BUILDING DAMAGE ASSESSMENT

Wen Dazhi, BSc, PhD
PE, PE(Geo), AC(Geo), CE, MICE, MIEAust, CPEng

BUILDING DAMAGE ASSESSMENT

- Damage categories
- Basis of damage assessment
- Staged design approach and design assumptions
- Case studies of buildings on mixed foundations
- Conclusions

DAMAGE CATEGORIES

Three broad categories that affect:

1) Visual appearance or aesthetics;

2) Serviceability or function; and

3) Stability.

DAMAGE CATEGORIES

Category	Typical crack width (mm)	Effects
Negligible	0.1mm	Hairline cracks only
V. Slight	<1mm	Damage mainly to internal wall finishes.
Slight	<5mm	Doors & windows may stick slightly
Moderate	5 – 15mm or several >3mm	Doors and windows sticking. Service pipes may fracture. Weather tightness impaired.
Severe	15 to 25mm	Windows and door frames distorted. Walls leaning, some loss of bearing in beams. Service pipes disrupted.
V. Severe	>25mm	Beams lose bearing, walls require shoring. Windows broken with distortion. Danger of instability.

DAMAGE CATEGORIES

Category	Typical crack width (mm)	Repair
Negligible	**0.1mm**	**Hairline cracks only**
V. Slight	**<1mm**	**Can be easily treated during normal decoration**
Slight	**<5mm**	**Can be easily filled. Some repainting may be necessary**
Moderate	**5 – 15mm or several >3mm**	**Patching by a mason. Repainting and replacement of a small amount of brickwork.**
Severe	**15 to 25mm**	**Extensive repair works involving breaking-out and replacing sections of walls.**
V. Severe	**>25mm**	**Major repairing work involving partial or complete rebuilding.**

AS2870 DAMAGE CLASSIFICATION FOR WALLS

Description of typical damage and required repair	Approximate crack width limit	Damage category
Hairline cracks	< 0.1mm	0
Fine cracks which do not need repair	< 1mm	1
Cracks noticeable but **easily filled.** Doors and windows stick slightly.	< 5mm	2
Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather tightness often impaired.	5mm to 15mm (or a number of cracks 3mm or more in one group)	3
Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window and door frames distort. Walls lean or bulge noticeably, some loss of bearing in beams. Service pipes disrupted.	15mm to 25mm but also depends on number of cracks	4

AS2870 - DAMAGE CLASSIFICATION FOR CONCRETE FLOORS

Description of typical damage	Approximate crack width limit in floor	Change in offset	Damage category
Hairline cracks, insignificant movement of slab from level.	< 0.3mm	<1/375	0
Fine but noticeable cracks. Slab reasonably level.	< 1mm	<1/300	1
Distinct cracks. Slab noticeably curved or changed in level.	< 5mm	<1/200	2
Wide cracks. Obvious curvature or change in level.	5mm to 15mm (or a number of cracks 3mm or more in one group)	1/200 to 1/120	3
Gaps in slab. Disturbing curvature or change in level.	15mm to 25mm but also depends on number of cracks	>1/120	4

AS2870 Residential slabs and footings - construction

DAMAGE CATEGORIES

- Category 2 - Slight: Results from within the structure itself or associated with ground movement.
- Category 3 - Moderate and above: Usually associated with ground movement.

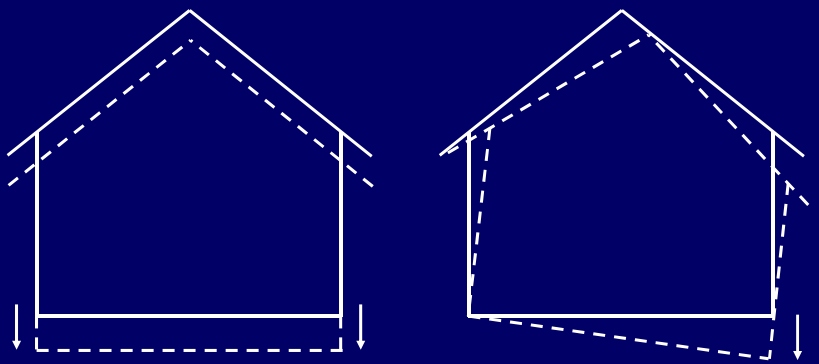
DAMAGE CATEGORIES

- Not economic to restrict to no damage.
- Typically allow up to ‘slight damage’ for most structures.
- Restrict to ‘very slight damage’ for buildings of historical or architectural significance, such as heritage buildings.

BASIS OF BUILDING DAMAGE ASSESSMENT

- Criterion for onset of visible cracking: Limiting tensile strain.
- Local strain at onset of cracking much smaller than limiting tensile strain.

MODES OF MOVEMENT - NOT DAMAGING



UNIFORM SETTLEMENT

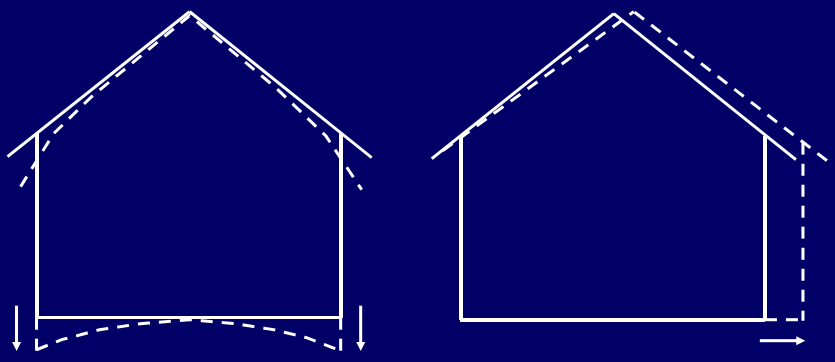
UNIFORM TILT

GeoSS 10112009 11

RIGID BODY TILT

GeoSS 10112009 12

MODES OF MOVEMENT - DAMAGING

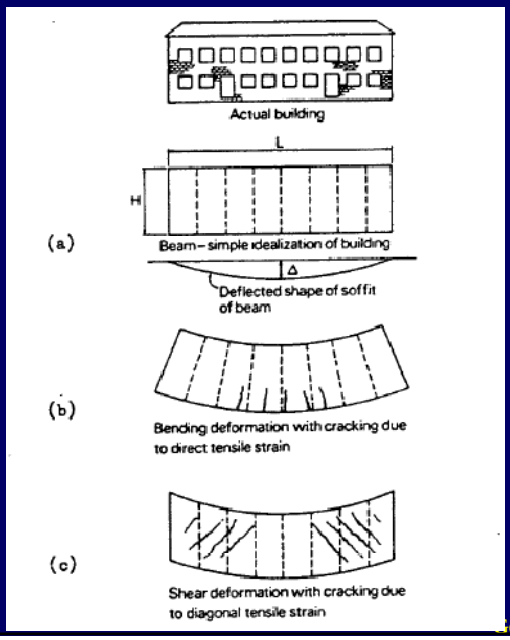


BENDING/SHEAR

HORIZONTAL EXTENSION

MODES OF MOVEMENT - DAMAGING

BENDING AND SHEAR STRAINS THAT CAUSE DAMAGE

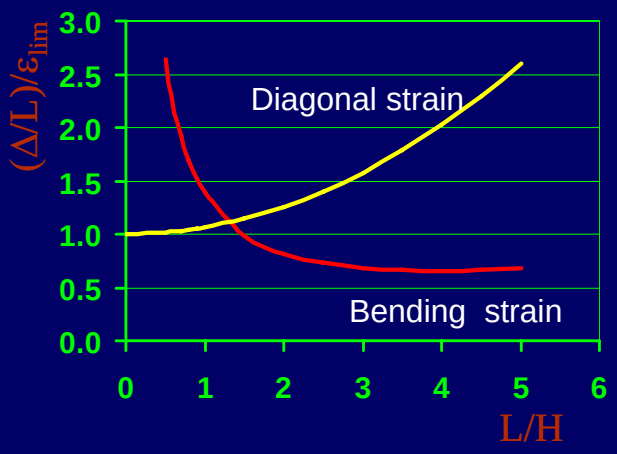


LIMITING TENSILE STRAIN VS DAMAGE CATEGORIES FOR MASONRY BUILDINGS

Limiting tensile strain (%)	Damage Class	Typical crack width (mm)
0.0 - 0.05	Negligible	<0.1
0.05 – 0.075	Very Slight	<1.0
0.075 – 0.15	Slight	<5.0
0.15 – 0.3	Moderate	<15
>0.3	Severe to Very Severe	>15

BENDING AND DIAGONAL STRAIN

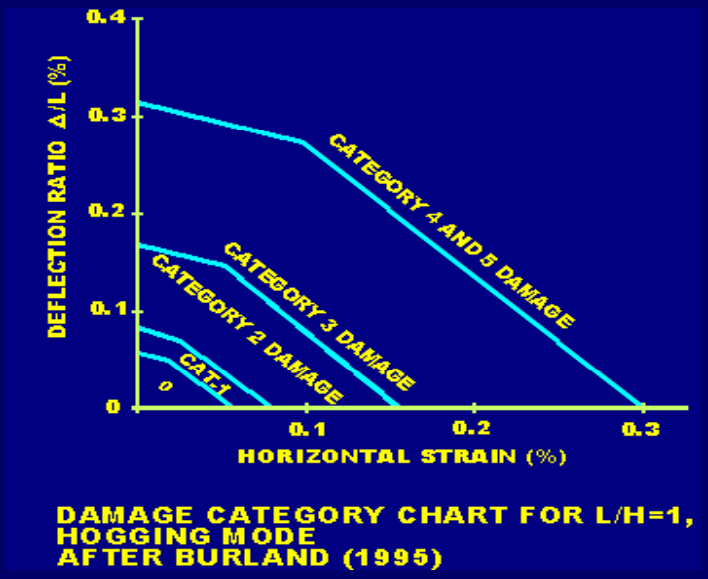
Beam (E/G = 2.6 for masonry structure) Undergoing Hogging with Neutral Axis at Bottom Edge



TOTAL CALCULATED STRAINS

- Horizontal strain and the bending strain
- Horizontal strain combined with diagonal strain using a Mohr's circle of strain.

INTERACTION DIAGRAM, Δ/L, ε_h & L/H



DAMAGE CATEGORY CHART FOR L/H=1, HOGGING MODE
AFTER BURLAND (1995)

STAGED ASSESSMENT OF BUILDINGS

- Stage 1 - if settlement <10mm,
- slope < 1:500

→ Negligible damage

- Stage 2 - Assume 'green field conditions', building stiffness not considered, if tensile strain < 0.15%

→ Slight damage ('conservative')

STAGED ASSESSMENT OF BUILDINGS

- Stage 3 - Detailed assessment, considering stiffness of building and three dimensional effects of tunnelling and excavation

ASSUMPTIONS FOR STAGE 2

- Building simply follows the ‘green field’ settlement.
- Building is made of masonry.
- Settlements due to consolidation are even, and do not induce bending or horizontal strain.
- First two assumptions are considered ‘conservative’ i.e. they over-predict strain and damage.

STAGE 3 ASSESSMENT

- Refinement of Stage 2 assessment.
- Foundation details are considered.
  - Ground beams will reduce horizontal extension to a negligible value.
  - Piles will reduce settlements and bending strains.
  - Continuous foundations, e.g. strip footings or rafts are less prone to damaging differential settlements.

STAGE 3 ASSESSMENT

- Effects of soil-structure interaction: building stiffness will modify ‘Green Field’ settlements, typically making them wider and flatter.

Summary Sheet

BUILDING DAMAGE ASSESSEMENT SUMMARY SHEET

Project/ Contract Number

Name of Building:

Address:

Description of Structure:

Description of Foundations

PHOTO

Drawings available YES/NO

Result of Preliminary Assessment
Maximum settlement:
Maximum slope:

Second stage assessment required YES/NO

Result of Second Stage Assessment
Maximum settlement:
Maximum ground slope:
Maximum tensile strain:

Detailed evaluation required YES/NO

Detailed Assessment attached YES/NO
Protection measures needed YES/NO

Protection measures proposed:

BUILDING DAMAGE ASSESSMENT

- The theory works well in buildings on uniform foundations.
- Reliance should not be placed on theoretical assessment alone.
- Careful inspection of buildings should be carried out. There would be tell-tale signs that indicate problems in the buildings.
- Detailed structural assessment will be necessary for those buildings.

CONSOLIDATION SETTLEMENTS - COMMON ASSUMPTIONS

- Consolidation settlements are generally relatively uniform if the depth and compressibility of the soft soils are uniform.
- If uniform,consolidation settlements do not cause tensile strain and do not cause damage.
- Consolidation settlements commonly assumed to have negligible effect.

CASE STUDIES OF BUILDINGS ON MIXED FOUNDATION

- For buildings on mixed foundations or founded over varying depths of soft clay, the common assumptions:
  - That it is conservative to assume that the building moves with the ground
  - That consolidation settlements do not induce significant differential settlement or tensile strain

ARE NOT APPLICABLE

FOOCHOW METHODIST CHURCH

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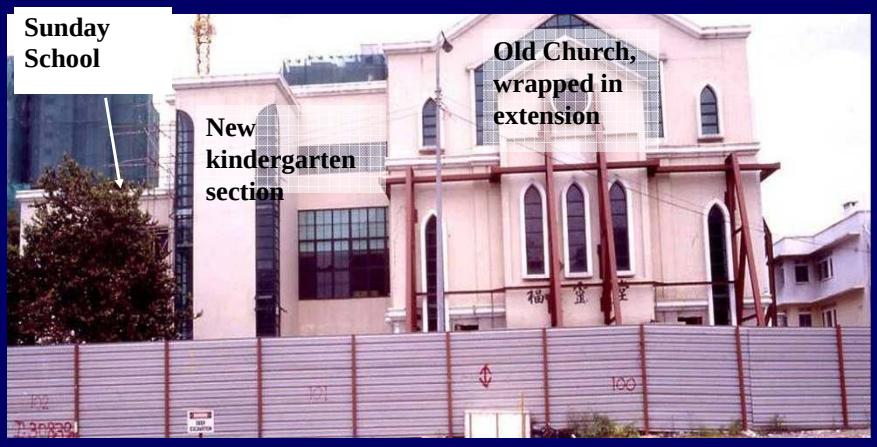

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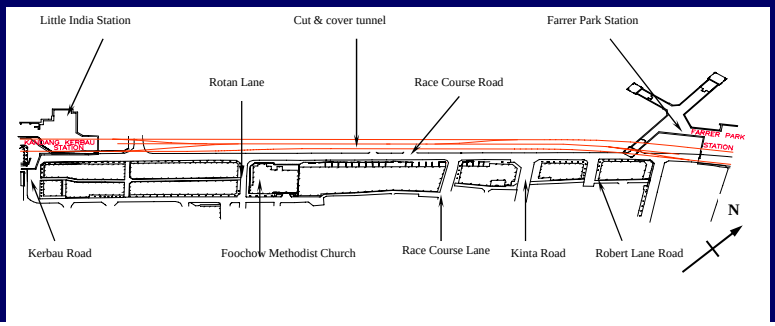

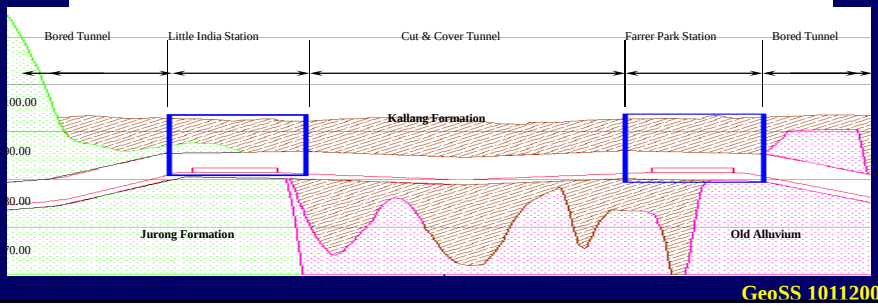

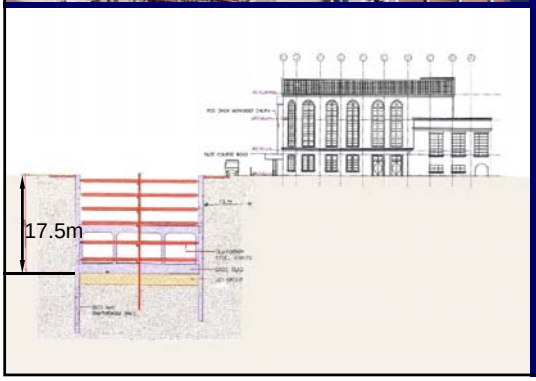

FOOCHOW METHODIST CHURCH

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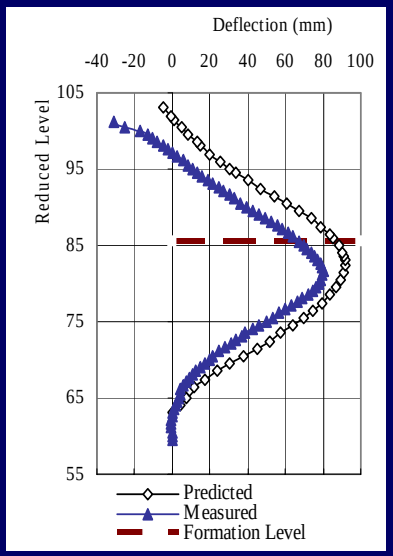

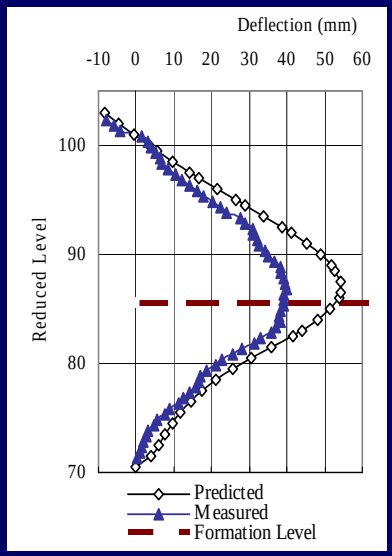

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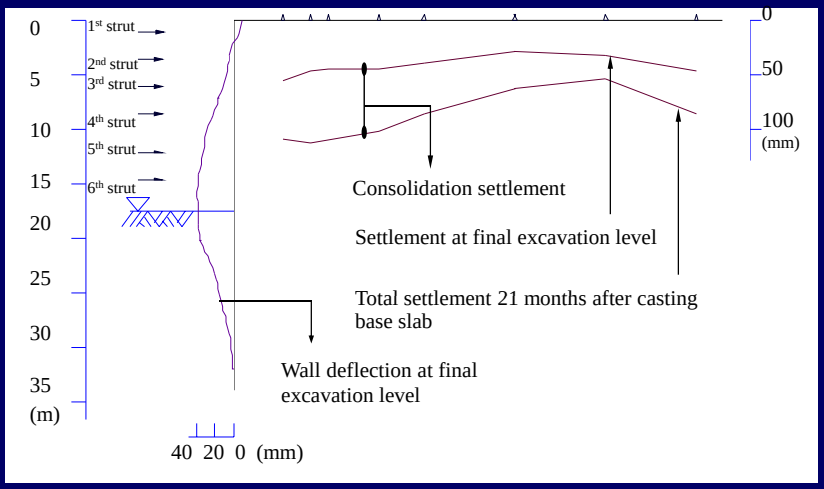

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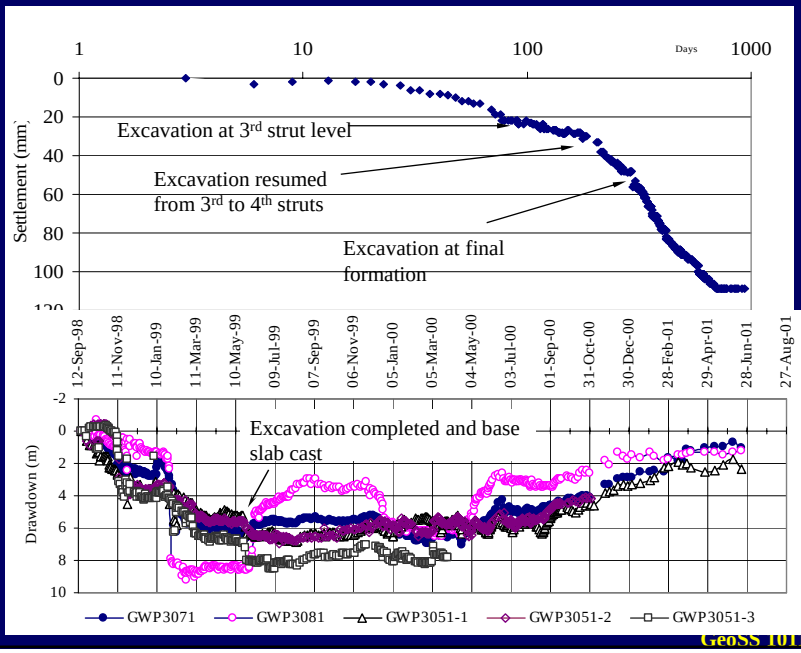

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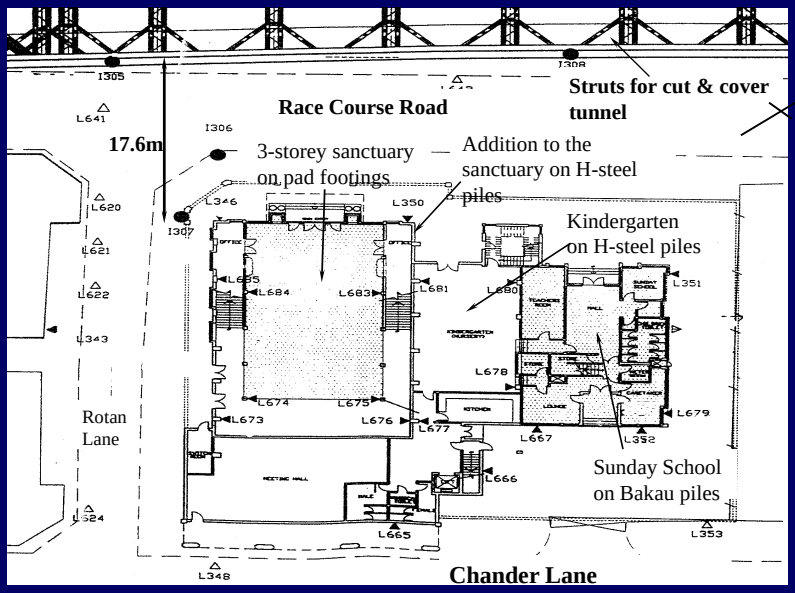

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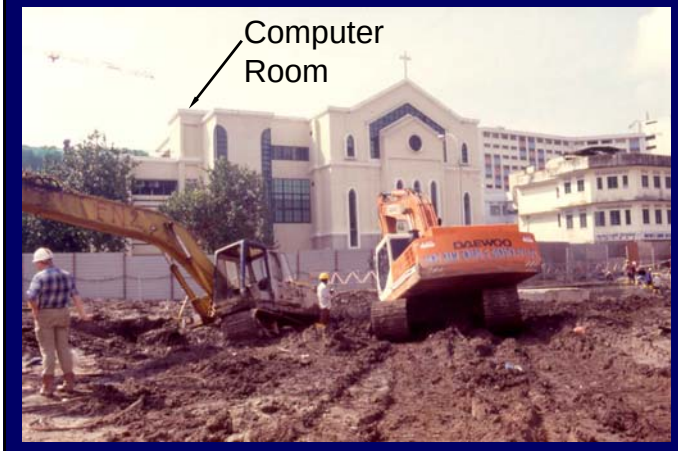
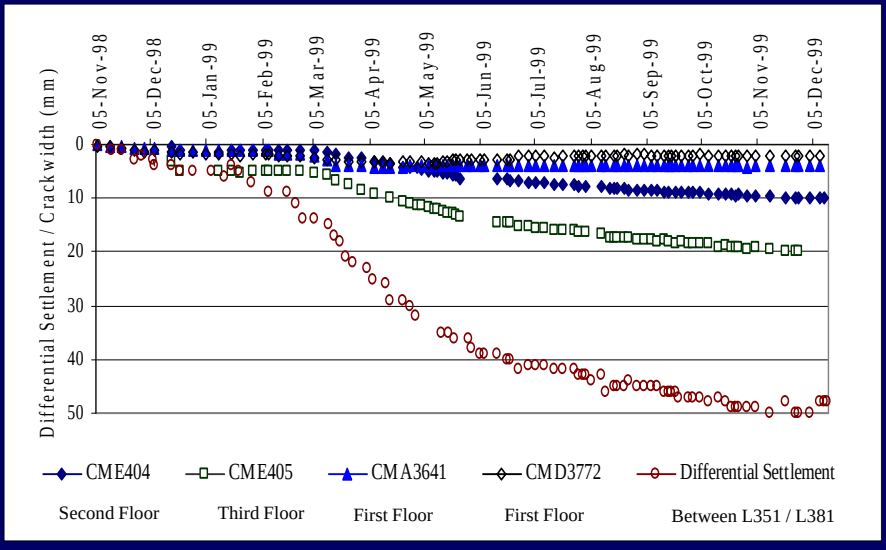


Moderate to Severe damage (12mm crack) at 15mm settlement, before excavation started

FOOCHOW METHODIST CHURCH

Computer Room

FOOCHOW METHODIST CHURCH



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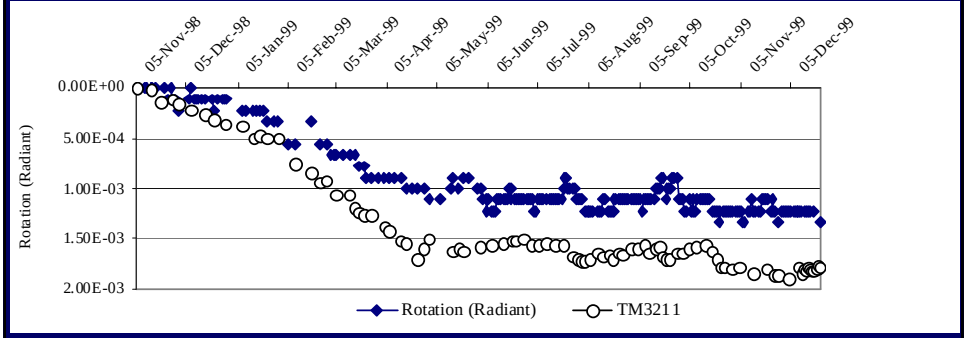
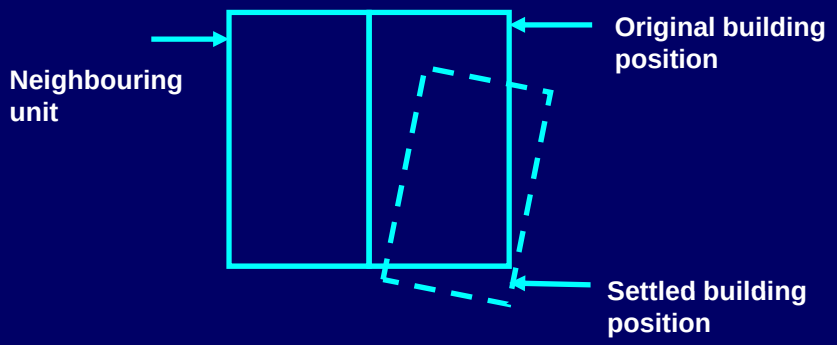


FOOCHOW METHODIST CHURCH

Junction of Sunday School and Kindergarten

FOOCHOW METHODIST CHURCH



For buildings in a terrace, rigid body tilting will lead to tearing at the junction with the neighbour unit.

148 RACE COURSE ROAD

148 RACE COURSE ROAD

Shirlaw, Wen, Algeo & Patterson-Kane (2003)

148 RACE COURSE ROAD

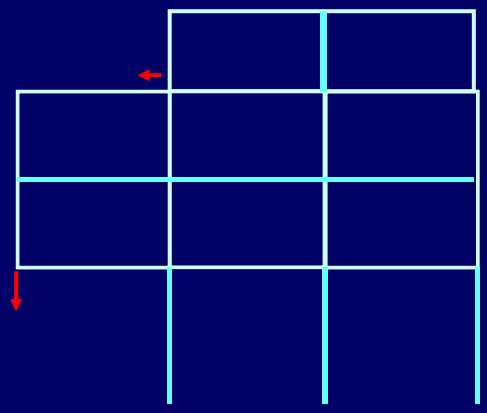
Settled by 107mm

No 146, piled

Building tilting away from the adjacent structure

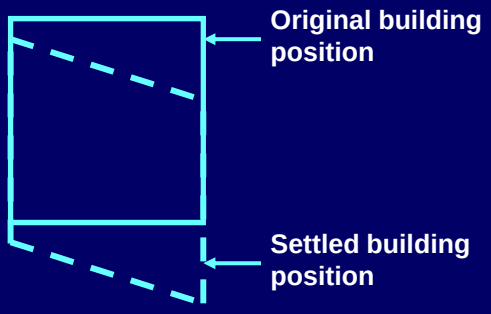
148 RACE COURSE ROAD

148 RACE COURSE ROAD



Adjacent buildings on different foundations: Old buildings on footings butted against newer buildings on deep foundations.

148 RACE COURSE ROAD



Racking action causes damage, in particular at door / window frames / arches.

Masjid Wak Tanjong

Masjid Wak Tanjong

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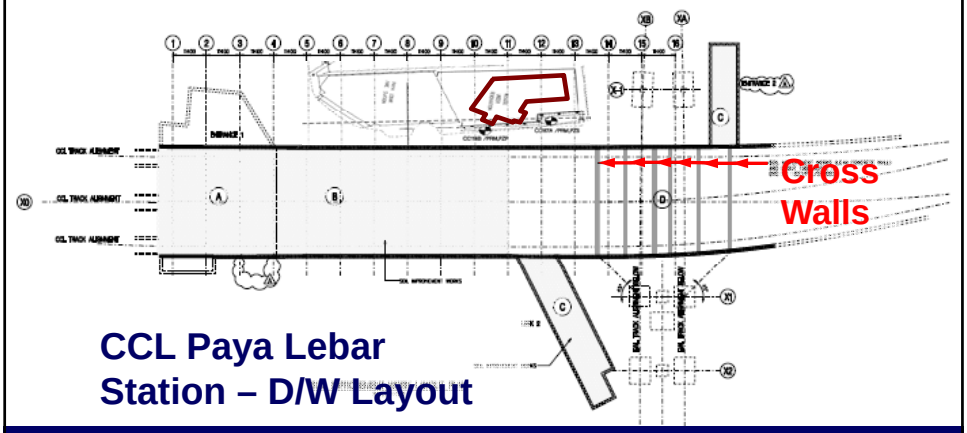

CCL Paya Lebar
Station – D/W Layout

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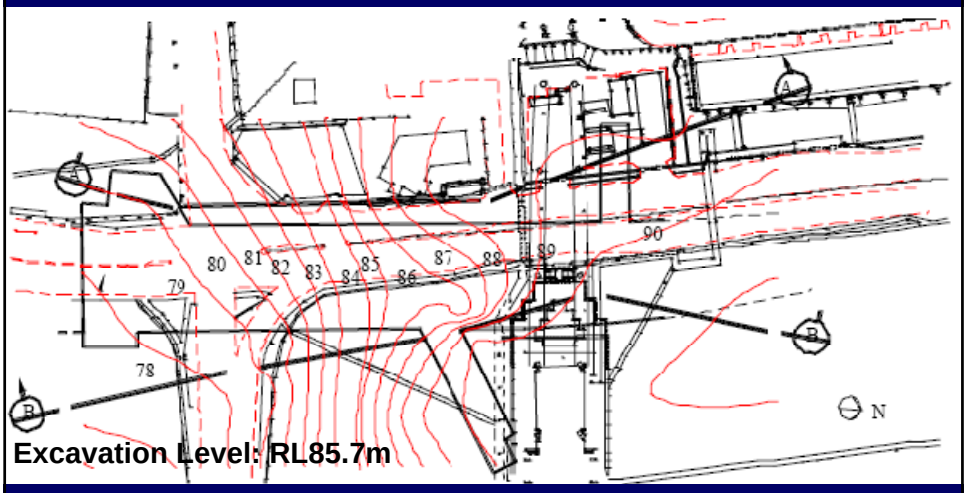

Excavation Level: RL85.7m

Interface between Kallang Formation and OA

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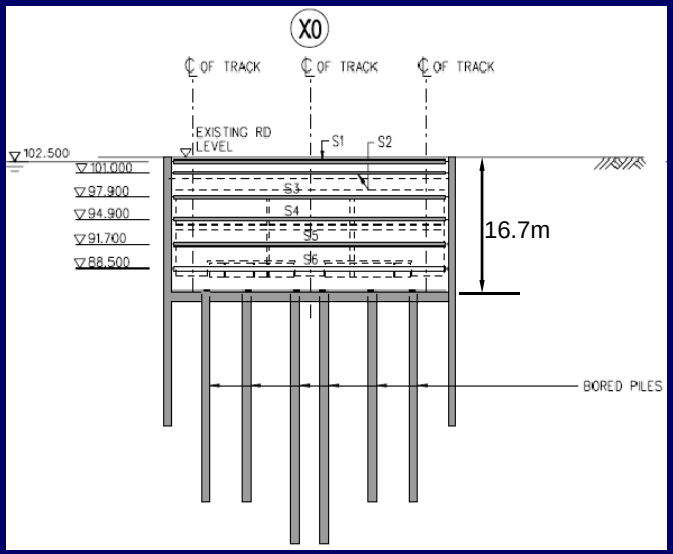

Typical Excavation Sequence

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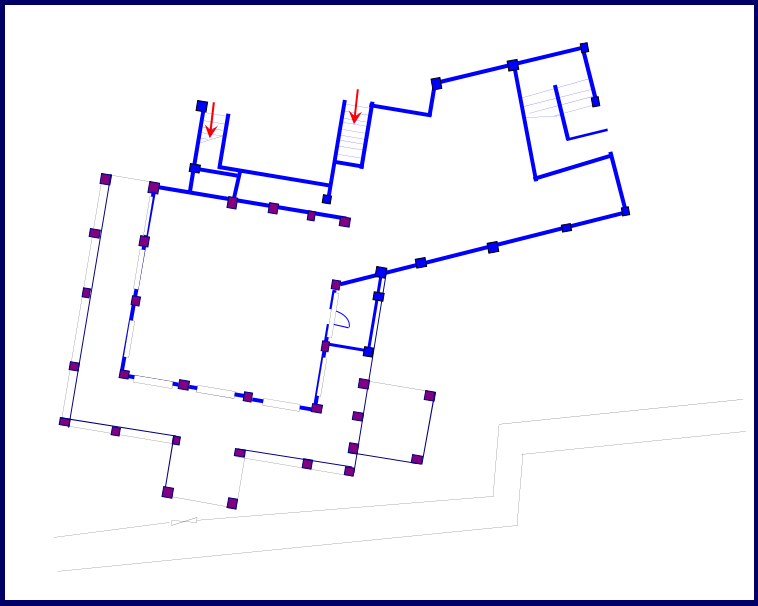

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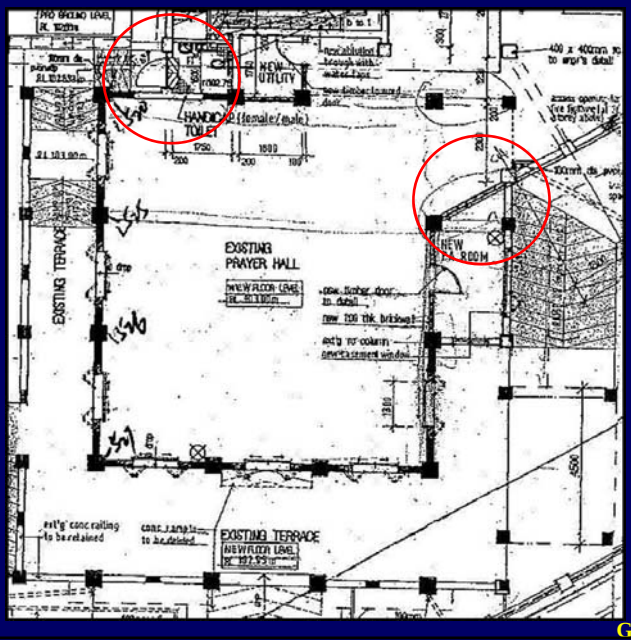

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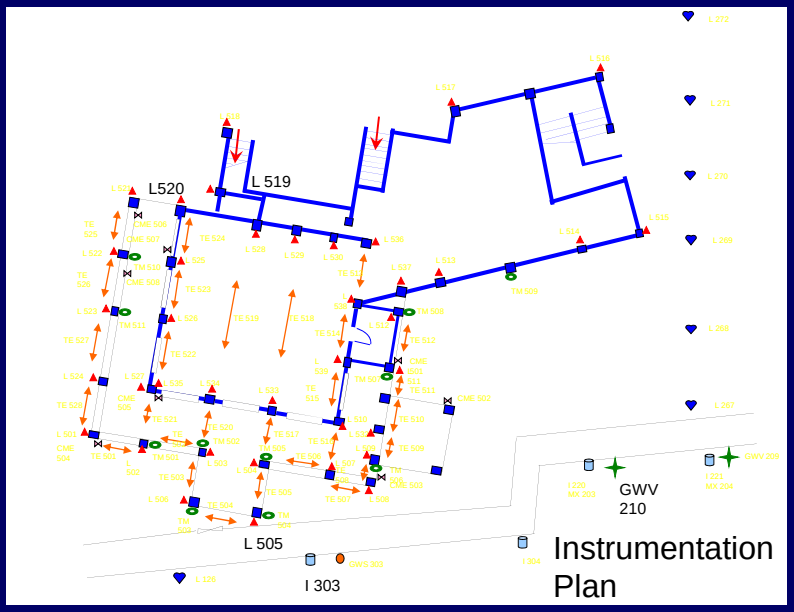

Instrumentation Plan

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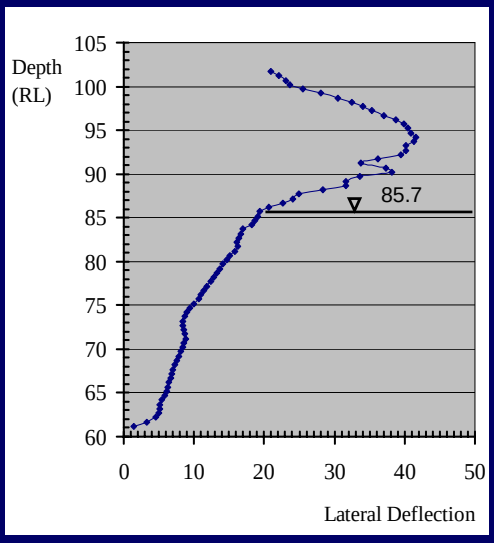

Lateral Soil Movement in Front of the Mosque

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- Max reduction in pore water pressure in piezometric level:
  - At 9m below ground: 1.5m
  - At 15m below ground level: 3m
  - 27m below ground level: 6m

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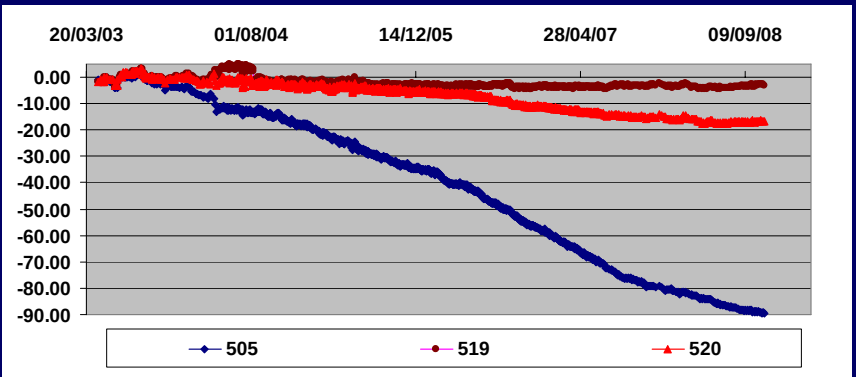

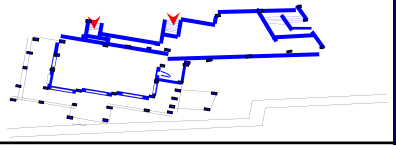

Building Settlements

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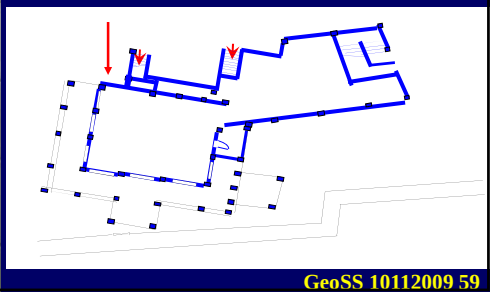

GeoSS 10112009 59

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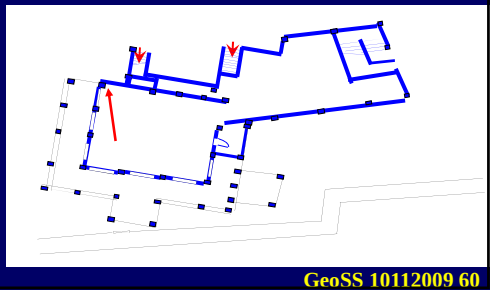

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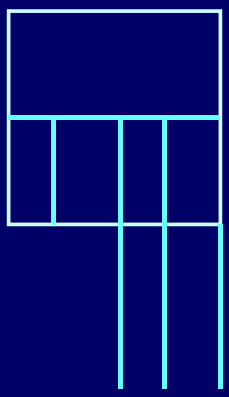
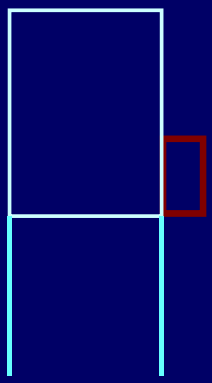


Part of the building on piles and part on footings – Damaging at small differential settlements.

Other Examples



Annex structure on footings abutting buildings on piles

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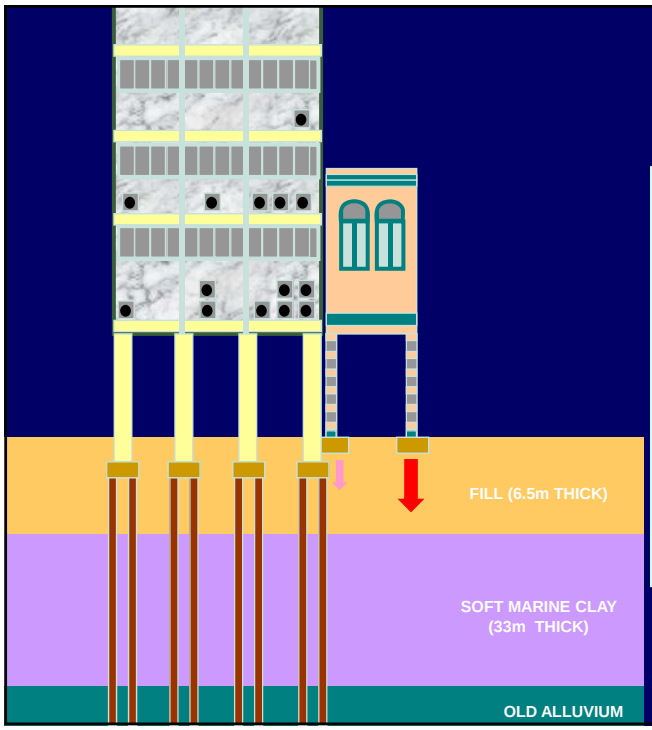
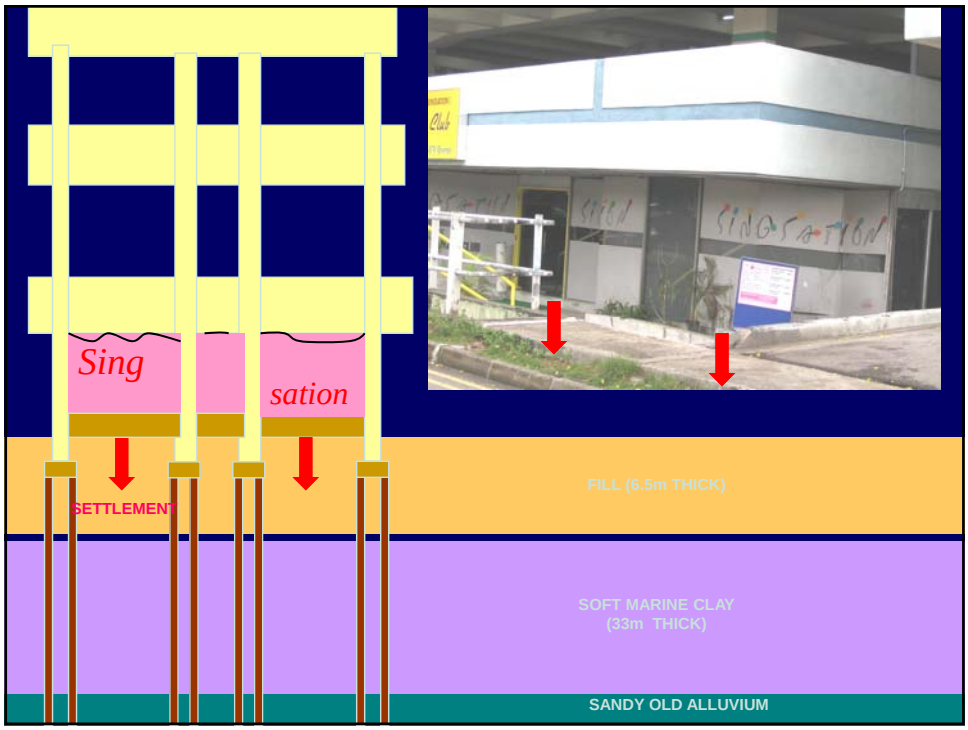


Piled

Footings

GeoSS 10112009 64

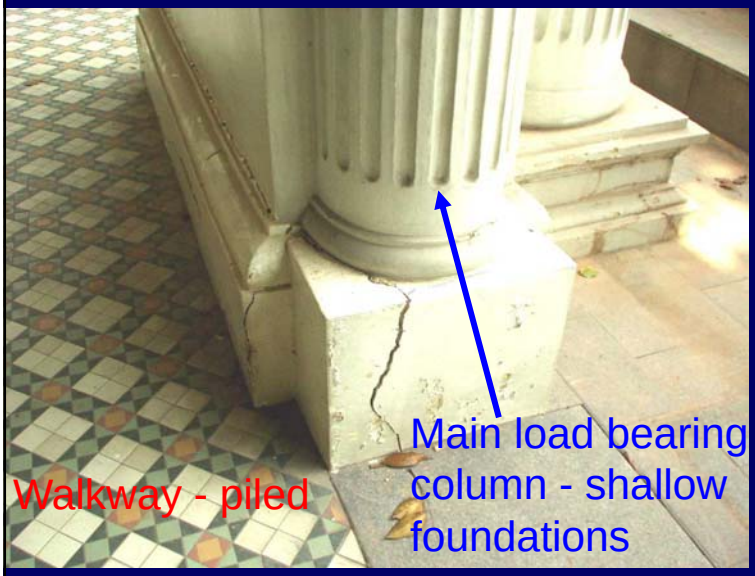

COLLECTIONS
PTE LTD
GeoSS 10112009 65

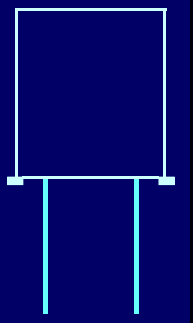

Sing
sation
SETTLEMENT
FILL (6.5m THICK)
SOFT MARINE CLAY
(33m THICK)
SANDY OLD ALLUVIUM

STAR SINGSATION KTV CLUB



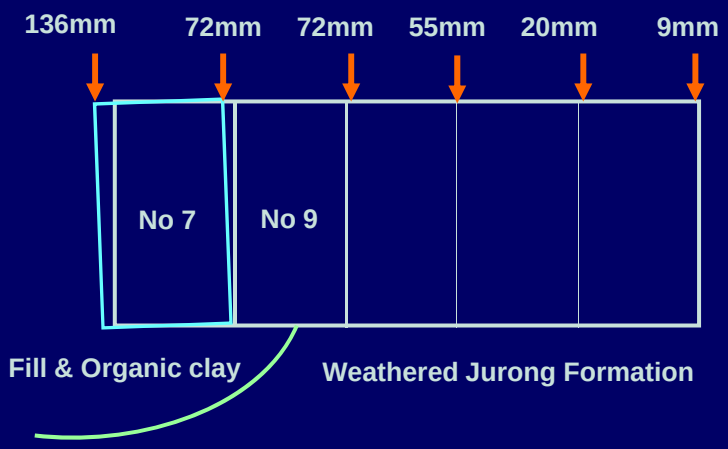

GeoSS 10112009 67





GeoSS 10112009 68

No 7 CANTONMENT ROAD



Shirlaw, Wen, Algeo & Patterson-Kane (2003)

GeoSS 10112009 69

No 7 CANTONMENT ROAD

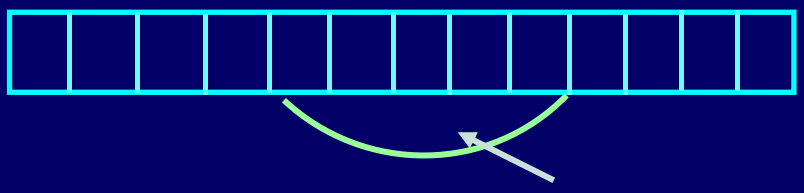
Shirlaw, Wen, Algeo & Patterson-Kane (2003)

GeoSS 10112009 70

No 7 CANTONMENT ROAD

Shirlaw, Wen, Algeo & Patterson-Kane (2003)

Buildings over varying depths of soft clay - usually a terrace problem



Pocket of soft clay

GeoSS 10112009 73

GeoSS 10112009 74

POSSIBLE MEASURES

- To identify buildings that are unusually sensitive to settlement
- To carry out protective measures

IDENTIFICATION

- To identify buildings on mixed foundations - A&A drawings
- To identify locations of variation in geology, in particular along terrace houses
- A general walk around the site – building inspection

IDENTIFICATION

- Look at the geological profile / soil investigation data - consolidation often associated with areas with soft clay (marine/estuarine)
- Sensitive buildings often show some signs of damage or repair - existing cracks / spalling
- Watch out for additions to old buildings or new buildings abutting old buildings
- With terrace houses, signs of local dips in the roof line, local settlements in the road outside or local damage to drains / aprons

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PROTECTIVE MEASURES

- Recharge wells to control consolidation settlement (only fully works with nearly water-tight wall and with wells installed before excavation starts)
- Separate the parts of the structure on different foundations
- Prop (where necessary for safety) and repair afterwards
- Underpinning

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CONCLUSIONS

- Methods of Mair, Taylor and Burland to be used.
- Stage 1 - if < 10mm, no need to consider further
- Stage 2 - ‘green field’ assessment. Assumes building is flexible and moves with ground
- Stage 3 - Detailed evaluation, taking into account building stiffness and foundations

CONCLUSIONS

- Buildings on mixed foundations are extremely sensitive to settlement and more susceptible to damage than other buildings.
- Stage 3 analysis for all buildings on mixed foundations are required.

THANKS