Recenzja - specjalne wymagania formalne

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PhD Thesis Review Report by Miguel Azenha

Title: *Behavior of external clay brick façade walls made of lime-based mortars – experiments and simulation approach of irregular settlements and seismic-type cyclic shear loads*

Supervisor: Prof. Jan Kubica, Silesian University of Technology, Gliwice, Poland

1. Formal assignment and object of the review

This review has been prepared on the request of the Faculty of Civil Engineering of the Silesian University of Technology, under contract UMC/2847/2025. The subject is the doctoral dissertation entitled *"Behavior of external clay brick façade walls made of lime-based mortars – experiments and simulation approach of irregular settlements and seismic-type cyclic shear loads"*, written by Mr. Armando Zagaroli, M.Sc., Eng., under the supervision of Prof. Jan Kubica.

The review concerns the fulfilment of the requirements defined in Article 187 of the Polish Law on Higher Education and Science. It aims to evaluate the scientific quality, originality, and practical relevance of the work, as well as the ability of the candidate to perform independent research.

2. Topic of the dissertation

The dissertation concerns the behaviour of external clay brick façade walls built with lime-based mortars, with reference to irregular settlements and cyclic or seismic-type loads. The general idea combines the study of a traditional material with structural performance and sustainability aspects. The theme is relevant and timely in view of the known need to move towards more sustainable construction, and the frequent 'back-to-basics'/past approach that has been revealing important benefits in regard to the practices of recent decades.

The work aims to contribute to the understanding of how lime mortars affect the mechanical response of masonry walls in specific scopes of their behaviour and whether

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they could be used safely in modern applications or in the conservation of old façades. This direction is well chosen and has practical significance. It also corresponds to the recent trend of re-evaluating low-carbon binders and of linking laboratory studies with durability and life-cycle considerations.

However, when examining the details, there seems to be limited coverage of one main physical situation announced in the title: *irregular settlements*. The part related to settlements is mostly conceptual. No specific experimental arrangement reproducing differential support movements was developed, such as a controlled rotation or imposed base displacement. The author instead applied vertical or slightly eccentric loads on the walls and discussed the resulting cracking as a possible analogy to settlement effects. While this approach provides some insight, it does not allow a direct quantitative understanding of settlement-induced stresses or deformations. Also, no analytical formulation or parametric simulation was performed to explore this mechanism in depth.

It is also worth noting that the candidate connects settlement mainly with subsidence phenomena linked to mining activity, which indeed has local relevance in parts of Poland. Yet the problem of ground settlement is far more general, affecting urban areas worldwide due to soil consolidation, underground works, and variable foundation stiffness. A broader discussion would have strengthened the international dimension of the research and placed the problem in a wider geotechnical context.

Despite these imbalances, the thesis touches on an important and timely subject. The focus on lime-based mortars as a more sustainable binder and their use in masonry façades remains relevant. Such motivation and the attempt to relate mechanical behaviour to sustainability considerations are appreciated. In summary, the topic of the dissertation fits a current research trend and shows professional awareness, even if the realised scope is narrower and more descriptive than the ambitious title initially suggests.

3. Layout of the dissertation and its parts

The dissertation is organised into six main chapters, followed by references and appendices. Its overall structure is conventional and easy to follow. The text is presented in a clear format, with tables and figures that help the reader. Minor language issues appear here and there, but the English is generally understandable and does not obstruct comprehension.

Chapter 1 – Introduction and objectives
This chapter introduces the general topic and motivation. It outlines the environmental argument for lime mortars and briefly mentions irregular settlements and seismic actions as the main research themes. However, the actual objectives and hypotheses are not defined in a concise way. Section 1.2, which should clearly establish the aim of the study, remains vague and somewhat narrative. The connection between sustainability, mechanical behaviour, and modelling is therefore not made explicit from the start.

Chapter 2 – Literature review (~37 pages)
The review gathers a significant number of references, mostly recent. It provides a broad overview of lime mortars and of masonry behaviour but tends to be descriptive

rather than analytical. There is limited discussion of how previous studies approached settlement or cyclic actions. Many citations refer to works from Poland, which are relevant in the context of mining subsidence, but the international literature on differential settlements, soil–structure interaction, or lime mortar performance in other climates seems largely omitted. A stronger comparative discussion would have clarified the real research gap.

Chapter 3 – Experimental campaign (~58 pages)
This chapter forms the core of the thesis and contains by far the most material compared to the next chapters on numerical simulation and the analytical approach. The composition of mortars, the preparation of specimens, and the testing procedures are presented with care. The figures and tables are generally clear, and the results are documented in detail. Nevertheless, the experimental programme is not balanced with the rest of the work. The chapter reads more like a technical report than a research synthesis. The lack of reference specimens without lime in the mortars could be considered a significant limitation for benchmarking. Still, the work clearly demonstrates the candidate's ability to conduct and document laboratory work independently.

Chapter 4 – Numerical simulations (~15 pages)
The modelling part is short compared with the extensive experimental section. It uses a plane-shell finite element approach to simulate wall behaviour under simplified loading conditions. The main assumptions and parameters are mentioned briefly, without sensitivity checks or discussion of limitations. The model serves more as an illustration of the concept and of simulation adherence to experiments, rather than as a tool for deeper analysis. Given the relevance of this part to the thesis title, one would expect a more comprehensive treatment, possibly including nonlinear response or further calibration using tests through other modelling approaches (e.g., micro-modelling).

Chapter 5 – Analytical or semi-analytical methods and procedures (~11 pages)
This chapter introduces simplified analytical formulations intended to complement the numerical modelling. It aims to provide approximate expressions and limits for wall stiffness and deformation/drift under vertical and lateral loads. The approach, however, remains generic and is not fully integrated with the thesis's experimental or numerical results. The chapter adds little to validation or comparison and therefore plays a limited role in the overall argument of the thesis.

Chapter 6 – Summary and conclusion (3 pages)
The final chapter summarises the main observations and conclusions. The conclusions are mostly descriptive of the observed and confirmed behaviour without further interpretation or quantitative reasoning.

The appendices contain supplementary tables and raw data from the experimental work. These additions are useful for completeness, although some material might have been integrated into the main text to support discussion. The inclusion of these detailed results confirms that the candidate has collected substantial information, even if its scientific interpretation is limited.
In summary, the dissertation is well structured in form but unbalanced in substance. The experimental part dominates, while the analytical and interpretative parts are concise.

The layout, therefore, supports readability, yet it reveals the main weakness of the work: the lack of equilibrium between data collection and scientific synthesis.

4. Aim and scope of the thesis

According to the introduction, the general aim of the dissertation is to study the mechanical behaviour of clay brick masonry façades constructed with lime-based mortars, particularly under irregular settlements and cyclic seismic-type loading. The author also mentions a broader ambition to contribute to sustainability in construction by reconsidering lime mortars as an alternative to cement-based ones. These objectives are timely and potentially valuable, as they link environmental concerns with the structural performance of masonry.

When analysing the thesis in detail, the scope turns out to be more limited than the formulation suggests. The experimental programme provides some insight into the compressive and shear behaviour of small wall panels, but it does not reproduce actual settlement mechanisms. The connection of conclusions with settlement-induced effects is indirect. The numerical study, although relevant as a concept, might be considered too simplified to extend the conclusions beyond the specific cases tested.

The sustainability dimension, presented as one of the motivations, appears primarily in the introductory chapter and briefly again in the conclusions. The life-cycle argument is not developed with quantitative indicators, and the environmental benefits of lime mortars are more assumed than demonstrated. Including a comparative LCA with clear boundaries and assumptions would have strengthened the message and connected better with current European research on low-carbon binders.

Still, the candidate has managed to define a coherent line of work on masonry with lime-based mortars and has produced a consistent set of laboratory results. The main goal of deepening the understanding of the mechanical response of walls built with lime mortars under specific conditions has been achieved to a meaningful extent. The broader objectives related to settlements and sustainability have only been partially achieved.

5. Applied methods and procedures

The research methods used in the dissertation combine laboratory testing and numerical modelling. The general approach is adequate for the subject and shows that the candidate has acquired practical experience with experimental work. The sequence of activities is logical: first, the characterisation of materials, then the testing of wall specimens, and finally an attempt to model their behaviour numerically. The documentation of laboratory procedures is quite detailed and indicates careful work.

In the experimental part, different lime-based mortars were prepared and tested for strength and deformability. The wall specimens were constructed with regular clay bricks and subjected to vertical and lateral loading. Instrumentation and data recording were adequate to capture the global response of the panels. However, the testing plan was relatively small and did not include a reference wall made with standard Portland-cement mortar, which would have been essential for comparison. More focus on curing control (and its effects) might have been beneficial to broaden conclusions, since the

mechanical behaviour of lime mortars is sensitive to moisture and carbonation. For these reasons, the results should be interpreted with caution.

The representation of irregular settlements was approached by means of slightly eccentric or non-uniform loading, but no physical simulation of differential foundation movement was implemented. The tests, therefore, illustrate the structural response under uneven compression rather than genuine settlement-induced bending or tilting. This methodological simplification restricts the conclusions that can be drawn regarding settlement effects.

Regarding seismic-type loads, the experimental choice for cyclic testing may under-represent the actual damage types and strain rates expected under seismic conditions. This could have allowed broadening analyses and conclusions.

The numerical analysis was carried out using a plane-shell finite-element model. The model reproduces the geometry of the wall specimens and applies simplified boundary conditions. The assumptions are presented briefly, and the material parameters are mostly based on experimental averages. There is no detailed evidence of a mesh-sensitivity study, nor any attempts to calibrate nonlinear behaviour such as cracking or softening. The analysis thus serves mainly as a visual confirmation that the observed load-displacement trend can be simulated, rather than as a predictive or explanatory tool. Other simulation levels (explicitly considering units and joints) might have brought further insights of relevance, in view of the current body of knowledge.

Overall, the chosen methods are consistent with the candidate's resources and level of experience. The work demonstrates technical ability and laboratory competence, yet it would benefit from a clearer experimental design, the inclusion of control cases, and a more analytical use of numerical tools. Despite these limitations, the procedures are documented transparently, and the results provide a reasonable basis for discussion.

6. Results and discussion

The results presented in the dissertation primarily come from laboratory testing of lime-based mortars and masonry wall panels. The data are clearly organised and supported by many tables and figures. The author reports the measured strengths, stiffness values, and failure patterns with sufficient detail. The presentation of load-displacement curves and visual documentation of cracking provides a useful record of the observed behaviour. The numerical simulations are then compared qualitatively with the experiments.

In general terms, the tests confirm what is already known in the literature: lime mortars exhibit lower strength and stiffness than cement-based mortars but higher deformability. The masonry walls built with lime mortar display a more gradual load-displacement response and larger ultimate deformation before failure. These findings are coherent with expectations and are consistent with results published by other authors.

However, the discussion of these results is limited in depth. The thesis tends to describe what was observed without analysing the underlying mechanisms in detail. Concepts such as shrinkage, creep, or microcracking, which strongly influence the performance of lime mortars, are not discussed. The correlation between mortar properties and wall behaviour remains qualitative. For example, it is not clear how variations in mortar

strength or stiffness influence the cracking pattern or load transfer through the wall joints.

Regarding settlements, the results are interpreted as if eccentric loading could reproduce the effects of differential foundation movement. This analogy is useful at a conceptual level but not fully convincing from a structural point of view. The observed cracks may indeed resemble those produced by settlements, but no parametric quantification or analytical link is made between applied eccentricity and equivalent ground movement. The numerical model does not explore this either, so the understanding of settlement-induced stresses remains limited.

The numerical analysis reproduces the general trend of the load–displacement curves and the position of main cracks. Yet, it remains a simplified representation, and the agreement with tests is evaluated mostly visually. No quantitative error measures or sensitivity analyses are provided. Important modelling parameters, such as the modulus of elasticity, tensile strength, or the assumed failure criterion, are briefly mentioned without justification or discussion of their influence. The model, therefore, serves as an illustrative complement, not as a verification or extension of the experimental work.

Despite these shortcomings, the thesis provides a coherent set of original observations. The material and wall tests are presented carefully, and the data can be useful for future comparative studies. The candidate has demonstrated diligence in data collection and processing. What is missing is a stronger analytical interpretation, capable of turning observations into generalised conclusions. With more emphasis on synthesis rather than description, the work could have reached a higher scientific level.

7. Significance for practice and research

The practical contribution of the work lies mainly in the experimental data collected on lime-mortar masonry walls. The tests were carried out with visible care, and the presented results can serve as reference information for future students or engineers working on similar materials. The photographs, tables, and documented failure modes illustrate the typical behaviour of walls with lower-strength mortars, which can help in understanding the safety margins of existing façades.

Nevertheless, the scientific originality or the novel contribution of the work may be perceived as limited. The experiments confirm tendencies already known in the literature rather than discovering new mechanisms. The environmental argument, which could have brought novelty, is only briefly discussed and without quantitative support. The numerical analysis, although conceptually interesting, is simplified and does not lead to predictive or general conclusions. For these reasons, the thesis stands closer to an original applied study than to a groundbreaking research work.

From a practical viewpoint, however, the thesis has significant value, which must not be downplayed. It adds to the growing body of evidence that lime mortars can perform satisfactorily in façade applications, offering better deformability and reduced cracking sensitivity. The experimental work can inform both restoration practices and further research into eco-friendly masonry materials. In this sense, the dissertation contributes modestly but positively to the applied knowledge base in its field.

8. Errors, inaccuracies, and remarks

The process of reading the thesis led to the identification of a few aspects (some of them already mentioned) that are briefly addressed in the list below:

- Title wording might deserve revising to "made with lime-based mortars."
- According to the Interinstitutional Style Guide of the European Union, UK spelling is recommended (https://style-guide.europa.eu/en/content/-/isg/topic?identifier=10.3-spelling). The title of the thesis is using the word 'behavior' instead of 'behaviour'. A change might be recommendable?
- Section 1.2 does not state the main aim or objectives clearly.
- The term *"crack resistance"* (p. 3) is undefined.
- Environmental discussion is superficial: unclear whether mortars are included in global CO_2 statistics; statements about lime's lower footprint lack life-cycle data support.
- Claim of 33 % CO_2 reduction from carbonation is not contrasted with Portland-cement carbonation; quantitative comparison missing.
- Implications of curing on strength, shrinkage, and durability not tested/discussed.
- Creep and shrinkage effects, relevant for settlement behaviour, are not addressed anywhere.
- Numerical modelling:
    - Plane shell element with 4 nodes — integration scheme not specified.
    - Mesh refinement finer than material heterogeneity; heterogeneities not explicitly modelled or justified.
    - No mesh-size sensitivity or convergence discussion.
- Lack of simulation of in-plane shear tests despite experimental relevance.
- Only two mortar types studied; absence of Portland-cement reference limits comparability.
- Use of homogenised macro-models not justified; a micro-model would improve understanding.
- Reproducibility might be perceived as difficult: limited raw experimental data is provided; simulation model files not shared.
- Phrase "unlock the full potential" in "Future developments" is subjective and not supported by evidence.

9. Assessment of the candidate's knowledge and research ability

Mr. Armando Zagaroli shows good working discipline and clear motivation to complete his research. The amount of laboratory work performed indicates persistence and technical autonomy. He appears comfortable with experimental procedures, data recording, and practical aspects of material preparation and testing. The appendices confirm that he is able to collect and organise a significant quantity of measurements.

At the same time, the thesis reveals limited maturity in the analytical interpretation of results. The candidate tends to document rather than to reason from the evidence. Some choices in the experimental design, such as the absence of a reference cement mortar or of controlled curing, suggest that the conceptual planning stage could have been more critical. In the numerical part, the modelling skills seem basic, and the understanding of

structural mechanics seems mainly operational, without deep reflection on model assumptions or boundary conditions.

Overall, Mr. Zagaroli has shown that he can carry out experimental research independently and present it in a structured form. He has reached the level of competence expected from a beginning researcher, although not that of a mature specialist. With more analytical training and international exposure, he could strengthen his understanding of structural behaviour and improve his scientific writing in the future.

10. Final conclusion

The doctoral dissertation of Mr. Armando Zagaroli, entitled "Behavior of external clay brick façade walls made of lime-based mortars – experiments and simulation approach of irregular settlements and seismic-type cyclic shear loads," deals with a topic of practical and environmental relevance. The author has shown determination and technical skill in developing an extensive experimental programme and in documenting his results with care and clarity.

The work is structurally coherent and technically correct, though it remains more descriptive than analytical. Its main contribution lies in the collection of experimental data on masonry walls made with lime-based mortars, which may be useful for future studies and for practical applications related to façade rehabilitation. The more ambitious aspects expressed in the title, namely the simulation of irregular settlements and seismic-type actions, were only partially realised, and the analytical depth is limited. Nevertheless, the thesis reflects a consistent personal effort and demonstrates that the candidate is capable of independent research within his field.

The thesis submitted for review falls within the scope of the Scientific Discipline of Civil Engineering, Geodesy and Transport and meets the requirements specified in Article 187 of the Act on Higher Education and Science of 20 July 2018 (Journal of Laws of 2024, item 1571 with subsequent amendments). Therefore, I apply for the acceptance of the doctoral dissertation of Mr. Armando Zagaroli, M.Sc. in the Scientific Discipline of Civil Engineering, Geodesy and Transport and admit it to public defence.

Guimarães, Portugal, 11th November 2025

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