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ARTICLE

AUSTRALIAN STANDARD AS 2870 – RESIDENTIAL SLABS & FOOTINGS *TIME FOR CHANGE*

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Introduction

Whilst much credit is due to the original authors of AS 2870, the authors of this article opine that it has gradually become an outdated code over its almost 30 year history, and that it is well overdue for a complete overhaul. We submit the following grounds for change:

- First and foremost, the so-called 'Slab heave' problem with prescriptive deemed to comply waffle raft slabs has escalated to untenable levels in recent years.
- AS 2870 is not a proper engineering design code.
- It uses a beam model to analyze what is obviously a plate problem.
- Last but by no means least, the AS 2870 design model is seriously fundamentally flawed.

Part 1 of this article has been written by Rowan Gregory, Part 2 by Frank Van der Woude, and Part 3 has been jointly written.

Part 1

1.1 Background of AS 2870

Prior to the introduction of AS 2870 builders largely decided themselves on the construction of residential slabs and footings, often with relatively minor input from Local Authorities. Slab-on-ground construction in those days consisted of a shallow perimeter strip footing, a bricked up base, and an in-fill slab. Steel reinforcement was minimal, just enough to control concrete shrinkage cracking.

Around the 1960s Local Authorities started to exercise a more regulatory and supervisory role, probably because slab-on-ground constructions were becoming popular and there was a growing awareness of structural damage due to foundation movement. Local Authorities began accumulating site details in the form of local maps, using the past performance of houses constructed in areas of similar site characteristics as a guide. They began specifying the type and size of slabs and footings they deemed appropriate to those characteristically similar building sites. In so doing, Local Authorities became potentially legally liable in the event of subsequent structural damage.

AS 2870 was introduced and adopted by Local Authorities in 1986. The first edition appeared to permit builders, architects, or drafts persons to select slabs and footings for houses. However, Local Authorities required that residential slabs and footings be designed and certified by registered professional engineers. This shifted professional and legal liability for residential slabs and footings to the engineering profession.

When AS 2870 was introduced it was claimed that *'Adherence to this standard will reduce future litigation'.* There is, however, a growing body of evidence this has not been the case. Frank Van der Woude advises a case study commissioned by the Queensland Building Services Authority (now Commission) in 1998 reported that a large percentage of structural damage compensation claims involved subsidence problems. More recently, *'The Age'* newspaper published an article on 08 June 2014 claiming *'Estimates suggest up to 4,300 homes in Wyndham, Melton and Hume Local Government areas may be suffering from slab heave'.*

The Victorian Building Authority (VBA) commissioned engineering consultants Meinhardt in 2011 to investigate what by then had become known as *'The slab heave problem'.* The VBA released some of Meinhardt's research findings in May 2014, stating *'The key issues relating to slab heave were associated with deficiencies in the storm water drainage systems of the dwellings'.* The Meinhardt report states elsewhere *'The peak in dwellings exhibiting defects occurred in 2009 towards the end of the drought'.* These two statements beg the question *'Is slab heave caused by wet weather or dry weather?'.*

1.2 Abnormal moisture conditions – the principal cause of failures?

Why are so many slabs failing prematurely? AS 2870 acknowledges that buildings constructed on sites subject to *'Abnormal moisture conditions'* have a higher probability of damage than those on normal sites. Provided all parties involved in the design and construction of the house have complied with AS 2870, as they normally do, structural damage investigators almost invariably blame premature failures on abnormal moisture conditions. Who is to blame for abnormal moisture conditions? AS 2870 suggests that classifiers, qualified engineers, designers, and builders are responsible for abnormal moisture conditions existing prior to or resulting from building construction, and owners are responsible for abnormal moisture conditions developing after construction. Clause 1.3.3 lists the following examples of abnormal moisture conditions developing after construction:

- The effect of trees too close to a footing.
- Excessive or irregular watering of gardens adjacent to the building.
- Failure to maintain site drainage.
- Failure to repair plumbing leaks.
- Loss of vegetation from near the building.

Anecdotal evidence suggests that when AS 2870 has been applied and there is a failure investigation, all too often the owner is blamed for abnormal moisture conditions, and is thereby prevented from proceeding to litigation. This has left many homeowners with no avenue of recourse after significant damage to their home.

1.3 Litigation

When litigation does proceed, the builder is typically alleged to have not provided adequate drainage during construction. Whilst this may be true in many cases, in the writer's opinion, the root cause of this problem is inadequate documentation.

The recent ASCEV seminar on site drainage appeared to opine that it was sufficient to provide arrows on the slab plan showing the direction of fall (away from the slab) along with an appropriate cross section through the edge beams, and appropriate site drainage notes, in order to specify drainage during construction. In the writer's opinion, this is not adequate, and a detailed site drainage plan should be prepared by a Civil Engineer for each reactive site. How is the Builder meant to adequately drain a flat site? What does he do if the only way to achieve adequate drainage during construction is to raise the finished floor level? Site drainage during construction is a 'design' issue, and should not be left to the Builder.

In a similar vein, site drainage post construction is also a 'design' issue, and it should not be left to the owner to interpret the CSIRO publication BTF18, titled *'Foundation maintenance and footing performance : A Home Owner's Guide'* ('BTF18') to install adequate drainage. As an example, BTF18 recommends the perimeter paving be more than 900mm wide in highly reactive soils (but does not advise how wide it should be). If the owner installs a 2m wide perimeter pavement, should this paving be drained? BTF18 only recommends drainage on the uphill site of the site. The Footings and Foundations Society Practice note No. 7, *Guide to Foundation Maintenance for Reactive Sites* goes further and opines *"… Ideally all runoff should be collected and drained via a silt pit to a legal point of discharge"*. The point here is the determination of the extent of drainage of perimeter paving is a 'design' issue; it forms an integral part of the footing system design, since its correct detailing is critical to the avoidance of abnormal moisture conditions. It should not be the responsibility of the home owner, who has no expertise in footing design, to effectively design the post construction site drainage.

The design for trees is another important issue. House allotments on new estates are typically relatively small these days, and compliance with AS 2870 Appendix B with respect to trees often means that only small trees may be planted on the property, because the footing design has not allowed for future trees, including the Council trees in the nature reserve.

In the writer's opinion, the fundamental reason for the development of abnormal moisture conditions during and post construction is the absence of a detailed site drainage plan (covering both construction, and post construction), and a landscaping plan which clearly indicates the limitations on planting assumed by the footing designer.

Owners and builders are unwittingly becoming part of the 'design team' due to inadequate documentation prior to construction. Whilst the owner and builder must of course retain some responsibility to ensure abnormal moisture conditions do not occur during construction, or develop at the site following construction, the majority of this responsibility should be borne by the design team (comprising the Architect / Building Design, Footing Design Engineer, and Geotechnical Engineer / Classifier). Significant changes are required in order for AS 2870 to achieve this, and thereby reduce the extensive litigation where the owner and / or builder are blamed for the abnormal moisture conditions.

Part 2

2.1 Structural failures

The term 'Failure' is used here in the context of failure to meet AS 2870 performance criteria. Whilst there is no doubt that foundation movement is the primary cause of structural failures of slabs on building sites with moisture reactive soil, investigators are not in a position to determine the extent to which foundation movement actually caused the failure. Most failures cited in Section 1.1 of Part 1 occurred a few years after construction, all a long time short of the AS 2870 design condition *'Foundation movement shall be assessed as the movement that has less than 5% chance of being exceeded in the life of the building, which is taken to be 50 years'.*

The author suggests that the growing number of incidences of premature structural failures demonstrates that residential slab designs that comply with AS 2870 are not designed to withstand foundation movements that have less than 5% chance of being exceeded in 50 years (refer typical example in the Appendix).

2.2 Flawed AS 2870 model

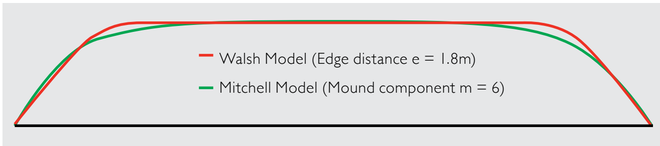
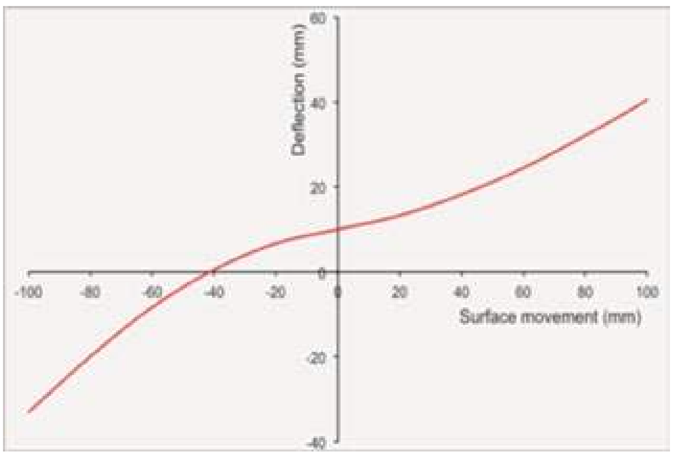


Figure 1 - Static mound profiles

The flawed AS 2870 model boils down to using a static analysis method to analyze the dynamic effect of foundation movement. Foundation movement is treated as a static load equal to soil stiffness times a function called the *'Mound profile',* shown here in Figure 1. This static analysis corresponds to superimposing a pre-fabricated structure on a building platform that has been pre-distorted into the assumed mound profile, and then analyzing the combined static effects of dead load, live load, and assumed foundation movement load. Mathematically correct as these static solutions are, they are solutions of a hypothetical problem.

2.3 Graphic evidence of the flaw

The most significant evidence that the AS 2870 model is flawed is that it uses linear elastic theory, but graphs of performance parameters versus surface movement, shown here in Figure 2, exhibit no linearity.



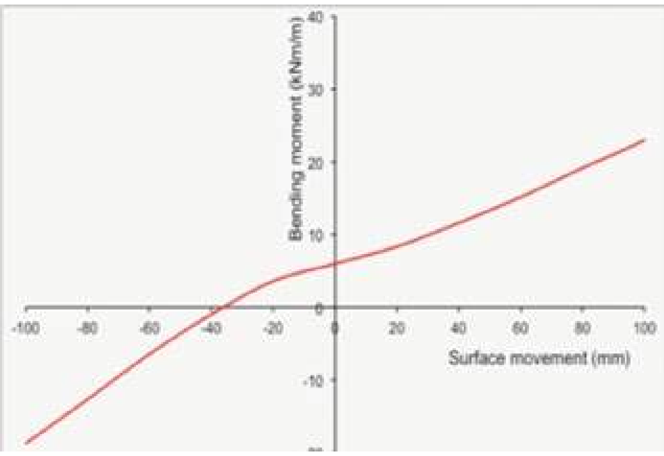


Figure 2 - Graphs of deflection and bending moment versus surface movement

The unusual shapes of the bending moment diagram and soil pressure diagram for the *'Centre heave'* condition, shown here in Figure 3, also demonstrate the flaws of the AS 2870 model. Intuitively, centre heave should produce peak bending moment and peak soil pressure at the centre of the beam, not near the edges.

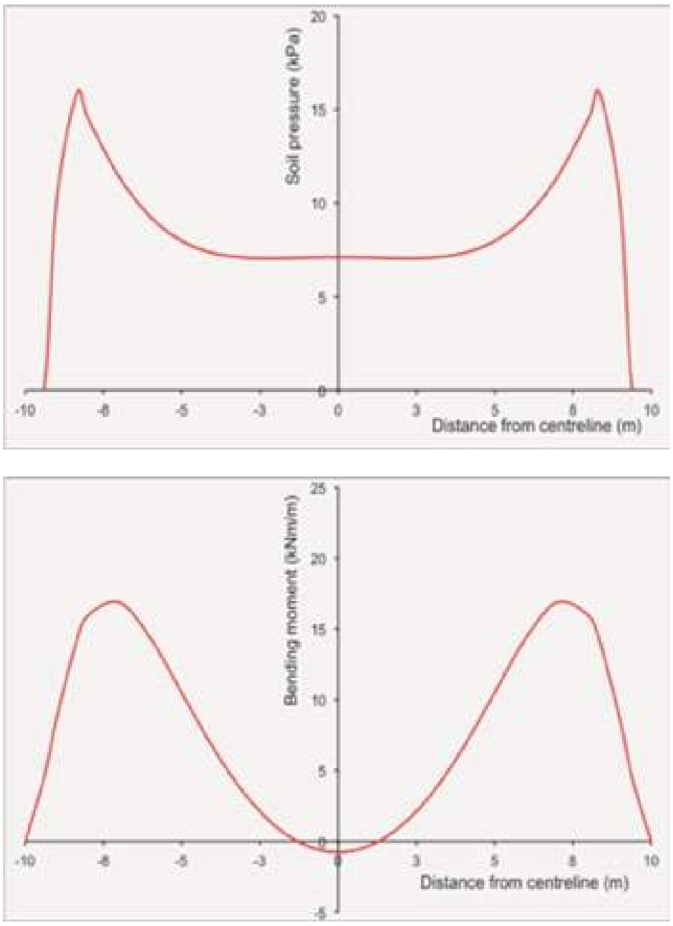


Figure 3 - Bending moment diagram and soil pressure diagram for centre heave

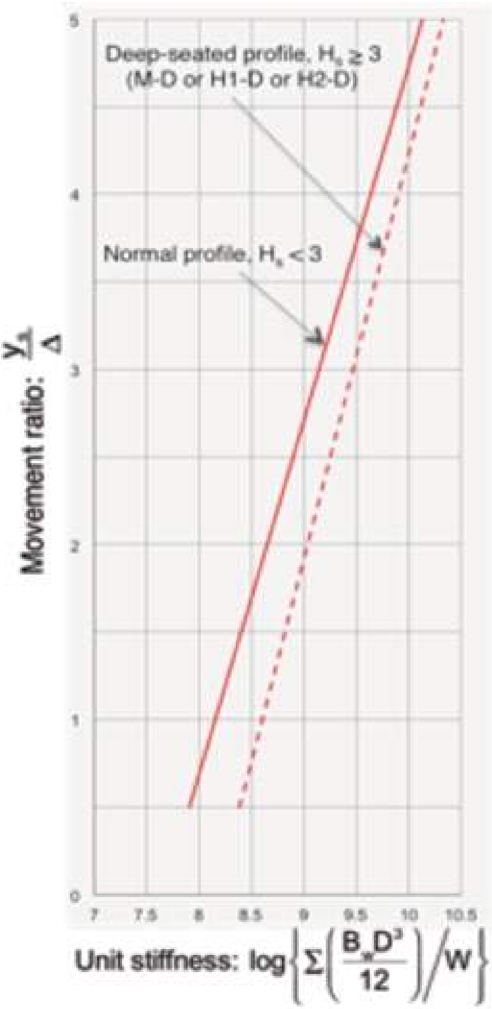


Figure 4 - Movement ratio versus unit stiffness

Last but not least, the graph of movement ratio versus unit stiffness, shown here in Figure 4, also suggests flaws in the AS 2870 model. Clause 4.5.1 of AS 2870-2011 suggests this graph covers a huge range of design parameters. Actually, it appears that the graph is an empirical fit to deemed to comply slab design solutions in Figures 3.1 and 3.4 of AS 2870-2011, taking the logarithm of unit stiffness on the horizontal axis of the graph to get a straight line. It does not take account of the dynamic nature of soil-structure interaction. Admittedly the term within the brackets of the logarithm is the sum of the second moments of area of the gross (that is, un-cracked) webs of the stiffening beam cross-sections divided by the overall width of the slab, but to call it *'Unit stiffness'* is misleading, and taking the logarithm of a number involving units of measurement breaches the fundamental principles of mathematics.

2.4 Proposed changes to AS 2870

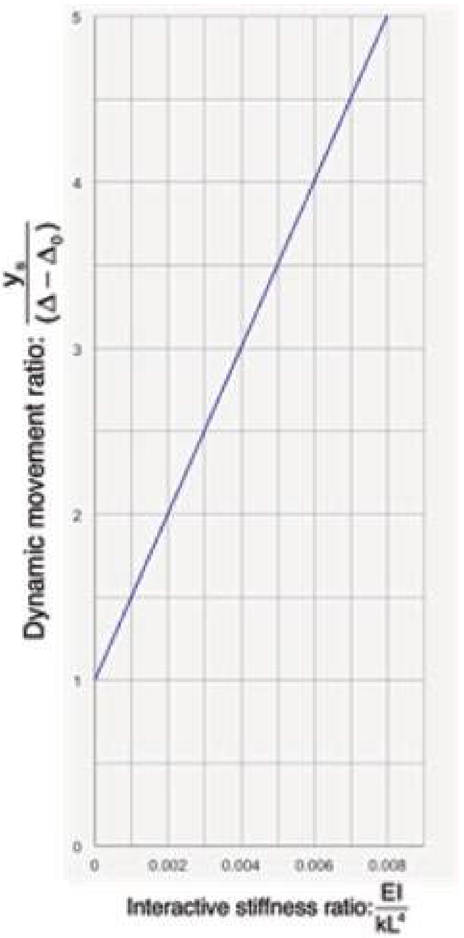


Figure 5 - Dynamic movement ratio versus soil-structure interactive stiffness ratio

The author proposes that the prescriptive deemed to comply slab design solutions in Figures 3.1 and 3.4 of AS 2870-2011 be replaced with a practical methodology for design by engineering principles. The author suggests that the flawed graph of movement ratio versus unit stiffness be replaced with the graph of dynamic movement ratio versus soil-structure interactive stiffness ratio, shown here in Figure 5. This graph can be used, as in Clause 4.5.2 of AS 2870-2011, to select a trial slab design based on elastic stiffness, using the deflection limits in Table 4.1 of AS 2870-2011. However, it should be mandatory for designers to demonstrate that the final slab design is strong enough to sustain the combined effects of static loading and dynamic foundation movement, for both heaving and subsiding soil moisture changes. The necessary mathematical process for this design methodology is somewhat tedious, but the calculations can be easily programmed into a spreadsheet.

The author also proposes to change the slab design model from elastic beam analysis to ultimate strength plate analysis. Fundamental engineering principles indicate that ultimate strength plate analysis calculates significantly lower deflections and lower bending moments than elastic beam analysis, and hence produces significantly more cost-effective slab design solutions than the deemed to comply solutions in Figures 3.1 and 3.4 of AS 2870-2011.

The proposed engineering design methodology adopts a limit states approach. Limit state methodology relies on the worst-case scenario of identifying and analyzing the governing failure mechanism and applying appropriate factors of safety and design criteria to ensure adequate in-service performance. The two major limit states in structural performance are serviceability and strength, and in the context of residential slabs on moisture reactive soil, these two limit states are inextricably linked through soil-structure interactive performance. The proposed limit states design methodology introduces load factors, surface movement factors for both heaving and subsiding soil moisture changes, capacity reduction factors, and a serviceability deflection factor. The introduction of factors on Ys values will enable slab designers to allow for possible abnormal moisture conditions. The proposed limit states design methodology will align AS 2870 with other similar Australian Standards, such as the engineering design codes for concrete, steel and timber structures.

Part 3 - Conclusions

Whilst the original authors of AS 2870 deserve much credit for a code that greatly advanced footing design technology at the time it was introduced, it has unfortunately gradually become outdated over time, and now requires a complete overhaul.

The usage of standard 'deemed-to-satisfy' footing systems selected from a code based on the site classification is no longer appropriate. It is now possible for footing systems to be readily individually designed, and a 'quantum' step between footing systems at nominated ys values is unnecessary and contrary to basic engineering principals.

Frank Van der Woude has previously presented his elegant theories on the design of slabs for soil-structure interaction; however, in the authors' opinion, these theories have not been given the attention they deserve to date. The authors suggest is time that his theories are closely examined by independent academics who do not have a vested interest in the theories currently endorsed by AS 2870.

In geotechnical terms, the cause of failures is almost always assessed to be related to the development of abnormal moisture conditions at the site, and owners and builders are being blamed for this, whereas, in the authors' opinion the root cause of abnormal moisture conditions is inadequate documentation of the drainage system. If a detailed site drainage plan, covering both the construction and post construction phases, and a landscaping plan, were prepared at the time of the design of the footing system, the risk of failures due to abnormal moisture conditions would be significantly reduced.

References

1. R. Gregory, *Waffle raft slabs and the edge heave problem following the recent severe drought in Victoria,* BDPS News, Issue 50 - August 2015.
2. F. Van der Woude, *Linear beam on mound model,* Australian Geomechanics, Volume 38 No 2, June 2003.
3. F. Van der Woude, *Limit state slab on mound model,* Australian Geomechanics, Volume 39 No 4, December 2004.

Appendix

The table below presents results of ultimate strength analysis* of deemed to comply stiffened raft and waffle raft slabs prescribed in AS 2870-2011. These results are for a typical single storey house, for five common types of construction. The overall length of the floor plan is 13.75 m and the overall width is 12.00 m.

Dead load for each type of construction has been taken from SAA HB28 – 1997, with a dead load factor of 1.25. Live load of 1.5 kPa has been used with a live load factor of 1.5

Slab proportions, stiffening beam layouts, and reinforcement details have been taken from Figures 3.1 and 3.4. in AS 2870-2011. Effective flange widths of stiffening beams have been calculated in accordance with Clause 4.4(e) of AS 2870-2011.

Ultimate bending moments have been calculated in accordance with AS 3600, using a capacity reduction factor of 0.8 The compressive strength of concrete has been taken as 20 Mpa, and the yield strength of steel reinforcement as 500 MPa.

Soil stiffness has been taken as 1000 kPa/m.

Table of results		*Surface movement capacities (mm)*				
Site class	***Type of slab***	***Clad Frame***	***Articulated Masonry Veneer***	***Masonry Veneer***	***Articulated Full Masonry***	***Full Masonry***
Class S $0 < y_s \leq 20$mm	Stiffened raft	$0^{(1),(2)}$	$0^{(1),(2)}$	$0^{(1),(2)}$	$0^{(1),(2)}$	$0^{(3)}$
	Waffle raft	$15^{(1)}$	$0^{(1)}$	$0^{(1)}$	$0^{(1)}$	N/A
Class M $20 < y_s \leq 40$mm	Stiffened raft	$2^{(2)}$	$0^{(1),(2)}$	$0^{(1),(2)}$	$15^{(3)}$	$0^{(3)}$
	Waffle raft	$25^{(1)}$	$0^{(1)}$	$0^{(1)}$	$17^{(3)}$	N/A
Class M - D	Stiffened raft	$16^{(2)}$	$9^{(1)}$	$41^{(3)}$	$15^{(3)}$	$0^{(3)}$
	Waffle raft	$25^{(1)}$	$0^{(1)}$	$9^{(1)}$	$17^{(3)}$	N/A
Class H1 $40 < y_s \leq 60$mm	Stiffened raft	$16^{(2)}$	$9^{(1)}$	$41^{(3)}$	$13^{(3)}$	$0^{(3)}$
	Waffle raft	$36^{(1)}$	$25^{(1)}$	$43^{(3)}$	$40^{(3)}$	N/A
Class H1 - D	Stiffened raft	$39^{(1)}$	$42^{(1)}$	$39^{(3)}$	$13^{(3)}$	$0^{(3)}$
	Waffle raft	$36^{(1)}$	$25^{(1)}$	$43^{(3)}$	N/A	N/A
Class H2 $60 < y_s \leq 75$mm	Stiffened raft	$84^{(1)}$	$64^{(1)}$	$37^{(3)}$	$9^{(3)}$	N/A
	Waffle raft	$36^{(2)}$	$25^{(1)}$	N/A	N/A	N/A
Class H2 - D	Stiffened raft	$117^{(3)}$	$73^{(3)}$	$37^{(3)}$	$9^{(3)}$	N/A
	Waffle raft	$55^{(1)}$	$44^{(1)}$	N/A	N/A	N/A

Notes

1. The suffix 'D' in site classifications means the soil moisture changes on the building site are deep-seated.
2. N/A means AS 2870 does not provide slab designs for the tabulated type of construction/site class.
3. Green fonts mean the tabulated surface movement capacities are within the range of characteristic values prescribed in AS 2870, as indicated under the tabulated site class in column 1 of the table.
4. Red fonts mean the tabulated surface movement capacities are below the range of characteristic values prescribed in AS 2870, as indicated under the tabulated site class in column 1 of the table.
5. Superscripts indicate the governing criteria for the tabulated surface movement capacities, as follows: $^{(1)}$ = Overall hogging strength $^{(2)}$ = Local slab panel strength $^{(3)}$ = Overall hogging deflection

* Technical Note published in *Australian Geomechanics, Volume 39, No 4, December 2004, pp. 97-101*