SFSI
PRESSURE CELL

STATIC & DYNAMIC CALIBRATION REPORT

February 26, 2004

Sensor acceleration sensitivity experiment

Background

Acceleration sensitivity of a pressure sensor plays a significant role on accuracy of the result of dynamic tests and particularly in circumstances that the sensor itself is subject to move, too. Our first set of experiments were conducted with the diaphragm-type of sensors from SENSOTEC which turned out to be fairly sensitive to acceleration and frequency range of our interest and made us curious enough to perform a few sets of experiments to measure the acceleration sensitivity of the sensors in 3 different directions.

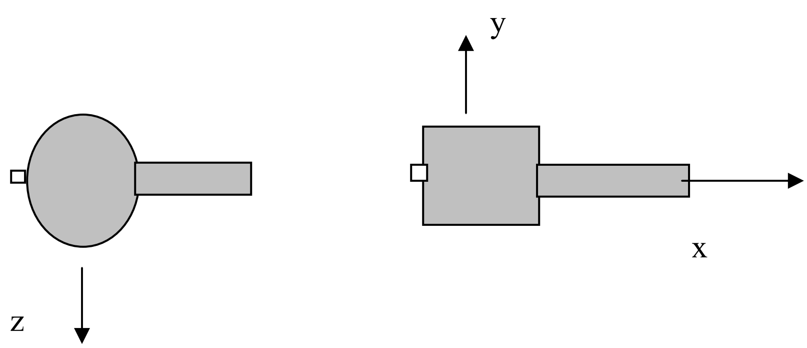
Experiment conditions

Considering all the possibilities in terms of having the sides full of liquid or air, we had to try out all the alternatives in different directions to find the least sensitive case possible. Sensor was firmly connected to the bracket on the top of the shaker and while was subject to vertical oscillation (with frequency of 1,10 and 50 Hz) the output voltage of the accelerometer and the pressure sensor were simultaneously recorded through channel (0) and (24) of our SFSI data acquisition system.

Analysis

Measuring the peak to peak amplitude of the acceleration and the sensor whilst the sensitivity of the system is set to 981 (to give us output in Volts), the results were meticulously measured and analyzed.

Knowing the sensitivity of the sensor (Sa=2.5 [Volts/100psi] as stated on manufacturer catalogue), we could simply compute the effect of the vibration on the output of the pressure transducer. Obviously the most critical direction would be the plane perpendicular to the diaphragm which is represented as Y direction throughout this report.



Freq.[Hz]	Sensitivity[psi/g]	Direction	Filter cutoff freq.
1	0.01189	x	5
10	0.0733	x	20
50	0.3	x	100
1	0.1	y	5
10	0.1	y	20
50	0.118	y	100
1	0.007995	z	5
10	0.0348	z	20
50	0.04	z	100

Table_ A : acceleration sensitivity result; both side Air

Freq.[Hz]	Sensitivity[psi/g]	Direction	Filter cutoff freq.
1	N/A	x	5
10	N/A	x	20
50	N/A	x	100
1	0.0896	y	5
10	0.098748	y	20
50	0.0987	y	100
1	N/A	z	5
10	N/A	z	20
50	N/A	z	100

Table_B : acceleration sensitivity result; one side air/one side liquid

Why Entran's PX model?

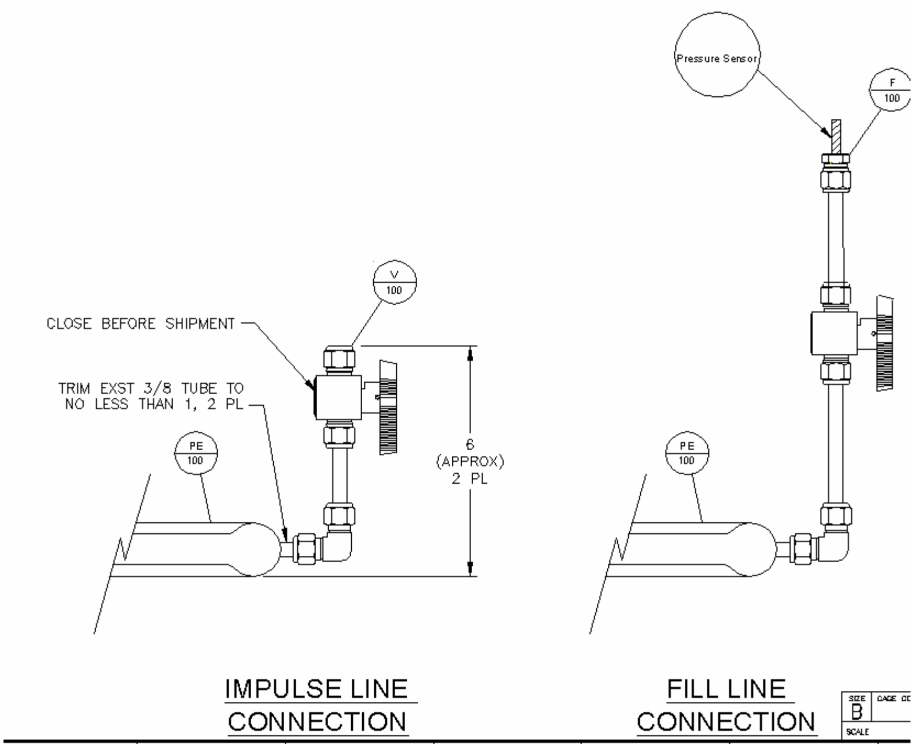
As we could expect from the mechanism of the sensor, the tabulated results computed for different frequencies didn't fall into an acceptable range. Next step, therefore, would be looking for an appropriate sensor with lower acceleration sensitivity; perhaps different working mechanism as well. Several types of products from different companies were studied and finally Entrans'n EPX model turned out to be a good practical choice.

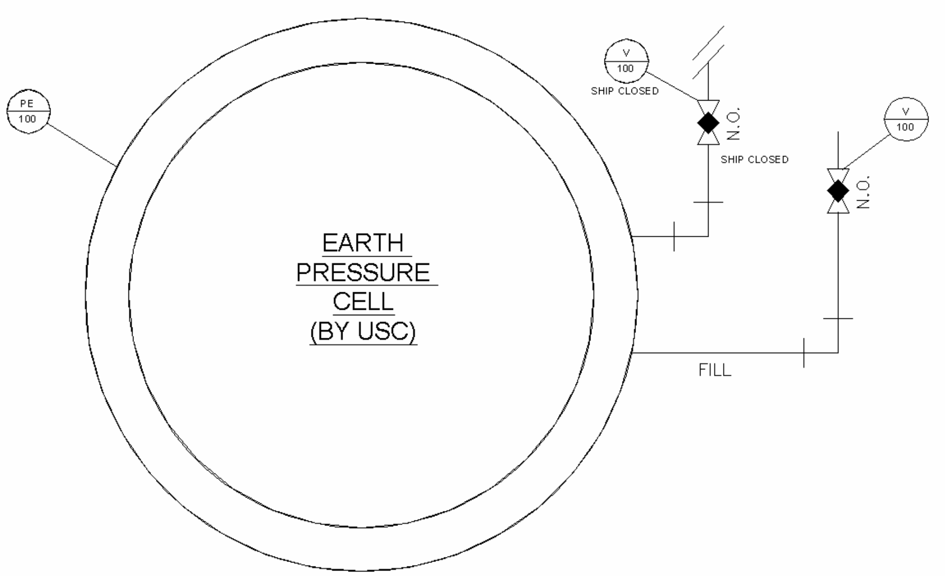
Entran's EPX pressure sensor has a unique design based on mounting ease and flexibility. The EPX offers an optimum combination of characteristics which permit static and dynamic pressure measurements when small size is of prime importance. Its beam welded stainless steel diaphragm, 10-32UNF or M5 metric thread and built-in O-ring seal allow simple mounting to test objects and use in corrosive media.

More detailed specification of the sensor will be available at
http://www.entran.com/epx.htm

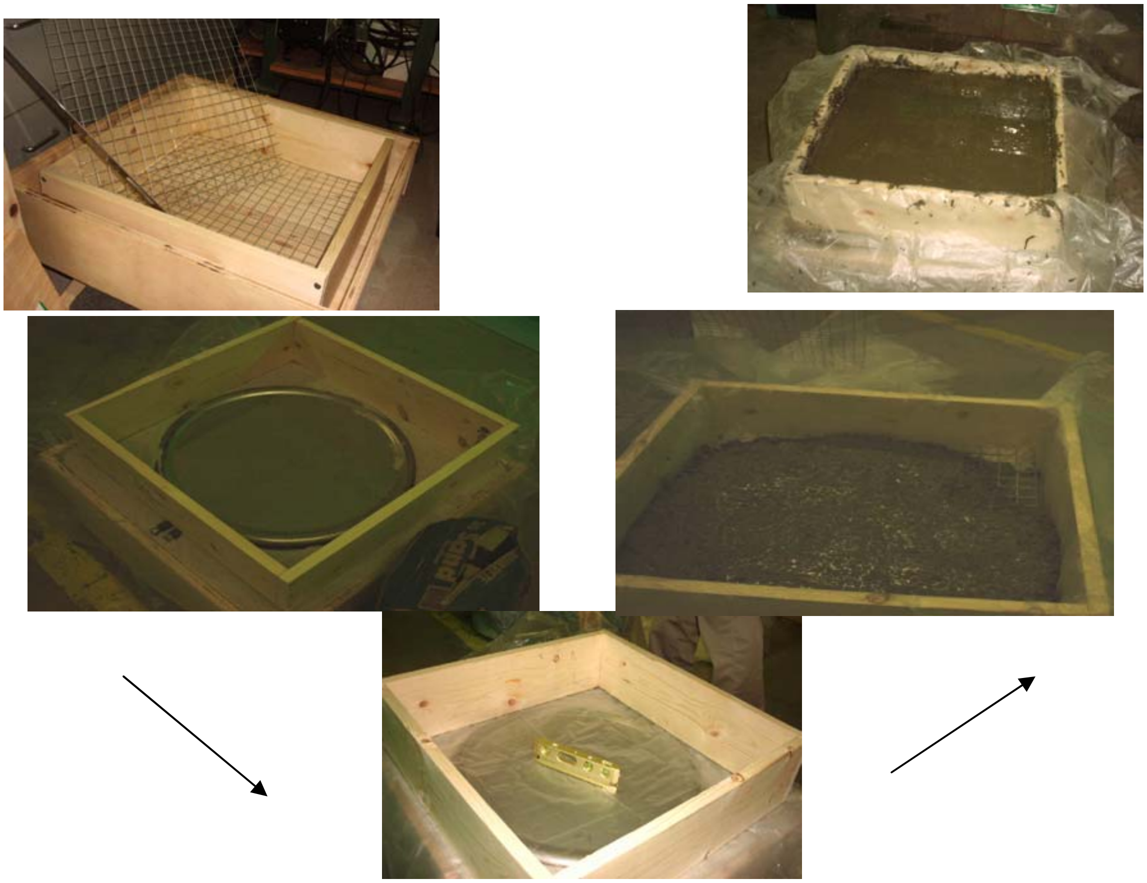
FAQ:

Q: What Fluid we used for the experiment?
A: Ethylene Glycol,
Q: Why Ethylene Glycol?
A: Not corrosive, convenient to work with, consistent physical characteristics at reasonable temperature range.
Q: Why dig a ring in sand?
A: To have just flat surface of the cell be in contact with the sand to get effective area.
Q: Why change the internal pressure in the system and how?
A: To see how consistent the whole system respond under different pressure level, and it can be obtained by changing the level of funnel by which the system is filled up with.
Q: Why you might need bridge sensor?
A: The Output voltage of some transducers (e.g. the Entrant's sensor we used) is required to be amplified to be more handy to be studied.
Q: What is the static weight we loaded the system up to?
A: 430 Kg.
Q: What type of shaker we used?
A: The APS Electro-Seis shaker with reaction mass
Q: What Soft-wares were used for the analysis?
A: DIGITEXX data viewer, MATLAB and excel

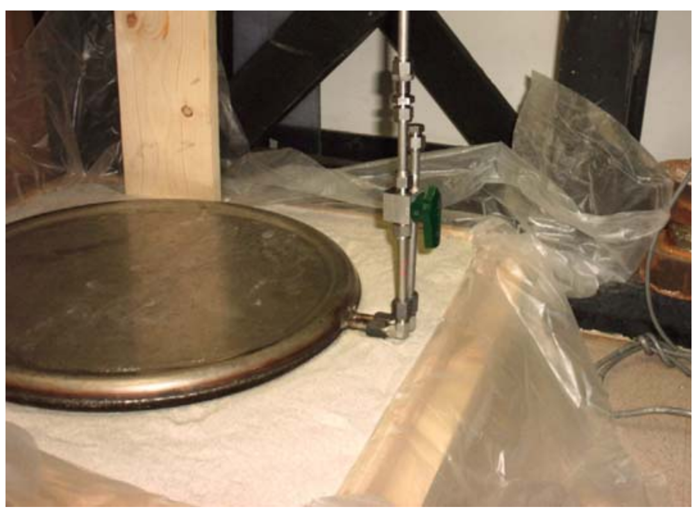




CAD drawing of pressure system, tubing and connections

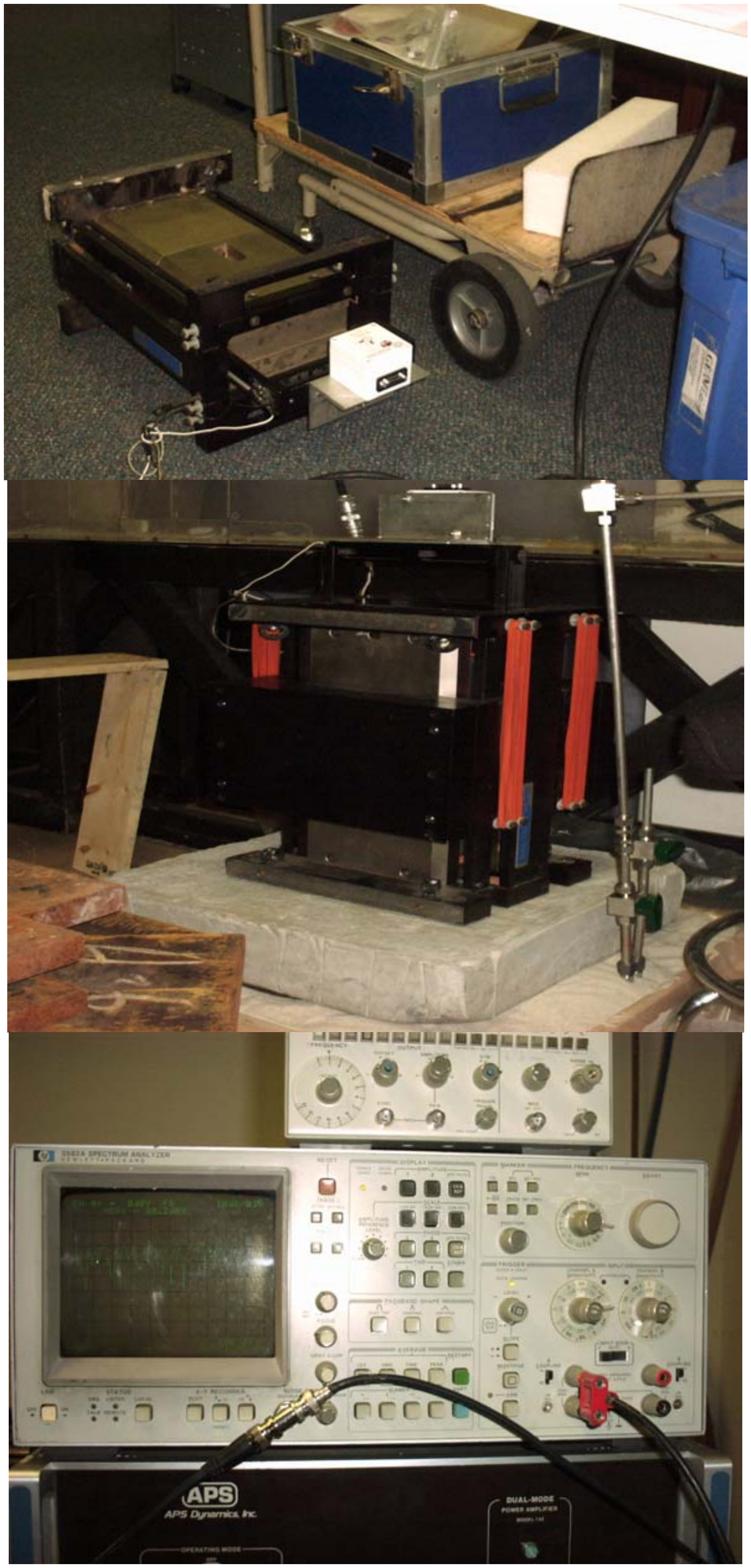


Preparation of wooden box, forming and concrete block at the lab

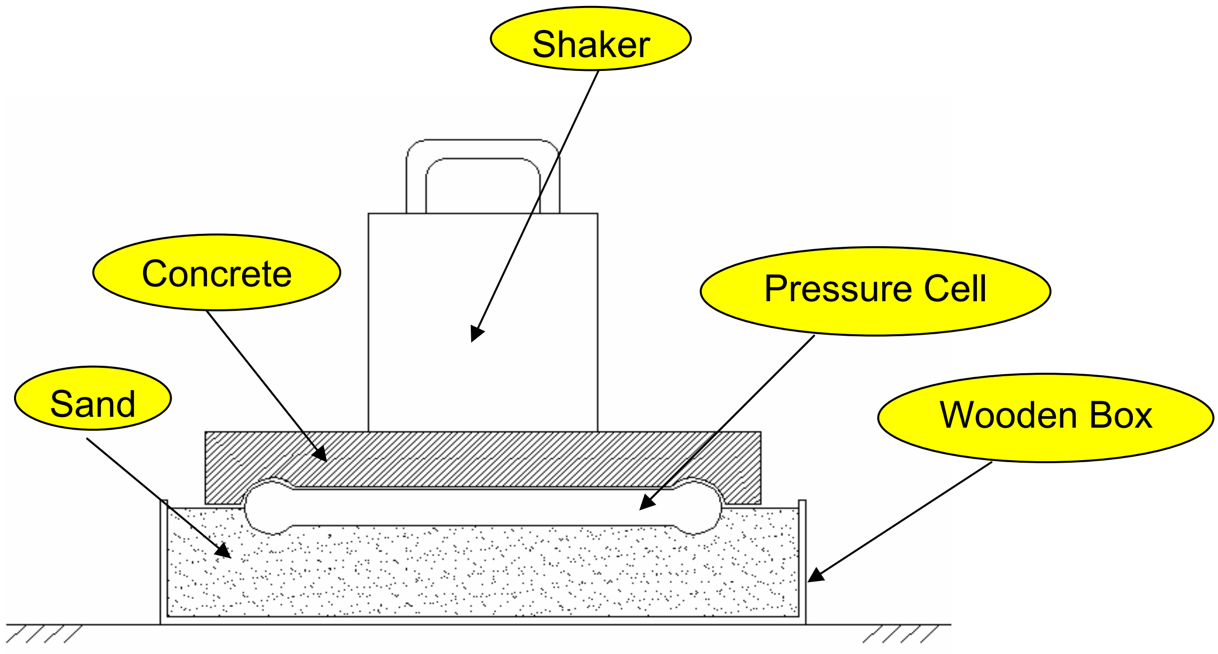


Pressure system, primary setup

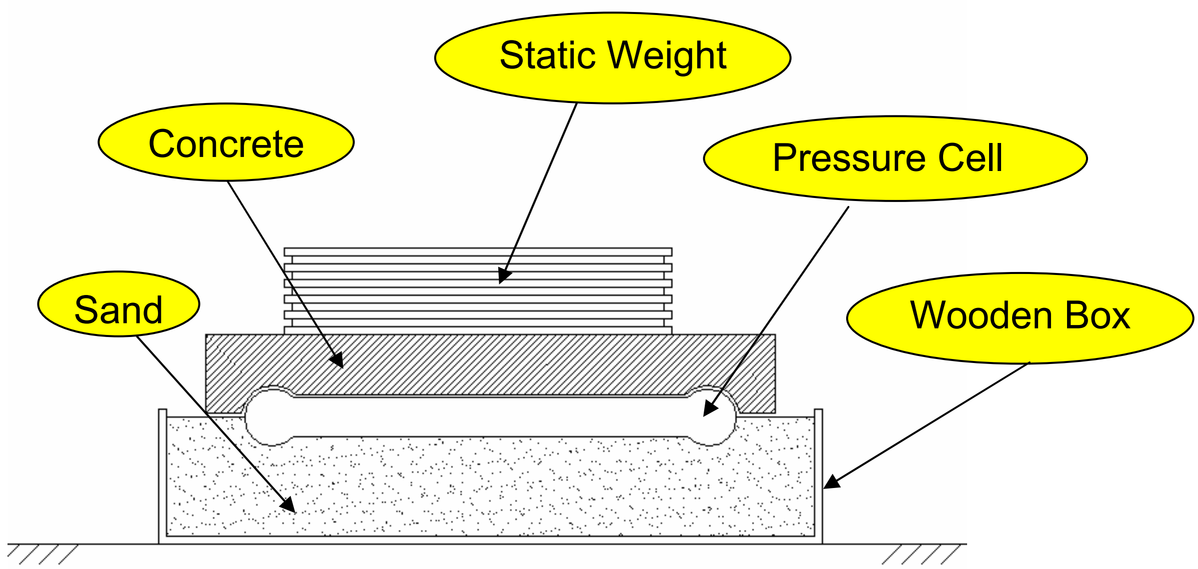
Static calibration system / data recording



Shaker setup, dynamic calibration and spectrum analysis system



Schema of Dynamic Calibration Test Setup



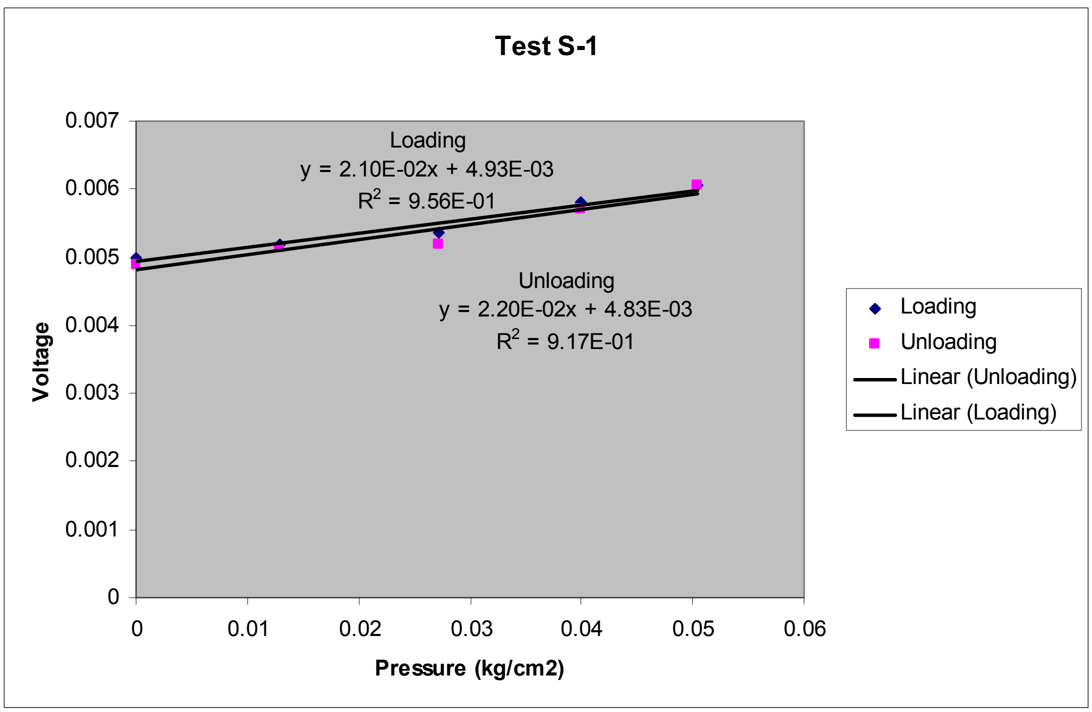
Schema of Static Calibration Test Setup

1) Pressure Sensor (S/N 04A03F05-K10)

a) Static Calibration:

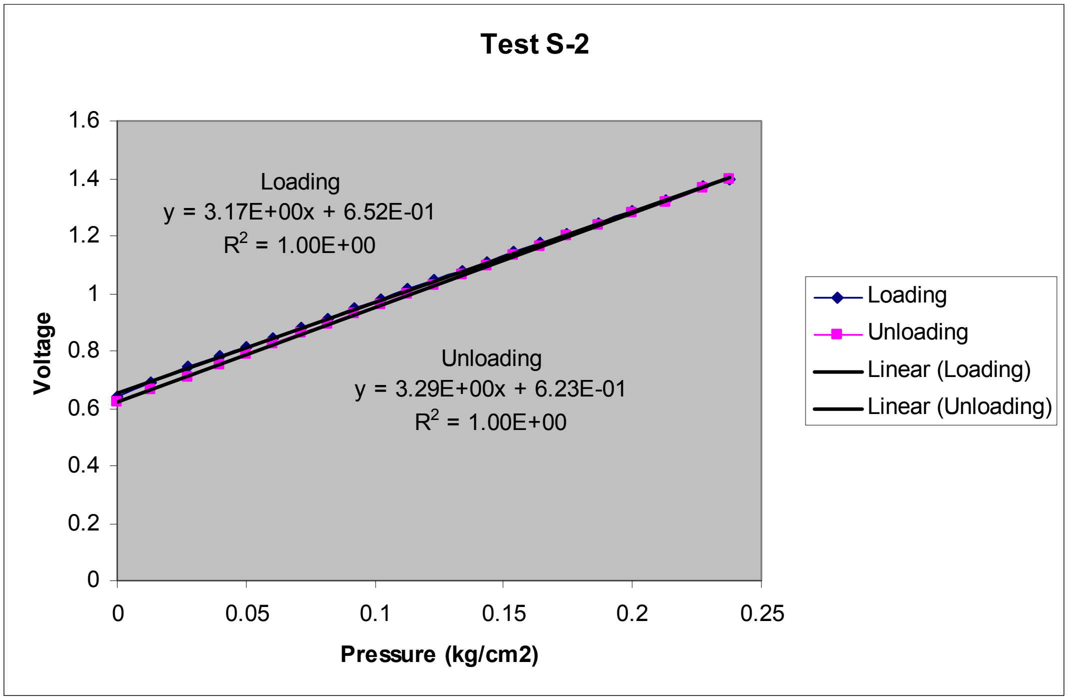
Test S-1 (02/02/2004):

Loading up to 91.1 kg and Unloading (Smoothed sand underneath). This was the first static test after installing "Entran" pressure sensors.



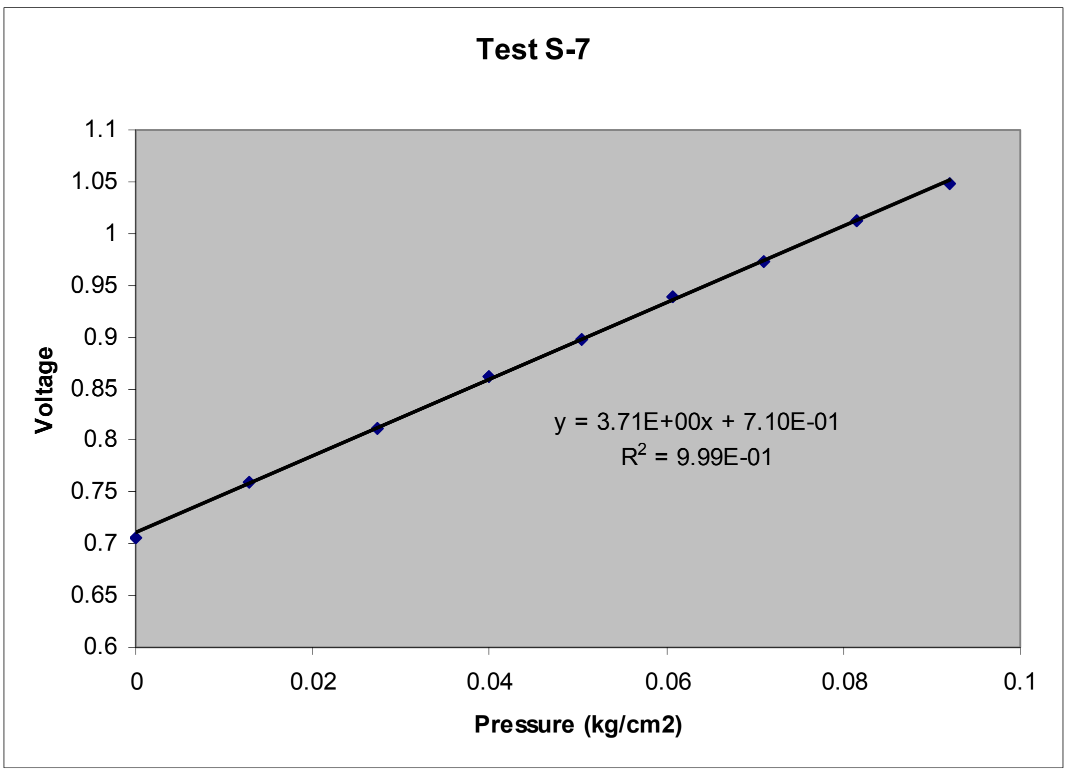
Test S-2 (02/06/2004):

This test was done after bridge sensor calibration (amplification factor=100). In order to do this test, we took off the shaker and concrete, cleaned the cell and smoothed the sand underneath. We did complete loading and unloading (up to 430kg).



Test S-7 (02/20/2004):

Loading up to 166.3 kg (after digging a ring underneath the pressure cell).



b) Dynamic Calibration:

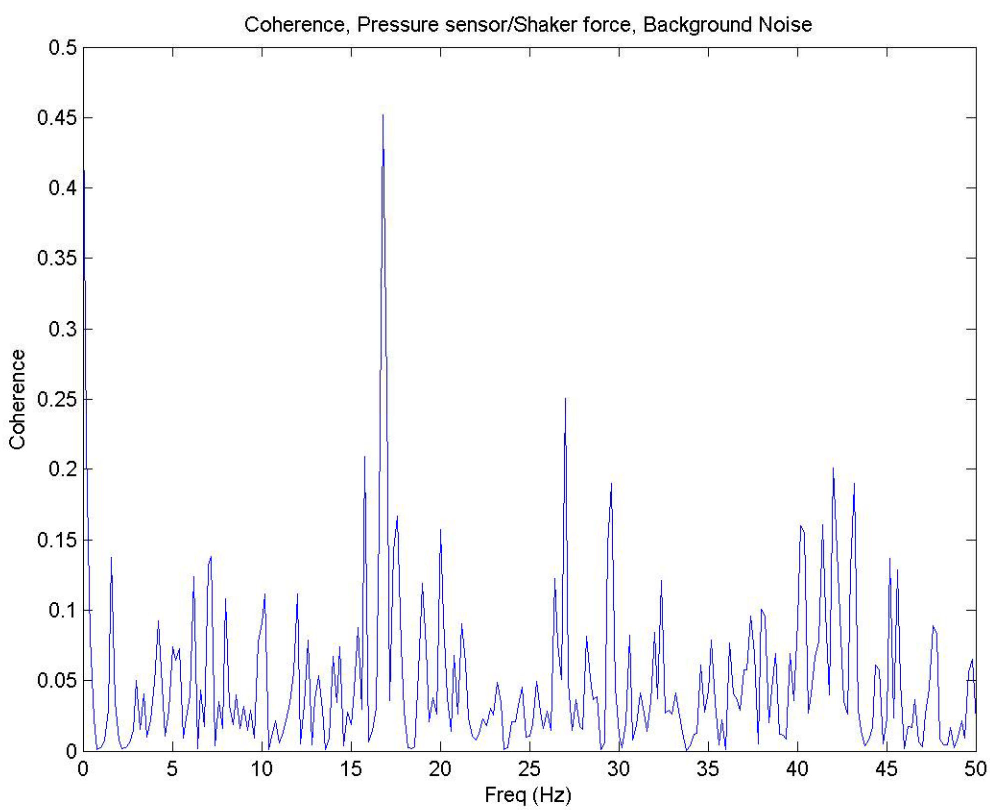
To study the dynamic response of the whole system, after analyzing the output of the sensor for each frequency, the spectrum of the system is demonstrated as follow:

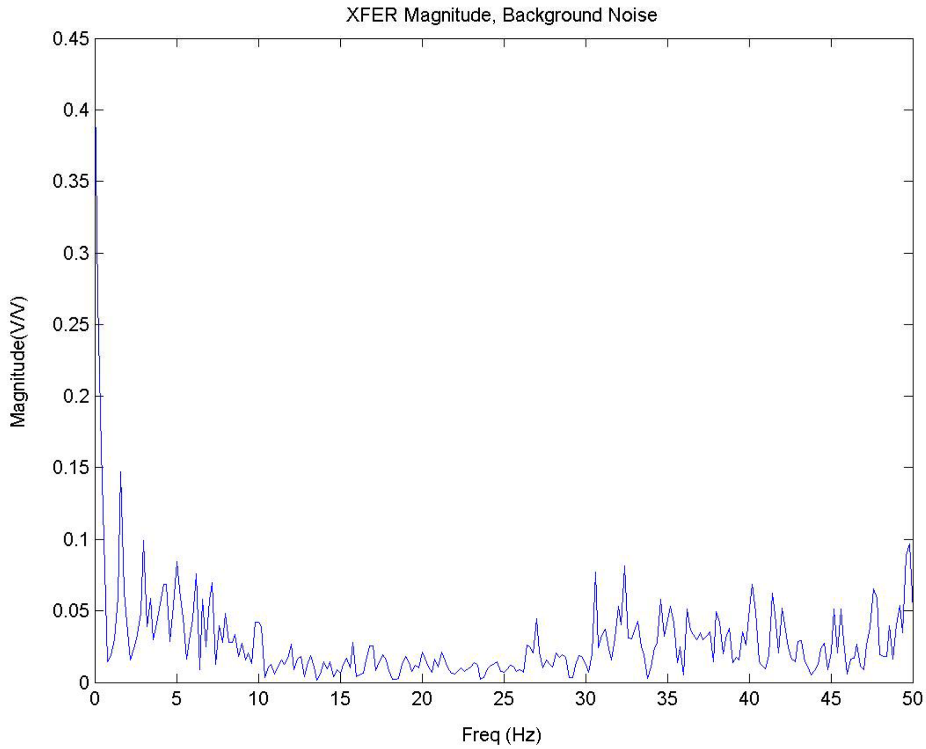
Test D-1 (02/02/2004):

We did this test while we had smoothed sand underneath the pressure cell.

i) Background Noise:

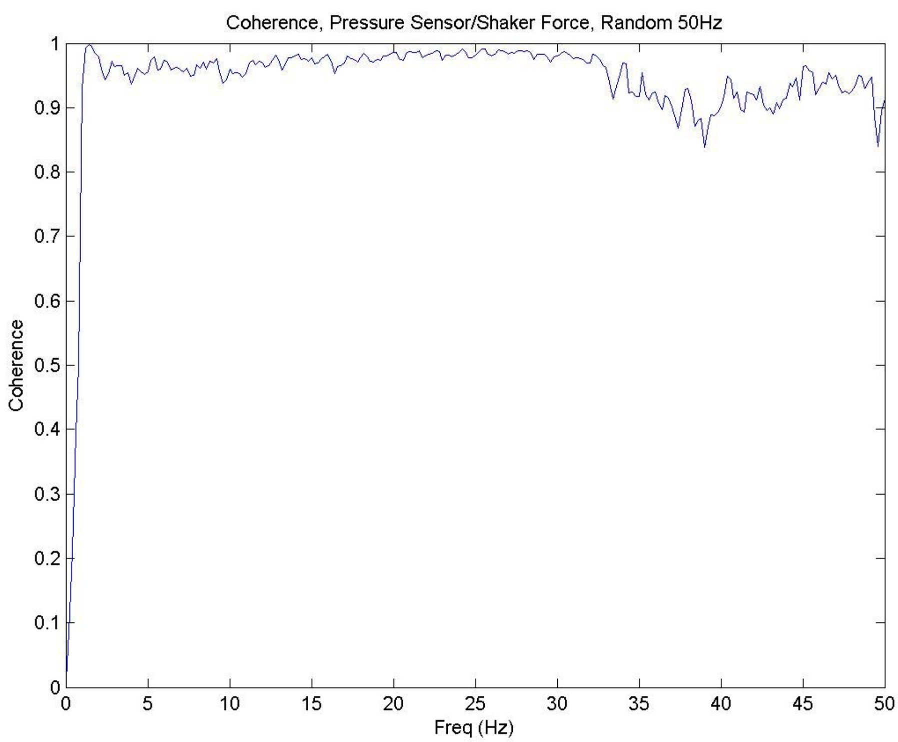
In this test we recorded the background noise for 1 min.

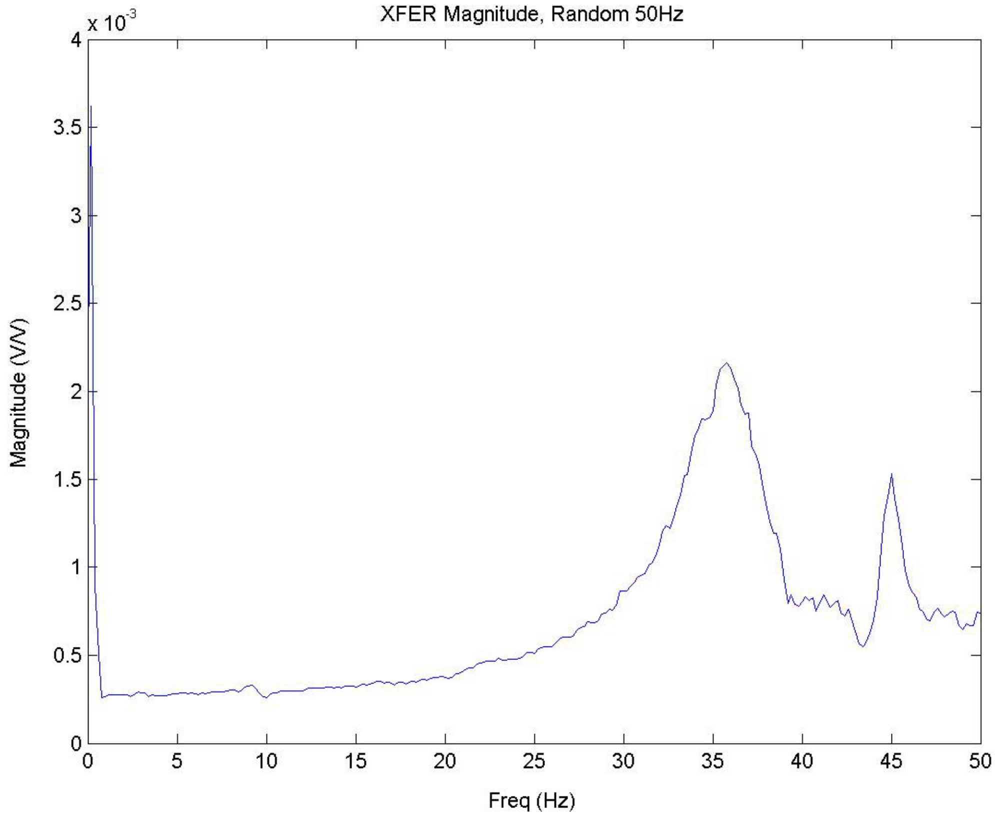




ii) Random 50Hz:

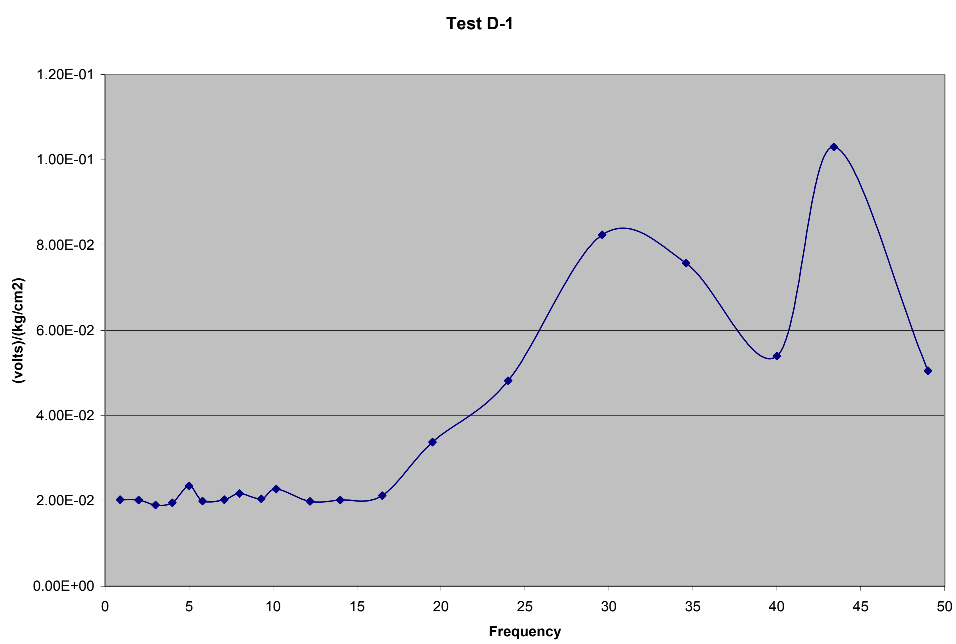
In this test, we recorded the Pressure and Acceleration for 1 min while the system was under random vibration up to 50Hz.



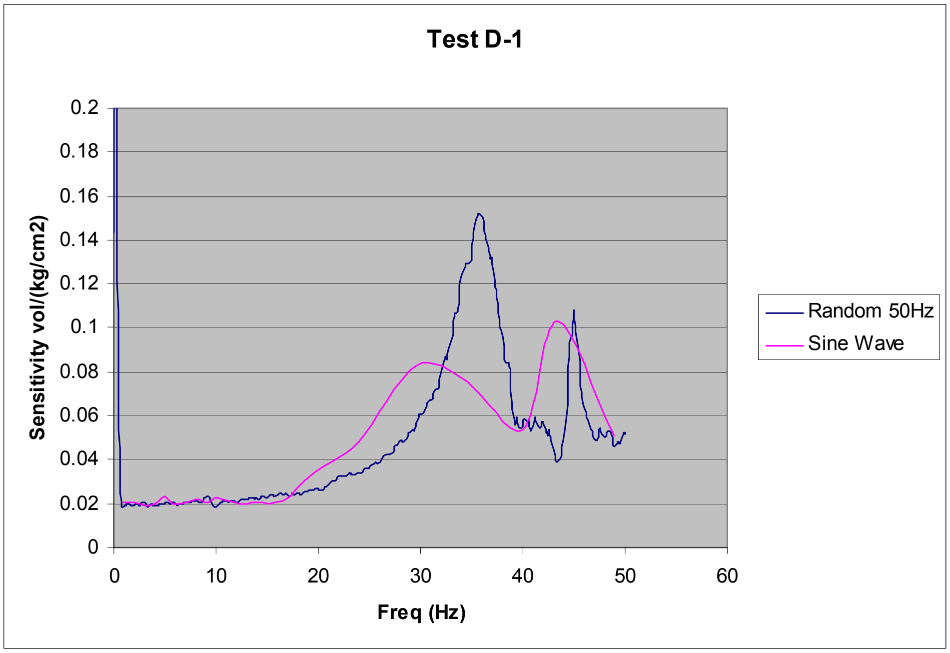


iii) Sine Wave:

In this test, we recorded the Pressure and Acceleration while the system was under sine waves from 1 to 50 Hz.



iv) Comparison between the Random 50Hz and Sine Wave results:

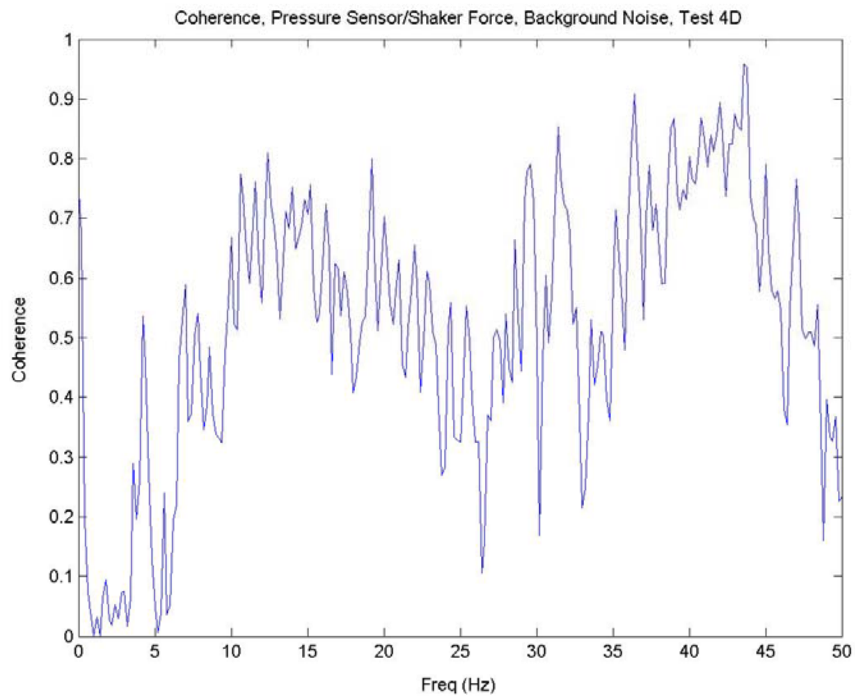


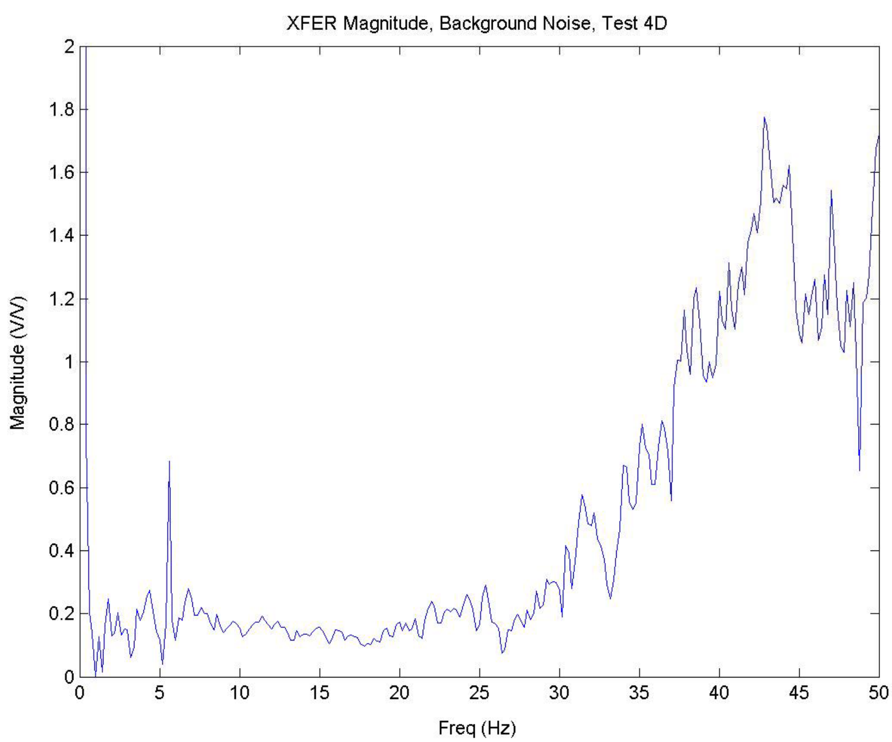
Test D-4 (02/24/2004):

We did this test after digging a ring underneath the pressure cell.

i) Background Noise:

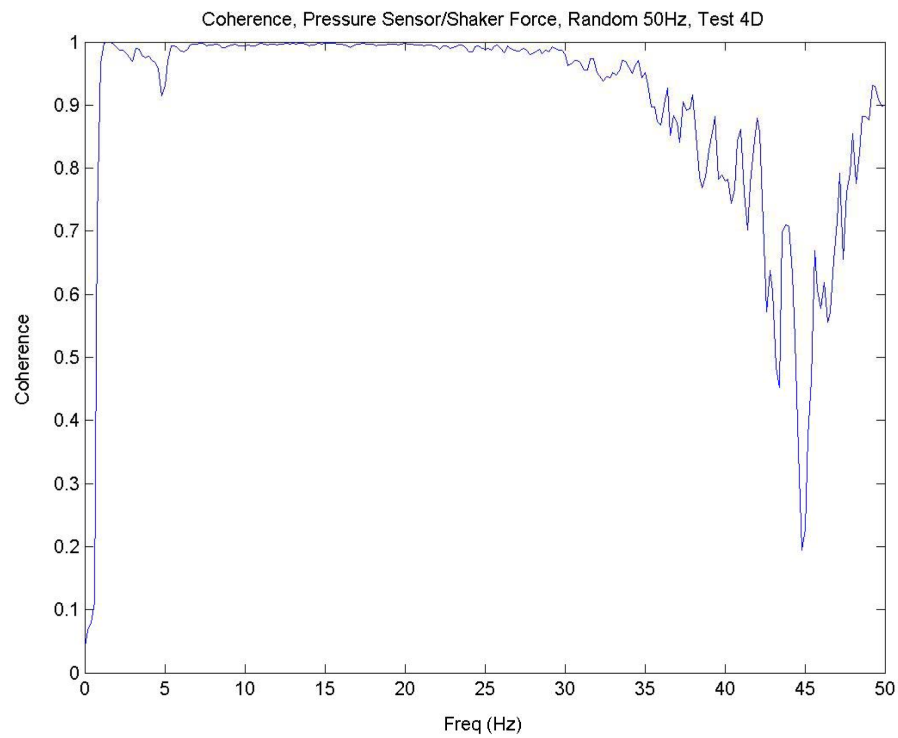
In this test we recorded the background noise for 1 min.

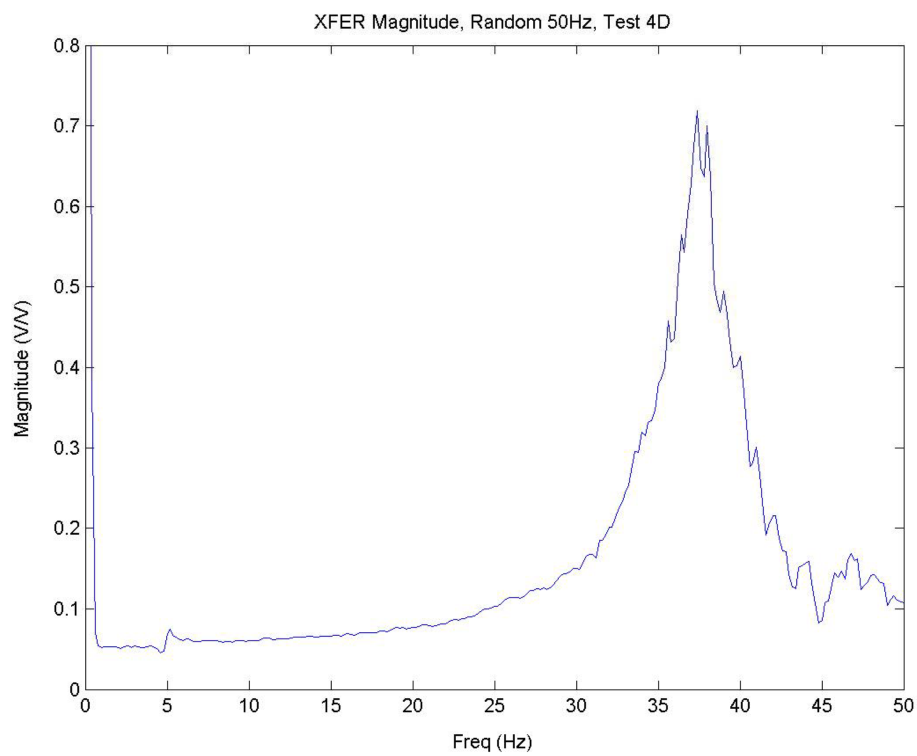




ii) Random 50Hz:

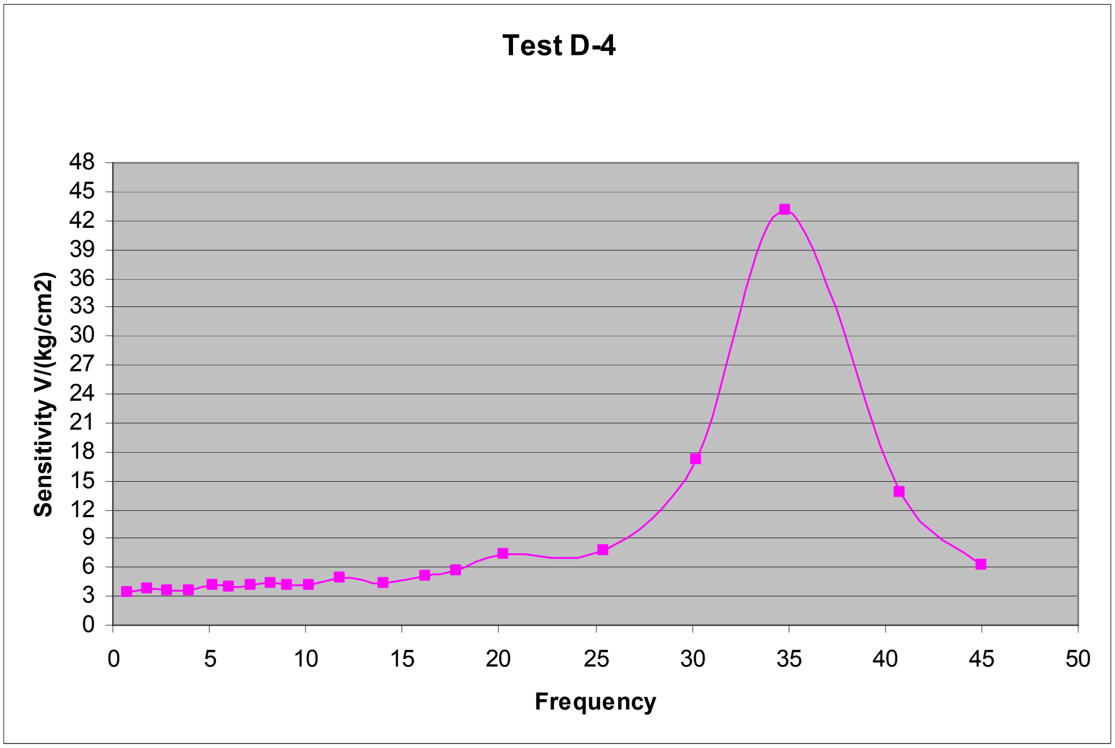
In this test, we recorded the Pressure and Acceleration for 1 min while the system was under random vibration up to 50Hz.



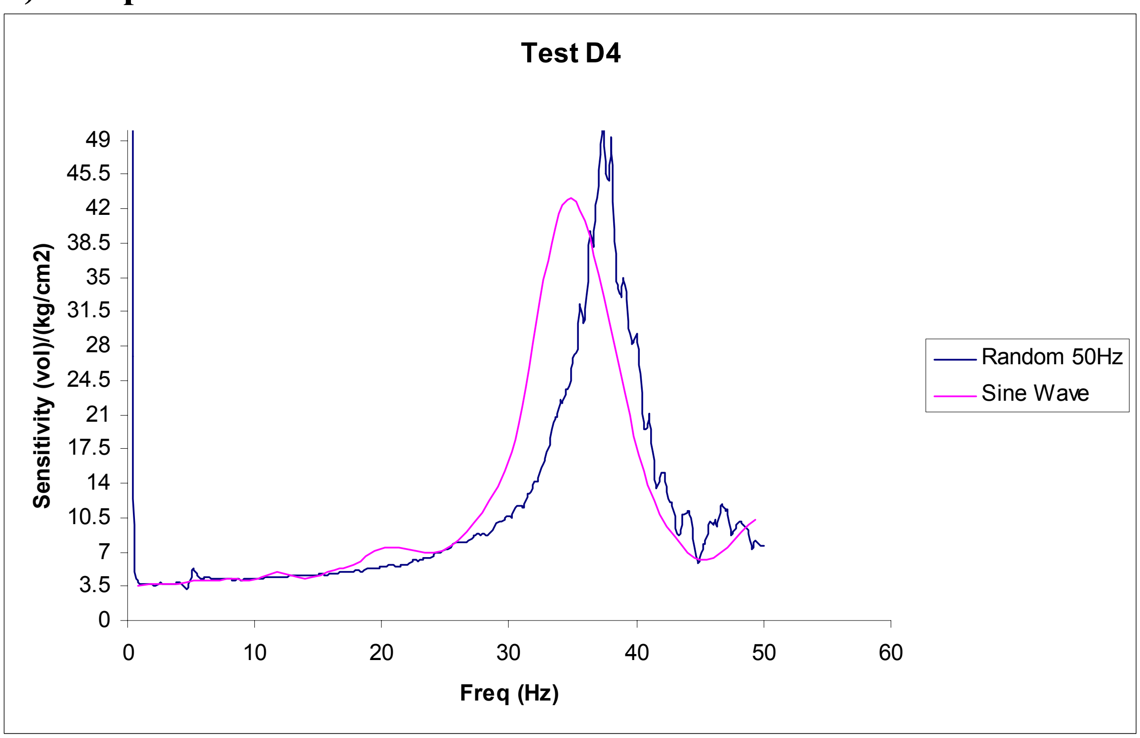


iii) Sine Wave:

In this test, we recorded the Pressure and Acceleration while the system was under sine waves from 1 to 50 Hz.



iv) Comparison between the Random 50Hz and Sine Wave results:

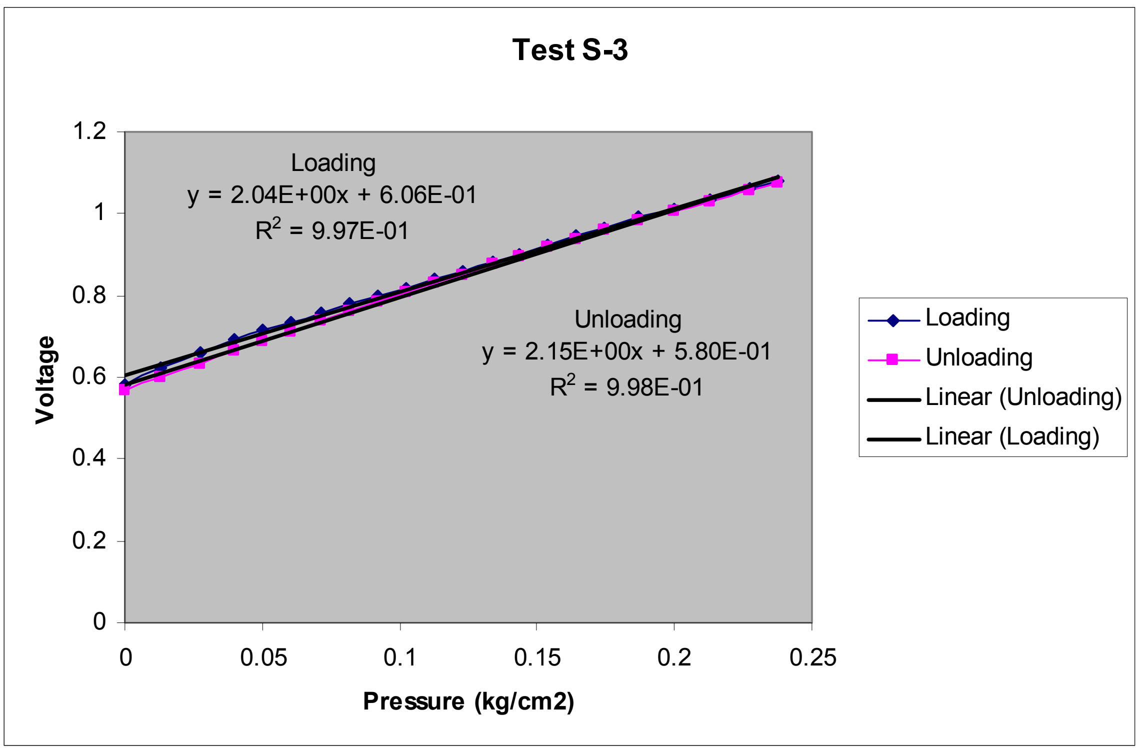


2)Pressure Sensor (S/N 04A03F05-K09)

a) Static Calibration:

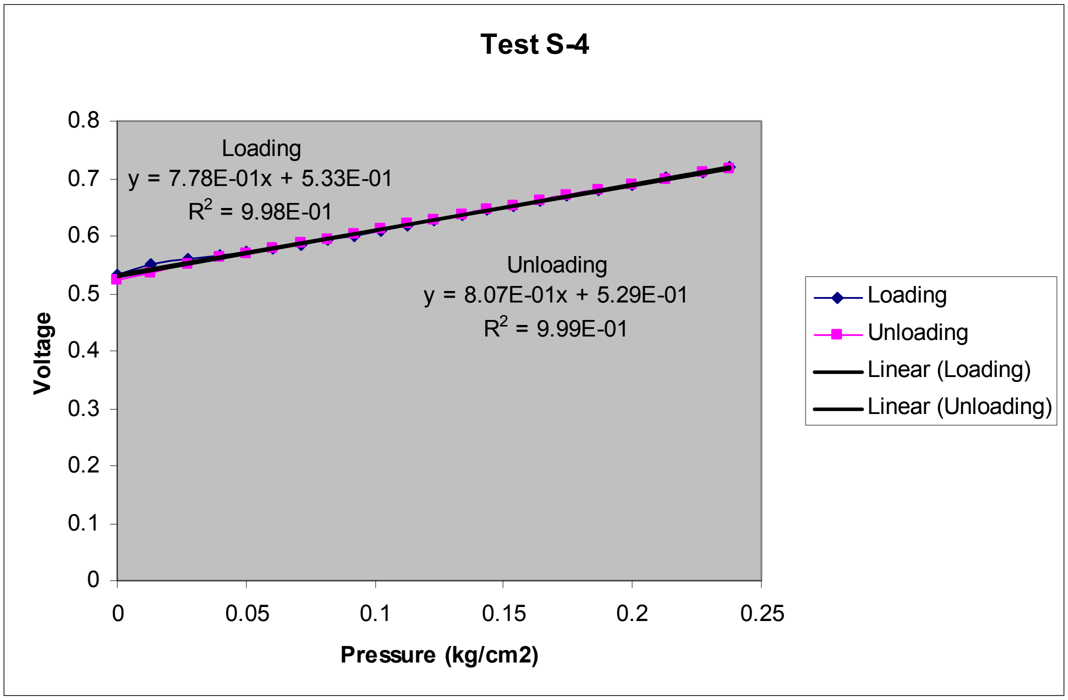
Test S-3 (02/12/2004):

Loading up to 430 kg and unloading (smoothed sand underneath). This test was done after bridge sensor calibration (amplification factor=100). The main goal of this and the next two tests, was to see the effect of the sand shape underneath the cell on the sensitivity of the system. As a result, before doing this test we removed the cell and concrete, smoothed the sand and put the cell and concrete back.



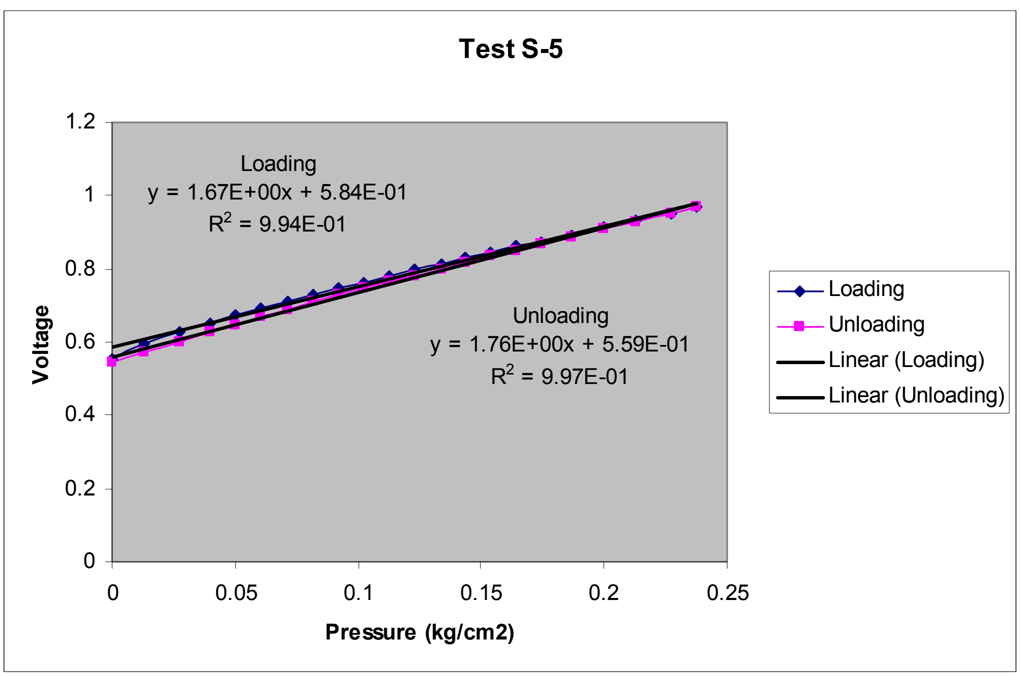
Test S-4 (02/12/2004):

Loading up to 430 kg and unloading (smoothed sand underneath), see the description of test S-3.



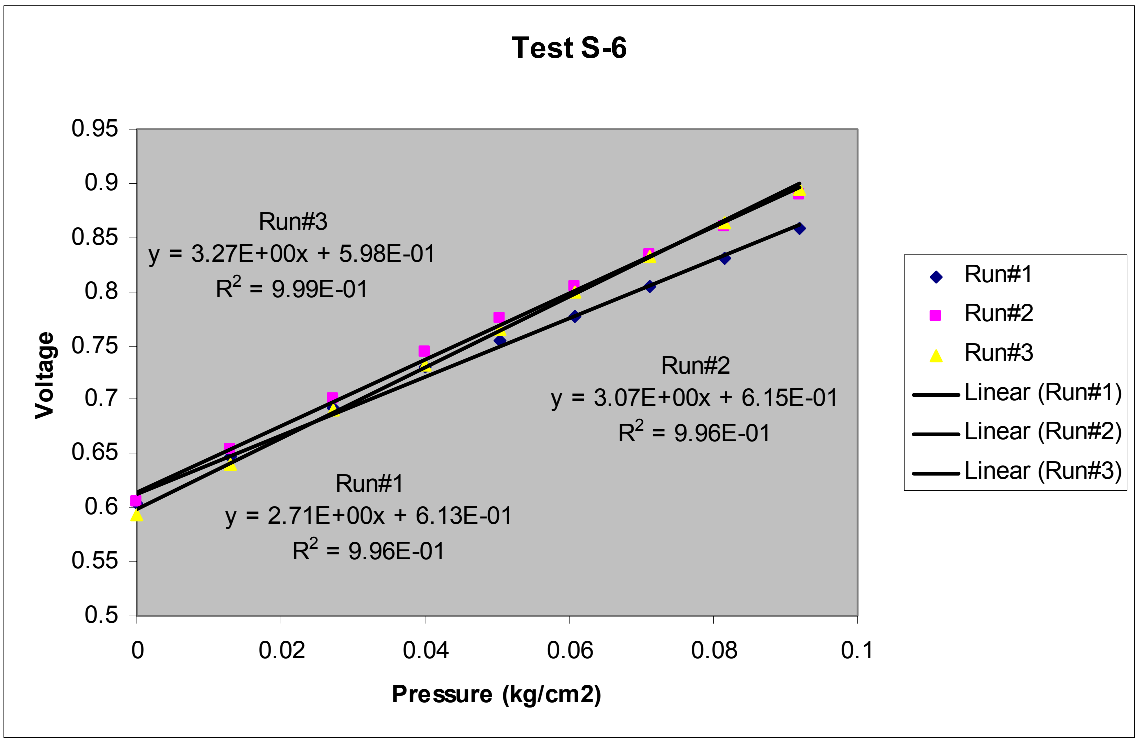
Test S-5 (02/12/2004):

Loading up to 430 kg and unloading (smoothed sand underneath), see the description of test S-3.



Test S-6 (02/17/2004):

Loading up to 166.3 kg (after digging a ring underneath the pressure cell). In order to do this test, we took off the concrete and pressure cell, dug a ring underneath and put the cell back. Then we released the internal pressure of the system. We repeated this test three times.



b) Dynamic Calibration:

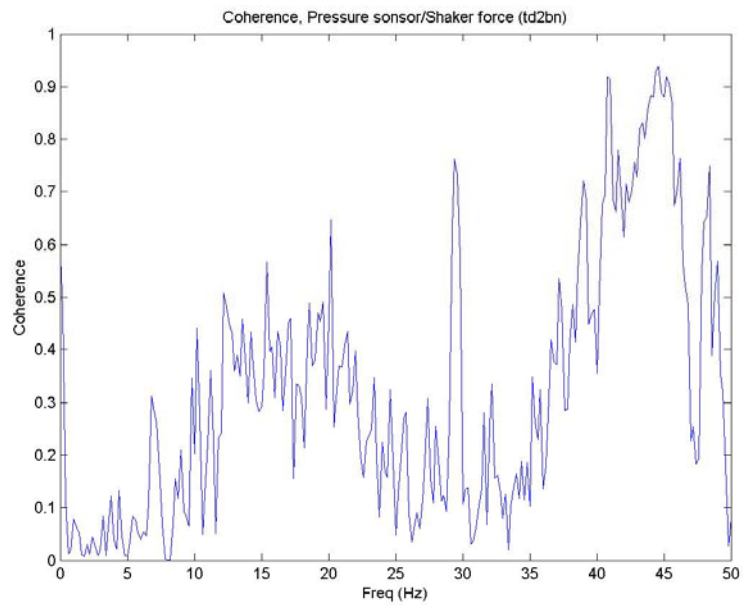
To study the dynamic response of the whole system, after analyzing the output of the sensor for each frequency, the spectrum of the system is demonstrated as follow:

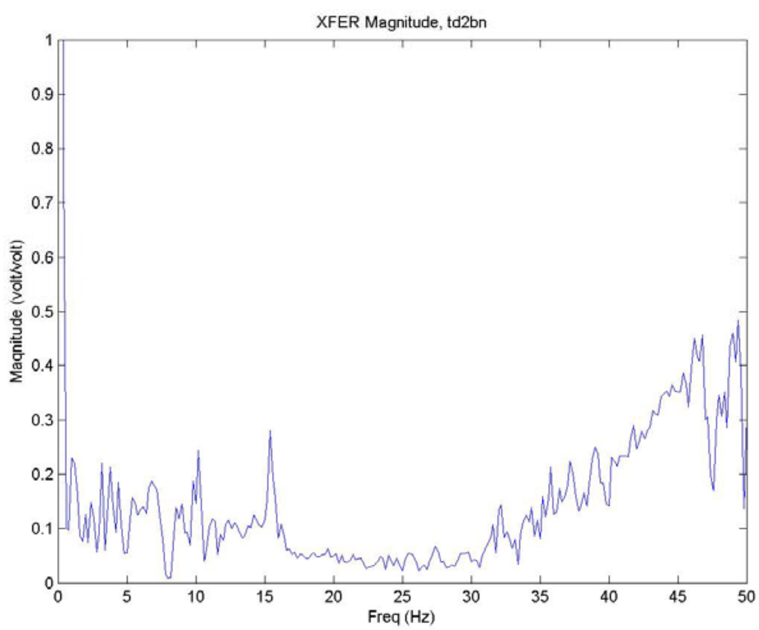
Test D-2 (02/06/2004):

We did this test while we had smoothed sand underneath the pressure cell.

i) Background Noise:

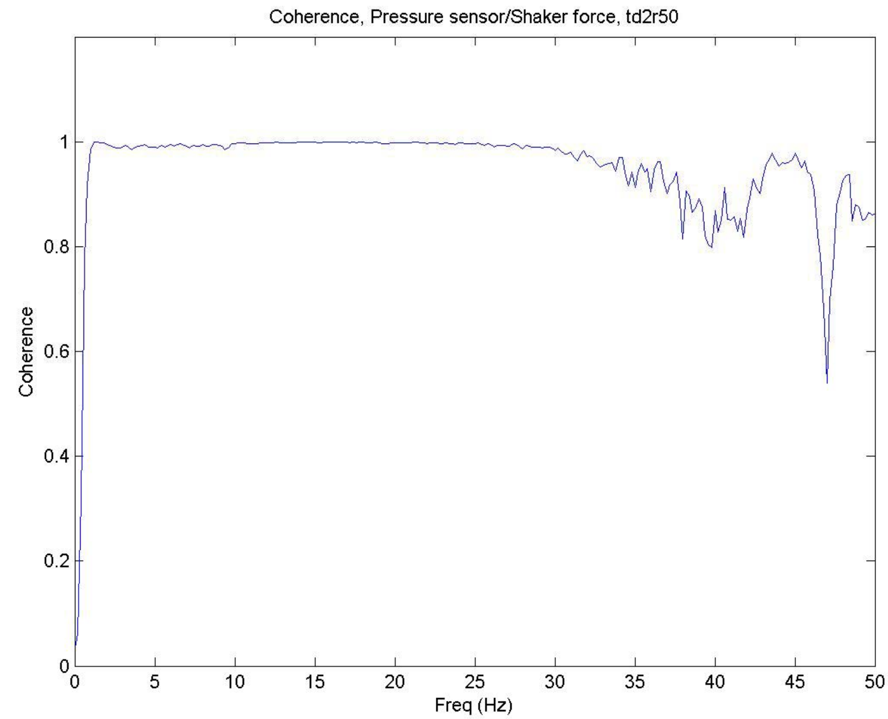
In this test we recorded the background noise for 1 min.

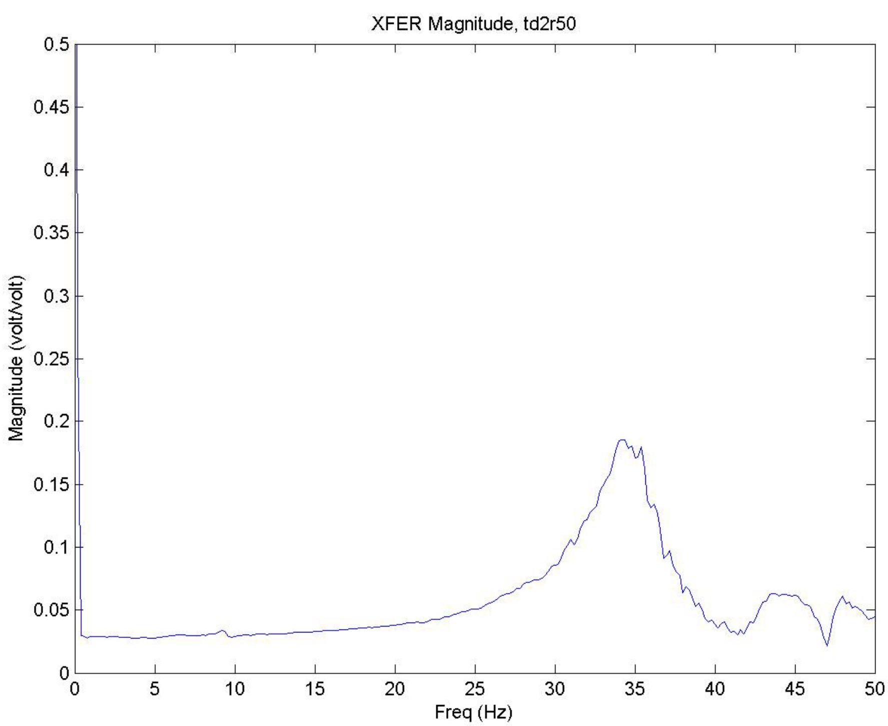




ii) Random 50Hz:

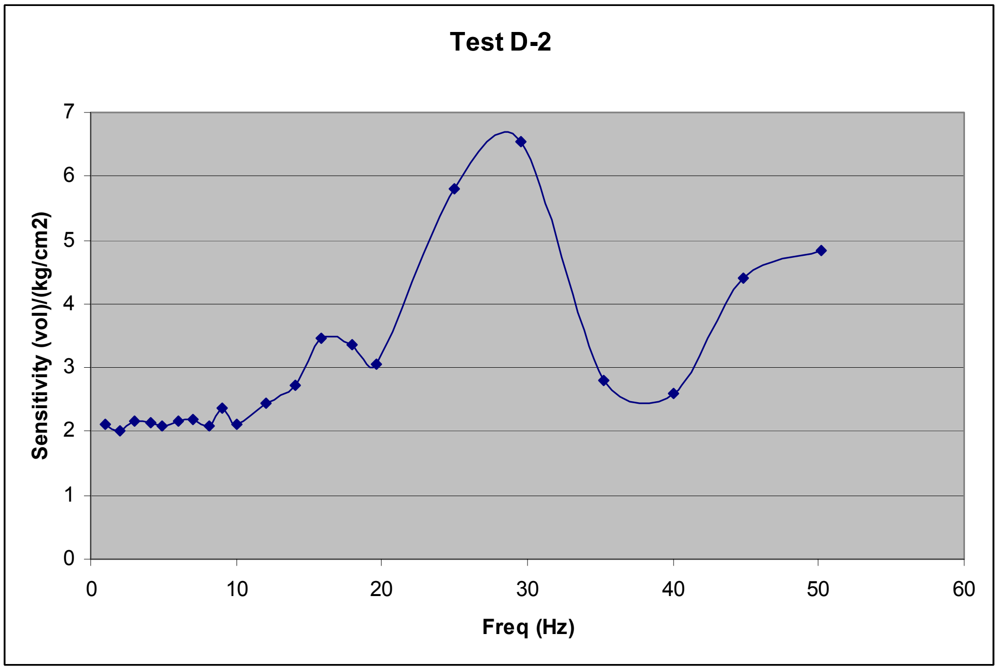
In this test, we recorded the Pressure and Acceleration for 1 min while the system was under random vibration up to 50Hz.



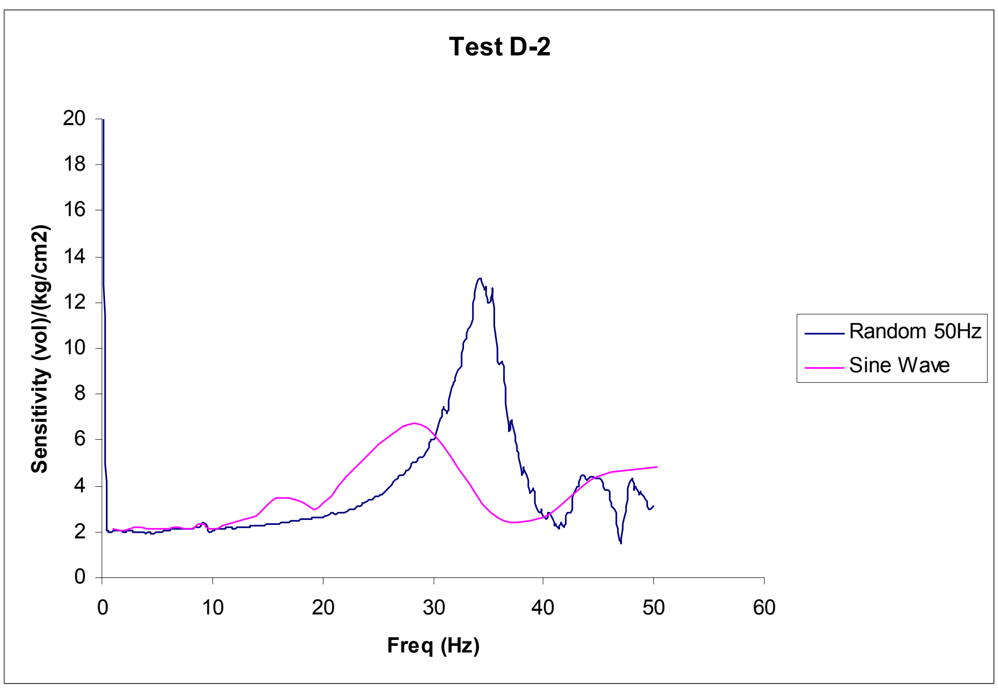


iii) Sine Wave:

In this test, we recorded the Pressure and Acceleration while the system was under sine waves from 1 to 50 Hz.



iv) Comparison between the Random 50Hz and Sine Wave results:

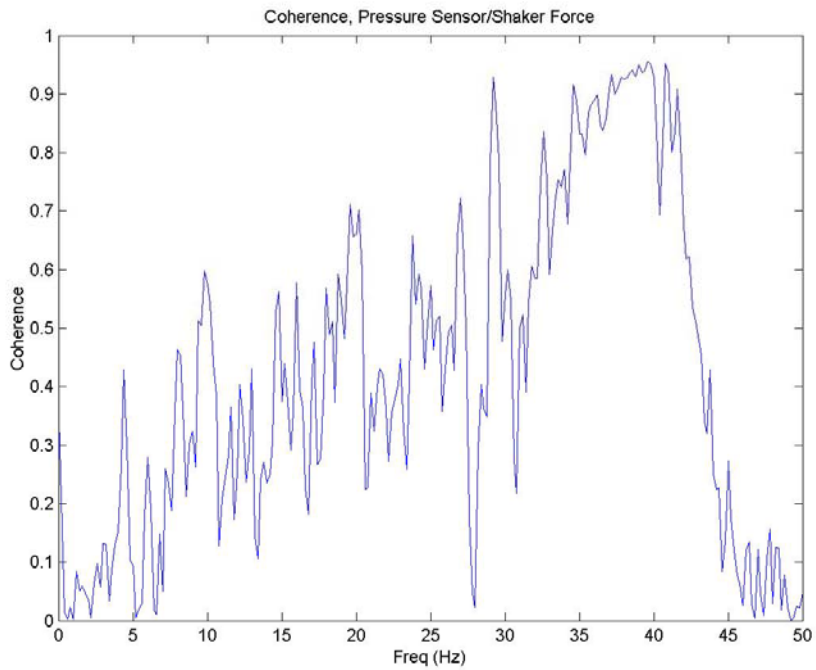


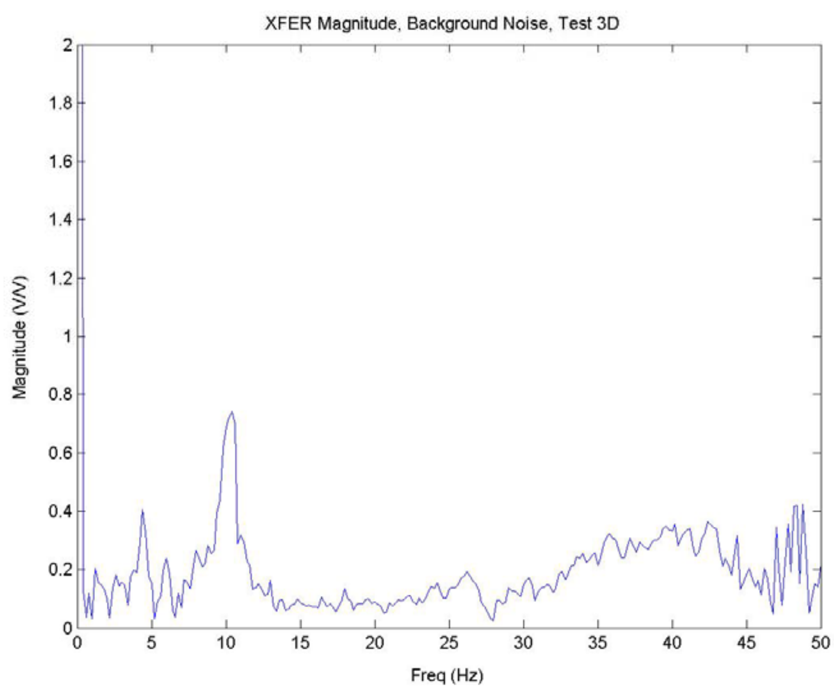
Test D-3 (02/17/2004):

We did this test after digging a ring underneath the pressure cell.

i) Background Noise:

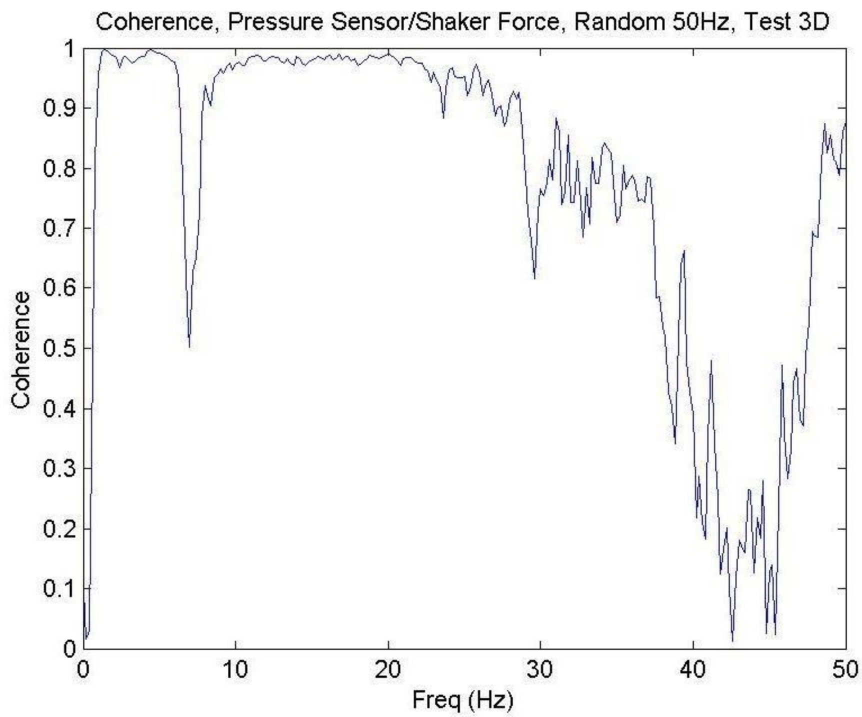
In this test we recorded the background noise for 1 min.

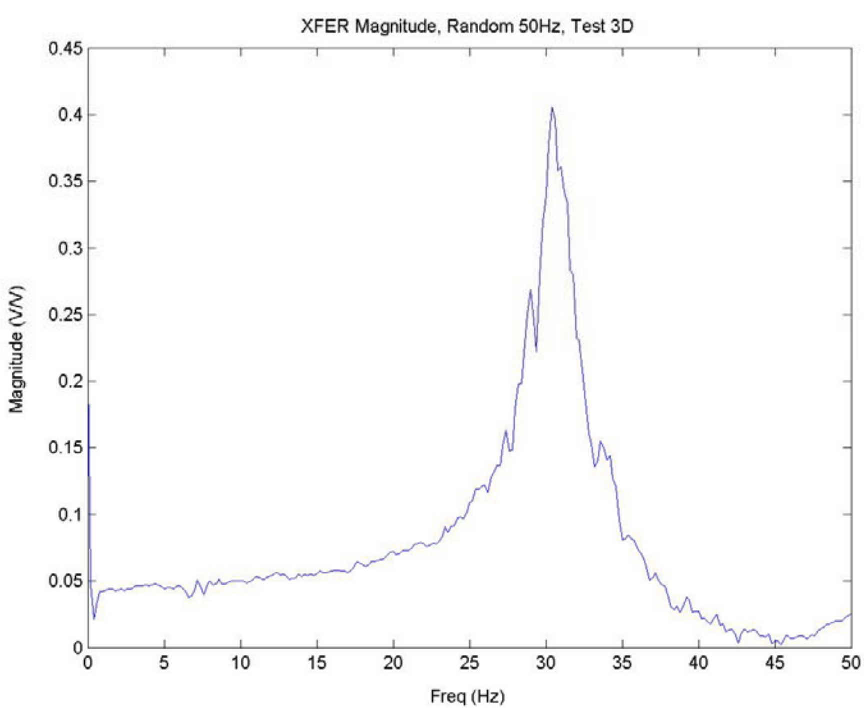




ii) Random 50Hz:

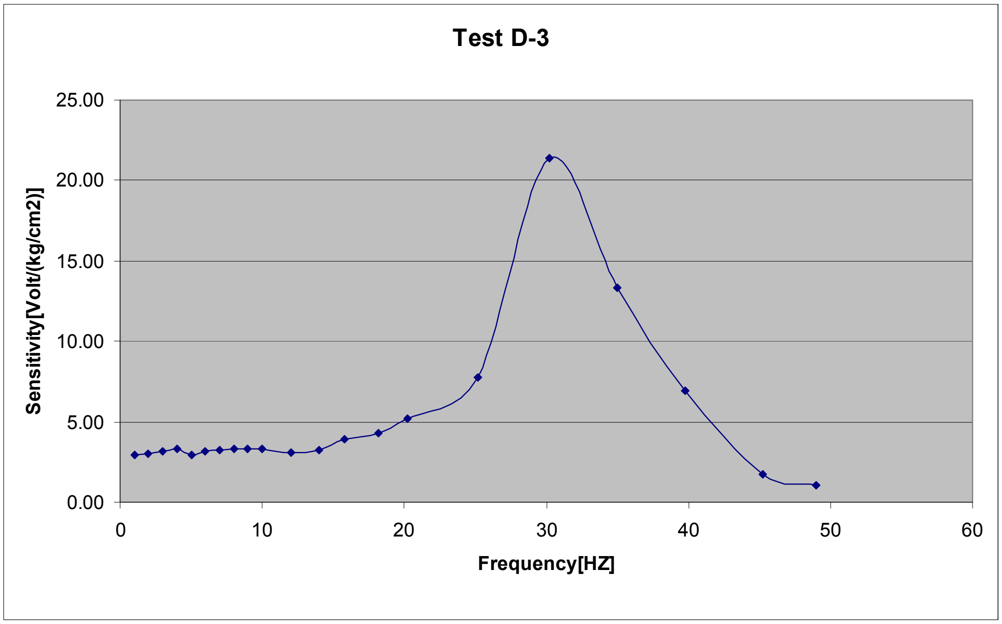
In this test, we recorded the Pressure and Acceleration for 1 min while the system was under random vibration up to 50Hz.



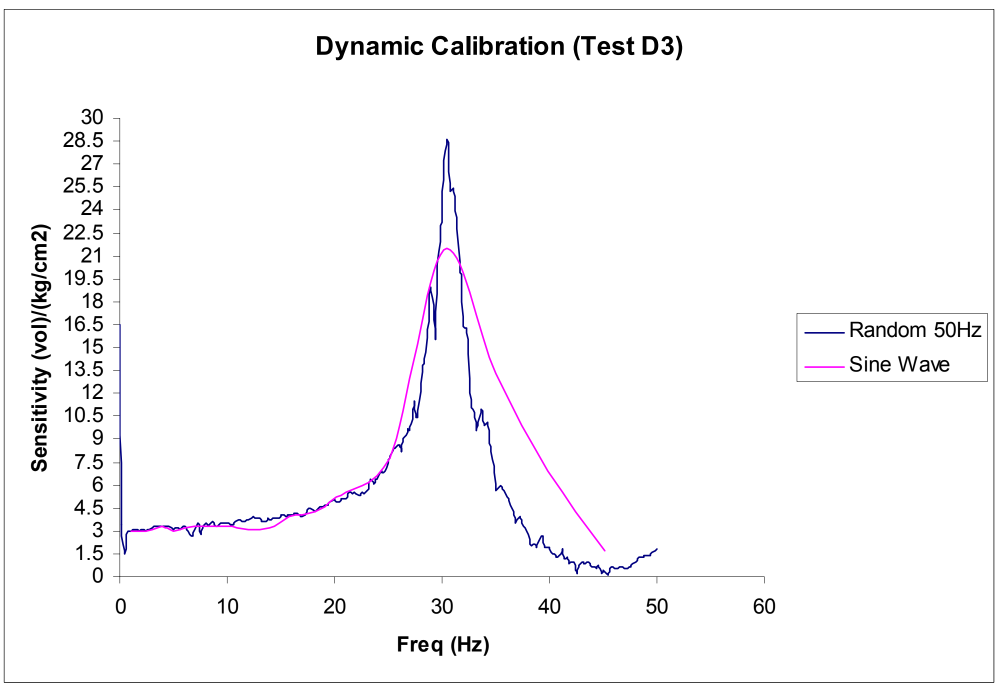


iii) Sine Wave:

In this test, we recorded the Pressure and Acceleration while the system was under sine waves from 1 to 50 Hz.



iv) Comparison between the Random 50Hz and Sine Wave results:



Conclusion:

The final results are shown in the following table:

Sensitivity (Vol)/(kg/cm2)				
	Ring Underneath		Smoothed Sand Underneath	
	Static	Dynamic	Static	Dynamic
Sensor K10	3.71	3.7	2.1 3.17	2
Sensor K09	2.71 3.07 3.27	3	2.04 0.78 1.67	2

Appendix A

Bridge sensor Calibration

Model 163MK Bridgesensor

Bakground

The CALEX 163MK Bridgesensor is a complete signal conditioning system on a card designed expressly for single half, or full bridge transducers. The 163MK consists of a high performance instrumentation amplifier, a user adjustable active filter, high stability bridge supply and all of the required circuitry, trimpots, etc., so that only point to point wiring need be made to the inputs, outputs and power to have a complete signal conditioning system up and running.

Model :163MK Bridgesensors
Filter cutoff Frequency: adjusted for 100 Hz
Input: 1.5V battery
Output: adjusted 100 times amplification
Power: 10V DC
Date of experiment: 02/06/2004

Calibration Process

The calibration steps were exactly followed in accordance with the DIGITXX manual. Using a millivolt calibrator, we desire to set the gain so that the proper full scale (100 times) is gained.

Adjusting the input from the battery

To precisely calibrate the sensors in millivolt range we needed to so temporally design a circuit consisting of a couple of resistors to reduce the voltage of the battery down to 50[mV], therefore the input and output are as follow:

Exact voltage input from battery: 43.9[mV]
Exact output after 100 times gain: 4.39 [V]

Appendix B

How we named the “EXCEL” files?

The name of each file identifies the following:
Manufacturer of the sensor:(It is either E which stands for ENTRAN or S as stands for SENSOTEC.)

S# which specifies the setup combination of P_cell and P_Sensor
S1: P_cell# 1 coupled with Sensor S/N (04A03F05-K10)
S2: P_cell#2 coupled with Sensor S/N (04A03F05-K09)

s/d#: specifies the number of run as well as static and dynamic state of the test.

(e.g. E_s1_d2_02022004_r_.xls contains the data that corresponds to the experiment on the sensor manufactured by Entran, System setup #1, dynamic calibration run #2 on 02022004 after digging a ring underneath.)

Appendix C

Pressure System Calibration

"SENSOTEC Sensors"

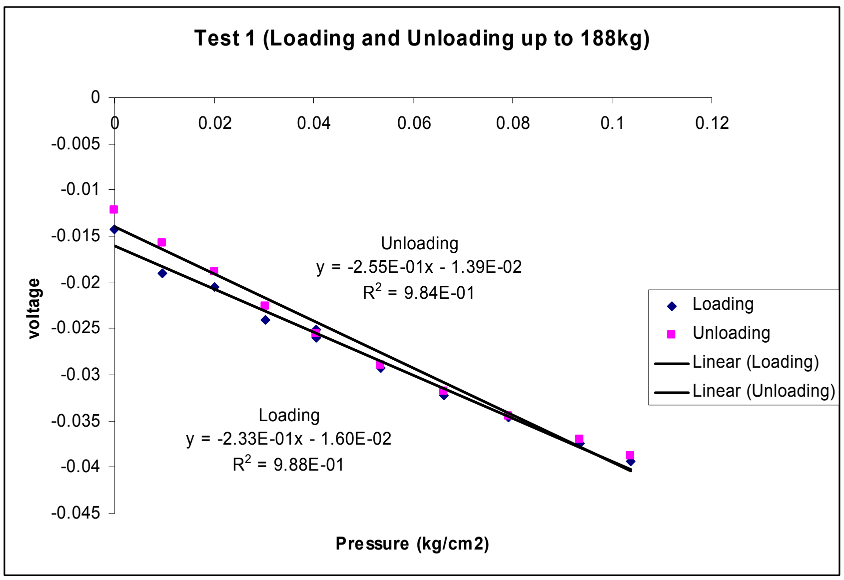
Static & Dynamic

01/15/2003

1) Static Calibration

Test 1 (12/23/03):

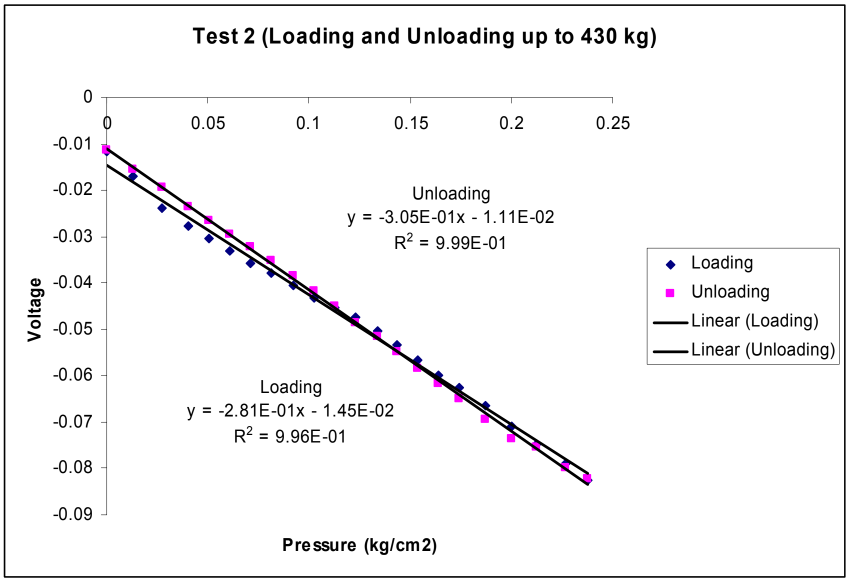
Loading up to 188 kg and Unloading (absolute pressure).



vol/ (kg/cm2)	Loading (absolute pressure)	Unloading (absolute pressure)
Slope	-2.33E-01	-2.55E-01

Test 2 (12/30/03):

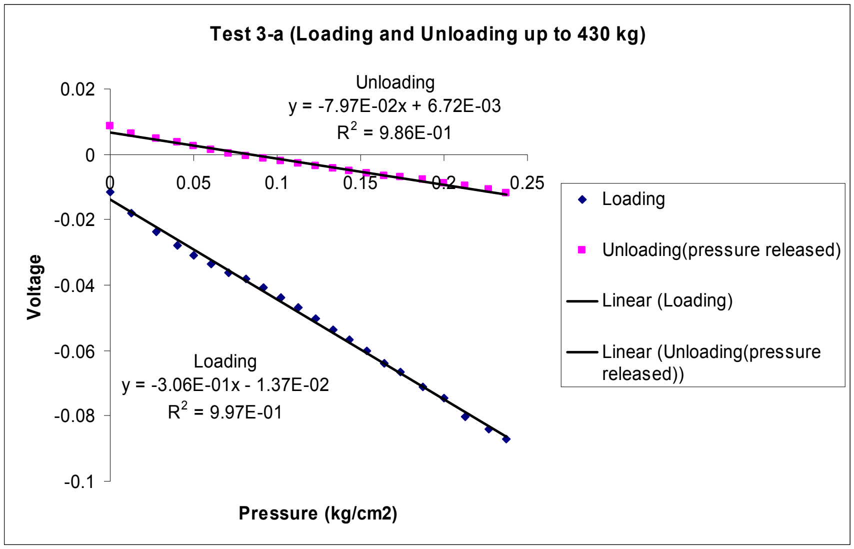
Loading up to 430 kg and Unloading (absolute pressure).



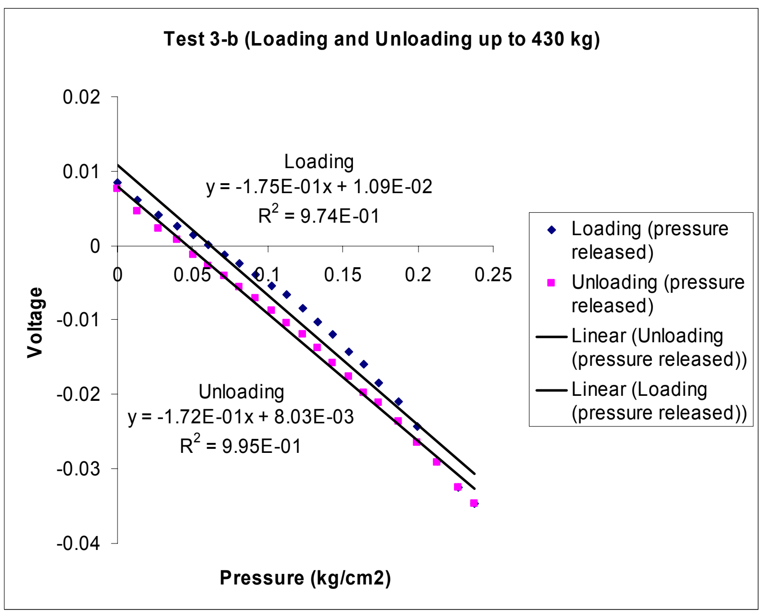
vol/ (kg/cm2)	Loading (absolute pressure)	Unloading (absolute pressure)
Slope	-2.81E-01	-3.05E-01

Test 3 (12/30/03):

3-a: Loading up to 430 kg with absolute pressure, then releasing the pressure and unloading.



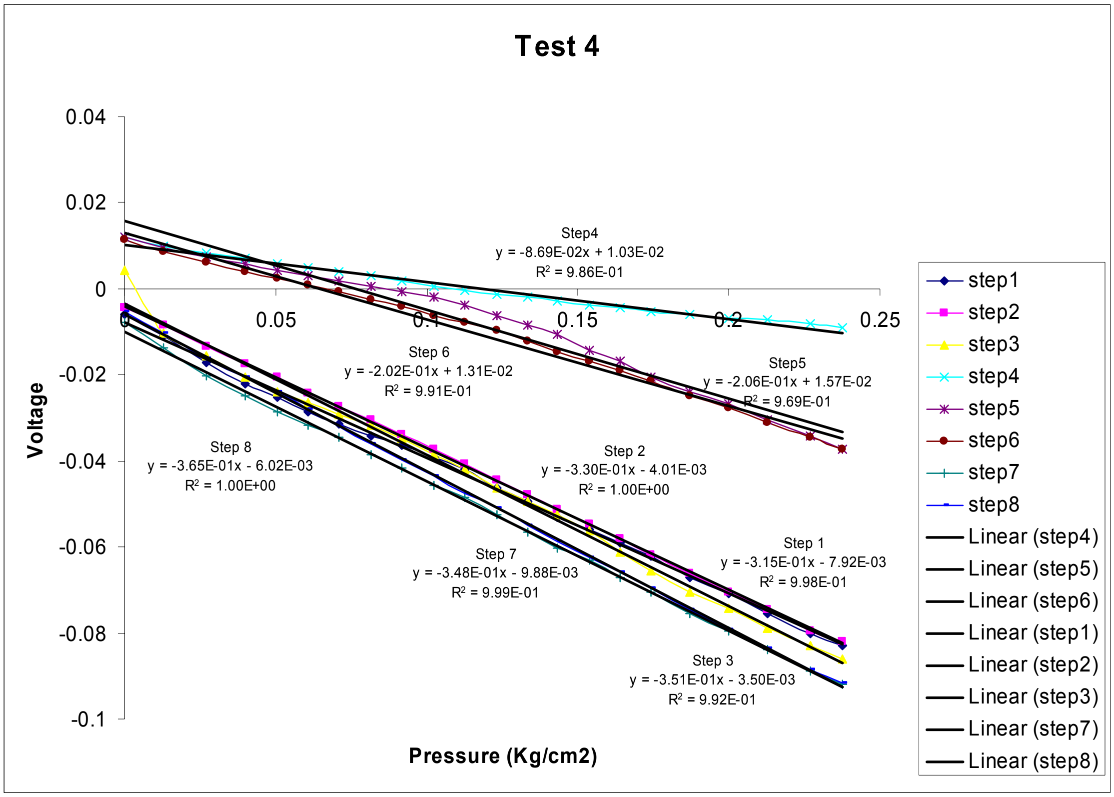
3-b: Loading and Unloading up to 430 kg with released pressure.



vol/ (kg/cm2)	**Loading (absolute pressure)**	**Unloading (released pressure)**	**Loading (released pressure)**	**Unloading (released pressure)**
Slope	-3.06E-01	-7.97E-02	-1.75E-01	-1.72E-01

Test 4 (01/05/04):

Step 1: Loading up to 430 kg (absolute pressure)
Step 2: Unloading (absolute pressure)
Step 3: Loading (absolute pressure)
Step 4: Releasing the pressure and unloading
Step 5: Loading up to 430 kg (released pressure)
Step 6: Unloading (released pressure)
Step 7: Loading up to 430 kg after digging a hole underneath the cell(absolute pressure)
Step 8: Unloading (absolute pressure and the hole underneath the cell).



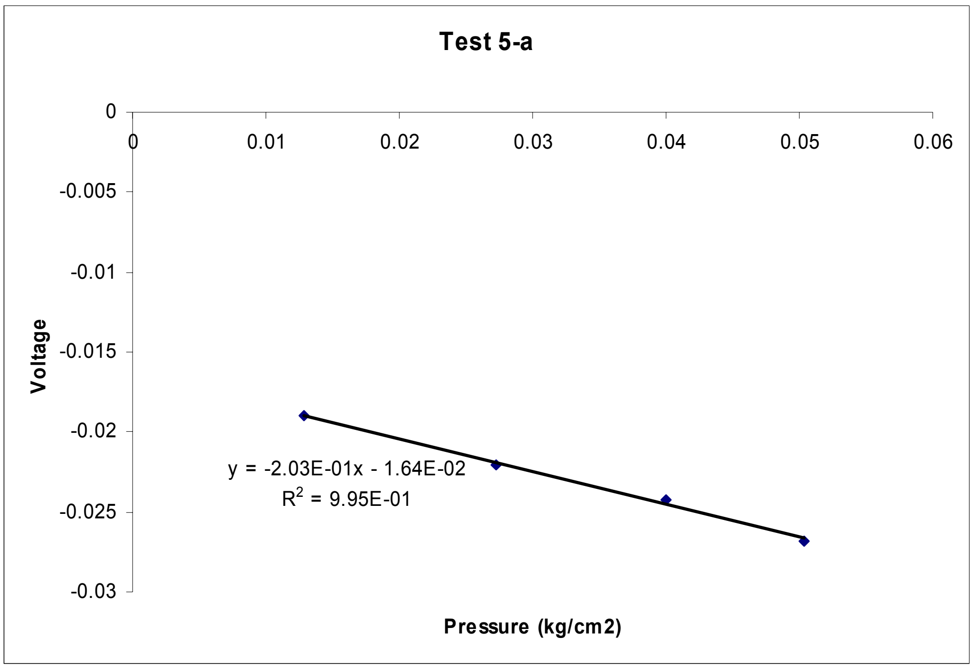
vol/ (kg/cm2)	Loading (absolute pressure)	Unloading (absolute pressure)	Loading (absolute pressure)	Unloading (released pressure)	Loading (released pressure)	Unloading (released pressure)	Loading (absolute pressure)	Unloading (absolute pressure)
Slope	-3.15E-01	-3.30E-01	-3.51E-01	-8.69E-02	-2.06E-01	-2.02E-01	-3.48E-01	-3.65E-01

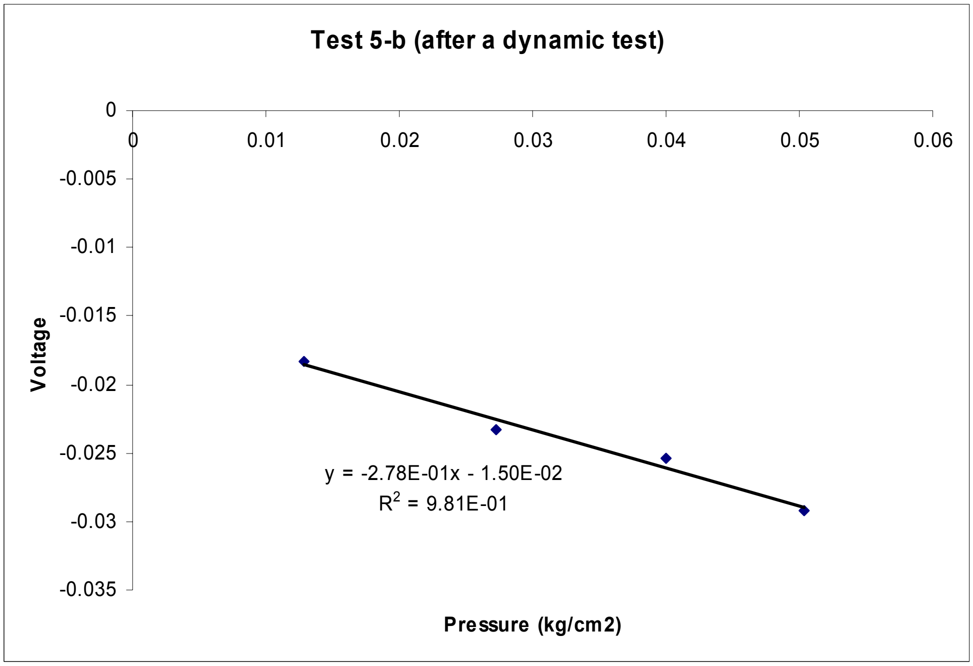
Test 5: (01/13/04)

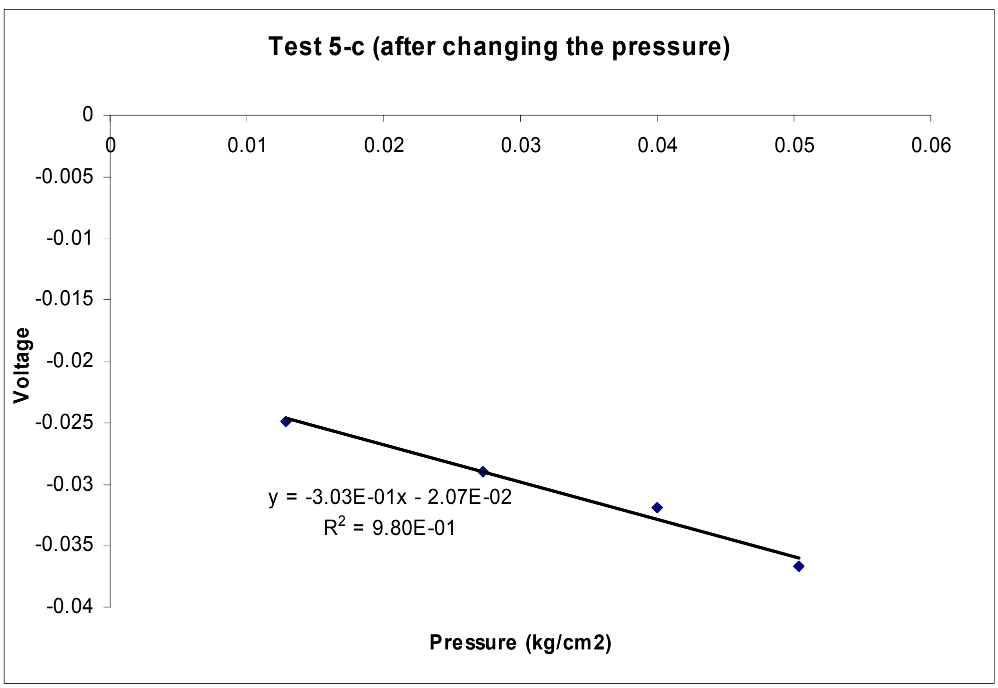
These 3 quick static tests have been done in order to study the change of slope (sensitivity) after dynamic calibration tests.

5-a: Quick static test before dynamic test 3-a.
5-b: Quick static test after dynamic test 3-a.
5-c: Quick static test after changing the pressure (Using a funnel in order to increase the liquid pressure).

Note: The pressure shown in graphs is the additional pressure on the cells when concrete and shaker are already on.







Vol/(kg/cm2)	**Test 5-a**	**Test 5-b**	**Test 5-c**
Sensitivity	**-2.03E-01**	**-2.78E-01**	**-3.03E-01**

2) Dynamic Calibration

Test 1: (01/08/04)

During this test a hole was underneath the pressure cell.

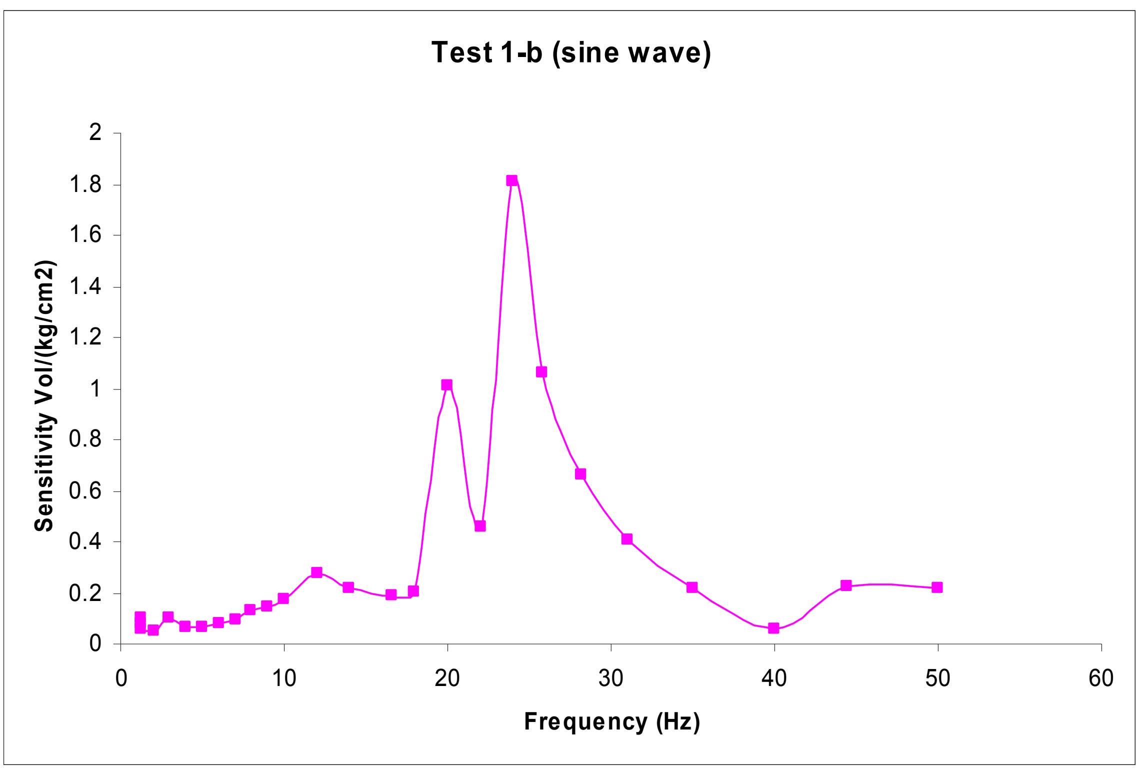
Test 1-a: (Random)

Run 1(1-ar1): 2 minutes recording of background noise.
Run 2(1-ar2): 2 minutes recording of random vibration (f=100Hz)
Run 3(1-ar3): 2 minutes recording of random vibration (f=50Hz)

Note: In all above mentioned runs the filter was off.

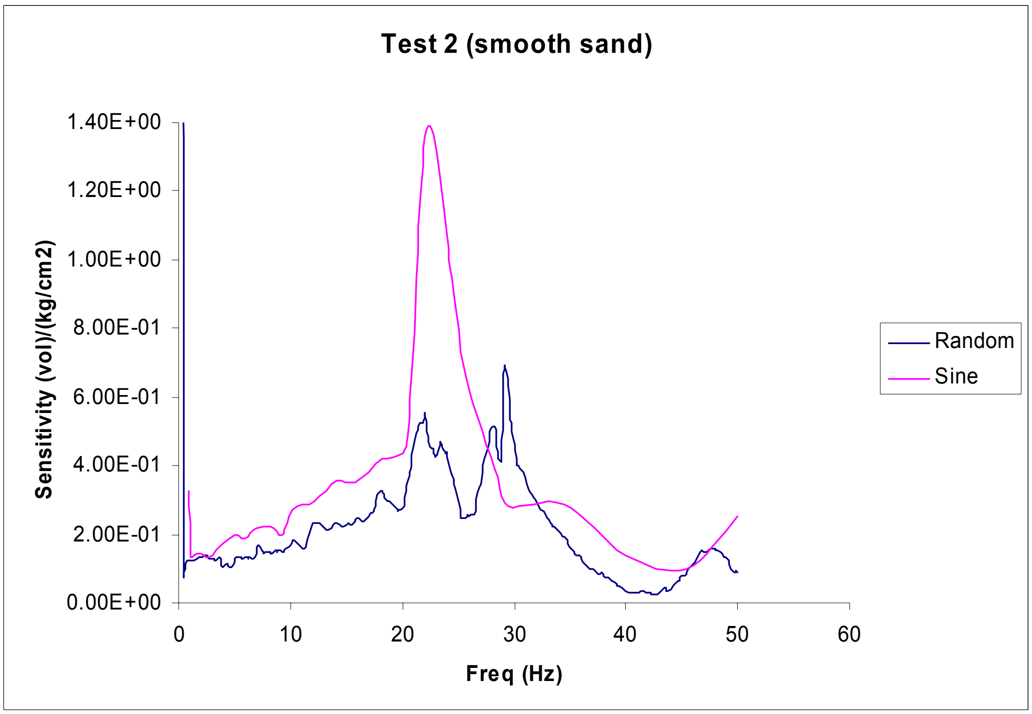
Test 1-b: (Sine Wave)

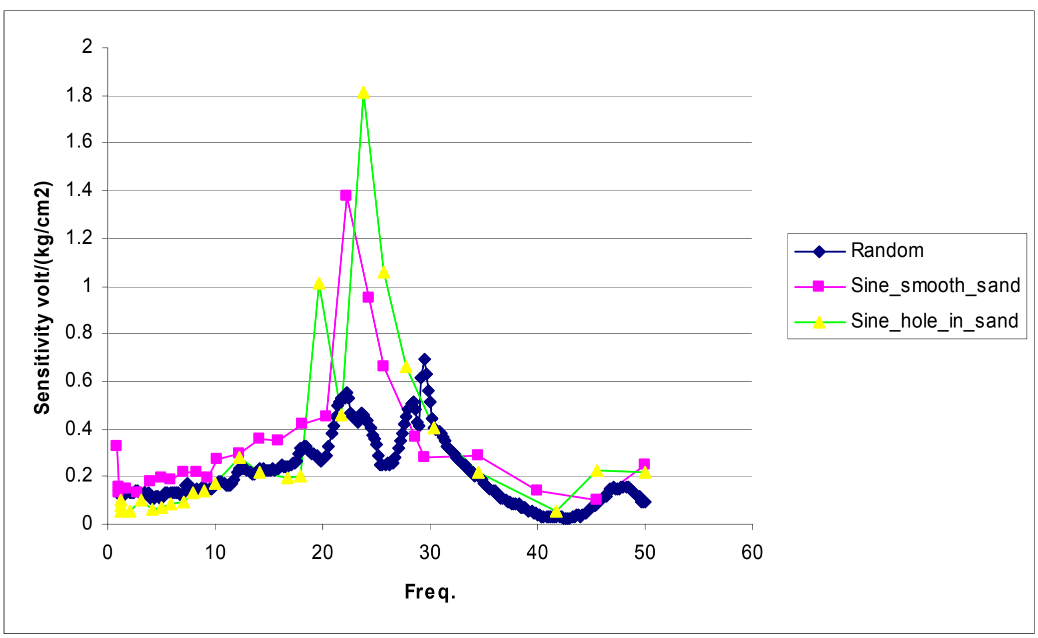
Recording was done for different frequencies (from 1 to 50) with different filters.



Test 2: (01/12/04)

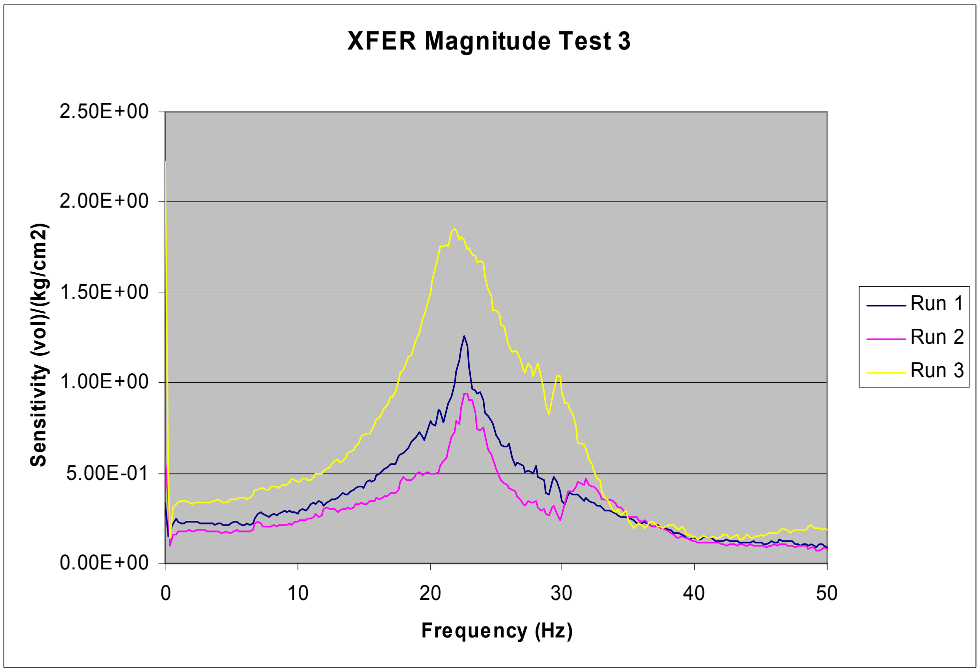
This test was done exactly same as test 1 but no hole was underneath the pressure cell (smoothed sand).

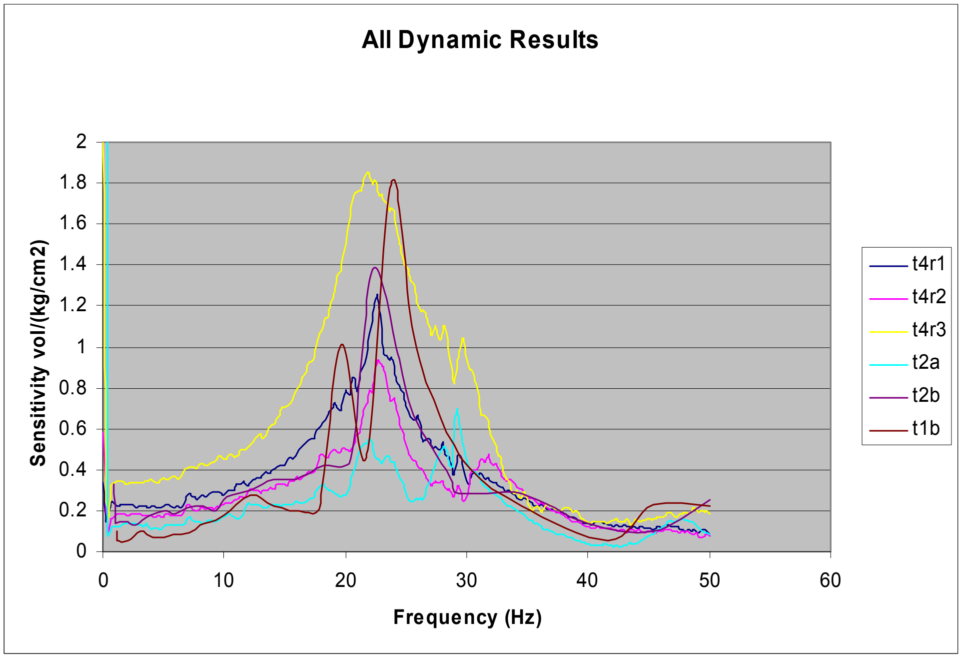




Test 3: (01/13/04)

Test 3-a: 1 minute recording of random vibration (f=50Hz) (absolute pressure).
Test 3-b: 1 minute recording of random vibration (f=50Hz) after a little change in liquid pressure. (increasing the pressure by using a funnel.)
Test 3-c: 1 minute recording of random vibration (f=50Hz) after more increase in liquid pressure.




All Dynamic Results
Sensitivity vol/(kg/cm2)
Frequency (Hz)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
t4r1
t4r2
t4r3
t2a
t2b
t1b

Surface foundation on homogenous stratum

Presuming a single degree of freedom system, we would like to compute the dynamic impedance of our calibration structure to verify the proximity of existing empirical values for static spring coefficients of surface foundation [1] comparing with our dynamic experiment. The calibration structure is composed of A block of concrete pressure cell and the sand underneath.

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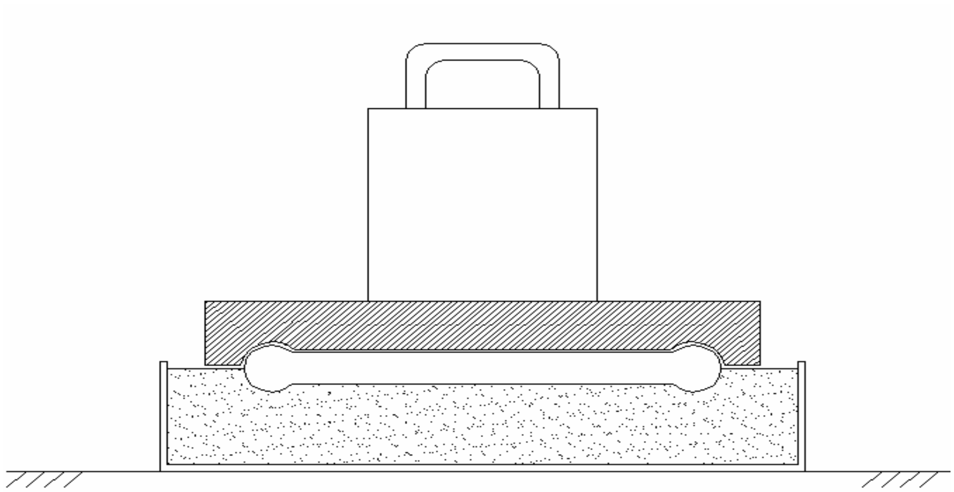


Schema of Dynamic Calibration Test Setup

V_s=100 [m/s]

ν= 0.35

ρ=1.7 e 03 [Kg/m^3]

G=1.7e 07 [N/m]

I_Z=9.65 [$Kg\,m^2$]

H= 0.15 [m]
R= 0.22 [m]

Where Vs, ν, ρ, G are Shear wave velocity, Poisson ration of dry sand, mass density of sand and shear module of the sand respectively.

$$Kz = \frac{8G R^3}{3(1-\nu)}(1+0.17\frac{R}{H})$$

Where Kz is rocking stiffness of the surface foundation.

Kz= 927792.093 [N/m]

$$\omega = \sqrt{\frac{kz}{Iz}}$$

ω=310 [Rad/s] => Fn = 49.34 [Hz]

Fequency obtained from the experiment : Fn= 36 [Hz]

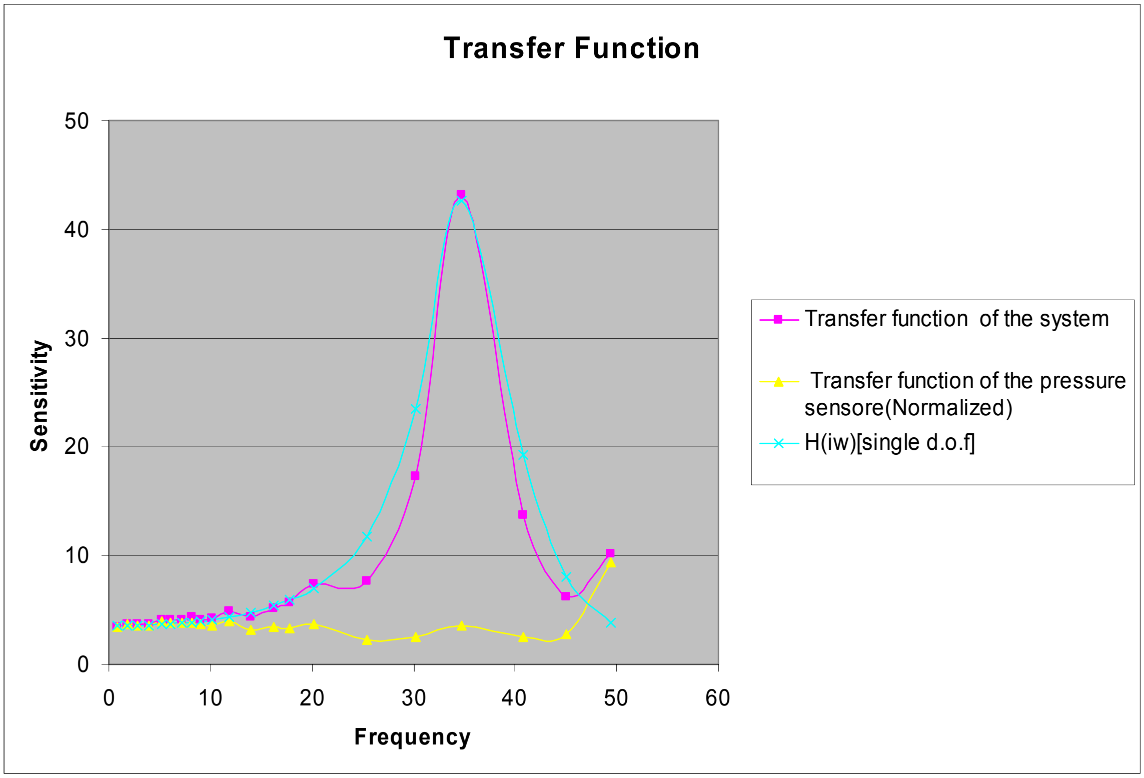
1- Development of Analysis and Design Procedures for Spread Footings by G. Mylonakis, G. Gazetas, S. Nikolaou and A. Chauncey, 10/02/02, MCEER-02-0003,

Transfer Function Normalization

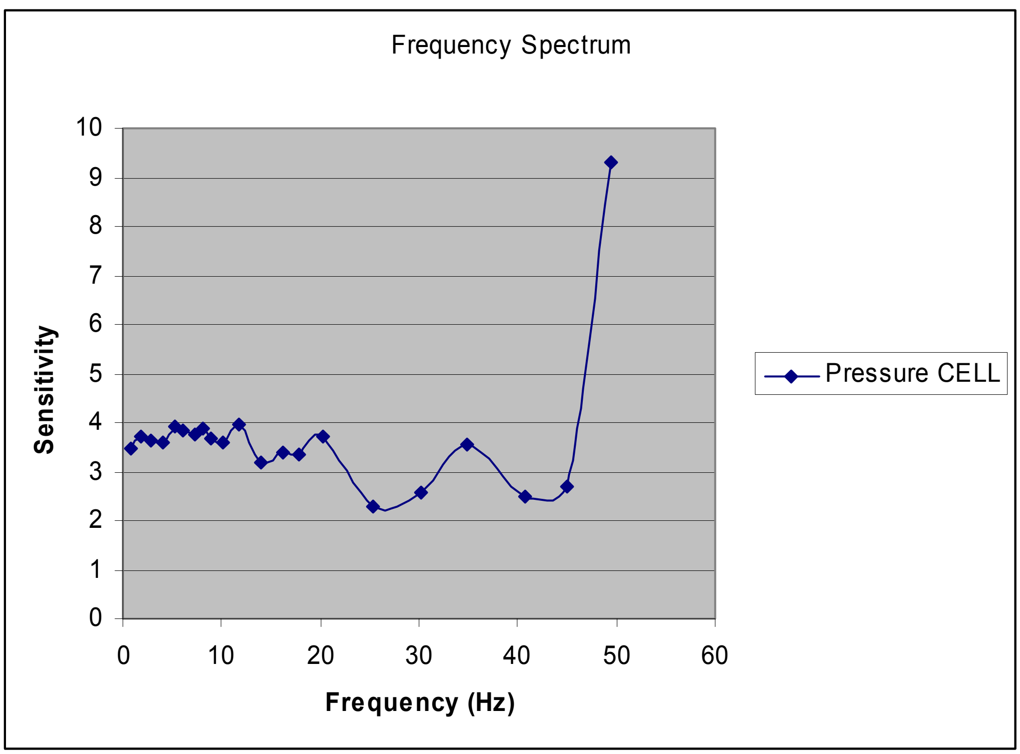
Wn	227		
ζ	0.2		
Ω	r=(Ω/Wn)	H(iw) single d.o.f	sensitivity/H(iw)
5.026548	0.022143	1.000941	3.460325
11.30973	0.049823	1.004775	3.693882
17.59292	0.077502	1.011612	3.619068
25.13274	0.110717	1.023908	3.596429
32.67256	0.143932	1.040892	3.924688
37.69911	0.166075	1.054979	3.832878
45.23893	0.19929	1.080569	3.760098
51.52212	0.22697	1.106322	3.885761
56.54867	0.249113	1.130092	3.663727
64.08849	0.282328	1.171582	3.594552
74.14159	0.326615	1.239351	3.976092
87.96459	0.387509	1.361142	3.178217
101.7876	0.448404	1.52678	3.377171
111.8407	0.49269	1.684718	3.35801
126.9203	0.55912	2.006313	3.698594
159.5929	0.703052	3.369866	2.278806
189.7522	0.835913	6.72456	2.562137
218.6548	0.963237	12.17038	3.540664
256.354	1.129313	5.506659	2.498368
282.7433	1.245565	2.310747	2.710906
310.3894	1.367354	1.097237	9.314646

Transfer function of the pressure sensor= TRF/ $|H(i\omega)|$

Where
TRF: is the transfer function of the whole system (mechanical and sensor) obtained from the experiment.
H(($i\omega$) is the transfer function of a single d.o.f system.



Response spectrum of the pressure system



Response spectrum of the pressure cell, only.