Tonkin & Taylor

1959 - 2009
50 YEARS

T&T Ref : 26586.002
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Hauraki District Council
PO Box 17
Paeroa 3640

Attention: Ken Thompson

Dear Ken

Hauraki Plains - house sites
Discussion of possible remedial measures

1 Introduction/Executive Summary

Hauraki District Council (HDC) have engaged Tonkin & Taylor Ltd (T&T) to consider and present options to mitigate the risk of settlements that adversely affect dwellings constructed on the Hauraki Plains. In this report the likely causes of the problems are discussed and the following possible mitigation options presented in detail:

(a) Surcharging (pre-loading) building platforms

(b) The use of lightweight fill

(c) Installation of subsurface wick drains

(d) Construction of settlement reducing piles

(e) Stiffening the structure to mitigate settlements

The costs of the various options are presented at the conclusion of the report. On the basis of the available information it appears that preloading and/or wick drains are likely to be the most cost effective ways of mitigating settlement risk.

2 Problem outline

We understand, from both previous T&T involvement and anecdotally, that a number of dwellings constructed on the Hauraki Plains have experienced significant differential settlements that have adversely affected the serviceability of the structures. This appears to have been increasingly prevalent in the last 10 years and may be exacerbated by the current tendency to construct relatively long, narrow single storey houses with on-grade floor slabs and brittle cladding systems (eg brick). T&T have reviewed a number of case histories on the Hauraki Plains and identified elements that are typically common to each site. These are summarised below:

(a) The primary cause of dwelling damage is differential settlement across a structure. The compliance documents for the New Zealand Building Code include Appendix B, which notes in Clause B1.02 that '*foundation design should limit the probable maximum differential settlement over a horizontal distance of 6 m to no more than 25 mm under serviceability limit state load* (1 in 240). From our experience it appears that differential settlements greater than about 1 in 150 can cause significant cosmetic damage to residential buildings. A table of differential settlements where damage is first observed is presented in Figure 2-1 below.

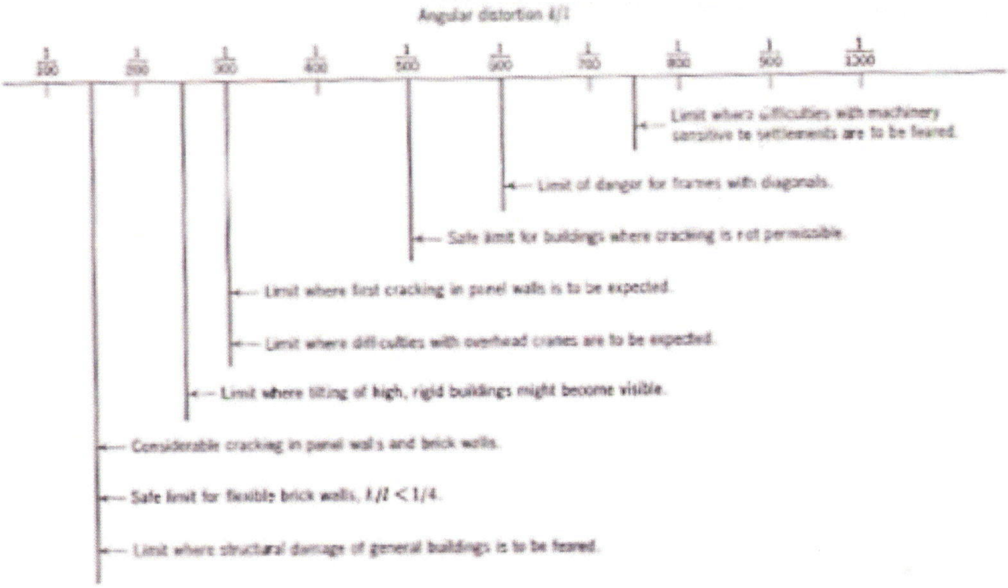

Fig. 14.8 Limiting angular distortions (From Bjerrum, 1963a).

Figure 2-1 Limiting angular distortion after Bjerrum 1963

(b) The primary cause of the differential settlement appears generally due to the weight of imported fill typically used to form building platforms. The fill is often required to achieve a minimum floor level specified by HDC to satisfy flood considerations.

(c) The weight of the house is usually relatively minor compared to the weight of the imported fill and hence makes only a minor contribution to settlements

(d) Differential settlements across the dwellings are associated with most dwelling damage.

3 Geological profile and mechanism of settlement

The Hauraki Plains typically comprise tens of metres thickness of compressible alluvial/estuarine (water deposited) sediments. These sediments consolidate (settle) when load (weight of house and fill) is applied to them. For residential sized structures and fill areas the amount of settlement is broadly proportional to the combined weight of the building platform fill and dwelling. The amount of settlement is also generally proportional to the width of the applied loading. A typical breakdown of the contribution to the weight from a single storeyed timber framed brick veneer clad house on a 600mm thick fill platform is presented below.

Average increase in pressure due to 600mm of filling	13kPa (72%)
Average increase in pressure due to 100mm thick slab	2.5kPa (14%)
Average weight of brick clad walls and roof	2.5kPa (14%)
TOTAL	**18kPa**

Consolidation settlement occurs as water is squeezed out of the underlying compressible materials. The duration of settlement depends on the distance the water has to travel to a more permeable layer such as a sand layer. The alluvial nature of the Hauraki Plains deposits mean that the spacing of permeable layers (that have a significant effect on the rate of consolidation) can vary significantly between sites and even within parts of the same site. Provided no additional load is imposed on the ground once the dwelling is constructed the rate of primary consolidation settlement constantly reduces with time.

4 Mitigation options

As the required or desired finished floor level is typically significantly higher than the existing ground level, and if the home owner desires an on-grade concrete slab , there will always be the potential for significant total and differential settlements. Accordingly, mitigation options that fall into the following categories have been considered:

(a) Surcharging (pre-loading) building platforms

(b) The use of lightweight fill

(c) The construction of subsurface wick drains to accelerate the rate of consolidation

(d) The construction of settlement reducing piles

(e) Stiffening the structure to mitigate settlements

Each is discussed in separate sections below. The hypothetical rate and magnitude of consolidation for a 'typical' dwelling is presented on Figures 1 and 2, attached in Appendix A. Figure 1 shows the calculated settlements over an 8 year period while Figure 2 shows only the first year. The figures have been developed based on assumed typical values of strength, compressibility and drainage rate for a purely theoretical example representing a possible site on the Hauraki Plains and should not be relied upon as a design example. The estimated settlements are expected to be higher than normally experienced and are presented to allow a comparison of possible mitigation methods to be made.

For a specific site, the detailed design should consider the actual site ground conditions, geometry and structure. In addition, preliminary cost estimates for various mitigation options are presented in Section 5, below. Again, these are presented on the basis of assumed conditions and will vary depending on the site location, access and type of solution selected.

4.1 Typical example

A typical example of the effects of mitigation options on a possible site is presented on Figures 1 and 2 using the adopted parameters presented in Table 4-1.

Table 4-1 Summary of adopted parameters for typical design assessment

Parameter	Value
Effective height of ground raising	0.85m (0.6m ground raising, 0.25m representing dwelling and slab weight) (total of 18kPa load)
Bulk fill density	22 kN/m^3
Drainage path length of compressible soil	4m
m_v	0.5 m^2/MN
Cv	4m^2/year
Ch	2m^2/year
Compressible thickness	30m
Area of building platform	500m^2 (for costing purposes only)
Stiffness of compressible soil (Ev)	2000 kPa

4.2 Do nothing

This option is included for completeness and is typically used where settlement risks are low. The building platform and dwelling are constructed and settlement occurs without any specific mitigation measures. This option has traditionally been used on the Hauraki Plains for house construction. It appears to be a satisfactory method where relatively flexible timber flooring and cladding are used but appears not to be appropriate with heavier structures and brittle cladding, particularly where the development fill height exceeds about 200mm.

4.3 Pre-loading (surcharging) the site

This option comprises the placement of additional fill (above the required development fill) over a slightly greater area than the building footprint. The rate of settlement is monitored and, once expected service load (house and permanent fill load) settlements are at tolerable levels the surcharge is removed. The pre-loading option on Figures 1 and 2 show the effect of pre-loading the site with a surcharge equivalent to twice the 'service load' height. In the example, doubling the surcharge height achieves effective completion in approximately 9 months when this would otherwise take more than 8 years.

It should also be noted that approximately 95% of the service load is achieved in about 4 years and that minimal settlement (less than 20mm) occurs after this. This is expected to be related to the observation that generally damage to houses on the Hauraki Plains manifests within 1 to 4 years after construction. The longer the surcharge can be left to pre-load the site, the lower the residual settlements.

4.4 Lightweight fill

The concept of lightweight fill is to reduce the amount of load applied to the underlying soils. The two lightweight fills considered here are structural polystyrene fill and pumice sands (typically AP3 from Winstones Puni, or similar). The relative weights of each and the effect of constructing a typical dwelling are presented in Table 4-2 below. It should be noted that, given the significant weight difference between lightweight and conventional fill, the weight of the dwelling can be balanced (compensated) by excavating the natural material and replacing in situ material with lightweight fill. Note that there is the potential for some lightweight aggregates to float during flood events if not designed with appropriate load balancing.

Table 4-2 Summary of effects of lightweight fill

Material	Unit weight (kN/m^3)	Typical fill settlement (mm)	Calculated dwelling settlement (mm)*	Total calculated settlements (mm)
Traditional bulk fill	22	200	80	280
Pumice sand	11.5	105	80	185
Polystyrene	0.25	3	80	83

* - Unless dwelling weight is 'load balanced'

Figures 1 and 2 indicate that pumice sand fill reduces the total settlement by about 45%, from about 280mm to about 180mm. The duration to residual settlements less than 20mm is at around 2.5 years.

Non-accelerated settlements are expected to take around 4 years to reach an acceptable level. However, 4 years is likely to be too long for home owners and builders to wait for settlements to occur. Accordingly, a method of accelerating the settlements could be attractive.

4.5 Subsurface wick drains

Wick drains are a potentially feasible settlement accelerating option. The option involves the installation of wick drains comprising strips of relatively stiff, permeable geotextile material with an HDPE core that are pushed into the ground using a mandrel. Photos showing the wick drains are presented in Figure 4.5-1 and 4.5-2 below.

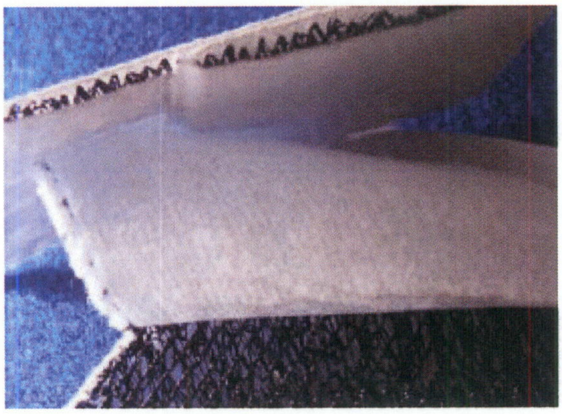

Figure 4.5-1 Typical wick drain

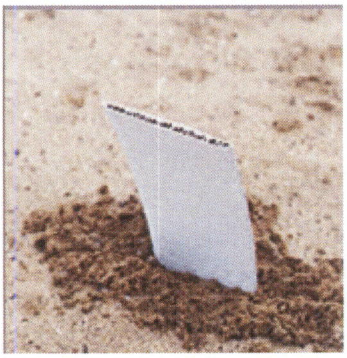

Figure 4.5-2 Installed wick drain in sand

Figures 1 and 2 show the accelerating effect of the wick drain on settlements at the site. The example shows accelerated wick drain settlements achieve effective settlement completion within a year as opposed to more than 8 years for conventional construction. The beneficial effect of further accelerating the settlement by constructing a pre-load surcharge is also shown. The rate of settlement can be adjusted by spacing the wick drains closer together or further apart as needed.

Dedicated wick drain installation rigs can be used but are unlikely to be cost effective on domestic sites due to the significant mobilisation costs. However, local contractors would readily be able to carry out wick drain installation with minimal adaption to their excavator. We consider that the most cost effective way of installing wick drains is using an excavator with a mandrel to push the drains to depth. Using this technique, the wick drains can typically be installed up to 8m below original ground level. While these drains do not reach to the base of the compressible layer, they assist in eventually creating a 'raft' of consolidated material that acts to significantly mitigate differential settlements at the surface.

4.6 Settlement reducing piles

This design concept comprises the installation of a very stiff, deep raft of settlement reducing piles beneath the building platform. The piles mitigate differential settlements by reducing both total and differential settlements, considerably stiffening the underlying ground beneath the building. As the piles attract skin friction for their length the bulding loads are progressively transmitted to the ground along the pile length which effectively creates a raft of thickness equal to the pile length. Driven timber poles are the most economical system and we are not aware of differential settlement problems where they have been used.

4.7 Stiffening floor slab with ground beams

This option mitigates the effects of settlements by creating a stiff concrete beam/slab raft system. The stiffened raft is able to span over a length of localised differential settlement and hence reduce the potentially damaging effects of such settlement. The cost and viability of this option depends heavily on the proposed dwelling footprint, in particular the length : width aspect ratio. Both stiffened slab and waffle slab foundations have been used on the Hauraki Plains with varying results. We are currently carrying out a structural assessment of these options.

5 Costs

5.1 General

This section has been developed to provide a preliminary cost estimate for each type of solution which should be reviewed for each specific site. These cost estimates will vary with time, location and design and are provided only as an indicator of relative cost estimates. All cost estimates exclude GST. The additional fill required to top up settlements is not considered in these analyses as the magnitude is difficult to quantify. This allowance can have a significant effect on the cost - eg 150mm of settlement for a 600mm thick layer will increase fill import costs by 25%.

5.2 Do nothing

This option comprises a standard dwelling construction, importing and placing rotten rock or similar granular fill from Tetley's or Smythes quarries. Discussions with a local contractor indicate a typical rate of around $25/m^3$ for crusher dust placed and compacted onsite.

$500m^2$ x 0.6m deep x $25/m^3$ = $7,500

TOTAL $7,500

5.3 Pre-load (surcharge)

This option comprises the placement of an additional pre-load weight of material on top of the fill platform to provide a surcharge load. The required surcharge load will vary depending on ground conditions but has been assumed to be double the effective service (permanent) loading. The cost estimate below allows for 'site won' material to be used (ie excavated locally and returned to the borrow area at the completion of the works. The fill platform is left in place and isolated from the fill by a geotextile separator.

Note that the surcharge costs will be additional to the costs of any imported fill to form the building platform.

Allow for, say, $10/m^3 and $1.70/m^2 for a geotextile separator. Assume site won fill with disposal onsite. Note that the cost for importing and then disposing of rock fill is likely to be in the region of $30-40/m^3 and the total cost could rise to approximately $10-13,000.

Earthworks cost = 500m^2 x 0.6m x $10/m^3 = $3,000
Geotextile = 500m^2 x $1.70/m^2 = $850

TOTAL $4,000

5.4 Lightweight fill – Pumice

Cost of Puni AP3 delivered to Paeroa = $45/m^3 (cost estimate from Winstone Aggregates)
Allow, say $10/m^3 for compaction

500m^2 x 0.6m x $55/m^3 = $16,500

TOTAL = $16,500

5.5 Lightweight fill – Polystyrene

Cost of structural polystyrene delivered to Paeroa = $100/m3. This allows for complete replacement of the fill platform with polystyrene.

500m^2 x 0.6m x $100/m^2 = $30,000

TOTAL = $30,000

5.6 Wick drains

Install from excavator up to 8m deep at 1.2m centres. Allow $12 per drain for installation and $0.85/m for the drains. Note that closer centres can speed up the rate of settlement and hence accelerate construction at an increased cost. The cost estimate has been reviewed by an Auckland contractor.

Cost per drain = $12 + $0.85/m x 8m = $19
No. of drains = 500m^2 x 0.8 drains/m^2 = 400 drains

TOTAL = $8,000

5.7 Settlement reducing piles

Allow for piles at 1.5m centres, say 6m long, 150mm small end diameter driven timber poles. Allow $20/linear metre for the pile installation (price from Auckland contractor):

Cost per pile = 6m x $20/m = $120/pile
No. of piles = 500m^2 / (1.5)^2 = 222 piles

Total =$26,500

5.8 Stiffening the structure to mitigate settlements

We have carried out a preliminary cost estimate for this work in conjunction with a local house builder. To prepare a 'waffle slab' floor would cost an additional $180 to $240 per square metre. Accordingly, for a 250m² dwelling, the total cost could be:

Cost = $120/m² x 250 m² = $30,000

Providing reliable cost estimates for this option is difficult as the exact cost will vary depending on the nature and degree of stiffening required and the type of slab constructed. We recommend that this cost estimate is carefully reviewed on a dwelling specific basis.

5.9 Summary

The costs presented above are summarised in Table 5-1 below.

Table 5-1 – preliminary cost estimates for mitigation measures

Option	Cost	Comments	Outcome
1 Do nothing	$7,5000	Imported fill only	Significant differential and total settlement over an extended period
2 Surcharge	$4,000	Assumes site won material, additional to (1) or (3)	Minimal post construction settlements
3 Lightweight fill - pumice	$16,500	Puni AP3	Significant differential settlements as a standalone solution
4 Lightweight fill - polystyrene	$30,000	Structural polystyrene	No settlement concern with full load compensation
5 Wick drains	$8,000	8m wicks at 1.2m c/c assuming drainage blanket present	Minimal post construction settlements
6 Settlement reducing piles	$26,500	150SED at 1.5m c/c	Differential settlements mitigated
7 Structural stiffening	$30,000	Provisional value for waffle slab	Differential settlements mitigated

(1) Options 1, 2, 3, 5 and to some extent 6 would require 'topping up' of the fill platform and hence additional fill costs.

(2) Some of the options will require settlement monitoring, the cost of which is excluded from these estimates

6 Applicability

This report has been prepared for the benefit of Hauraki District Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

TONKIN & TAYLOR LTD

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor by:
....	....
Pierre Malan	Grant Loney
Geotechnical Engineer	Project Director

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Appendix A: Figures

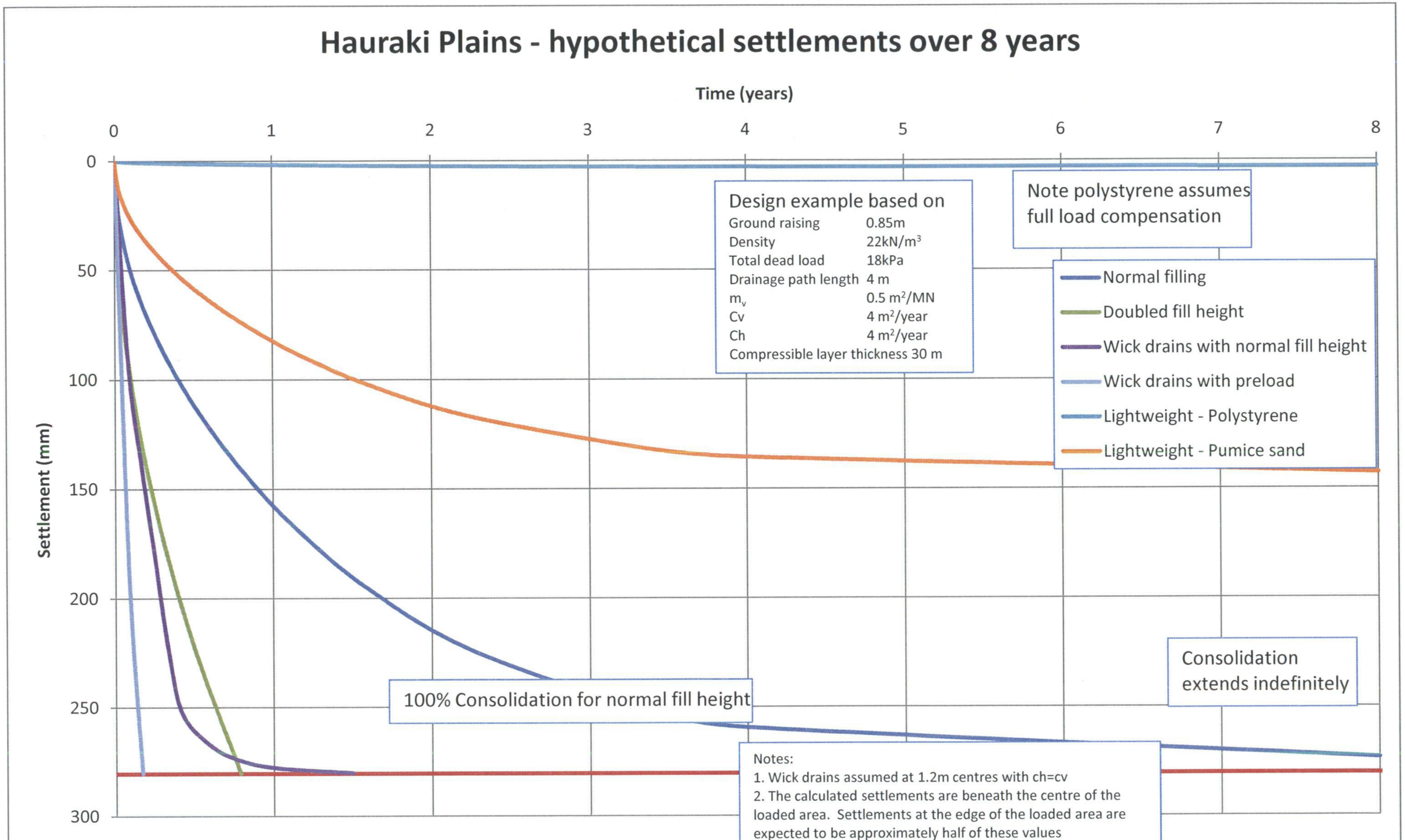
Hauraki Plains - hypothetical settlements over 8 years
Time (years)
0
1
2
3
4
5
6
7
8
Settlement (mm)
0
50
100
150
200
250
300
Design example based on
Ground raising 0.85m
Density 22kN/m³
Total dead load 18kPa
Drainage path length 4 m
mv 0.5 m²/MN
Cv 4 m²/year
Ch 4 m²/year
Compressible layer thickness 30 m
Note polystyrene assumes full load compensation
Normal filling
Doubled fill height
Wick drains with normal fill height
Wick drains with preload
Lightweight - Polystyrene
Lightweight - Pumice sand
100% Consolidation for normal fill height
Consolidation extends indefinitely
Notes:
1. Wick drains assumed at 1.2m centres with ch=cv
2. The calculated settlements are beneath the centre of the loaded area. Settlements at the edge of the loaded area are expected to be approximately half of these values
3. No allowance for load reduction with depth has been assumed

Figure 1

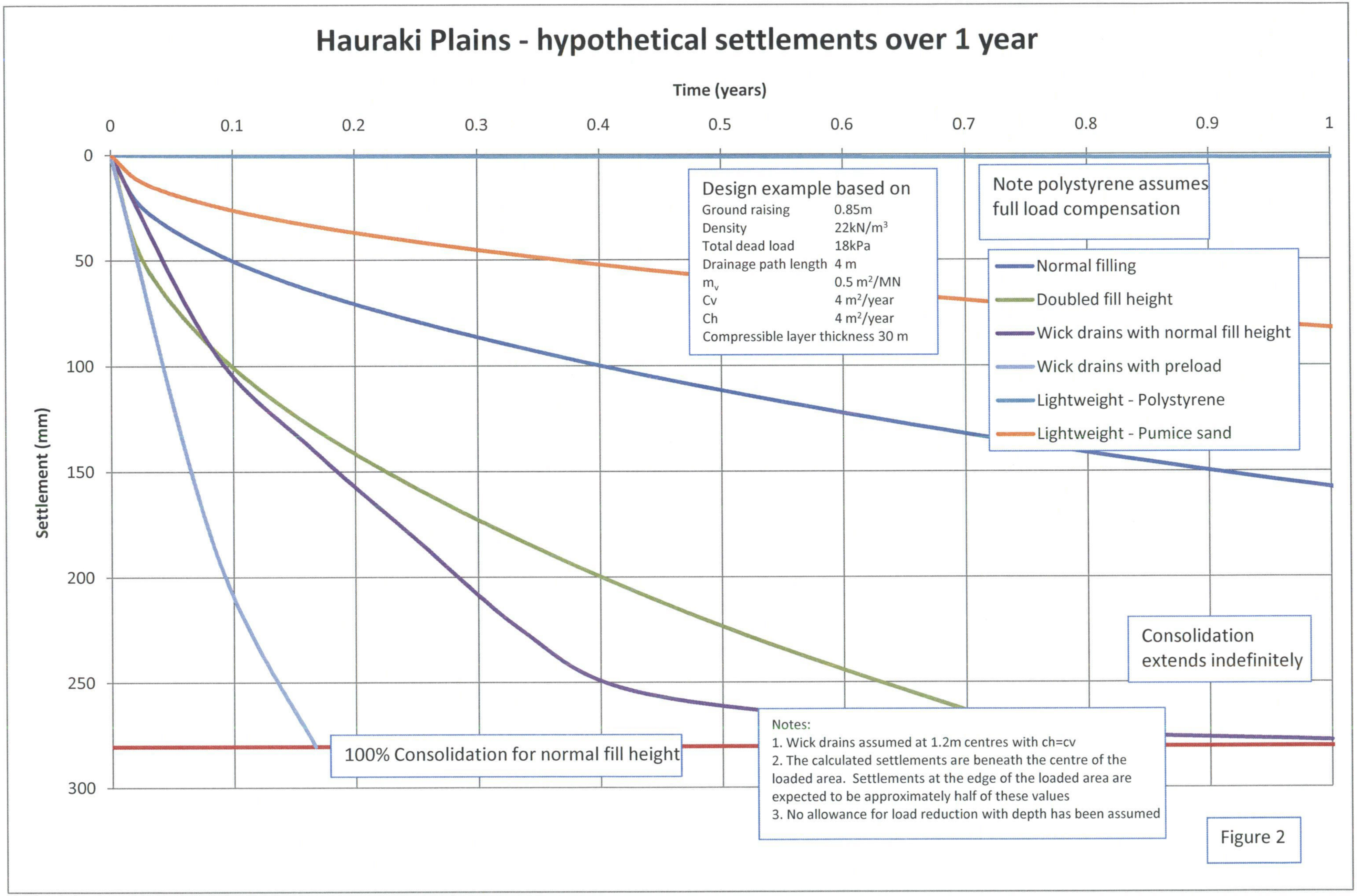
Hauraki Plains - hypothetical settlements over 1 year
Time (years)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Settlement (mm)
0
50
100
150
200
250
300
Design example based on
Ground raising 0.85m
Density 22kN/m³
Total dead load 18kPa
Drainage path length 4 m
m_v 0.5 m²/MN
Cv 4 m²/year
Ch 4 m²/year
Compressible layer thickness 30 m
Note polystyrene assumes full load compensation
Normal filling
Doubled fill height
Wick drains with normal fill height
Wick drains with preload
Lightweight - Polystyrene
Lightweight - Pumice sand
Consolidation extends indefinitely
100% Consolidation for normal fill height
Notes:
1. Wick drains assumed at 1.2m centres with ch=cv
2. The calculated settlements are beneath the centre of the loaded area. Settlements at the edge of the loaded area are expected to be approximately half of these values
3. No allowance for load reduction with depth has been assumed

Figure 2