Ayhan IRFANOGLU*

FACING UNCERTAINTY: THE PRACTICE OF EARTHQUAKE ENGINEERING

Abstract: The realm of earthquake engineering practice is rife with uncertainties. The constraints imposed by regulations on this creative profession are often for good reason as they, sometimes, help tame the forces from finance with realities known from Nature. However, there are assumptions built into the current practice of earthquake engineering, whether stemming from or feeding into some of the regulations, which go against the maxim „know what you know and what you do not know" which defines engineering. While many examples may be given from earthquake engineering practice around the World, the dominating attitude in two contrasting cases could be used to illustrate how uncertainty is taken into consideration. One is the case of identifying low to mid-rise buildings with seismic vulnerabilities in large urban areas. This is a case where vast inventories of buildings, and as such, at least an order of magnitude more people, are impacted by the decisions of the earthquake engineers involved. The other case is the practice of designing high-rise buildings in earthquake country where the subject matter is often a single, monumental structure. Both cases are defined by how uncertainties are perceived, quantified, and taken into consideration by various parties involved (owners, local jurisdiction/government, and engineers) and by the actions taken, or not taken, in the face of these uncertainties. Typical outcomes in these cases may be surprising to the untrained in the current practice of earthquake engineering.

Key Words: *earthquake engineering, uncertainty, risk, decision making*

INTRODUCTION

Earthquake engineering as a well-defined profession is about a hundred years old. Earliest modern engineering approaches to seismic design of structures were developed in Italy and Japan, in early 20th century [1]. Spurred by the 1924 Kanto (Japan) and 1933 Long Beach (USA) earthquakes, with the

* Ayhan Irfanoglu, Professor and Associate Head, Lyles School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907, U. S. A.

first strong earthquake ground motion records obtained during the latter event, there was keen interest in expressing fundamental concepts governing earthquake demands and response of buildings to ground motions, and that with stunning insight [2, 3, 4]. These original works were, unfortunately, forgotten or ignored for several decades. Later, the ideas and insight presented in them are proven to be true by independent researchers [5, 6, 7, 8].

Meanwhile, following the first World conference on earthquake engineering in 1956 and accelerated by growth in the science of seismology as well as engineering research, laboratory data and field observations, earthquake engineers around the World have started using similar models to characterize earthquake demands, expressions for building seismic performance, and guidelines/provisions for design and construction. The resulting lingua franca has allowed rapid exchange of ideas. However, at the same time it has increased the pressure to adopt similar approaches to design and field implementation. Certainly, it is not true that all seismic design provisions around the World are identical. But apart from the acceptable seismic performance levels considered in different countries with seismic design codes, one could see that not only the language but more importantly the quantification of earthquake hazards (tied to uncertainties in earthquake occurrences as well as representation of earthquake demands) and the tools used in earthquake engineering practice (modeling structures, analysis, simulation, design principles, construction guidelines and specifications) are practically the same around the World. It is important to ponder whether such nearly uniform thinking and implementation are in the best interest of all affected by the resulting outcomes.

TWO ILLUSTRATIVE CASES REGARDING FACING UNCERTAINTY

The most common task one comes across in earthquake engineering practice is, by far, designing a low to mid-rise building, say, up to ten stories tall following a local design code. Perhaps a distant second most common task is carrying out detailed inspection of an existing building, again, low to mid-rise, for possible seismic vulnerabilities. While there are many other tasks earthquake engineers may do occasionally, two of the much less common tasks but with very high impact on the society in earthquake country appear diametrically opposite in the spectrum of earthquake engineering practice. One is inspecting large inventory of buildings, i. e., tens to tens of thousands of buildings, for possible seismic vulnerabilities and, if necessary, taking action to retrofit or demolish them. The other one is designing high-rise buildings.

Case I — Inspecting Large Inventory of Buildings

After every strong earthquake in an urban area with a large population, there is heightened interested in inspecting buildings, in the same region and sometimes elsewhere, to identify the most vulnerable buildings rapidly for further, detailed study, and, if need be, for retrofit or demolition. Most earthquake engineers approach this task with the training and mentality they have acquired from designing new buildings. Meaning, they use a „high-pass filter" and work to identify those buildings that are not vulnerable. This often results in vast majority of the buildings in the inventory to be categorized as vulnerable [9]. Certainly, the element of fear, namely the „fear of failure" is what drives such thinking [10], and it originates from the engineers acting conservatively in the face of uncertainty. Ironically, and unfortunately, such thinking and action by the engineers often guarantee inaction by the powers-to-be, i. e., political leaders and financiers.

In dealing with large inventory of buildings with varied characteristics and facing numerous uncertainties, one should take a simplifying and practical approach [11, 12] and, effectively, execute a „low-pass filter" to identify the most vulnerable buildings. Such an approach is more likely to result in action as the political will and financial means may be possible to build or find.

Case II — Designing High-Rise Buildings in Earthquake Country

The design of high-rise buildings is different from that of low- or mid-rise buildings in that, often, the resulting design of such large, monumental structures is reviewed, and a recommendation is made to the authority with jurisdiction, by a panel of peer reviewers.

There are several orders of magnitude more low- to mid-rise buildings than high-rise buildings. Our experience with low- and mid-rise buildings, with regards to their design basis and how they perform during strong earthquake ground motions, is more robust and firm-footed simply because we have large collections of evidence gather over the decades and in different parts of the World. Even on the engineering seismology front, we have greater experience: low- and mid-rise buildings are influenced primarily by seismic waves with relatively shorter period. The amplitudes of these shorter period waves are known to saturate with earthquake magnitude. In other words, they are capped. Meaning, even in the case of rare events considered in design of low- and mid-rise buildings, such as those earthquakes represented with 500 year or even 2,500 year return periods, the earthquake demands could be estimated and accounted for with reasonable confidence [13, 14].

What we know about the shorter period waves and how low- and mid-rise buildings respond to them is unlikely to change by much with new data.

Statements like those made above for low- and mid-rise buildings cannot be made for high-rise buildings. Our experience with of high-rise buildings is limited. Data about long-period wave characteristics of near-source ground motions from large earthquakes are also limited. Simply, we do not have enough empirical data to calibrate our understanding, put a cap on demands, or even assign a true level of confidence on what we know about these demands let alone what we do not know about them. There is justified skepticism about what is claimed to be known about these long-period demands during intense, near source ground motions. For example, we do not know what type of probability distribution might be appropriate to use to model these near-source long-period seismic waves, or simply how big they may get [13, 14]. As a result, we are not quite sure how high-rise buildings affected by them might perform. Yet, some of the dominant concepts currently used in design of low- and mid-rise buildings are applied practically as-is in designing high-rise buildings [14]. Despite such limited understanding, in the face of uncertainty and against such odds with dire consequences if realized, high-rise buildings are being built with reportedly high confidence.

CONCLUSION

Uncertainty is unavoidable in earthquake engineering practice. When making decisions in the presence of uncertainty, earthquake engineers need to weigh the possible consequences of their actions, and inactions, against the odds of being wrong and tested in the future versus missing an opportunity to help reduce future losses. Whatever they do, they must know what they know and what they do not know.

BIBLIOGRAPHY

[1] R. K. Reitherman: *Earthquakes and Engineers: An International History*. American Society of Civil Engineers, 2012.
[2] G. E. Howe GE: „Requirements for buildings to resist earthquakes" American Institute of Steel Construction, 1936.
[3] H. M. Westergaard: „ Measuring earthquake intensity in pounds per square foot." *Engineering News Record,* 20 April 1933, p. 504.
[4] H. M. Westergaard: „Earthquake-shock transmission in tall buildings." *Engineering News Record,* vol. 111, no. 22, 1933, pp. 654–656.

[5] M. A. Sozen: „Review of earthquake of R/C buildings with a view to drift control." In *Proc. Of the 7th World Conference on Earthquake Engineering, State of the Art Panel Reports,* 8–13 September 1980, Istanbul, Turkey, pp. 383–418.
[6] J. F. Hall, T. H. Heaton, M. W. Halling, D. J. Wald: „Near-source ground motion and its effects on flexible buildings" *Earthquake Spectra,* vol. 11, no. 4. 1995. pp. 569–605.
[7] M. A. Sozen: „On first reading Westergaard's „Measuring Earthquake Intensity..." Engineering News Record, 20 April, 1933." In *Proceedings of the Otani Symposium*, 2003, pp. 317–320.
[8] M. A. Sozen: „The velocity of displacement" In *Seismic Assessment and Rehabilitation of Existing Buildings,* Springer, Dordrecht, 2003, pp. 11–28.
[9] T. Paret, A. Irfanoglu: „From complexity to simplicity — How Mete Sozen arrived at Priority Index" in *11th National (U. S.) Conference on Earthquake Engineering,* Los Angeles, June 25–29, 2018.
[10] M. A. Sozen: „Fear of Failure" In *World Bank Meeting on Assessment and Repair,* Ankara, Turkey, 5–6 May 2000
[11] A. Hassan, M. A. Sozen: „Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes" *ACI Structural Journal,* vol. 94, no. 1.1997, pp. 31–39.
[12] A. Irfanoglu, S. Pujol: „Earthquake-vulnerability evaluation of buildings" in *17th World Conference on Earthquake Engineering,* Sendai, Japan, September 27—October 2, 2021
[13] M. Yamada, A. H. Olsen, T. H. Heaton: „Statistical features of short-period and long-period near-source ground motions." *Bulletin of the Seismological Society of America,* vol. 99, no. 6, 2009, pp. 3264–3274.
[14] T. H. Heaton: „Will performance-based earthquake engineering break the power law?" *Seismological Research Letters,* vol. 78, no. 2, 2007, pp. 183–185.