ANALYSIS OF MICRO-VIBRATION IN BUILDINGS

Haridayal Jaswal

Home Institution: College of Engineering, The City College of New York, 138th Street & Convent Avenue, New York, NY 10031

Host Institution: College of Engineering, The City College of New York

Advisor: Dr. Anil Agrawal

ABSTRACT

Vibrations are produced during various operations from railway and roads to foot traffic, it propagates in different mediums. Following are examples of the reactions, due to vibrations, caused in parent-mediums and its surrounding:

- damage during the production of Micro-Nano scale equipments, for instance silicon-chips and devices related to Nanotechnology;
- produces error during experiments in labs equipped with lasers, sensors or micro-scopes;
- creates hazardous environment in operation-theaters at hospitals, particularly Neurosurgery;
- long-term contact causes damages in buildings; minor effects such as cracks, which in critical cases could result in collapse, especially in historical buildings.
- Perceptible sustained vibration can cause nuisance for occupants of buildings.

Our proposal is a structural-design that will resist vibration. The design is of a floor isolated from its vibrating base, which has sandwiched a system of isolator, dampers and springs. This Single Degree Of Freedom (SDOF) structure reduces intensity of propagating vibration.

This research will be helpful in different areas of industries. The application of technology includes: semi-conductor facilities, hospitals, high precision labs, and manufacturing and maintaining equipments related to Nanotechnology. This out come could be applied to protect historical buildings and resist vibrations in industrial machineries. The objective of this research is to investigate the effectiveness of floor isolation systems in isolating vibration transmitted to a building in New York.

INTRODUCTION:

PROBLEM STUDIED:

Vibration is one of the main factors for fatigue in structures. Produced by different sources vibrations propagate from one medium to another. This could cause serious damage in industries producing Micro and Nano scale equipments. Vibrations could also produce error during experiments in high-precision labs equipped with lasers, sensors or microscopes. Surgery could be hazardous in operation-theaters affected of vibrations. Long-term contact to vibrations can causes damages in buildings, minor effects such as cracks, which in critical cases could result in collapse, especially in historical buildings. Perceptible sustained vibration can cause nuisance for occupants of buildings, which could cause diseases such as mild-deafness, memory-loss, and aggressive-behavior.

My research was done to: analysis effect of vibration in building, and find efficient way to reduce intensity of vibration propagating in structures. A building at Riverside at 158th Street, New York City, USA, was chosen as the site for investigation. Accelerometer was used to collect the data for theoretical analysis; acceleration of vibrating floor was measured. Computer programs, Matlab™ and Working Model™, were used to calculate and analysis theoretical results. Analysis was done to reduce intensity of the vibration.

OBJECTIVE

Objective of this investigation is to:

1. Analyze the effects of micro-vibrations in structures
2. Conduct research on various buildings heavily effected by vibration, especially bridges and tunnels
3. Build a model that demonstrate feasibility of the researched theoretical calculations

BACK GROUND RESEARCH

Common sources of vibration were investigated (*Table 1*). *Table 1* gives us an idea of the magnitude of frequency and amplitude of vibrations induced by sources in a typical urban area. This information is helpful to understand the characteristics of the vibration-sources and the vibration induced.

Source	Freq. (Hz)	~Amplitude(in.)
Air Compressors	4–20	10^{-2}
Handling Equipment	5–40	10^{-3}
Pumps	5–25	10^{-3}
Building Services	7–40	10^{-4}
Foot Traffic	0.55–6	10^{-5}
Punch Presses	< 20	10^{-2} -10^{-5}
Elevators Up	< 40	10^{-3} -10^{-5}
Building Pressure Waves	1–5	10^{-2}
Building Motion	< 46 / height(m)	10^{-1}
Railroads	5–20	∓0.15g
Highway Traffic	5–100	∓0.001g

Table 1: Common environmental sources of vibration.

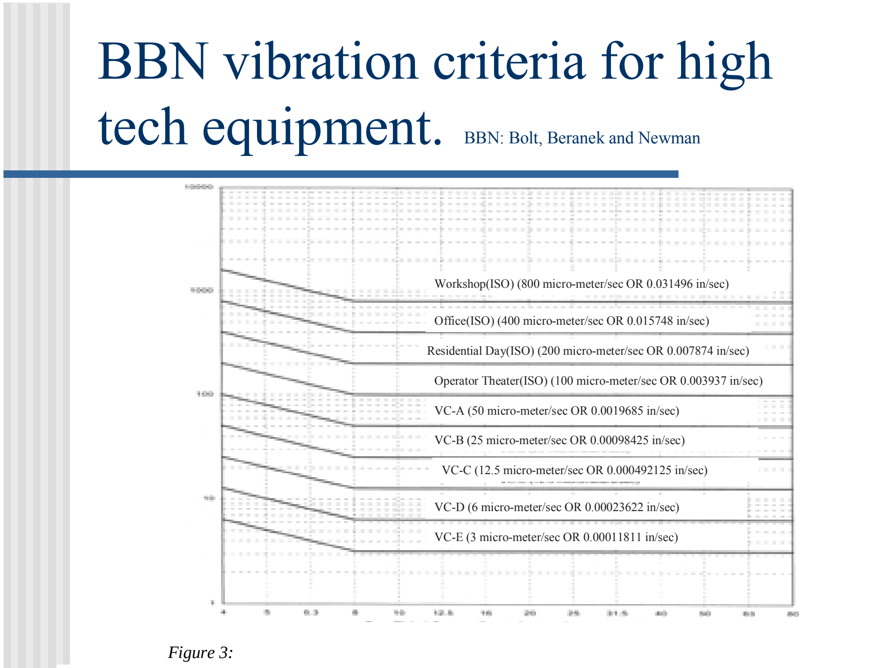


Figure 1: BBN vibration criteria for high tech equipment

A BBN vibration criterion is used to analyze micro-vibration efficiently. International Standard Organization (ISO) has considered safety level of vibration in structure as shown in figure 1. The use of BBN plot for data plot makes it easy to compare experimental-result with the recommended level of vibrations. Below table (*Table 2*) shows detail description of safety criteria for micro-vibration.

Criterion Curve	**rms Amplitude (μm/sec)***	**Detail Size (μm/sec)***	**Description of Use**
Workshop	800	N/A	Distinctly discernible vibration. Appropriate to workshops and nonsensitive areas
Office	400	N/A	Discernible vibration. Appropriate to offices and nonsensitive areas
Residential Day	200	75	Barely discernible vibration. Probably adequate for computer equipment, probe test equipment and low-power (to 20x) microscopes
Operating Theatre	100	25	Vibration not discernible. Suitable in most instances for microscopes to 100x
VC-A	50	8	Adequate for most optical microscopes to 400x, microbalances, optical balances, proximity and projection
VC-B	25	3	Appropriate for optical microscopes to 1000x inspection and lithography equipment (including steppers) to 3 micron line widths
VC-C	12.5	1	A good standard for lithography and inspection equipment to 1 mm detail size
VC-D	6	0.3	Suitable for the most demanding equipment, including electron microscopes (TEMs and SEMs) and E-beam
VC-E	3	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for long-path laser-based interferometers and other systems requiring extraordinary dynamic stability

Table 2: Effects of Vibration on People and Buildings according to Transport and Road Research Laboratory (U.K.)

Usually micro-vibration in buildings is expressed in terms of amplitude of *micro-vibration in one-third octave band* versus the center *frequency of the band*. The one-third octave plot of any velocity time history is calculated from its Fourier transformation as (Yang and Agrawal, 2000):

$$\dot{X}_{1/3}(n_c) = \left[\sum_{0.89}^{1.12 n_c} \dot{X}(n) \Delta n \right]^{1/2}$$

Where,
Δn = resolution of FFT;
n = Frequency in Hz;
n_c = Centre frequency

The centre frequency is given by $n_c = 2^{(m/3),}$ where m is an integer. The one-third octave bandwidth is approximately 23% of its centre frequency. One-third octave plot obtained from Eq. (1) is constant in the frequency band from $0.89n_c$ to $1.12n_c$. To evaluate $X_{1/3}$ (n_c) in terms of the BBN vibration criteria it is also expressed in dB referenced to V0 = 1 μin./s, that is

$$V(nc) = 20 \log[\dot{X}_{1/3}(nc) / V0]$$

Peak Particle Velocity (PPV) (mm/s)	**Human Reaction**	**Effect on Buildings**
0 – 0.15	Imperceptible	Unlikely to cause damage of any type
0.15 – 0.3	Threshold of perception	Unlikely to cause damage of any type
2.0	Vibrations perceptible	Effects ancient and historical monuments
2.5	Continuous exposure to vibrations is annoying	Virtually no risk of “architectural” damage to normal buildings
5	Vibrations annoying to people in buildings	Threshold for risk of “architectural” damage in houses with plastered walls and ceilings
10 - 15	Continuous vibrations are unpleasant and unacceptable	Would cause “architectural” and possibly minor structural damage.

Table 3: Effects of Vibration on People and Buildings according to Transport and Road Research Laboratory (U.K.)

Following is comparison of solution currently available:

1. Building wave barriers to isolate from vibration sources by digging trenches around building boundary. Wave barriers are expensive to build and take lots of space for implication thus it is not viable for urban area.
2. Building facility far away from the vibration sources. (i.e. away from railways and roads). Site of location increases transportation cost of human and goods also it makes facility isolated for individuals.

RESEARCH APPROACH

Primary study was done to measure vibration in building under Riverside in New-York. Objective is to use building for office, Building seems to have high level of traffic-induced vibration, one possible solution is to use isolated floor.

Acceleration of vibrating floor was measured using sensitive accelerometer for theoretical analysis; this data was collected during medium rush hour. Computer programs, Matlab™ and Working Model™, were used to calculate and analysis theoretical results. Acceleration data was passed through high-pass filter to remove low frequency static component in Matlab. A high pass filter with cutoff frequency of 1 Hz was used. Acceleration data was integrated using Simpson's Method to obtain velocity and time history. Further analysis was done to obtain One-Third Octave Spectrum from velocity data. This analysis was done to reduce intensity of the vibration.

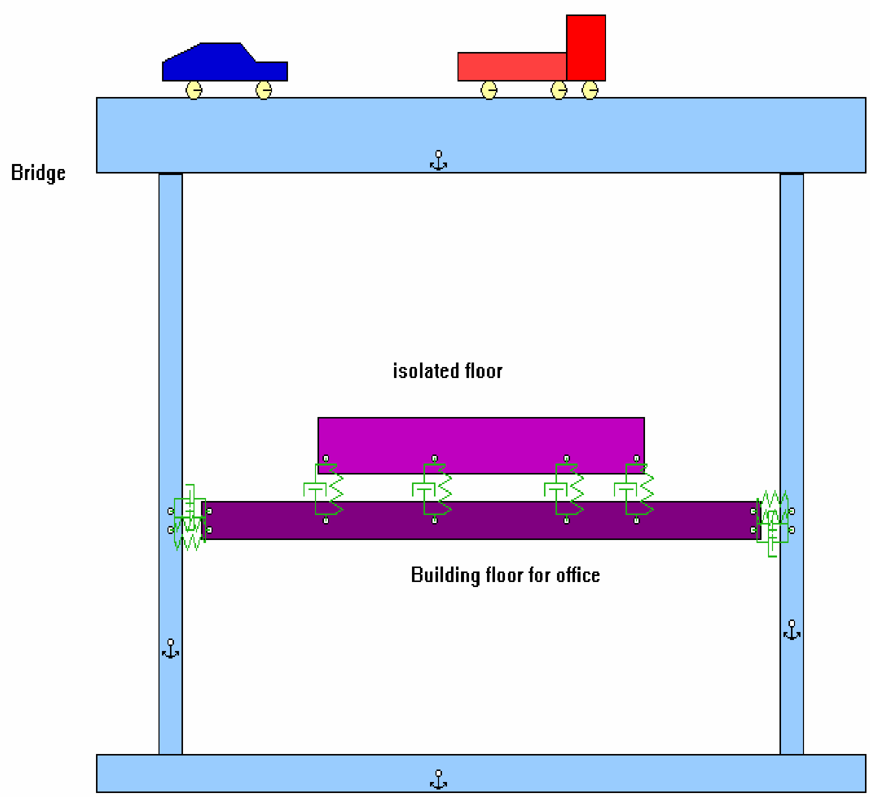


Figure 2: Building at 158th Street and Riverside in New York with Micro-Vibration. (Working Model™)

RESULTS

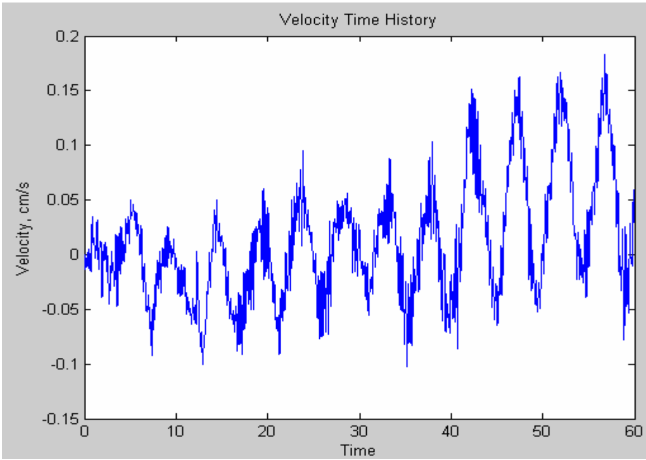


Figure 3: Velocity vs. Time History

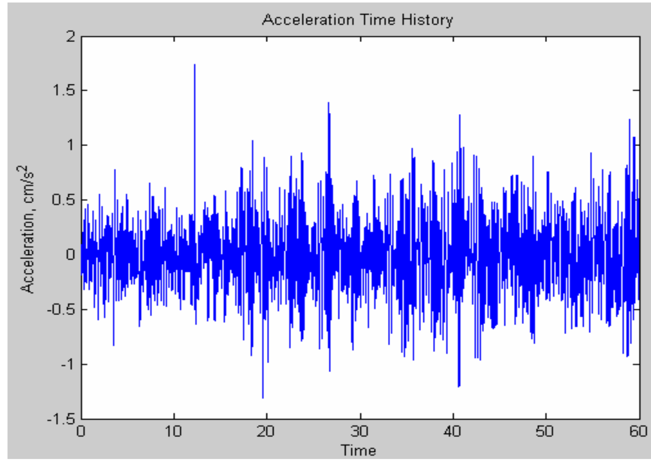


Figure 4: Acceleration vs. Time History

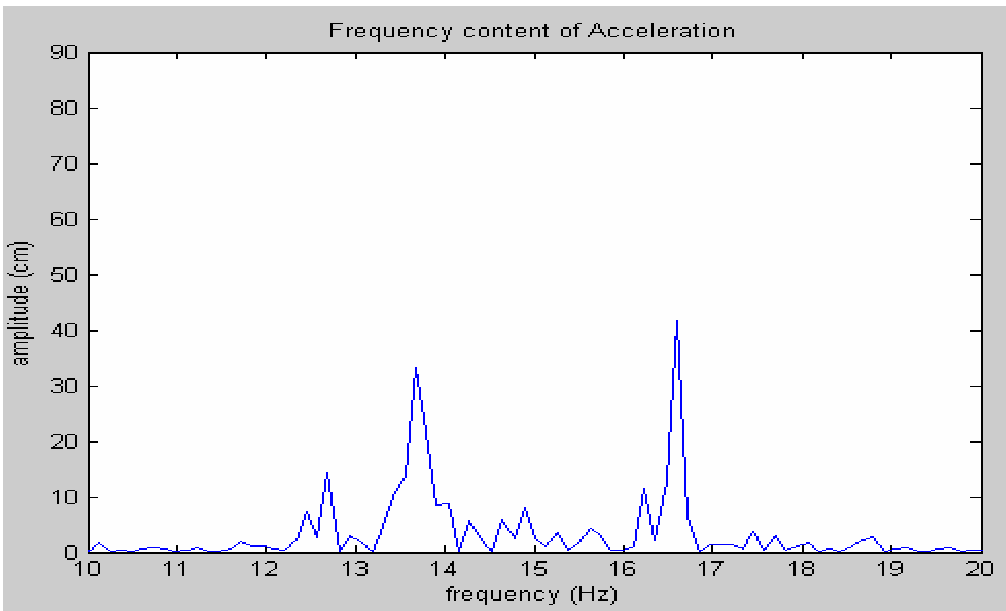


Figure 5: Frequency content of Acceleration (FFT Transformation)

Above is graphical illustration of experimental results obtained by the accelerometer. *Figure 3* is a graph of *Velocity vs. Time* was obtained using the Simpson's Method. *Figure 4* is graphical illustration of *Acceleration vs. Time* was obtained from the accelerometer. *Figure 5* is a graph of Amplitude vs. Frequency was obtained from the Fast Fourier Transformation.

	Room 1		Room 2	
Test	**CH01 (mm/s)**	**CH02 (mm/s)**	**CH01 (mm/s)**	**CH02 (mm/s)**
1	2.434	2.275	2.329	2.987
2	2.152	1.978	2.234	2.086
3	1.961	1.756	1.386	2.427
4	2.037	1.945	1.833	2.723
5	3.266	2.824	2.506	2.725
6	2.271	2.010	3.299	4.445
7	2.406	2.153		
	< 2.0 mm/s			
	< 2.5 mm/s			

Table 4: Peak Particle Velocity (PPV) for the vibrating floor

The experimental data was obtained 7 and 6 times respectively for room 1 and room 2 using two accelerometers, this makes a total of 26 cases. Above table has been prepared calculating the Peak Particle Velocity (PPV) of each case. Comparing these data with the background research it could be concluded that for blocks in yellow, vibrations exceeds the safety level of (<2.0 mm/s) and is harmful for historical building. While data in red blocks in the table (velocity < 2.5 mm/s) shows that vibration level is harmful for human. Further analysis could be done from reported data; as discussed in background research this data was taken during medium rush hour(i.e 3pm), the intensity of vibration could change if data is taken during rush-hour(i.e. 5pm).

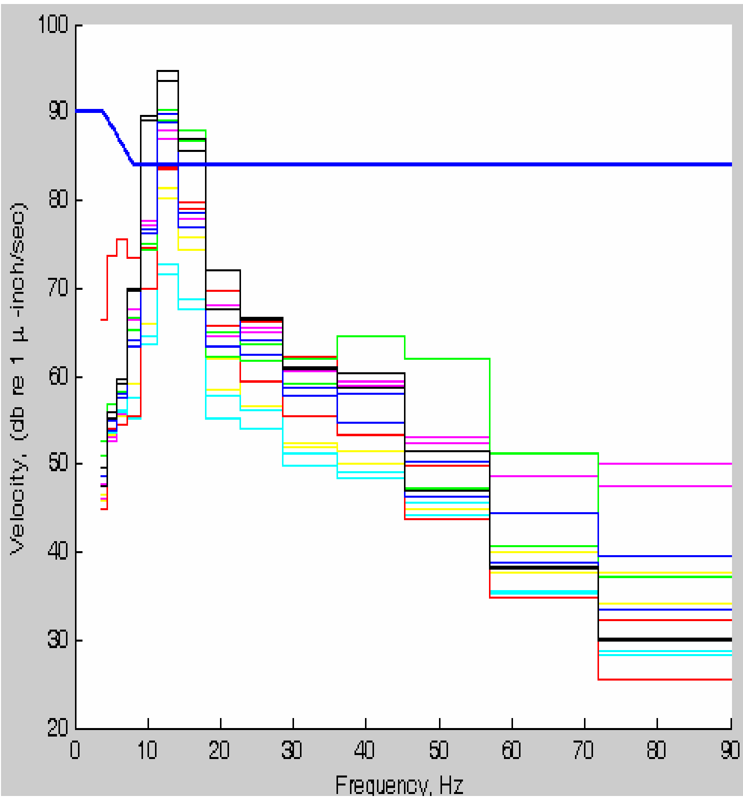


Figure 6: Room 1, Velocity vs. Frequency

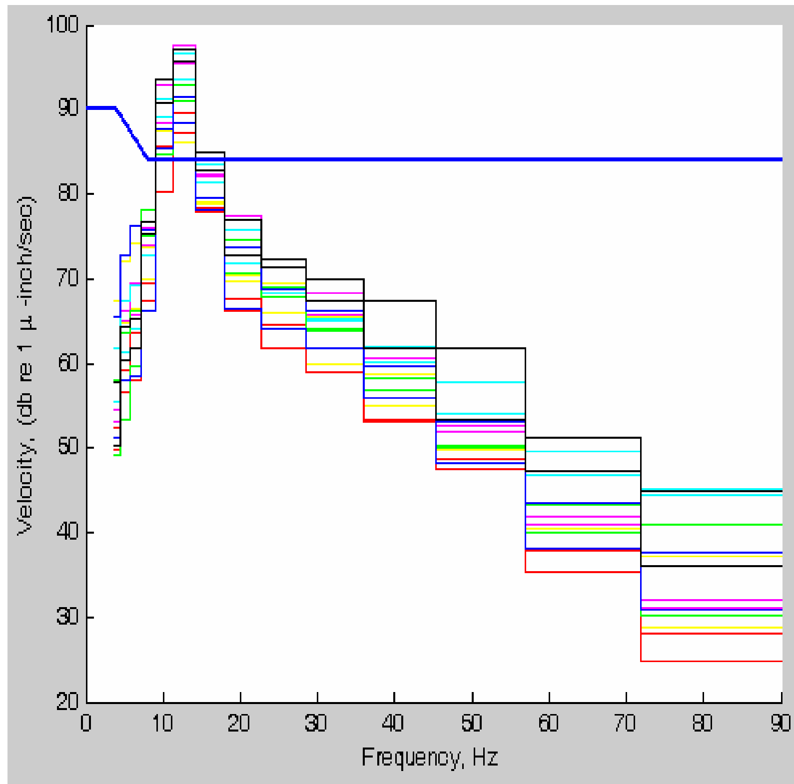


Figure 7: Room 2, Velocity vs. Frequency

Above is a One-Third Octave Spectrum, graphical demonstration of Fourier Transformation (FFT) of the data obtained through the experiments, where *Velocity vs. Frequency* is axis. The thick blue-line (at 90 db re 1 micro inch/sec) is safety level of vibration in a typical office.

By a Matlab program the data was analysis to a visual illustration as shown in above graphs. The Acceleration data was passed through high-pass filter to remove low frequency static component in Matlab. A high pass filter with cutoff frequency of 1 Hz was used.Further analysis was done to obtain One-Third Octave Spectrum from velocity data. The data could be easily compared with the safety level in this program.

The safety level of the vibrating floor could be approach by changing the variable in the Matlab program, i.e. damping and weight of floor. This approach is helpful to understand the required amount of damping and the weight of floor to reduce intensity of vibration to safety level.

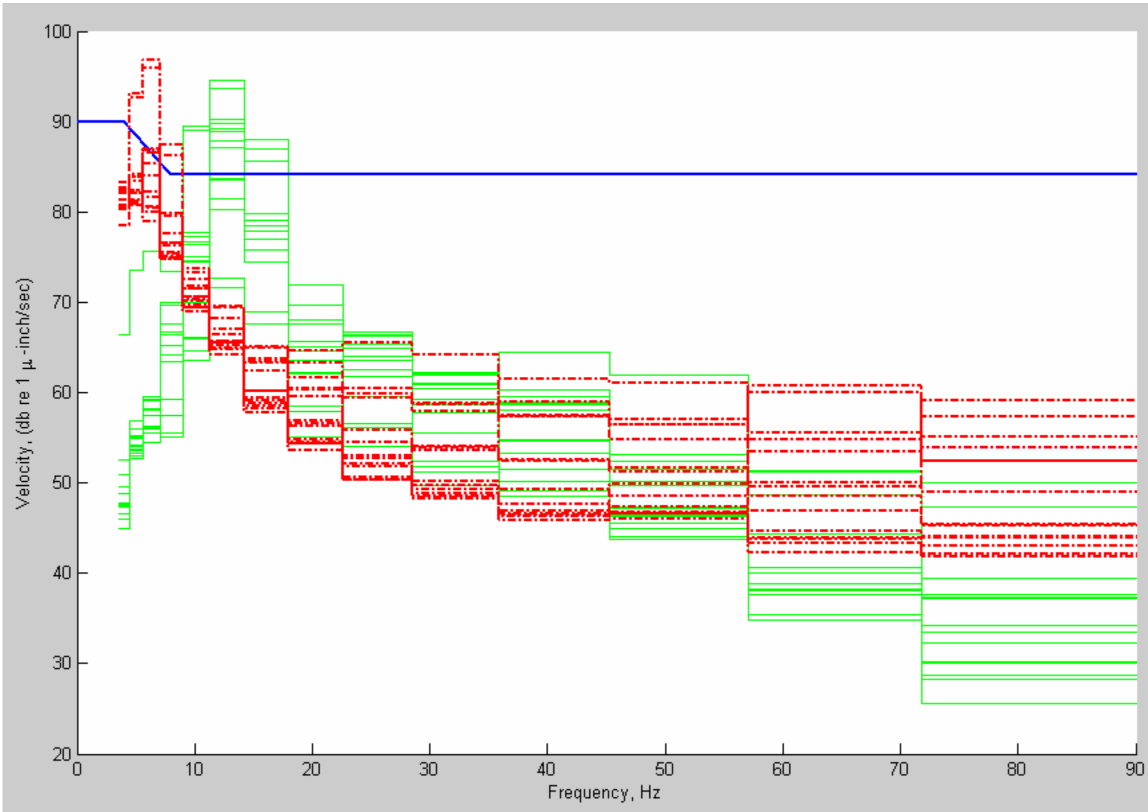


Figure 8: Comparison of Isolated base with vibrating base

Matlab program was used to analysis the data plotting One-Third Octave Spectrum from velocity data. Visual data could be easily compared with the safety level (i.e 90 db re 1 micro inch/sec) in this graph.

The level of the vibration in the floor could be approach isolating the vibrating floor using dampers and isolators. Theoretical calculations are done using this Matlab program to decide required damping and the mass of the floor. This approach is helpful to understand the required quality of dampers and the weight of floor in order to reduce intensity of micro-vibration.

Model of proposed structure:

A structural design is introduced; a floor isolated from its vibrating base, which has sandwiched a system of isolator, dampers and springs. This Single Degree Of Freedom (SDOF) structure was analyzed using Matlab™ for various values for: damping of the sandwiched system (i.e. isolators, dampers and springs), mass of the isolated floor, and the natural frequency of the isolated floor. The design will reduce vibration at location.

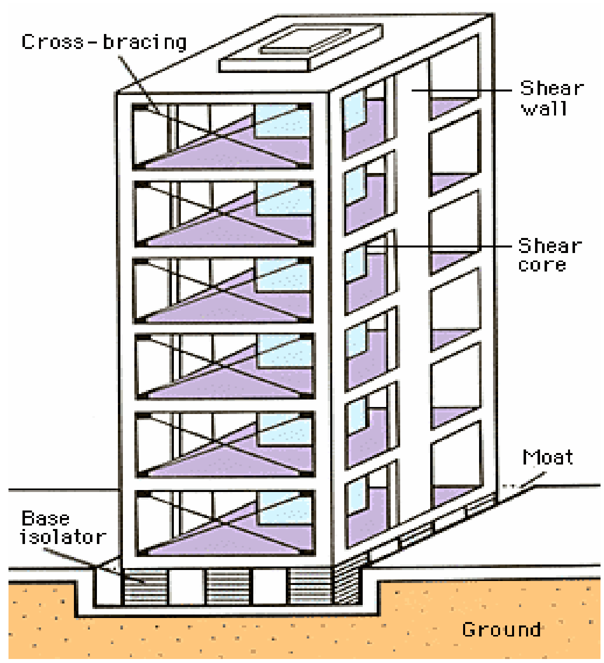


Figure 9: Vibration resistant Base Isolator (NASA)

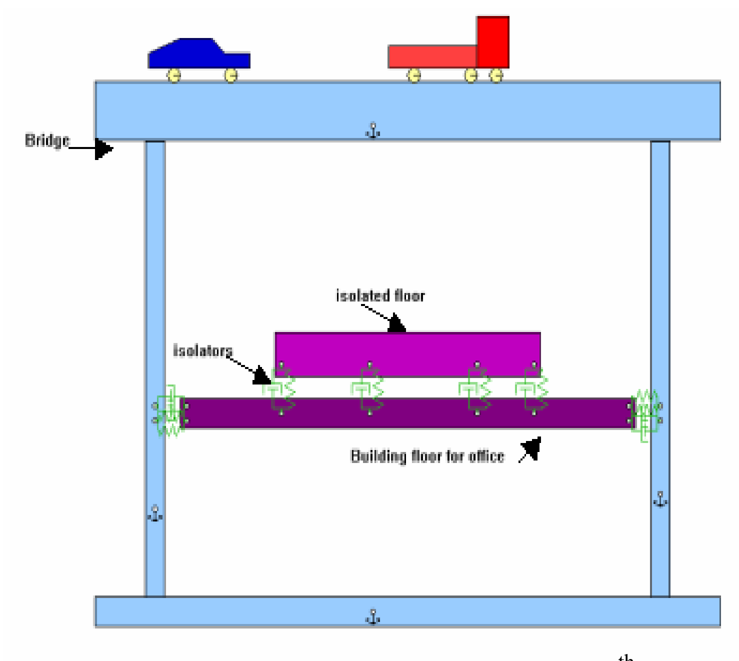


Figure 10: 2-D Model of Building at 158th Street and Riverside in New York with Micro-Vibration. (Working Model™)

Figure shows a 2-D model of proposed design were the floor (light violet) is isolated from its vibrating base (dark violet), which has sandwiched a system of isolator, dampers and springs. This Single Degree Of Freedom (SDOF) structure reduces intensity of propagating vibration.

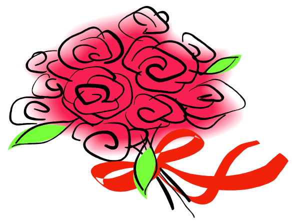
Building floor has significant vibration contribution in the frequency range of 14 to 17 Hz.

Following are possible dimensions of the design of an isolated floor:
Floor size = 50ft x 50ft
Floor mass=~ 130000 lb OR 6000 Kg
Isolated floor freq.=~ 5 Hz
Damping = 5 %

POSSIBLE FUTURE WORK

Further investigation is continued to apply active control concept.

ACKNOWLEDGEMENTS



Thanks to my advisor, Dr. A.K.Agrawal, and to the MCEER Education Program for providing the opportunity to participate in the NSF REU program.

Special thanks for Cooperation:
Mr. Zhihua Yi, PhD Mentor
Department of Transportation, New York City

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