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OVERVIEW OF RESEARCH PROJECTS: PROJECT STREP AND PROJECT MPC

As a former scholarship holder of the SEEFORM PhD program, the first author would like to express his gratitude for participation in the program by publishing an overview of two ongoing research projects in the special issue of the Scientific Journal of Civil Engineering dedicated to the celebration of 15 years of SEEFORM. Both projects are reflecting the current research interest and show the progress after the graduation.

The project STREP targets experimental investigations of mechanical properties of two repointing mortars, polymer fibre-reinforced cement-based mortar, Reparatur Mortar FZ + polypropylene straps and lime mortar with crushed brick. The main target of the second project, MPC, is testing of a real-time digital structural health monitoring solution applied to a representative structure, reinforced concrete bell tower of a church.

Keywords: masonry, strengthening, structural repointing, monitoring, vibration, ambient

1. RESEARCH PROJECT STREP

The research project "Masonry strengthening by structural repointing-Project STREP" aims to experimentally investigate the mechanical properties of two repointing mortars, polymer fibre-reinforced cement-based mortar, Reparatur Mortar FZ + polypropylene straps and lime mortar with crushed brick. The experimental program is designed to assess the physical and mechanical properties of masonry components and strength characteristics of masonry exposed to compressive and diagonal compressive stresses, both on unstrengthened and strengthened test specimen. The main aim of the testing campaign is to compare the behavior of the masonry, its bearing capacity and to determine the effect from the structural repointing method in favor of recommendations and procedures of its application for seismic protections of existing masonry buildings.

The motivation of this research arises from the inherent seismic vulnerability of masonry structures and the aspiration for upgrading their seismic resistance by using affordable and reliable strengthening techniques. Structural repointing is considered as a commonly used strengthening method, generally for brick and block masonry buildings. Although many papers dealing with experimental and analytical investigations of strengthening methods have been published [1-8], their practical application many times is based solely on engineering judgement and workman experience. Therefore, the motivation of this research was based on the need for detailed investigation of the seismic behavior of strengthened masonry with traditional methods.

The research project STREP targets on experimental research of structural repointing method, Fig. 1, by using 2 different mortars (1) traditional lime mortar with crushed brick powder and (2) contemporary polymer fibre-reinforced cement-based mortar, Reparatur Mortar FZ + polypropylene straps.

1.1 RESEARCH METHODOLOGY

The greatest part of the research is laid on experimental testing [9-14], to determine:

- Mechanical properties of solid clay bricks
- Mechanical properties of 2 mortar types: lime mortar with brick powder and Reparatur mortar
- Compressive strength of unstrengthened (W-AP) and repointed masonry by 2 mortars (WS-AP-RPP and WS-AP-LM)
- Diagonal tension strength of unstrengthened (W-DP) and repointed masonry by 2 mortars (WS-DP-RPP and WS-DP-LM)

A part of the investigation will address the mathematical modeling and simulation of experimental results.

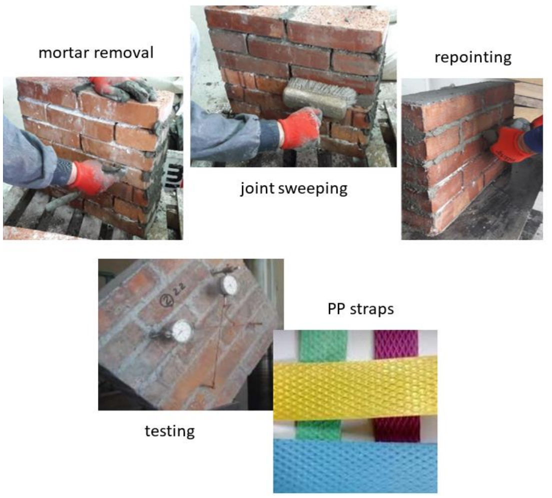

Figure 1. Structural repointing and testing in STREP

1.2 PROJECT OUTCOMES

The main scientific contribution of the project shall be determination of:

- Strength and deformation properties of masonry components
- Strength and deformation properties of structural masonry for both unstrengthened and strengthened conditions
- The effect of the structural repointing method to the advantage of delivering provisions and guidelines for seismic protection of existing masonry structures
- The adaptability, construction method and financial effects of the strengthening method.

The investigated strengthening method is considered as traditional, cost-effective and effortless seismic upgrading method of masonry buildings. The used materials are available in the country and neighboring region and one mortar type is currently produced in the partner institution in this project.

1.3 PROJECT PARTNER INSTITUTIONS

The project STREP was established and funded by a mutual collaboration between academia and industry institutions. The consortium was created from Faculty of Civil Engineering-Skopje (FCE), Institute of Earthquake Engineering and Engineering Seismology (IZIIS) and an industry partner for production and sale of construction chemicals ADING. It was originally proposed by FCE as an extension of a master thesis of a student employed at ADING and mentored by the first author.

1.4 PROJECT STRUCTURE

The project work is structured in 3 work packages (WP) as shown in Fig. 2.

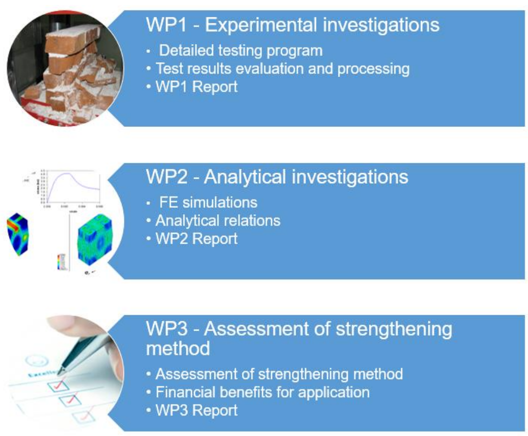

Figure 2. Structure of project STREP

The research activities in the work packages are divided between the project partner specialties and expertise. Testing of the compressive strength and initial shear strength of masonry wallets is responsibility of FCE, testing of diagonal tension strength of masonry walls will be performed at IZIIS, while testing of masonry components, modelling and calibration of mortar batches by testing is performed in ADING.

Since the project is still on-going, no results can be published yet. At the moment, compressive strength tests of W-AP and WS-AP-RPP series, as well as diagonal tension strength tests of W-DP series were completed. Some photos from the building of the specimens and performed testing are shown in Fig. 3.

Figure 3. Activities in project STREP

2. PROJECT MPC

Structural Health Monitoring (SHM) is considered as a process of implementing a damage detection and characterization strategy for engineering structures in order to maintain their functionality, safety and stability during exploitation. The SHM process involves assessment of the performance of a structural system by monitoring selected set of typical properties over time, extracting characteristic and damage-sensitive features from those observations and performing statistical analysis of those features to determine the current state of the structural system health.

This second research project led by the first author is entitled “Long-term monitoring of the bell tower of church of St. Clement of Ohrid in Skopje – project MPC”. The main target of the project is testing of a real-time digital structural health monitoring solution applied to a representative structure, a reinforced concrete bell tower of a church. In the following paragraphs the project structure, research team, the expected results and outcomes of the project are clearly outlined. The performed activities within the project are briefly discussed.

The main motivation of the research project was based on an attempt to highlight two targets: (1) testing of new monitoring solution and (2) long-term monitoring of a representative structure.

Lately, structural health monitoring was intensively applied at relatively tall and slender structures, such as high-rise buildings, telecommunication towers, masts, bell- and clock-towers and etc. The range of benefits obtained from such monitoring applications includes damage detection, assessment of maintenance and operability conditions and structural assessment for regular and incidental loadings.

Many published papers in this field describe the monitoring solutions, used equipment, obtained results and provoked decisions of the monitored structures [15-20].

2.1 RESEARCH METHODOLOGY

The SHM is relatively new scientific area, but its progress is quite extensive in the last few years. The development of new techniques and analysis tools lead the development, but also give the overall motivation of this research project.

The investigations foreseen have two targets: (1) to examine, test and compare the new monitoring solution from Digitex Systems and (2) to study the structural behavior of a RC bell-tower by continuous monitoring of selected parameters: acceleration, temperature, wind speed and direction and air humidity.

The targets set have scientific, but also applicative contribution. The testing of the new real-time structural health monitoring solution xDAS [21] for its calibration, fine-tuning and further development is of primary interest, Fig. 4. The SHM system is the development of a network of sensors and gages throughout a structure to monitor its health. This system of sensors combined with computer software and data collection methods are used to develop the SHM system that can be used in any structure.

2.2 PROJECT OUTCOMES

The greatest part of the planned investigations is directed to:

- Defining the structural geometry and materials of the bell-tower
- Long-term monitoring of selected parameters
- Acquisition, initial processing and archiving of recorded signals
- Interpretation of recorded data by analysis tools and methods
- FEM simulation of the structural behavior in correlation with recorded data from ambient vibrations
- Development of an approach for identification of critical events, automatic event-based data processing and in-time alerting after exceeding threshold values.

2.3 PROJECT STRUCTURE

The project run time is determined within 2 years, starting from early 2019.

Figure 4. xDAS real-time SHM solution

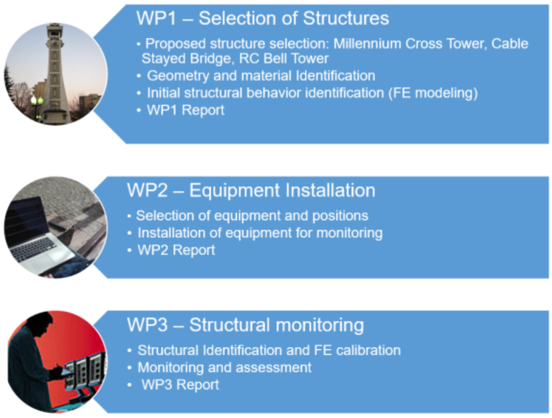

Figure 5. Structure of project MPC

The project activities are divided in three work packages (WP), Fig. 5.

The WP1 was established to select a representative structure for the project goals set. The final selection was made among several different structural types, such as steel tower, cable-stayed bridge and RC bell-tower. These activities started in the end of 2016, while the final decision and start of the preparatory works were committed in the beginning of 2019. Within the WP1, the bell-tower was extensively measured for determination of its geometry by means of manual measuring methods, but also by drone photogrammetry and LiDAR technology.

WP2 aims to select the appropriate monitoring sensors, select the sensor locations and perform the necessary hardware and software installation. The initial tests were performed to compare the results with a well-known portable ambient vibration testing solution from the same company. The system set-up is schematically presented in Fig. 6.

The largest part of WP3 contains in structural identification of the bell-tower under influence of traffic, wind and bell action loads. FEM model was developed to calibrate the model and simulate the structural behavior. Also, an on-line monitoring, maintenance and management system of the SHM solution was developed.

2.4 PROJECT PARTNER INSTITUTIONS

As with the previous project, MPC aims to connect and enforce collaboration between academia and industry institutions. The consortium was created from Faculty of Civil Engineering-Skopje (FCE) and industry partner Digitex Systems and Makedonski Telekom AD that supported the project by providing broadband internet at the bell-tower location.

Figure 6. xDAS Bell-tower application

Digitex Systems are responsible for acquisition of the equipment, installation, maintenance of all system components, as well as for development on-line management tools and decision supported tools for the SHM system. FCE is responsible for geometry and material identification, data processing, FEM modeling, calibration of mathematical models and structural analysis.

2.5 CURRENT PROJECT RESULTS

Most of the activities in the WPs were successfully implemented. The structural geometry was fully determined and technical drawings were prepared. Drone photogrammetry and LiDAR scanning were applied and 3D models are expected to be delivered soon, Fig. 7.

SHM system is composed of 4 MEMS tri-axial accelerometers xWave attached along the height of the tower, 1 weather station for monitoring wind speed and direction, temperature and air relative humidity positioned at the top and data acquisition system xPlorer.

FEM modelling, calibration and bell-induced vibration analysis were performed, Fig. 8.

Initial structural identification was performed and dynamic characteristics of the bell-tower were established. The on-line SHM management system was developed during summer 2019, Fig. 9.

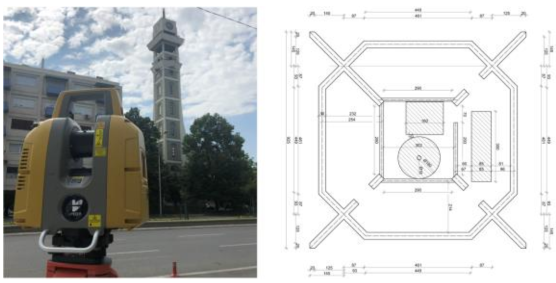

Figure 7. Geometry identification of the bell-tower

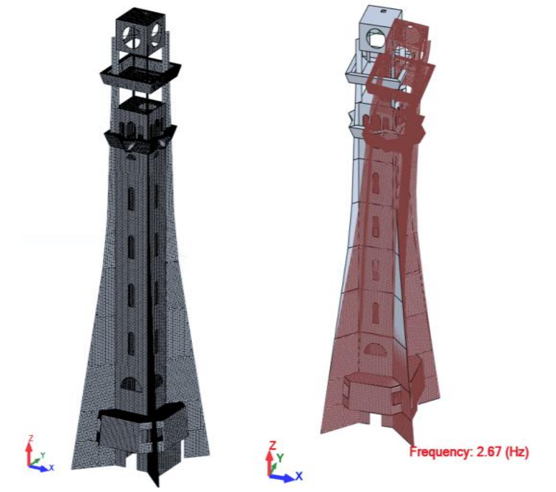

Figure 8. FEM modelling and modal analysis

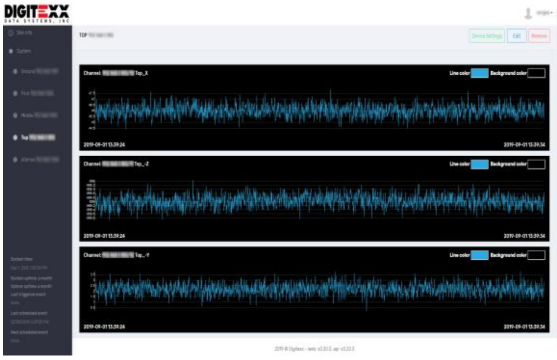

Figure 9. On-line monitoring management system

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