DAMPING IN TALL BUILDINGS AND TOWERS

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This tutorial is a follow-up to Reference 1.

Introduction

Damping is a dissipation mechanism in which vibration energy is transformed into heat or some other energy form which is lost from the vibrating system. Engineering structures such as buildings require a certain minimum amount of damping for vibration control, particularly if the structure is excited at is natural frequency. The vibration response must be limited to avoid failures due to fatigue, yielding, loss of clearance, etc.[1]

This tutorial is primarily concerned with buildings constructed from steel beams, columns and girders. Some consideration is also given to reinforced concrete buildings.

Both measured data and recommended damping ratios are given.

Dynamic Excitation Sources

A building must withstand excitation from earthquakes and wind gusts.

In addition, there are other possible vibration sources including HVAC systems, machinery, plumbing, human footfall, outdoor traffic, etc.

Damping Sources

Potential damping sources in a building include:

1. Joint slip friction
2. Gas pumping in the gaps between connected members
3. Material dissipation
4. Boundary interactions between the foundation and soil
5. Aerodynamic drag
6. Permanent deformation
7. Sound radiation

Joint slip friction is most likely to be the dominant source of damping in an open framework per Reference 1. Buildings with floors, walls, ceilings and non-load bearing elements may have significant material damping, potentially exceeding joint damping.

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[1] In addition, human comfort is a concern for occupied buildings, because people at the top of a swaying building may experience symptoms of motion sickness.

The damping from three types of joints was considered in Reference 1: welded, friction bolted, bearing bolted. Empirical damping data was given for several small, laboratory-size beams and frames with joint connections.

In addition, Reference 1 gave generic damping values for buildings from standards for the case where measured data was unavailable.

The next step is to consider the damping of tall buildings with steel frameworks. Natural frequency and damping data sets for numerous buildings are available in journal articles and dissertations. Unfortunately, these references usually omit whether the joints were welded or bolted. Nevertheless, the damping values in Reference 1 provide a useful comparison basis.

San Diego Gas and Electric Company Building

The San Diego Gas and Electric Company Building has a moment resistant ductile steel frame. The joint type is not immediately available.

The building consists of a 22-story tower and a two-story U-shaped building at the base, as shown in Figure 1.

The tower height is 291 ft (89 m).

The building was excited by two eccentric mass vibration shakers mounted on the 20th floor. The measured frequency and damping data is given in Table 1, as taken from Reference 2, Table II.

Table 1. San Diego Building, Forced Vibration Test Results

Mode	North-South		East-West		Torsional	
No.	Freq(Hz)	Damping	Freq(Hz)	Damping	Freq(Hz)	Damping
1	0.382	1.6%	0.394	2.5%	0.425	2.0%
2	1.10	2.7%	1.20	1.6%	1.23	3.4%
3	1.99	3.7%	2.27	3.1%	2.15	2.9%
4	3.00	3.9%	3.40	2.8%	3.36	3.0%
5	4.10	3.1%	4.46	3.0%	4.75	4.4%
6	5.10	4.4%	5.30	4.0%	5.78	3.4%

The damping ratio for the first mode in each direction ranges from 1.6% to 2.5%.

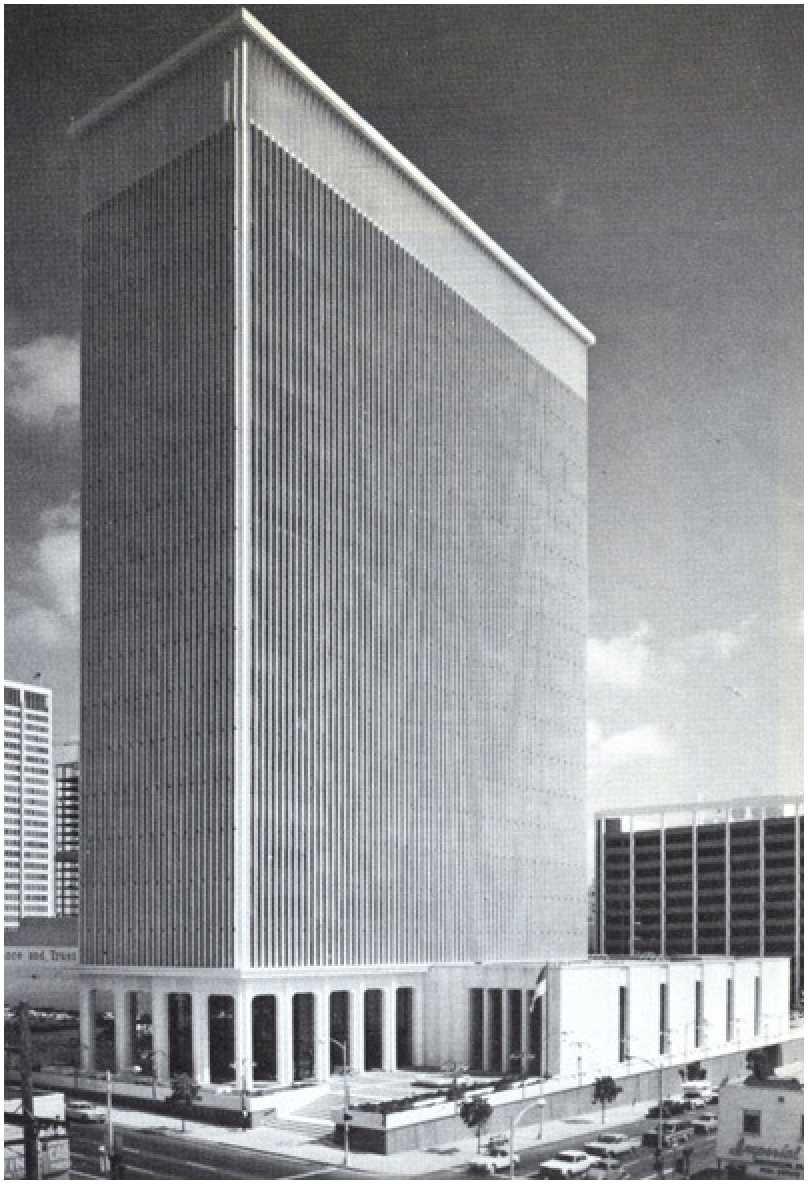

Figure 1. San Diego Gas and Electric Company Building

The building was completed in 1968. It survived the magnitude 6.5 Borrego Mountain earthquake of April 9, 1968.

Transamerica Building

Figure 2. Transamerica Pyramid

The Transamerica Pyramid is built from a steel frame, with a truss system at the base. The height is 850 ft (260 m),

Reference 3 gives natural frequency and damping as obtained in the 1989 Loma Prieta earthquake and due to ambient vibration. The ambient vibration was presumably due to wind, low level micro-tremors, mechanical equipment, outside street traffic, etc.

Table 2. Transamerica Pyramid, Modal Parameters

Direction	Loma Prieta Earthquake		Ambient Vibration	
	fn (Hz)	Damping	fn (Hz)	Damping
North-South	0.28	4.9%	0.34	0.8%
East-West	0.28	2.2%	0.32	1.4%

The results show non-linear behavior with an increase in damping during the severe earthquake relative to the benign ambient vibration.

Pacific Park Plaza

Figure 3.

The Pacific Park Plaza height is 308 ft (94 meters). It has a reinforced concrete moment-frame/shear-wall structure. The natural frequencies and damping are given in Table 3, as taken from Reference 3. Again, the damping is non-linear. Some of the damping is presumably due to micro-cracks in the concrete.

Table 3. Pacific Park Plaza, Modal Parameters

Direction	Loma Prieta Earthquake		Ambient Vibration	
	fn (Hz)	Damping	fn (Hz)	Damping
North-South	0.38	11.6%	0.48	0.6%
East-West	0.38	15.5%	0.48	3.4%

California State University Hayward

Figure 4. CSUH Administration Building, Warren Hall

The Warren Hall height is 200 ft (61 m). Its design has a steel moment frame core with a concrete exterior. The natural frequencies and damping ratios in Table 4 are taken from Reference 3.

Table 4. CSUH Warren Hall, Modal Parameters

Direction	Loma Prieta Earthquake		Ambient Vibration	
	fn (Hz)	Damping	fn (Hz)	Damping
North-South	0.76	3.4%	0.92	0.6%
East-West	0.76	2.3%	0.86	0.6%

Note that plans have been made to perform a seismic retrofit on this building because it is built on the Hayward Fault, per Reference 7.

Self-Supporting Steel Lattice Towers

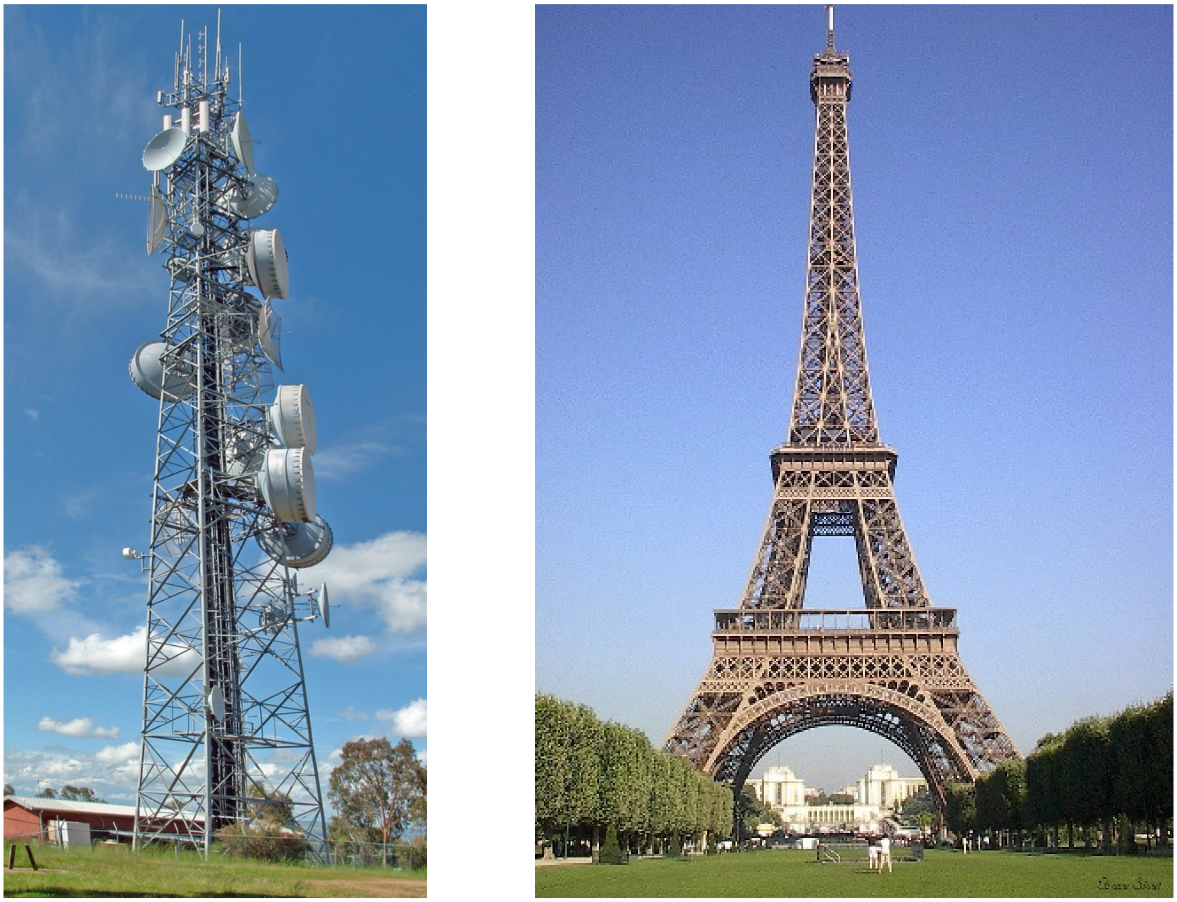

Figure 5. Sample Lattice Towers

Lattice towers are used for power lines and telecommunication equipment. The most elegant example is the Eiffel Tower in Paris.

Sample test data for a lattice tower is not immediately available, but Reference 4 recommends the damping values in Table 5.

Table 5. Lattice Tower Damping

Type	Damping
Fully Welded Steelwork	1.2%
High Strength Friction Bolted Steelworks	2.0%
Normal Bolted and Riveted Steelwork	3.0%

Reference 4 states that the original source is *The International Association for Shell and Spatial Structures, IASS 1991,* but this source is not immediately available.

Bachmann, Recommended Damping Ratios

Reference 5 gives recommended values in Tables 6 and 7 based on building height and construction type. These are generic values that do not account for the specific joint type, foundation-soil interaction, etc.

Table 6. Recommended Damping Ratios,
Building Height > ~ 100 m (328 ft)

Construction Type	Minimum	Mean	Maximum
Reinforced Concrete	1.0%	1.5%	2.0%
Steel	0.7%	1.0%	1.3%

Table 7. Recommended Damping Ratios,
Building Height ~ 50 m (164 ft)

Construction Type	Minimum	Mean	Maximum
Reinforced Concrete	2.0%	2.5%	3.0%
Steel	1.5%	2.0%	2.5%

The Architectural Institute of Japan (AIJ), Damping Ratios

AIJ, Reference 6, gives the natural frequencies and damping ratios in Table 8. Note that *Rec.* is an abbreviation for recommended.

Table 8. AIJ Steel Building, Natural Frequencies & Damping Ratios, Recommended and Standard

Height		Habitability			Safety		
(ft)	(m)	Natural Freq (Hz)	Damping Rec.	Damping Standard	Natural Freq (Hz)	Damping Rec.	Damping Standard
98	30	1.7	1.8%	2.5%	1.4	2%	3%
131	40	1.3	1.5%	2%	1	1.8%	2.5%
164	50	1	1%	1.5%	0.83	1.5%	2%
197	60	0.83	1%	1.5%	0.69	1.5%	2%
230	70	0.71	0.7%	1%	0.6	1.5%	2%
262	80	0.63	0.7%	1%	0.52	1%	1.5%
295	90	0.56	0.7%	1%	0.46	1%	1.5%
328	100	0.5	0.7%	1%	0.42	1%	1.5%
492	150	0.33	0.7%	1%	0.28	1%	1.5%
656	200	0.25	0.7%	1%	0.21	1%	1.5%

The Habitability damping values are lower because they are intended for human comfort. Humans become uncomfortable at a lower amplitude level than that which would compromise structural integrity.

The recommended damping ratios are lower than the standard values for conservatism.

Conclusions

Some of the damping data in this tutorial was taken from measurements on specific buildings. The remaining data was taken from recommended values which are presumably based on measured data sets.

The following conclusions apply to the fundamental mode.

1. Tall buildings can have damping ratios as low as 0.6% under ambient vibration conditions.

2. The damping is non-linear such that it increases with the excitation level. The damping of a steel building can be as high as 5% in a severe earthquake.

3. Lattice Steelwork Towers appear to have similar damping values as office buildings, although further data is needed.

References

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