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prof. dr hab. inż. Danuta Leśniewska
Instytut Budownictwa Wodnego PAN
Zakład Geomechaniki
ul. Kościerska 7
80-328 Gdańsk

REVIEW
of PhD dissertation of **Worku Firomasa Kabeta**
entitled:
Centrifuge Modelling of Tapered Pile Installation Effects in Sand

1. Legal basis and scope of the review

The review was conducted in response to a PhD, DSc, Eng letter of prof. dr hab. Inż. Ewa Wojciechowska, dated 07.07.2025. The basis for the review is Article 187 of the Act of July 27, 2018 – The Law on Higher Education and Science, and its interpretation contained in the Council of Scientific Excellence guidebook *Reviews in scientific promotion proceedings*, introduced on June 30, 2022 and modified on April 12, 2023. According to this interpretation, a doctoral dissertation review should consist of three elements:

1) an assessment, along with a justification, of whether the doctoral dissertation presents the general theoretical knowledge of the person applying for the award of a doctoral degree in a specific discipline or disciplines;
2) an assessment, along with a justification, of whether the doctoral dissertation demonstrates the ability to independently conduct scientific or artistic work by the person applying for the award of a doctoral degree;
3) an assessment, along with a justification, of whether the doctoral dissertation constitutes an original solution to a scientific problem, an original solution in the field of applying the results of one's own scientific research in the economic or social sphere, or an original artistic achievement.

2. Structure, subject and objectives of the dissertation

The dissertation is 168 pages long, of which 49 are a literature review, 15 are a bibliography, and 5 are additional appendices. It includes 84 figures and 10 tables.

The subject of the thesis is the behavior of tapered piles, during installation and subsequent loading, studied by centrifuge modeling and numerical analysis in plane strain conditions. The difference in performance of tapered and straight piles is primarily investigated.

Although the Author does not formulate a clear thesis, it can be concluded that he verifies the opinion that tapered piles can be an alternative to straight piles due to their increased load-bearing capacity and lower material consumption, reported in the literature. The centrifuge tests discussed in the thesis has shown that it is not always true, because bearing capacity of tapered piles appeared lower than straight ones, despite larger extent of elevated stress zones created in soil. It is important finding, suggesting that further research on the topic is required. What seems interesting to me is the fact that very small taper angles (0.75^0 and 1.5^0) can cause measurable effects on the pile performance.

The objectives of the thesis consist of five points:

1. Developing physical models for simulating the behavior of tapered piles in dense sand under plane-strain conditions.
2. Investigating the effects of taper angle on the load-displacement behavior and bearing capacity of piles installed in dense sand.
3. Analyzing stress redistribution and mobilization around tapered piles during installation and subsequent static loading.
4. Evaluation of soil deformation and strain patterns during pile installation using Particle Image Velocimetry.
5. Performing numerical simulations to validate and complement experimental observations.

3. Discussion of the doctoral thesis

The following part of the review will include critical comments regarding implementing the adopted research objectives.

Objective 1. *Developing physical models for simulating the behavior of tapered piles in dense sand under plane-strain conditions.*

The experiments that form the basis of the doctoral dissertation were carried out at the Geotechnical Centrifuge Laboratory of Gustave Eiffel University in France as part of the European Union project GEOLAB EU-Horizon 2020 and were performed by a team. It is impossible to conclude from the thesis how significant the doctoral student's contribution to the experimental program was. The content of the doctoral dissertation suggests that his main task was developing and analyzing the results of centrifuge experiments. However, assessing the quality of this work requires a comprehensive description of the tests performed. Instead, information is scattered in several sections and sometimes seems to be inconsistent.

For example, the testing procedure is mentioned in Section 4.2.5 (Testing procedure), Section 5.2 (Load-settlement behavior of walls) and 5.2.2 (Static loading phase). In each case the procedure is described a little differently, leaving the reader in doubt as to the correct testing scheme.

page 67: *The installation phase involved pushing the model wall vertically into the dense sand at a constant rate of **0.1 mm/s** until reaching a target embedment depth of 224 mm. …*
*Upon completion of the installation phase, **a static loading test was conducted** to evaluate the load-displacement response of the embedded wall. **The wall head was loaded incrementally** in compression using the actuator **at a reduced rate of 0.1 mm/s to ensure quasi-static loading conditions**. The load was applied until the wall displacement reached a magnitude equivalent to its average base breadth (16 mm), after which the wall was gradually unloaded, and a final pull-out test was also performed.*

page 74: *In each test, the wall was pushed into the subsoil at 0.1mm/s rate to a depth of 224mm. Once the final depth was reached, slow unloading of the model head was performed, and then*

the static compression loading *up to the displacement corresponding to the mean wall breadth B=16mm was applied followed by unloading head wall to zero and final pull-out test.*

page 78: *After installation, each wall was subjected to* ***monotonic axial loading*** *to evaluate its load settlement behaviour.*

So what was the difference between installation and static loading? It can be understood from page 67, that both were monotonic loading of the same displacement rate. What means then, that the wall head was loaded incrementally? Why different terminology is used in pages 74 and 78? On page 67 there is no information about unloading after the installation phase, present on page 74.

Objective 3. *Analyzing stress redistribution and mobilization around tapered piles during installation and subsequent static loading.*

Stress mobilization for tapered and straight piles is presented in Section 5.4. The Author selected the way of presenting the installation stress readings from 5 sensors embedded at three levels in soil, following work of Jardine, R. J. et al. Geotechnique, 2013, as a function of a position of a pile tip (penetration depth, Figs 5.8-5.13). This way of plotting may suggest that soil stress profiles are presented, what is confirmed by some figures' captions: Fig.5.11 - *Stress distribution in the soil mass ...* and Figs 5.12 and 5.13 - *Mobilized lateral stress in the soil ....* It is confusing, because the figures show in fact stress evolution in time at the sensor locations. Recalculating pile penetration depth from measurement time is correct, but using it as a coordinate does not give stress profile in soil.

Objective 4. *Evaluation of soil deformation and strain patterns during pile installation using Particle Image Velocimetry.*

The first mentions of deformation analysis using the DIC and PIV methods can be found in Sections 2.6.3 and 2.6.4. Characteristics of DIC and PIV methods given there suggests that the Author is not aware that both (not only the PIV method) are based on the same principle of finding a maximum of autocorrelation function.

Section 3.4.2 discusses some DIC and PIV analysis results from the literature. Section 4.3 (*Image analysis using Particle Image Velocimetry*) contains very general information on the deformation analysis performed using the PIV method on images taken during experiments conducted with the Author's participation in the centrifuge. He used *GeoPIV-RG* software, but did not present in any detail, what are the applications, possibilities and limitations of this program and the method itself. It is not known what was the resolution of the images, what was the image patch size and patch overlap. Without this information and without an example of the displacement field in a vector form it is not possible to judge the quality of PIV analysis, which final results are given in Chapter 6 (*Soil displacements and strain fields*). To present soil deformation, contour plots of horizontal and vertical displacements and vertical and shear strains were selected. They show some lack of continuity, especially in the case of strains, which may result from inaccuracy related to the accepted patch size – no study of patch size influence is presented. Section 6.4 is inappropriate titled (*Displacement of soil particles*) - *GeoPIV-RG* can trace elements of PIV mesh (soil patches), not soil particles.

The Author seems to be aware that some information is lacking in the description of PIV analysis – Appendix C, entitled *Image-based analysis using PIV*, promises to present the mesh configuration (which in PIV method consists of identical rectangles) and procedural steps used. In reality the Appendix contains one camera image and two meshes generated by the OPTUM G2 finite element software, having nothing to do with image analysis. It is difficult to interpret this fact in any other way than a lack of understanding of the methods and programs used.

Objective 5. *Performing numerical simulations to validate and complement experimental observations.*

The impression of misunderstanding of the applied methods deepens in Chapter 7 – *Numerical analysis of load-settlement and failure mechanism.*

Section 7.2 - *Finite element method results* – contains, according to the Author, finite element analysis of the embedded pile models using OPTUM G2 numerical software. Description of this package is limited to quoting its name and mentioning that soil behavior can be modelled by Mohr-Coulomb or Hardening Mohr-Coulomb models. As a result, the Author seems not to be aware of the fact, that OPTUM G2 is a package consisting of many tools, including elasto-plastic analysis and limit analysis (Fig.R.1).

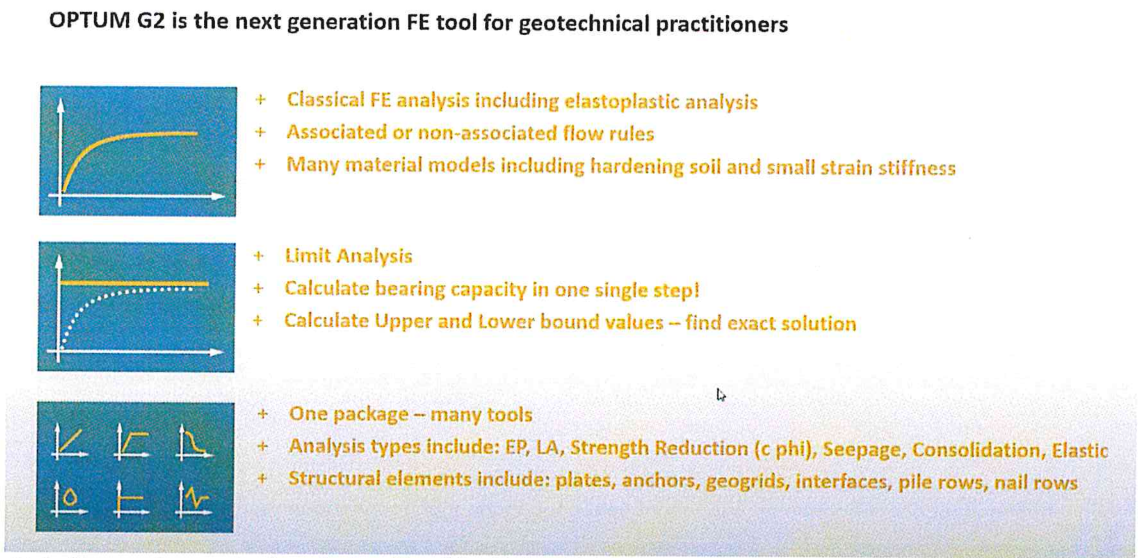

Fig.R.1. Types of numerical analysis offered by OPTUM G2 (from educational movie *OPTUM G2 – the basics*)

Figs 7.1-7.4, 7.6 in Section 7.2 present, according to the Author, results of numerical analysis performed using the finite element method. This contradicts the contents of the figures, which are the pairs of curves, designated as the upper and lower bounds of load-bearing capacity.

My conclusions are:

a) The author is unaware that upper and lower bounds are elements of limit analysis, so he does not realize he is performing limit analysis.
b) He is also not aware that any displacements taken from limit analysis have no physical meaning and no valid load-displacement curves can be obtained for upper and lower bound estimates (only two values of limit force or stress).
c) He does not realize that lower and upper bound theorems hold only for the associated flow rule (Fig.7.4 compares upper and lower bounds for associated and non-associated flow rule).

Basic educational video materials issued by OPTUM CE and available in Internet, confirms all three points:

A common misconception is that displacements are calculated in Limit Analysis – they are not. Instead a collapse mechanism is calculated and scaled. When you in OPTUM G2 for a Limit Analysis plot displacements, you will notice that no units appear in the distribution – this is to indicate that a collapse mechanism has been plotted and units are not relevant. Also, if you go to the model and click on a certain material, you will notice on the parameters grid that only strength parameters appear. In the settings not relevant to the analysis you will find the stiffness parameters as well as the flow rule and the initial conditions. This is because these parameters are not relevant in a limit analysis. In a limit analysis the flow rule is always associated and stiffness parameters do not enter the problem.

It seems probable that the Author made a mistake and has taken limit analysis for finite element elasto-plastic analysis. But if so, how he could obtain results for non-associated flow rule, which is available only in elasto-plastic analysis (Subsection 7.2.2.3)? And where the displacement values in a range from 0 to 16 mm come from in Figs 7.1-7.4 and 7.6, if no displacement units are relevant in Limit Analysis? Fig.R.2 shows an example of how the upper and lower bound analysis results should look like in OPTUM G2, and Fig.R.3 shows a comparison between limit and elasto-plastic analysis.

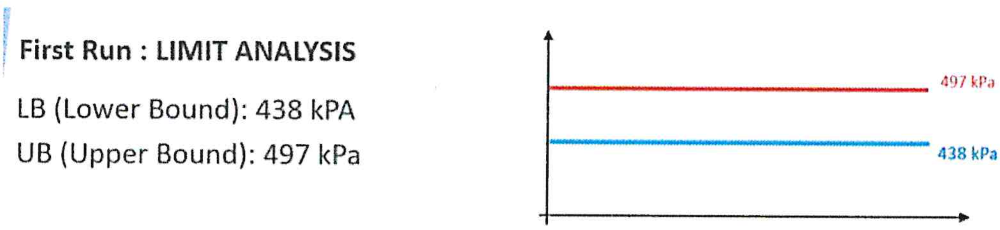

Fig.R.2. Result of limit analysis from OPTUM G2 educational video.

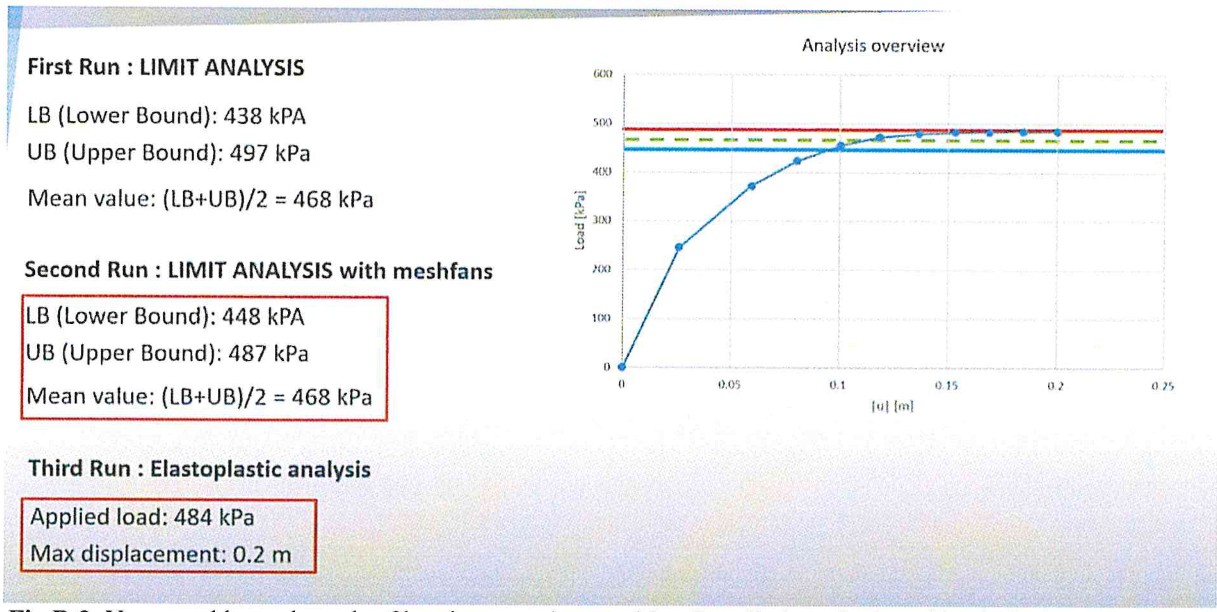

Fig.R.3. Upper and lower bounds of bearing capacity, resulting from limit analysis and load-displacement curve resulting from elasto-plastic analysis (OPTUM G2 educational video).

Overall, it is clear that Section 7.2 contains significant factual errors that should not appear in a doctoral thesis.

Section 7.3, entitled *Limit analysis results*, presents the results obtained by *Limit State Geo* software. There is again no description of this package, so it is not clear, whether the results represent lower or upper bound, or some other ultimate limit state. However values of load bearing capacity are higher than the upper bound from Section 7.2, so maybe this is the upper bound solution. Nevertheless it should be compared to Section 7.2 results, as obtained by the same approach.

It is done indirectly in Section 7.4 (Fig.7.9 a and b), which shows that the results of limit analysis depend on the software used. It is not surprising, but should be commented. I cannot agree with the conclusion from comparing the limit analysis results and experiments that any differences between them are related to lack of installation effects in numerical analysis – this is a scientifically unfounded claim with no proof for that in the thesis. Installation effects are not the only possible factor which could cause the difference. And how the difference between *OPTUM G2* Limit Analysis and *Limit State Geo* Limit Analysis could be explained by installations effects?

4. Conclusion

Concluding this review of the doctoral thesis by Worku Firomasa Kabeta I have no impression that he achieved general theoretical knowledge, sufficient to independently conduct scientific work. Especially I cannot see enough scientific inquisitiveness, which would encourage a thorough recognition of the problem studied and tools and programs used to analyze it.

However, based on the dissertation, I am not able to assess value of his contribution to centrifuge model tests in France and I cannot completely rule out the possibility that some of the reservations presented in the review could be resolved in his favour. Taking this into account, I accept his admission to the next stage of the doctoral procedure.

A. Lisowska