Performance of embankments on soft ground:

A1033 Hedon Road Improvement Scheme, UK

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INTRODUCTION

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A1033 Hedon Road Improvement Scheme

- New dual carriageway alongside existing two-lane carriageway close to Hull estuary
- Underlain by about 8.0m depth of soft alluvial deposits

- Paper focuses on instrumentation and ground response during construction of approach embankment to flyover at Salt End junction, Hedon

- Specifications include:
- Limit ongoing settlements to those agreed with Highways Agency
  - For higher embankments, achieve 100% primary consolidation in alluvial deposits under final working load and seek to over-consolidate to some degree to limit secondary compression settlements

  - Limit total differential settlements to between 20 and 50 mm over five-year defect correction period following completion of construction

  - Restrict ground movements along embankment toe due to close proximity of existing carriageway

Embankment construction

- Stage construction in conjunction with ground improvement (prefabricated vertical drains and temporary surcharge)
  - Triangular grid pattern, centre spacing of 1.0 to 2.0 m
- Basal reinforcement layer across full embankment width in transition zone to bridge abutments (founded on pile groups end-bearing in glacial sandy gravel stratum)
  - Reduced lateral movements in ground beneath existing carriageway
- Reinforced embankments steepened to 60 degrees on flyover approach
- Constructed in series of short bursts of activity and included use of some marginal fill improved by addition of cement
- Different surcharges (up to 2 m depth) and periods (typically two to four months) were adopted to fit contractor's program
- Surcharge remained in place until such time as back analysis of monitoring data proved geotechnical design specification achieved

GROUND INSTRUMENTATION

Site bounded to north by existing carriageway and to south by open drain

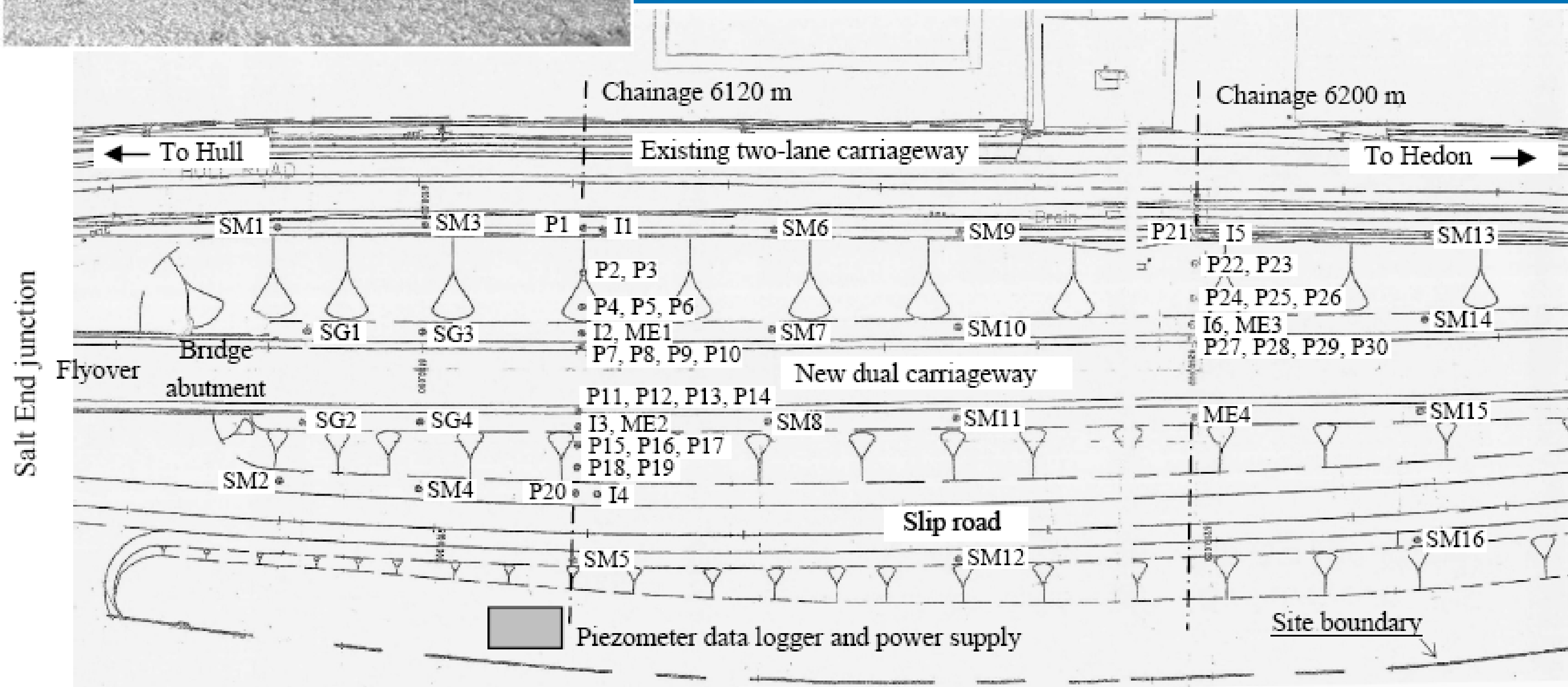


Figure 1. Ground instrumentation at Salt End junction (east). Note: P, piezometer; ME, magnetic extensometer; I, inclinometer; SG, rod and plate settlement gauge; SM, surface settlement marker.

Stratum	Chainage 6120 m Level (mOD)	Chainage 6120 m Thickness (m)	Chainage 6200 m Level (mOD)	Chainage 6200 m Thickness (m)
Ground surface level	+1.5		+1.9	
Crustal alluvium (firm silty clay)	–0.2	1.7	+0.1	1.8
Very soft alluvium	–5.3	5.1	–2.5	2.6
Soft, mottled organic clayey silt	–6.7	1.4	Not encountered	
Firm to very stiff glacial till	–16.2	9.4	–16.0	13.5
Glacial sandy gravel	–32.5	16.3	–32.5	16.5
Highly weathered chalk bedrock			Not proven	

Glacial till included gravelly sand lenses and underlain by sandy gravel deposits under artesian pressure

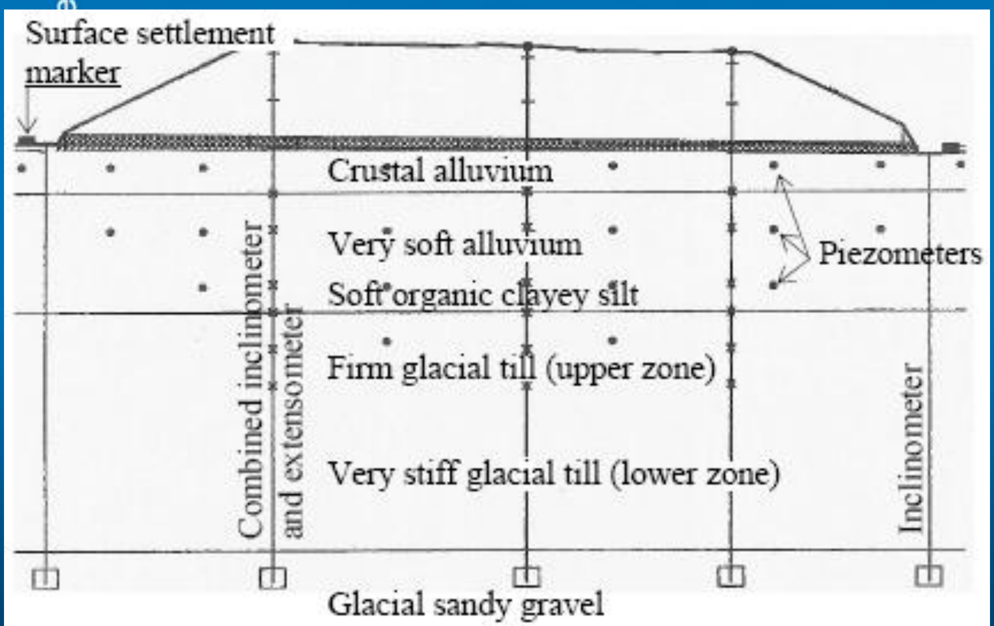
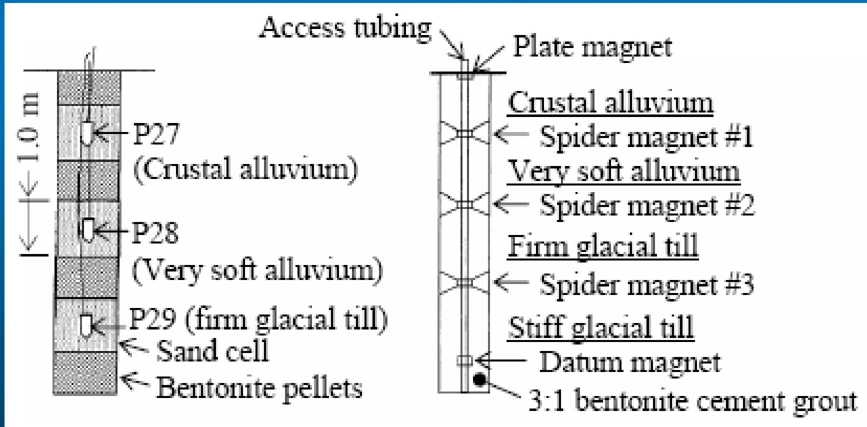


Figure 3. Layout of instrumentation at chainage 6120 m.



(a) Piezometer. (b) Extensometer.

- Construction rate controlled from geotechnical standpoint based on build up in pore water pressure (pwp), lateral deformation beyond toe and guarding against general shear failure, assessed from inclinometer deformations and toe heave recorded by surface settlement markers

- Piezometers initially recorded at 10 min intervals over two-week period to study variation in natural groundwater level due to tidal effects
  - Fluctuated periodically with tides, initially by up to 0.3 m in soft alluvial deposits, although tidal effect reduced considerably with increasing effective stress during construction

- Data shown in figure spans over three month period leading up to and including surcharge, with 4.0 m depth of fill already in place
    - P21 shows natural groundwater level
    - Immediate pwp build up when fill material placed although dissipated relatively quickly

  Maximum excess pwp = 25 kPa for increase in vertical stress of 135 kPa

- At no stage did recorded pwp reach critical values from geotechnical stability standpoint
- Excess pwp largely dissipated by end of two-month surcharge period
- Complete pwp dissipation on removing surcharge indicating 100% consolidation of alluvial deposits achieved under final embankment height

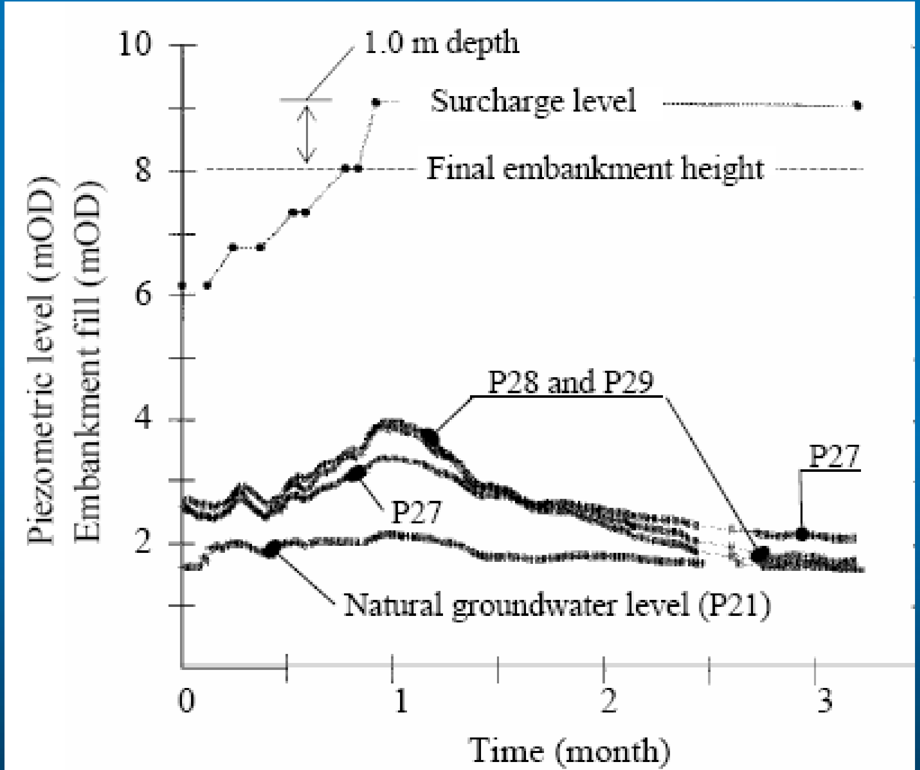


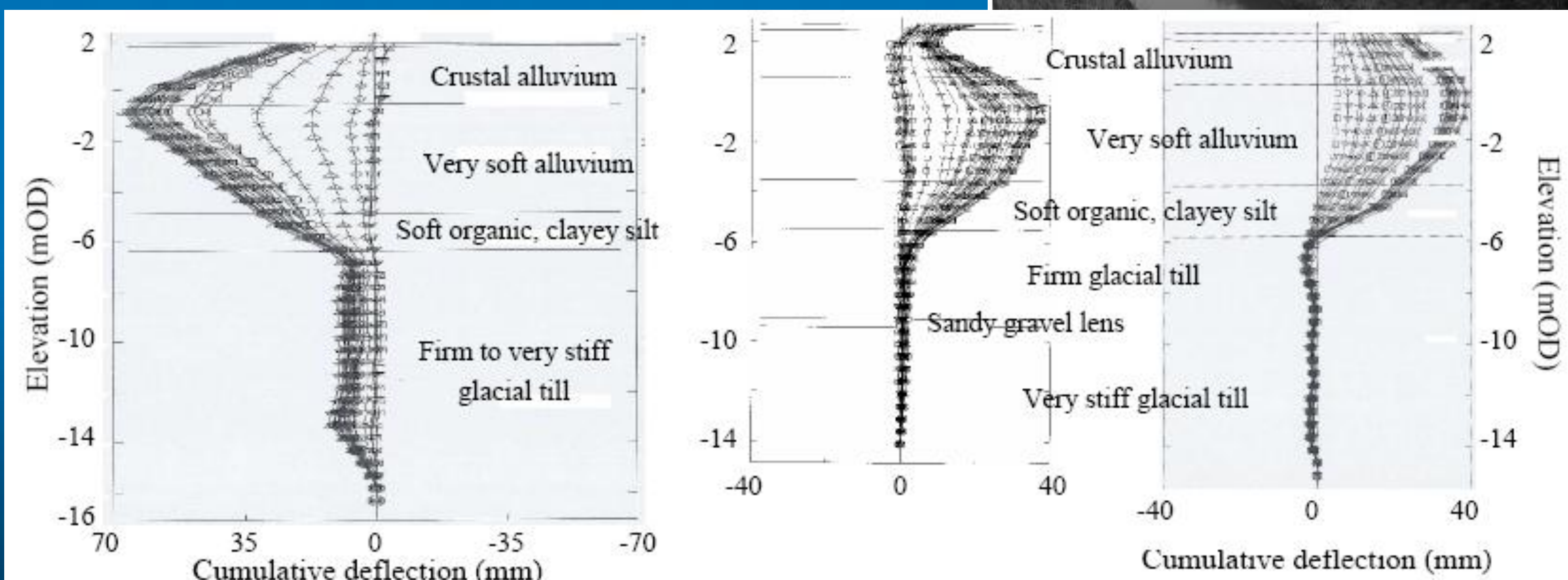
Figure 6. Pore water pressure response at chainage 6200 m.

Deformation response largely 1D compression, particularly within basal reinforcement area

Next to existing carriageway, max lateral movement of 40 mm within soft clayey silt layer, No significant heave along embankment toe

Larger lateral movements of up to 70 mm near open drain (reduction in shear capacity of ground foundation)

Recorded deformations in good agreement with lateral deformations modeled using PLAXIS (stiffness determined from pressuremeter tests)



(a) South crest (I3). (b) North crest (I2). (c) North toe (I1).

Figure 9. Lateral ground movements at chainage 6120 m.

- Actual values of primary consolidation parameters were determined from back analysis (curve fitting) of recorded magnetic extensometer and load–time history data
- Iterative process continued until theoretical consolidation curve matched recorded settlements

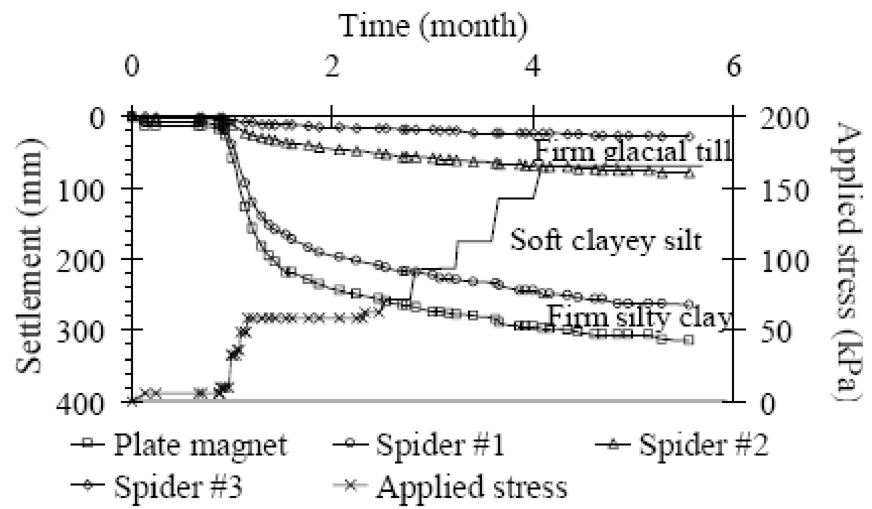


Figure 7. Settlement response from extensometer ME1 at chainage 6120 m.

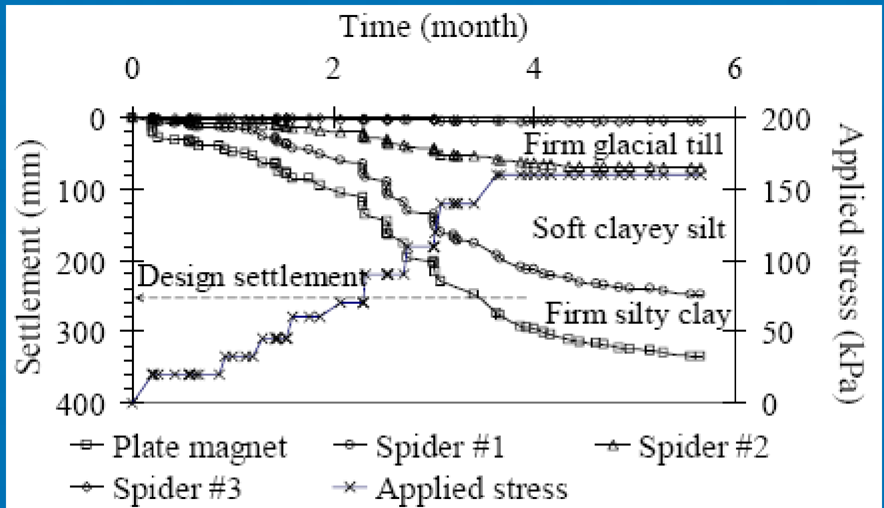


Figure 8. Settlement response from extensometer ME4 at chainage 6200 m

Stratum	Coefficient volume change (m^2/MN)	Coefficient of consolidation (m^2/year) Vertical direction Initial	Final	Horizontal direction Initial	Final	Horizontal to vertical coefficient of consolidation ratio
Crustal alluvium	0.30 to 0.50	3.0 to 7.0	1.0 to 2.0	3.0 to 7.0	1.0 to 2.0	1.0 to 1.2
Very soft alluvium	0.40 to 0.70	4.0 to 12	1.0 to 2.0	8.0 to 24	2.0 to 3.0	2.0
Soft, mottled organic clayey silt	0.40 to 0.60	3.0 to 4.0	1.0 to 2.0	6.0 to 7.0	2.0 to 3.0	1.7 to 2.0
Glacial till (firm upper zone)*	0.05 to 0.15	3.0	2.5	3.0	2.5	1.0
(stiff lower zone)	0.01 to 0.05	3.0	—	3.0	—	—

* Penetrated over full depth by vertical drains and included sand lenses of up to 0.2 m in thickness.

Back-analysed values were compared with design values from laboratory tests on undisturbed specimens

- Overall, coefficient of volume change values in good agreement

- Back-analysed coefficient of consolidation values two to four times greater than the values determined from oedometer data
  - Discrepancy most likely due to scale effects
- Soft soil layers cross-anisotropic with consolidation occurring up to twice as fast for horizontal (radial) flow rather than for vertical flow
- Secondary compression index values estimated from $C\alpha = 0.04Cc$, where Cc is the compression index. For the calculation of the secondary compression settlements, $C\alpha/(1 + e)$ values of between 0.0035 and 0.0090 were used (where e is void ratio).
- Target settlements for strata under final embankment height (achieving 100% consolidation of alluvium) were calculated using back-analysed parameters
- Recorded settlements for each layer exceeded target values proving that design specification achieved
- Soft soil deposits were lightly over-consolidated (OCR = 1.3) on removing surcharge material

Summary

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- Array of ground instrumentation monitored pwp and deformation response of ground during construction of approach embankments
- Inclinometers indicated ground foundation, aided by the basal reinforcement to embankment, essentially deformed one dimensionally
- Actual values of primary consolidation and secondary compression parameters were determined from back analysis of magnetic extensometer data
- After two-month surcharge period, recorded settlements for strata exceeded target values set by design specification, and settlements to date in accordance with design specification
- Back-analysed and laboratory-measured coefficient of volume change values in good agreement but actual coefficient of primary consolidation values two to four times greater than values determined from oedometer data
- Soft soil layers were cross-anisotropic with consolidation occurring up to twice as fast for horizontal flow rather than vertical flow

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Thank you