



Evaluation of ancient bricklayers' skills using numerical estimations of the masonry strength of the walls of Churches from the Broumov Group

Shantanu S Kulkarni

Czech Republic | 2020



ADVANCED MASTERS IN STRUCTURAL ANALYSIS OF MONUMENTS AND HISTORICAL CONSTRUCTIONS

Master's Thesis

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DIPLOMA THESIS ASSIGNMENT FORM

I. PERSONAL AND STUDY DATA

Surname: Kulkarni Name: Shantanu Personal number: 497053

Assigning Department: Department of Mechanics

Study programme: Civil Engineering

Branch of study: Advanced Masters in Structural Analysis of Monuments and Historical Construction

II. DIPLOMA THESIS DATA

Diploma Thesis (DT) title: Evaluation of Ancient Bricklayers' Skills Using Numerical Estimations of the Masonry Strength of the Walls of Churches from the Broumov Group

Diploma Thesis title in English: see above

Instructions for writing the thesis:

1. Virtual (due to covid-19) preliminary inspection of the Churches from the Broumov Group, historical survey.
2. Discussion on results from nondestructive and destructive testing in laboratory.
3. Summary of information sources.
4. Creation of FEM models for calculation of strength in compression, tension and shear
5. Introduction of results of calculation employing NLFEA – ATENA software packages.
6. General comments on bricklayers skill and some conclusion and recommendations.

List of recommended literature:

Bathe, K. (1996). Finite element procedures. Up Saddle River, New Jersey, USA: Prentice Hall, Inc.
Bohumir Prokop, Jiri T. Kotalik, Pavel Suva. (2007). Broumov group of churches: Guide in Czech.
ATENA. (2020). ATENA Engineering Documentation. Cervenka Consulting Ltd.

Name of Diploma Thesis Supervisor: Pavel Kuklik

DT assignment date: April 6, 2020

DT submission date: July 12, 2020

DT Supervisor's signature

Head of Department's signature

III. ASSIGNMENT RECEIPT

I declare that I am obliged to write the Diploma Thesis on my own, without anyone's assistance, except for provided consultations. The list of references, other sources and consultants' names must be stated in the Diploma Thesis and in referencing I must abide by the CTU methodological manual "How to Write University Final Theses" and the CTU methodological instruction "On the Observation of Ethical Principles in the Preparation of University Final Theses".

Assignment receipt date

Student's name

DECLARATION

Name: Shantanu S Kulkarni

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Title of the Msc Dissertation: Evaluation of ancient bricklayer's skills using numerical estimations of the masonry strength of the walls of Churches from the Broumov group

Supervisor(s): Prof. Ing. Pavel Kuklik, Csc

Year: 2019-2020

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

I hereby declare that the MSc Consortium responsible for the Advanced Masters in Structural Analysis of Monuments and Historical Constructions is allowed to store and make available electronically the present MSc Dissertation.

University: Czech Technical University in Prague

Date: July 10, 2020

Signature: _____

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“Sometimes it is the people no one can imagine anything of, who do the things no one can imagine”

- Alan Turing

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Firstly, I would like to express my sincere thanks to my supervisor, Prof Ing Pavel Kuklík, CSc. for his support and valuable suggestions throughout this study. His knowledge, vast experience, available resources, and willingness to help were integral to the development of this study during difficult times of Covid-19. The work was carried out remotely but Prof Kuklík made sure that I at least once get to see few churches of Broumov region and get a feel for baroque architecture when we traveled to the Broumov region on June 11, 2020, for a one-day trip after the lockdown restrictions were eased. That gave me extra motivation and a perspective and for that, I would be grateful.

I am thankful to my co-supervisor Radomir Pukl for his availability and quick and detailed email responses during this study and for providing me with access to Atena program and relevant documentation on Atena theory, tutorial manual and other program documentation. I would also like to thank my other co-supervisor Ing. Radek Zigler, Ph.D. for his guidance.

Special thanks to Charalampos Paschopoulos for meetings, phone calls and providing me with his expertise on the use of Atena UI, tricks and shortcuts in Atena program, and validating my models.

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I wish to also thank Mr. Bruce Ensor, PE, and Mr. Ryan English, PE from BE Structural PC for allowing me to work part-time remotely during this one year. Without your support and workflow, it would have been difficult to maintain financial independence.

I also wish to express my gratitude to all my family but in particular to my parents, grandparents, and my brother for their unconditional love, blessings, and endless support.

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Finally, special shout out to my windows computer for not dying on me and working continuously for several days and nights and successfully converging and providing me with post-peak behavior for all 12 models presented in this study.

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ABSTRACT

Despite relatively extensive research in masonry structures, the issue of reliable identification of the load-bearing capacities of existing, mainly historic masonry structures has still not been solved satisfactorily. The identification of the load-bearing capacities of existing historic masonry structures is an extremely difficult task because of the variability and vagueness of the parameters describing the physical and mechanical characteristics of masonry units and mortar.

The main objective of this study is to calculate and evaluate the strength of the walls of different bricklayer's patterns of broumov churches in compression, tension, and shear. A detailed 2-D Micro-modelling approach was used to numerically predict capacities of walls loaded under compression, tension, and in-plane shear by developing stress-strain curves.

In this study, four different broumov wall sections of 1m long x 1m tall x 0.5 m thick were modeled in Atena 2D for non-linear finite element analysis. Material and geometric non-linear models with interface elements were analyzed using Finite element method. Post-peak behavior was achieved to compute compressive, tensile, and in-plane shear strengths of wall assemblies.

Results were also analyzed to compare and observe the predicted development of cracks and crack widths. Considering that expected failure will happen in the head or bed mortar joint, the same mechanical properties of hydraulic lime mortar were applied for all four wall assemblies. The difference in strength parameters are then compared directly based on the different stone bricklayer's pattern.

Keywords: Non-linear Finite element analysis, Micromodelling, Masonry bricklayer's patterns, Strength parameters

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ABSTRAKT

Navzdory velmi rozsáhlému výzkumu zděných konstrukcí, nebyla dosud spolehlivě vyřešena otázka spolehlivého posouzení únosnosti stávajících, především historických zděných konstrukcí. Identifikace jejich je velmi obtížný úkol z důvodu řady nejistot týkajících se parametrů, které popisujících fyzikální a mechanické vlastnosti jednotlivých konstituentů, zejména pak malty.

Hlavním cílem této studie je určit a zhodnotit pevnost vybraných částí stěn Broumovské skupiny kostelů v tlaku, tahu a smyku s uvážením všech jedinečností skladby zdiva. Pro řešení byl použit 2 D mikromodelovací přístup, pomocí něhož byly počítány pracovní diagramy, vztahy mezi napětím a deformací, pro jednotlivé skladby zdí.

Pomocí software Atena 2 D, fy Červenka consulting s.r.o., byly modelovány části stěn rozměru 1 m x 1 m o tloušťce 0,5 m. Studie byla provedena na zdivu čtyř zvolených kostelů broumovské skupiny. V nelineárním konečně prvkovém modelování byly využity kontaktní prvky, aby se lépe vystihl styk jednotlivých skladebných prvků zdiva. Pozornost byla věnována povrchové části pracovního diagramu, aby se transparentně stanovily jednotlivé pevnosti skladby zdiva ve 2 D.

Analýza byla zaměřena na vznik a progresi trhlin a porovnání jejich předpokládaného či zjištěného vývoje s výpočtem. Vzhledem k tomu, že porucha se šíří zejména v maltě, byly ve všech případech zvoleny pro maltu stejné parametry. Tímto byl zvýrazněn vliv skladby zdiva a místních zednických dovedností.

Klíčová slova: nelineární analýza MKP, mikromodelování, skladby zdiva, parametry pevnosti

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सारांशः

एका वर एक दगडाची लावण करुण निवारा साठी वापरणे हे मानूस अनेक शतकपासून करत आहे आहे. आणि माणसाने काळानुसार तंत्रामध्ये सुधारणा केल्या आहेत. अलिकडच्या वर्षात काँक्रीट व स्टीलचा अधिक वापर करून आधुनिक बांधकाम करण्यासाठी, संरचनेचा घटक म्हणून दगडांचा वापर कमी झाला आहे.

अस्तित्वात असलेल्या ऐतिहासिक दगडी बांधकामांच्या सुरक्षा पातळीची सध्याची स्थिती मोजणे आणि विश्वासाने ओळखणे हे एक कठीण काम आहे. या अभ्यासाचे मुख्य उद्दीष्ट संकुचन (compression), तणाव (tension) आणि कातरण (shear) मधील ब्रूहमोव्ह चर्चच्या वेगवेगळ्या ब्रिकलेयरच्या नमुन्यांच्या भिंतींच्या ताकदची गणना करणे आणि त्याचे मूल्यांकन करणे आहे. सूक्ष्म-मॉडेलिंग दृष्टीकोन तणाव-तणाव वक्र विकसित करून कम्प्रेसन, तणाव आणि कातरणेखाली लोड केलेल्या भिंतींच्या क्षमतेचा अंकीयपणे अंदाज लावण्यासाठी केला गेला. या अभ्यासामध्ये, Atena 2D मध्ये 1 मीटर लांबीच्या x 1 मीटर उंच x 0.5 मीटर जाडीचे चार वेगवेगळे ब्रॉवमोव्ह भिंत विभागले गेले.

क्रॅक्स आणि क्रॅक रूंदीच्या अंदाजानुसार केलेल्या विकासाची तुलना आणि निरीक्षण करण्यासाठी परिणामांचे विश्लेषण केले गेले. हेड किंवा बेड मोर्टार संयुक्तात अपेक्षित अपयश येईल हे लक्षात घेता, हायड्रॉलिक लाइम मोर्टारच्या समान यांत्रिक गुणधर्मांना चारही भिंत असेंब्लीसाठी लागू केले गेले. सामर्थ्य पन्नामीटर्समधील फरक नंतर थेट भिन्न दगड विटाच्या पत्राच्या आधारावर तुलना केली गेली.

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