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Non-Destructive Evaluation to Document Historic Structures

Essais non destructifs pour l'évaluation de bâtiments historiques

Zerstörungsfreie Untersuchungstechniken für historischer Bauten

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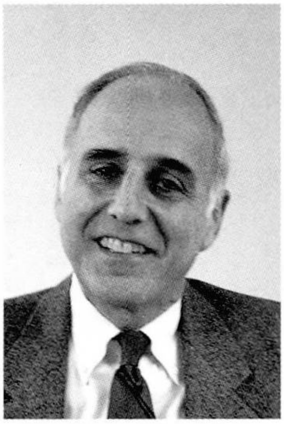

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SUMMARY

Five nondestructive evaluation techniques were investigated for use in documenting structural components of historic buildings. Traditionally, nondestructive evaluation has been used to search for structural defects. This research sought to extend the effectiveness of said techniques and to evaluate their usefulness in documenting framing systems. A brief description of each technique is presented coupled with an evaluation of the effectiveness.

RÉSUMÉ

Cinq méthodes d'essais non destructifs sont analysées en vue de leur application dans l'évaluation des éléments structuraux de bâtiments historiques. Ces méthodes ont été utilisées, dans le passé, dans la recherche de faiblesses structurales. La présente étude a pour objet d'étendre le champ d'application des méthodes d'essais non destructifs et de déterminer leur utilité dans l'évaluation des systèmes à cadres. Chacune des méthodes est brièvement décrite et leur efficacité est présentée.

ZUSAMMENFASSUNG

Fünf zerstörungsfreie Versuchsmethoden und ihre Anwendungsmöglichkeiten bei der Beurteilung von Tragwerkselementen in historischen Bauten werden analysiert. Diese Techniken wurden in der Vergangenheit für den Nachweis von Schwachstellen eingesetzt. Die gegenwärtige Studie zielt darauf hin, weitere Einsatzmöglichkeiten aufzuzeigen, vor allem hinsichtlich Rahmenwerke. Jede Technik wird kurz vorgestellt und ihre Zuverlässigkeit dokumentiert.

1. INTRODUCTION

The authors conducted a research program to evaluate nondestructive evaluation (NDE) techniques for purposes of determining size, location and type of structural components in historic buildings. Many investigators have employed NDE techniques with a good deal of success to locate deficiencies in structural materials in historic buildings. This paper describes extending the uses of NDE beyond diagnosing defects and into the realm of documenting existing framing systems.

Many, if not most, historic structures do not have original drawings of the framing and support systems. When engineers are asked to evaluate these buildings for purposes of a condition survey or for the purposes of knowing their structural capability to function as useful contemporary spaces, the absence of original drawings is a serious impediment. Traditionally the only method of determining the sizes and positions of framing member was to make destructive probes into the original fabric, to measure and record the results of these observations and to recreate framing plans and details. This method implies several serious shortcomings, the two most important being the destruction of original fabric and the need to repair it at probe locations and the limitation that the knowledge gained is only valid at the specific site of the probe and any attempt at extending the assumption to other parts of the structure runs the risk of being inaccurate.

This paper will present the results of research conducted by the authors' firm in partnership with the United States Army Corps of Engineers' Construction Productivity Advancement Research program. Five techniques used for examining concealed features of historic buildings were:

1. Radar
2. Impact Echo, Pulse Velocity and Spectral Analysis of Surface Waves.
3. Electromagnetic Detection
4. Infrared Thermography
5. Fiber optics.

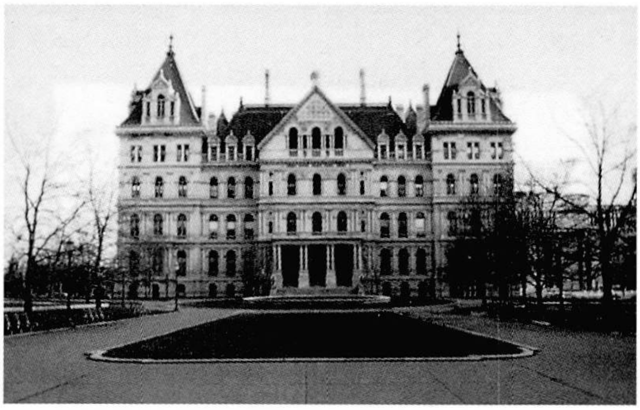

Fig. 1 New York State Capitol Building

The research was conducted in parallel with a structural survey being conducted by the authors' firm on the New York State Capitol building in Albany, New York (Figure 1). This large brick and stone masonry bearing wall structure was constructed during the period 1867 to 1899. It contains approximately 50,000 square meters of floor space on five floors plus attic and basement. Exterior building dimensions are approximately 95 m. by 115 m. The structural survey's purpose was to recreate the framing plans for the structure (the original 1911) and to evaluate the live load capacity of all levels of the structure including the foundation. For purposes of the original survey, destructive probes were made at many locations throughout this building to reveal thicknesses of masonry walls, brick arch and concrete slab floors; the location of wrought iron and steel beams and columns, pipes and ducts and flues; footing depth profiles. In conjunction with these destructive probes, NDE techniques were applied side-by-side so that the results could be verified exactly and determine the success or failure of the various methods.

2. RADAR

The surfaces of floors and walls were scanned with an impulse radar device known as subsurface interface radar. Initial calibration was obtained for the relative permittivity of stone (granite), concrete and brick masonry by using samples recovered from the building. The equipment consisted of a 900 MHz transducer which emitted short pulses of high frequency, low power electromagnetic energy into the subsurface and a receiver within the antenna. The emitted pulses were in the band from 50 MHz to 1.5 GHz and were 1.1 nanoseconds in duration. As the transducer was moved along the surface, reflected pulses were recorded as digital information on magnetic tape; this was later processed in a computer in the office.

Fig. 2 Radar Equipment in Use

The imaging technique used is known as backward propagation. The radar data is a function of the transducer position and the delay time experienced between the emission and reception of the signal. From this information a holographic record along the path of the transducer is produced. Ultimately images are reconstructed using an algorithm by superimposing these coherent backward propagations [1].

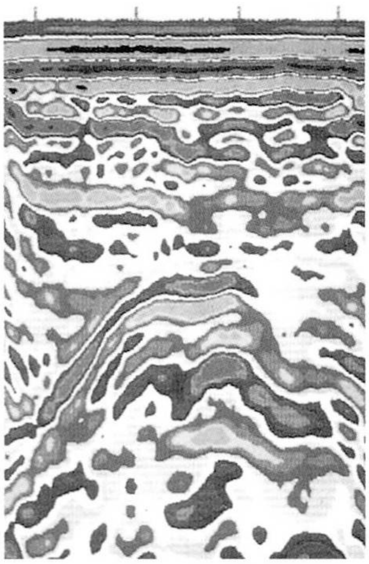

Fig. 3 Radar Output, Raw Data

The waves reflect off of changes in materials, voids or discontinuities, the rear boundary of a material or a buried object. Thus radar is capable of determining many features beneath the surface of a historic wall or floor or ceiling. One of the most successful uses of the radar was in profiling floors where brick arches span approximately 900 mm between wrought iron rolled I beams. In other areas H shaped columns were located in walls and the orientation of the flanges was established. Where masonry walls were thoroughly bonded, their thicknesses were readily measured. The presence of steel reinforcement in concrete floors and metal ties in masonry was also recorded. Flues and pipes could also be detected in walls up to 800 mm thick. New techniques are being rapidly developed to enhance the processed images so that they bear a resemblance to the actual in situ features.

Radar was tried as a means of profiling large 4.0 meter wide stepped, pyramidal stone footings. However due to the presence of a high water table the readings were inconclusive. In other projects, subsurface applications of radar have been useful in mapping footing profiles as well as locating buried pipes. Other features which causedthe radar method to fail were large quantities of metal near the surface, conductive surfaces such as slate and false floors or walls with air spaces.

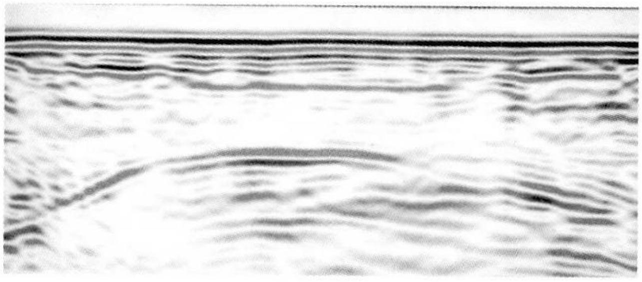

Fig. 4 Radar Output, Computer Enhanced Image of Data From Fig. 3

The radar equipment is expensive to purchase, requires a highly skilled operator and must be compiled with a sophisticated computer software program. Of course this is all quite expensive. In addition, there are several potential technical pitfalls such as accurate calibration of the pulse propagation velocity in a given material and errors due to the manual towing of the transducer across the surface.

3. IMPACT ECHO, ULTRASONIC PULSE VELOCITY & SPECTRAL ANALYSIS OF SURFACE WAVES

3.1 Impact Echo

This equipment consists of a hammer and receiver which are both wired to a computer which processes the data. The surface to be read is struck, the computer records the input energy, and the receiver picks up the reflected compression wave energy. In general, the more dense the material, the higher the wave velocity response [2]. This technique is the "high tech" version of sounding a material.

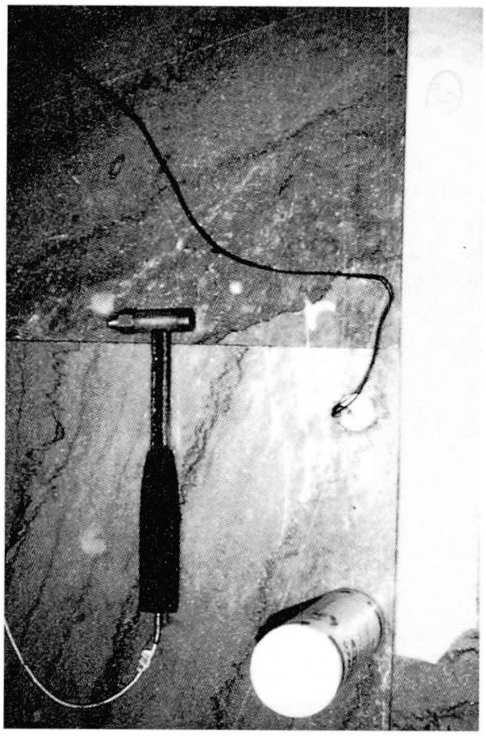

Fig. 5 Impact Echo Equipment

The equipment produced good data for reading thicknesses and integrity on granite and sandstone columns, veneer walls, and brick walls less than 600 mm thick. A steel column behind granite facing was located using this technique but the orientation of the flanges was not discernible. Brick walls over 600 mm thick could not be fully measured. Multiple layers (terrazzo floor over setting bed over brick) did not produce good results; brick arches and beams were not detected as they were using radar. The equipment is best used to detect cracking parallel to the surface (in this case, stone). Optimum results were obtained on homogeneous materials (solid stone) where thicknesses and hidden defects were easily read.

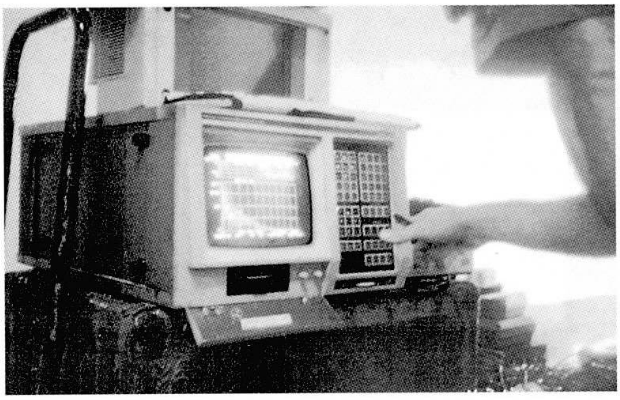

Fig. 6 Impact Echo Data on Field Computer

The data is, like radar, not easy to read. The output is plotted in linear frequency versus distance displaced per unit of force. A specially trained technician or engineer must interpret the results. The cost of the measuring devices is moderate; this does not include the computer equipment or the rather expensive software required.

3.2 Ultrasonic Pulse Velocity

This technique is widely used to assess concrete quality (ASTM C597-83). The process uses a transmitter and receiver to pass ultrasonic energy through a test member; therefore, access is required from both sides of the object. The faster the measured velocity, the denser or stronger the material [3]. Characteristic velocities were obtained for various materials: brick, granite and sandstone. This was used as baseline data for sound materials.

Fig. 7 Pulse Velocity Equipment in Use

In composite walls, the velocity and signal strength dropped across mortar joints. Low frequency pulse velocity signals can provide good results for thick brick walls where multiple mortar joints would otherwise block the transmission of higher frequency signals. In solid materials, such as granite columns, the results were excellent for determining thicknesses and soundness of the material. In general the results correlated well with the impact echo results, giving better results for brick walls over 600 mm than impact echo. The two techniques should be used in conjunction; ultrasonic pulse velocity provides accurate baseline velocity measurement for the test material and impact echo assesses thicknesses (only need access from one side) and hidden damage. Since low frequency energy penetrates concrete and brick better than high frequency energy, signals were received using this method. The disadvantage is that the long wavelengths result in an

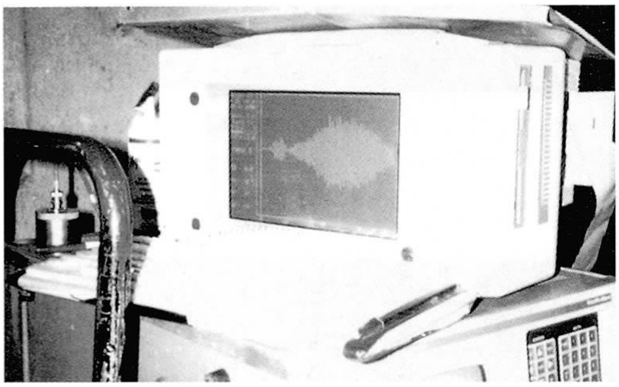

Fig. 8 Pulse Velocity Data on Field Computer

"averaging" effect which decreases the resolution of the method and does not allow the location of smaller scale damage such as individual brick unit debonding.

As with radar and impact echo, the data is not easily readable and requires a specially trained technician or engineer to interpret. The output is given in time (microseconds) versus signal amplitude (millivolts). The equipment costs are quite high.

3.3 Spectral Analysis of Surface Waves (SASW)

This is a seismic method developed at the University of Texas in Austin to read shear wave velocities and modulus profiles in layered systems (such as pavements and earth). In this technique the surface of the test material is struck on line with two surface mounted receivers to measure surface wave velocity as a function of wavelength. With increased surface shear wave velocity, the material modulus is higher, therefore, the quality of the material is better [4].

Access to only side of the material is required to perform measurements, as was the case for impact echo. This is important as a practical concern in the field where access is often limited. In its usual application for pavements, the SASW method can determine thickness of slabs on grade quite accurately. However where there is an air void behind the material or where a corner of structure occurs, a great deal of interference is experienced by the sensing equipment and accuracy is seriously impaired. For thick stone and brick walls the method was satisfactory in measuring thickness but for thinner walls and framed slabs, the SASW technique was not suitable. For both impact echo and SASW, the presence of energy absorbing materials (e.g. plaster) is an impediment.

As with the other techniques, the data is not easy to read. The output is given in frequency (KHz) versus phase angle (degrees). The equipment costs are moderately high.

4. ELECTROMAGNETIC DETECTION

Most available instruments are cover meters for locating rebar. Two instruments were tested: Profometer and the Fisher M-100 Meter.

The basic principle of operation is that an alternating current passing through a coil generates a magnetic field. When a magnetic material is encountered the field is disturbed. The magnitude of this disturbance is related to the size of the metal object and proximity to the probe. The probes are generally directional, that is there is a sharp maximum reading when the long axis of the probe and the long axis of the object are aligned.

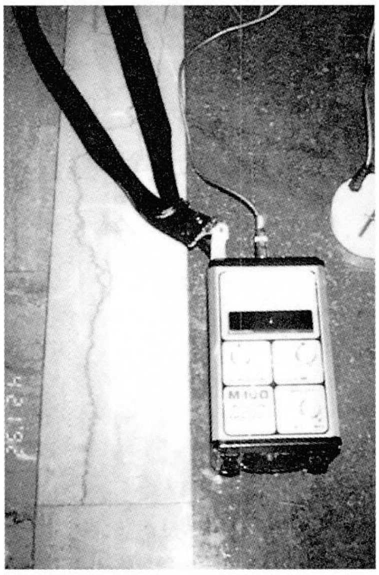

Fig. 9 Magnetic Detection Equip.

Both instruments worked very well at locating iron beams and girders supporting brick arch construction with about 9 inches of cover where no wire mesh was present. A steel column behind 8 inches of granite cover was easily located. Iron anchors in stone walls were also easily located. At the flat concrete slabs with draped wire mesh the results were variable. The instruments must be "fine tuned" to avoid reading the mesh only.

Fig. 10 Magnetic Detection & SASW Equipment

Costs are quite low for the equipment. The less expensive Fisher instrument worked just as well as the higher cost Profometer instrument for these purposes. Electromagnetic detection is recommended for use with all other methods to ascertain whether hidden objects are metallic. Specially trained operators are not required.

5. INFRARED THERMOGRAPHY

Infrared thermography is typically used to perform energy efficiency surveys of buildings and to assess roofing membranes for leaks. This technique could be referred to as heat imagery. The equipment consists of camera/video equipment with a special cooler containing semi-conductor crystals in liquid nitrogen. A photograph is taken of the subject and the resulting colors are indicative of surface temperature variations. The colors typically translate as black/violet being cool, and red/white being warm.

Fig 11. Infrared Equipment in Use

The basic principle is than an object having a temperature above absolute zero will radiate electromagnetic waves. Wavelengths fall within certain bands depending on temperature. At room temperature, typical wavelengths are 4 to 40 micrometers which is outside the visible spectrum. At very high temperatures the wavelengths are less than 1 micrometer and fall within the visible spectrum. Hence when metal is heated and begins to glow red, the electromagnetic waves emanating from the object fall within the visible range.

Water content reduces the transmission of infrared radiation, therefore thermoscans taken on a humid day may adversely affect the results. The ambient temperature and time of day are also important aspects of infrared thermography. The readings are only of surface temperature; the equipment is not capable of deeper penetration such as electromagnetic detection, radar, etc.

Hidden structure could not be detected through the roofs or walls. The technique did prove to be very useful for locating hidden pipes and flues which were at different temperatures within the thick walls. It is also useful for documenting surface deterioration of masonry which were at different temperatures. This is primarily related to the different moisture content in porous, deteriorated stone and brick.

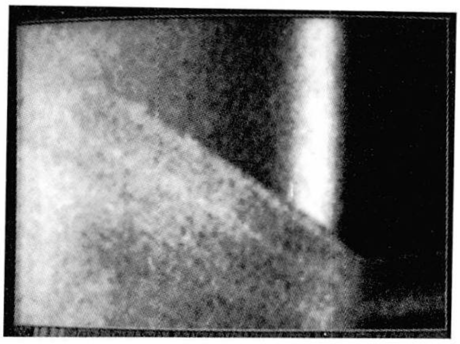

Fig. 12 Infrared Thermoscan Data

6. FIBER OPTICS

This technique was originally developed by physicians for internal examinations. An instrument called a fiberscope is constructed of a bundle of flexible optical fibers (or a borescope of rigid optical fibers), some of which carry high intensity light along their length to the end of the probe. Others of the fibers are used to view the object by means of focusing lenses. The viewing end or head can be rotated to give variable viewing angles.

Although these instruments have applications in evaluating historic structures, the type of structure is critical. It is mandatory that there be void spaces into which the fiber optic tube can be inserted for visual observation. Solid masonry structures are generally not suitable candidates for fiber optics because they have few voids. Good success has been experienced in timber structures where a small hole can be made in a plaster or wood finished surface, the flexible fiber optic tool inserted and a great deal of information gathered. One critical feature of the equipment is the focal length; for structural evaluation a long focal length is important.

Cost is fairly moderate, depending upon the number of accessories purchased.

7. CONCLUSION

Of the five NDE methods employed on this heavy masonry building , radar proved to be the most generally successful. Next in order of success were impact echo/pulse velocity and infrared thermography. Electromagnetic detection was very useful but its scope is limited to buildings which contain iron or steel and to locations where framing members can be isolated from pipes, conduits and other iron features. Fiber optics was found to be of minimal use in this type of building because void spaces were not present. A problem to be considered in the utilization of the three most successful methods is the need to have highly trained equipment operators present as well as sophisticated computer programs which can translate the raw data into meaningful results; these imply significant costs which must be borne by the NDE users. However there is great promise for NDE as a tool for exploring historic structures. The rapid changes and improvements in existing technology as well as the expectation for new techniques to be introduced are causes for future investigators to be extremely optimistic about the ability of NDE to delineate features of historic structures.

8. REFERENCES

1. MAST, J.E., EDGAR, B., WALL, T.W., MURTHA, J.P and LEE, H., Impulse Radar Imaging: Applications to Historic Buildings. Advanced Construction Technology Center Document No. 92-30-25, Newark Civil Engineering Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL. October 1992.

2. SANSALONE, M. and CARINO, N.J., Impact Echo Method. Concrete International, April 1988.

3. Standard Test Method for Pulse Velocity through Concrete, ASTM C597-83. 1987 Annual Book of ASTM Standards.

4. BAY, J.A. and STOKOE, K.H., II, Field Determination of Stiffness and Integrity of PCC Members Using the SASW Method. Proceedings of Nondestructive Evaluation of Civil Structures and Materials Conference, University of Colorado at Boulder, 1990.

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