Timber Pole Retaining Wall Design Guide (SESOC) – Methodology and Validation

G. Bird
SESOC Management Committee plus Software Portfolio, and Senior Associate with Beca, Auckland

ABSTRACT

Some years in development, the SESOC Cantilever Timber Pole (CTP) Retaining Wall Design Guide has been prepared in response to the need for a comprehensive, coherent design basis, albeit for low rise, cantilever, walls. Though based on long established Geotechnical principles, the nuances of incorporating the multiple facets in to a single, consistent and coherent whole has been, well, challenging.

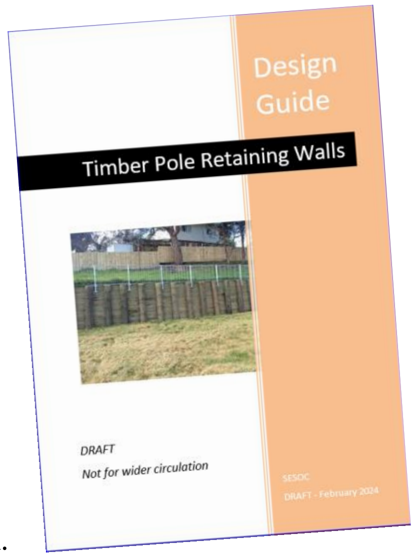
In addition to independent review by some key senior NZSEE members, it was recognised early on that robust, independent, validation would be crucial to ensure consistency of results and alignment with best practice.

This paper will :

a) Overview the basic principles, briefly, with more detailed coverage on :

b) The verification plan, validation process, and the multiple approaches (and software solutions) employed.

1 INTRODUCTION



Upon taking responsibility for the SESOC Software portfolio circa 2010, it was the author's particular question and concern regarding the SESOC Soils program – "What is the Technical Basis ?". In the absence of a national standard, or any substantive, comprehensive, and generally recognised design guidance, - or any such pending design guide, SESOC – perhaps naively - embarked on the journey of developing such a design guide.

This paper can, of necessity, merely introduce some of the basic concepts underpinning the design guide, which runs to 50 pages plus, including numerous appendices. There was, however, additional content in [1], and the hope that that the design guide will be publicly available shortly following this conference. The primary focus of this paper, however, is to provide an insight in to the validation and verification processes employed.

Additional, related, material may also be found in [2] and [3], presented by John Wood.

2 BASIS

The following is some brief commentary along with a number of graphics outlining some of the key points in terms of the technical basis of the guide.

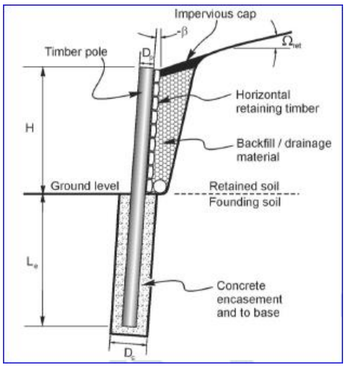


Fig 2.0 Generalised CTP layout, extract from CTP guide

2.1 Pole Spacing Effect

- 'Continuous' pole wall basis, using a simplified approach
- Above ground: full contributory area/load between poles applied
- Below ground loads:
  - <u>soil</u> assumes a maximum effective pressure width of $3.5D_c$ i.e. EPW = MIN [Sp, $3.5D_c$]
  - <u>water</u>: based simply on the width of the pole D_c

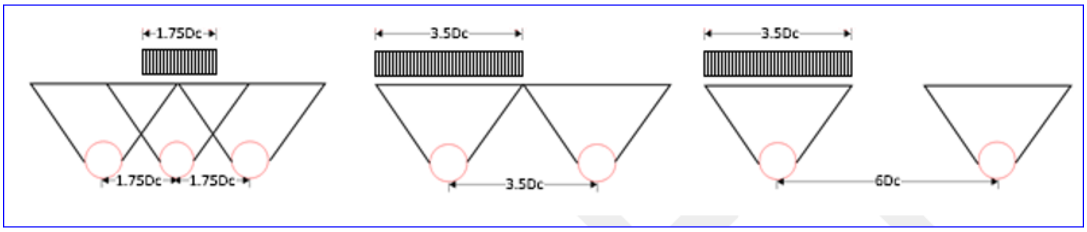


Fig 2.1 Pole spacing load basis, extract from the CTP guide.

2.2 Pressure Blocks :

Embedded pole is assumed to rotate about point Zo below ground, with pressure blocks as below:

- 1, 2: active pressure due to retained soil
- 3: active pressure due to superimposed loading
- 4: active pressure below Zo
- 5, 6: passive pressure resisting rotation; 7 = water

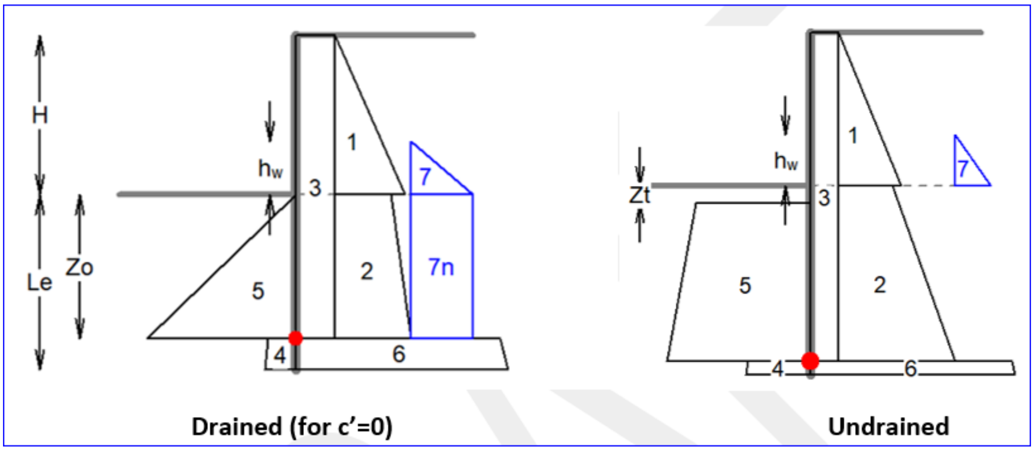


Fig 2.2 Sample structural mechanics pressure block diagram, extract from the CTP guide.

2.3 Water Table

The presence of water has a significant impact, even if just at ground level. The diagram shows the nett effect of water pressure, presented as the blue pressure blocks on the right.

Some brief comments :

- Direct pressure from water shown as blocks F7 & p7
- Buoyancy adjustment to p1 (backfill active pressure)
- Additional active pressure from water below ground (drained analysis)

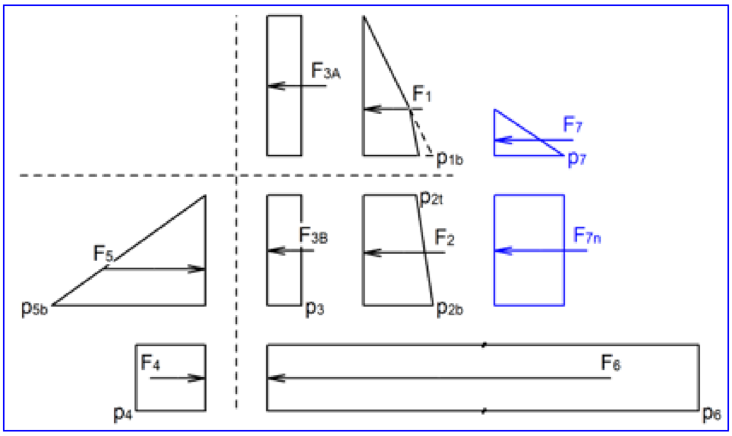


Fig 2.3 Water pressures (in blue), extract from CTP guide

2.4 Composite Action :

- Design guide allows for a composite strength increase factor, Cc, if pole is concrete-encased
- Equals the ratio between the design flexural strength of the composite pole and that of the bare pole
- Requires specific evaluation by engineer
- Strongly recommend set Cc = 1.0
- Only exception may be when the design engineer has undertaken an appropriate risk analysis, including consideration of relevant ‘decision factors’, and is confident that an increased Cc is justified

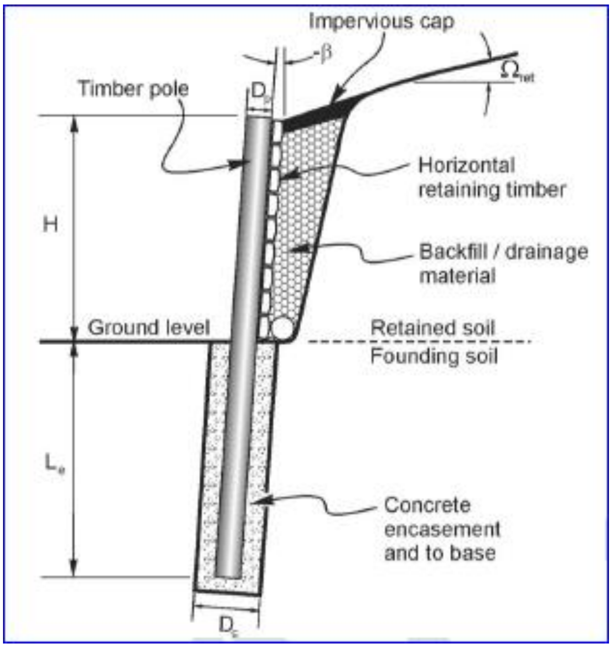


Fig 2.4 Concrete encasement

3 VALIDATION AND VERIFICATION

3.1 Introduction :

Notwithstanding the long-standing and broadly accepted Geotech principles upon which this above content is based, it must nevertheless be recognised that the structural mechanics model is just that – a model, an approximation, of the real-world behaviour. Further, whatever the model, it must still align with best practice and generally accepted results by other tools or methods.

For this reason, since the outset, the authors have been very much aware of the need for validation and verification. Validation, of the methodology – including nuances, and verification, or (quantifiable) alignment with current best practice.

To this end, a comprehensive series of analysis models have been run, for both drained and undrained conditions, across multiple facets, including surcharge loading, seismic loading, water, retained slope angle, strong/weak soils, etc. These analyses have been independently undertaken using multiple software applications and approaches.

3.2 NZGS Review :

We actively sought substantive Geotech input during the development process, plus a review by a very experienced structural engineer with extensive soils/retaining experience.

Nevertheless, we also considered it important to have independent review by NZGS - undertaken by three senior and experienced Geotech professionals, nominated by NZGS. Their input has been greatly appreciated, resulting in a number of refinements and improvements.

3.3 Further Details :

Our 'base case' verification scenario is broadly based on the MBIE Module 6 CTP example, namely :

- 2.5m retained height
- 300mm dia pole, 500mm encasement, spacing = 1.5m

However, beyond the single Module 6 worked example, we have implemented a multiplicity of variations, intended to test, and validate, the many options available in the methodology, and as may be expected across a range of real world designs. These include:

- Wall backslope
- Retained soil slope
- Low/high founding soil properties
- Variations in pole spacing
- Concrete encasement
- Water table: none, or varying between ground level and 2H/3
- Static or seismic loading conditions
- Surcharge loading
- Low/high backfill material properties
- Variations of surface ineffective depths (cohesive only)

The basis is to change <u>just one</u> aspect for each of the test items, i.e. each test case representing a single variation from the base. This approach provides clarity around the impact, if any, of the particular variation from the base case. As well as the impact, whether positive or negative, small or large, it also provides a direct comparison with the equivalent analysis scenario undertaken by the alternative softwares or methods.

4 VERIFICATION OUTPUTS

As introduced above, the verification plan outlines intentional variations to a number of design aspects. These are now expanded as per 4.1 below. 4.2 and 4.3 below present a summary of the results for Cohesive, and Cohesionless, soil types, respectively.

4.1 Verification Scenarios :

Test ID	Brief title	Description
1.0	Base	Base: no water, no seismic, vertical, base case founding and backfill soil properties, etc
1.1.1	Fo 0.25	Reduced fo – ineffective depth
1.1.2	Fo 0.9	Increased fo
1.2.1	Water GL	Water table at ground level
1.2.2	Water H/3	Water table at 1/3 height of wall
1.3.1	LL 5kPa	Surcharge load of 5 kPa
1.3.2	LL 10 kPa	Surcharge load of 10 kPa
1.3.3	EQ 0.15g	Seismic loading, 0.15g
1.3.4	EQ 0.25g	Seismic loading, 0.25g
1.3.5	EQ 0.35g	Seismic loading, 0.35g
1.4.1	BF 20 Deg	Retained slope angle of 20 degrees
1.5.1	Wall 15 deg	Wall backslope of 15 degrees
1.6.1	Low Found ϕ	Low founding soil properties
1.6.2	High Found ϕ	High found soil properties
1.7.1	High Found ϕ	Low backfill material properties
1.7.2	High BF ϕ	High backfill material properties
1.8.1	Sp = 1.25	Pole spacing = 1.25m, i.e. 2.5 D
1.8.2	Sp = 1.75	Pole spacing = 1.75m, i.e. 3.5 D
1.8.3	Sp = 2.0	Pole spacing = 2.0m, i.e. 4.0 D
1.9.1	Sp = 0.9, Dc, Dp 0.3	Pole dia = 0.3, no encasement, spacing = 0.9m, i.e. 3 D
1.9.2	Sp = 1.5, Dc, Dp 0.3	Pole dia = 0.3, no encasement, spacing = 1.5m, i.e. 5 D
1.9.3	Sp = 1.5, Dc, Dp 0.5	Pole dia = 0.5m, no encasement, spacing = 1.5m, i.e. 3 D

The above scenario list was run for both cohesive and cohesionless soils, amounting to some 40+ analyses per analysis run.

4.2 Verification Process :

In terms of process, the original intent was to use just one suitable program, (eg Wallap) to run a parallel series of analyses.

In the event, however, we had the following :

- Beca, Auckland, directed and oversaw a summer student to undertake a full series of analyses.
- John Wood very generously undertook a substantive series of analyses, comprising :
  - An Excel spreadsheet developed on the basis of the Design Guide
  - Two Wallap analyses series, one using an LFRD approach, the other using the strength method
  - Two LS Geo analyses series, one using an LFRD approach, the other using the strength method
  - An ‘Isolated pile’ methodology, based on recent research out of University of Canterbury

SESOC is very grateful for the input by both Beca and John, as well as my SESOC colleague Allan McPherson, who is the very able 'pen holder' of this design guide.

4.3 Verification Results Summary

The following two graphs provide a visual summary of the verification outputs, for undrained (cohesive), and drained (cohesionless), respectively.

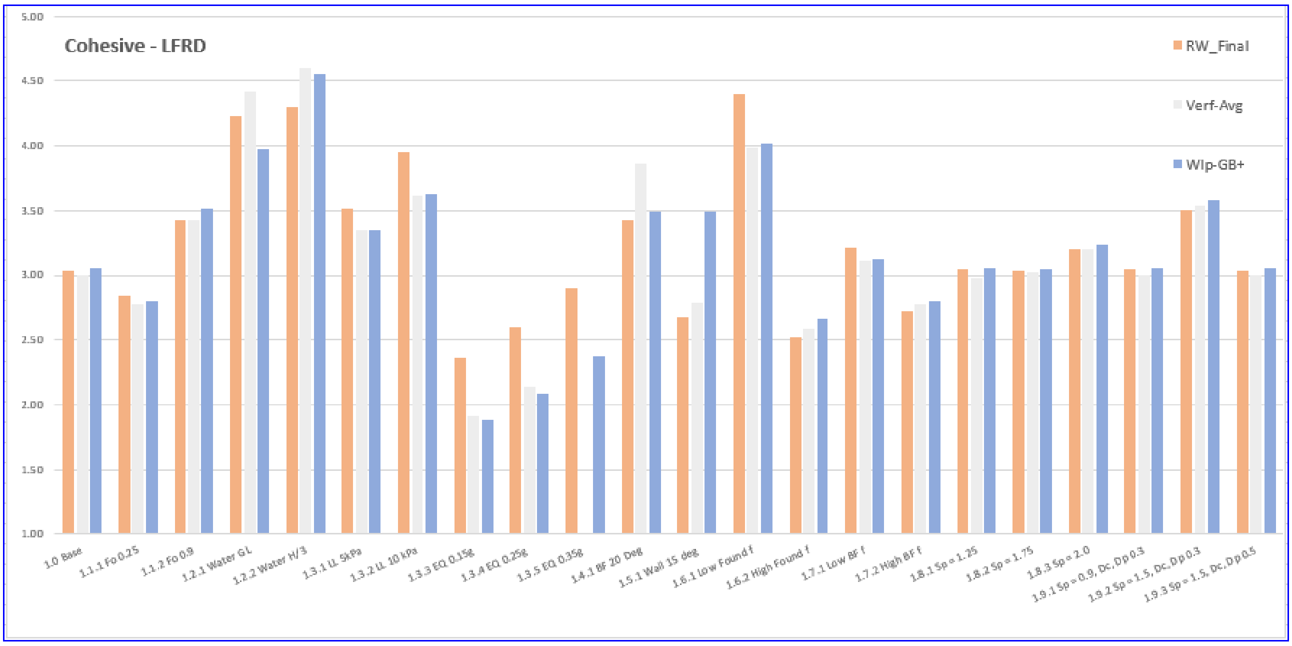


Fig 4.3.1 Undrained (cohesive) results summary

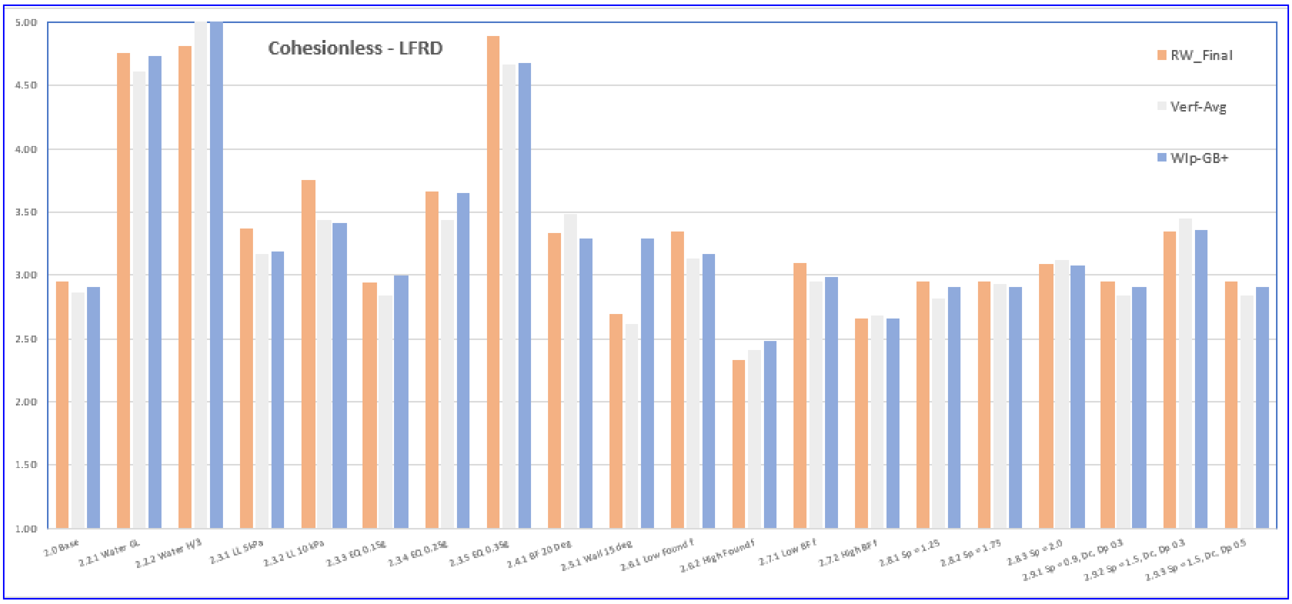


Fig 4.3.2 Drained (cohesionless model) results summary

5 OTHER MATTERS

As alluded to above, both the NZGS T3 review, and the independent verification process, tested and presented challenges around a number of aspects, including:

- Strength Reduction Factors (SRFs) and Load Factors (LFs) – and the combination thereof
- Seismic behaviour and results
- Water table level
- Theoretical, limit state pressure block basis
- Unfactored design, and alignment with Wallap/other

Each of these will be covered, briefly, below.

5.1 Load Factors :

From the outset, our intent was to provide a coherent and consistent set of SRFS & LFs, so as to obtain appropriate results. This is in contrast to the wide disparity of factors across various approaches, both within NZ and internationally. Our recommended factors are presented below.

Aspect	*Active earth pressure α_a*	*Earth pressure from super-imposed α_q*	*Dead Load Factor*	*Live Load Factor*	*Drained Reduction Factor*	*Undrained Reduction Factor*	*Effective FoS (for no superimposed LL)*	
							Drained	*Undrained*
SESOC Recommended Gravity	1.5				0.75	0.65	2.0	2.31
SESOC Recommended EQ	1.0				0.75	0.65	1.33	1.54
SESOC Recommended Gravity		1.3	1.2	1.5	0.75	0.65	2.08	3.0
SESOC Recommended EQ		1.0	1.0	0.4	0.75	0.65	1.33	1.54

Fig 5.1 Recommended load factors and strength reduction factors, extract from CTP guide

5.2 Seismic Behaviour :

There was much debate around the handling of seismic design, whether incremental or total, model basis (esp. for cohesive), etc. Of concern also is that, for cohesive anyway, the seismic design case requires lesser embedment depth than for static. In another aspect, we have had some instability aspects with the FE analyses, as well as indications of potentially substantive displacements (cohesionless).

For these reasons, we have limited seismic design to 0.3g maximum, and also provided an additional margin to the embedment depth in order to reduce (permanent) displacements under a major seismic event.

5.3 Water table level :

Water table level presented a number of challenges, in particular around the treatment of a cohesive soil under long term (drained) behaviour. Early advice was to treat as drained, with appropriate/equivalent phi properties, and no cohesion. However, even with water at GL, with reduced (buoyant) soil density, embedment depths became unreasonable. As a result, we (re-)introduced c’ – while acknowledging this is not an easy parameter to quantify.

5.4 Unfactored Design, 'Limit State' Pressure blocks :

As a responsible national technical society, with a document that has the potential to become somewhat of a default standard, SESOC is concerned that the methodology will not produce unconservative results with respect to eg an equivalent FE/Wallap design. While our LFRD designs generally provided similar design results to Wallap, some of the unfactored designs did not.

One facet is the idealisation of soils pressures via the limit state stress block approach. We implicitly understand that a 'limit state stress block' is, fundamentally, an engineering convenience only. In terms of an embedded pole, we also implicitly understand that in the real world the passive pressure does not switch from limit state passive maxima in front of the pile to limit state passive maxima behind the pile over an infinitesimal distance at the rotation point.

A further aspect is that the pressure block below Zo may not even reach the limiting passive pressure due to the small angular rotation and lever arm distance from the rotation point.

We have compared the SESOC assumed pressure diagrams with outputs from the more rigorous Wallap analyses. Combining all these aspects has led us to introduce the ability to modify the passive pressure diagram adjacent to the rotation point via a 'Taper Ratio' factor (λ), as well as a 'Stress Block Multiplier' (SBM). These are both demonstrated in the diagram below, with the Wallap analysis shown on the left, and the modified SESOC pressures on the right.

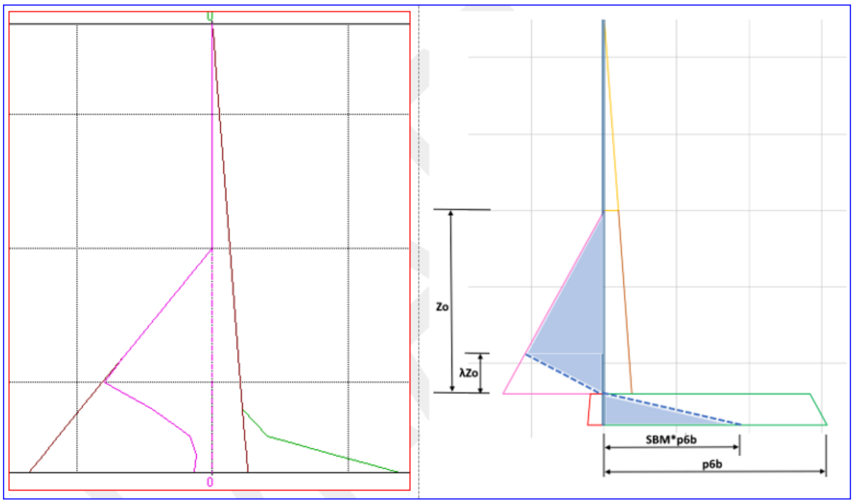


Fig 5.4 Pressure blocks, ex Wallap (left), theoretical, & adjusted (right)

6 CONCLUSIONS

This paper has briefly covered the technical basis of the CTP, followed by further detail around the validation and verification process.

Although based around a single 2.5m high CTP example, we believe the scope and detail embodied in the verification process is overall pretty robust, thus providing a high degree of confidence around the validity of the methodology.

REFERENCES

[1] Bird, G. (2022), NZSEE Conference, Paper 0020, "Retaining Wall Design – SESOC"

[2] Wood, J. (2021), NZGS News Issue 101, June 2021, "Cantilever Pole Retaining Walls"

[3] Wood, J. (2021), NZGS Webinar, Oct 2021, "Cantilever Pole Retaining Walls"
https://www.youtube.com/watch?v=NC_LFdbrpvY