Comparison and Analysis of the Strength, Stiffness, and Damping Characteristics of Concrete with Rubber, Latex, and Carbonate Additives

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In

Civil Engineering

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June 27, 2011

Blacksburg, VA

Keywords: Damping, Concrete Admixtures, Rubber, Latex, Calcium Carbonate

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Title: Rubberized Portland Cement Concrete

Author: Zaher K. Khatib, Fouad M. Bayomy

Publication: Journal of Materials in Civil Engineering

Publisher: American Society of Civil Engineers

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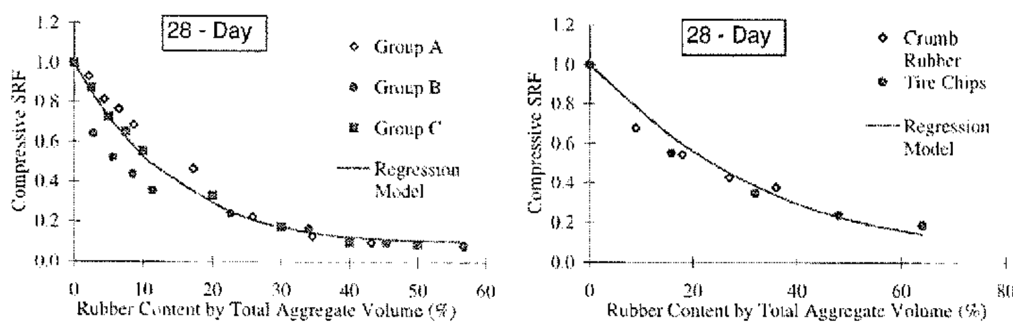
is obtained when plotting the SRF against the percentage of rubber content (Figure 3-1). The model was fit to both their data set as well as data from Eldin and Senouci (1993) with the results shown in Figure 3-1. Table 3-1 lists the model parameters for each set of data. It was found that the model parameters $a = 0.1$ and $b = 0.9$ fit both data sets while the sensitivity measure m differed.



a) Data from Khatib and Bayomy (1999) b) Data from Eldin and Senouci (1993)

Figure 3-1. Relationship of Compressive SRF and Rubber Content (From Khatib and Bayomy, 1999 p. 211; Reprinted with permission)

Table 3-1. Parameters for SRF Compressive Strength Model (Adapted from Khatib and Bayomy, 1999 p. 211; Reprinted with permission)

Researchers	Model Parameters	28-day Compressive SRF Model
Kahtib and Bayomy (1999)	a	0.10
	b	0.90
	m	7
	r^{2*}	0.93889
Eldin and Sencouci (1993)	a	0.10
	b	0.90
	m	3
	r^{2*}	0.963466

*r^2 's coefficient of determination

190

Due to the significant reductions in strength the researchers conclude that any practical rubberized concrete should be not exceed 20% of the total aggregate volume.

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Title: Rubber-Tire Particles as Concrete Aggregate

Author: Neil N. Eldin, Ahmed B. Senouci

Publication: Journal of Materials in Civil Engineering

Publisher: American Society of Civil Engineers

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Eldin, N. N., and Senouci, A. B. (1993). "Rubber-Tire Particles as Concrete Aggregate." *Journal of materials in civil engineering*, 5(4), 478-496.

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porosity reflects the fact that there is a level of porosity for which the compressive strength becomes zero. Popovics (1998) recommends a value of 60% be used for a_{cr}

Eldin and Senouci (1993) used this model to predict the compressive strength of concrete with rubber chips. The authors showed that because the strength of the rubber chips were very low, the model was acceptable by substituting the percentage of rubber for the variable a in Eq. 6-1. The model fit quite well as illustrated in Figure 6-1.

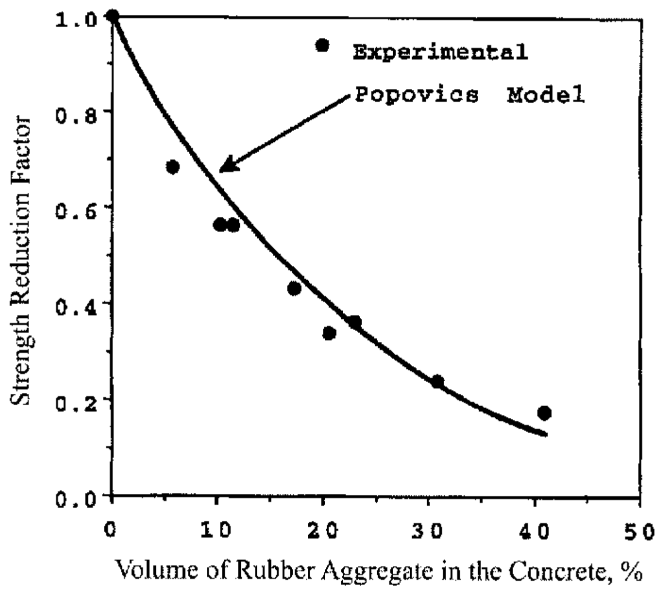

Figure 6-1. Comparison of Experimental Results with Eq. 6-1 (From Eldin and Senouchi ,1993 p. 494; Reprinted with permission).

A disadvantage to Eq. 6-1 is that it can only be applied to a single parameter for porosity (either air or rubber). Eldin and Senouci (1993) did not report air content in their study and only used rubber concentration as a measure of porosity.

One possibility for the inclusion of both rubber and air as parameters would be to use Eq. 6-2

Adam Bowland

From: Brad Davis <bdavis@engr.uky.edu>
Sent: Thursday, June 30, 2011 6:29 PM
To: 'Adam Bowland'
Subject: RE: Greetings from Blacksburg

FIGS FROM ANOTHER VPI DISSERTATION

PERMISSION FOR FIGS 7-10
7-21
7-28
7-29
7-30

Adam,

Congratulations and I hope your new job goes well.

You can certainly use those figures. Just in case you need additional references, the force glitch is covered in great detail in the following paper. Also, the DLFs are in Davis and Murray (2010) AISC NASCC presentation which is available online (they don't have proceedings other than that).

Davis, D.B., Barrett, A.R., and Murray, T.M. "Use of a Force Plate Versus Armature Accelerometer for Measuring Frequency Response Functions," *Experimental Techniques*, January/February 2011.

Keep in touch! I'd love to have a copy of your dissertation pdf file if you don't mind sending it.

DBD

From: Adam Bowland [mailto:abowland@vt.edu]
Sent: Thursday, June 30, 2011 11:54 AM
To: bdavis@engr.uky.edu
Subject: Greetings from Blacksburg

Brad,

I hope all is going well at Kentucky. I am in the process of finishing up my Dissertation (I successfully defended on Monday!) and I need to get your permission to use some figures from your dissertation.

Davis, B. (2008). "Finite Element Modeling for Prediction of Low Frequency Floor Vibrations Due to Walking." *VPI & SU. Civil Engineering. Ph. D. 2008.*, University Libraries, Virginia Polytechnic Institute and State University, Blacksburg, Va.

I would like to use the following 5 figures which I have attached in 2 PDF documents.

1) Comparison of the force autospectrum measured using a force plate and an accelerometer on the armature mass (p. 25)

2-5) The DLF amplitude plots showing the DLF data and equations for the first –fourth harmonics on pages 182 -183 of your paper.

I have accepted a consulting job at Digioia Gray and Associates in Pittsburgh and will be starting in about a month. It is such a relief to finally be finished!

Adam Bowland

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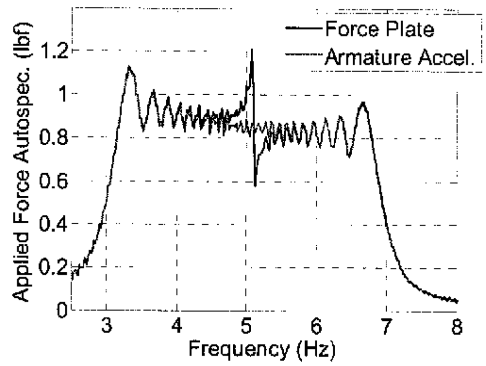

Figure 7-10. Force Autospectrum Measured using a Force Plate and an Accelerometer on the Armature Mass. (From Davis, 2008 p. 25: Reprinted with Permission)

A burst chirp with a frequency range of 4 Hz to 15 Hz was selected so that the natural frequencies of the footbridges (estimated to be around 9 Hz) would be included in the sweep. Only the fundamental mode of vibration was of interest and limiting the chirp signal to 15 Hz did not allow higher frequency modes to be excited.

The FRF for each DOF was measured by averaging the results from three separate burst chirp tests. Each FRF had a bandwidth of 20 Hz with a frequency resolution of 0.05 Hz. The decision on the number of averages and the frequency resolution was driven by the time it took to complete the tests. Using more averages or a finer resolution would provide higher quality of data at the expense of time. For these tests, it was deemed important to test both footbridges on the same day to limit the effects of environmental factors such as temperature and extraneous noise caused by other constantly changing actives in the lab.

The modal properties were obtained in the following sequence. First a series of modal tests were conducted by keeping the shaker at the quarter-span and measuring the acceleration response at different points along the footbridge. The DSP unit had the capability to record 4 measurements per test: the force input and acceleration at the driving point and two points along

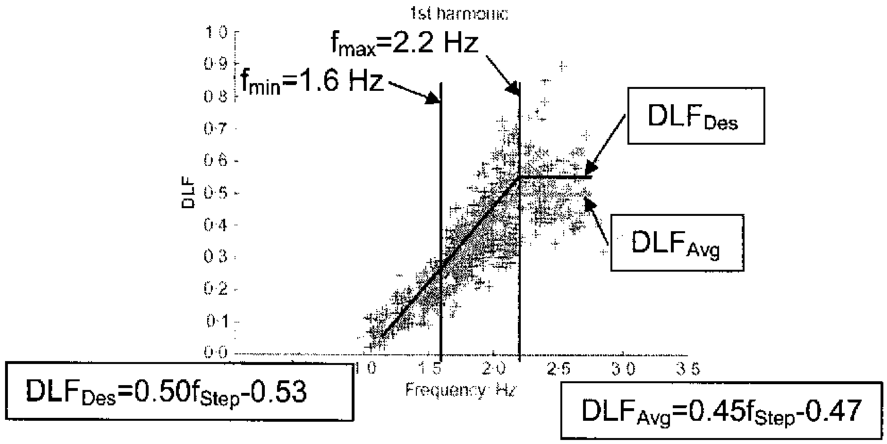

Figure 7-27. First Harmonic DLF Amplitudes (From Davis 2008 p. 182: Reprinted with Permisison).

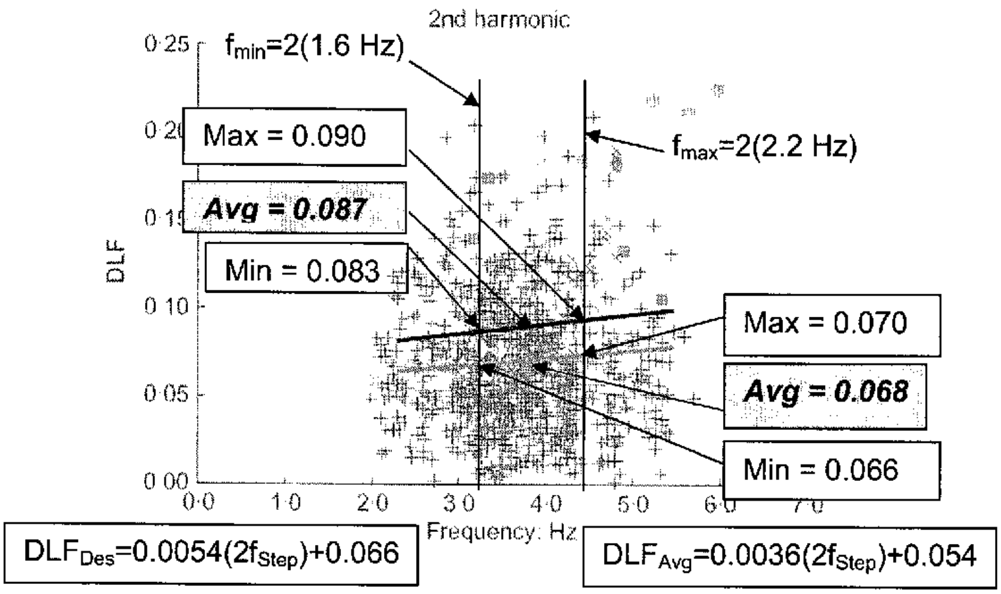

Figure 7-28. Second Harmonic DLF Amplitudes (From Davis 2008 p. 182: Reprinted with Permission).

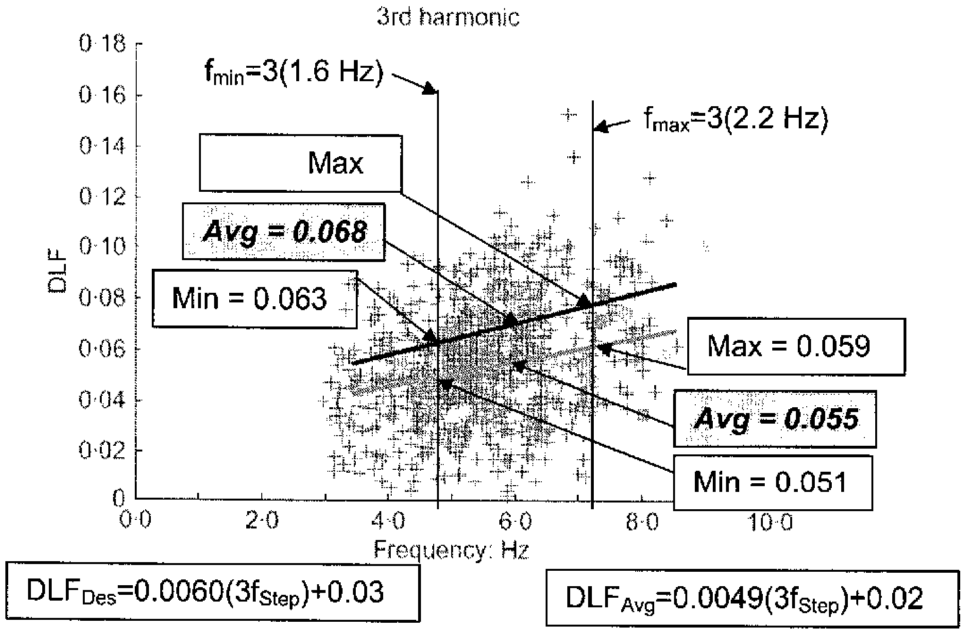

Figure 7-29. Third Harmonic DLF Amplitudes (From Davis 2008 p. 183: Reprinted with Permission).

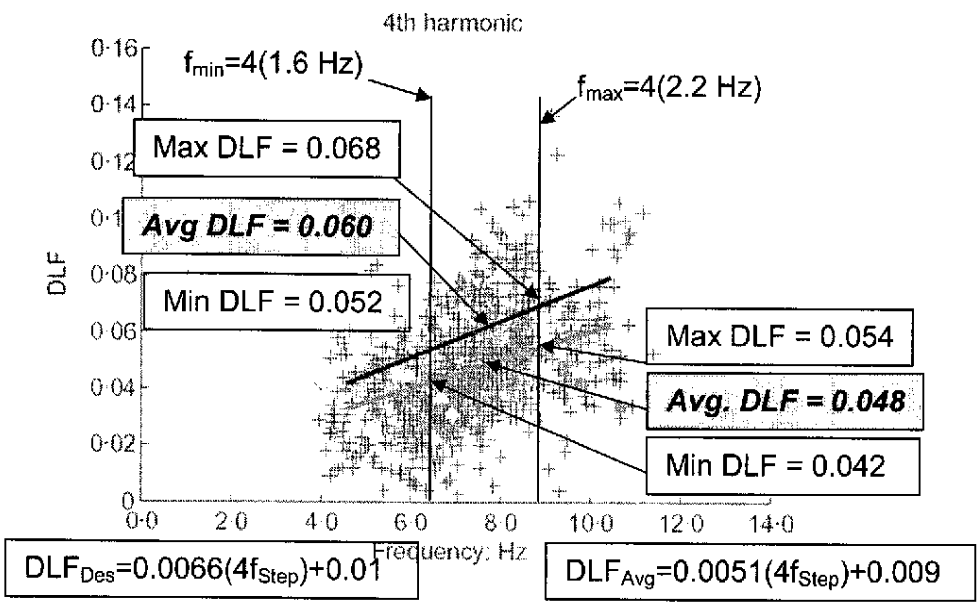

Figure 7-30. Fourth Harmonic DLF Amplitudes (From Davis 2008 p. 183: Reprinted with Permission).