LA-UR-12-22590
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Title: Application of Nonlinear Elastic Resonance Spectroscopy For Damage Detection In Concrete: An Interesting Story

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Intended for: 17th International Conference on Nonlinear Elasticity in Materials, 2012-07-01/2012-07-07 (Cefalua, ---, Italy)

1/26/1999

APPLICATION OF NONLINEAR ELASTIC RESONANCE SPECTROSCOPY FOR DAMAGE DETECTION IN CONCRETE

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ABSTRACT

Nonlinear resonance ultrasound spectroscopy experiments conducted on concrete cores, one chemically and mechanically damaged by alkali-silica reactivity, and one undamaged, show that this material displays highly nonlinear wave behavior, similar to many other damaged materials. We find that the damaged sample responds more nonlinearly, manifested by a larger resonant peak and modulus shift as a function of strain amplitude. The nonlinear response indicates that there is a hysteretic influence in the stress-strain equation of state. Further, as in some other materials, slow dynamics are present. The nonlinear response we observe in concrete is an extremely sensitive indicator of damage. Ultimately, nonlinear wave methods applied to concrete may be used to guide mixing, curing, or other production techniques, in order to develop materials with particular desired qualities such as enhanced strength or chemical resistance, and to be used for damage inspection.

An interesting story

Submitted: Journal of Cement and Concrete Research, 1999

History: (1) Back in the 1990s there was a big push by the US DOT to fund research on concrete and how it degrades and how to test and how to improve it (e.g., super-concretes). (2) The Concrete and Cement Research group at Northwestern University (now the *McCormick Infrastructure Technology Institute*) pretty much "owned" that research at the time. (3) Guthrie, Carey, Johnson, and TenCate (with grad student Byers) all tried hard to get a LANL "foot in the door" with some novel concrete research. (4) Nuclear Energy interest at the time was nil.

R&D 100

WINNER

1997 R&D 100 Awards Winner

ASR Detect™—Diagnostic Method for Analyzing Degrading Concrete

Features

- Identifies alkali-silica reaction (ASR) in concrete through colorful, easy-to-interpret staining of two ASR gels
- Differentiates ASR from other causes of degradation with ASR-specific reagents
- Eliminates need for special equipment and extensive training
- Diagnoses ASR deterioration in time for remediation that forestalls structural repairs or replacements
- Reveals proximity of ASR to different aggregate components
- Avoids the radioactive materials of other diagnostic methods
- Provides reliable diagnosis in less than five minutes for less than $1 per concrete sample

Applications

- Analyzing the integrity of concrete in structures such as highways, bridges, dams, railroad ties, and culverts on the site
- Finding ASR before structures are irreparably damaged
- Identifying aggregate components triggering ASR
- Evaluating concrete mix designs for ASR potential
- Expanding studies of all factors associated with ASR's occurrence

Benefits

- Allows many structures to be tested quickly
- Opens the door to discovering and eliminating widespread degradation in the nation's infrastructure
- Eliminates expensive repairs and replacements by identifying ASR early enough for remediation
- Enables research into improved concrete mixes and better remediation treatments
- Supports efforts to develop ASR-free concrete for the future

Pergamon

Cement and Concrete Research, Vol. 27, No. 9, pp. 1407–1417, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00123-3

A SIMPLE ENVIRONMENTALLY FRIENDLY, AND CHEMICALLY SPECIFIC METHOD FOR THE IDENTIFICATION AND EVALUATION OF THE ALKALI-SILICA REACTION

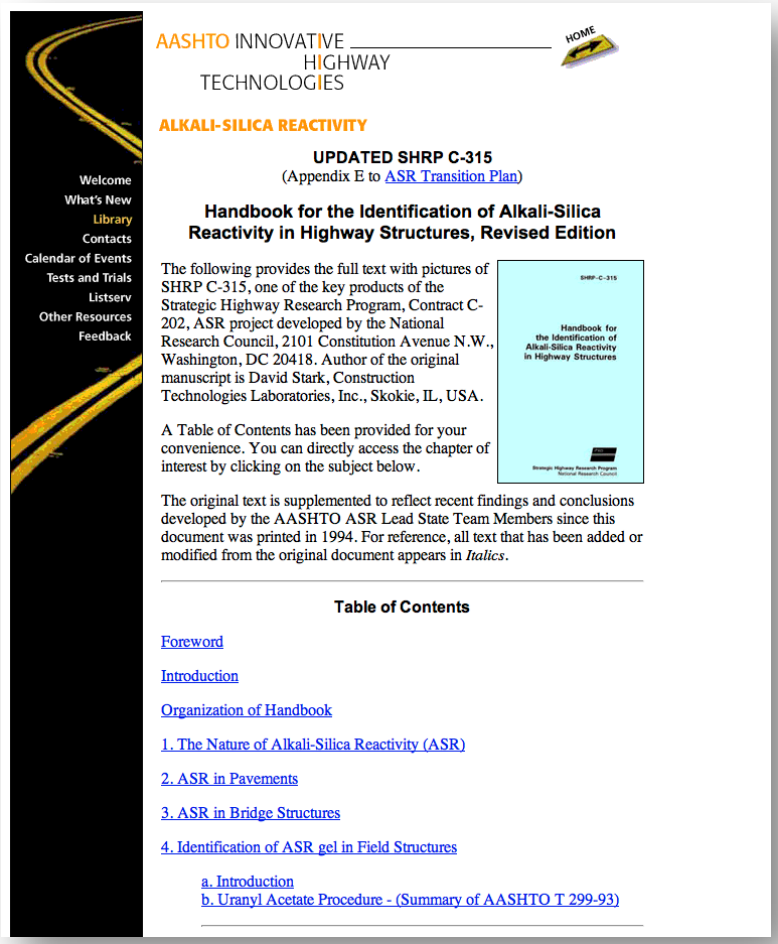
George D. Guthrie, Jr. and J. William Carey
Geology and Geochemistry Group, Los Alamos National Laboratory

(Refereed)
(Received February 13, 1997; in final form July 9, 1997)

ABSTRACT

A rapid, dual staining method is described whereby reaction products associated with the alkali-silica reaction (ASR) are readily identified by their pink or yellow color following treatment in the laboratory or field. The method is based on both the compositional and physical characteristics of the ASR gel; hence, it provides greater information than non-chemical-specific techniques (such as the uranyl acetate method). In addition, the chemicals used in the staining method pose minimal health risks and are environmentally benign.

ASRdetect™ is now a standard



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HOME

ALKALI-SILICA REACTIVITY

UPDATED SHRP C-315
(Appendix E to ASR Transition Plan)

Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures, Revised Edition

The following provides the full text with pictures of SHRP C-315, one of the key products of the Strategic Highway Research Program, Contract C-202, ASR project developed by the National Research Council, 2101 Constitution Avenue N.W., Washington, DC 20418. Author of the original manuscript is David Stark, Construction Technologies Laboratories, Inc., Skokie, IL, USA.

A Table of Contents has been provided for your convenience. You can directly access the chapter of interest by clicking on the subject below.

The original text is supplemented to reflect recent findings and conclusions developed by the AASHTO ASR Lead State Team Members since this document was printed in 1994. For reference, all text that has been added or modified from the original document appears in *Italics*.

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Figure 2. Image of concrete core treated with sodium cobaltinitrite and rhodamine B base solutions. Fractured core from a pavement in Albuquerque (NM) showing significant distress in the field. Treated core shows staining by sodium cobaltinitrite around reactive aggregates and within some air voids, but only minor staining by rhodamine B base. Petrographic examination using optical and electron microscopies confirmed that yellow stained material was a K-rich alkali silica gel. Image is scaled to approximately double actual size.

Figure 3. Image of concrete core treated with sodium cobaltinitrite and rhodamine B base solutions. Fractured core from a highway pavement in New Mexico showing severe distress in the field. Treated core shows extensive staining by both sodium cobaltinitrite and rhodamine B base. Petrographic examination using optical and electron microscopies confirmed that yellow stained material was a K-rich alkali silica gel whereas the pink-stained material included a Ca-rich, alkali-bearing silica gel. Image is scaled to approximately double actual size.

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Los Alamos NATIONAL LABORATORY

Earth & Environmental Sciences

Just part of the collection of highway concretes (US-20 in Iowa*), pavement cements and concretes—even the Lucite "standard" that was used—trying all the usual *Nonlinear* acoustic testing done at the time to characterize these samples, all of which had been tested already with ASR Detect.

* The state of Iowa is in the process of upgrading US 20 into a four-lane, limited-access highway for its entire length in Iowa. [Still!] (Wikipedia, accessed 27 June 2012).

Public Relations: George even got an audience with our Senator (and a "line item")

MARCH ISSUE 1999

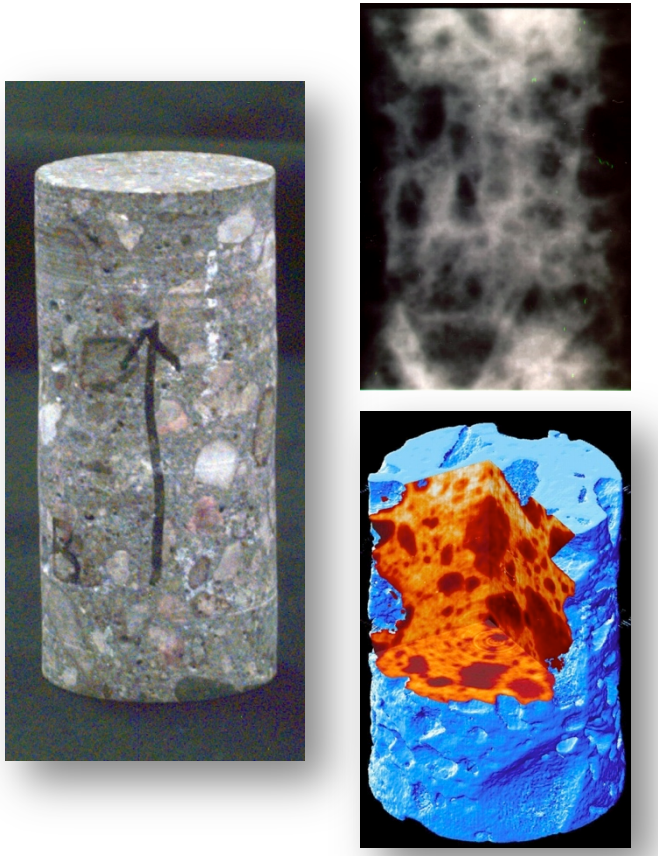
DATELINE: LOS ALAMOS

Graduate student Loren Byers checks data from testing samples for damage.

Byers likens it to playing a piano. "For a sample of undamaged material, it's comparable to hitting a key harder and making the sound louder," he said. "In a nonlinear sample, when you hit the key harder, the response is not only louder, it's a different note."

Moreover, the frequency shift is greater in samples that are more damaged, even with microscopic cracks. So, in a piece of plastic that contains no cracks, there will be no change in resonant frequency as the wave volume is increased. In a sample with a small crack, the resonant frequency will shift readily with amplitude.

Nonlinear acoustics: good press



LANSCE: Neutron radiography, and *FlashCT*, another R&D 100 winner

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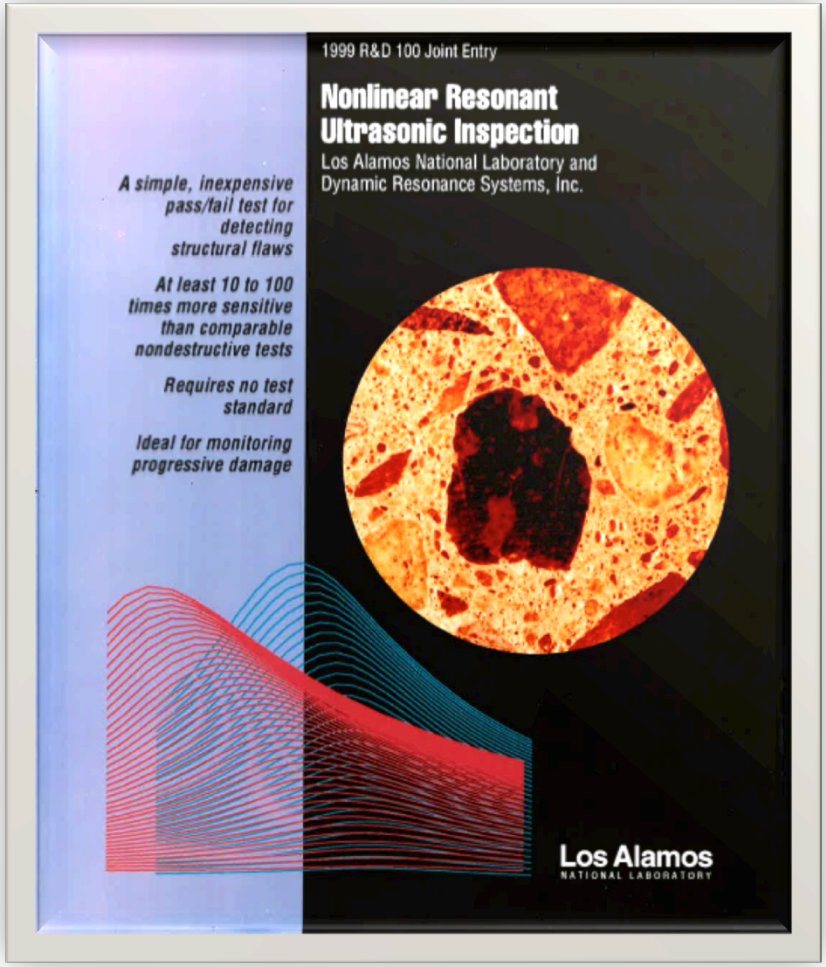


Nonlinear Resonant Ultrasonic Inspection

Paul Johnson and James A. TenCate

—geoengineering

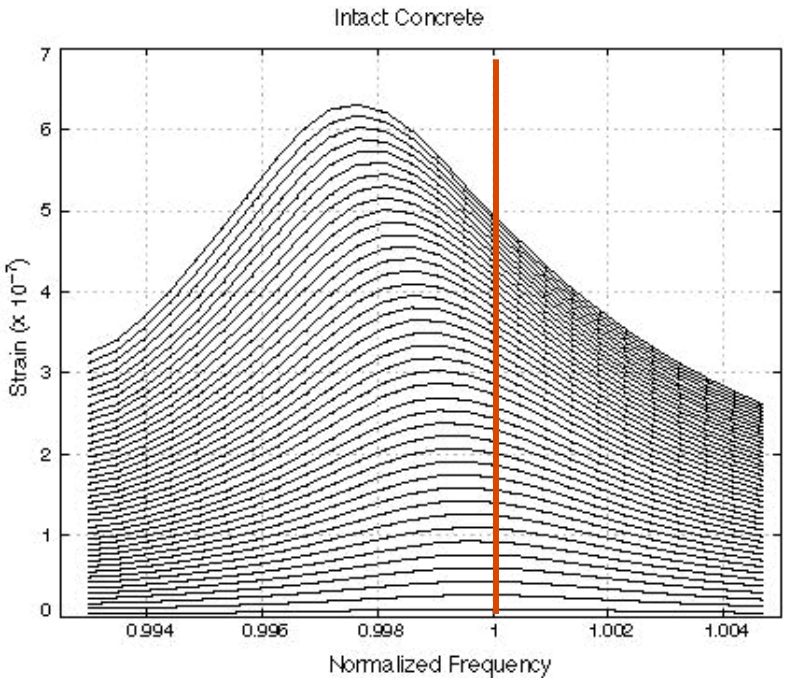
Nonlinear acoustical techniques of interrogation are the frontier of acoustical nondestructive testing. These techniques offer the most sensitive acoustical measurement of damage in existence today. Nonlinear resonant ultrasonic inspection (NRUI) is the first of several nonlinear methods that will eventually be available. NRUI offers previously unimagined sensitivity, fast application, and easy interpretation.The photo shows a concrete core like ones being tested to find damage using the NRUI technique. Very small interior cracks, like those in this core sample, often escape detection by conventional nondestructive evaluation techniques. NRUI, on the other hand, detects tiny flaws very easily and can track the evolution of such flaws over time.

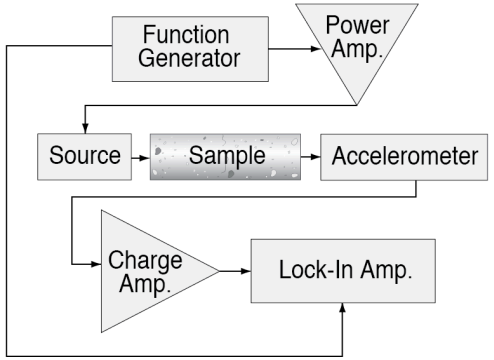
We were finalists in the competition. Got to attend a nice reception and got some attaboys but did not win anything.

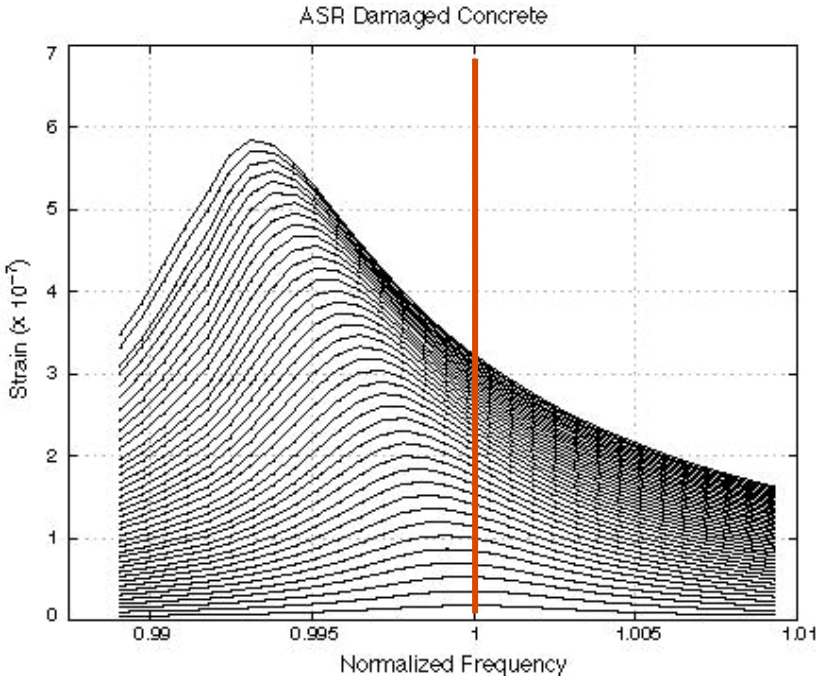
NRUI?

What kind of testing did we do and what was finally reported in that journal article we submitted (and what happened)?

- We examined a whole suite of concretes, including some super-concretes—Sasha Sutin was involved together with a Civil Engineering group from Wayne State.
- For the paper, we finally decided to carefully examine and test two samples taken from a 40 year old pavement pad (concrete).
- One sample (from the edge of the pad) showed no significant ASR damage but showed visible age effects, the other sample had significant ASR damage (with similar environmental ageing) [for those of you visiting Los Alamos soon, I can show you some of the "cores" drilled in the pavement near SM-40].
- Tests included (1) quantifying the peak bending during a resonance experiment, (2) measurements of sound speed and Q, VERY similar, (3) slow dynamics recovery times and slopes and (4) quantifying the maximum frequency shift for a given strain level.



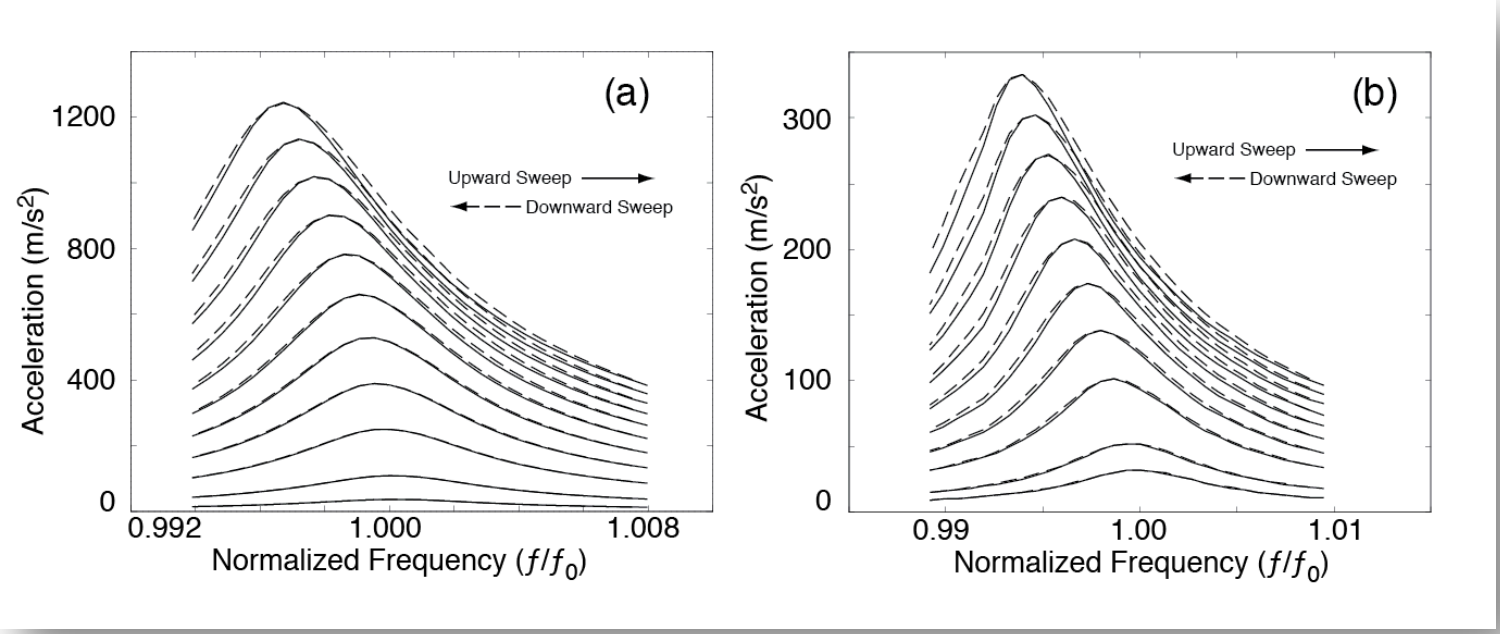




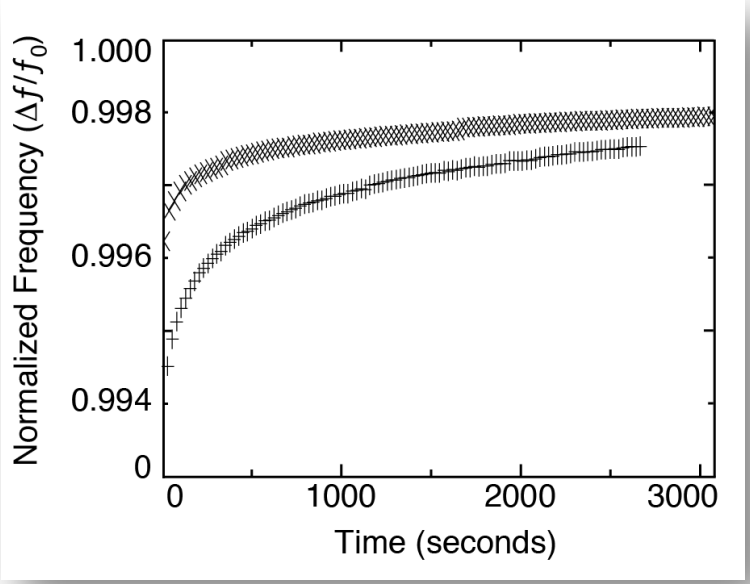
This shows the non-linear response of the two pavements we looked at. The measurements show the change in resonance frequency as a function of driving force—a non-linear material shifts in frequency at higher forces due (essentially) to resonance of internal fractures. The "intact concrete" looked good when we cored it but still showed a small shift in resonance (deflection to lower frequency). The ASR concrete showed a marked shift. The non-linear acoustic work is being done in EES-11 (Jim TenCate and Paul Johnson are the contacts). The (bio)geochemistry of cement/concrete is being done in EES-6 (Bill Carey and I are the contacts). If you have any more questions, please feel free to give me a call.

-George [in an Email to Senator Domenici's science advisor at the time]

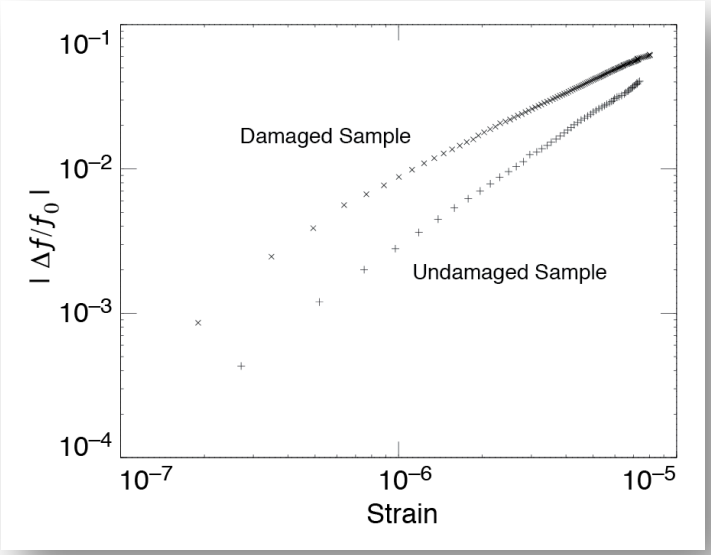
Peak bending was easy to see and quantify and up/down sweeps differ indicating a slow dynamics measurement should be done. Big difference between the two samples!



A slow dynamics recovery measurement was done on both samples (ASR damaged sample is the lower curve). Eric Smith and I were doing slow dynamics on lots of rocks at the time and doing the concretes too was easy so was added to the suite of rocks we looked at.



Finally, this plot shows (normalized) frequency shift as a function of applied strain showing again how easy it was to tell the difference between the two samples.

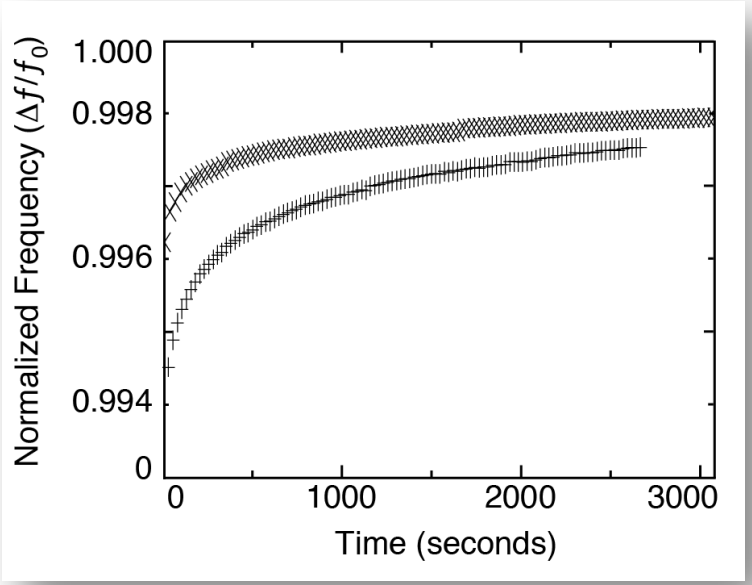


Clearly the nonlinear measurements had a lot to offer the Cement and Concrete Research community, or so we thought. We submitted the paper.

A novel and interesting non-destructive test but too much of a teaser and not enough real engineering science to appeal to our readers. The authors really need to set up an exhaustive suite of test samples and compare their nonlinear results with all the traditional testing we read about in this journal. Sounds like a good Ph.D. thesis in fact. However, in spite of the correlation between ASR Detect and these nonlinear tests, both are too new to give us any hint whether the technique will ever be useful. I cannot recommend it for publication.

Can the non-linear results be quantified, with something measureable like crack density? ASR detect is novel but also unknown and untested and cannot be used to validate the non-linear results shown here. I do not know these researchers, they have no reputation in concrete research. Their work is interesting but should be validated and compared with the standard concrete testing on the full 50 standard benchmark samples. I do not recommend publication.

This result showed up in an ISNA Proceedings and later in a PRL with Eric Smith with the suite of slow dynamics discussion and recoveries.



These techniques had been described in a patent application about the time of the R&D 100 award submission. One of us pushed the LANL patent office and got this through. RNUS?! Have a look at the figures we chose to use in this patent!

Date
December 18, 2001

Patent Number
6,330,827

James A. TenCate

INVENTOR

RESONANT NONLINEAR ULTRASOUND SPECTROSCOPY

The Commissioner of Patents and Trademarks has received an application for a patent for a new and useful invention. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.

Therefore, this

United States Patent

Grants to the person or persons having title to this patent the right to exclude others from making, using or selling the invention throughout the United States of America for the term of this patent, subject to the payment of maintenance fees as provided by law.

Acting Director of the U.S. Patent and Trademark Office

N.B. Guyer, Johnson, Van den Abeele were co-inventors

10 years later and we're looking to apply nonlinear NDE techniques to a different kind of concrete problem: