Seismic Assessment & Improvement of Buildings & Foundations

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Charles Clifton
Jason Ingham

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Introductory comments

- Phones, toilets, evacuation procedure
- Collaborative exercise between:
  - NZSEE
  - SESOC
  - NZ Geotechnical Society
  - University of Auckland
- Underpinning research funded by FRST through the Public Good Science Fund

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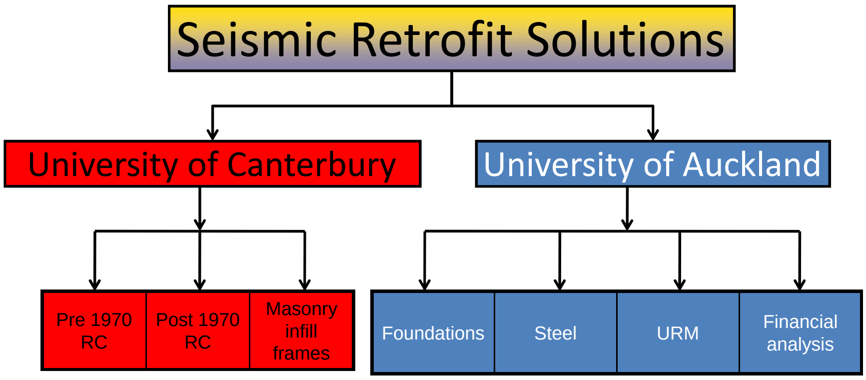
Genesis of seminar series 07/2004-10/2010



- Commitment to produce a suite of user guides at conclusion of research project
- Companion documents to be produced by UOC

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Programme

- 1.00 - 1.10 Welcome & Introduction
- 1.10 - 2.10 Assessment & Improvement of Foundations (Mick Pender)
- 2.10 - 3.10 Assessment & Improvement of Steel Frames with Semi-Rigid Connections (Charles Clifton)
- 3.10 - 3.30 Afternoon Tea
- 3.30 - 5.30 Assessment & Improvement of URM Buildings (Jason Ingham)
- 5.30 – 6.00 Q&A

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URM structures and EQs

Can geotechnical insight help?

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Content of MJP volume

- Shallow and deep foundations
- Design of foundations in cohesive soils
- Part of the content of a Masters course on **Design of Foundations to Resist Earthquakes** I teach in Italy and will teach in Auckland later this year

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Context of project

- Jason suggested that as part of the Retrofit project that consideration needed to be given to benefits of foundation rocking
- Strongly supported by advisory panel

What we did

- At a site in Albany we did field testing on shallow foundations and driven piles
  - thorough site investigation – CPT and SASW
  - excitation with an eccentric mass shaker on both foundation types
  - snap-back testing on both foundation types

Basis of this presentation

- **Quality data obtained from field testing** with back-up computational work

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Field test arrangements

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Shallow foundation set-up

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Shallow foundation snap-back set-up

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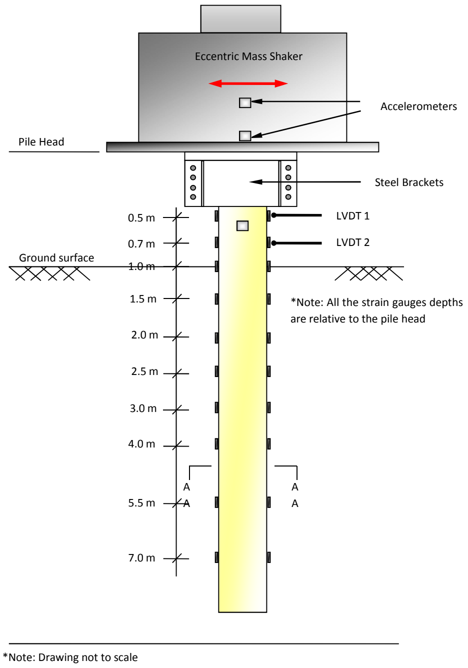
Pile instrumentation



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Pile foundation set-up

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Pile foundation snap-back set-up

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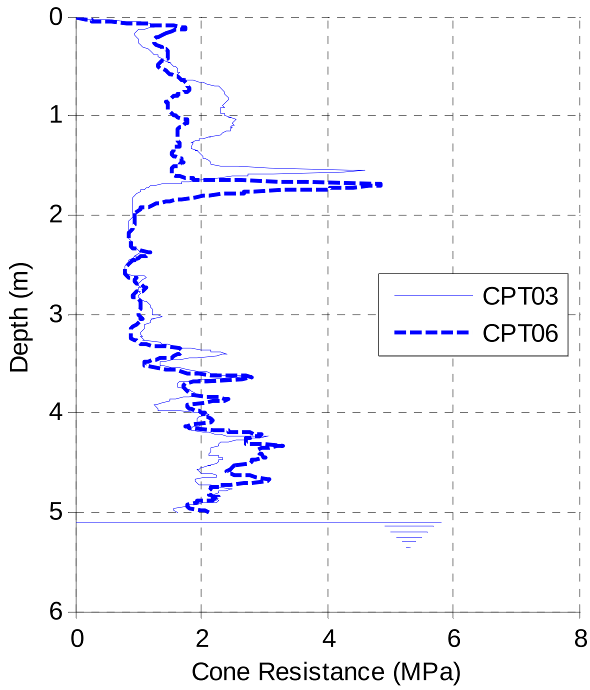
CPT profile



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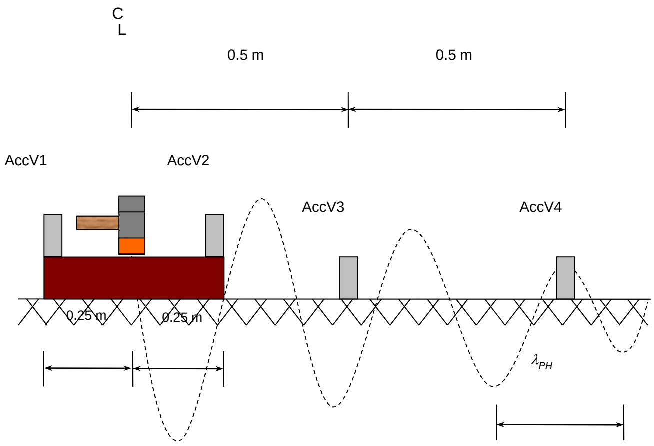
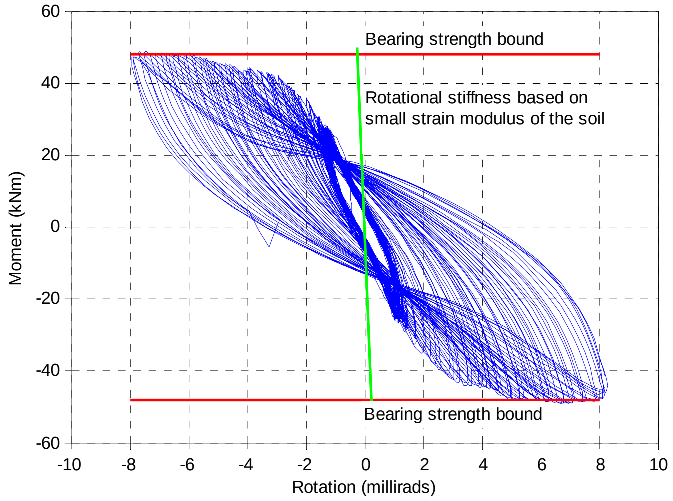
SASW test set-up



Shallow foundation results

Shallow foundation shaker



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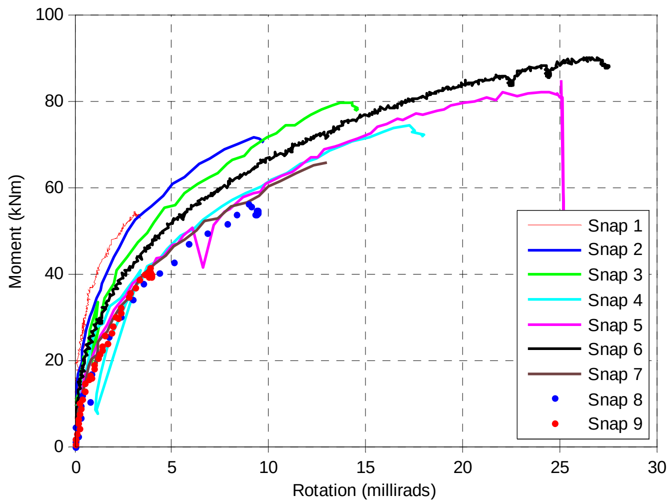
Shallow foundation pull-back



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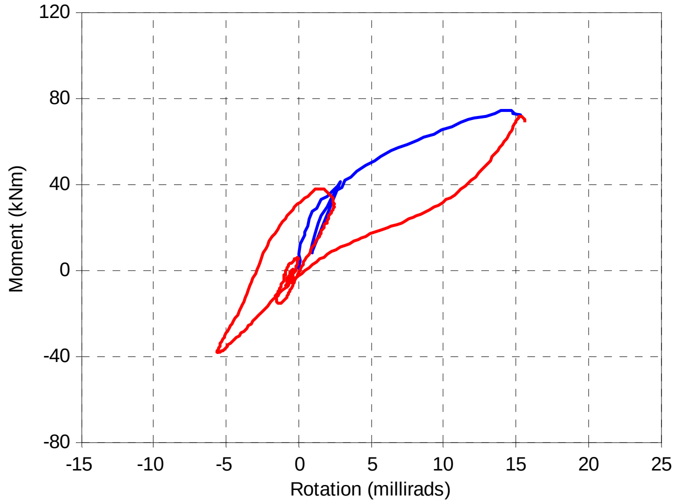
Shallow foundation snap-back



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Shallow foundation interpretation

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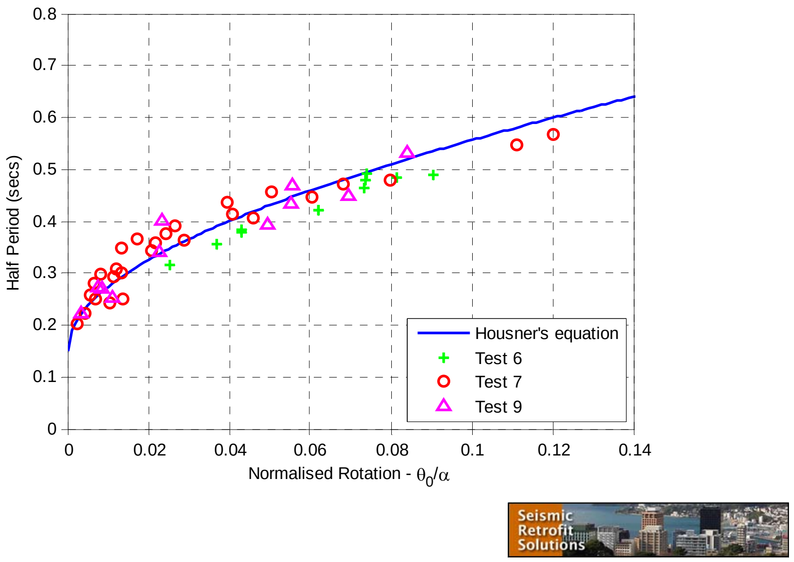
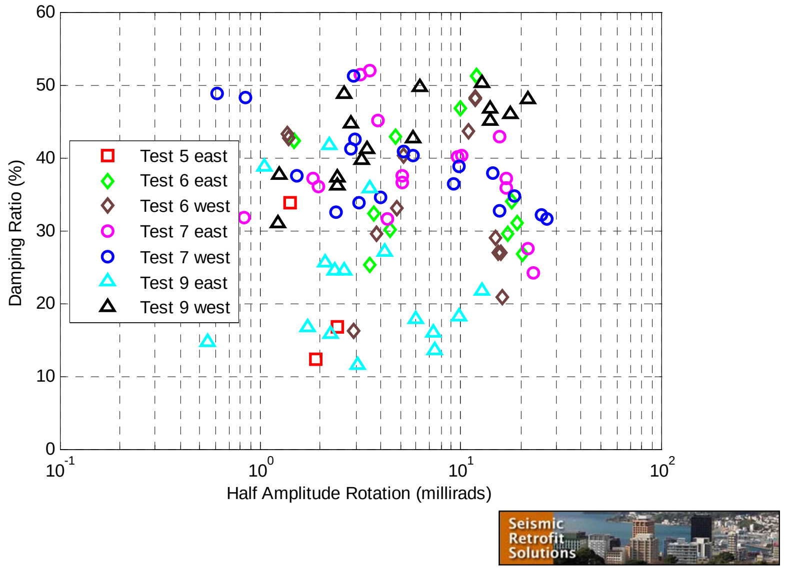
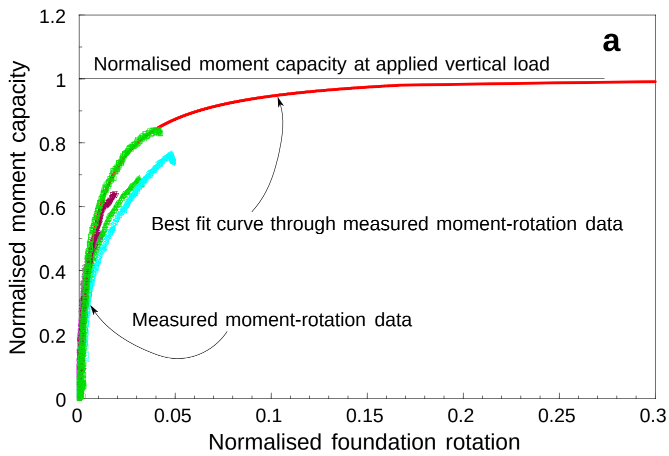
Snap-back periods



Snap-back damping



Pull-back Fig. 5.4a



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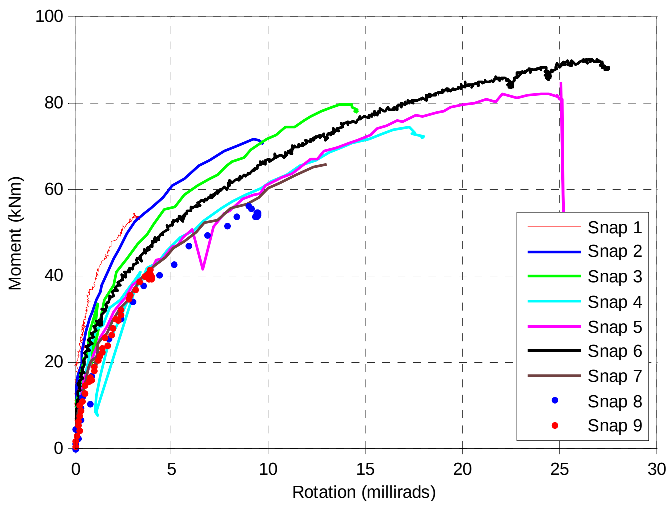
Shallow foundation pull-back



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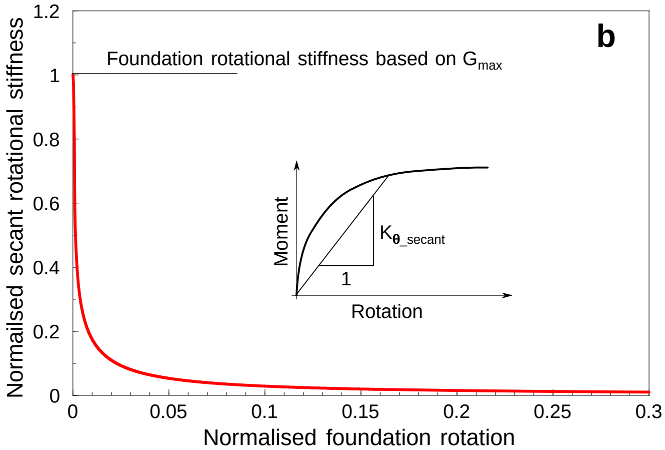
Pull-back Fig. 5.4b



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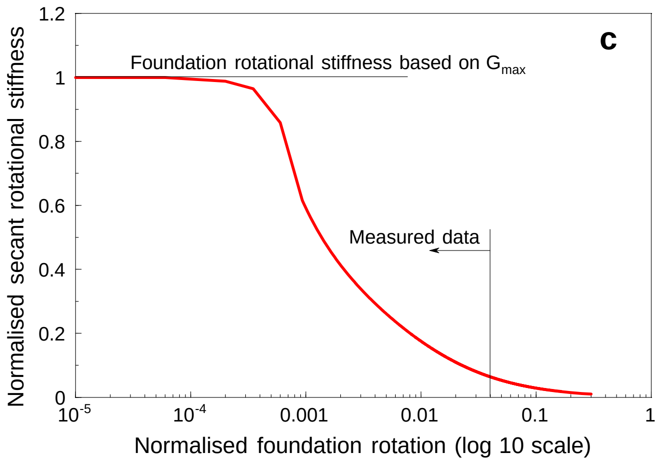
Pull-back Fig. 5.4c



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Shallow foundation application

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Foundations for URM walls

- In-plane wall response
- DDBD - direct displacement based design
- contribution of foundation rotation
- limited displacement capacity of walls
- foundation rotation rather than rocking

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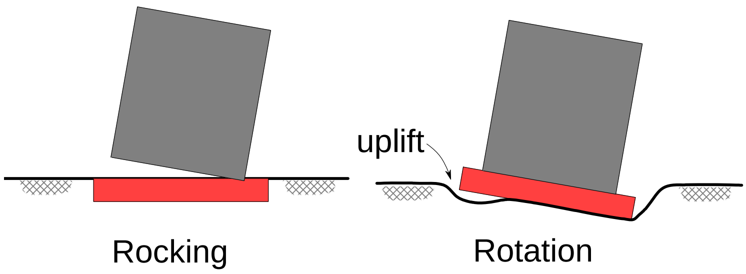
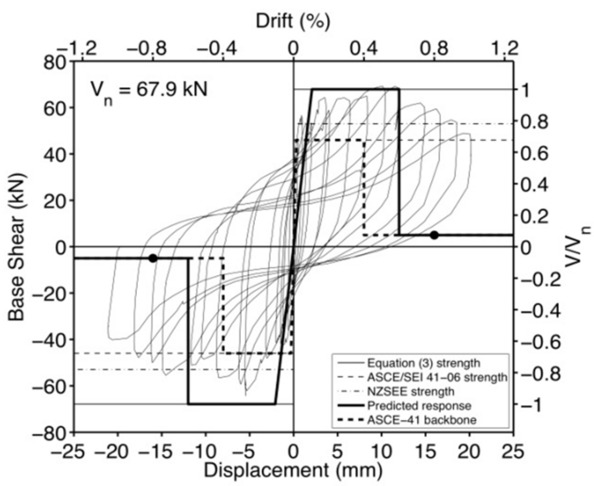
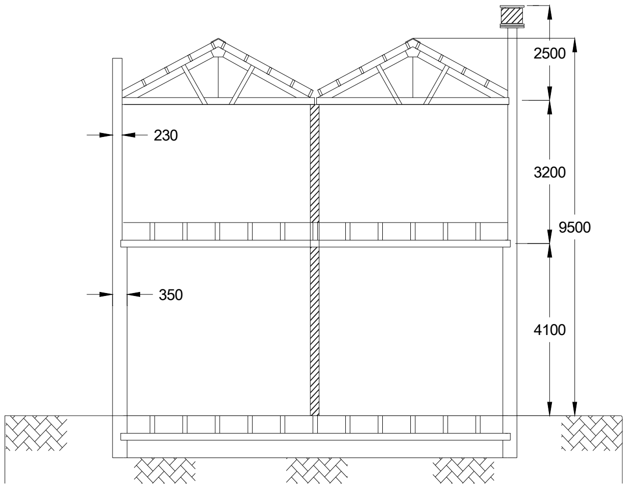
Foundation rocking and rotation



Wall displacement limits



Wall configuration Fig. 7.1



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Displacement based design (page 7-3)

- Section 7 of the MJP volume
- based on Priestley (2007), Sullivan (2010) and Paolucci (2011)
- uses EQ displacement spectrum rather than acceleration spectrum
- choice of allowable displacement gives system period

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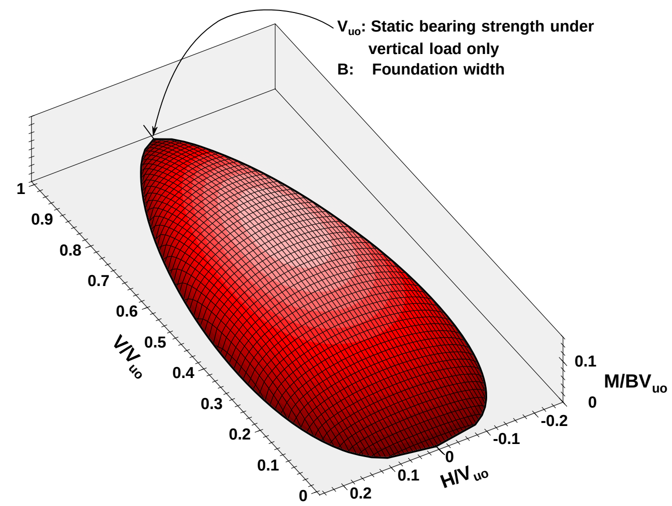
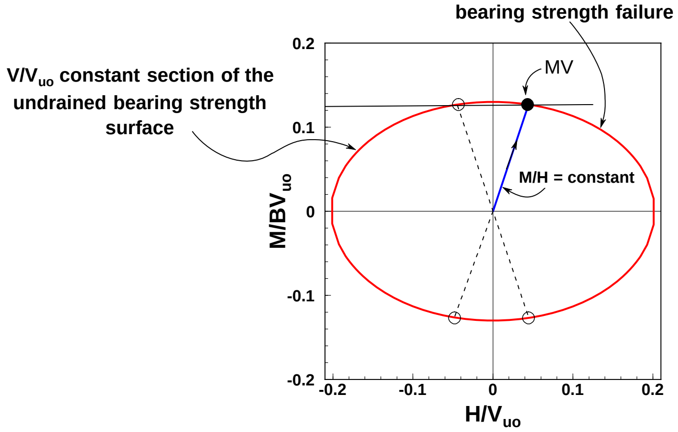
Two important steps

- Development of an equivalent SDOF model
  - follows Priestley (2007)
- estimation of ultimate moment capacity of the foundation

Foundation moment capacity



Example 4-2 Calculation of MV



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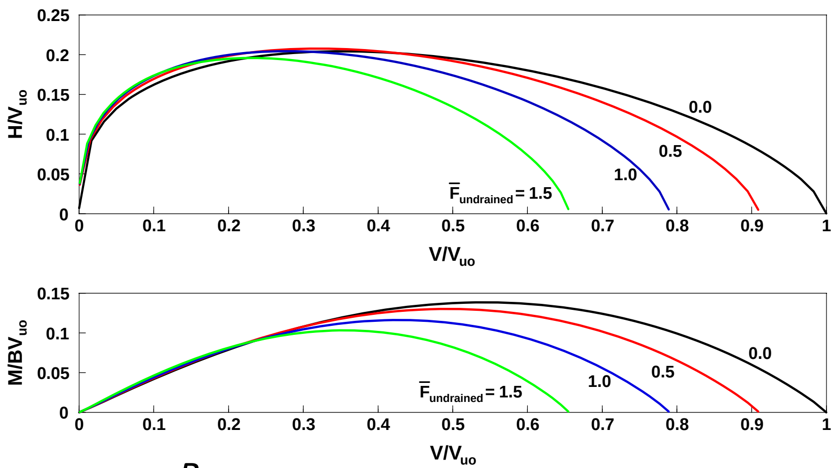
EQ and bearing strength



$$\overline{F}_{undrained} = \frac{\rho a_g B}{s_u}$$

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Wall configuration

- Wall height 8.4m
- Length 6.9m
- Weight 1300 kN

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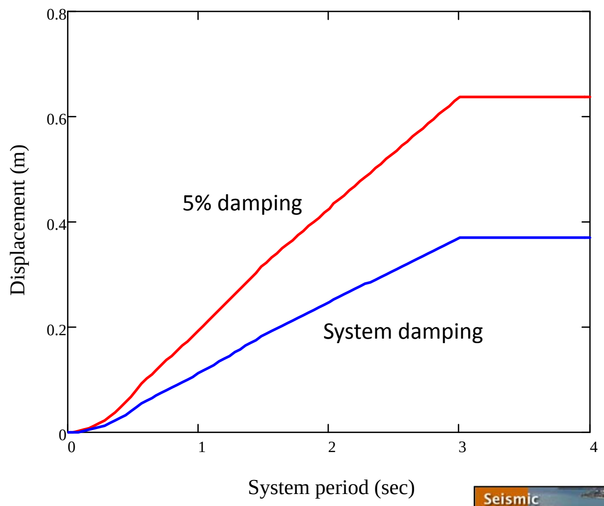
Design displacement spectrum



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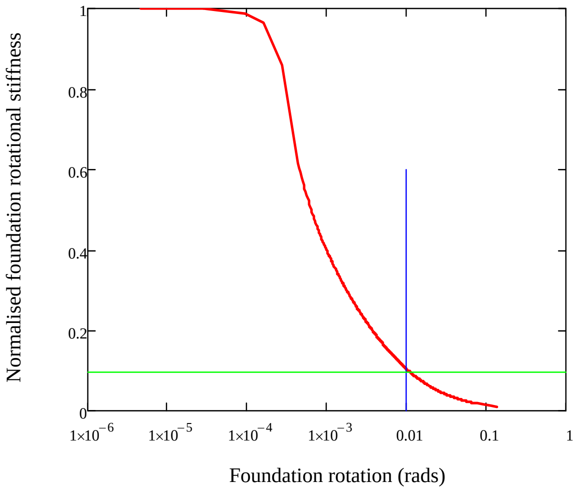
Design moment-rotation curve



Rotation is assumed (blue line)

then iterate until the stiffness matches (green line)

Results page 7-5

s_u (kPa)	θ_f (rad)	Δ_d (m)	B (m)	L (m)	FoS_{static}	ξ_f (%)	T_e (sec)	$\frac{M_{found}}{MV}$	$\frac{K_\theta}{K_{\theta\_elast}}$
50	0.0075	0.091	3.0	8.7	4.4	40	0.90	0.65	0.14
100	0.0075	0.087	2.0	7.7	6.1	35	0.88	0.74	0.13
150	0.01	0.105	1.8	6.9	7.8	30	0.93	0.87	0.10
150	0.04	0.323	0.7	6.9	3.4	15	2.13	0.72	0.03

MV – foundation moment capacity
K_{θ_elast} - foundation elastic rotational stiffness

Is the foundation rotation OK?

- Foundation rotations of 0.01 radians (≈0.5 degrees) or larger are needed for URM to give good performance with reasonable sized foundations
- do these rotations take us too far around the curve?

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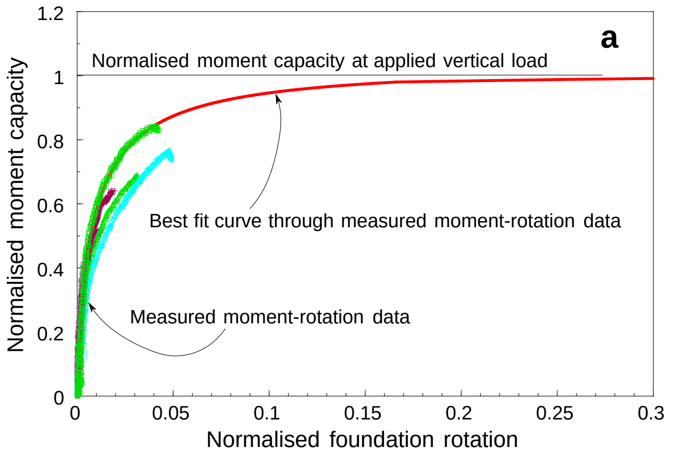
Pull-back Fig. 5.4a



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Is bearing failure tolerable?

- **Yes**, provided it occurs for brief periods only
- the residual displacement is then the criterion for acceptable performance
- we have another armoury of techniques that allows time history analysis of structure-foundation response
- these can be used as a final design step

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Computer modelling

- 3D finite element computations with Abaqus
- field data provides a test that the FEM work is modelling correctly
- enables us to check on the effect of foundation static reserve of bearing strength

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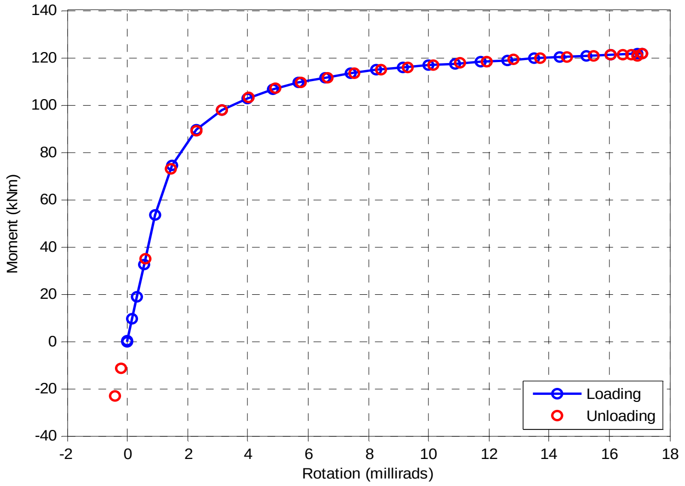
Abaqus elastic shallow foundation M-θ



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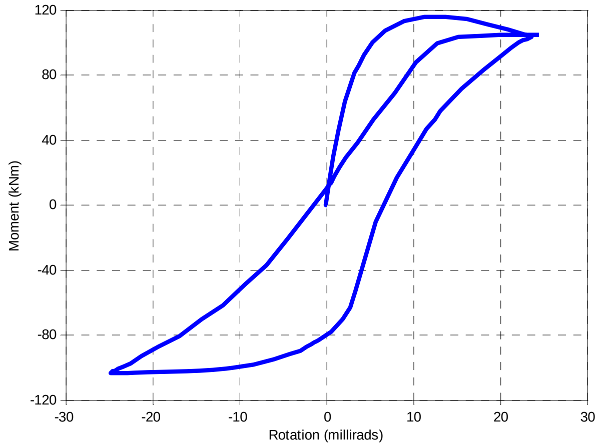
Abaqus computed snap-back



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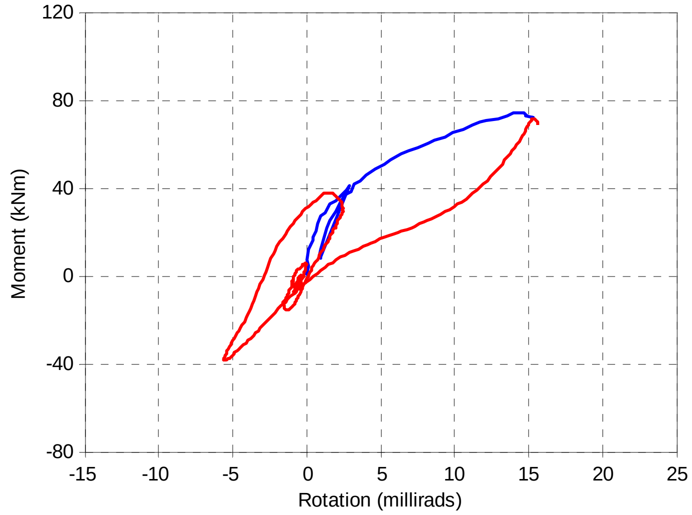
Measured snap-back



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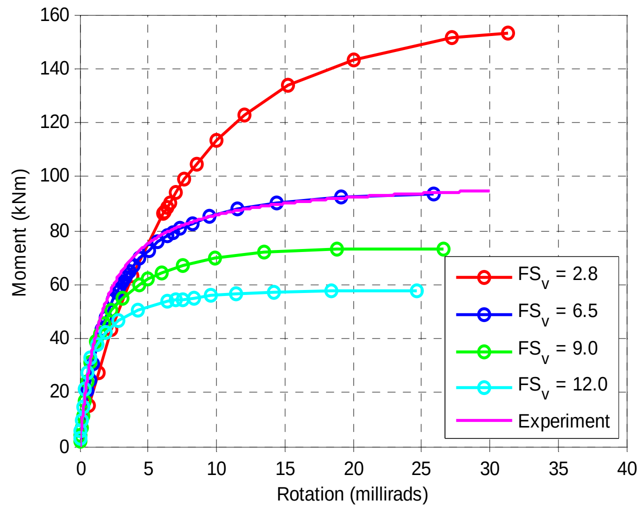
Effect of different static FoS



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Shallow foundation conclusion

- If the foundations for URM walls can rotate **half to one degree** then there is considerable potential for "shielding" of the URM against EQ
  - basis of this conclusion is the field testing we have done
  - realistic 3D finite element analysis with uplift and nonlinear soil

Return to question on the title slide

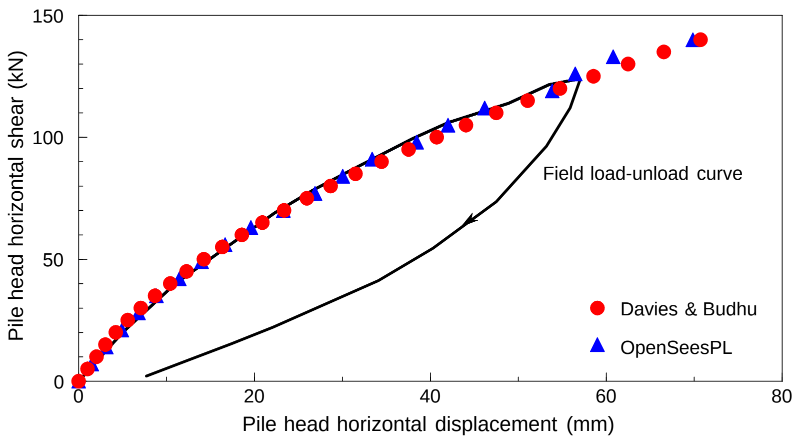
- Can geotechnical insight help?
- **YES** (with geotechnical-structural cooperation)

Pile foundation interpretation

Pile foundations - sections 12 - 14

- Shows that we have a realistic method for estimating nonlinear lateral load behaviour
- generally piles do not show as much nonlinearity as shallow foundations
- pile damping not as large as that for shallow foundations

Nonlinear pile lateral loading



OpenSeesPL is a 3D nonlinear FEM software

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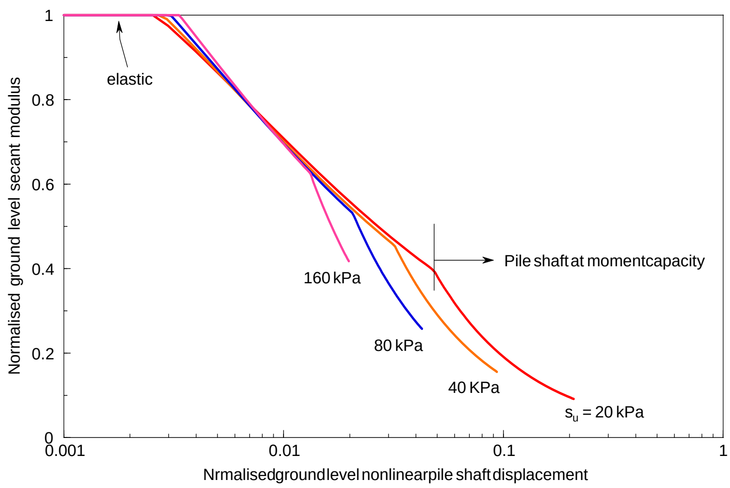
Nonlinear pile deformation (page 14-3)



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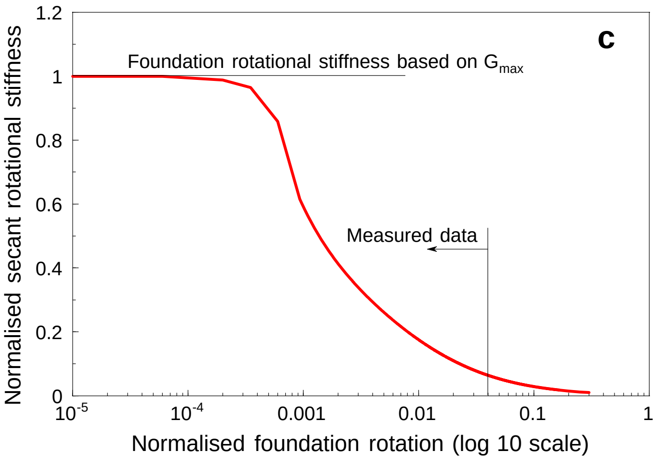
Pull-back Fig. 5.4c



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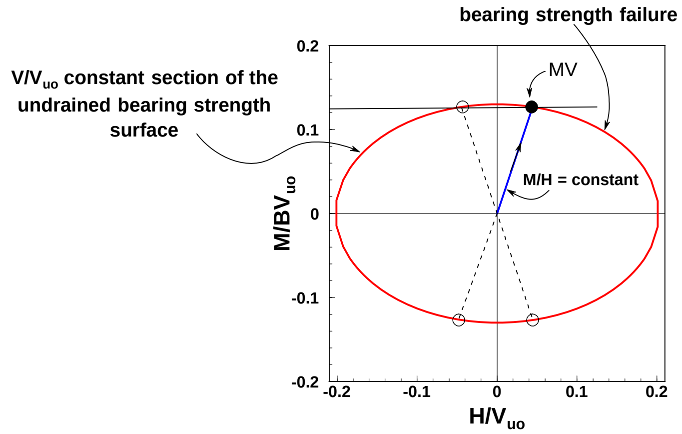
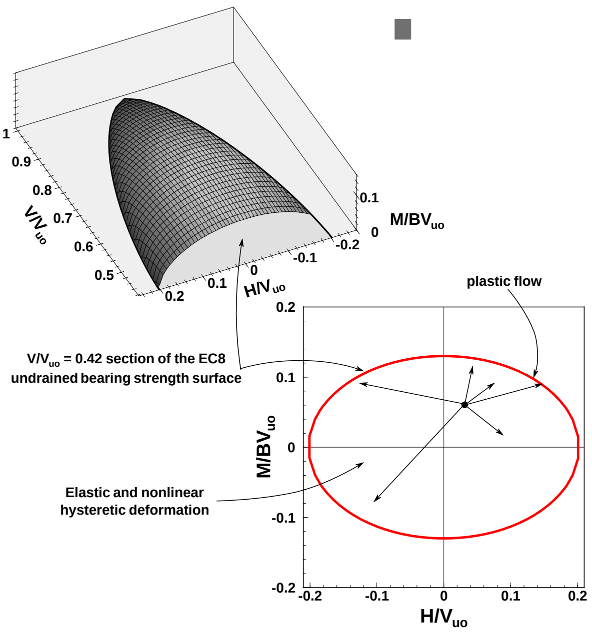
Example 4-2 Calculation of MV





Constant vertical load section of BSS

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Nonlinear pile lateral loading

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