PRELIMINARY STUDY OF CORRELATION OF NATURAL PERIODS AND DAMPING PERCENTAGES OF TALL BUILDINGS IN SEVERAL COUNTRIES

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ABSTRACT

Fundamental periods (T) and critical damping percentages (ζ) of 41 tall buildings in several countries form the basis of this preliminary study. Correlation between building height and fundamental period for steel and reinforced concrete buildings clearly shows a linear variation but with a large standard deviation, most likely due to considerable variation in the designs of structural systems. No credible correlation was attainable for critical damping percentages against the heights of the buildings. However, the main and important trend is that the critical damping percentages are clearly lower than <3%, consistent with recent tall building studies.

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Fundamental periods (T) and critical damping percentages (ζ) of 41 tall buildings in several countries form the basis of this preliminary study. Correlation between building height and fundamental periods for steel or reinforced concrete buildings clearly shows a linear variation but with a large standard deviation, most likely due to considerable variation in the designs of structural systems. No credible correlation was attainable for critical damping percentages against the heights of the buildings. However, the main trend is that the critical damping percentages are clearly lower than <3%; consistent with recent tall building studies.

Introduction

Dynamic response characteristics [fundamental periods (T) and critical damping percentages (ζ)] are identified from seismic response data for 41 instrumented tall buildings, including 14 from the United States, 22 from Japan, two from Mexico, and one each from Turkey, Dubai and Abu Dhabi. Data used in this paper are from our own as well as others’ studies. Heights of the buildings in the current database range from 51m to 292m, and additionally includes the current tallest building in the world, the 828m tall Burj Khalifa in Dubai [1,2]. The compiled response data have a wide variation of magnitudes of causative earthquakes, site conditions, peak accelerations at the basement and frequency contents. For example, the data base includes responses of (a) four tall buildings in Japan to the 2011 Mw9.0 Tohoku earthquake [3,4,5], (b) a tall building in Los Angeles, CA, to several near and distant earthquakes that include the 1994 Mw6.7 Northridge earthquake [6], (c) two tall buildings in San Francisco, CA, to the 2014 Mw6.0 Napa, CA, earthquake [7,8], (d) two tall buildings from Mexico [9] and also a database by Tamura and others [10]. Ambient data, when available, were also used to compare with results of earthquake data.

The response data studied by the author and collaborators were previously analyzed using a variety

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of methods (spectral analyses, coherency-phase analyses, system identification and modal property extraction and time-frequency distribution) to identify fundamental periods and critical damping percentages. Many important and consistent findings came from these studies include: (a) significant effects on the responses of tall buildings due to long-period motions from events that originate at far distances (e.g. 100-800km), (b) substantial average drift ratios resulted (~0.5%), even at hundreds of km away from epicenters of earthquakes, (c) local site effects and basin effects were significant, (d) in most cases, prolonged responses were observed - contributing to low-cycle fatigue and perhaps beating effects, (e) permanent shift of fundamental frequencies in some cases, and (f) in general, identified critical viscous damping percentages are low (<3%) and consistent with recent recommendations of the Tall Buildings Initiative (TBI) [11] in clarifying those guidelines. These are significant for both analyses and design For example, additional damping generating elements can be considered during design processes to decrease the prolonged and amplified responses. In addition, while basin effects are not considered during design, it is important to at least consider looking into such effects as these can result in resonance and amplified responses as shown in recent studies.

In this paper, I use the same building database to establish a correlation of period versus building height, and also consider a correlation between height and critical damping percentage. In this study, the “polyfit” routine in Matlab software version 2017 [12] is used.

**Data, Analyses, and Discussion**

After careful sorting through available but limited data, I selected 21 steel buildings, 14 reinforced concrete buildings and 6 mixed (steel and reinforced concrete) buildings. The range of heights of these 41 buildings is summarized in Table 1. It is important to note that obtaining such data has been and is difficult at best.

<table>
<thead>
<tr>
<th>Type of construction</th>
<th>No of buildings</th>
<th>Range of Heights (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>21</td>
<td>30-257</td>
</tr>
<tr>
<td>RC</td>
<td>14</td>
<td>51-828 (828= Burj Khalifa)</td>
</tr>
<tr>
<td>Mixed (Steel+RC)</td>
<td>6</td>
<td>41-157</td>
</tr>
</tbody>
</table>

Fundamental periods against building heights is plotted in Figure 1 for (a) steel, (b) reinforced concrete (RC) and (c) mixed (Steel+RC) buildings. Figure 1 shows a general linear trend between T versus H in each classification (steel, concrete and mixed buildings).

Damping percentage versus height of buildings (Figure 2), however does not exhibit any correlation. The TBI recommendation of a maximum damping of 2.5% for buildings with H<~60m (dashed line in the figure) is thus well justified. This compares well with the current recommendations included in TBI which recommends $\zeta_{\text{critical}} = 0.20/H^{1/2} \leq 0.05$ (H in meters) [under SLE shaking] (PEER, 2017) [11] and for MCE, $\zeta_{\text{critical}}$ can be taken as 2.5% for H>60m (see Figure 3).
Figure 1. Spread of fundamental periods versus height of (a) steel, (b) reinforced concrete and (c) mixed buildings
Figures 2. Damping percentage versus height of (a) steel, (b) RC and (c) mixed buildings. Dashed lines show the 2.5% critical damping percentage recommended by TBI in Figure 3.

Figure 3. Critical damping percentage versus height of the building above grade, $\zeta_{\text{critical}} = 0.20/H^{1/2} \leq 0.05$ as recommended by the TBI (Figure from PEER 2017/06) [11].

A linear relationship is fit to the data for period as a function of building height, for steel buildings (Figure 4) and reinforced concrete buildings (Figure 5). As indicated before, “polyfit” routine in Matlab software version 2017 [12] is used. In each case, I determined the fit for the north-south (“a” panels in each figure), east-west (“b” panels in each figure) and combined NS+EQ directions (“c” panels). A linear fit was chosen because it is the most simple form, and the data have a clear direct correlation.
It is noted that due to small number (sample number) of mixed buildings, correlation curves are not attempted. Also, data for the tallest building in the world (Burj Khalifa in Dubai - 828 m) are not used in the correlation as it prejudices the rest of the data and most likely affects the outcome slope of the correlation.

Figure 4. Fundamental periods versus height for steel buildings. The ±std (standard deviations) are shown as thinner lines, and the determined linear relationship is given.

Figure 5. Fundamental periods versus height for reinforced concrete buildings. The ±std (standard deviations) are shown as thinner lines, and the determined linear relationship is given.
A more detailed study that includes tables of particulars of buildings and cross-referencing of the source of data base supplemented with additional data is under preparation.

Conclusions

Preliminarily studies of a database of fundamental periods (T) and critical damping percentages (\(\zeta\)) of 41 tall buildings in several countries suggest a linear correlation between building height and fundamental periods for steel and reinforced concrete buildings with a large standard deviation, most likely due to considerable variation in the designs of structural systems. Secondly, no credible correlation exists between heights and critical damping percentages. Lastly, average critical damping percentages are less than <3%, which is consistent with recommendations of the Tall Buildings Initiative recommended guidelines (PEER Report [12]). Future work will aim to incorporate more data as it is obtained.

References

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