CHARACTERIZING THE RADIATION DAMPING OF MULTI-STORY BUILDINGS THROUGH THE FORCED EXCITATION OF A NINE-STORY BUILDING

LISA SARMA, COLUMBIA UNIVERSITY SCHOOL OF ENGINEERING AND APPLIED SCIENCE
JAVIER FAVELA, CALIFORNIA INSTITUTE OF TECHNOLOGY
THOMAS HEATON, CALIFORNIA INSTITUTE OF TECHNOLOGY

SUBMITTED : OCTOBER 12, 1998

CHARACTERIZING THE RADIATION DAMPING OF MULTI-STORY BUILDINGS THROUGH THE FORCED EXCITATION OF A NINE-STORY BUILDING

by

L. Sarma[1], J. Favela[2], T. Heaton[2]
[1]Columbia University School of Engineering and Applied Science
[2] Seismological. Laboratory, California Institute of Technology

ABSTRACT

Seismic waves were generated through forced vibration of the nine-story Mill
located on the campus of the California Institute of Technology in Pasadena, Calif
1998, at the building's east-west natural frequency of 1.135 Hz.. The wave veloci
vibrations were recorded at distances of 1 to 6 kilometers away from the building.
floor of the building in both the north-south and the east-west directions were al
mathematical model was developed, which predicts the radiation pattern from the ro
rigid disk on the surface of a homogenous half-space. The inputs to the model wer
the rocking moment that the structure transfers to the ground as a result of its m

The acceleration data was used to calculate the forces and the moments from
experimental data was plotted as a function of its distance to the building and sh
velocity decreases with distance according to a power law that varies for each com

Further work needs to be done, ultimately comparing the experimental data to
assessing the accuracy of the model. The forces and moments will be input into th
the radiation pattern produced. Since February of 1998, seismometers have been pla
locations throughout the San Gabriel Valley between 1 and 7 kilometers away from M
from the Southern California permanent broadband instrument network was also colle
from the building can be seen as far away as Barrett (~230 km South East of the bu
where data was collected, the energy predicted by the model will be compared to th
point. The ratio between the radiated kinetic energy and the input kinetic energy
calculating the damping of the building due to energy radiation.

INTRODUCTION

Following excitation by an earthquake or other source of motion, the motion
damped as energy is dissipated. This energy can be lost to friction and inelastic
and to the radiation of seismic waves excited by the building's vibration. Buildi
mechanism through which energy can be dispersed so that ruin and collapse of the s
In order to develop this type of mechanism, the manner in which damping occurs mus
The damping of buildings is typically 2-5%. To best design a damping system, it
what portion of this percentage of damping is due to the energy being dissipated b
what part is due to the transferal of energy into the ground.

If the damping is completely due to inelastic properties of the building its
energy must be absorbed by the building which may be deleterious to the structure
internal framework undergoes inelastic strain from the motion. Instead, if the dam
excitation of seismic waves, then by the laws of reciprocity, vibrations which ori
efficiently excite vibrations in the building. This is of particular concern when
where the ground naturally vibrates at low periods which are typical of multi-stor
seconds). Since only 2-5% of this energy is dissipated per cycle, these structure
energy accumulates within the building. During extended exposure to low-frequency
amplified with each vibration.

The purpose of this study is to characterize the damping of multi-story bui
based on the idea that if we control the total amount of energy input into the bui
energy dissipated into the ground and then calculate the amount that is being tra
Knowing how the energy is dissipated is instrumental in designing a damping mecha
comprehensive picture of the energy that is radiated away from the building throug

mathematical model was developed which predicts the radiation pattern from the rocl
rigid disk on the surface of a homogenous half-space. The main idea of this resea
accuracy of this model through comparison to experimental data.

Millikan Library, a 9-story reinforced concrete structure on the campus of th
Technology in Pasadena, California, was the building used in this study. Using ar
vibration generator, the building was excited at its East-West natural frequency o
recorded on each floor of the building as well as 1 to 6 kilometers away from the
recorded within the building is used to solve for the resultant forces and moments
continuing work, this data will be input into the model, the output of which will
recorded on the field. The accuracy of the model can then be evaluated. If the mo
matches that recorded in the field, inferences about damping can be made. Otherw
have to be developed.

This problem is of particular interest to civil engineers, who must design l
associated damping mechanisms. It also has direct effects on society, because unt
implemented, those living in earthquake-prone areas, especially in basins, will be
collapse since there is not enough knowledge available now to prevent it.

EXPERIMENTAL METHODS AND PROCEDURE

Building Data. The structure under study was the Robert A. Millikan Librar
in Pasadena, California, on the campus of the California Institute of Technology.
system of the building is composed of exterior shear walls on the east and west fa
center (elevator shaft), and a concrete moment-resisting frame on the north and sou
system consists of 9 in. slabs of 2-way reinforced concrete and supported by reinfo
(Jennings and Kuriowa, 1968). The resonant frequency in the E-W direction was fou
experimentation to be 1.135 Hz. The masses, assumed to be concentrated at each fl
Table 1.

Table 1 Building Data

FLOOR	HEIGHT (m)	MASS (kg)
BSMT	-4.267	
1	0.000	1,0
2	4.877	1,1
3	9.144	
4	13.411	
5	17.678	
6	21.946	
7	26.213	
8	30.480	
9	34.747	
ROOF	39.014	1,1

(Jennings and Kuriowa, 1968)

Apparatus. The eccentric-weight vibration generator which produced the sinu building is mounted on the roof of Millikan Library (Foutch, Luco, Trifunac, Udwac vibration generator is powered by an approximately 1-horsepower motor (Dr. Thomas personal communication). For data collected within the building, the 36-channel K Whitney system operated by the United States Geological Survey(USGS) was employed building. The accelerometers in this system were 1G and 2G FBA (Force Balance Acc collecting data in the field, 2 L4C3D 1-second seismometers operated by the Southe Earthquake Center(SCEC) were used.

Procedure. In February of 1998, the Millikan Library building was subjected at its east-west natural frequency of 1.135 Hz. The seismic wave velocities produ recorded at 1-kilometer increments along lines up to 6 kilometers east of the buil kilometers south of the building. The accelerations of each floor of the building w the north-south and east-west directions. A model was developed which derives the the seismic waves from the rocking and shearing of a rigid disk on the surface of a It used the problem set-up from Bycroft (1955) and followed the method used by Cher transversely excited rigid disk.

To compare the field data with the data produced by the model, the moments ar to the ground from the building were calculated. The displacements due to shearin as shown in Figure 2, produced moments due to rocking and bending of the building due to shearing and bending of the building. The maximum accelerations at each flo the building data; in order to do this, a program was written which looked at the maximum values of each sinusoidal period. These values were largest in the 0.88-s reduce anomalous peaks, the values were restricted to be within 50% of the average frequency of previously found maximum values. This procedure found the maximum va eliminating anomalous data which may have resulted from unintended electrical sign occurrences. The acceleration data along with the masses, heights, and frequency the forces and moments on the soil from the building.

The field data velocities were plotted on a log-log plot with respect to dis input energy decayed with distance.

CHALLENGES

During my internship, I gained depth in my understanding of the research pro research is more than just getting results. It encompasses the entire process of researching what has been done in the area, and determining a reasonable portion t involves the design of a method through which to solve the problem, as well as al which aid you in getting results. Research includes dealing with setbacks or unex reevaluating your initial hypothesis. The investigator must be flexible to change the creativity to conceive of explanations for the unanticipated.

Although the main objective of my work was to find the forces and moments fr and analyzing the numerical model, a large part of my research experience was spent code to find the average maximum accelerations from the wave forms of each floor of which would then be used to find the resultant forces and moments from the buildin was challenging since there were no specific figures to compare the output against the output of the program was reasonable until the program had been run on all of it could be looked at as a whole and determined to be either sensible or inconsis way to sort through the data so the analysis could be done, but I soon realized th preparatory work which is the most time-consuming. The analysis then follows, wit and manipulation of data collected yielding the most fruitful results. These are experiences in research which make it so appealing.

RESULTS AND CONCLUSIONS

The shearing force and the overturning moment for an east-west shake of Milli calculated. The total overturning moment was 40,237.593 N*m and the total shearir N. The data is contained in Tables 2 through 4, and will be entered into the moc compared to the experimental data which is found in Table 5 and 6 and Figure 3 anc

For the seismometer line south of the building, the transverse component is other components, as expected (Figure 3). This component is indicative of the amo energy trapped as Love waves. Initially, the amplitude of the Love waves decays w ~r^2/3. The radial and vertical channels should theoretically not contain any sig Rayleigh waves. It is also expected that the N-S transverse component be bigger t components in the E-W line, since the building does not rock very much in the E-W line east of the building, the components indicative of the Rayleigh wave dominate and radial components. The amplitude of these two channels has a varying power la point. Theoretically, the transverse component should not have a signal, as this

Since February of 1998, seismometers have been placed in 68 different places Gabriel Valley and the building was vibrated at its east-west, north-south, and tc frequencies. The data from these shakings will be input into the model as well. close to the experimental data, it can be used to predict wave velocities all thı wave velocities will also tell us about the shallow subsurface soil structure. Ot evaluated and another type of model, such as a finite element model, may have to b

	Table 2 Rigid Body Rocking		
FLOOR	DISPLACEMENT (m)	VELOCITY (m/s	ACCELERATION (m/s2)
1	0.000E+00	0.000E+00	0.000E+00
2	5.375E-08	3.833E-09	2.734E-08
3	1.008E-07	7.188E-09	5.126E-08
4	1.478E-07	1.054E-08	7.518E-08
5	1.949E-07	1.198E-08	9.910E-08
6	2.419E-07	1.725E-08	1.230E-07
7	2.889E-07	2.060E-08	1.469E-07
8	3.360E-07	2.396E-08	1.709E-07
9	3.830E-07	2.731E-08	1.948E-07
ROOF	4.300E-07	3.067E-08	2.187E-07

	Table 3 Ben		
FLOOR	DISPLACEMENT (m)	VELOCITY (m/s	ACCELERATION (m/s2)
1	0.000E+00	0.000E+00	0.000E+00
2	3.698E-07	2.637E-06	1.881E-05
3	9.017E-07	6.431E-06	4.586E-05
4	1.630E-06	1.163E-05	8.292E-05
5	2.450E-06	1.747E-05	1.246E-04
6	3.059E-06	2.181E-05	1.556E-04
7	3.747E-06	2.672E-05	1.906E-04
8	4.723E-06	3.368E-05	2.402E-04
9	5.459E-06	3.893E-05	2.776E-04
ROOF	6.251E-06	4.458E-05	3.179E-04

	Table 4 Rigid Body Shearing		
FLOOR	DISPLACEMENT (m)	VELOCITY (m/s	ACCELERATION (m/s2)
1	4.417E-07	3.150E-06	2.246E-05
2	4.417E-07	3.150E-06	2.246E-05
3	4.417E-07	3.150E-06	2.246E-05
4	4.417E-07	3.150E-06	2.246E-05
5	4.417E-07	3.150E-06	2.246E-05
6	4.417E-07	3.150E-06	2.246E-05
7	4.417E-07	3.150E-06	2.246E-05
8	4.417E-07	3.150E-06	2.246E-05
9	4.417E-07	3.150E-06	2.246E-05
ROOF	4.417E-07	3.150E-06	2.246E-05

Figure 1 Building Displacements

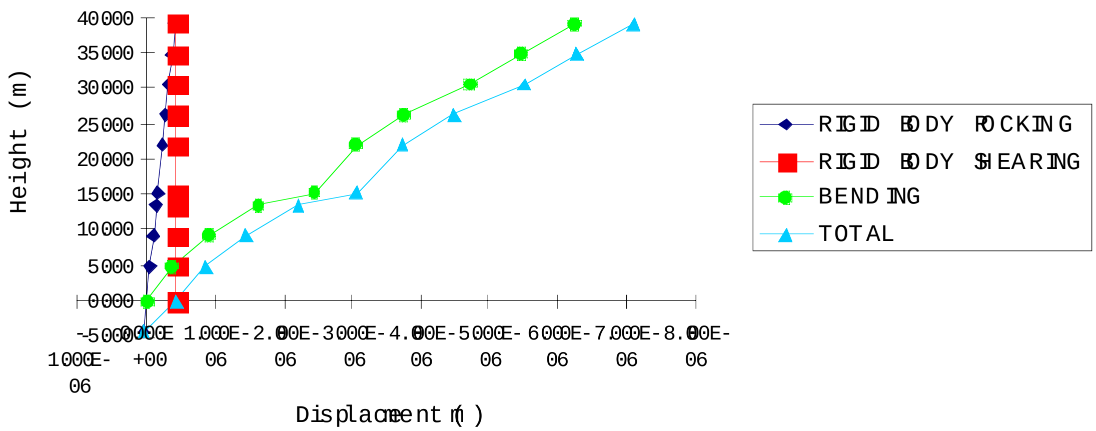


Table 5 Field Data						
Distance (km)	E-W Vertic	E-W Transverse	E-W Radia	N-S Vertica	N-S Radi	N-S Transvers
1	2.73048E-	1.00552E-0	1.9533E-07	-1.004E-0	1.1603E-07	-6.17118E-0
2	8.39711E-	5.84311E-0	1.7789E-07	9.4813E-08	8.1195E-08	-3.73901E-0
3	5.52359E-	1.40677E-0	7.5182E-08	6.3302E-09	-4.865E-0	2.86208E-0
4	4.58739E-	3.77055E-0	3.9448E-08	3.0193E-08	7.2978E-08	-1.45451E-0
5	1.0734E-0	2.08312E-0	2.218E-0			
6	5.16135E-	9.99682E-0	2.3704E-08			

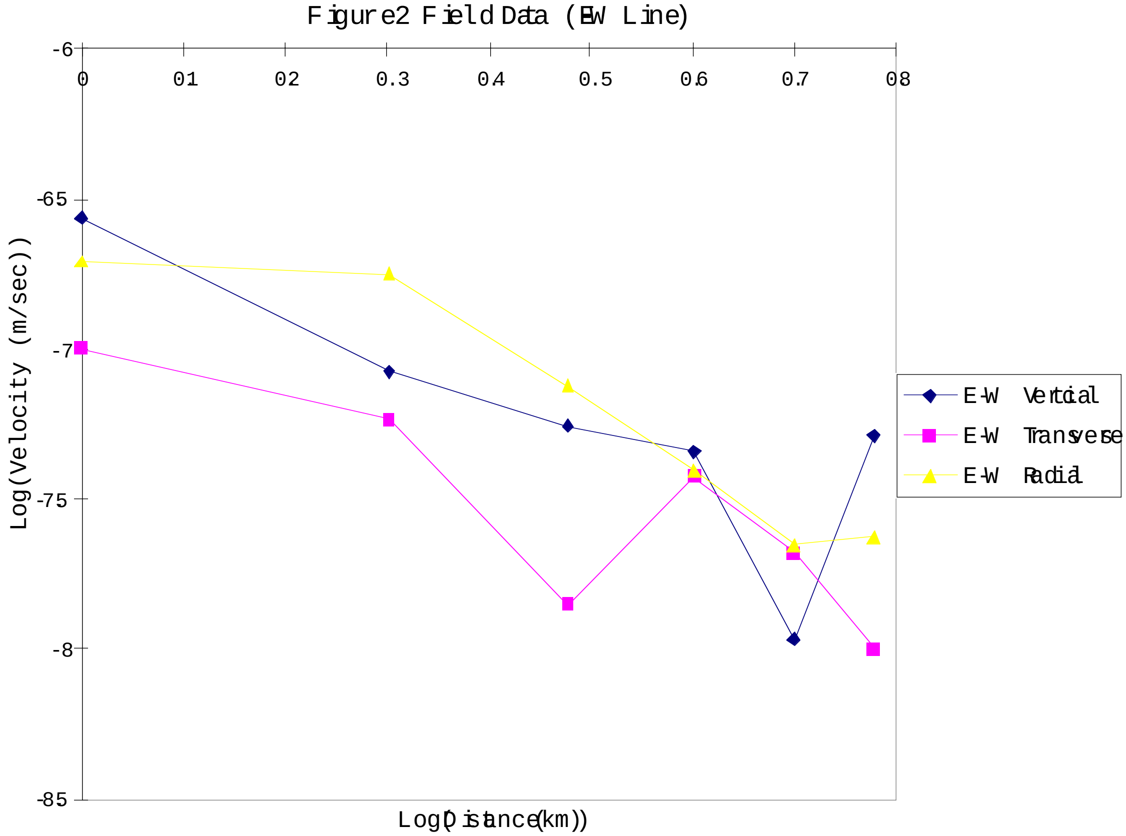
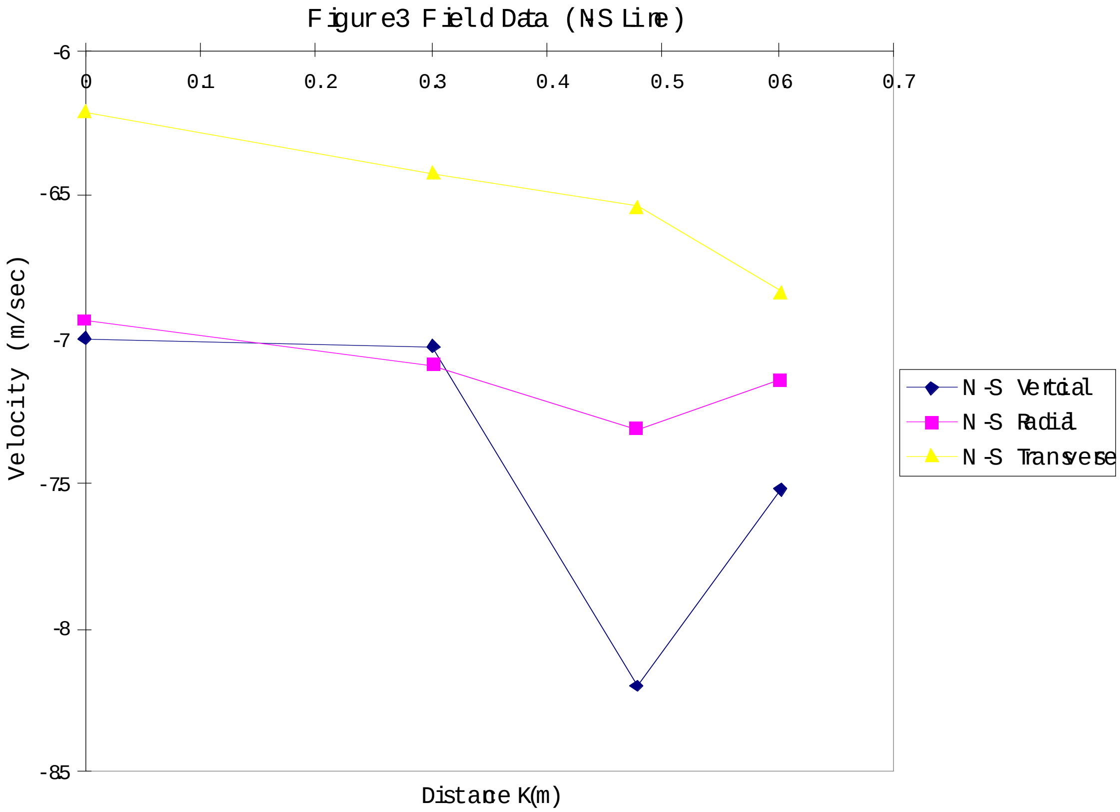


Figure2 Field Data (EW Line)
-6
-6.5
-7
-7.5
-8
-8.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Log(Velocity (m/sec))
Log(Distance(km))
E-W Vertical
E-W Transverse
E-W Radial



APPLICATIONS

Results of this research project are important to engineers, geologists, and have important effects on the safety and security of individuals living in earthqua a model which predicts a natural response to an interaction between technology and us to better understand earth processes and our effects on the earth. It helps u its history, as developing a picture of the shallow soil structure gives geologist and seismologists understanding of wave deflections. This project leads to better damping in multi-story buildings and more accurate hazard mitigation in earthquake

ACKNOWLEDGEMENT

Sincerest appreciation for assistance and guidance in this project is extend
Thomas Heaton.

The authors are also grateful to the United States Geological Survey and the
Earthquake Center for providing the instruments used in this research, and to the
Earthquake Center and the Pacific Earthquake Engineering Research Center for provid
the means to make this project possible.

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