New Plant Seismic Issues Resolution Program

Summary of
Task S2.2 June Working Meeting

by
Greg Hardy, ARES

August 23, 2005

A.R.E.S CORPORATION Applied Research & Engineering Sciences — EPRI

August 23rd S2.2 Meeting Agenda

- **Welcome and Introductions– (Hardy)**
- **Summary of June meeting Results and Actions for Task S2.2 (Hardy)**
- **NRC Feedback on S2.2 from June Meeting (Murphy)**
- **NEI Comments on Overall ESP Process/Schedule (Jobe)**
- **S2.2 Current Project Activities (Merz)**
  - **Development of Simplified Models and Reduction Procedure**
  - **Application of Spectrum Reduction Procedure**
  - **In-Structure Amplification Factor**
  - **Inelastic Behavior of Anchorage Connections (Static and Dynamic)**
  - **Eastern North America Ground Motion Records**
- **Suggestions and Directions**
  - **TRAG**
  - **NRC**

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B-14

ESP Task Overall Schedule (Tasks S2.1, S2.2 & G1.2)

Status

- **NRC/TRAG Technical Meetings at ARES Offices June 22/23**
- **Next G1.2 meeting in October – add to agenda of August meeting on S Tasks (Carl Stepp to attend)**
- **NRC/TRAG Technical Working Meeting at ARES So Cal Office August**
  - **Tuesday, August 23 = S2.2 Status**
  - **Wednesday, August 24 = S2.1 and G1.2 Status**
- **Full NEI/NRC Meeting in October in Washington DC**
- **Draft Reports November 2005**

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Purpose of June Working Meetings

Introduce NRC to Industry Progress on 3 ESP Tasks

Discuss:

- Status of Task S2.1 on Ground Motion Incoherence Effects to Foundation and Building Response
- Status of Task S2.2 on High Frequency Negligible Inelastic Behavior
- Status of Task G1.2 on Characterization of Lower Bound on Earthquake Magnitude (Move Forward of the Scheduled July Meeting)

Provide Forum for Suggestions and Comments:

- Technical Review and Advisory Group
- NRC (Individual Comments)

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New Plant Structural Task 2.2

Primary Purpose

To develop reduction (KD) factors to apply to the high frequency portion of ground response spectra to conservatively account for the fact that typical power plant equipment and structures are not damaged by high frequency motions (i.e. due to extremely limited displacement demand)

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S2.2 Project Tasks

- Task 1 - **Strengthen Key Assumptions**
  - ***In structure Amplification Factor***
  - ***Develop Simple Nonlinear Response Examples***
  - **Limiting Displacements (0.01")**
- Task 2 - **Develop an Improved Procedure for Knock Down Factor Implementation**
- Task 3 - **Define Limiting Failure Modes for Nuclear Plant Equipment**
- Task 4 - **Recommendations for Equipment with Functional Failure Modes**
- Task 5 - **Documentation of Results of S2.2 in a Report**

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Tasks S2.2 - Effect of limited inelastic behavior on response to HF input motions

Action Items

1) Apply reduction procedure for range of F_{SM} , F_{SM}/e from 0.4 to 4 (by August Meeting)
   - Consider 3 cases if possible – soil, moderate, rock sites
   - Normalize spectra shapes to 0.75 g at 10 hz
   - Run cases with amplitudes changed to 1.5X 0.75 g and 0.67X 0.75 g
   - Total of 9 cases if possible
2) Amplification Factor Task
   - Use Rock Site input, fit a time history for the shear beam
   - Also run the cantilever model (bound the problem with two models)

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Tasks S2.2 - Effect of limited inelastic behavior on response to HF input motions

Action Items

3) Research and Plot the Load vs Deformation for Actual Connections (bolts, expansion anchors, fillet welds transverse/longitudinal, etc.) – use quantitative plots
4) Research Diablo Amplification Recordings – High Vertical Amplification
5) Compile Known Eastern North America HF Earthquake records and proximity to engineered structures (useful for G1.2 also) – provide as section of report

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New Plant Seismic Issues Resolution Program

Structural Tasks Working Meetings
Task S2.2 –Amplification Study

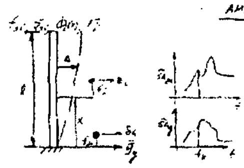
by
K. L. Merz, ARES

August 23, 2005

In-Structure Amplification

- Reduction procedure assumes a constant scale factor F_{SM} to account for amplification effects in > 10 Hz range
- Amplification measured by ratio of in-structure to ground spectrum (5% damping)
- Three basic uniform beam types considered
  - Flexure
  - Shear
  - Timoshenko
- Fundamental frequencies
  - 3, 5, 7, and 9 Hz
  - 7% modal damping
- Three input motions considered

AMPLIFICATION EFFECTS



① ground response of SDOF oscillator

$$\ddot{\delta}_k + 2\xi_k \omega_k \dot{\delta}_k + \omega_k^2 \delta_k = -\ddot{y}_g$$

$$SA_{kg} = \ddot{\delta}_k + \ddot{y}_g$$

$$\max|SA_{kg}| = \widetilde{SA}_{kg}$$

② structure response

given $f_{si}, \xi_{si}, \phi_i(x), \Gamma_i$ $\qquad \ddot{\Delta}_x = \sum_1^M \Gamma_i \phi_i(x) \ddot{\delta}_i$

$$\ddot{\bar{\Delta}}_x = \ddot{\Delta}_x + \ddot{y}_g$$

$$= \sum_1^m \Gamma_i \phi_i(x) \ddot{\delta}_i + \sum_{m+1}^M \Gamma_i \phi_i(x) \ddot{\delta}_i + \ddot{y}_g$$

for $f > f_{m+1}$, $\ddot{\delta}_i \simeq 0$

$$\sum_1^M \phi_i(x) \Gamma_i = 1$$

$$\ddot{\bar{\Delta}}_x = \sum_1^m \Gamma_i \phi_i(x)(\ddot{\delta}_i + \ddot{y}_g) + \left(1 - \sum_1^m \Gamma_i \phi_i(x)\right)\ddot{y}_g$$

$$= \sum_1^m \Gamma_i \phi_i(x)\, SA_{ig} + \left(1 - \sum_1^m \Gamma_i \phi_i(x)\right)\ddot{y}_g$$

where SA_{ig} is SDOF associated with $f_k = f_{si}$, $\xi_k = \xi_{si}$

③ in-structure response of SDOF oscilator

$$\ddot{z}_j + 2\xi_j \omega_j \dot{z}_j + \omega_j^2 z_j = -\ddot{\bar{\Delta}}_x$$

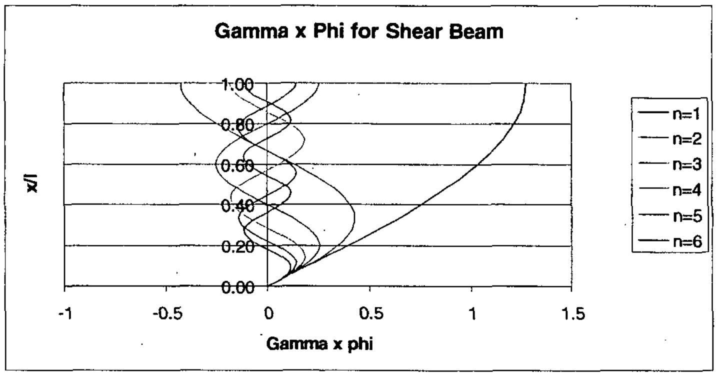
$$SA_{jx} = \ddot{z}_j + \ddot{\bar{\Delta}}_x$$

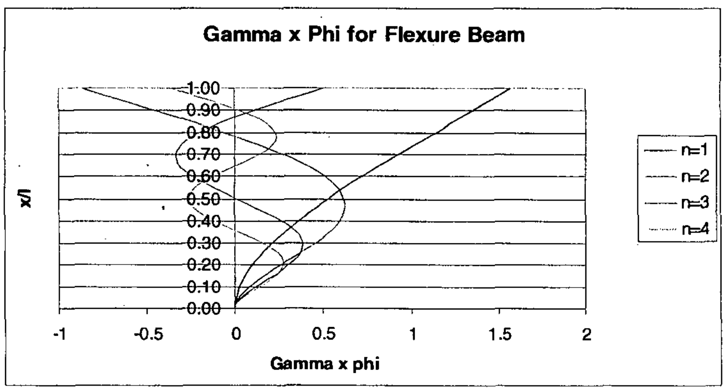
$$\max|SA_{jx}| = \widetilde{SA}_{jx}$$

④ Amplification is measured by

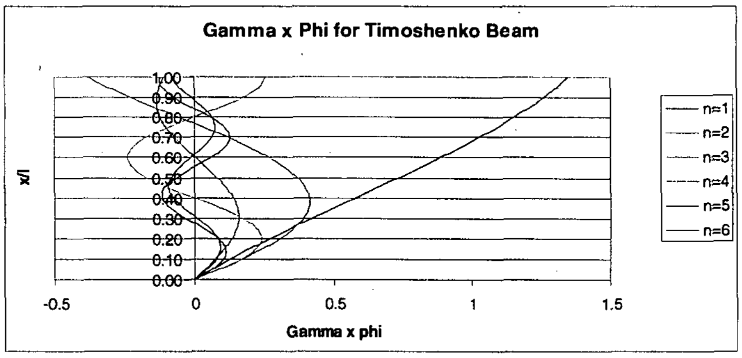
$$AF = \frac{\widetilde{SA}_{jx}}{\widetilde{SA}_{kg}}$$

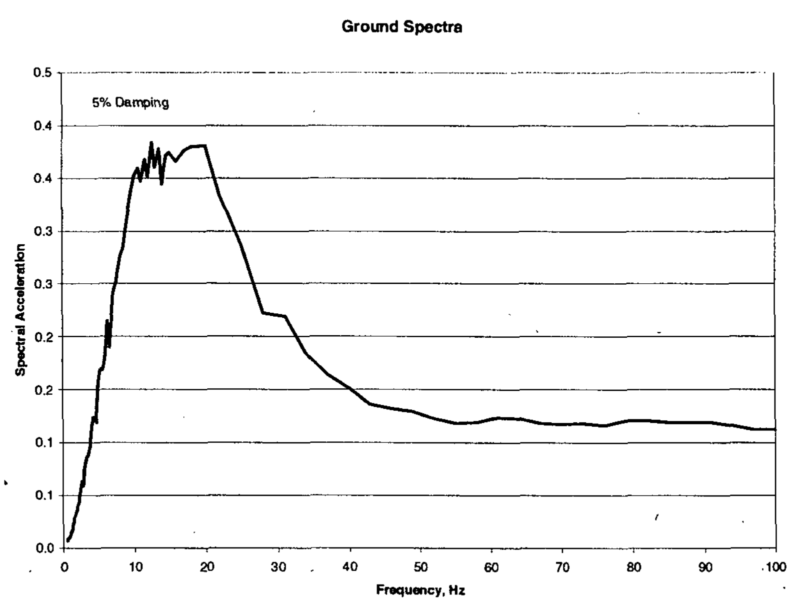
for $\xi_j = \xi_k = \xi_{ref}$


Gamma x Phi for Shear Beam
x/l
1.00
0.80
0.60
0.40
0.20
0.00
-1
-0.5
0
0.5
1
1.5
Gamma x phi
n=1
n=2
n=3
n=4
n=5
n=6

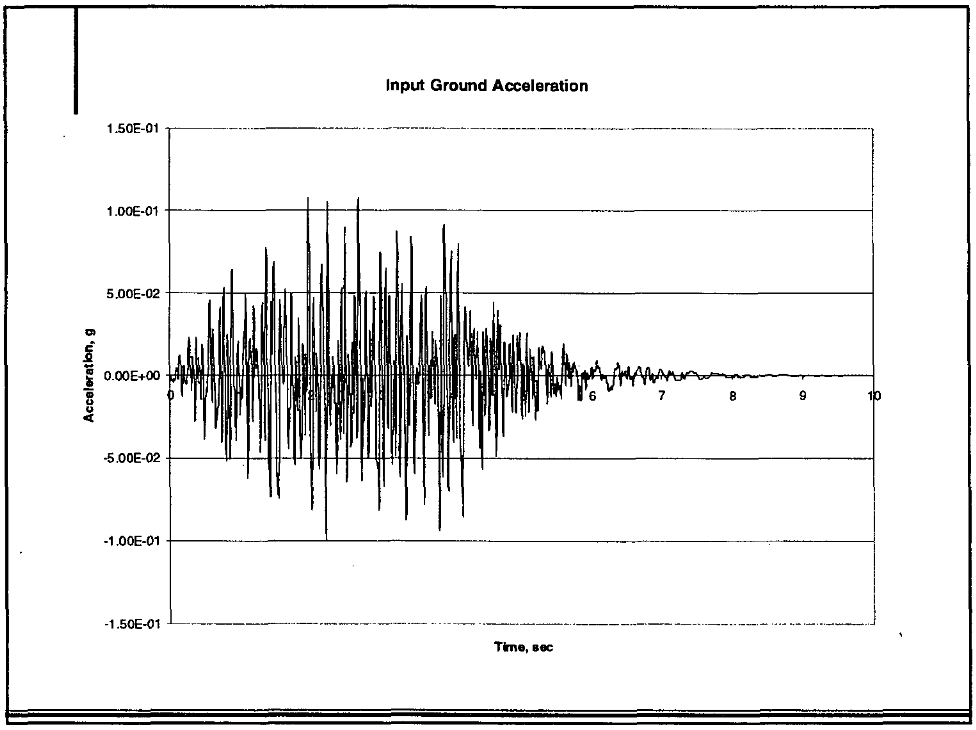

Gamma x Phi for Flexure Beam
x/l
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-1
-0.5
0
0.5
1
1.5
2
Gamma x phi
n=1
n=2
n=3
n=4

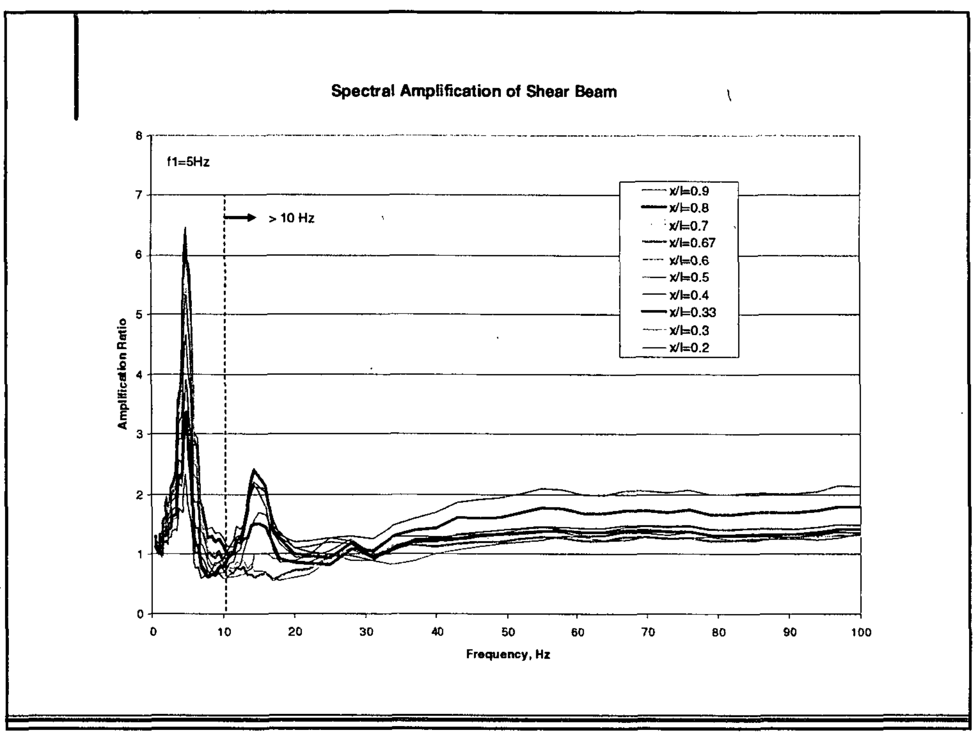
$r^2/L^2 = 0.1$ $E/(k'G) = 4.6$





Artificial time history which satisfies Swedish spectra

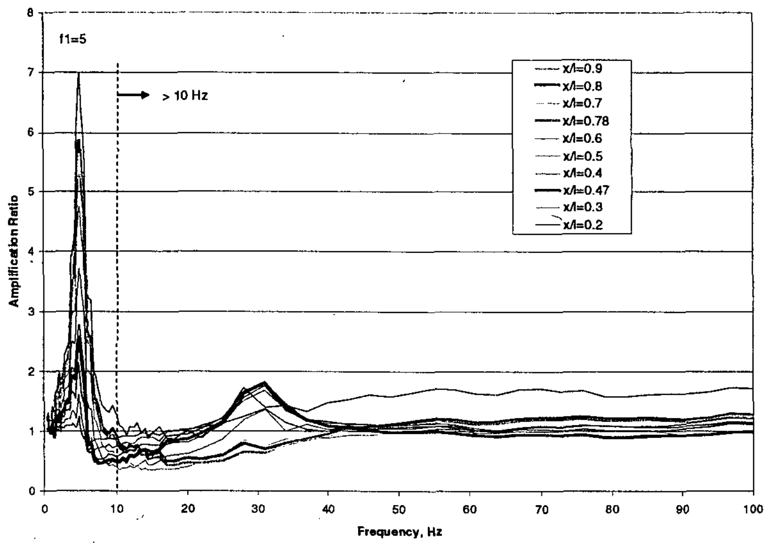

Input Ground Acceleration
1.50E-01
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
Acceleration, g
0
6
7
8
9
10
Time, sec


Spectral Amplification of Shear Beam
f1=5Hz
> 10 Hz
x/l=0.9
x/l=0.8
x/l=0.7
x/l=0.67
x/l=0.6
x/l=0.5
x/l=0.4
x/l=0.33
x/l=0.3
x/l=0.2
Amplification Ratio
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90
100
Frequency, Hz

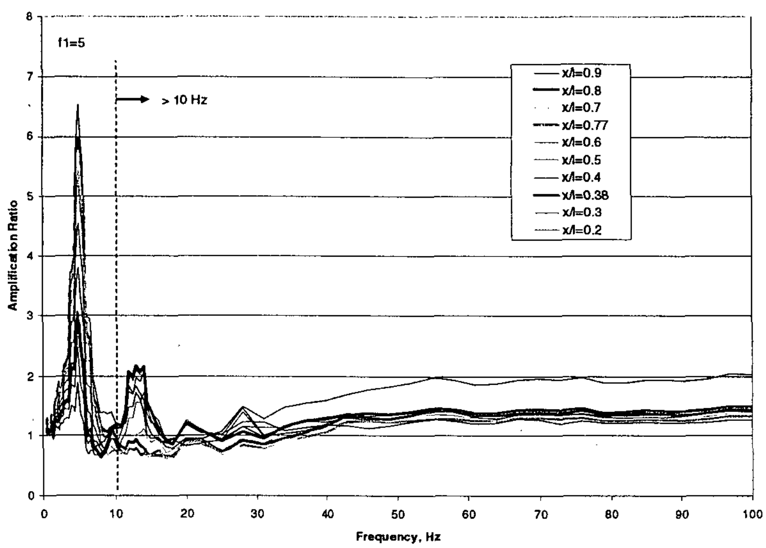
$H_2 = \overline{\epsilon}_{hz}$

$\frac{S_A}{S_F}$ spectral Acc in structure / SA on ground

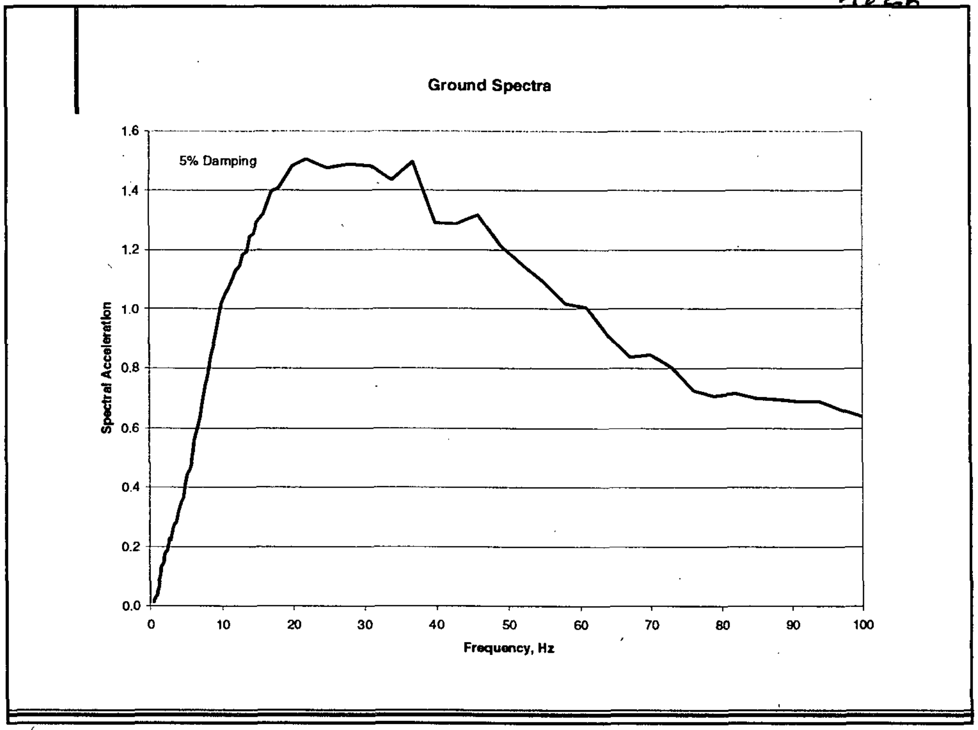
Spectral Amplification of Flexure Beam



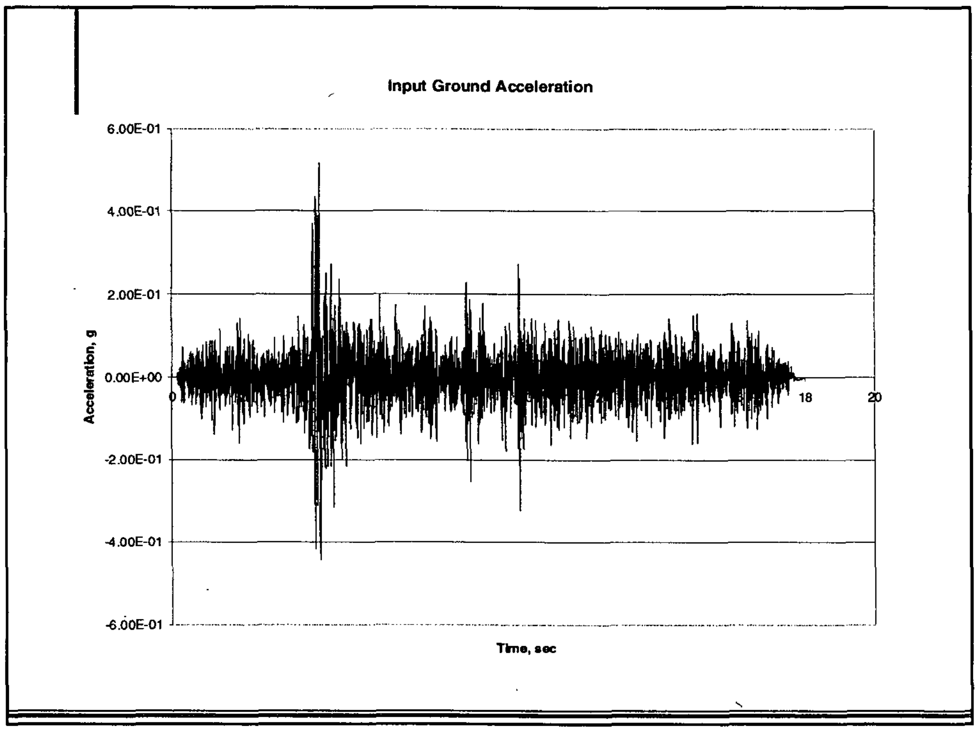
Spectral Amplification of Timoshenko Beam



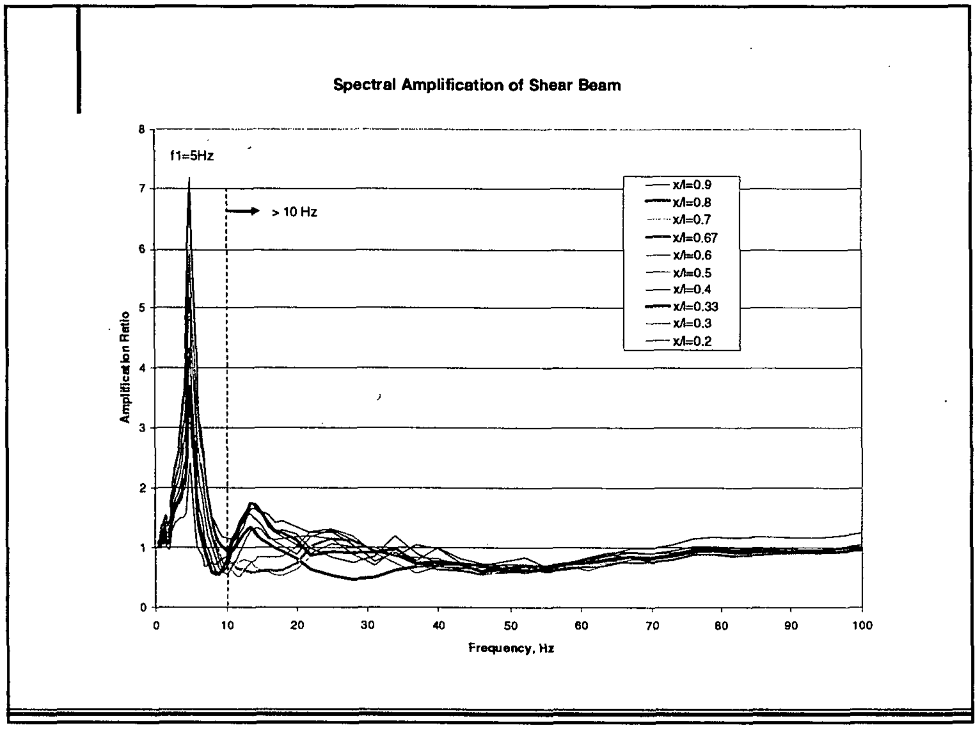
CEUS Rock

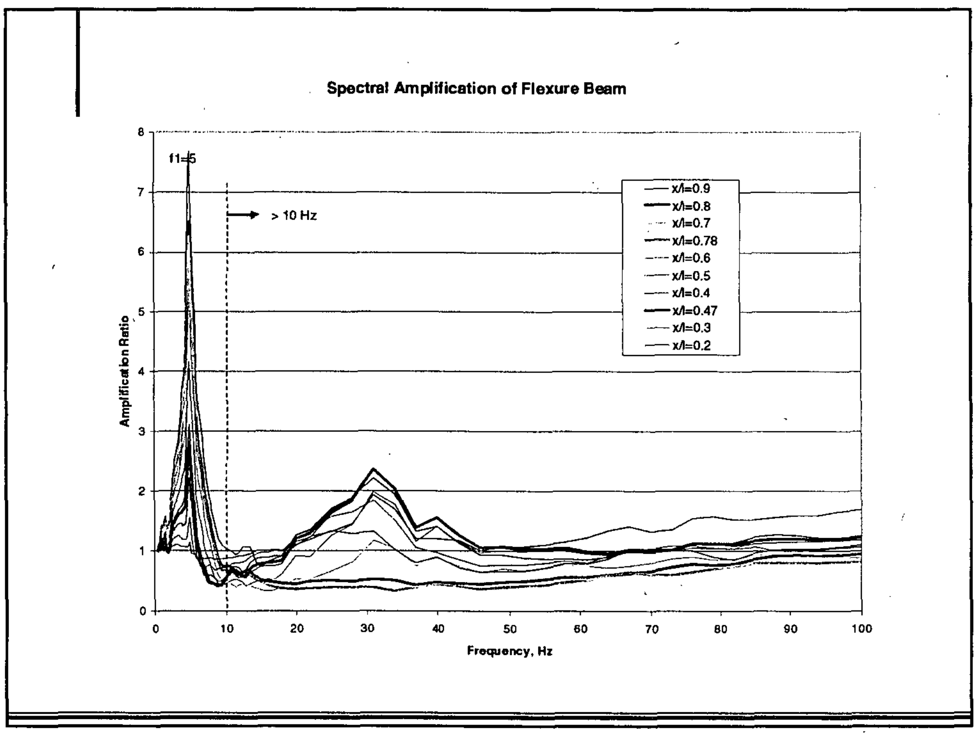


Ground Spectra
5% Damping
Spectral Acceleration
Frequency, Hz
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
10
20
30
40
50
60
70
80
90
100

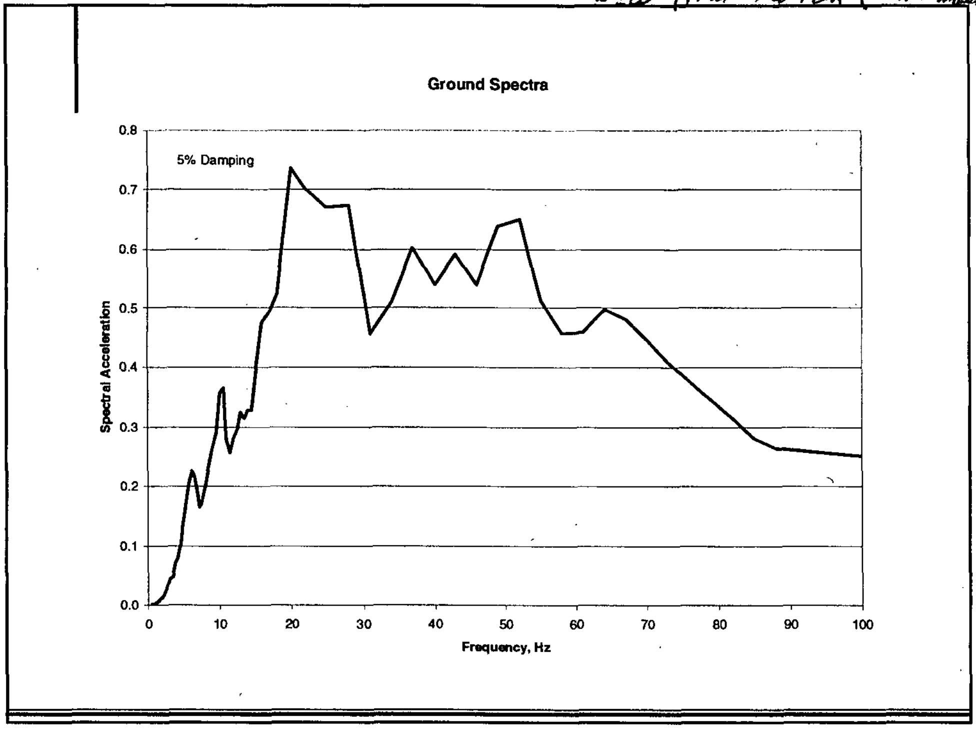


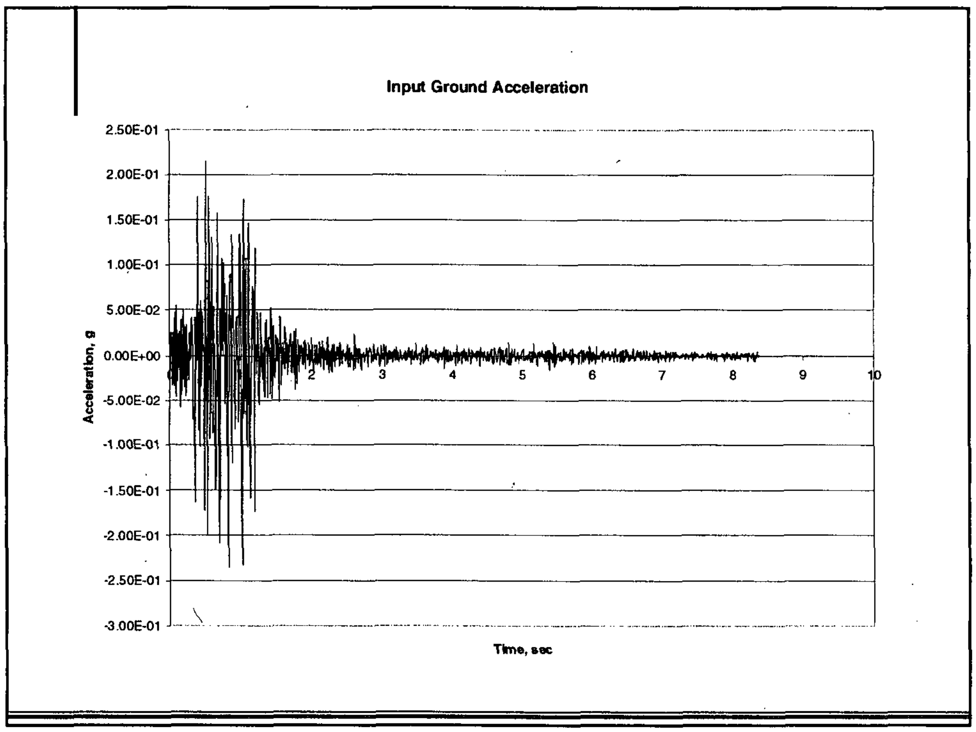
Input Ground Acceleration
Acceleration, g
Time, sec
6.00E-01
4.00E-01
2.00E-01
0.00E+00
-2.00E-01
-4.00E-01
-6.00E-01
0
18
20


Spectral Amplification of Shear Beam
f1=5Hz
> 10 Hz
x/l=0.9
x/l=0.8
x/l=0.7
x/l=0.67
x/l=0.6
x/l=0.5
x/l=0.4
x/l=0.33
x/l=0.3
x/l=0.2
Amplification Ratio
Frequency, Hz

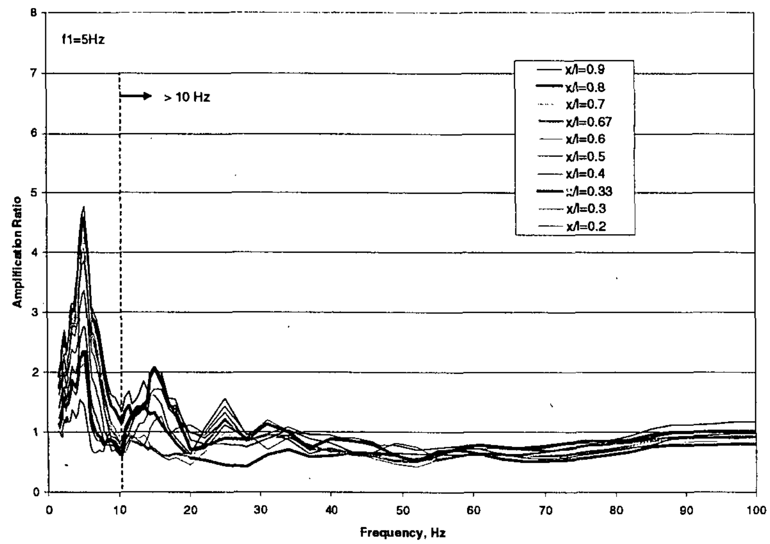

Spectral Amplification of Flexure Beam
f1=5
> 10 Hz
x/l=0.9
x/l=0.8
x/l=0.7
x/l=0.78
x/l=0.6
x/l=0.5
x/l=0.4
x/l=0.47
x/l=0.3
x/l=0.2
Amplification Ratio
Frequency, Hz

Mitchel
New Brunswick (Mitchell Lake)

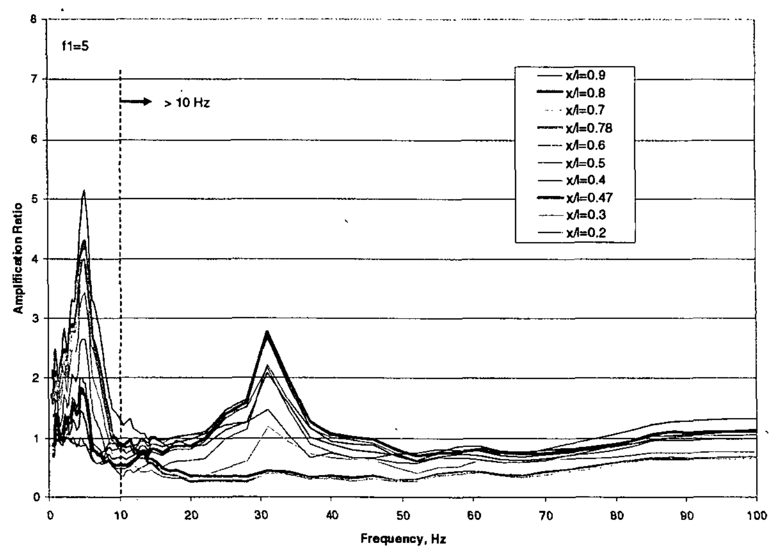




Spectral Amplification of Shear Beam

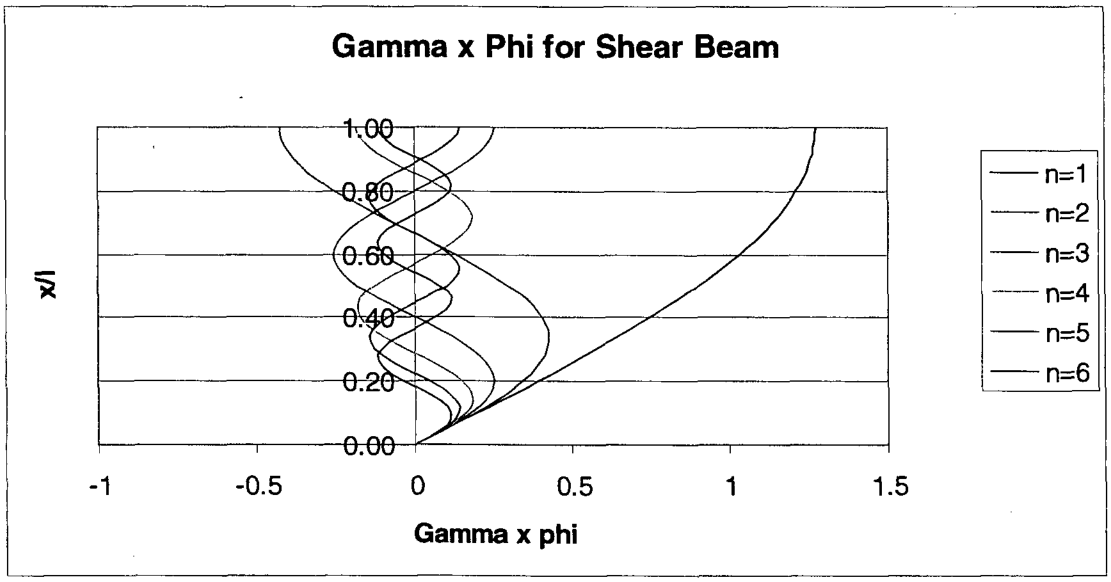


Spectral Amplification of Flexure Beam



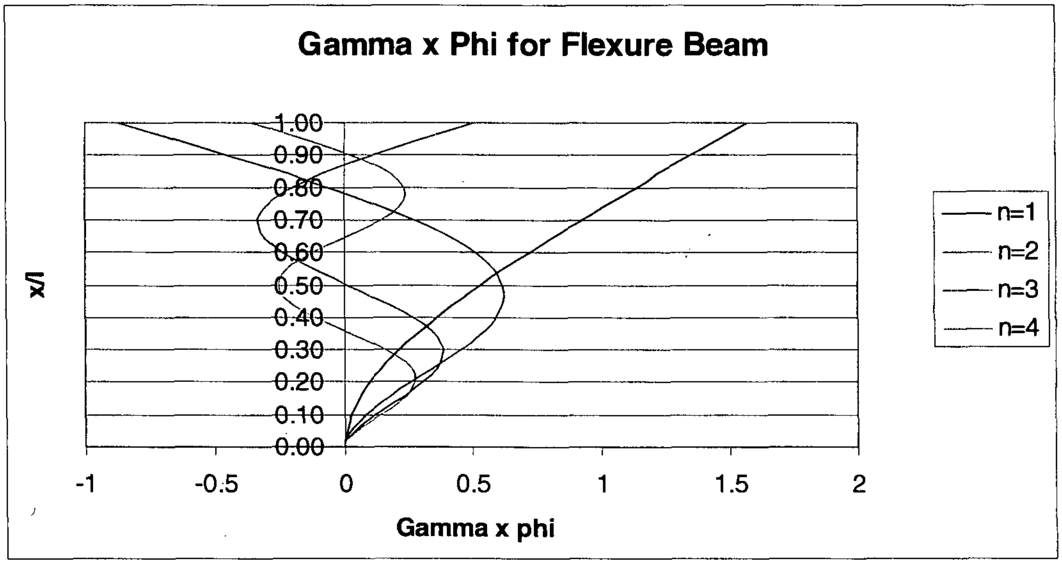
Shear Beam Model

n	Gamma	Beam1	Beam2	Beam3	Beam4
1	0.900316	3 Hz	5 Hz	7 Hz	9 Hz
2	0.300105	9 Hz	15 Hz	21 Hz	27 Hz
3	0.180063	15 Hz	25 Hz	35 Hz	45 Hz
4	0.128617	21 Hz	35 Hz	49 Hz	63 Hz
5	0.100035	27 Hz	45 Hz	63 Hz	81 Hz
6	0.081847	33 Hz	55 Hz	77 Hz	99 Hz
7	0.069255	39 Hz	65 Hz	91 Hz	
8	0.060021	45 Hz	75 Hz		
9	0.05296	51 Hz	85 Hz		
10	0.047385	57 Hz	95 Hz		
11	0.042872	63 Hz			
12	0.039144	69 Hz			
13	0.036013	75 Hz			
14	0.033345	81 Hz			
15	0.031045	87 Hz			
16	0.029042	93 Hz			
17	0.027282	99 Hz			



Flexure Beam Model

n	Gamma	Beam1	Beam2	Beam3	Beam4
1	0.782992	2.9 Hz	5 Hz	7 Hz	9 Hz
2	0.433936	18.2 Hz	31.3 Hz	43.87 Hz	56.4 Hz
3	0.254425	50.9 Hz	87.7 Hz		
4	0.181898	99.7 Hz			



Timoshenko Beam Model

n	Gamma		Beam2		Beam4	Beam5
1	0.8445	*	5 Hz	*	9 Hz	6.05 Hz
2	0.3986	*	13.09 Hz	*	23.56 Hz	15.84 Hz
3	0.1471	*	21.03 Hz	*	37.86 hz	25.45 Hz
4	0.1798	*	29.36 Hz	*	52.84 Hz	35.52 Hz
5	0.0948	*	40.84 Hz	*	73.51 hz	49.42 Hz
6	0.1013	*	42.6 Hz	*	76.68 Hz	51.54 Hz
7	0.1000	*	54.4 Hz	*	97.91 Hz	65.82 Hz
8	0.0620	*	65.33 Hz	*		79.05 Hz
9	0.0502	*	67.72 Hz	*		81.84 Hz
10	0.0691	*	78.67 Hz	*		95.19 Hz
11	0.0591	*	90.79 Hz	*		
12	0.0145	*	92.32 Hz	*