Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 70 (1993)

Artikel: Historic preservation: high and low tech diagnostic technology

Autor: Thomasen, Sven E. / Searls, Carolyn L.

DOI: https://doi.org/10.5169/seals-53282

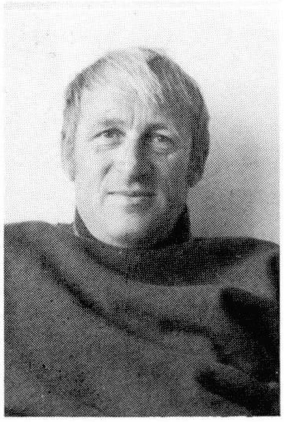
Historic Preservation - High and Low Tech Diagnostic Technology

Conservation de monuments historiques, méthodes d'analyse sophistiquées et simples

Historische Bauwerkserhaltung - hochentwickelte und einfache Diagnoseverfahren

Sven E. THOMASEN
Affiliated Consultant
Wiss, Janney, Elstner Assoc.
Emeryville, CA, USA

Carolyn L. SEARLS
Consultant
Wiss, Janney, Elstner Assoc.
Emeryville, CA, USA



S. Thomasen has a Struct. Eng. degree from the Techn. Univ. of Denmark, while with WJE, he has investigated building failures and material deterioration, taught at California Polytechnic in San Luis Obispo and designed large projects.

C.Searls has a BS in Architectural Eng. from California Polytechnic in San Luis Obispo, a MS in Struct. Eng. from UC Berkely. She has done field investigations and analysis of structural failures, evaluation and rehabilitation of masonry, marble and terra-cotta facades.

SUMMARY

A key to preservation and continued use of buildings is an accurate assessment of the existing structure. Historically, the engineer has relied on traditional investigative procedures, experience and intuition. Lately, sophisticated technology has become available for use in diagnostic examinations, but its use requires understanding its limitations. Best results are often achieved by a synthesis of the art of structural engineering and the science of modern diagnostic and analysis techniques.

RÉSUMÉ

Une solution pour la conservation et l'utilisation permanente d'un bâtiment dépend de l'évaluation précise de l'état de la structure existante. Dès le début, l'ingénieur s'est basé sur des procédures d'études traditionnelles, son expérience et son intuition. Plus récemment, pour l'examen de l'état de structures, une technologie sophistiquée est devenue possible, mais son emploi requiert la compréhension de ses limites. Les meilleurs résultats sont souvent obtenus par la synthèse de l'art de l'ingénieur civil et la science d'un examen méthodologique moderne et des techniques d'analyse.

ZUSAMMENFASSUNG

Einer der Schlüssel zur Erhaltung und weiteren Nutzung von Gebäuden ist die richtige Einschätzung des bestehenden Bauwerks. Von alters her hat sich der Ingenieur auf traditionelle Verfahren, seine Erfahrung und Intuition gestützt.. In neuerer Zeit ist eine hochentwickelte Technologie für diagnostische Untersuchungen verfügbar geworden, aber der Gebrauch dieser Technologie erfordert ein Wissen um deren Grenzen. Die besten Resultate werden oft durch eine Synthese der Ingenieurbaukunst und der modernen wissenschaftlichen Diagnose- und Analysetechniken hervorgebracht.

1. INTRODUCTION

A key element in planning for the preservation of a building is the correct assessment of the existing structure based on results from a diagnostic analysis. To make this assessment, the engineer searches for patterns and measurable conditions. Historically, the engineer has relied on traditional investigative procedures, simple analyses and a mixture of experience and intuition to make the assessment. A structural engineer faced with the task of preserving a historic structure requires qualitative information for the general evaluation of the structure's condition and quantitative data for the engineering assessment. Traditionally, qualitative evaluations have been by visual inspection, supplemented by field and laboratory tests, while quantitative assessment has required destructive testing and removal of material specimens for laboratory analyses. Lately, sophisticated modern technology has become available for diagnostic examination and analysis of historic structures, but the use of such technology has not always improved the quality of the investigation. This article describes a few high tech and low tech systems and when they may be appropriate.

2. SELECTION OF DIAGNOSTIC TECHNIQUES

The condition evaluation and structural assessment of a historic building requires a carefully planned program of exploration and testing. Some of the factors that influence the choice of appropriate diagnostic techniques are:

- The historic value of the structure and the effect of any destructive testing on the historic materials must be considered. Destructive testing may be acceptable in less exposed areas of a structure, such as a closet in a church or the inside face of a spandrel beam at an arch bridge, but for most investigations nondestructive testing is preferred.
- The practical experience and technical expertise of the investigator. High-tech equipment often produces a lot of data, and requires an expert operator to interpret the readings.
- The cost of high-tech diagnostic technology versus the benefit from the investigation. For example, hourly computer readings of a dozen climate controls installed in a historic structure can generate an impressive amount of data in a year, but the benefit might not justify the cost of maintaining the system and sorting the results.

3. VISUAL INSPECTION AND DOCUMENTATION

3.1 Visual Inspection

Inspection and documentation of existing conditions is used in detecting patterns of failures, designing repairs and identifying areas for further close-up examination and testing. A visual survey of the structure, usually from grade using binoculars, is supplemented by close-up examination of selected areas. Close-up inspection can be performed from stationary or from suspended scaffolds, telescopic truck-mounted lifts, and from specially built snooper scaffolds for inspecting the underside of tall bridges. When more ordinary types of scaffolding are inappropriate or too expensive, modern mountaineering techniques can be applied to the inspection of high rise buildings, large domes, and towers.

3.2 Documentation Techniques

Sketches accompanied by photos are often the most effective documentation technique.

Recording existing conditions on the sketches allows the investigator to assimilate information about the structure and can lead to insights about its behavior.

Drawings of small simple structures can be made by hand measuring techniques. Rectified photography, where a metric camera produces an orthophoto, is used to make exact scale drawings. If less precision is acceptable, a hand operated semi-metric camera will deliver good results in much less time.[1] When the drawing does not have to be to an exact scale, a low tech alternative is to enlarge a 35 mm negative to the format of a baseline drawing to indicate existing damage and required repair (Fig. 1).

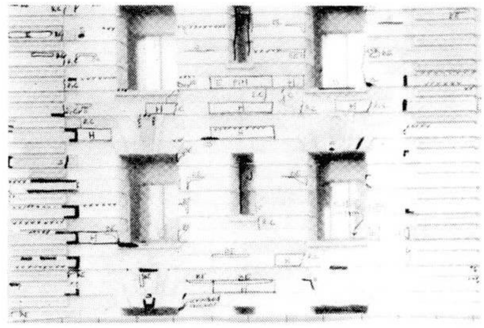


Fig. 1 - Repair drawings made from photo

Macro stereo-photogrammetry has been used to record the weathering of building stone.[2,3] The techniques include depth measurements between weathered and unweathered surfaces, metal plugs set in the stone as a reference surface, the assessment of the depth of inscriptions remaining on tombstones, and comparative thickness measurements made with calipers.[2]

For the investigation at York Minster, the observed cracks were drawn on a plexiglas model of the church, allowing correlation of interior and exterior crack patterns and allowing the cracks to be viewed in three dimensions.[4] A similar high tech technique can be utilized by plotting the crack pattern on a computer model of the structure.

Several nondestructive techniques, described later in the paper, are used for documentation of an historic structure. They include pachometers for locating embedded steel, X-ray and gamma radiography for photographing the interior of a structure, and the use of soniscope and impact echo tests for detecting internal flaws.

3.3 Inspection Openings

Inspection openings are destructive, but they are also the surest, and often the only way, to verify the condition of the internal parts of a structure. Sometimes the inside of a structure can be observed in a less destructive manner by using a fiberoptic borescope. The instrument's light transmitting wand is inserted into a 12 mm diameter drilled hole. The interior can then be viewed through the eyepiece on the end of the wand. The observations can be documented by a camera that attaches to the eyepiece (Fig. 2).

Fig. 2 - Fiberoptic Borescope

A veterinarian's portable x-ray unit, designed for diagnosing cows in the field, was used to document the structure of wooden plank houses. The portable x-ray system provided a fast, nondestructive technique to record the width of the planks, the location of nails, and the details otherwise hidden by finishes.[5]

4. MONITORING STRUCTURAL MOVEMENTS

4.1 General

Structures are monitored, either continuously or intermittently, to detect and quantify structural movements. Monitoring is done when deformations gradually increase with time, and could eventually result in damage or collapse. Monitoring is also used in determining the cause of observed distress and the appropriate intervention.[6]

Before selecting a diagnostic technique, the purpose of the monitoring and the use of the information from the monitoring should be considered. High tech monitoring techniques often create copious amounts of data, and the analysis can be very time consuming unless it is well planned from the start.

4.2 Crack Width

It is often important to determine if the width of a crack is constant or if it has daily, seasonal or long-term changes. In many investigations, a dab of nail polish across the crack is an appropriate technique for finding out if the crack is dormant. For larger cracks, an inexpensive plastic tell-tale can be placed across the crack, or a deformeter can measure deformation between two set points across the crack with an accuracy of 0.0025 mm. Cracks can be measured continuously with a gage that records movement as scratches on a replaceable brass button, which can be read with a calibrated microscope, and electronic or electromechanical gages, connected to a computer on site or in the engineer's office, can be used to trace movement continuously or at preset intervals.

4.3 Total Movement of a Structure

The traditional technique for monitoring total movement of a structure is to periodically survey targets which have been placed on the structure.

The investigation of the Cape Hatteras Lighthouse used an electro-optical device (EOD) to measure horizontal motion of the tower relative to its base. With the EOD installed at the base, the horizontal motion was monitored by tracking a Halogen light source mounted 45 m above the base. The EOD resolved motions into north-south and east-west deflections which were plotted on a strip chart recorder. A low speed strip chart recorded long-term, low frequency response to solar radiation, while a high speed chart, triggered by a pre-selected wind velocity, recorded high frequency responses to wind.[7]

5. CONCRETE CONDITION SURVEYS

5.1 Delamination of Surface Layers

Thermal strains, freeze/thaw cycles, moisture or salt movement within concrete, and corrosion of embedded metal can delaminate large surface areas. The flaws are seldom detected by visual observation, but are easily found by acoustical testing or, as it is commonly called, tapping with a rubber or wood mallet. On large concrete slabs, this low-tech test is done by dragging a steel chain across the slab while listening for hollow sounds. The pulse-echo test, which transmits a stress wave into the material and measures the time of reflection, is useful for mapping surface delaminations in large areas of fairly homogenous materials such as concrete, but is less successful in materials with many internal voids, as is often found in stone and masonry.

5.2 Structural Properties

Quantitative data for evaluation and engineering analysis has traditionally been obtained by laboratory testing of core samples removed from the structure. Many samples are required for a representative picture of the varied conditions found in a historic structure. The procedure is expensive and the visual scars left in the historic fabric are objectionable. However, testing core samples is an established standard procedure, the results are well understood and can be correlated with many different material properties.

Several nondestructive tests of concrete provide broad coverage of large areas for a low cost. These tests require compression testing of a limited number of companion core samples to calibrate the non-destructive tests. The rebound hammer, or Schmidt Impact Hammer, is fast and gives an estimate of the surface hardness, and therefore compressive strength, but the test is most useful for detecting suspect locations that warrant further investigation.

Pulse-velocity measurement with soniscope is used for locating internal defects in concrete and masonry. A signal transducer is placed on one side and a signal-receiving transducer directly opposite on the other side of the test member. Velocity measurements indicate relative strength, modulus of elasticity and presence of cracks and voids. The alignment of the transducers is both critical and time consuming.

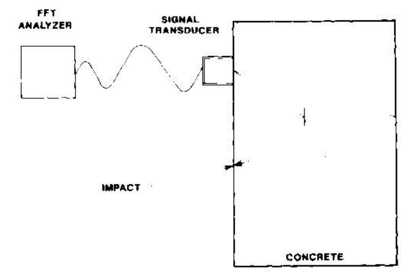


Fig. 3 - Impact Echo Technique

In the impact-echo technique, a short stress pulse, introduced into the structure by striking the surface with an impact hammer, is reflected from external boundaries and from internal discontinuities, such as cracks or voids. A transducer, mounted on the same surface as the impact, measures the motion in the time domain and this signal is sorted into frequencies by a Fast-Fourier Transform (FFT) analyzer (Fig. 3). The technique is used for locating internal flaws, measuring thickness of concrete members where only one surface is accessible, and for evaluating concrete strength. The relationship between propagation velocity and concrete strength is influenced by many factors, including mix design, moisture content and age of concrete, and a calibration curve must be established for each tested material. The impact-echo technique was recently used to estimate the concrete strength in the piers of an eleven arch concrete bridge in California. Strength information was required for seismic analysis of the 80 year old bridge. The concrete surface of the massive piers was soft and deteriorated. The impact-echo testing provided many measurements quickly and inexpensively. The results reflected the more useful average strength of the concrete rather than the site specific values obtained from traditional core testing[8].

5.3 Locating Embedded Steel

Embedded metal items can be located with a pachometer, a metal detector that measures disturbances in the magnetic field at the surface. The pachometer is calibrated to directly read bar sizes versus distance from the probe. The radar or microwave technique utilizes electromagnetic or radio waves to detect internal discontinuities and to locate reinforcing steel. The pachometer and the radar and microwave techniques are most useful when the steel is not too congested and is located fairly close to the surface.

Gamma radiography and X-ray radiography can be used when the steel is deeply embedded, or where several steel sections are close together. The technique provides a projected picture of the section on a sensitive film, placed on the opposite side from the radiographic source. The systems are portable, but the setup, especially the alignment of the film on the opposite face of a wall from the radiographic unit, can be time consuming. Special safety features are also required to avoid harmful exposure, and in some localities special licenses are required for the transportation and use of the equipment.

5.4 Corrosion of Embedded Steel

The pachometer is used to locate the steel, but it provides no information about the condition of the steel, such as corrosion. The copper-copper sulfate test will detect active corrosion by measuring the electrical resistance and the potentials between the steel and the concrete surface. This isopotential test is performed by connecting one electrical lead of the copper-copper sulfate half cell system to the embedded steel. The presence of active corrosion can now be detected by placing the other lead, which has a porous plug and a copper rod immersed in copper solution, on the surface of the concrete. A large surface area can be tested from one setup, since most structural framing and reinforcing steel is connected into a conductive grid. The readings are fast, and the data acquisition is often computerized with the readout in form of a map showing the contours of the measured electrical resistance and potentials.

The isopotential test is simple and useful, but it only shows active corrosion. In historic structures, corrosion might have been active at one time but it has now stopped. The detection of active or inactive corrosion by the use of X-ray photograms or by gammagrams is sometimes possible when the corrosion is greater than 0.2 mm, but the results are only qualitative. The measurement of steel thickness loss from corrosion can only be established with any degree of accuracy by cutting inspection openings.

6. MASONRY CONDITION SURVEYS

6.1 General

Several previously described diagnostic techniques are available for inspecting and monitoring the effect of environmental degradation on masonry. Other techniques, some of them unique to masonry structures, have been developed for the quantitative testing of material strength.

6.2 Strain Build-Up in Masonry

Built-up stresses in masonry structures without expansion joints results from the long term expansion of most fired clay masonry and certain marbles during thermal and/or wet/dry cycles. The built-up strain can be quantified using a destructive test. Electrical resistance strain gages are attached to the surface of a masonry block and read. The block, with the gages attached, is cut loose and the gages are read again. The change in reading is a measure of the released built-up strain. The stress in the masonry is then found by multiplying the strain by the modulus of elasticity, as determined for the material by a compression test.

The flatjack method is a "semi-destructive" test used to directly measure built-up stress in unit masonry structures (Fig. 4). Targets are placed above and below a horizontal mortar joint and the exact distances are measured. The mortar is cut out, which causes the joint to close by a small amount because of the built-up stresses. A hydraulic flatjack, a flexible steel envelope thin enough to fit within a mortar joint, is inserted into the joint and pressure is applied until the original distance between targets is restored. The method provides for fast measurements of the direct compressive stress in the masonry[9].

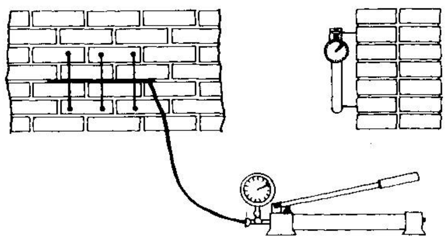


Fig. 4 - Flatjack stress test

6.3 Structural Properties of Masonry

Traditionally, as for quantitative testing of concrete, cores or larger specimens are removed from the masonry structure for destructive laboratory testing. The quality of materials and construction of masonry structures varies widely and for statistical significance a large number of specimens are required. The samples are difficult to transport without damage. For these reasons, in-situ testing of masonry has become the preferred method.

Several previously mentioned nondestructive tests are used on masonry structures. The rebound hammer, which measures surface hardness, has a limited use on thin masonry and stone veneers. While both the pulse-velocity Soniscope and the impact-echo technique have been used successfully to map variations in density and to locate flaws, their effectiveness for evaluating strength and material properties in masonry and stone structures has been limited because of the voids often found in these materials.

The in-place shear test measures the shear strength of horizontal joints in unit masonry, an important value for evaluating seismic capacity. In this test, a masonry unit is removed and the vertical joint on the adjacent test unit is cut. A hydraulic jack applies sufficient force to cause movement of the test unit. The measured shear strength depends on the normal stress at the mortar joints. In a modification of the test, the normal stress on the tested joints can be varied by applying loads to flatjacks inserted in joints above and below the test unit.

Flatjacks can also be used to develop a stress-strain curve for masonry. Two flatjacks are inserted above each other, separated by several courses of masonry. The deformation is measured as the compressive load on the masonry is varied. If flatjacks are not available, the test can be made with ordinary hydraulic jacks, but this requires removal of several masonry units and not just cutting of mortar joints.

7. CONCLUSION

Both high-tech and low-tech diagnostic techniques have appropriate use in evaluating historic structures. The inspection and diagnostic testing of any but the simplest structure is a skilled task and the inspector must be an experienced engineer. He or she must understand that sophisticated techniques are now available to perform many tests better and faster than traditional methods, that these techniques require highly skilled operators both for running the equipment and for interpreting the results, and that, sometimes, experience and intuition are superior to high-tech technology.

8. REFERENCES

[1]Mann, F. M., Photo Drawings - A Practical Alternative, in APT Bulletin, Vol. XIX, No. 2, 1987.

[2]Winkler, Erhard M., The Measurement of Weathering Rates of Stone Structures, in APT Bulletin, Vol. XVIII, No. 4, 1986.

[3]Winkler, E.M. "A Macro Stereo-photogrammetric Technique for Measuring Surface Erosion Losses on Stone." CleaningStoneandMasonryEd. J.R. Clifton, ASTM, STP 935 (1986): pp. 153-161.

[4]Beckmann, P., "Structural analysis and recording of ancient buildings", in Papers on the Seminar on Structures in Historic Buildings, ICCROM, Rome, 1977.

[5]Kevlin, Mary Joan, Radiographic Inspection of Plank - House Construction, APT Bulletin XVIII, No. 3, 1986.

[6]Alva, Alejandro, Structural Monitoring, Building Conservation 88 Symposium, Helsinki, 22-26, August, 1988.

[7]Slaton, Deborah, Hunderman, Harry J, and Stockbridge, Jerry G, The Cape Hatteras Lighthouse Diagnostics and Preservation, APT Bulletin, Vol. XIX, No. 2, 1987.

[8]Limaye Hemant S. and Thomasen Sven E., Estimation of Concrete Strength of the Colorado Street Bridge using the Impact-Echo Technique. Review of Progress in Quantitative NDE, University of California San Diego, July 1992.

[9]Atkinson R.H., Schuller M.P., Noland J.L., Nondestructive Test Methods Applied to Historic Masonry Structures. The Seismic Retrofit of Historic Buildings Conference, San Francisco, CA, Nov. 1993.

9. BIBLIOGRAPHY

9.1 Hunderman, Harry J. and Slaton, Deborah, Diagnostics for Preservation: The Science and the Art, The Construction Specifier, July 1990.

9.2 Thomasen, Sven E. and Searls, Carolyn L., Assessment of Building Facades in Masonry and Stone, ASTM STP 1098, Stephen J. Kelley and Philip C. Marshall, Eds, American Society for Testing and Materials, Philadelphia, 1990, pp. 108-116.

9.3 Recording Historic Structures/Historic American Building Survey/Historic American Engineering Record; edited by John A. Burns and the staff of HABS/HAER, National Park Service, U.S. Department of the Interior, The American Institute of Architects Press, Washington, D.C., 1989.