Technical Note on Use of BR470 in Soft Clay

In the design of working platforms the design document BR470 states in Appendix A2:

"Where c_u<20kPa the ground will be so soft that special measures will be needed to construct a working platform, and a more sophisticated type of design calculation is appropriate."

This immediately begs the question as to what type of design is appropriate and whether a relatively simple adjustment of the BR470 method can be developed to extend its range of validity. This technical note considers this question and indeed whether the stipulation of a minimum undrained shear strength of 20kPa is an appropriate value.

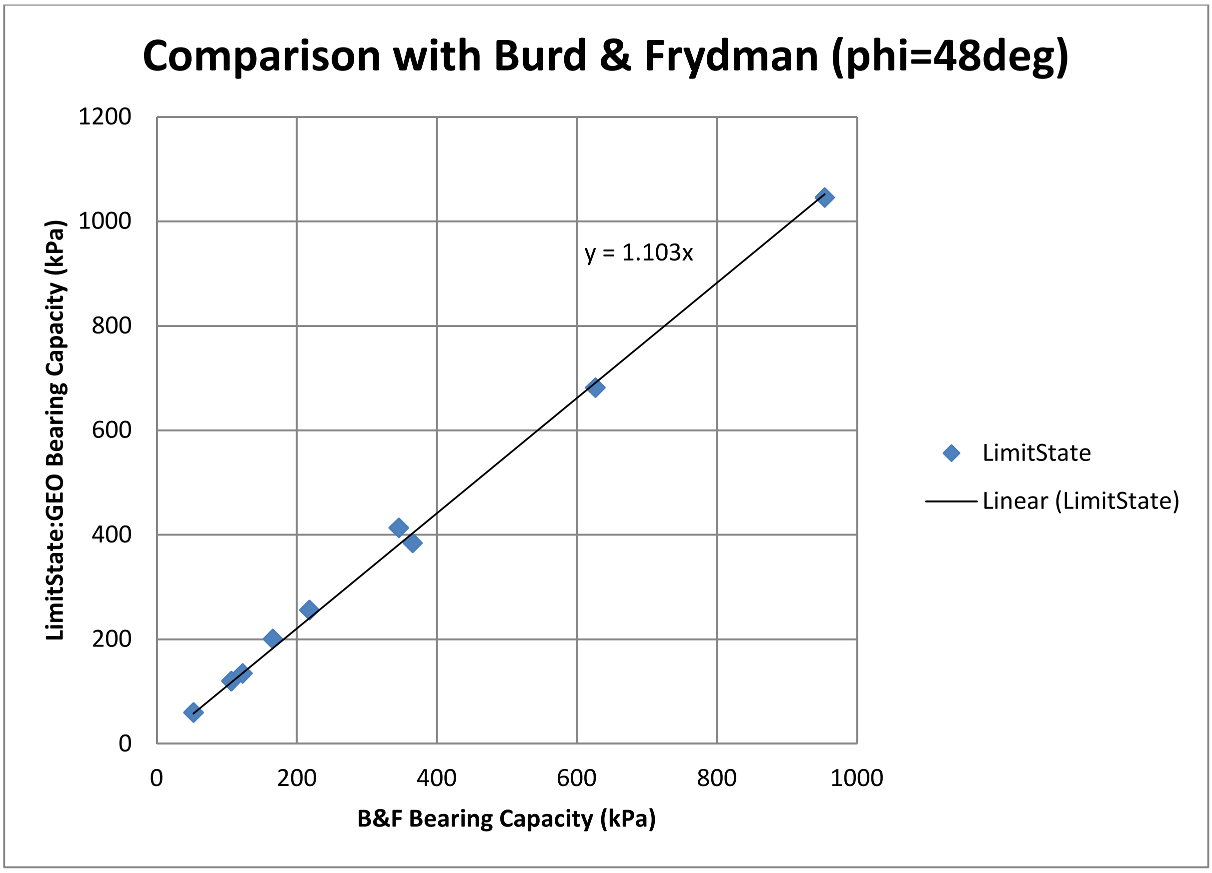
The main problem in considering this question is the dearth of experimental field testing of working platforms. In the absence of such testing all that can be done is to consider theoretical analyses. To use one theoretical analysis to evaluate another theoretical analysis leads to concerns over the validity of the theoretical methods. In general, though, more sophisticated theoretical analyses can be considered to give a more accurate representation of field behaviour than simple methods and thus it is considered valid to use a more sophisticated method to assess a simple one (the BR470 method).

Burd and Frydman (1997)

One of the most highly regarded analyses of the problem of the bearing capacity of plane-strain footings on a two-layered soil (granular over clay) is that given in the Paper by Burd and Frydman (1997). In their study of the problem they carried out a parametric study using both finite element and finite difference methods. Extremely good agreement was obtained between the two methods giving internal assurance of the validity of their results. Notwithstanding this, an independent assessment of their results has been carried out by the author using the commercially available software LimitState:GEO.

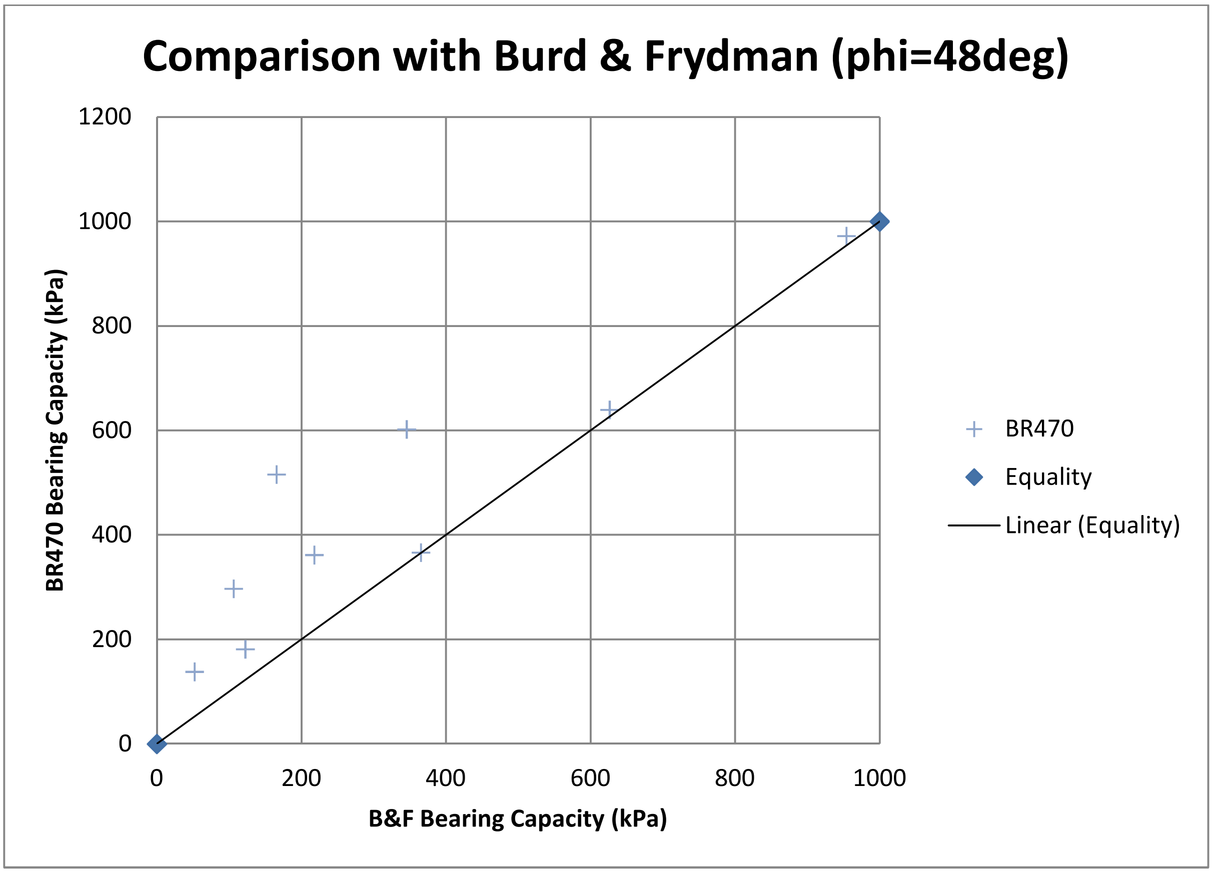
Burd and Frydman present their results in terms of charts of the non-dimensional parameters ($p/\gamma B$) and ($c_u/\gamma D$) for granular upper layer friction angles of $\phi=32^0$, 40^0 and 48^0. These friction angles can be considered appropriate for loose, medium dense and dense soils. To make the analysis realistic for piling rigs a breadth of footing B=0.9m (implying granular layer thicknesses D of 0.6m, 0.9m and 1.2m) and soil unit weight of γ=20kN/m^3 have been taken for the LimitState analyses. The parameter ($c_u/\gamma D$) was investigated over the range 0.3 to 4 for all friction angles implying a range of c_u from 3.6kPa to 96kPa in our example. This means their analysis adequately covers the full range of soil strengths encountered on sites and specifically extends comfortably either side of the BR470 lower strength limit. Since working platforms are constructed of well compacted well graded materials the assessment has been based on the highest friction angle of 48^0.

The results of the comparison between LimitState and Burd and Frydman are shown below in terms of the ultimate bearing capacity of the footing (p) determined by each method. It can be seen that there is excellent agreement between the two methods over the whole range of parameters with very little scatter (some scatter may be due to estimating the Burd and Frydman values off their charts). On average LimitState gives bearing capacity values 10.3% higher than Burd and Frydman. LimitState is an upper bound solution, so would be expected to give slightly higher values, though it may also indicate the Burd and Frydman values are slightly on the low side. In any case, it may be taken from this that Burd and Frydman provide a realistic assessment of bearing capacity and may be reliably used in assessing the validity of the BR470 method.



BR470 Comparison

The same example has then been used to assess the BR470 method. For a friction angle of 48^0 a value of $K_p\tan\delta=14.96$ has been used. The results are shown below once again in terms of ultimate bearing capacity of the footing. The concerning result emerges that the BR 470 method gives higher bearing capacities over the full range of results, with a wide degree of scatter over the lower half of the range (ultimate bearing capacity $<$ 600kPa). As the BR470 design applies a factor of safety of just 1.2 to Case 2 loading conditions, this implies the method is unsafe for applied track bearing pressures up to about 500kPa – precisely the range found for typical piling rigs and crawler cranes. In the worst case the BR470 bearing capacity exceeds the Burd and Frydman value by a factor of 3.1, greatly exceeding the 1.2 factor of safety and implying that failure of the working platform would occur. The three worst results are for the three lowest shear strengths of 3.6, 5.4 and 7.2kPa, whilst the three results close to the equality line are for the three highest shear strengths of 48, 72 and 96kPa. This highlights the fact that the problem lies with very soft clays, whilst the method appears to give satisfactory results for firm to stiff clays. The analysis appears to partly at least validate the guidelines given in BR470 on its use, though the degree of scatter in the results raises considerable concern and indicates that a better understanding of the method is needed.

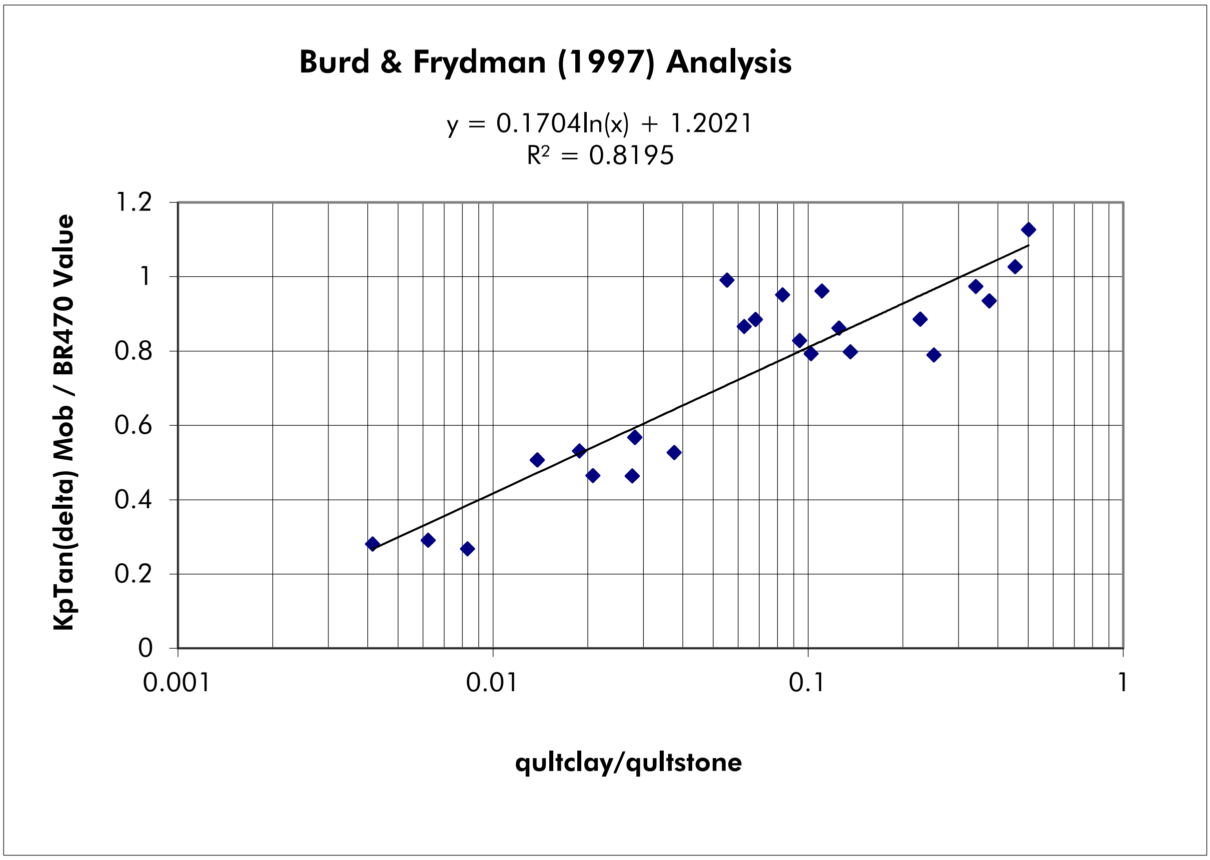


Refinement of BR470

Although Burd and Frydman provide charts for determining the ultimate bearing capacity of plane-strain footings, they are of limited use for real applications in that they have not provided an overarching theory or chart for all values of friction angle, shear strength and problem dimensions. It is therefore necessary to interrogate their results more deeply to see if any overarching theory can be derived from them.

The BR470 design method is based on the concept of punching shear failure and uses a coefficient of punching shear resistance ($K_p\tan\delta$). The properties of this parameter were investigated by Hanna and Meyerhof (1980). They found that the value of the parameter reduced with the shear strength of the clay and suggested that the value of the parameter would be related to the ratio of the bearing capacity of the clay to the bearing capacity of the granular layer. This concept has been investigated in considering the Burd and Frydman results.

The Burd and Frydman ultimate bearing capacities have been taken and the ultimate bearing capacity of the clay ($N_c c_u$) subtracted from them to give the contribution from the stone. From this the mobilised value of $K_p\tan\delta$ has been determined. The ratio of this value to the BR470 value for this parameter has then been plotted against bearing capacity ratio, as shown below. The figure includes all relevant results (where the bearing capacity of the stone has not been exceeded) for all three friction angles.



Although there is a wide degree of scatter, there is a clear trend demonstrating that the value of $K_p\tan\delta$ is far from constant but steadily reduces with reducing bearing capacity ratio. Most importantly it shows that when the bearing capacity ratio is below about 0.3 the BR470 method overestimates the contribution from the stone.

The above analysis offers a simple correction to the BR470 method based on the ratio of the bearing capacities of the clay and overlying stone, calculations which are automatically carried out as part of the method. The correction simply involves applying a factor to the value of $K_p\tan\delta$ currently used in BR470 using the correlation derived above. Different corrections are required for Case 1 and Case 2 loadings due to the different shape factors.

As an example consider the example given in Appendix A2 of BR470. For Case 1 loadings:

$q_{ultclay} = c_u N_c s_c = 24 \times 5.14 \times 1.04 = 128\text{kPa}$

$q_{ultstone} = 0.5\gamma_p W_d N_{\gamma p} s_\gamma = 0.5 \times 20 \times 0.7 \times 109 \times 0.94 = 717\text{kPa}$

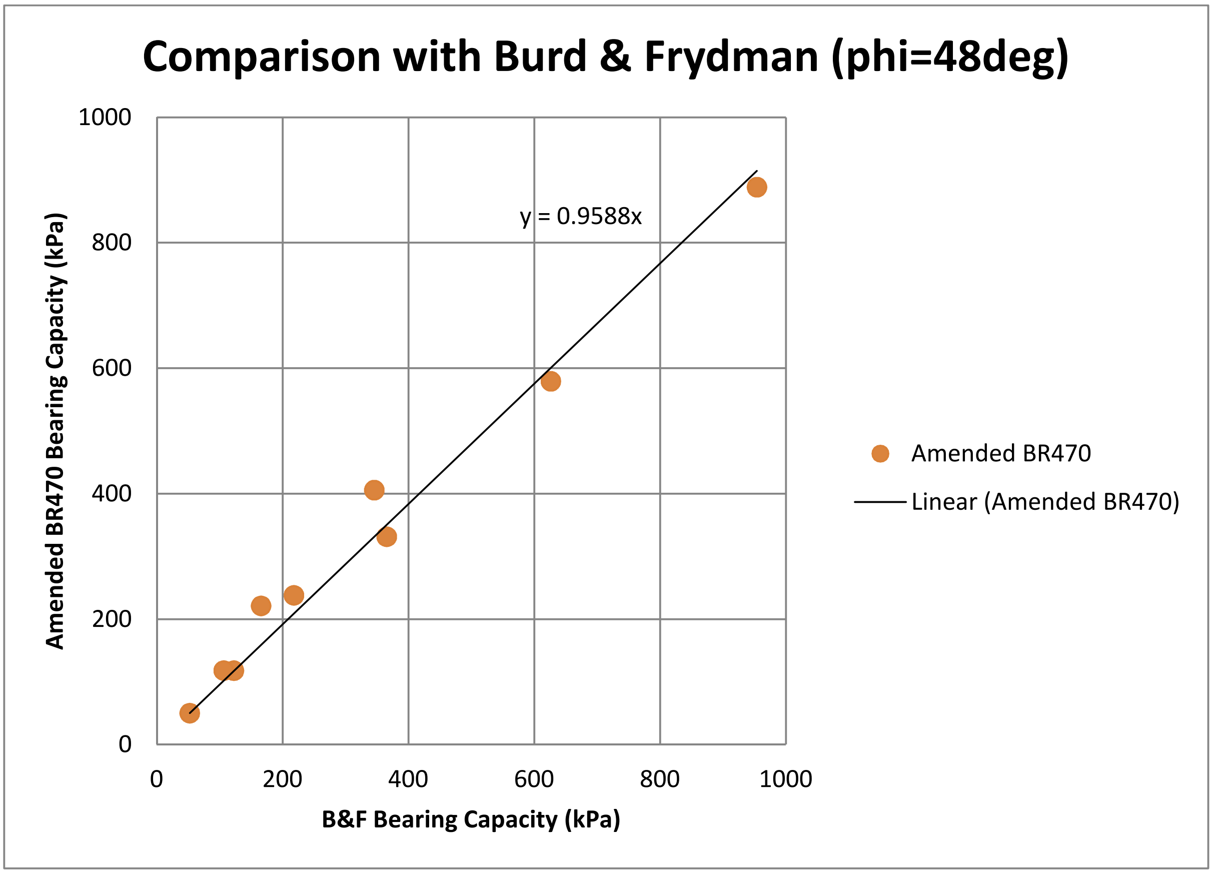
$q_{ultclay} / q_{ultstone} = 128/717 = 0.179$

The value of $K_p\tan\delta$ should then be multiplied by the factor 0.1704ln(0.179)+1.2021=0.909. The value of $K_p\tan\delta$ to be used in calculations is then not 5.5 but 0.909x5.5=5.0. The effect of this is to increase the calculated Case 1 design thickness from 0.72m to 0.75m.

Although the correction is not that significant in this case it can be in others, particularly where higher friction angles are used for the platform stone as determined from field testing. In fact the most likely reason platform failures have not been recorded to date is that conservative design input parameters have been used. With higher input parameters there runs a much greater risk of platform failure occurring if the existing BR470 design method is continued to be used.

Amended BR470 Comparison

In order to test the proposed amendment of the BR470 method it is necessary to assess it over the full range of shear strengths by comparison with the Burd and Frydman values for a friction angle typical of a properly constructed working platform. The same ultimate bearing capacity comparison as before has therefore been undertaken and the results are shown below. It can be seen that a much closer spread of results is now obtained (compared with the original BR470 method) with the proposed method giving on average values 4.1% lower than the Burd and Frydman values, although at worst the values are up to 33.8% higher. This indicates that when using factors of safety as low as 1.2 some degree of conservatism still needs to be applied when selecting appropriate design parameters. The proposed method does though offer a significant improvement on the present BR470 design method and allows more accurate design parameters derived from field testing to be used with greater confidence. With this amended method no limitation on its use with clays of low shear strength is now needed.



References

BRE (2004). *Working platforms for tracked plant.* BR470.

Burd HJ and Frydman S (1997). *Bearing capacity of plane-strain footings on layered soils.* Canadian Geotechnical Journal 34: 241-253.

Hanna AM and Meyerhof GG (1980). *Design charts for ultimate bearing capacity of foundations on sand overlying soft clay.* Canadian Geotechnical Journal 17: 300-303.

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