Experimentální Analýza Napětí 2001
Experimental Stress Analysis 2001
39th International Conference
June 4 - 6 , 2001 Tábor, Czech Republic

CONTACT-LESS METHODS FOR IDENTIFICATION OF COHESION LOSS IN LIME MORTAR RENDERS

[1]Drdácký Miloš, [2]Lesák Jaroslav, [3]Michoinová Dagmar, [4]Svoboda Jiří, [5]Urushadze Shota

Paper presents pilot tests on lime mortar rendering with artificially made defects of cohesion between the plaster and brick wall. Two experimental methods and a FEM computational model were applied. Differential vibration analysis takes advantage of differences in rigidity of loosed parts of plaster against firmly fixed parts to a stiff wall, which generates differences in modes of vibration. These modes can be recorded using laser Doppler interferometry and a scanning camera to pick up signals across the measured field. The measured modes were compared to those calculated using a FEM model which was used for prediction of reasonable excitation frequencies. The determined defects were compared to indications given by thermal radiation measurements on the test specimen which was cooled after prior long term heating. Both methods proved to be sufficiently sensitive for the problem under discussion. Surface temperature measurement is simpler and economic, even-though in practical application it may be substantially affected by moisture content differences and this fact must be taken into account.

Keywords: rendering delamination, Doppler interferometry, thermal radiation, thermovision

1. Introduction

Interior as well as exterior plaster, as a part of historic buildings, is permanently subjected to mechanical and physical-chemical processes, which can cause and accelerate their chemical and mechanical degradation. Such a degradation can occur on the surface or under the surface of a built element. This paper focuses on the under-surface mortar deterioration.

Under-surface defects of historic mortars can arise due to a number of unfavourable influences, as e.g. open porosity of renders, atmospheric pollutants, water action, changes of temperature and humidity of surrounding environment, seismic movement, industrially or naturally induced vibrations, overloading and/or neglected maintenance. Those well known negative influences contribute substantially to the development of under-surface degradation of historic renders, often in their mutual combination and interaction. Further, the defects can be generated as a consequence of an original imperfect construction process or use of materials of poor quality. Nevertheless, more often, the defects are due to an application of inappropriate materials and technologies during later conservation interventions [1], [2].

1 Ing. Miloš Drdácký, PhD, Institute of Theoretical and Applied Mechanics (ITAM) of the Academy of Sciences of the Czech Republic in Prague, Prosecká 76, 190 00 Praha 9, Czech Republic, drdacky@itam.cas.cz
2 Jaroslav Lesák, M.Sc., ITAM, lesak@itam.cas.cz
3 Ing. Dagmar Michoinová, State Institute for Care for Monuments in Prague, Valdštejnské náměstí 3, 110 00 Praha 1, Czech Republic, michoinova@supp.cz
4 Ing. Jiří Svoboda, TMVSS Ltd., Nedvězská 23, 100 00 Praha 10, Czech Republic, tmvss@tmvss.anet.cz
5 Ing.Shota Urushadze, ITAM, urushadze@itam.cas.cz

2. Characteristics and mechanisms of the under-surface degradation

One of the main features of the under-surface degradation is a loss of cohesion of historic renders. It appears mainly in places where a higher moisture concentration is present and the render is contaminated by salts.

One important result of the under-surface mortar degradation is delamination of individual layers of the render system consisting of three layers: a wall, a render and a painting layer. This type of degradation is primarily caused by different structure and mechanical properties of the individual layers in the system. Every change of temperature, moisture and/or mechanical loading in an inhomogeneous system results in different dilatation, vapour permeability or elasticity of each layer, which generates an increase of stresses on the interface between them. A separation of last soft render layer, or even painting layer from the substrate belongs to the damages of crucial importance. Such a type of degradation rises mainly due to different physical and mechanical properties of the surface layers and also due to use of inappropriate materials for consolidation of those layers.

However, most of the above defects of historical renders occur due to a combination and interaction of the mentioned actions during their long-time exposure. Determination of true causes is rather complicated and not always successfully completed.

3. Identification of under-surface defects

Location and description of under-surface defects is similarly complicated and tedious process. A traditional way of surveying occurrence, location, extent and characteristics of under-surface defects is represented by a contact method based on percussion and auscultation technique. This method is widely used and reliable but it is time consuming and can not be used when the mortar is heavily degraded.

More sophisticated, modern methods are based on the same principle, i.e. that the signals introduced into the system propagate differently in different media and materials. Diagnostic methods process the differences between the emitted and received signals and evaluate maps of size and distribution of areas of under-surface defects. Nevertheless, those methods are contact methods and the measurement is made point-by-point, so the main advantage of such methods is a more exact and objective determination of delamination boundaries.

For technological inspection and documentation of delamination of historic renders it seems to be optimal to visualise the defects before an after consolidation in order to check the efficiency of conservation measures. A suitable diagnostics method for such a purpose should be simple to use, easy and quickly to evaluate, sufficiently sensitive and accurate, and without harmful additional loading or impact on the damaged rendering system.

New approaches of contact-less measurements take advantage from the fact, that the loosing parts of renders have natural frequencies different from those of the integral render-wall system. Of course, the problem of non-harmful excitation of walls with precious paintings effects substantially practical applications of such approaches and their importance can be seen especially in the inspection of quality of restoration and consolidation works. In any case, contact-less measurement of vibrations creates the base for new non-invasive diagnostics of loosed parts of historic buildings.

4. Laser interferometry for inspection of under-surface defects

Laser interferometry methods proved to be useful in investigations of dynamical problems of structures of a very complex geometry or lightweight elements where even a small mass of a sensor can distort the structural response. This method can be used also for detection of delaminated parts of historic rendering.

4.1 Method and equipment

In the presented study the laser doppler interferometry has been used. It relies upon the interference between a signal and a reference laser beam. From interference between a beam reflected on the vibrating surface and a reference beam, the velocity on the moving surface is derived.

One of the most powerful tool in this research area is the VPI device (Vibration Pattern Imager). It enables contact-less measurements of vibration up to a range of 200 m with a 1 mW laser beam using retroreflective surface preparation and up to 15 m on unprepared surfaces. The minimum detectable velocity is 0.005 $mm.s^{-1}$. In combination with a controlling PC or microcomputer, the VPI sensor affords full field images of vibration patterns even at random or service loading, [4].

4.2 Physical model and experimental set-up

The method has been tested in laboratory on brick walls bearing an imperfectly fixed plaster specimens or plaster layers. The rendering had to posses mechanical characteristics as close as possible to the historical plasters. Therefore, it has been made of a lime mortar composed of lime and quartz sand in volume ratio of 1 to 5. There were made two testing walls. On the first one, a prefabricated layer of plaster of dimensions approximately 20 cm by 30 cm, with thickness of 4 mm was partially fixed to the wall along by two strips of special mortar [3]. The second was rendered by two types of lime plaster – poor lime mortar and lime cement mortar. Here were made artificial defects using separation of rendering by means of thin plastic foils, Fig.1a,b.

The vibration was introduced into the test specimen from an electromagnetic exciter and transmitted through a thin rod connected to the wall. The vibration frequences varied continuously from 40 to 1500 Hz and the natural frequences were determined. Under those frequences, the velocities were scanned across the measured field which was a rectangle with dimensions of 234 mm by 262 mm, in the first case. In the second case, the full rendered area was scanned. The intensity of excitation generating the maximum velocity of about 5 $mm.s^{-1}$ was used. The experimental set-up is shown on the Fig. 2.

4.3 Numerical model

Dynamic behaviour of the plaster specimen fixed to the wall was calculated using a numerical FEM model and the ANSYS 5.4 software. For the numerical modelling, there were used 241

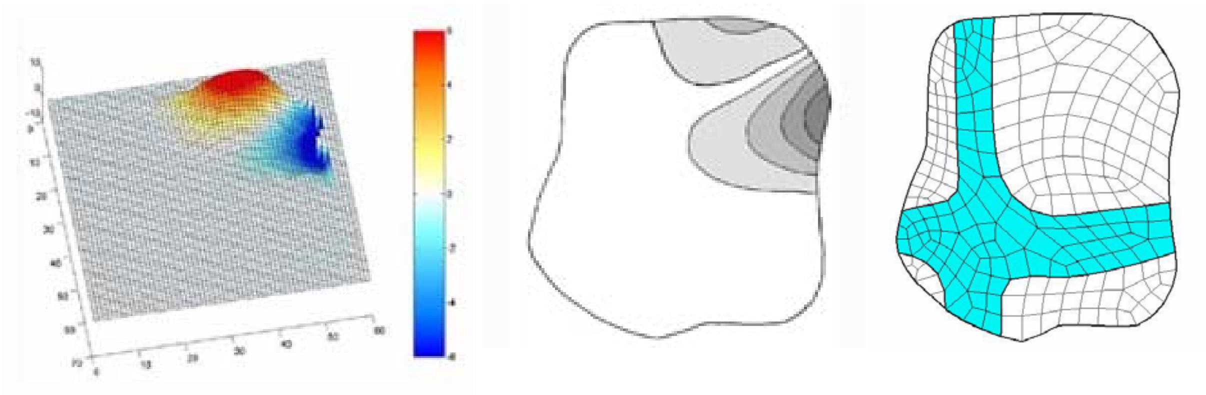
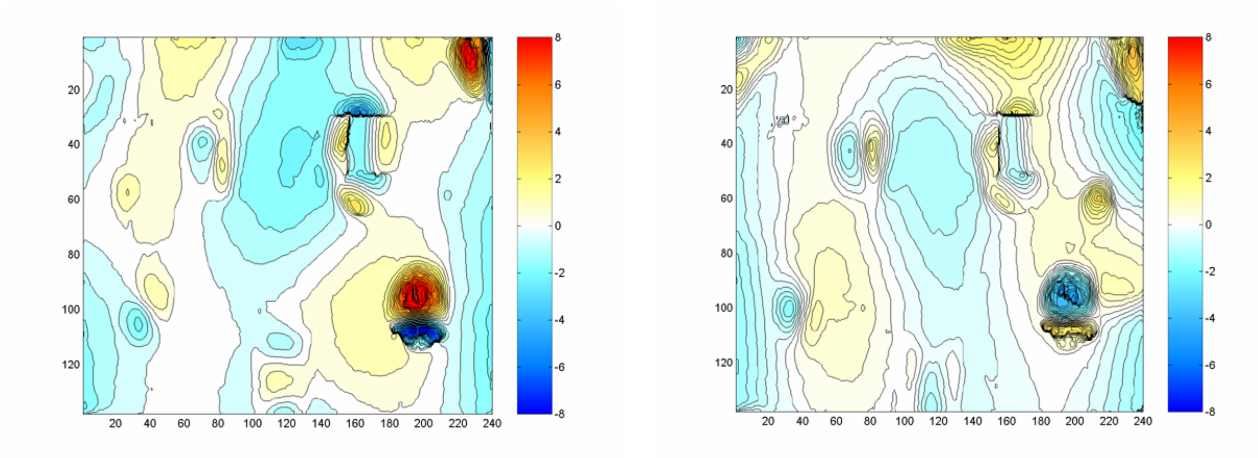


plate elements SHELL 63 with membrane and bending characteristics. This element has six degrees of freedom in all four nodes.

4.4 Experimental and numerical results

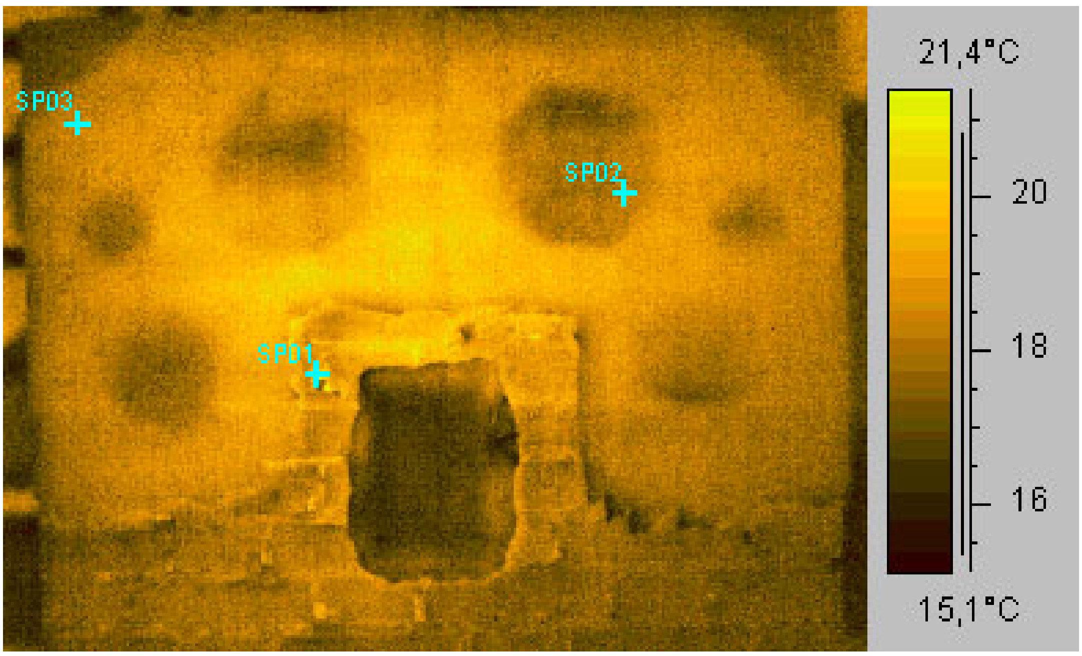
The measured vibration velocities describing the mode at natural frequencies are compared in Fig. 3 to the calculated mode. The picture includes also the applied mesh for FEM computations. There was a shift in absolute values, which is, of course, dependent on material characteristics involved into the computation. In the case documented by the Fig.3, the



measured natural frequency attained 638 Hz and the computed 412 Hz. It was found, that the measured and calculated natural frequencies and the distribution of velocities or amplitudes are in a good correlation. Further, it was even possible to detect small defects at higher frequencies, as is shown on Fig. 4, taken on the testing specimen with artificial defects. Here the vibration modes of loose parts were measured at the frequency corresponding to the maximum amplitude of the vibration velocity. The picture further presents differences in vibration modes due to phase shift of 90°. Resolution of measurements was 5 mm.

5. Thermal radiation measurement

Thermal radiation measurement was used as an alternative experimental technique. Here the detection of loosed parts is based on an idea to measure their differential cooling or heating compared to the heavy and integral parts with higher thermal inertia and different conductivity. There were tested several combinations of thermal change excitation and results of one of them are presented in Fig. 5. Here the wall was preheated and the drop of surface temperature in the course of time was followed by means of a classical thermovision camera. It is clearly seen that this method is sufficiently sensitive to visualise differences in the composition of a layered wall and that it is able to detect loosed parts. Nevertheless, we must take into account that interpretation of measured data in real conditions need not be so easy due to disturbing effects, especially due to thermal reflection and moisture.



6. Conclusion

Dynamic identification of plaster damages seems to be one of promising technologies. However, it is possible to identify only sufficiently large defects. The size of a detectable defect is obviously dependent on bending deformability of the loosed layer of mortar, on the induced vibration frequency and on the technology of excitation.

The excitation used in the described tests, i.e. through vibration of the wall, is not the best method and other technologies, enabling direct excitation of the plaster should be studied. Very good results may be achieved by means of acoustic exciting systems, namely the piezo actuator and the acoustic mirror, [5], [6]. Nevertheless, the above described approach is suitable for quality control of restoration works consisting in fixation of detached parts of rendering.

The thermovision technique seems to be more promising for practice, because the excitation of measurable differences is simpler and the measurement quicker than in the case laser interferometry. However, this method requires a wide experimental verification on real structures including investigations of disturbing effects in order to facilitate reliable interpretation of the measured data.

7. References

[1] Toraca G. – "*Conservation des enduits des batiments anciens, méthodes et moyens de la consolidation et de la prote*ction", ICOMOS, 1995

[2] Michoinová, D. – "*Lime based mortars for restoration of historical mortars especially under wall paintings*", In: Historic Mortars: Characteristics and Tests, pp. 297-306, edited by P.J.M. Bartos, C.J.W.P Groot and J.J. Hughes, RILEM, 2000

[3] Michoinová, D., Lesák, J., Drdácký, M., Urušadze, Sh. – *"Inspection and Efficiency of Consolidation of Delaminated Parts of Historic Lime Plasters"*, CD ROM Proceedings of the 5th Int. Congress CICOP „Restoration of Architectural Heritage Firenze 2000", Florencie, September 17-24, 2000

[4] *OPERATOR´s MANUAL*, The Ometron 4010 Series for SPATE and VPI, Ometron, 1997

[5] Castellini, P., Esposito, E., Paone, N., Tomasini, E.P.- *"Non-invasive measurements of damage of frescoes paintings and icon by Laser scanning Vibrometer: experimental results on artificial samples using different types of structural exciters"*, Proc. of the VI Int.al Conf. on Non-destructive Testing and Microanalysis for the Diagnostics and Conservation of the Cultural and Environmental Heritage, pp. 185-198, Roma, 1999

[6] Tomasini, E.P., Castellini, E., Esposito, E., Paone, N.- *"Laserart: A European research project for cultural heritage"*, CD ROM Proceedings of the 5th Int. Congress CICOP „Restoration of Architectural Heritage Firenze 2000", Florencie, Sept., 2000

8. Acknowledgement

The work reported herein was made possible by research grants of the Grant Agency of the Czech Republic No.103/97/S051 *Historic structures and materials under repeated loads* and the Ministry of Culture of the Czech Republic No. PK99P04OPP004 *Technological inspection of historic paintings by means of non-invasive methods,* and PK99P04OPP006 *Monitoring of environmental influences on cultural monuments and diagnostics of their damages.*