed{u \leq u_{adm}}$$

force based approach

$$\boxed{\beta \cdot a_{max} \leq a_c}$$

critical acceleration, a_c
full mobilisation of strength

PERFORMANCE BASED SEISMIC DESIGN

displacement based approach

$$u \leq u_{adm}$$

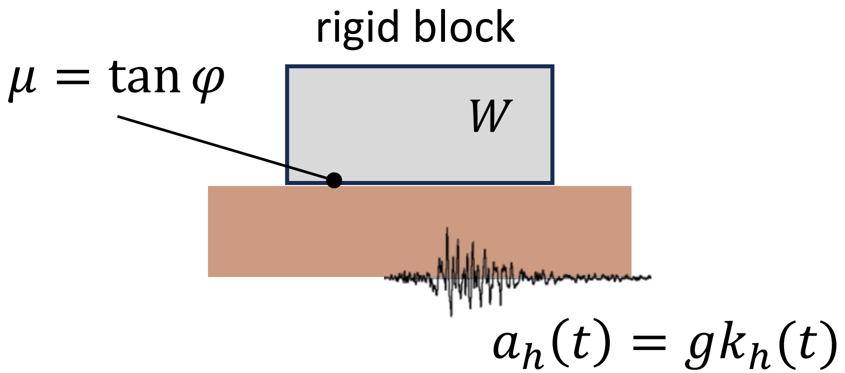
force based approach

$$\beta(u_{adm}) \cdot a_{max} \leq a_c$$

critical acceleration, a_c

full mobilisation of strength

NEWMARK'S APPROACH



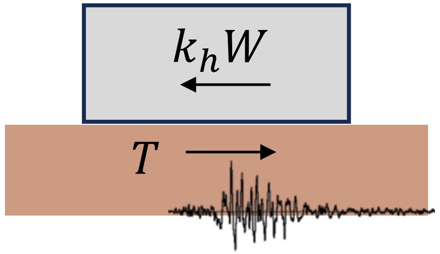
NEWMARK'S APPROACH

$a_h < a_c$

relative displacement $u_\mathrm{r} = 0$

absolute acceleration $a = a_h$

internal force $T = k_h W$



$a_h(t) < a_c$

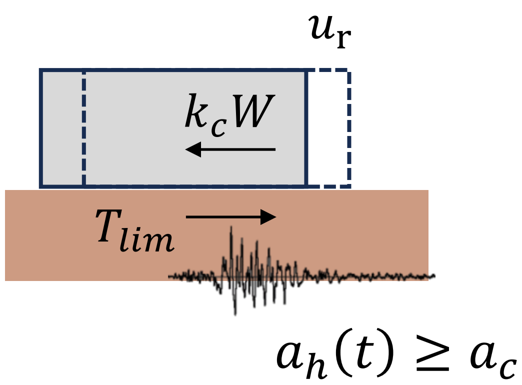
NEWMARK'S APPROACH

$a_h \geq a_c$

relative displacement $u_r \neq 0$

absolute acceleration $a_h = a_c$

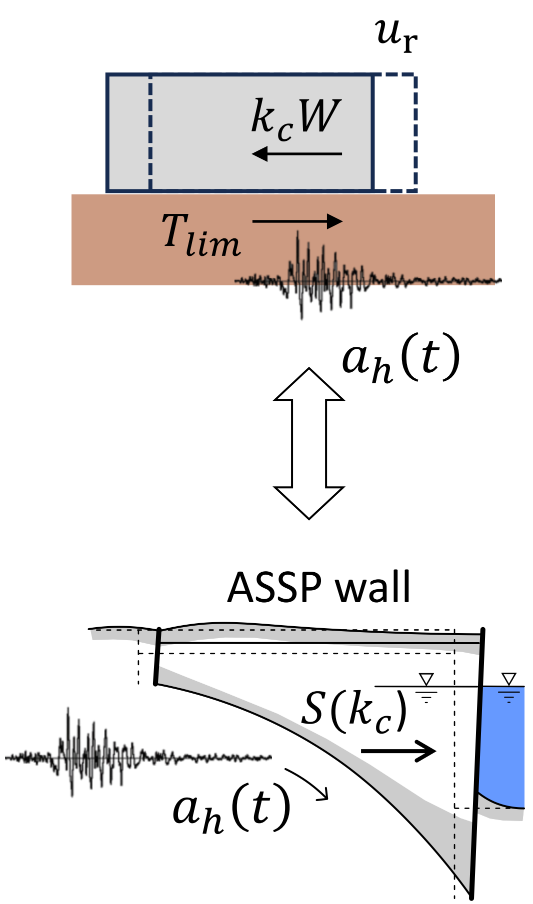
internal force $T = T_{lim}(a_c)$



$$u_r = -\eta \iint [a_h(t) - a_c]\, dt^2$$

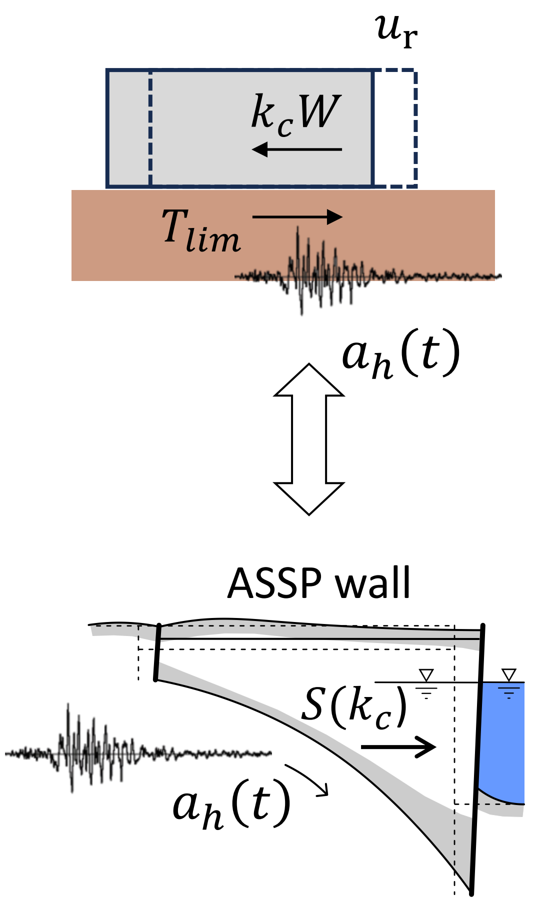
NEWMARK'S APPROACH

1. How to compute a_c?
   what failure mechanism(s)?



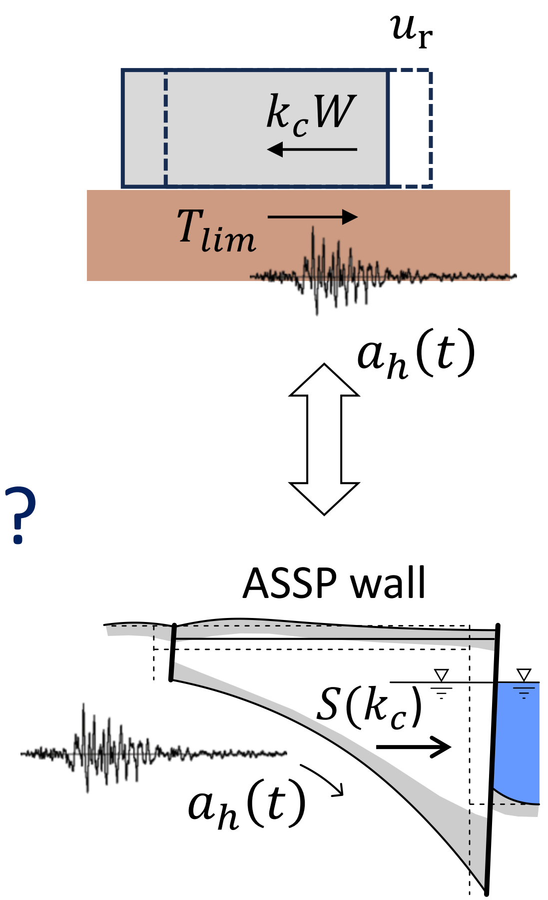
NEWMARK'S APPROACH

1. How to compute a_c?
   (what failure mechanism?)
2. Maximum internal forces?
   (really bounded by their critical values?)

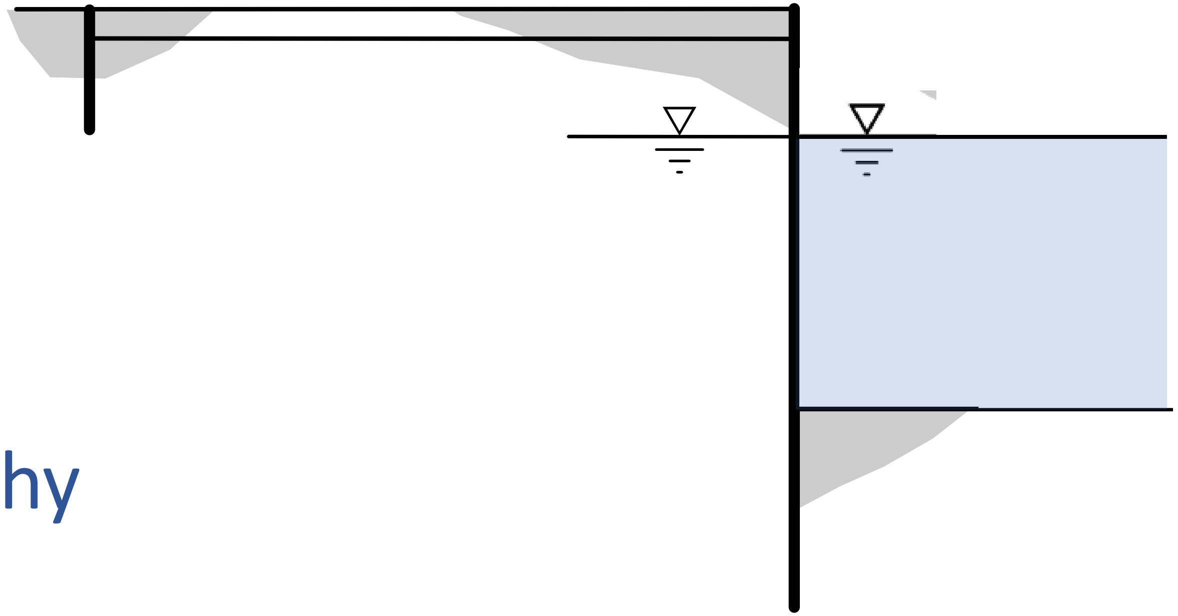


NEWMARK'S APPROACH

1. How to compute a_c?
   (what failure mechanism?)
2. Maximum internal forces?
   (really bounded by their critical values?)
3. How to compute permanent displacements?
   (rigid block assumption reasonable?)



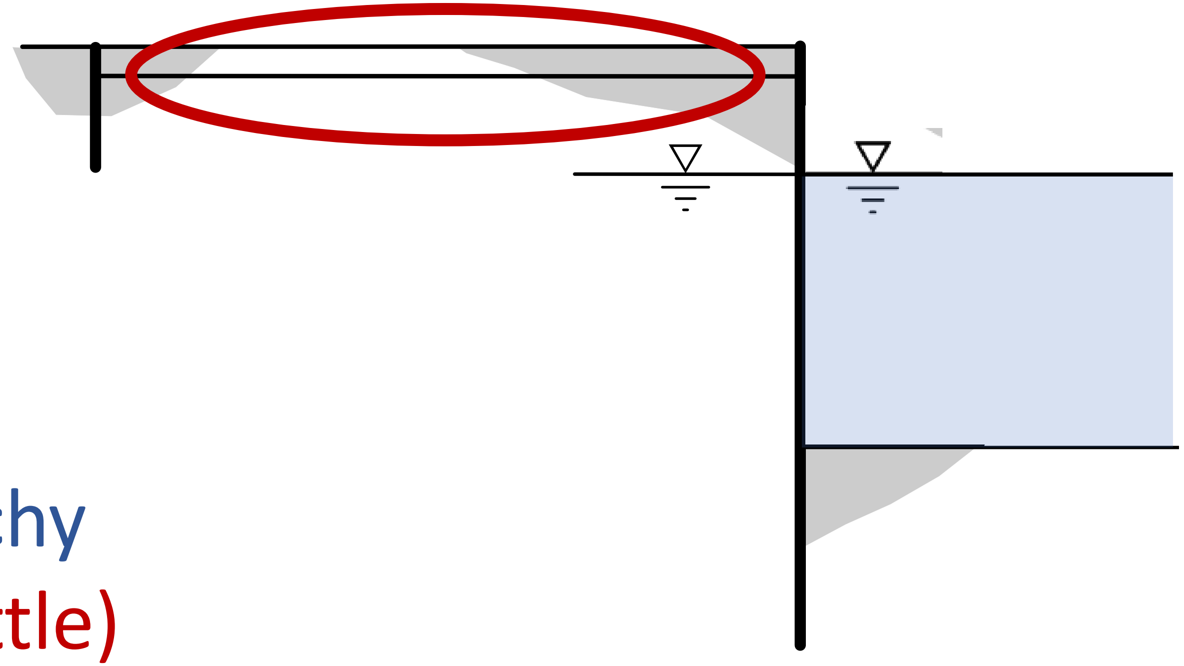
PLASTIC MECHANISMS



strength hierarchy

- tie-backs
- main wall
- soil

PLASTIC MECHANISMS



strength hierarchy

- tie-backs (brittle)
- main wall
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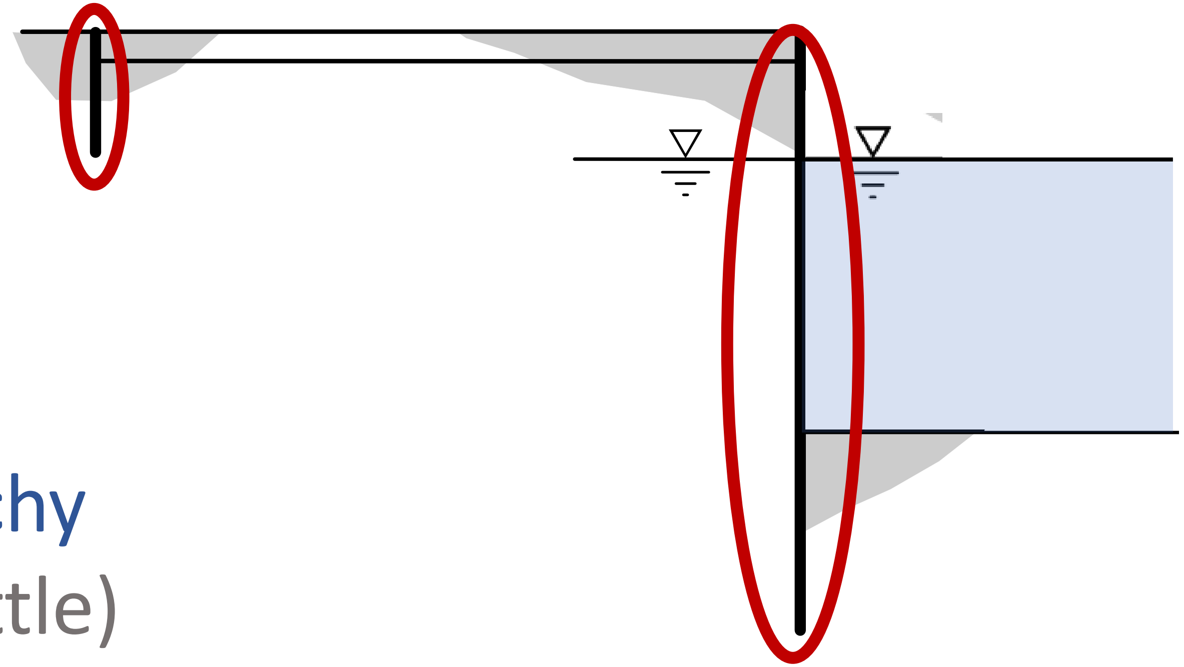
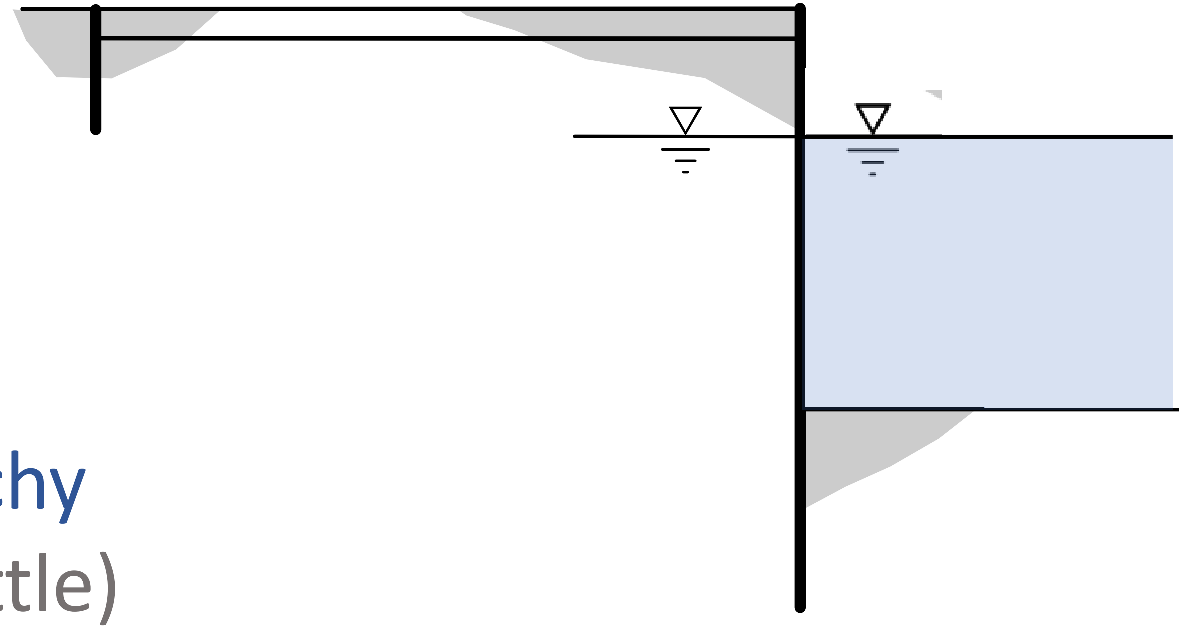
PLASTIC MECHANISMS



strength hierarchy

- tie-backs (brittle)
- wall (difficult to repair)
- soil

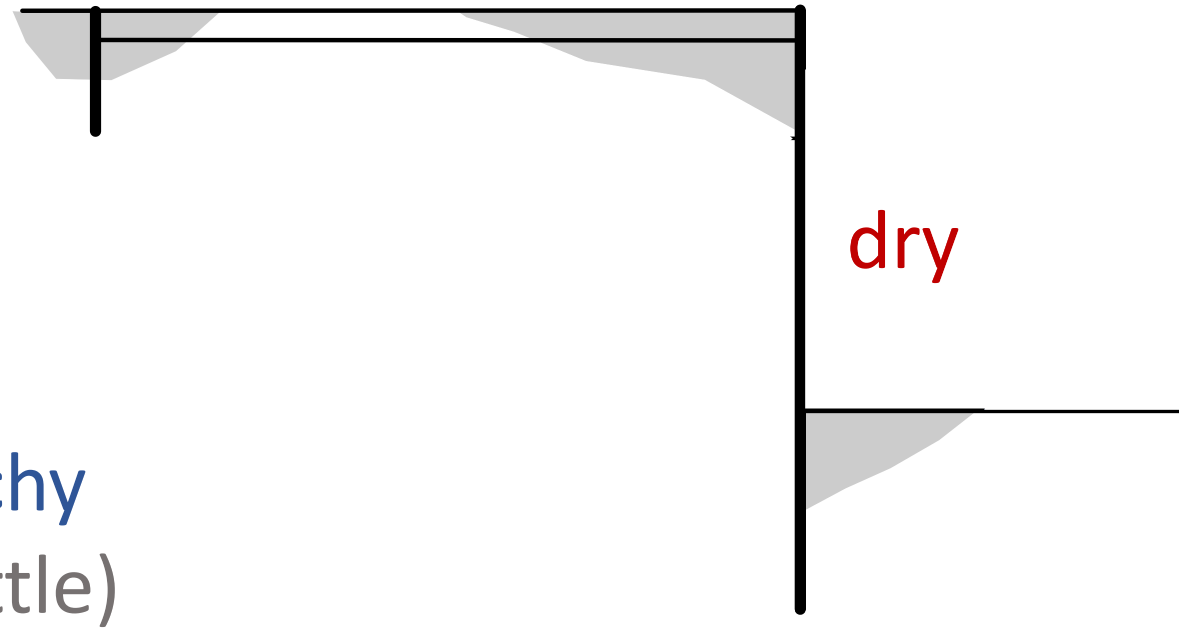
PLASTIC MECHANISMS



strength hierarchy

- tie-backs (brittle)
- wall (difficult to repair)
- **soil**

PLASTIC MECHANISMS



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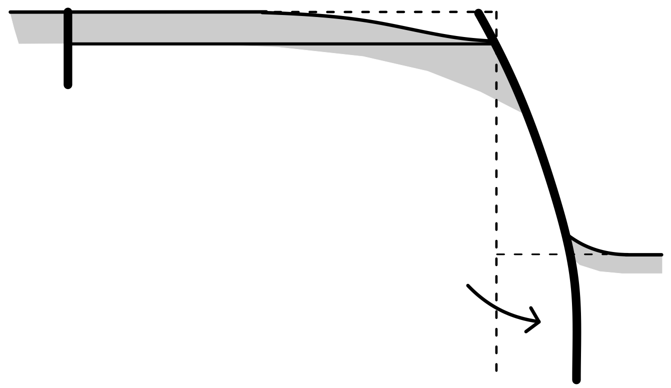
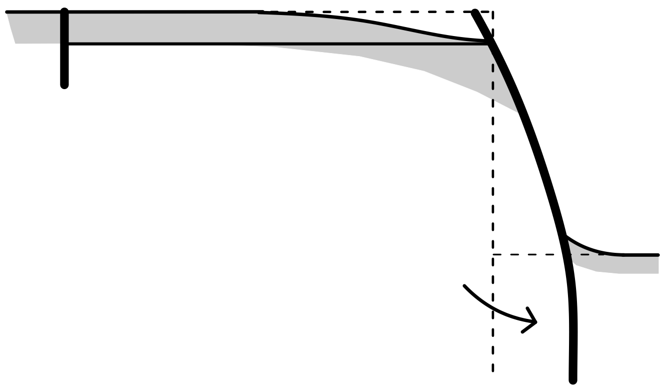


toe failure

PLASTIC MECHANISMS



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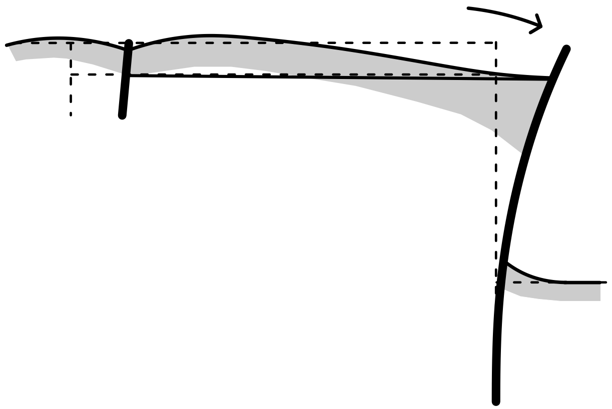
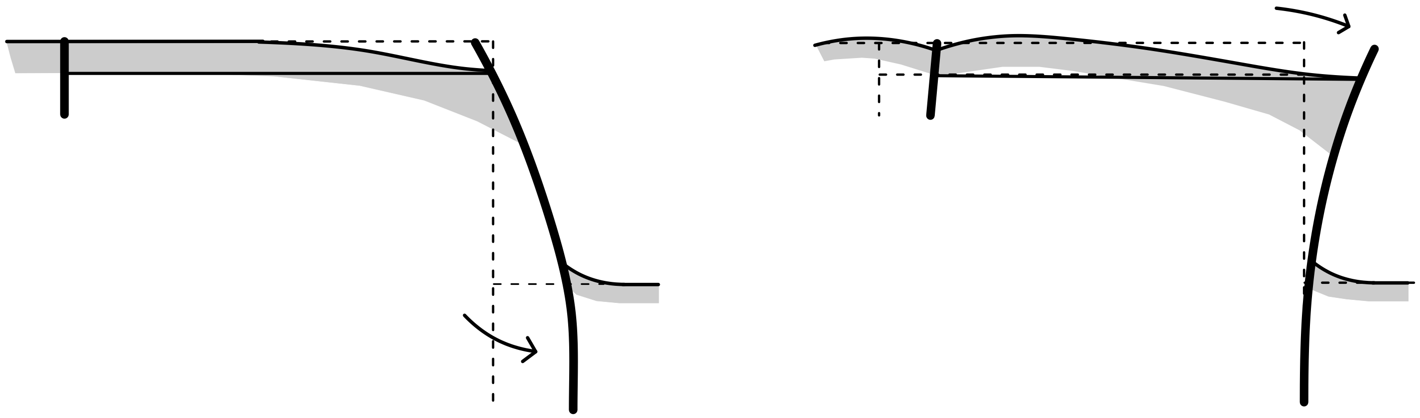


anchor failure

PLASTIC MECHANISMS



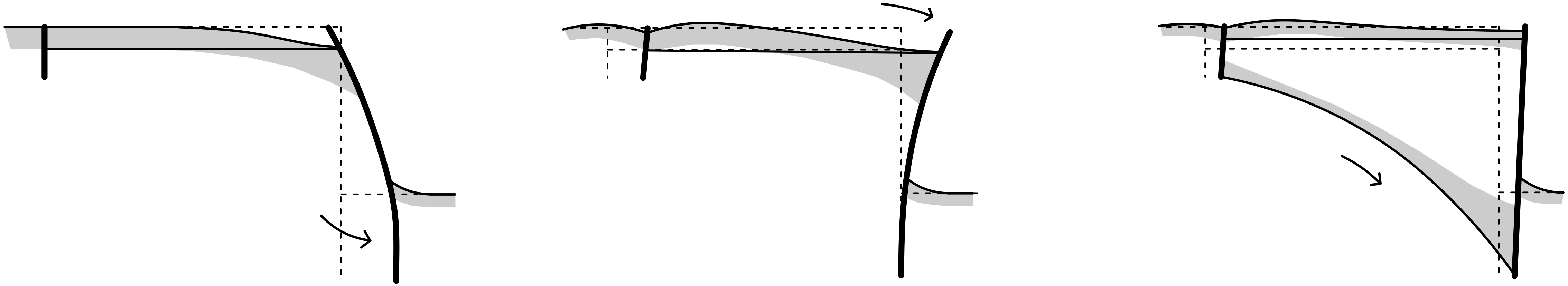
toe failure

anchor failure

local failure

PLASTIC MECHANISMS

critical mechanism?



toe failure

anchor failure

global failure

local failure

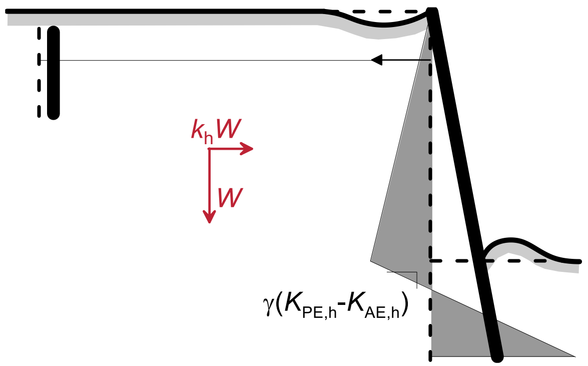
PLASTIC MECHANISMS

critical acceleration

limit equilibrium (pseudo-static)

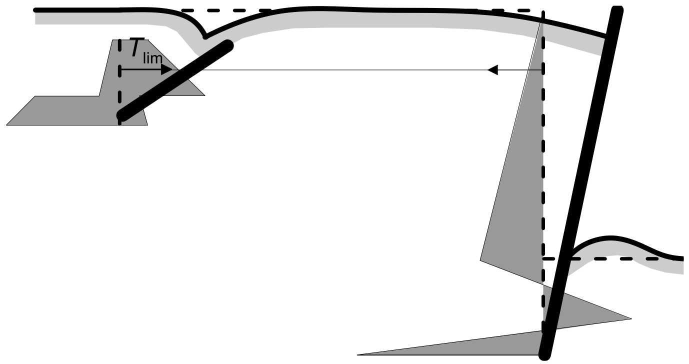
earth pressure distribution around the wall

internal forces



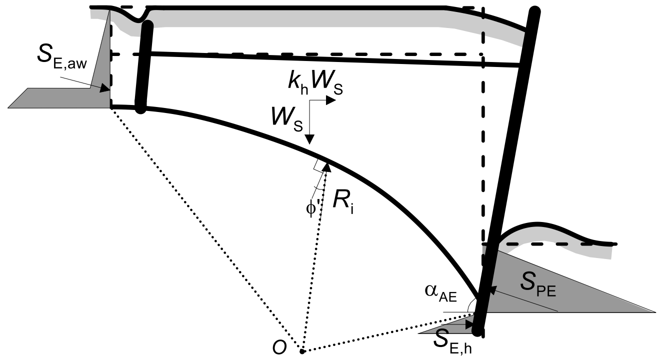
toe failure

$(k_{y,TF})$



anchor failure

$(k_{y,AF})$



global failure

$(k_{y,GF})$

critical mechanism $k_c = \min\{k_{y,i}\}$

Caputo G, Conti R, Viggiani GMB, Prüm C. (2021) J Geotech Geoenviron. Eng 147(2): 04020154

NUMERICAL ANALYSES

FLAC V.5.0 (2D)

explicit

soil

elastic-perfectly plastic

($V_S=(G/\rho)^{0.5}$, $\nu=0.2$)

Mohr-Coulomb yield criterion

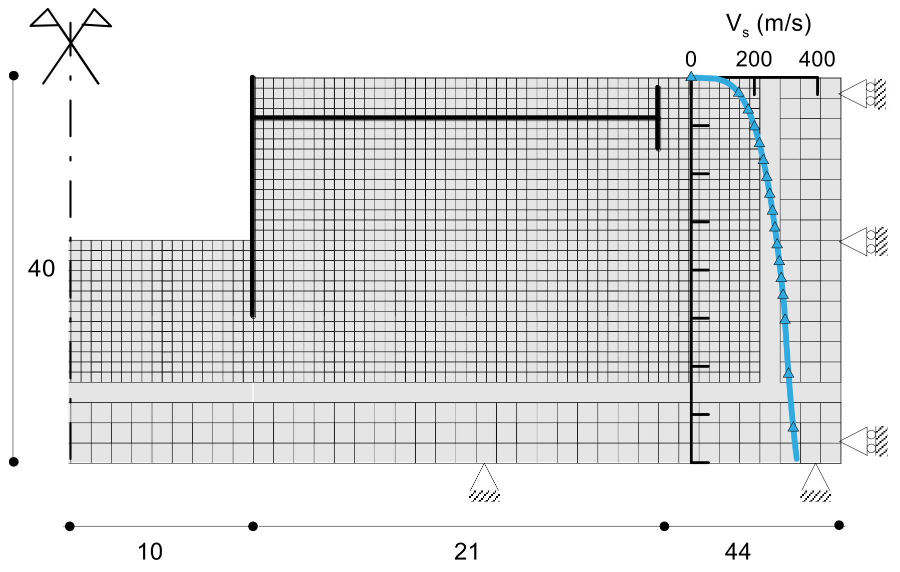
($c'=0$ kPa, $\varphi'=35°$)

non-linear/hysteretic

(Masing rules)

structural elements (beam/cables)

linear elastic



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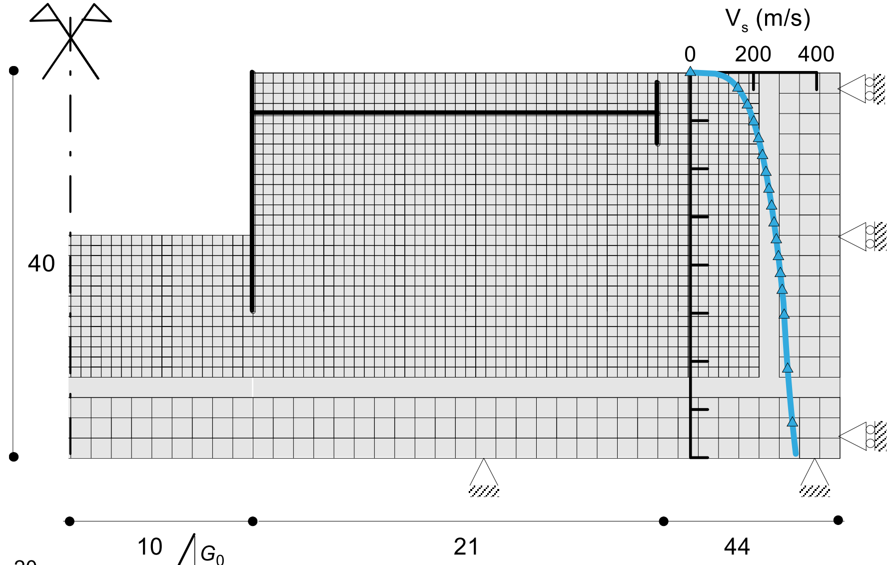
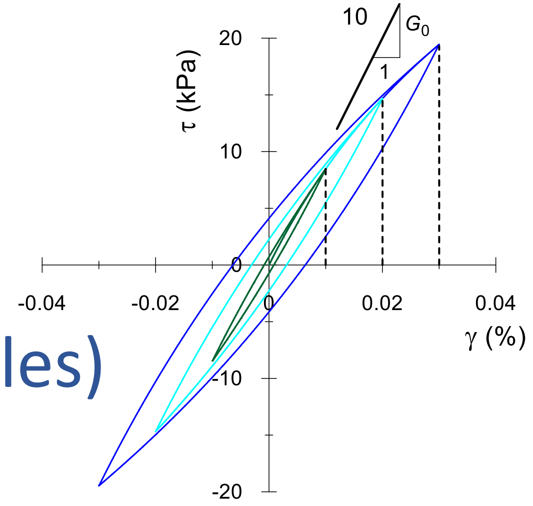
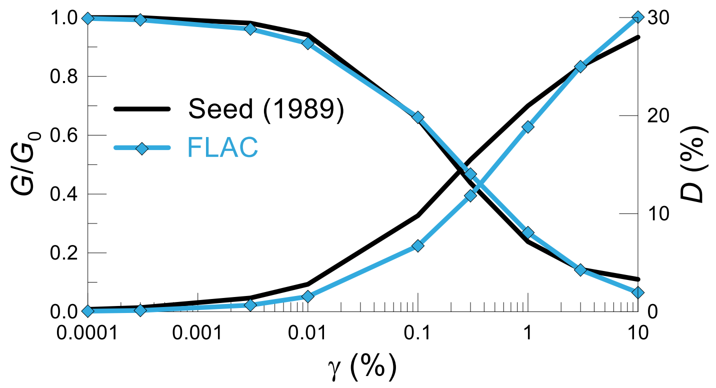
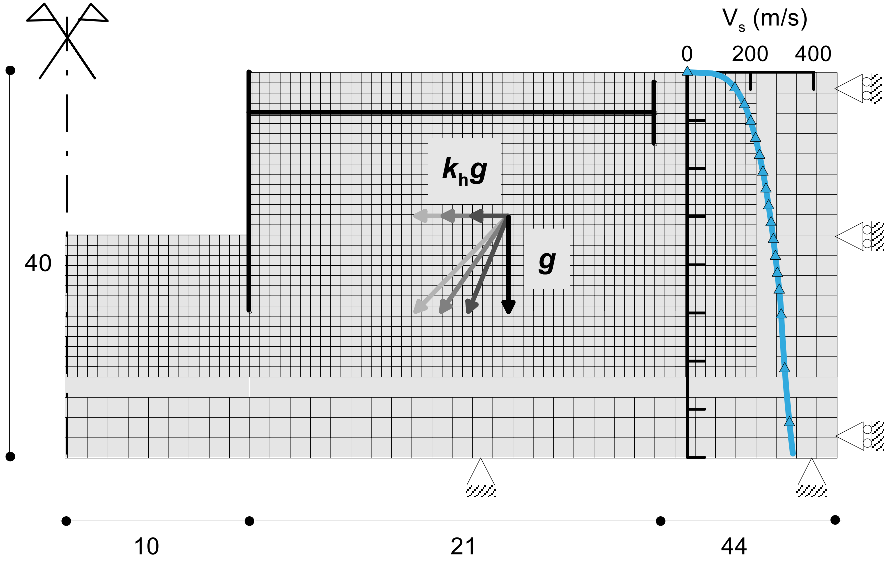






NUMERICAL ANALYSES

pseudo-static (pushover) analyses



dynamic analyses

periodic boundaries

real acceleration time histories

different layouts

parametric study

NUMERICAL ANALYSES

pseudo-static (pushover) analyses

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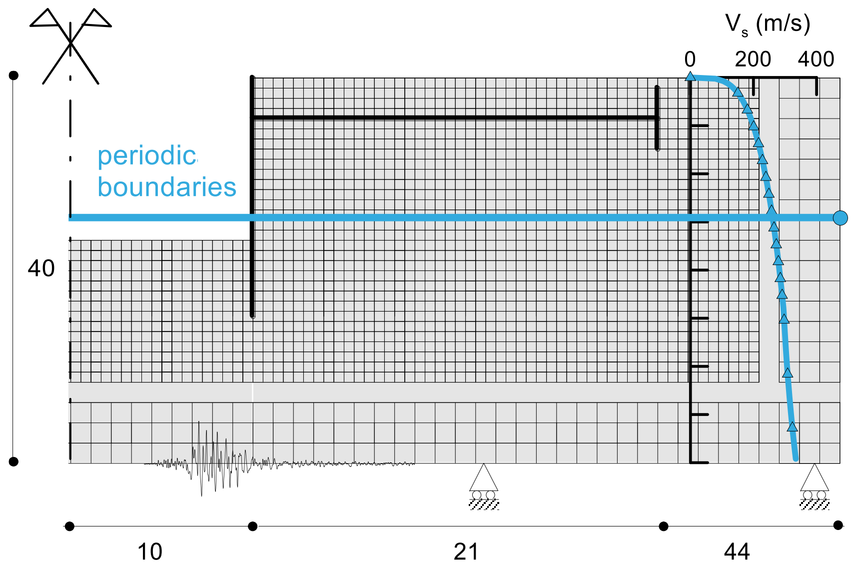

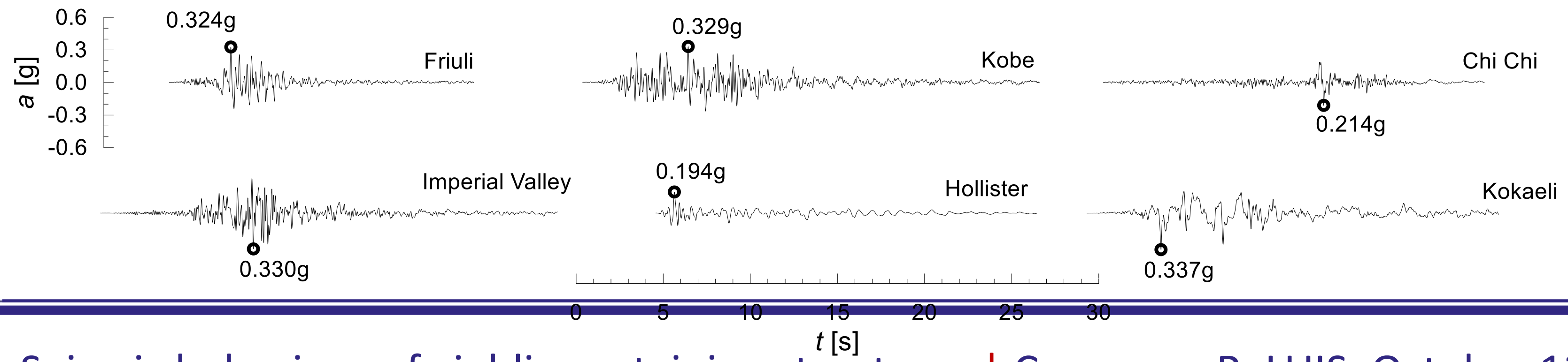

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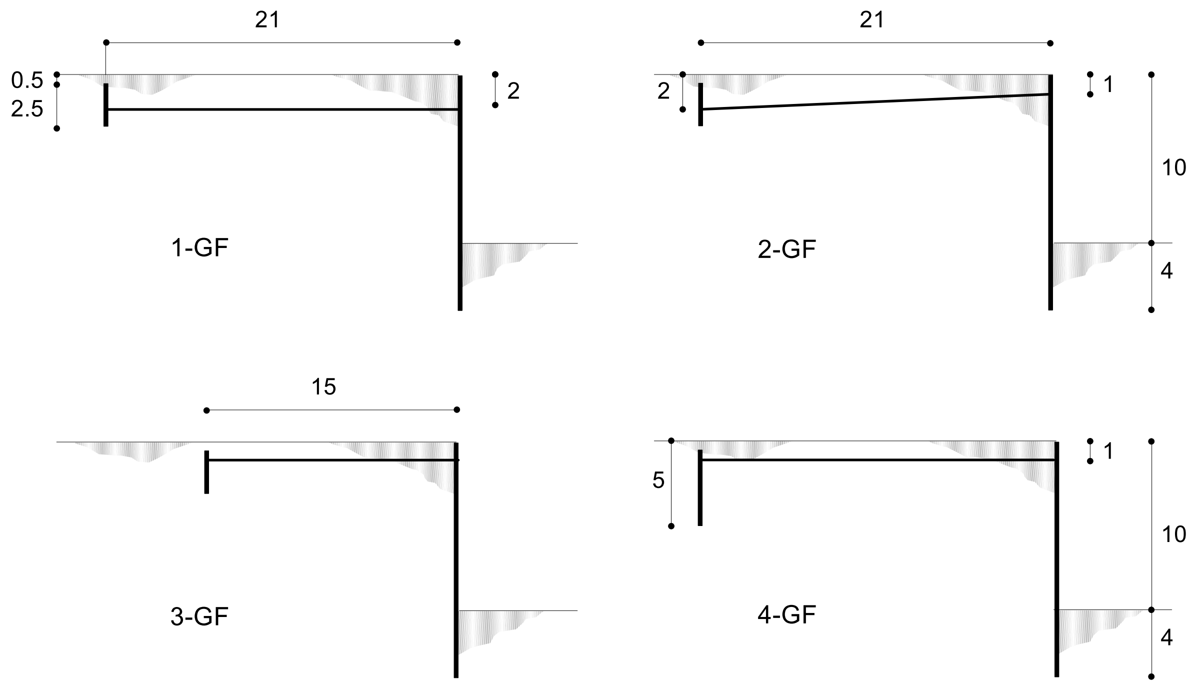


PARAMETRIC STUDY

soil

γ = 20kN/m^3

c' = 0 kPa, φ' = 35°

$\Delta = \varphi'/3$

walls

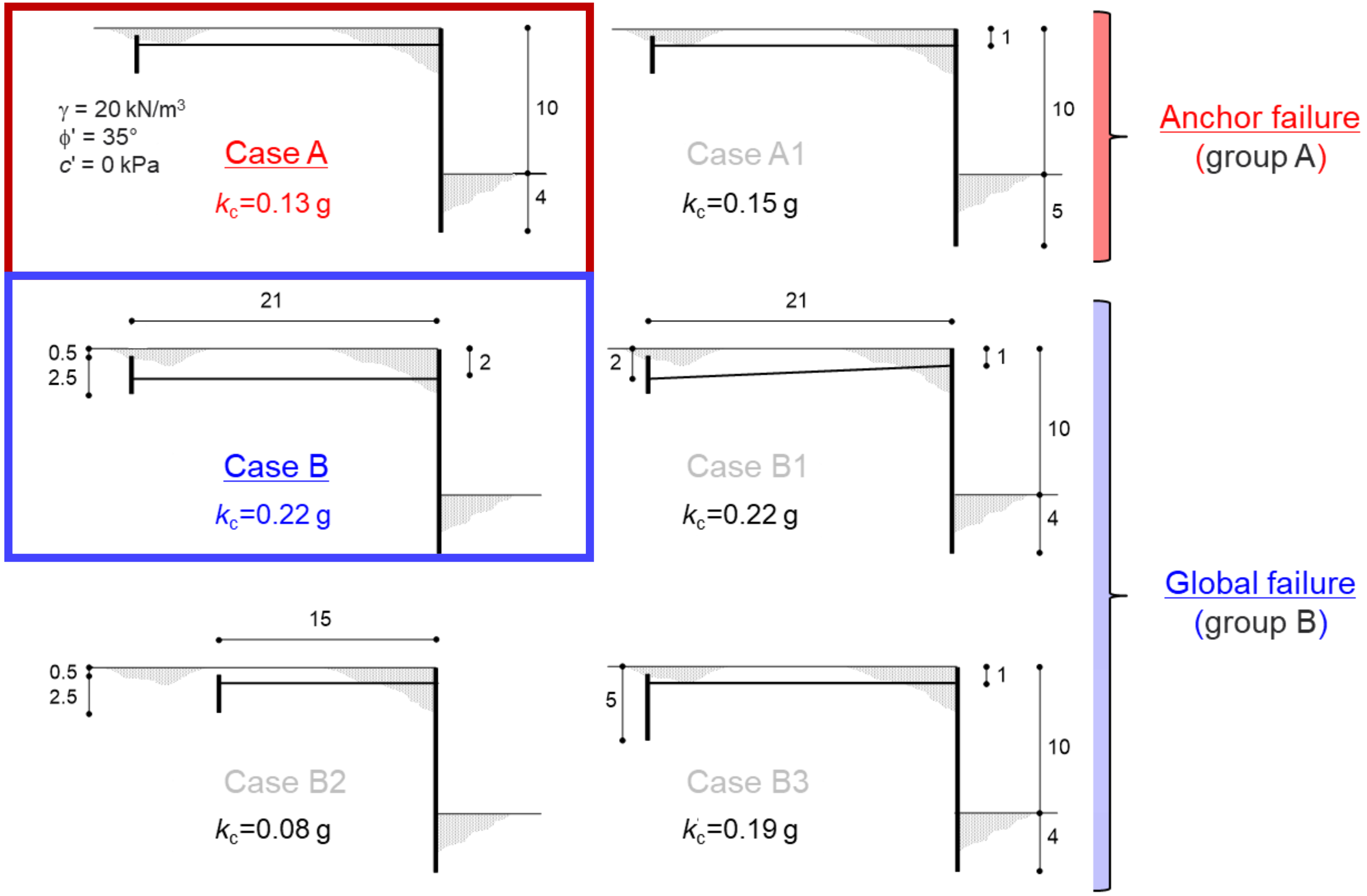
AZ 24-700 (E=210 GPa, I=55820 cm^4/m)

S355 GP (M_y=1017 kNm/m)

tie rods

D = 45 mm

S460 (Ty=730 kN/mm)

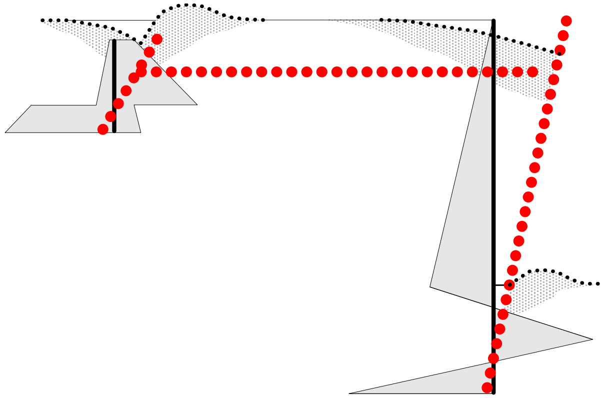


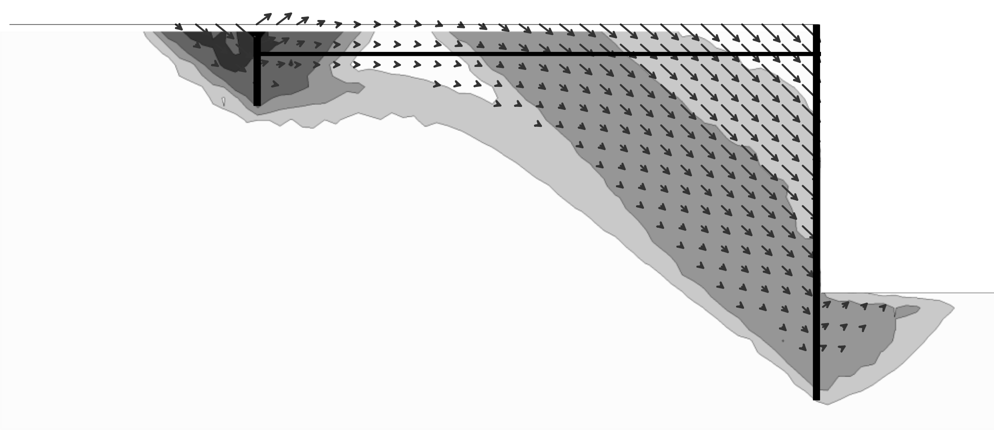
RESULTS

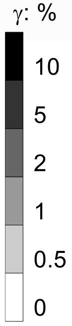
case A

$k_{c,NUM} = 0.12$

$k_{c,LE} = 0.13$



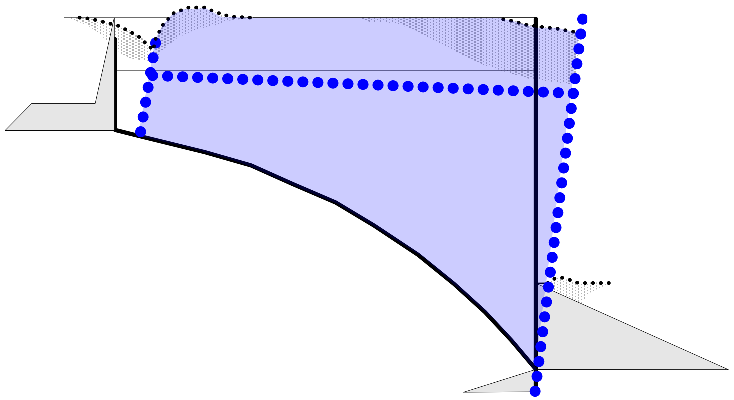


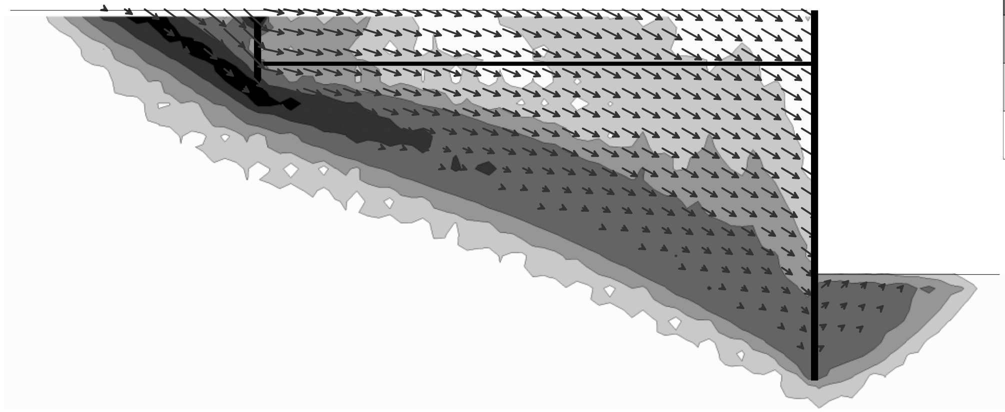


case B

$k_{c,NUM} = 0.21$

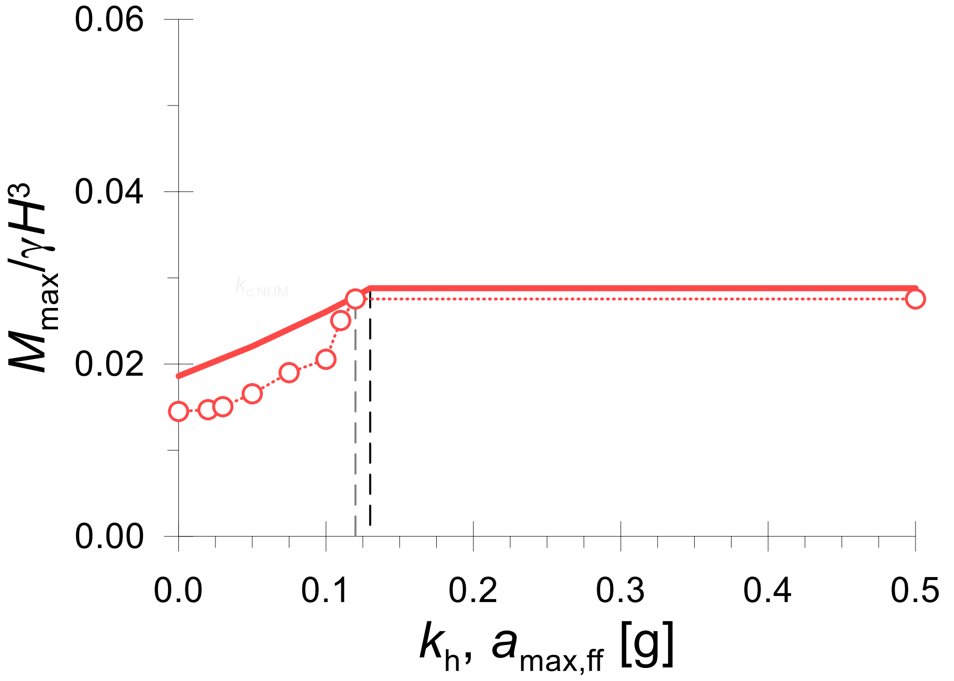
$k_{c,LE} = 0.22$

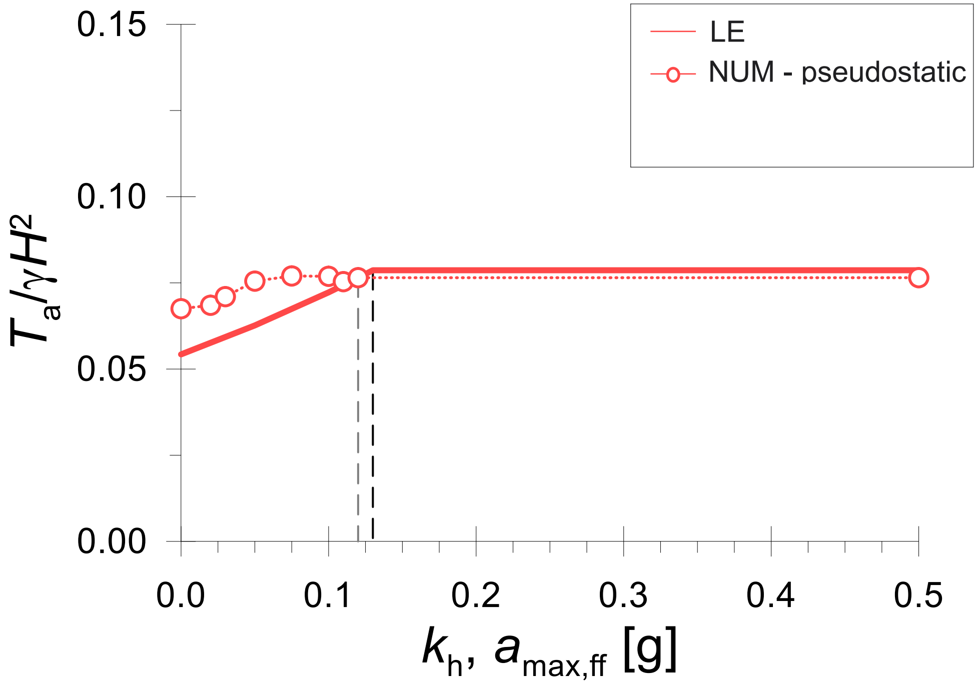




RESULTS

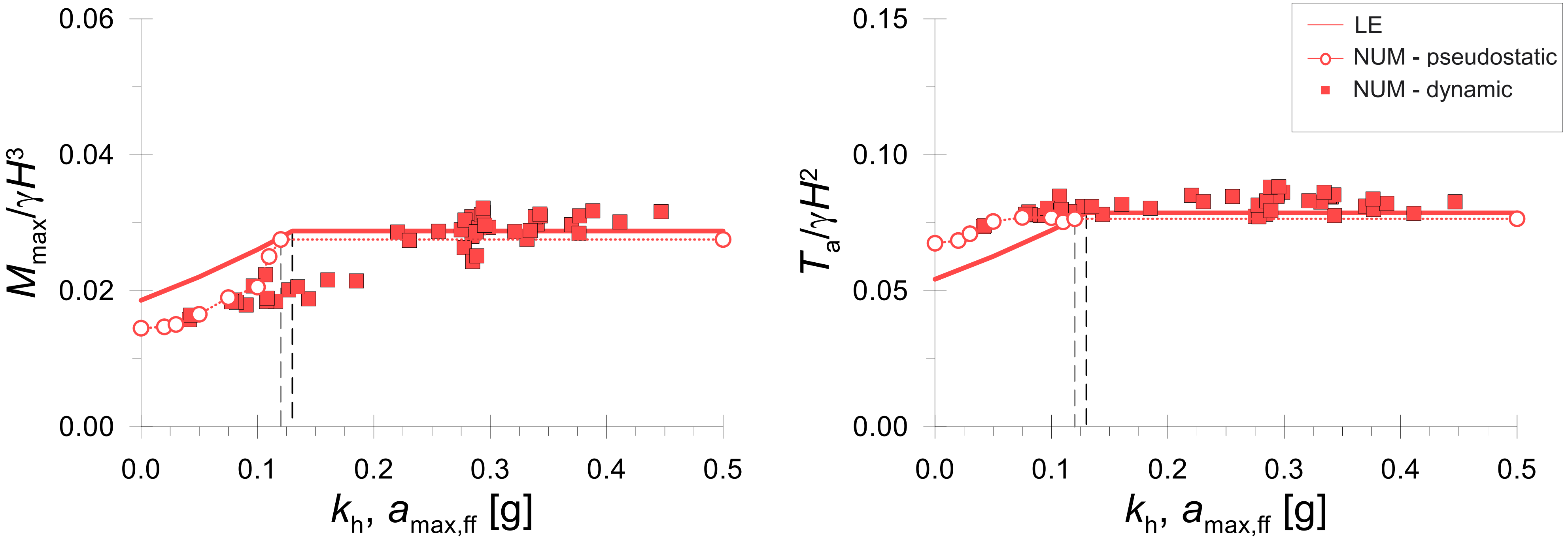
case A





RESULTS

case A

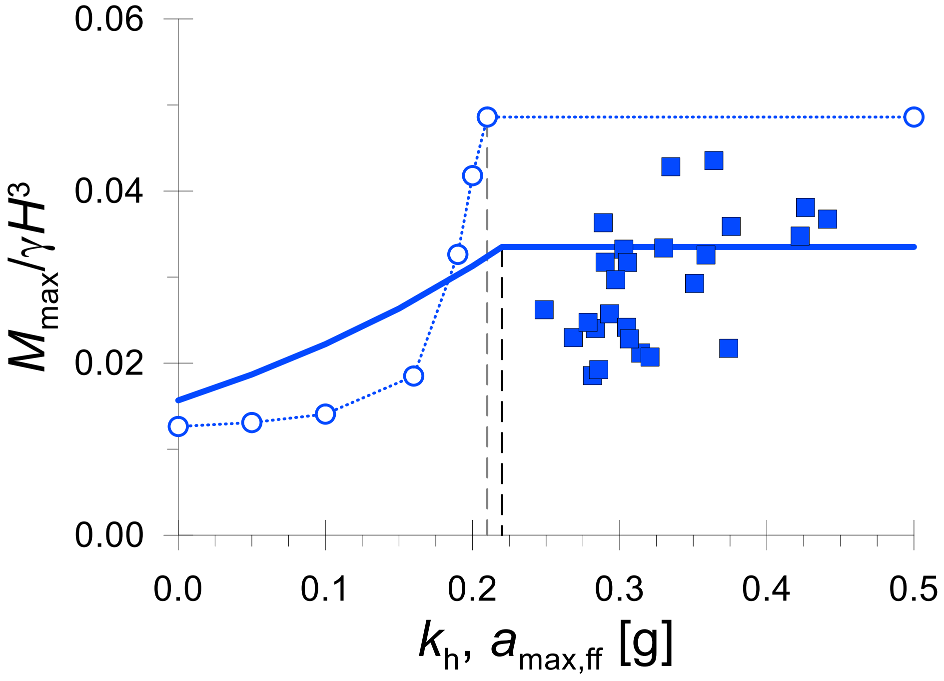


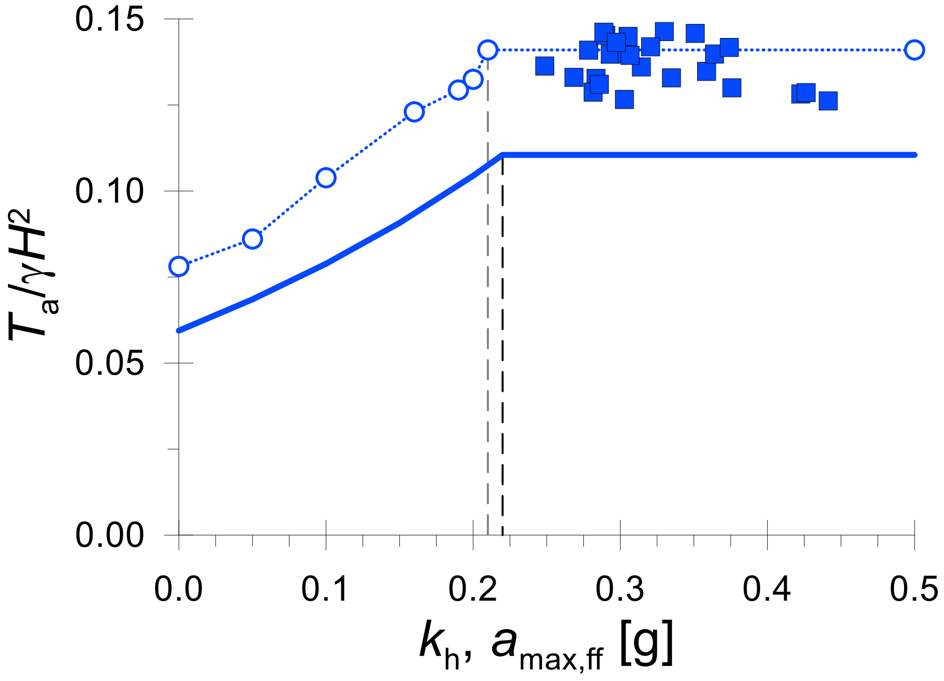
M_{max}, T_a bounded

use a_c for structural design

RESULTS

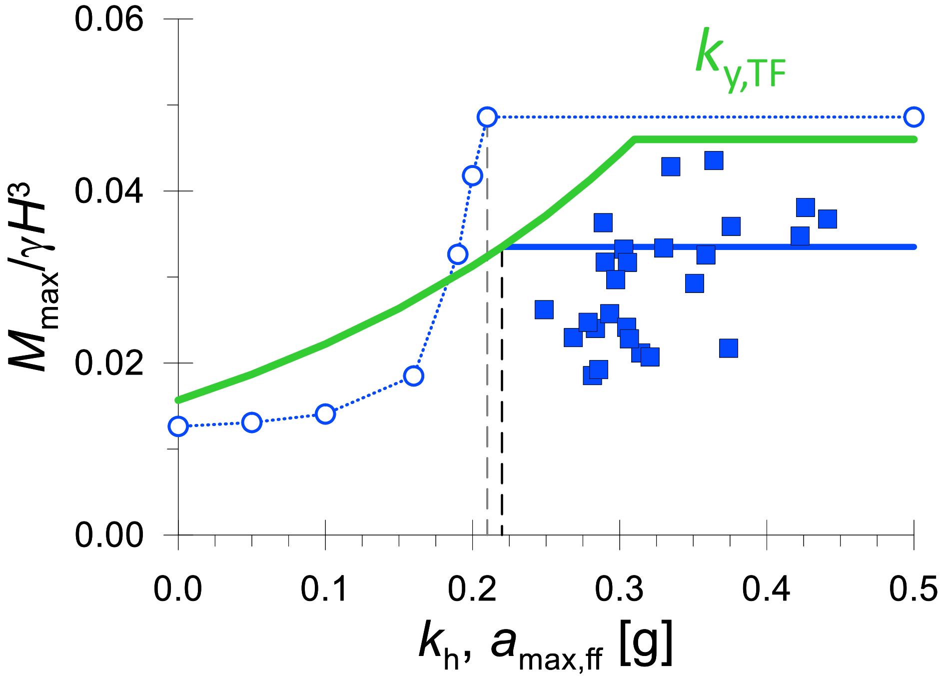
case B

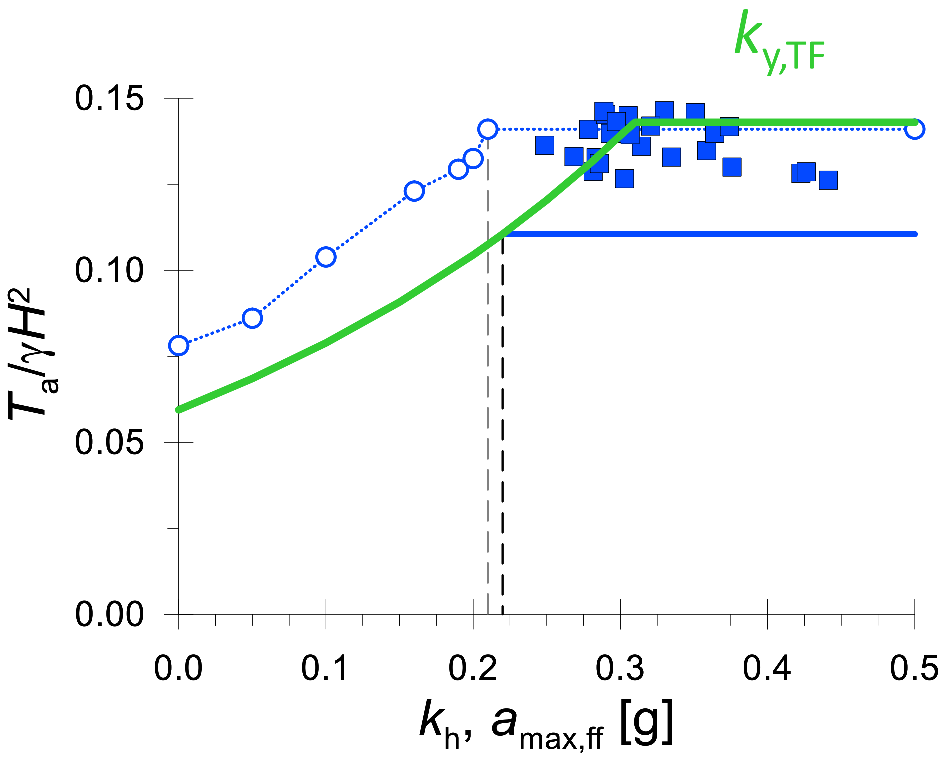




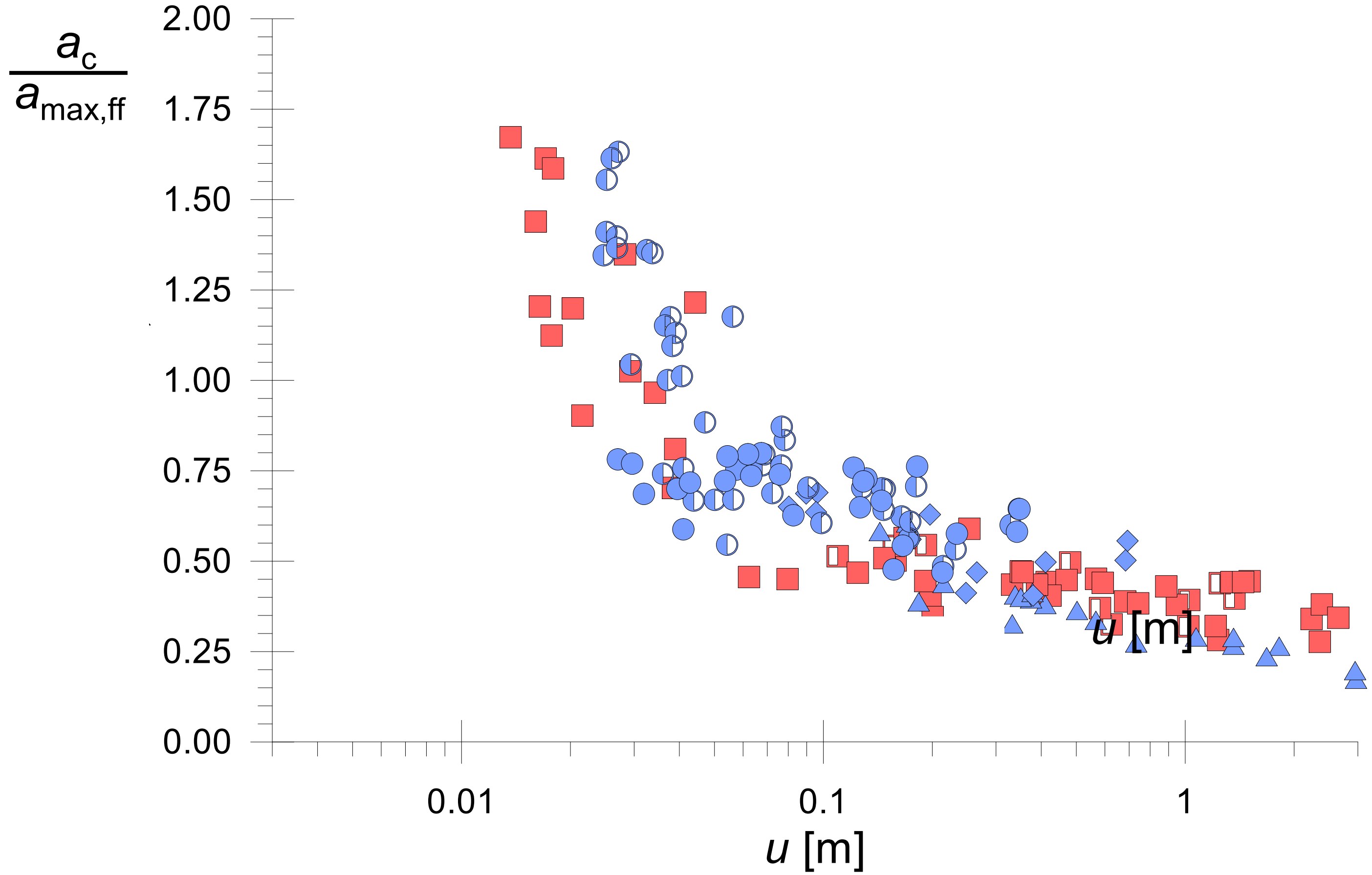
RESULTS

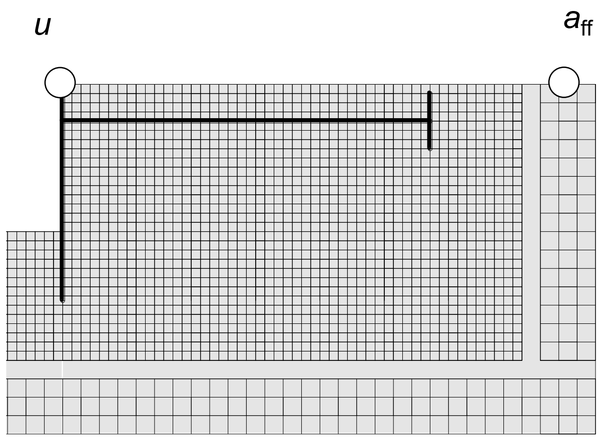
case B





DISPLACEMENTS

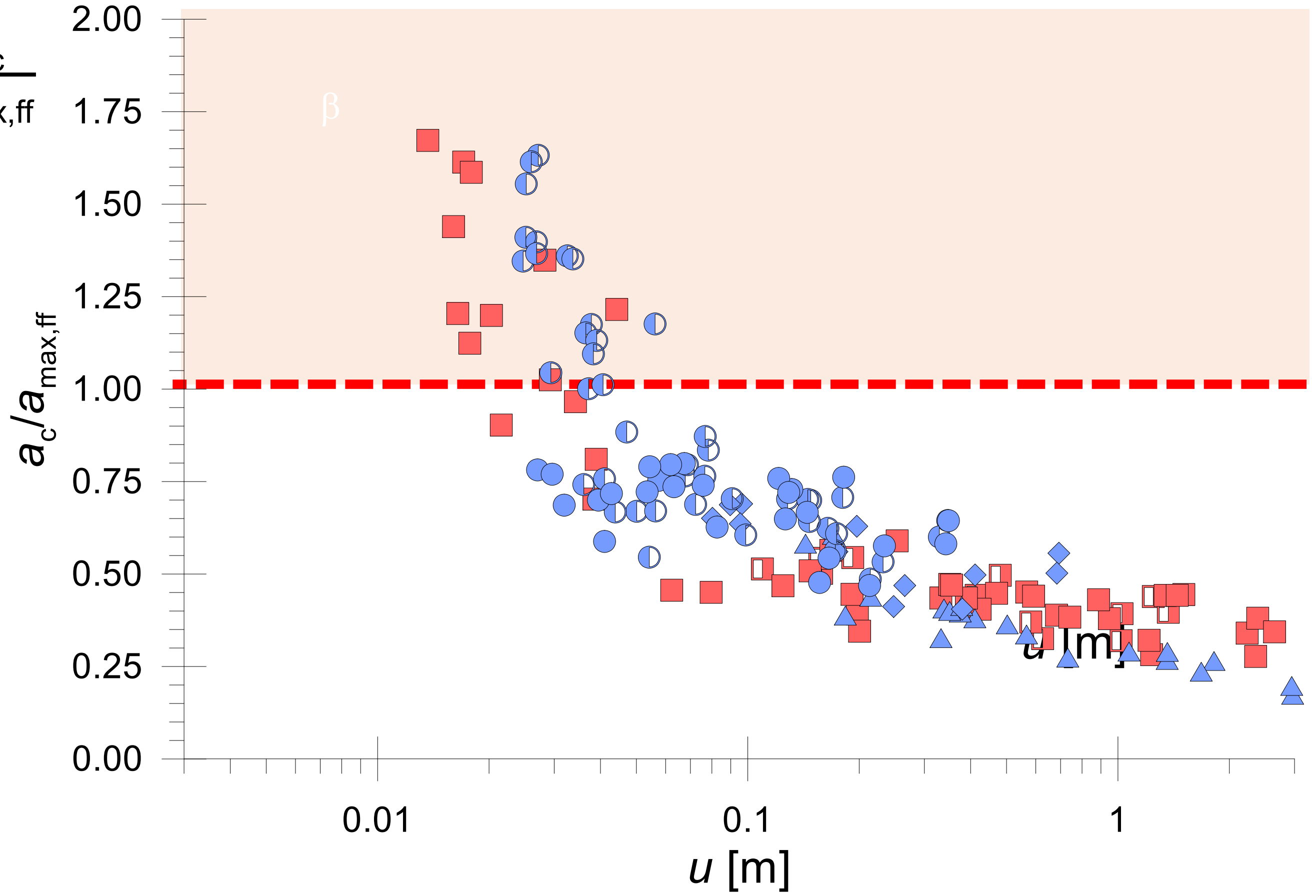


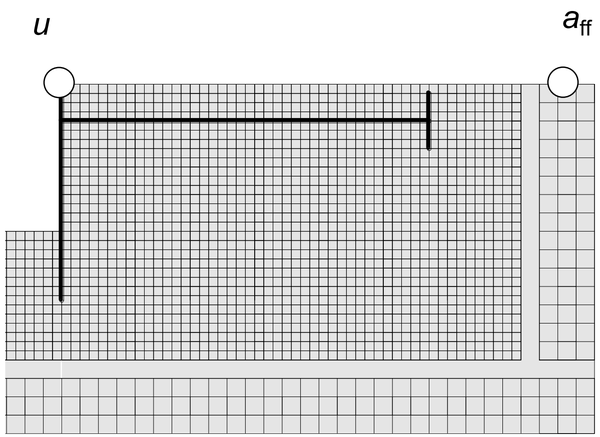


- local mechanisms
- global mechanisms

DISPLACEMENTS

$$\beta = \frac{a_c}{a_{max,ff}}$$





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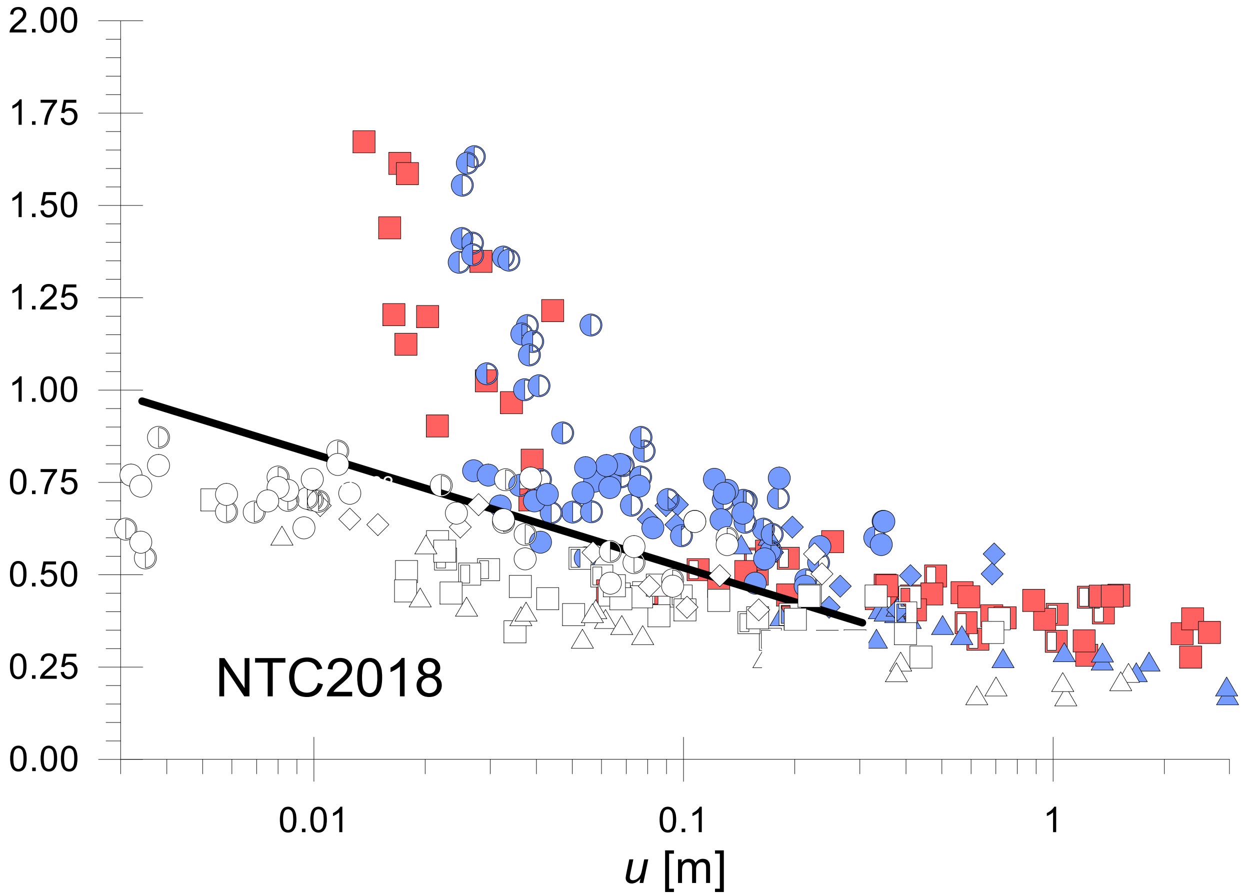

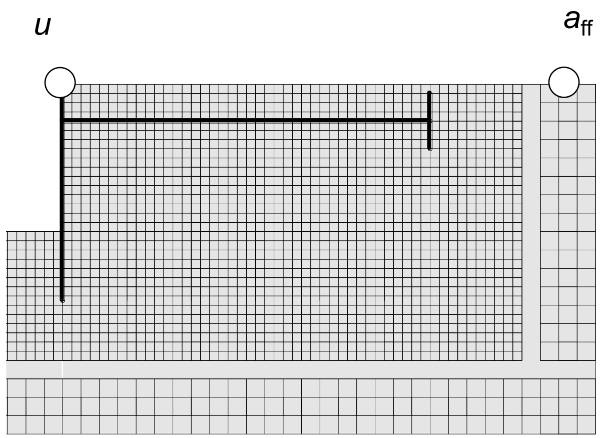

- local mechanisms
- global mechanisms

DISPLACEMENTS

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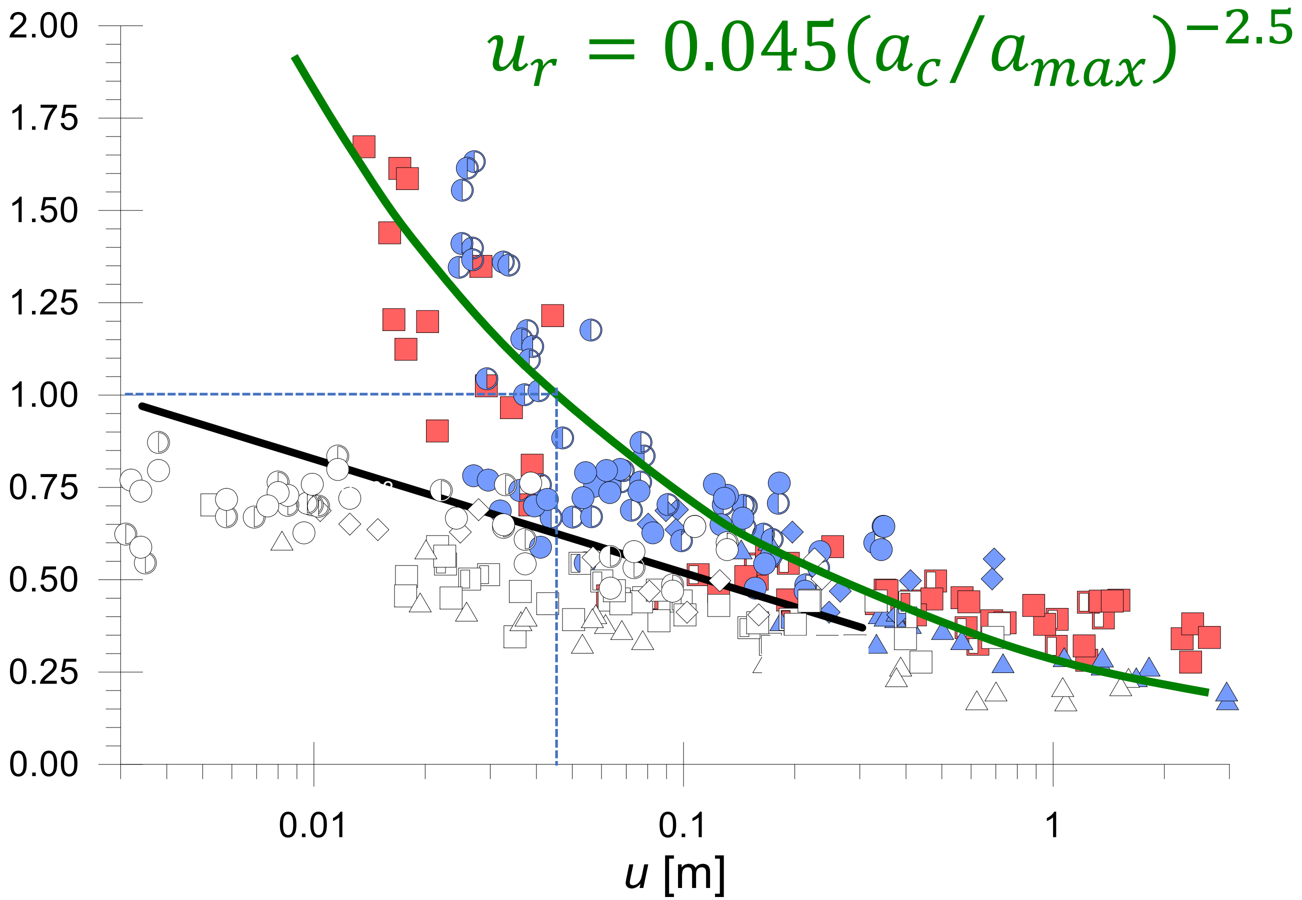

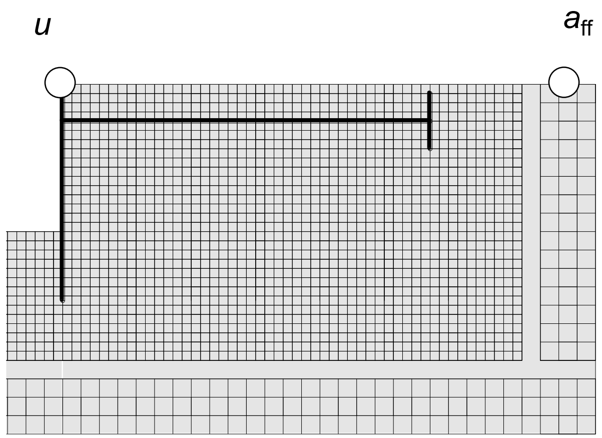

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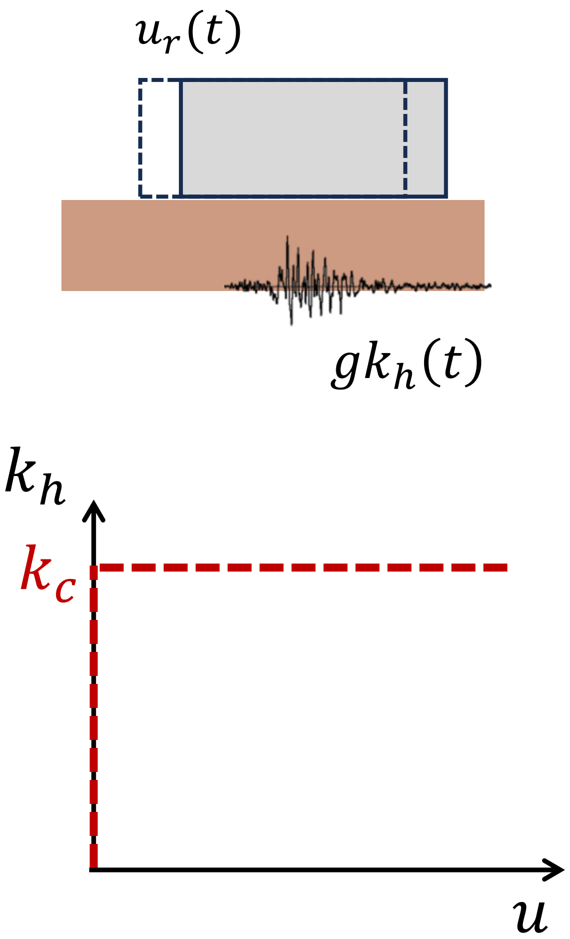
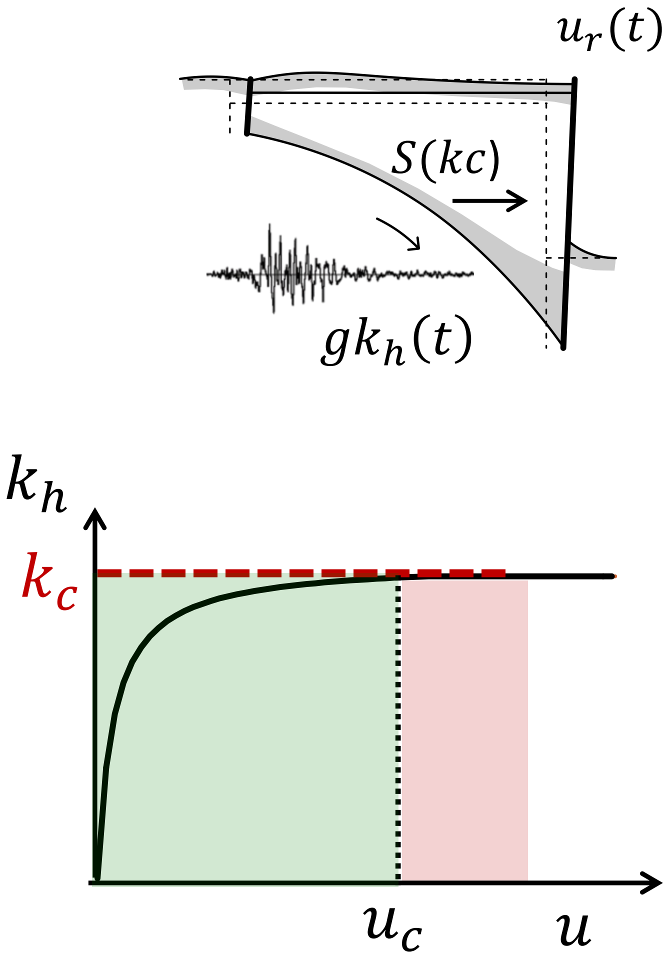
Conti, R, Viggiani G.M.B (2023). *On the performance-based seismic design of yielding retaining structures*. Soil Dynamics and Earthquake Engineering 174 (2023) 108172

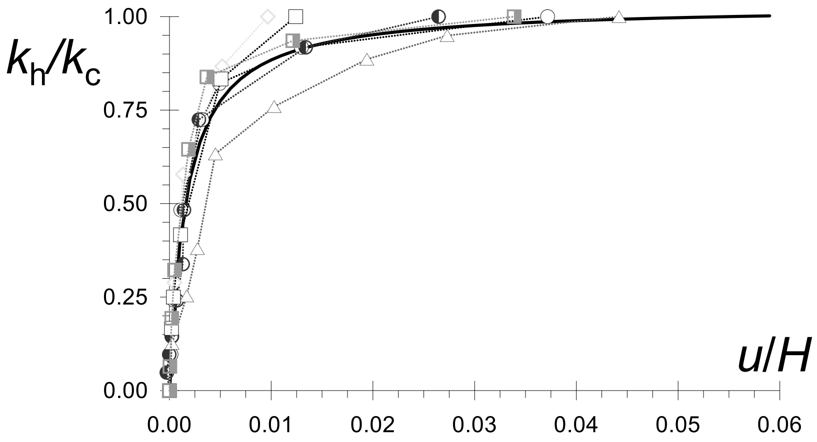
DISPLACEMENTS





DISPLACEMENTS

simplified dynamic methods



Non linear SDOF

(Callisto, 2019)

Generalised Newmark method

(Cattoni *et al.*, 2019; Oliynyk *et al.*, 2022)

Dynamic Limit Equilibrium

(Caputo, 2021)

non-linearity accounted for by pushover curve

Caputo G, Conti R, Viggiani GMB (2023). *Effects of Displacement Hardening on the Seismic Design of Anchored Walls*. J Geotech Geoenviron Eng ASCE. 04023112-1

DISPLACEMENTS

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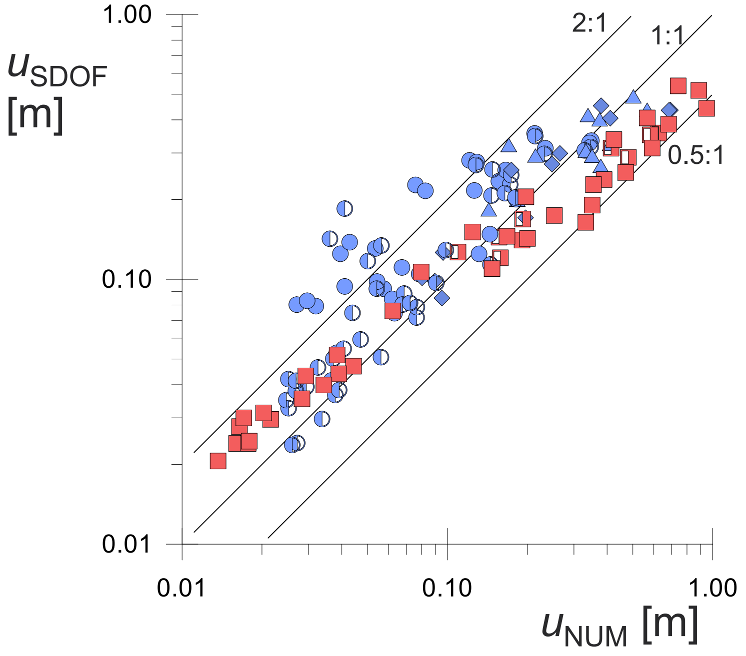
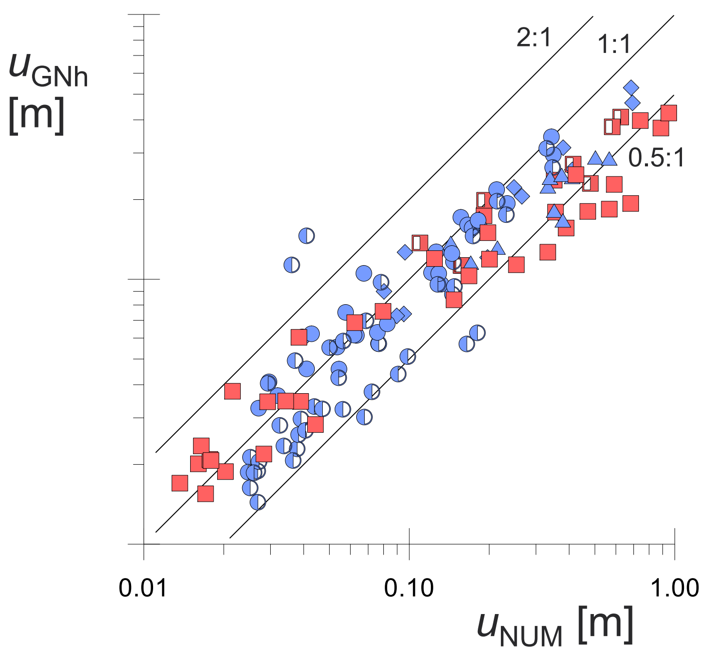
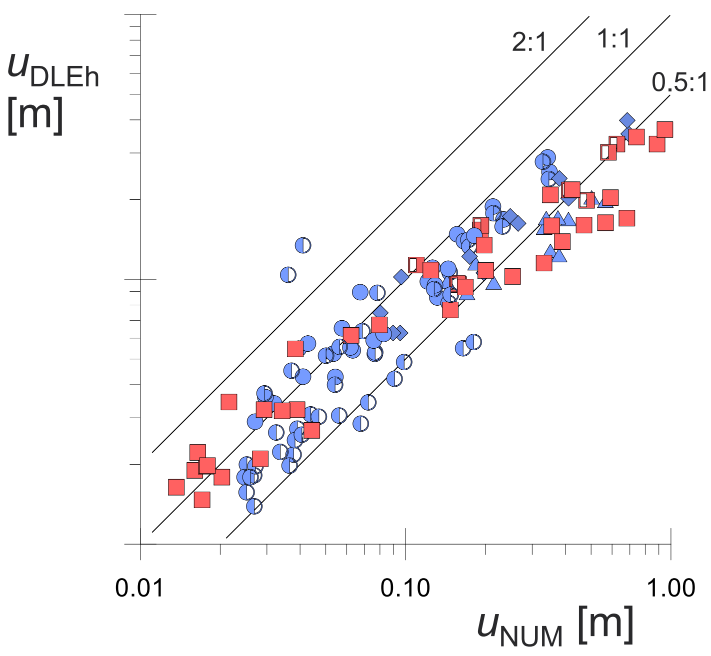
SDOF



GNh



DLEh



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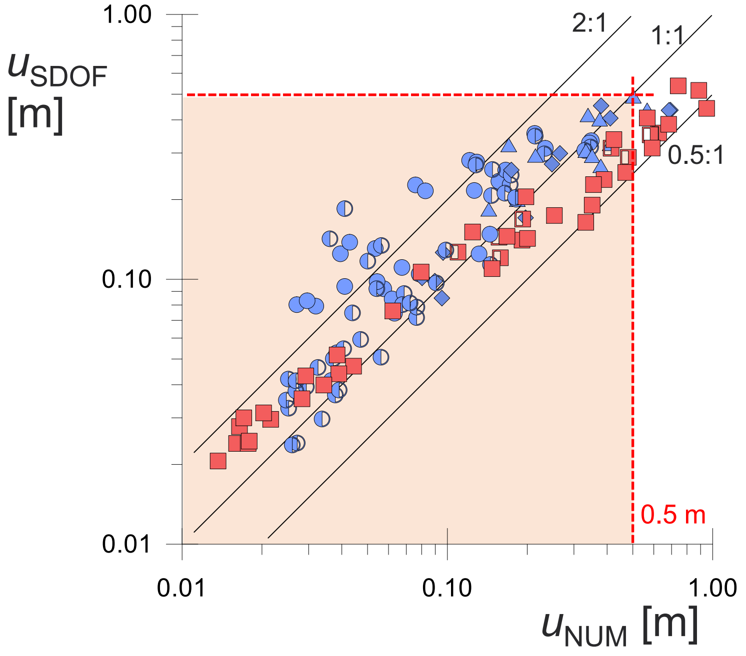
SDOF GNh DLEh



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- global mechanisms

CONCLUSIONS

a_c crucial ingredient
structural design (maximum internal forces)
geotechnical design (displacements)

pseudo-static LE methods
failure mechanism and critical acceleration
maximum internal forces

maximum internal forces bound by critical values
activation of ductile plastic mechanism → structural elements inherently safe

permanent displacements
rigid block assumption NOT applicable
other simple methods (SDOF, GN, DLE) exist
non linear behaviour ($a(t)<a_c$)
complex kinematics

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Riccardo Conti
Università di Roma Tor Vergata

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