Discussion on ANCHORED WALL DESIGN: COMPARING THE GLOBAL AND PARTIAL FACTORS OF SAFETY INCORPORATING THE AUSTRALIAN STANDARDS. Int. J. of GEOMATE, Sept., 2015, Vol 9, No. 1 (S1. No. 17), pp. 1395-1402.

While the authors are to be applauded for their attempts to look at design considerations with regard to anchored retaining walls, there appear to be a number of important misunderstandings and misconceptions which impact the results and conclusions. Unfortunately these can have an adverse effect when the paper is read by people unable to apply a number of corrections.

For example, in Australia, gravity retaining wall design has been carried out to limit state principles sine at least 2002 (AS4678:2002), as noted in reference [4] in the paper. This involves the application of partial factors, which are not factors of safety as such, to various elements of the design, with the factors selected in relation to the perceived uncertainty and risk associated with that element. By contrast, the working stress method previously used, required a global factor of safety between the ultimate strength and the mobilised strength. It is not possible to check the workings of the MATLAB program, but it seems reasonable to assume that the figure of 124.1 kN for the "Resultant Active lateral earth pressure force" according to the PFS method, includes all the strength reduction factors and load factors referred to in Tables 2, 3 and 4. In that case, if these pressures are applied to overturning, it seems reasonable that they are equivalent to the figure of 61.6 kN for the GFS method, to which a global factor of safety of 2 must be applied, making the GFS equivalent 123.2 kN. Similarly with the passive pressure the numbers would be 98.9 kN and 82.2 kN, showing that the limit state design method with its partial factors is less conservative, since passive pressures are restoring equilibrium. Incidentally, it is also not clear why the forces are quoted in kN, since the model is 2-dimensional and it is assumed that they should be in kN/m. It should also be noted that, regardless of the conclusions of any comparison, retaining walls in Australia must be designed to limit state principles using partial factors in order to comply with AS 4678:2002.

Rather more importantly, there is reference to retaining wall designs which comply with AS 4678:2002, yet this is a standard for gravity walls, and specifically excludes embedded retaining walls such as sheet piles. Figure 1.1 in the standard and the failure modes illustrated in Chapter 3 show that the retaining and revetment structures "encompassed" by the standard do not have any embedment, while the end of Clause E1 states that "where retaining walls using "embedded piles" are adopted at a site, the design of such structures should be carried out as suggested in AS 2159 for laterally loaded piles." Even this advice is questionable, since there are significant differences between a bored pile which is subject to a lateral load, as envisaged by AS 2159, and a bored pile used to retain soil. It is noted that AS 4678:2002 is also rather confusing in other ways since (i) it relates to gravity walls, (ii) it includes an informative Appendix B on Ground Anchors, (iii) it includes an informative Appendix C on soil nailing in a manner which is normally applied to cut slopes, and (iv) it includes an informative Appendix H on reinforced fill which fits within the general definition of gravity walls.

The authors claim to have validated their MATLAB results using Finite Element analysis through the application of PLAXIS software. It is by no means clear how this has been done, since there is no easy way of incorporating load and strength factors into an FE model, where stiffness is paramount. It is considered to be much safer to use FE methods to evaluate the serviceability limit state, but there is no indication that this has been done. Table 8 suggests that the anchor force from the PLAXIS model was 44.12 kN, yet the shear force plot in Figure 5(b) appears to show a maximum shear force of -63.7 kN/m, with a small positive shear force at the anchor level, suggesting an anchor force of nearer to 70 kN/m, which would be much more than 44 kN per anchor at any reasonable horizontal spacing. Also Table 8 gives the maximum bending moment from PLAXIS as 21.25 kNm, while Figure 5 (c) shows a value of 92.63 kNm/m. It may also be noted that, where the anchor has been modelled in PLAXIS, the authors have used the fixed end anchor which is probably not an appropriate model.

In summary, the conclusions are considered to be unsound and, more importantly irrelevant since a designer does not have an option as to whether to use limit state design or working stress design methods.

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<u>Authors Response for the Discussion on ANCHORED WALL DESIGN: COMPARING THE GLOBAL AND PARTIAL FACTORS OF SAFETY INCORPORATING THE AUSTRALIAN STANDARDS. Int. J. of GEOMATE, Sept., 2015, Vol 9, No. 1 (S1. No. 17), pp. 1395-1402.</u>

The authors highly appreciate the comments the associate editor and the respected reviewers and time spent to review the paper very carefully. The authors highly appreciate the comments provided by Dr. S. Buttling the Principal of the National Geotechnical Consulting for reading through the paper and providing constructive comments. The major purpose of this paper was to develop a MATLAB model in order to continue working on the design of anchored sheet-pile structures, using both the global factor of safety [GFS] method and the partial factor of safety [PFS] method, abiding AS 4678-2002. This part of the model, published in Geo-mate 2015, was added to the main program which previously was developed by the authors to compare the applications of these two methods for geotechnical aspects of various retaining walls (gravity, cantilever and embedded walls). The main purpose of this project was to compile an educational guide on the holistic design and analysis of retaining walls through fundamentals of soil mechanics and structural analysis incorporating the Australian Standard (AS4678:2002) specifications and procedures.

Since the paper must not exceed the maximum limit of 8 pages, the authors inevitably had to omit some parts from the original research report. As a result, this paper actually was intended to provide the visualisations of the ongoing development of the MATLAB model on designing of different retaining walls. The paper, in particular, focused only on the design of anchored walls.

It should be noted that the global factor of safety method does not provide sufficient assessments of loading and unforeseen stress redistribution within the retaining walls. As a result, unrealistic retaining wall designs can be resulted from the combined use of load and strength factors in the design calculations as elaborated by Day et al. 2011. In contrast, the partial factor of safety method takes into account of different adjustment factors for loading and material properties, commensurate with different reliabilities and consequences, in compliance with the Australian Standard AS 4678-2002 (Simpson 1992).

The developed MATLAB program was validated by closed-form equations, with several sample sets of test scenarios. A sample is provided at the Appendix of this document. It is acknowledged that the forces should have been presented in kN/m, as being suggested in the discussion. It is obvious that all the retaining walls in Australia must strictly adopt the PFS method for design strength and safety aspects, as GFS method has only been presented to highlight the importance of using different adjustment factors for loading, material properties, the perceived uncertainty and the associated risks based on a particular design condition.

Moreover, the use of AS 4678-2002 for the design of embedded retaining walls was carried out in the previous stage of the model development but not covered in this short paper. The decision to stick to AS 4678-2002 for the case of embedded retaining walls should be stated as one of the limitations of this MATLAB model. The equations used to develop the model were based on the closed form equations of classical geotechnical engineering. The use of PLAXIS software to validate the results generated by the MATLAB model contained a number of compromises. Furthermore, the process of incorporating various values for the load and strength factors into a Finite Element analysis required considerable level of expertise and it was beyond the scope of this paper. As a result, the authors would like to advise that this is an ongoing research and as such, the validation process using PLAXIS requires much work to be conducted as at this date of publication.

In summary, it should be noted that this MATLAB model can provide the following features associated with the design of anchored walls:

- The required depth of embedment for given load combination
- The total wall height for determining the amount of material required
- The minimum length of the anchor
- The anchor force
- The maximum moment acting on the sheet-pile wall.

Moreover, the developed model has been mainly intended to provide the basic and fundamental knowledge associated with the design of anchored retaining walls and how the variations of a particular component, mentioned above, could affect on other aspects of the design procedure. In other words this program serves as an educational tool rather than a design tool for industry.

References

Day, R.A., Wong, P.K. & Poulos, H.G. 2007, 'Fifteen years of geotechnical limit state design in Australia Part 1- Soil retaining structures', *Common ground Proceedings of the 10th Australia New Zealand Conference on Geomechanics (2007)*, vol.2, pp. 2-596-2-601.

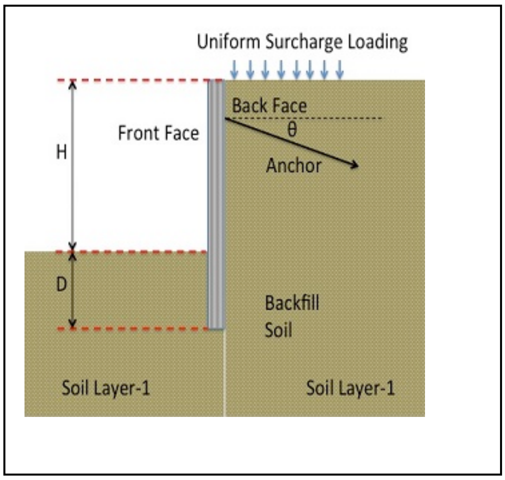
Simpson, B. 1992, 'Partial factors of safety for the design of retaining walls', *Geotechnique*, vol. 42, no. 1, pp. 131-136.

Appendix

Example: Closed-Form Validation Procedure

(i) Anchored Wall – Only one soil layer subjected to Uniform Surcharge Loading

Soil Properties



Unit weight, γ_s [kN/m^3] = 18

Friction angle, ϕ_S [°] = 30

Cohesion, c [kPa] = 0

Uniform Surcharge, q [kPa] = 10

y [m] = 1 [Point of anchor from the ground surface]

Excavation Height, H [m] = 3

Factor of Safety, FoS = 1.5

Note: This factor of safety is incorporated into the passive earth pressure when using GFS Method.

Fill conditions: (select)

In situ material – $\Phi_{U\Phi}$ = 0.85, Φ_{UC} = 0.70

Structure classification: (select)

C (significant) – Φ_n = 0.9

Table A.1: Closed-form calculations for the partial factor of safety (PFS) Method

Step	Action	Output From Model	Diff-erence	Comments
P1.	PFS Calculations steps are also used to determine: ❖ Embedment depth ❖ Location of maximum moment ❖ Maximum moment ❖ Anchor force ❖ Length of Anchor			Note that subscript "P" or "A" is added to each term to identify that partial factor has been applied. In most cases the subscript "P" is added to the terms that are contributing to the resisting effect and subscript "A" is added to the terms that are contributing to the disturbing effect.
P2.	PFS method requires modification of the relevant input parameters. Backfill soil: $\gamma_{SP} = 0.8\gamma_s$ = 14.4 $\gamma_{SA} = 1.25\gamma_S$ = 22.5 $\Phi_P = tan^{-1}(\Phi_{u\Phi} * tan\Phi_S)$ = 26.14° Surcharge Loading: If surcharge loading is less than 5 kPa, then set surcharge loading $q_p =$ 5 kPa. If surcharge loading is greater than or equal to 5 kPa, then $q_p = 1.5 * q\ (kPa)$ $q_p = 15$ kPa			Apply partial factors as per AS4678-2002. General idea is to reduce parameters that are contributing to the resisting actions and increase parameters that are contributing to the disturbing actions. Thereby, uncertainty associated with accuracy of each parameter is accounted for. Please note that the parameters input used along the same steps of the calculation process

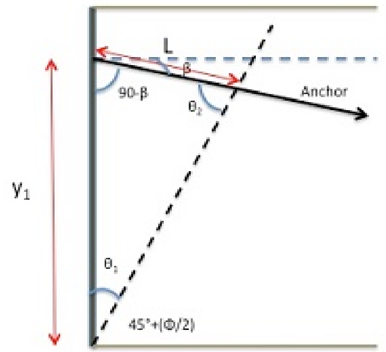
P3.	$\theta_a = sin^{-1}\left(\frac{\sin\beta}{\sin\Phi}\right) - \beta + 2\eta$ $K_A = \frac{\cos(\beta-\eta)\sqrt{1+sin^2\Phi-2\sin\Phi cos\theta_a}}{cos^2\eta(\cos\beta+\sqrt{sin^2\Phi-sin^2\beta)}}$ = 0.3883 $\theta_p = sin^{-1}\left(\frac{\sin\beta}{\sin\Phi}\right) + \beta - 2\eta$ $K_P = \frac{\cos(\beta-\eta)\sqrt{1+sin^2\Phi+2\sin\Phi cos\theta_a}}{cos^2\eta(\cos\beta-\sqrt{sin^2\Phi-sin^2\beta)}}$ = 2.575	$K_A = 0.388$ $K_P = 2.575$	OK OK	Determine active and passive lateral earth pressure coefficients using Rankine's theory. Assume that the front of the wall is vertical and frictionless. The values Φ used are modified by: $\Phi_P = tan^{-1}(\Phi_{u\Phi} * tan\Phi_S)$
P4.	function [V_Stress] = getSigma (G,x,qp) V_Stress = qp + G*x; end			This function is used to determine the vertical stress at the certain point of interest. Where, V_Stress = Vertical Stress (kPa) x = Distance from the top of the ground surface (m) qp = Surcharge loading (kPa) (Note: q_p is used in the PFS method) G = Unit weight, γ_S [kN/m^3] (Note: $\gamma_{SA} = 1.25\gamma_S$ & $\gamma_{SP} = 0.8\gamma_s$ are used in the PFS method)
P5.	function [HA_Stress] = getAH (Ka,VA_Stress,c) HA_Stress = Ka*VA_Stress - 2*c*sqrt(Ka); end			This function is used to determine the **Active horizontal stress** corresponding to the relevant vertical stress at the certain point of interest. Where, HA_Stress = Active Horizontal Stress (kPa) Ka = Active lateral earth pressure coefficient VA_Stress = Corresponding Active Vertical Stress at the point (kPa) c = Soil Cohesion (kPa)

P6.	function [HP_Stress] = getPH (Kp,VP_Stress,c) HP_Stress = Kp*VP_Stress + 2*c*sqrt(Kp); end			This function is used to determine the **Passive horizontal stress** corresponding to the relevant vertical stress at the certain point of interest. Where, HP_Stress = Passive Horizontal Stress (kPa) Kp = Passive lateral earth pressure coefficient VP_Stress = Corresponding Passive Vertical Stress at the point (kPa) c = Soil Cohesion (kPa)
P7.	D = sym('D','positive'); T = sym('T','positive'); S = sym('S','positive');			Declaring the parameters that are required to be determined: D = Embedment depth T = Anchor force S = Point of maximum moment
P8.	% Finding Vertical and Horizontal Stresses VA_Stress1 = 15 + 14.40*0 = 15 HA_Stress1 = 0.3883*15 - 2*0*sqrt(Ka) = 5.8245 VA_Stress2 = 15 + 22.50*(3+D) = 22.50D + 82.50 HA_Stress2 = 0.3883*(22.50D + 82.50) = 8.737D + 32.03 VP_Stress3 = 0 HP_Stress3 = Kp*VP_Stress2 + 2*c*sqrt(Kp) = 0 VP_Stress4 = 14.40*D;			The above functions are used to determine the vertical stresses and the horizontal stresses at the relevant points. Suffixes "A" and "P" are used to classify between active and passive. G = Unit weight, γ_S [kN/m^3] Note: In the PFS method, $\gamma_{SA} = 1.25\gamma_S$ is used for active vertical and horizontal stresses $\gamma_{SP} = 0.8\gamma_s$ is used for passive vertical and horizontal stresses qp = Surcharge loading (kPa) (Note: $q_p$is used in the PFS method) Ka = Active lateral earth pressure coefficient Kp = Passive lateral earth pressure coefficient H = Height of the wall D= Embedment Depth VA_Stress = Corresponding Active Vertical Stress at the point (kPa)

	HP_Stress4 = 2.575* 14.40D + 2*c*sqrt(Kp) = 37.08D			HA_Stress = Active Horizontal Stress (kPa) VP_Stress = Corresponding Passive Vertical Stress at the point (kPa) HP_Stress = Passive Horizontal Stress (kPa)
P9.	% Forces Fa1 = 5.8245*(3+D) Fa2 = 0.5*((8.737D + 32.03) - 5.8245)*(3+D) Fp1 = 0 Fp2 = 0.5*(37.08D-0)*D = 18.54D^2			Once all the horizontal stresses are determined, they are used to determine the forces acting on the wall. Forces are mainly due to: ❖ Back face surcharge loading ❖ Front face active soil pressure ❖ Back face passive soil pressure
P10.	% Distances of each force from the point of anchor d_a1 = ((3+D)/2)-1 = 0.5D + 0.5 d_a2 = ((2/3)*(3+D))-1 = 0.667D + 1 d_p1 = (D/2)+(3-1) = 0.5*D + 2 d_p2 = ((2/3)*D)+(3-1) = 0.667D + 2			Arm lengths have to be determined to get the required moments acting around the point of anchor. d_a1 = Distance of Fa1 from the point of anchor d_a2 = Distance of Fa2 from the point of anchor d_a3 = Distance of Fa3 from the point of anchor d_a4 = Distance of Fa4 from the point of anchor
P11.	% Moments Ma1 = (5.8245*(3+D))*(0.5D+0.5) Ma2 = (0.5*((8.737D + 32.03) - 5.8245)*(3+D))* (0.667D + 1) Mp1 = 0 Mp2 = 0.9*(18.54D^2*(0.667D + 2));			Moments due to the determined forces usually due to: ❖ Back face surcharge loading ❖ Front face active soil pressure ❖ Back face passive soil pressure
P12.	Finding Depth of Embedment:			There is only one unknown, which is “D”, in this moment equation.

	M_eq1 = Ma1+Ma2-Mp1-Mp2 = 0 This gives the value "D" = 2.6786 m	D = 2.68 m	OK	Uses "solve" function of MATLAB to solve for the embedment depth "D". The calculated "D" value will be substituted back to determine the magnitude of forces and moments.
P13.	Substituting the Value "D" obtained: Fa1 = HA_Stress1*(H+D) = 33.08 Fa2 = 0.5*(HA_Stress2-HA_Stress1)*(H+D) = 140.85 Fp1 = 0 Fp2 = 133.02 Fa = Fa1+Fa2 = 173.93 kN Fp = Fp1+Fp2 = 133.02 kN F_eq1 = Fa-(Fp+T) = 0 This gives the value of "T" = 40.91 kN	Fa = 173.99 kN Fp = 133.07 kN T = 40.92 kN	OK OK OK	
P14.	% Finding point of maximum moment Sigma_V1 = 15; Sigma_H1 = 0.3883*15 = 5.8245 V1 = 5.8245*S; Sigma_V2 = 15 + 22.5*S; Sigma_H2 = 0.3883*(15 + 22.5*S) = 5.8245 + 8.737*S V2 = 0.5*((5.8245 + 8.737*S)- 5.8245)*S;			Determine the location, S, of zero shear (maximum moment) by equating all the calculated horizontal forces and the determined anchor force above the point of rotation and using numerical method in MATLAB to calculate this value. Where, Sigma_V = Corresponding Active Vertical Stress at the point (kPa) Sigma_H = Active Horizontal Stress (kPa) c = Soil Cohesion (kPa)

	F_eq2 = (V1+V2) - T; S = solve(F_eq2); This gives the value “S” = 2.4653 m	S = 2.47 m	OK	qp = Uniform surcharge loading (Note: $q_p$is used in the PFS method) G = Unit weight, γ_S [kN/m^3] Ka = Active lateral earth pressure coefficient Kp = Passive lateral earth pressure coefficient
P15.	% Substituting the “S” value determined: Sigma_V1 = qp; Sigma_H1 = Ka*Sigma_V1 – 2*c*sqrt(Ka); V1 = Sigma_H1*S = 14.36 Sigma_V2 = qp + Ga*S; Sigma_H2 = Ka*Sigma_V2 - 2*c*sqrt(Ka); V2 = 0.5*(Sigma_H2-Sigma_H1)*S = 26.55			The “S” value determined above is to be substituted into the equations to determine the horizontal forces. Where, Sigma_V = Corresponding Active Vertical Stress at the point (kPa) Sigma_H = Active Horizontal Stress (kPa) c = Soil Cohesion (kPa) qp = Uniform surcharge loading (Note: $q_p$is used in the PFS method) G = Unit weight, γ_S [kN/m^3] Ka = Active lateral earth pressure coefficient Kp = Passive lateral earth pressure coefficient
P16.	d_V1 = S/2 = 1.2327 d_V2 = S/3 = 0.8218 d_T = S-y = 1.4653			Determine the moment arms corresponding the above forces from the point of maximum moment.
P17.	M_max = (V1*d_V1 + V2*d_V2) - T*d_T; = -20.43 kNm M_max = abs(M_max)= 20.43 kNm	M_max = 20.44 kNm	OK	Determine the maximum moment by multiplying the forces and the distances determined earlier.

P18.	$\theta_1 = 90° - \left[45° + \frac{\Phi}{2}\right]$ = 31.93 $\theta_2 = 180° - [90° - \beta + \theta_1]$ = 73.07 $y_1 = H + D - y$ = 4.6786 $$\frac{L}{\sin\theta_1} = \frac{y_1}{\sin\theta_2}$$ Get "L" from the above sine rule equation This gives the value of "L" = 2.5865 m	L = 2.59 m	OK	 Finding the Length of Anchor (Single Layer of soil)

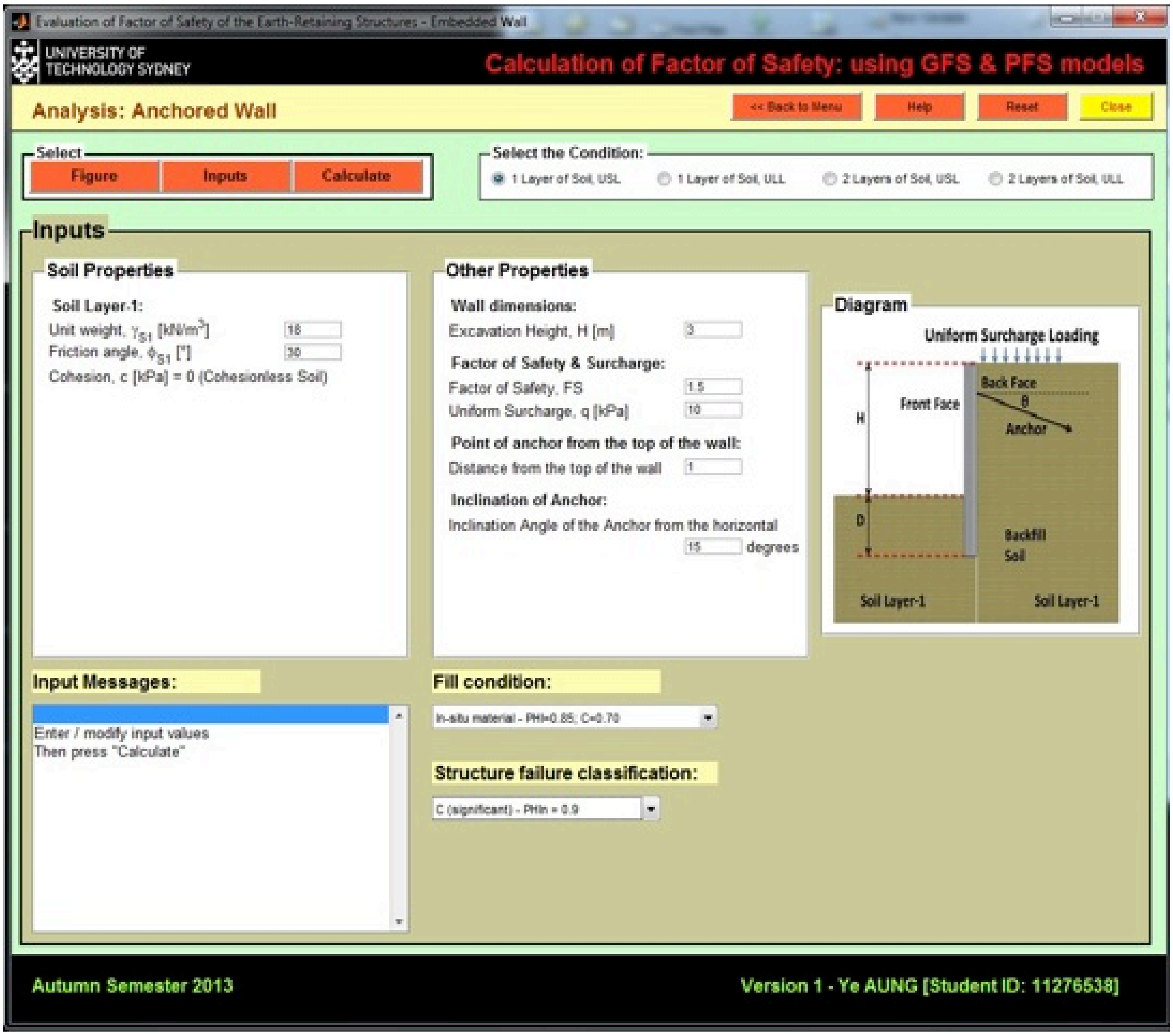


Figure A1: Inputs for the design scenario-1 (MATLAB model)

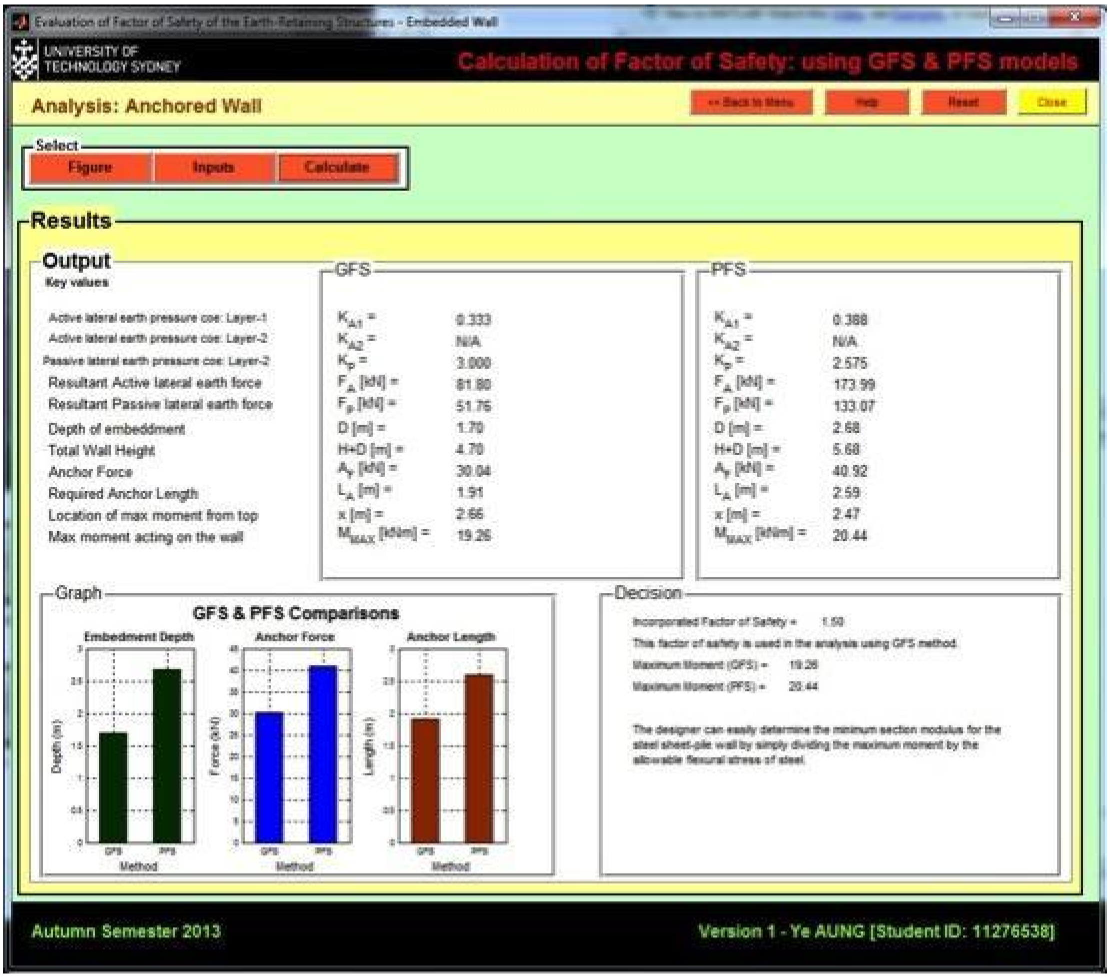


Figure 2A: Results for design scenario-1 (MATLAB model)

Output values from the model match the results obtained from the closed-form calculations for both GFS and PFS methods, thus the MATLAB model can be considered to be reliable.