The Economic Benefits of Impulse Response Testing

Bernard H. Hertlein

ABSTRACT

Most nondestructive tests were developed for a specific purpose, and have been successful in that application, often providing significant economic advantages. Some methods have been readily adapted to other applications, and have been proven to provide significant economic advantages over previously used or traditional methods for those applications. The Impulse Response Spectrum test method was originally developed for quality control of drilled shaft foundations, but has since also proven to be valuable as a nondestructive tool for assessing condition of floors, pavements, and concrete structures of all types.

In this paper the author briefly reviews the test method, and describes case histories of several very different situations and applications where the economic benefits of using the method were substantial, compared with performing the same work using traditional techniques.

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INTRODUCTION

The Impulse Response Spectrum (IRS) test method was originally developed by the French national construction industry research institute (CEBTP) in the 1970's for quality control of drilled shafts, and gained acceptance throughout Europe by the early 1980's. The author was part of the team that introduced the method to several countries outside of France.

As experience with the method and its capabilities has grown, several other applications for the method have been developed. The IRS test has proven to be of value as a nondestructive tool for assessing the condition of floors, pavements, and concrete structures of all types.

THE IMPULSE RESPONSE SPECTRUM METHOD

The Impulse Response Spectrum (IRS) test is performed by instrumenting the surface of the structure with a geophone velocity transducer, and striking the surface with a small hammer which has a load-cell built into the tip to record the force of the impact. (Fig. 1) The signals from the geophone and the load-cell are recorded on a digital data acquisition system which processes the signals via Fast Fourier Transform (FFT) to convert them into frequency based data, or spectra. The velocity spectrum is then divided by the force spectrum to provide a normalized response curve, or transfer function, which is plotted as a graph of mobility against frequency. (Fig. 2)

The response curve contains information about the dynamic stiffness of the test point, the quality of the concrete, and the integrity of the structure at the test point. In the case of a drilled shaft, significant changes in concrete quality, soil conditions, shaft cross-section, and continuity can be detected by the way in which they reflect stress wave energy, and change the mechanical impedance of the shaft/soil system.[Ref. 1]

IRS test data has also been proven to be a reliable indicator of distress or anomalous conditions within reinforced concrete on other structures. [Ref. 2] The mechanical impedance of sound concrete is relatively uniform in the frequency range 100 Hz to about 800 Hz, whereas poorly consolidated (honeycomb) concrete, or concrete suffering from disruptive chemical reaction, such as Alkali-Aggregate Reaction or sulfate attack, typically exhibits a progressive change in impedance with increasing frequency.

The resonant behavior of concrete in a pavement slab-on-grade is affected by both the quality of the concrete, and the degree of damping provided by the subgrade beneath the slab. The IRS test has proven to be of value in locating voids or reduced support conditions beneath concrete pavement and floors on grade. [Ref. 3]

CASE HISTORY No. 1 - Permitted Increase in Foundation Load

The earliest acceptance of the Impulse Response method was by the French construction industry, and the nationwide laboratory network of the CEBTP facilitated the compilation of a database that demonstrated a marked improvement in foundation construction quality over the first few years that the method was widely employed.

Confidence in foundation construction methods and quality, if monitored by IRS or allied NDT methods, was such that the federation of the construction industry in France revised the code requirements for foundations to allow a 20% increase in working load, if all shafts were tested and produced test results within a certain range of parameters.

On a large project, the cost of testing using the IRS method is typically 1% or less of the cost of construction of the foundations. The 20% load increase, or conversely, 20% reduction in the number of shafts needed, represents a substantial cost saving to the owners, which more than offsets the cost of testing on any project site where more than 10 or so drilled shafts are required.

CASE HISTORY No. 2 - Assessment of Pile foundations for Re-use in New Design

The redevelopment of the McCormick Place Exhibition Center in Chicago, Illinois included the demolition of an existing exhibition hall, and a high-rise hotel. To maximize economy of construction, it was decided to incorporate, where possible, the foundations of the previous buildings into the design of the new structure. The foundations in question were originally constructed using the Raymond "Step-taper" design, which left each shaft encased in a 24-inch diameter corrugated steel casing.

Such re-use of the foundations was contingent upon verifying the bearing capacity of the foundation piles, and on proving the integrity of the foundations after demolition and removal of the pile-caps had been completed. The issue of capacity was resolved by performing "Statnamic" dynamic load tests on selected shafts.

The integrity of all shafts intended for re-use was then checked using the Impulse Response method. More than a dozen of the shafts tested were found to be discontinuous, and were further investigated by excavation and exposure. In every case the discontinuity was found to be at least one flat, almost horizontal crack.

In most cases multiple cracks were found in the upper few feet of the shafts. The damaged material was removed, and the shafts retested with the IRS method until continuity of the remaining shaft was proven.

Due to the need for excavation and removal of the corrugated steel casing direct visual inspection of the concrete involved considerable effort and expense. Apart from using the IRS test or a similar technique, the only viable alternative for assessing concrete integrity would have been core drilling, which would have been costly and very difficult in the small diameter shafts.

It is difficult to calculate the cost saving that resulted from the re-use of the existing piles, since much more than the simple construction cost of new foundations is involved. It is likewise difficult to calculate the cost benefit of using the Impulse Response test, compared with excavation and inspection, or core-drilling, because of the multiple cracks often found. However, the total cost of integrity testing was in the order of $12,000, which is about the construction cost of two replacement shafts on that site.

CASE HISTORY No. 3 - Pavement Assessment and Joint Evaluation

Oklahoma Department of Transportation was the first in the United States to perfom pavement assessment trials using the IRS method. Approximately 14 miles of concrete pavement was assessed on I-40 and US-69 near Checotah, in eastern Oklahoma.

The undowelled pavement slabs had tipped slightly or "faulted" due to heavy truck traffic and water ingress at the joints. As the trucks passed over each joint, the weight transfer of the vehicle had a squeezing effect, pumping the water back and forth, causing erosion of the subgrade. As the voids grew larger, slab cracking began to occur. One repair method was to pressure grout the voids, but this often lifted the slab unintentionally, leading to further cracking. (Fig. 3) The IRS test was used to map out the extent of the voids, and plan a more effective grout injection pattern.[Ref. 4]

During the course of this work, it was noted that a joint repair program at a nearby site on I-40 was in difficulty because of the nature of the damage. In many cases joint failure occurred because cracks propagated horizontally from the load transfer dowels, along the plane of the reinforcing mesh. The mesh position was not positioned at a uniform depth in the slab, and if the concrete below the mesh was thinner than the concrete above it, failure of the joint began in the lower layer, and the true extent of the damage was not visible at the slab surface. (Fig. 4)

Thus, when a sawcut was made to remove the visibly damaged portion of the slab, it was often found that the lower layer was still damaged beyond the sawcut, and additional cuts had to be made until sound material was encountered.

IRS testing proved able to map the true extent of the damage, thus allowing the engineers to place their sawcut with much greater reliability, and so reduce the number of cuts needed, and the time involved in breaking out the damaged concrete.

Again, the cost saving is hard to estimate, because the number of additional sawcuts made before Impulse Response testing was performed varied from joint to joint, but typically about one half-day of time was saved at each joint. With the cost of maintaining interstate traffic control and lane closures, the savings afforded by the IRS testing could certainly be counted in thousands of dollars.

CASE HISTORY No. 4 - Detection of Honeycomb Concrete in Airport Pavement

A new aircraft parking area for wide-bodied jets was being constructed at Geneva airport in Switzerland. The concrete for each slab section was placed in two lifts. The lower lift of 16 inches thickness was compacted by vibrating poker, and the upper lift of 8 inches was compacted by vibrating beam.

A series of longitudinal saw cuts were made in the edge of each slab section for the installation of the load-transfer mechanism. During one set of cuts it was observed that the rate of cutting was extremely variable, and physical sampling showed zones of honeycomb material.

Enquiries by the engineers revealed that the vibrating poker had broken down several times during the placement of the lower layer of concrete, and that the vibrating beam had to be lifted past a number of box-outs in the upper layer. The material in between the box-outs was hand-trowelled. The result was several zones of inadequately compacted concrete, most at different locations in the upper layer than in the lower layer.

IRS testing was used to examine the affected area, which was approximately 6,000 square feet. The testing was completed in one day on site, and identified several anomalous zones, which were variously interpreted as upper or lower layer honeycomb. Subsequent core sampling verified the IRS test interpretation. If core sampling alone had been used to locate the affected zones, a large number of cores would have been required, or it is likely that much of the honeycomb material would not have been found.

It is difficult to estimate the cost that would have resulted from pavement failure in service, and possible damage caused by debris to aircraft or engines, but at a minimum, use of the IRS test saved several days of core-sampling and repairing core holes, which would have cost in the order of $ 1500 per day.

CASE HISTORY No. 5 - Utility Chimney Condition Assessment

Tall chimneys generally only get inspected every couple of years or so, because of the difficulties of access. Traditional inspection methods have relied primarily on visual survey, with little or no testing. The little testing that has been done has consisted largely of hammer sounding, to detect delaminations and cracked concrete, applied by a technician in a bosuns chair or on a swingstage

This approach has proven inadequate because many chimneys are now covered with some form of protective mastic coating, and because many facilities with tall chimneys, such as foundries, refineries, and electricity generating stations, are inherently noisy environments.
This means that the changes in the tone of a hammer impact on concrete that the operator is trying to hear are deadened by the mastic coatings, and masked by the ambient noise level within the plant, particularly on the lower portions of the chimney. The result is dubious reliability in the initial assessment, and very poor repeatability in follow-up surveys to track deterioration.

A further drawback has been that many chimneys are constructed with an external concrete sheath, and an independent liner in the interior. The annular space between the liner and the sheath is often too small to permit access for direct visual inspection, and accumulations of flyash and dust limit what can be seen with remote video cameras. Thus deterioration originating from the interior surface of the sheath, caused by flue gas leaks through the liner system, can be almost impossible to detect until it has made its way through to the exterior surface of the sheath. [Ref. 5]

The IRS test has proven to be sensitive to concrete integrity, and changes in section and dynamic stiffness caused by delamination, or the planar cracking that typically precedes delamination. The author has used the method in condition assessments of more than 30 concrete chimneys and storage silos in various parts of the U.S. During the course of this work, the author's team had the opportortunity to perform the test on a badly deteriorated chimney, and on a brand new chimney of practically identical proportions that was constructed as a replacement for the deteriorated one. [Ref. 6]

The IRS data for the new chimney demonstrates how the uniformity of the structure's shape readily lends itself to assessment by criteria such as dynamic stiffness and mechanical mobility profiling. In comparison, the data from the deteriorated chimney shows how sensitive these criteria are to changes in section and integrity caused by corrosion of reinforcing, and subsequent cracking and spalling of concrete. (Fig. 5)

The cost of performing the IRS test, and allied NDT methods such as rebar location, carbonation depth testing, and corrosion risk assessment, as part of a chimney inspection probably doubles the overall. cost of the inspection, due to the time involved, and the extra access equipment often required.

A typical inspection on a 300-foot chimney would be in the order of $20,000. However, the information gained could give the plant maintenance personnel as much as two or three years head start on deterioration problems, compared with visual survey and hammer sounding. Those extra years can mean the difference between proactive maintenance, and reactive repairs. In a business where chimney outage costs are measured in tens of thousand of dollars per day, the cost of testing is truly in the "pocket change" category if it contributes to keeping the chimney online.

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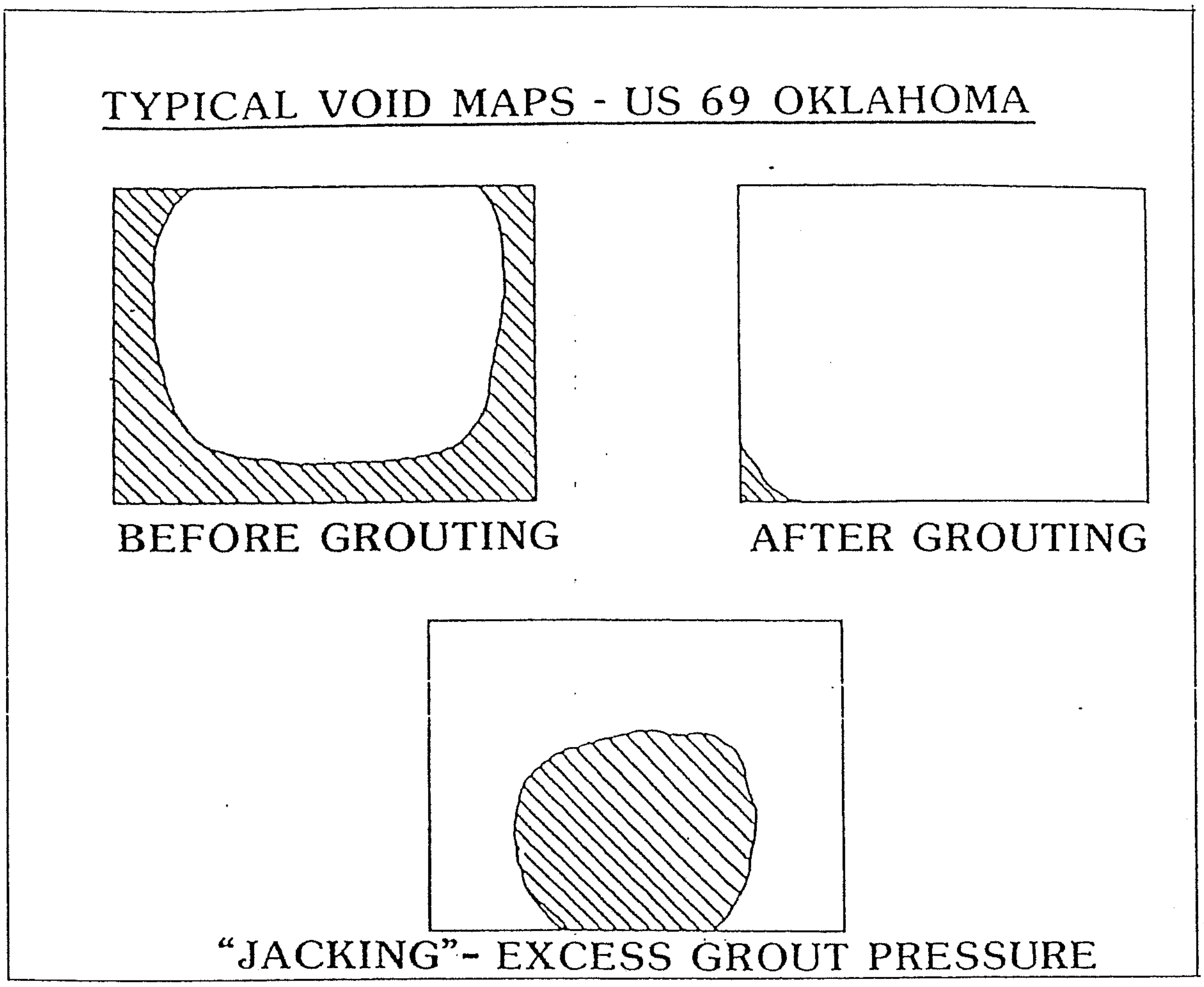

Figure 3

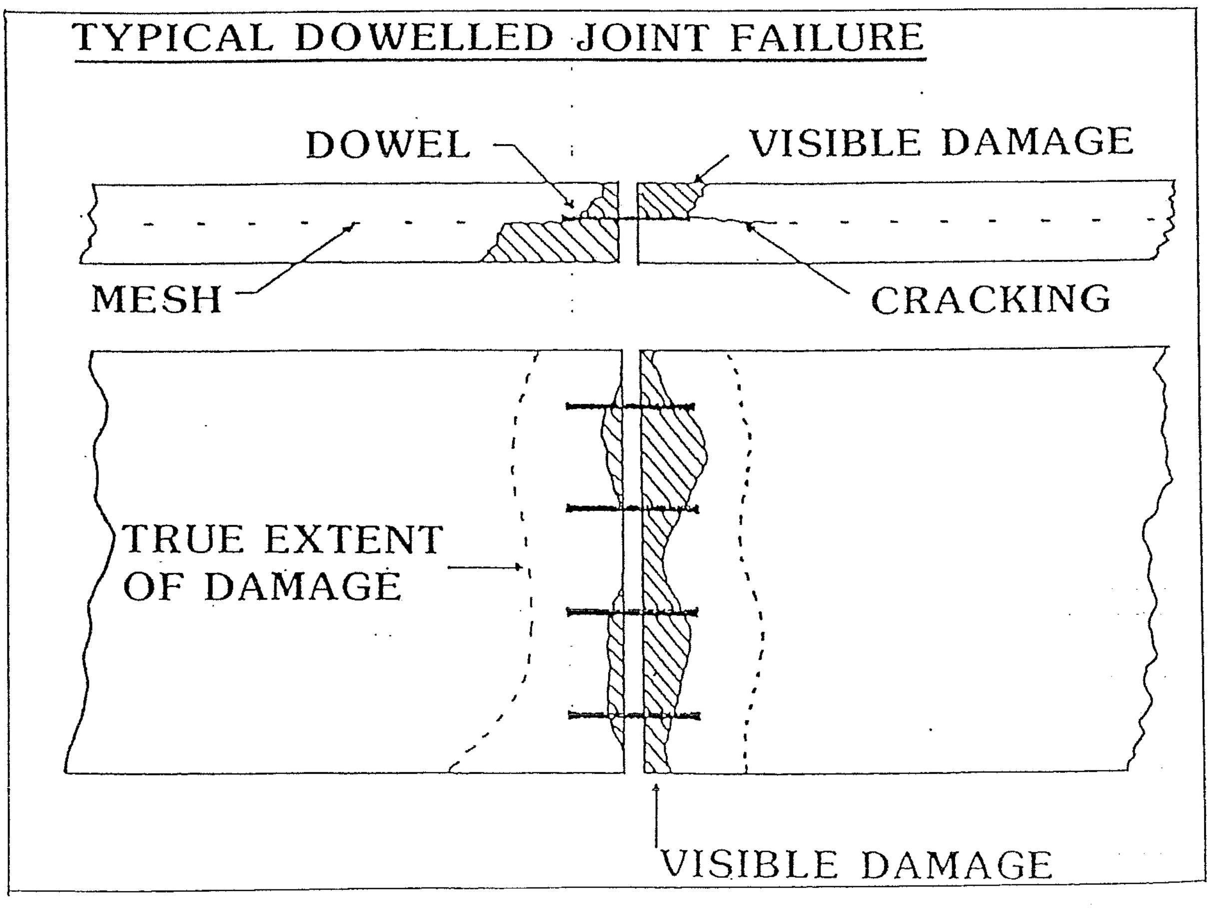

Figure 4

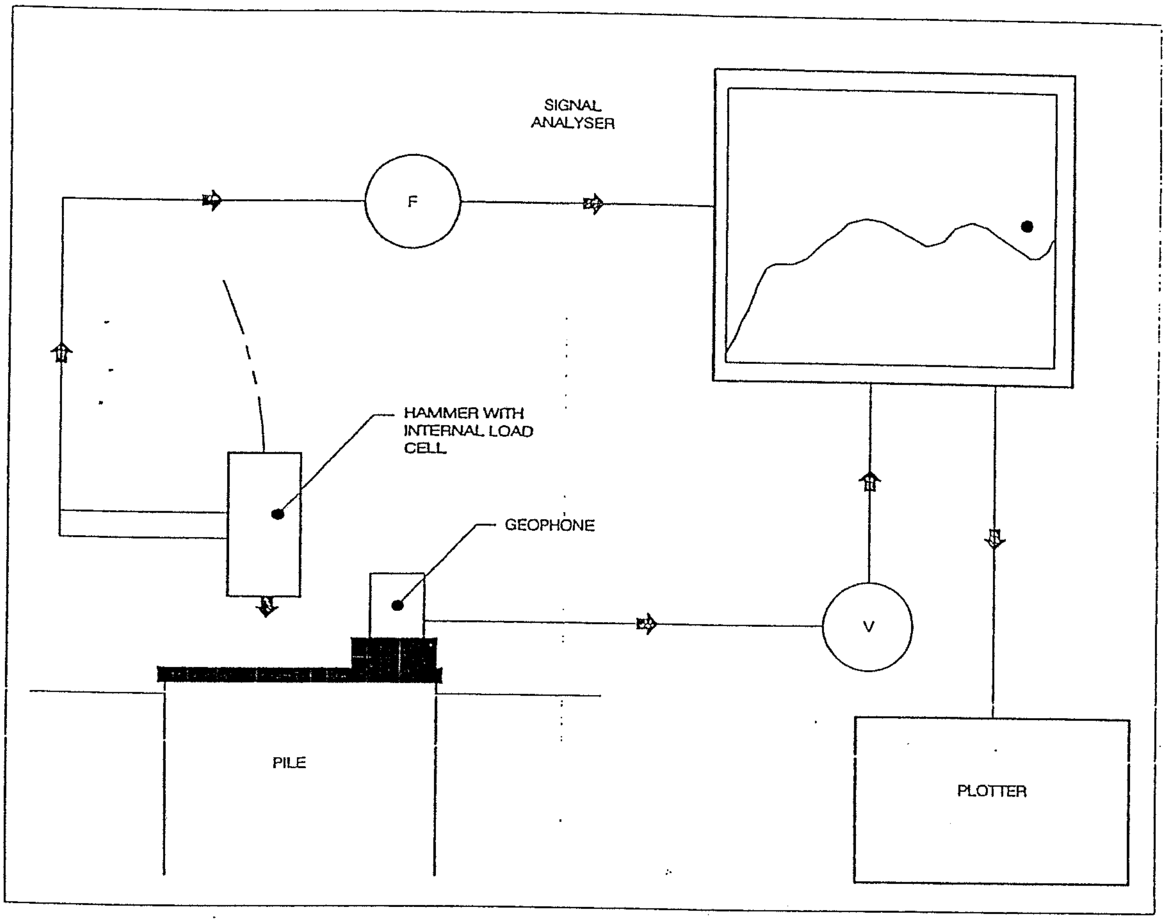

Figure 1. Impulse Response Test Schematic

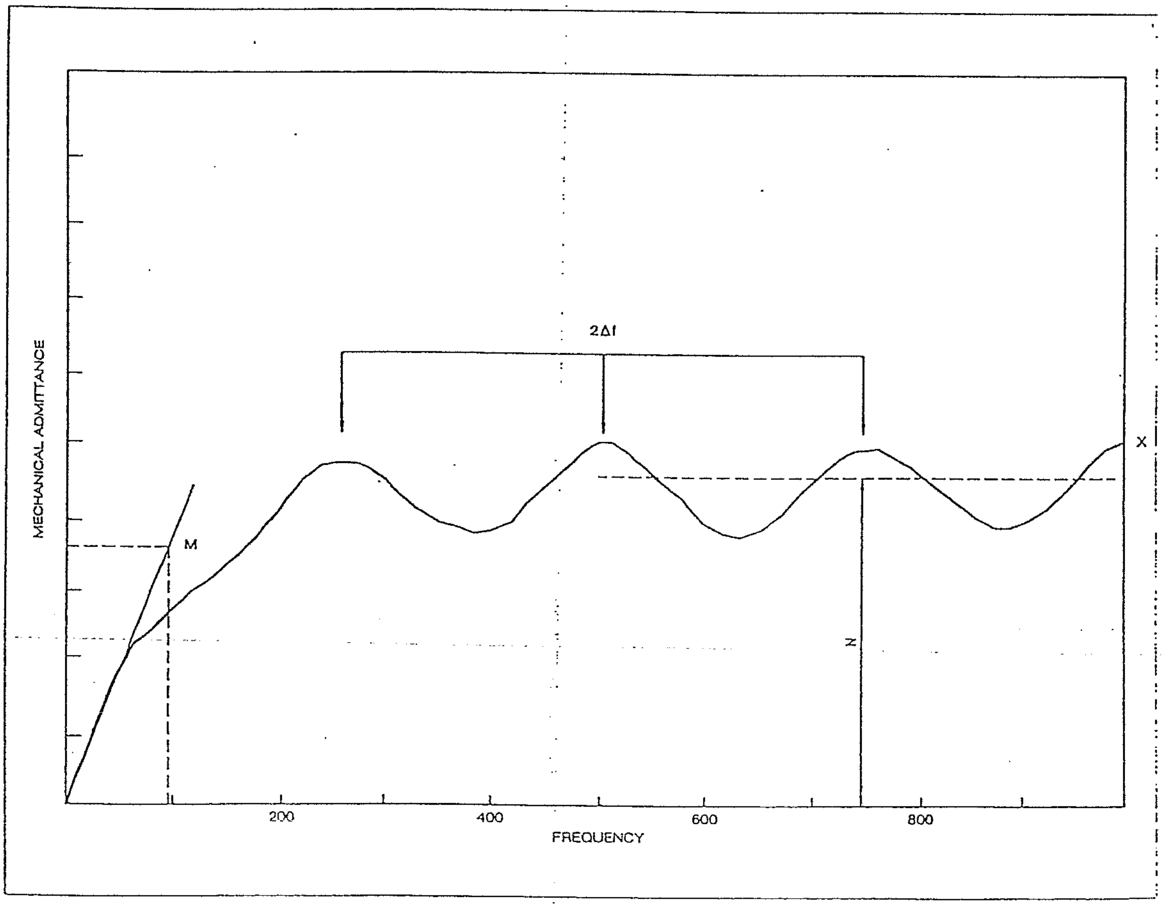

Figure 2. Impulse Response Test Data

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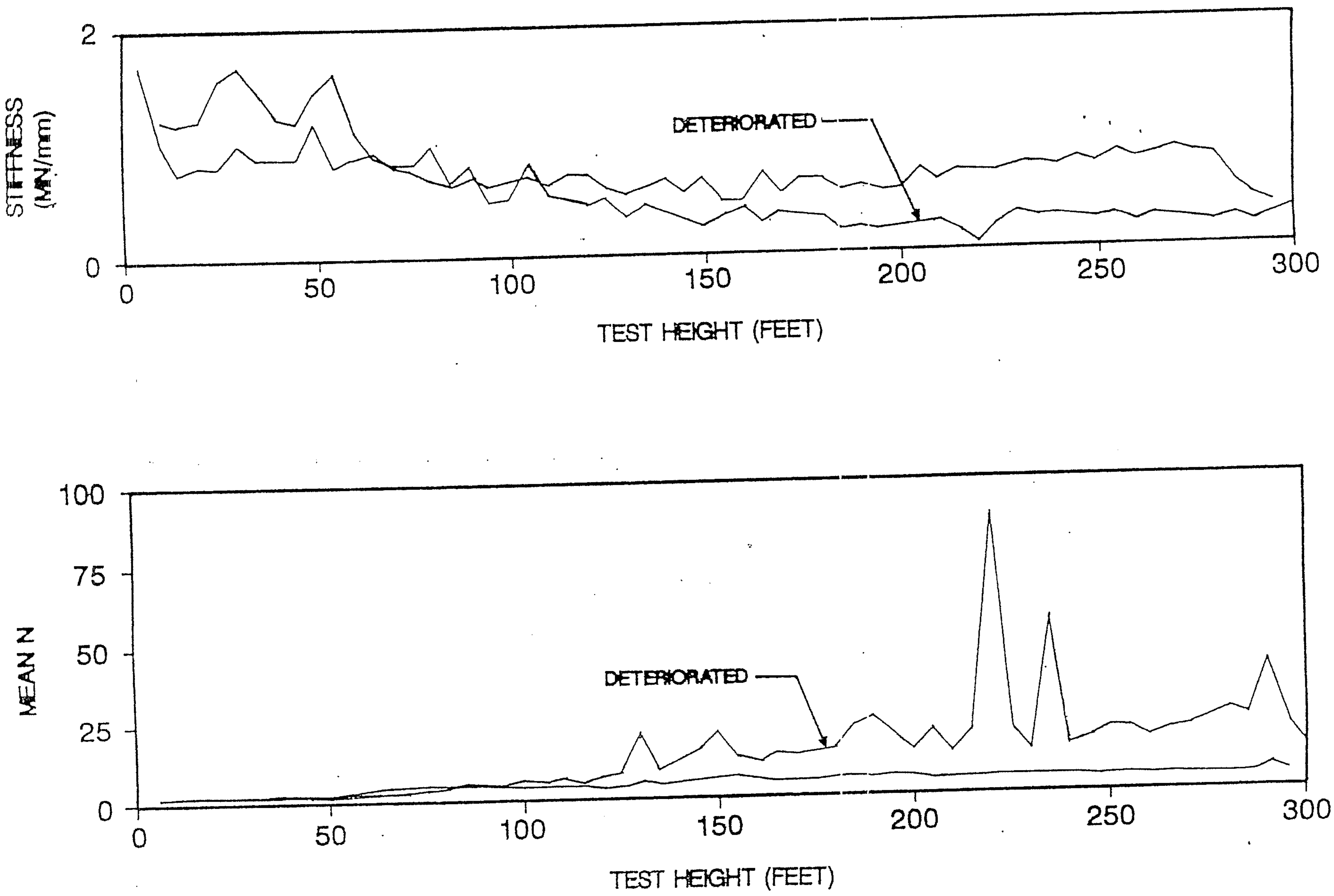

Figure 5. Impulse Response Test Results on 300 ft Chimney

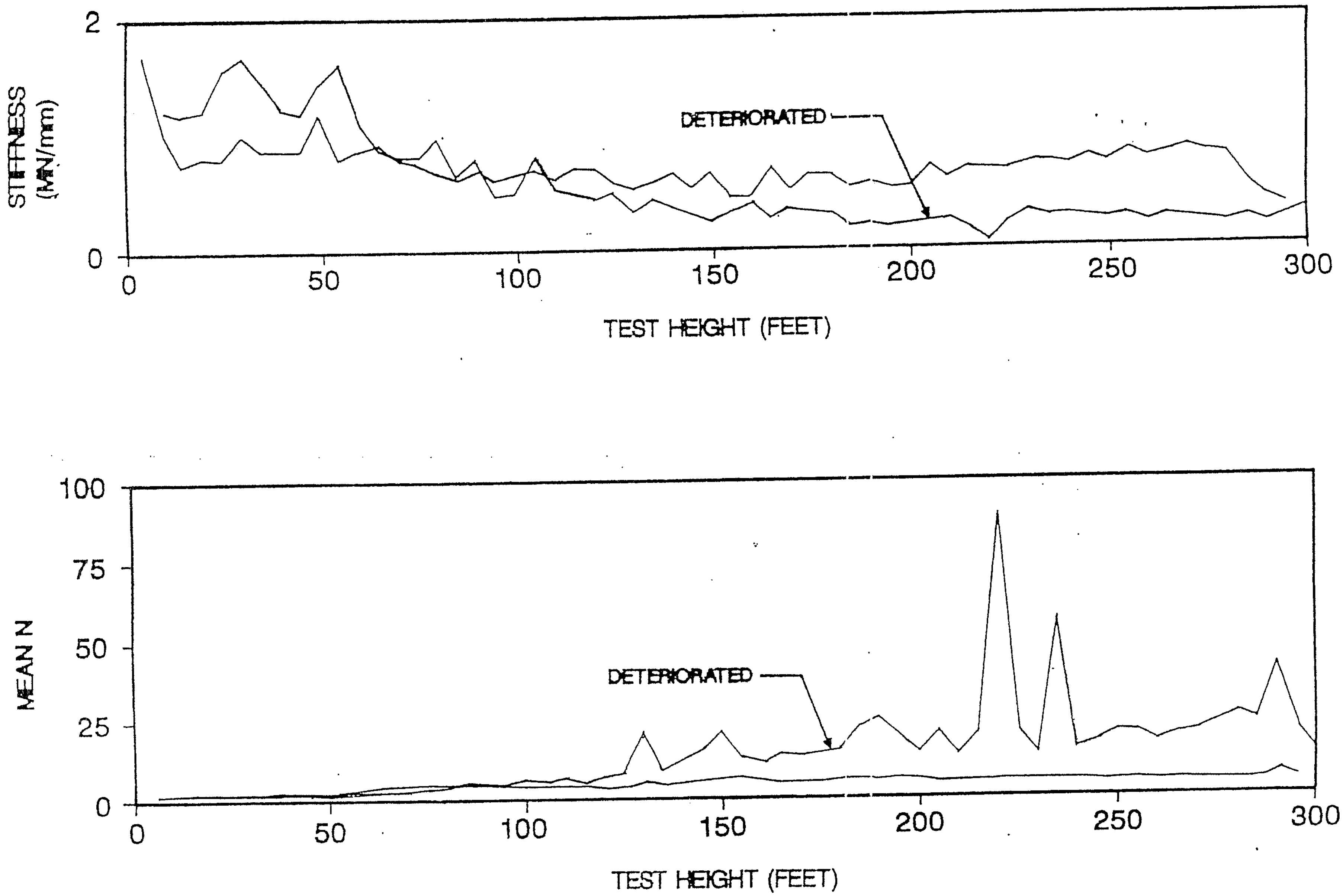

Figure 5. Impulse Response Test Results on 300 ft Chimney