Integrating structural research activities and field experience with engineering education

Tamas BALOGH[1] **and Zoltan ORBAN**[2]

[1] *University of Pécs, Pollack Mihály Faculty of Engineering and Informatics – Department of Structural Engineering*
[2] *University of Pécs, Pollack Mihály Faculty of Engineering and Informatics – Department of Construction Materials*

Abstract

The Structural Diagnostics Research Group of Pollack Mihály Faculty of Engineering was established in 2010 with members from the departments of Structural Engineering and Building Materials, unifying some of the laboratory facilities of these departments. The principal objective of the research group is to carry out research targeted towards the analysis of the degradation processes of engineering structures, to analyse the effectiveness of various diagnostic and testing methods on damage identification, structural condition assessment and to develop numerical methods for residual life expectancy. In our research special attention is given to in-situ non-destructive testing procedures. The results of the research activities and our field experience are highly utilised in the development of course materials for structural engineering studies. The purpose of the presentation is to give an overview on the current activities of our research group via structural case studies and the introduction of domestic and international research projects in which the Reserch Group is participating. Course materials based on these activities are also demonstrated.

Keywords: *Diagnostics, NDT, assessment, lifetime expectancy, engineering, education.*

1. The Structural Diagnostics & Analysis Research Group

The research group was established in 2010 at the University of Pécs, Faculty of Engineering with members from the departments of Structural Engineering and Construction Materials unifying some of the laboratory facilities of these departments.

The principal objectives of the research group are to carry out research targeted towards the analysis of the degradation processes of engineering structures, to analyse the effectiveness of various diagnostic and testing methods on damage identification, structural condition assessment and to develop numerical methods for the reliability analysis and residual life expectancy of structures. The results of the research activities are continuously integrated with the teaching course materials.

2. Research areas

The research activities of the research group are focusing on the following areas:

2.1. Research area No.1: Optimised diagnostic procedures of masonry structures

The aim of the research is to develop of examination and testing procedures for the determination of the mechanical and structural characteristics of masonry structures. The research focuses on methods that cause minimal or no destruction to the examined structures and have appropriate reliability for practical application. In he first phase of research laboratory tests are carried out on masonry specimens using various test methods. Based on the experience gained by the laboratory tests the methods are used in-situ on real structures too, such as masonry bridges and buildings. As expected results of the survey the reliability and efficiency of various non-destructive and semi-destructive methods are compared using mathematical statistics, and optimised examination procedures are developed tailored for different structure types taking into account their importance and technical condition.

Figure 1. Examples for laboratory and in-situ diagnostic procedures. From left to right: compression strength test of a stone core sample, compression strength test of bricks, radar survey on an arch.

Most assessment procedures require the masonry strength and other mechanical properties as major input parameters.

Destructive Testing (DT) of masonry structures is therefore necessary in many instances, although it should be noted that the results of most destructive tests are affected by significant uncertainties and may provide only localised information on some part of the structure. The results cannot necessarily be directly extended to the whole structure unless the parameters are determined using a method which obtains statistically reliable results.

Semi or Minor Destructive Testing (SDT, MDT) methods are based on in-situ localised measurements and considered as surface or small penetration techniques that can provide only qualitative information on the masonry condition and be used only for preliminary investigation.

While conventional DT methods focus mainly on the mechanical characteristics of the materials, **Non-destructive Testing (NDT)** methods can provide an overall qualitative review of the condition of the structure or additional information on its internal geometry.

Monitoring systems are occasionally installed on masonry structures in order to follow the evolution of damage patterns such as cracks or deformations. The knowledge of this evolution can help prevent more serious damage or a total collapse of the structure.

The following list summarises testing methods that are frequently used on masonry buildings and bridges:

Destructive Testing Methods: mechanical tests on cored samples, physical and chemical tests on cored samples, tests on soil, backfill properties.
Semi-Destructive and Non-Destructive Testing methods: boroscopy, flat-jack test, hammering (sounding), surface measurements (hardness, Schmidt hammer, penetration, pull-out tests), georadar, infrared thermography, sonic methods, conductivity measurements,
Monitoring methods: crack monitoring, deflection and relative displacement measurements, dynamic tests, load tests (in special cases).

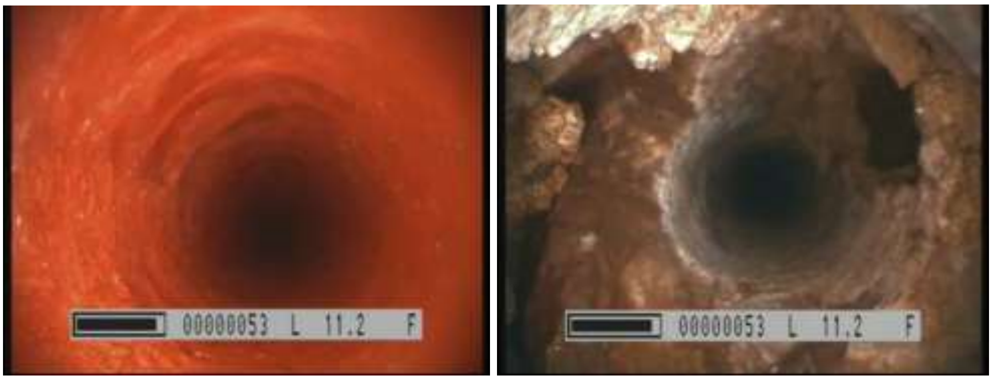

Figure 2. Boroscopy/endoscopy images of masonry arch bridge. Homogenous brick material (left), cavities and internal defects in the stone material (right).

Figure 3. GPR and infrared termography testing on stone arch bridges.

2.2. Research area No.2: Condition assessment of masonry bridges and buildings using structural diagnostics and modelling tools

The aim of research is the development of a multi-level assessment procedure for masonry bridges and structures. The multi-level procedure combines and links methods of numerical analysis and methods of diagnostics applied for providing input parameters for the calculations. Different diagnostic procedures are developed for each level of condition assessment and structural analysis. These procedures are optimised with respect to the range and required accuracy of parameters used by the numerical analyses. As an anticipated result of the research cost-efficient condition assessment tools are provided for masonry structures, such as bridges and historic buildings. It is expected that these tools will help optimise decisions regarding the future of the structures and prepare intervention, if necessary. The main areas of application: monumental structures, masonry arch bridges, masonry load bearing elements of engineering structures.

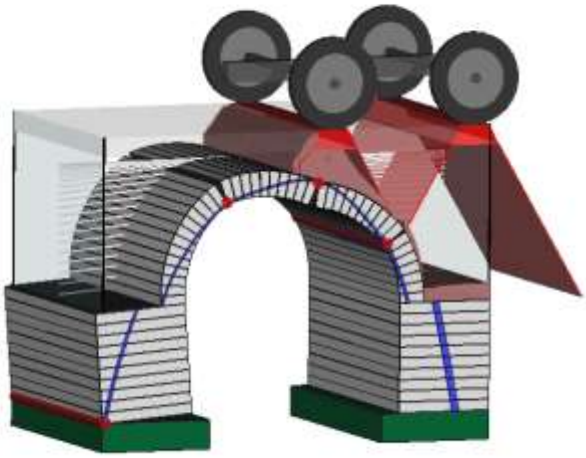

Figure 4. Analysis of a masonry arch bridge with RING 2.0 software

Research area No.3: Modelling of degradation processes of structures

The aim of research is the experimental and theoretical analysis of the degradation processes of the building materials of historical and other engineering structures. The research is focuses on the following structure types: concrete and reinforced concrete structures, masonry structures. The effect of the degradation processes of building materials (e.g. defects caused by the corrosion of concrete and steel reinforcement in RC structures, weathering and freeze-thaw cycles in masonry structures, fatigue damage of masonry and RC structures due to repetative loading, etc.) on their mechanical characteristics and variability and also on the reliability of structures are analysed. The structural reliability analyses are carried out with the use of probabilistic methods. As a results of research we obtain a structural assessment system for the determination of the residual service life of structures and the optimised timing of intervention based on the required level of reliability. Besides theoretical research the efficiency of non-destructive testing and monitoring methods is analysed with regard their ability to track degradation processes.

2.3. Research area No.4: Diagnostic procedures for the rehabilitation of structures

The aim of research is the development of diagnostic procedures for testing the quality and efficiency of technical solutions used for the rehabilitation of structures. Our research focuses on the following specific areas:

1. Rehabilitation of concrete and reinforced concrete structures with high performance fibre reinforced concrete,
2. Rehabilitation of concrete, reinforced concrete and masonry structures (primarily bridges and tunnels) with sprayed concrete,
3. Rehabilitation of concrete and masonry structures by injection.

During our research laboratory tests are carried out on specimens and site tests on structures in conjunction with real rehabilitation projects. As a result of research guidance will be developed for test procedures for the quality control of rehabilitation measures. Besides the description of various test methods guidance will be provided on the optimal selection of the number of measurements, measurement locations and timing.

Figure 5. Site tests on real rehabilitation projects. From left to right: ultrasound test, Schmidt-hammer hardness test, penetration.

3. Case studies

3.1. Curved, single lane bridge connecting to an overcrossing

Overview

In 1973 a single-lane bridge was built to decrease the traffic volume of the traffic junction that leads to the overcrossing. The structural system of the bridge is a 9-span Gerber made of reinforced concrete, having a full length of 137,23 m and direct connection to the overcrossing bridge. To avoid the differential soil settings the bridge was designed as a statically determined structure. The pillars supporting the articulated, fixed and the moving joints are on the superstructure. The final width of the bridge cross-section is 7,50 m, the width of the traffic lane is 6,50 m and the two edge beams are 0,50 m wide. The maintenance works of the bridge were not sufficiently carried out for almost 30 years of service. During this period only minor repair worsk were made. There was a larger intervention in the year 2000. During this intervention a pavement reconstruction was made. Because of these circumstances and the environmental conditions the overall condition of the structure continuously degradated. The signs of the degradation processes were the following: concrete cover spalling, corrosion of the rebars, leaching. Overall, the structure was in a bad condition and made the renewal works imminent.

Figure 6. Side view of the curved bridge.

The applied diagnostic assessment methods and diagnostic procedure

The visual signs of the degradation processes explained the global diagnostic assessment. The flowing water on the pavement during raining and thorugh the cracks, and appearing on the edge beams, continously damaged the reinforced concrete materials. The effect of the dissolving water can be seen on the superstructure and the pillars, too. There was a risk of concrete corrosion at the level of foundations because of the dissolving water. Therefore first step was the examination of the foundations. The excavation of the soil around the foundations confirmed that the concrete material of the foundations were undamaged.

Figure 7. Side view of the curved bridge.

The structural elements that were mainly affected by strong concrete corrosion were the pillars and the superstructure sections on the pillars (in the vicinity of the dilatation and the edge beam gaps). The expansion joints were the critical points of the renewal plans because of the high replacement cost and the price of the new expansion joint elements. It made the diagnostic assessment even more important. With several minor pavement excavations the actual state of the expansion joints could be measured. The steel parts of the joints had only a minor surface corrosion and the rubber parts were accurately placed which led to a minor leaking of the superstructure.

Four of the eight pillars had drainpipes, however there weren’t any sinkholes on the pavement. After the minor excavations on the pavement level we recognized that the sinkholes are disassembled and the drainpipe connections were covered by a metal plate. At the renewal works in the year of 2000, after the disassembling of the sinkholes and the covering the pavement layers were built on this metal covering completely closing the drainage system.

Figure 8. Sinkhole covered with metal plate under the pavement layers.

After the pavement excavations the causes of the corrosion and the extent of the structural degradation was known. The pavement reconstruction works ahve modified the complete drainage system of the bridge. Before the pavement reconstruction the drain pipes deflected the gathering water on the pavement level. With this modification the whole amount of water which gathered on the bridge pavement had to move to the lower part of the bridge to a sinkhole at the abutment. This amount is more than a sinkhole at the abutment could let through and the flowing water could penetrate into cracks and the gaps on the curved edge beam. This effect was the main cause of the degradation and if this process continued it would have led to a serviceability and durability problem.

The new renewal plan

The renewal documentation made in 2009, wasn’t actual anymore. The continuous degradation process of the structure became exponential without any renewal works. In the year 2012 a new renewal documentation was made which took the results of the condition assessment in account. Instead of the complete change of the expansion joints a partial change was planned by modernizating the present expansion joints with new structural elements. With new sinkholes and drainage elements the original correct drainage system was refurbished.

Unfortunately the precise plan lost its actuality when in the summer of 2012 the parts of the edge beams begin to fell off. A quick examination was made of the actual confition of the edge beams. The results were terrifying. During approximately one year the speed of the deterioration has grown exponentially. The structure had reached a critical state so the renewal building needed to be started as soon as possible and during this time the safety of the structure was in danger. The renewal plans needed some modifications to guarantee a satisfactory serviceability for the next 50 years.

The renewal works of the bridge

From the summer of 2012 to the summer of 2013 till the start of the renewal works there was a speed limit of 30 km/h on the bridge. The works had started in July, 2013. After building the scaffolding several work phases started on the pillars and on the supertructure too. These work phases were the following: the demolition works of the full pavement structure and the loosing corroded elements of the pillars and the superstructure. After the demolition works of the loosing parts of reinforced concrete structures the next phases were the protection of the rebars and the reprofiling with shotcrete.

The renewal works had focused on the key working phase: the rehabilitation of the expansion joints, the drainage system and the pavement. After the full demolishing of the old pavement layers and preparing the raw concrete surface the building of the complete new drainage system was the following. The new drainage system consists of new sinkholes, drain pipes, pavement drainage channel. The new expansion joints were builted on the old ones which stayed inside the structure giving a good foundation for the new ones. After the asphalt paving, the protection of the reinforced concrete elements against environmental effects (salt corrosion, weather), the last phases were the placing of guard-rails and the complete paintig of the structure.

Figure 9. The bridge during the reconstruction works.

Figure 10. The bridge after the reconstruction works.

3.2. Historical building

Overview

The renewal of the building which are historical or part of the historical heritage is continuous. The reason is that these buildings are in the center of the towns and cities and the price of the estates are high and can’t be demolished.

In the 19th century a six storey high building with 4 meters clear height was built. The building had offices and flats and also a pub and an air shelter in the basement. The structural walls made of brick with prussian vault type floors with hot-rolled I cross-sectioned beams.

The importance of the building and the age of the construction materials was the main causes for the diagnostic assessment and is necessary for the efficient structural calculations.

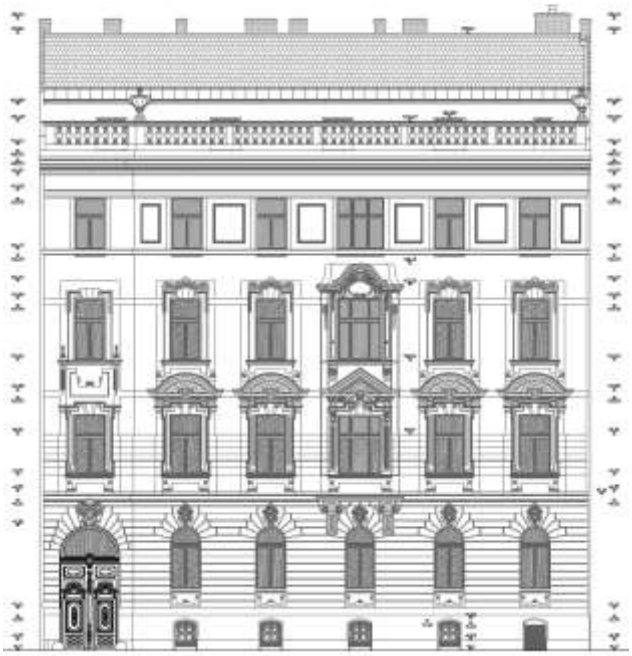

Figure 11. Front view of the building.

The diagnostic assessment of the building

Because the valuable and unique decorative elements the destructive methods cannot be used on the facade walls and floors just for the inner structural walls and just for limited sections on each storey. It was necessary to obtaining good results for the mechanical properties and the structural types and layers and to determine the orientation of the beams in the floors the distance between the beams without damaging the existing floor structure.

For determining the strength of the structural walls different diameter core drilling needed to be made on different storeys. In laboratory the cores were tested with compression testing machines after laboratory preparation. In the basement there was a bunch of bricks weren't bulit in. Samples made from the bricks in the laboratory for standard compression tests. For the hidden structural elements and defects videoendoscopy was used through pre-drilled holes in the walls.

For non-destructive assessment of the walls and floors we used a georadar system which is widely used during geological and geophysical surveys. The aim of this type of assessment method was to get a view about the structural inhomogenity and specify the areas which have different condition than the other areas. The radargrams from the georadar surveys showed the arches between the beams, the exact location of the beams, the layers over the arches and the wall sections under the prussian vault floors.

With in-situ visual inspection the corrosion level of the I cross-sectioned steel beams was determined. On part of the surface of the steel beams intensive corrosion occured. By further visual inspections we got informations about the overall condition of the whole building. There weren't any larger cracks in the walls and the mortar joints were correctly filled up.

Figure 12. Diagnostic assessment of the building, from left to right: core drilling, videoendoscopy, radar survey.

Laboratory tests

The following materials were tested: the individual bricks from the basement, the different diameter drilled cores. After laboratory preparation the strength properties were determined. From the drilled cores mortar samples were separated. These samples were tested in compression testing machines to obtain the strength of the material. After the compression tests the remaining material parts were examined by a scanning electron microscope (SEM) to obtain further data about the material composition.

Figure 13. Laboratory tests on samples.

The conclusions of the in-situ and laboratory tests

By comparing the results of the measured and calculated strength of the bricks there was a good correlation in the achieved data. With the results from compression tests of the mortar samples and the brick strength a recommendation for the characteristic wall strength was made.

The floor of the upper level is a timber floor. After analysing the samples cleared up that the timber beams are not reliable structural elements because the damages are in an advanced state.

By using videoendoscopy the layers of the floors can be determined and with the georadar surveys the orientation and the distance between the beams of the prussian vault floors were determined and this results were highly important during the structural calculations.

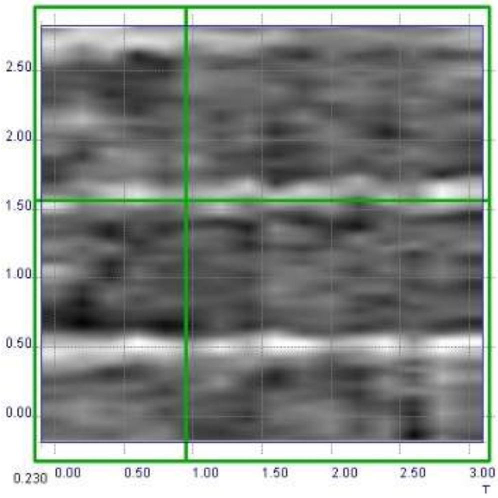

Figure 14. Radargram of the Prussian vault floor. The distance between the beams can be measured correctly.

4. The importance of the diagnostic assessment

By using diagnostic assessment for obtaining a preliminary condition evaluation the results are useful to aid the renewal planning and the construction works. With an exact condition assessment a cost-effective renewal planning can be made and during the construction the contractor can meet hidden structural defects less times.

The diagnostic assessment can aid the renewal works almost at every phase. As seen in the first case study by choosing the most appropriate expansion joint elements without wrecking the complete old expansion joints decreased the time of the construction. By knowing the amount of degradated structural parts and elements both of the renewal and the construction works can be cost- and time-efficient.

To knowing the geometrical data of the hidden structural elements in the floors are necessary and good basic data to obtain good and efficient structural calculations. Depending on the type of structure by using NDT (non-destructive tests) and SDT (semi-destructive tests) methods together in a diagnostic assessment procedure good results can be obtained and the structural damages can be minimalized.

5. Course materials

Our participation in structural engineering research projects and field experience helps develope course materials for the subject of structural diagnostics and other civil engineering subjects where the demonstration of test procedures is necessary. It is desired to make an optimal combination of subjects related to structural mechanics, building materials and structural diagnostics.

References

[1] Z. Orbán, T. Balogh, “Examination of existing structures and preparation of their rehabilitation helped by in-situ testing methods”, *6th PhD & DLA Symposium*, Pécs, 25-26. October 2010.

[2] Z. Orbán, T. Balogh, "Assessment of masonry arch bridges using non-destructive testing methods", *ARCH’13 - 7th International Conference on Arch Bridges*, Trogir-Split, 2-4. October, 2013.

[3] www.structuraldiagnostics.eu

Authors

Principal Author: Tamas Balogh, holds an MSc in Civil Engineering and member of the Hungarian Chamber of Engineers, structural and bridge designer. At present he is an assisstant lecturer at the University of Pécs, Pollack Mihály Faculty of Engineering and Information Technology.

Co-author: Zoltán Orbán holds a PhD degree in Civil Engineering, member of the Hungarian Chamber of Engineers and bridge expert. At present he is the Head of Department of Structural Engineering at the University of Pécs, Pollack Mihály Faculty of Engineering and Information Technology.