GUEST EDITOR'S NOTE

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A comprehensive review of the conditions that prepared the key players to create the concept of the response spectrum method is beyond the scope of this brief introduction. Thus, I will mention only a few examples. First, the teaching of physics, and, in particular, of engineering mechanics and applied mathematics, started to expand in Europe around the end of 19th and the beginning of 20th century (Timoshenko, 1968; von Karman and Edson, 1967; Cornwell, 2003). Second, several earthquake disasters (in 1906, 1908, and 1923) in densely populated areas made it clear that defensive mechanisms needed to be developed to prevent future loss of life and property from destructive earthquakes. Third, the arrival of leading scientists and engineers in earthquake-prone areas (e.g., Milne in Japan; Compte de Montessus de Ballore in Chile; Millikan, Gutenberg, and von Karman in Southern California), and their organizational abilities, interest, and curiosity to examine yet another challenging group of physical phenomena, created new critical mass and organization, which in turn attracted the next generation of talented students.

The first practical steps which initiated the engineering work on the design of earthquake-resistant structures accompanied the introduction of the seismic coefficient (shindo in Japan, and rapporto sismico in Italy, for example), which started to appear following the destructive earthquakes in San Francisco, California, in 1906, Messina-Reggio, Italy, in 1908 (Sorrentino, 2007), and Tokyo, Japan, in 1923. The first seismic design code was introduced in Japan in 1924 following the 1923 earthquake. In California, the work on developing a code started in 1920s, but it was not until after the Long Beach earthquake in 1933 that the Field Act was finally adopted in 1934 (Reitherman, 2006).

In early 1900s, at most American universities engineering curricula did not include advanced mathematics and mechanics, both essential for teaching analysis of the dynamic response of structures. This lack of theoretical preparation is reflected in the views of C. Derleth (1874–1956), a civil engineering professor and Dean of the College of Engineering at University of California Berkeley, who commented after the 1906 earthquake: "Many engineers with whom the writer has talked appear to have the idea that earthquake stresses in framed structures can be calculated, so that rational design to resist earthquake destruction can be made, just as one may allow for dead and live loads, or wind and impact stresses. Such calculations lead to no practical conclusions of value" (Derleth, 1907).

A comment made three decades later by A. Ruge, the first professor of engineering seismology at the Massachusetts Institute of Technology (Ruge, 1940), that "the natural tendency of the average design engineer is to throw up his hands at the thought of making any dynamical analysis at all" shows that progress was slow (Reitherman, 2006).

In 1929, at University of Michigan in Ann Arbor, the first lectures were organized in the Summer School of Mechanics by S. Timoshenko (1878–1972), with the participation of A. Nádai, R.V. Southwell, and H.M. Westergaard. "After the first session of the summer school in 1929", Timoshenko wrote later, "the number of doctoral students in mechanics … started rapidly to increase" (Timoshenko, 1968). In the summer of 1933, M.A. Biot was among the young post-doctoral students who took part in Timoshenko's summer school (Mindlin, 1989; Boley, 2005; Biot, 2007).

In Southern California, studies of earthquakes and research in theoretical mechanics were expanded and energized by R. Millikan (1868–1953), who became the first president (chair of the executive council) of the California Institute of Technology (Caltech) in 1921. Millikan completed his Ph.D. studies in physics at Columbia University in 1895, and following recommendation of his advisor M. Pupin (1854–1935) spent a year in Berlin and Göttingen. This visit to Europe appears to have influenced many of Millikan's later decisions when he recruited the leading Caltech faculty members two decades later. In 1921, H.O. Wood (1879–1958) invited Millikan to serve on the Advisory Committee in Seismology (Geschwind, 1996). The work on that committee and Millikan's interest in earthquakes were also significant for several subsequent events. In 1926, J. Buwalda (1886–1954) was asked to set up the division of geological sciences at Caltech, and in 1926 C. Richter (1900–1985), and then in 1930 B. Gutenberg (1889–1960), joined the seismological laboratory. In the area of applied mechanics, Millikan invited Theodor von Karman (1881–1963) to join the Caltech faculty, and in 1930 von Karman became the first director of the Guggenheim Aeronautical Laboratory. It was Millikan's vision and his ability to anticipate future developments that brought so many leading minds to a common place of work, creating an environment that made the first theoretical formulation of the concept of the response spectrum method (RSM) possible.

This issue of the ISET Journal commemorates the 75th anniversary of the formulation of the concept in 1932. Since then, RSM has evolved into an essential tool and the central theoretical framework—in short, a conditio sine qua non—for earthquake engineering. The mathematical formulation of the RSM first appeared in the doctoral dissertation of M.A. Biot (1905–1985) in 1932, and in two of his papers (Biot, 1932, 1933, 1934). Biot defended his Ph.D. thesis in June 1932 (Biot, 2007) and presented a lecture on the method to the Seismological Society of America meeting, which was held at Caltech the same month. Theodore von Karman, Biot's advisor, played the key role in guiding his student and in promoting his accomplishments. After the method of solution was formulated, Biot and von Karman searched for an optimal design strategy. A debate at the time was whether, to better resist earthquake forces, a building should be designed with a soft first floor or be stiff throughout its height. An excerpt from New York Herald Tribune in June 1932 illustrates this:

> **Shock Proof Buildings Sought by Scientists.**
> **Rigid or Flexible Materials, Their Difference in Theory**
>
> A building proof against earthquakes is the goal of Dr. Theodor von Karman and Dr. M. Biot, of California Institute of Technology. Dr. von Karman described to the American Society of Mechanical Engineers, whose convention was held recently at Yale, studies of the amount of shock, which various types of buildings have undergone in Japan, South America and California. Their researches are being conducted at the Institute's Guggenheim Aeronautical Laboratory.
>
> One of the principal problems is to decide whether a rigid or flexible structure is better. Some scientists contend the first is preferable; others would make the ground floor of tall buildings flexible.
>
> Pointing out that reinforced concrete is superior to steel in absorbing the shocks, Dr. von Karman's personal belief is that buildings should be constructed to shake "with the rhythm of the earth's movements".

Another newspaper article, describing the same meeting, stated:

> **QUAKE STRAINS DISCUSSED**
> **Von Karman Tells New Haven Meeting Engineers Are Divided between Rigid and Flexible Buildings**
>
> The most interesting piece of research now being conducted at the California Institute of Technology by Dr. M. Biot on the calculation of stresses occurring in buildings during an earthquake was described informally this morning by Dr. T.H. von Karman, director of the Guggenheim Aeronautical Laboratory at the school, under whose direction Dr. Biot is doing the work.
>
> **Seek "Quake-Proof" Building**
>
> By a study of past earthquakes in California and Japan and along the Pacific Coast of Central America, engineers interested in building problems have accumulated a record on which they believe they can calculate the rhythm or characteristic of the earth movement in these particular regions. They have sought to evolve an "earthquake proof" building on the basis of this data.
>
> As a result of this research, said Dr. von Karman, there have arisen two schools of thought. One asserts only the most rigid structures should be built in the earthquake regions and the second, which Dr. von Karman supports, contends a flexible type of building, which can swing with the earthquake, is the better.

Biot's interest in the maxima of the transient response in solids and fluids preceded, and extended beyond earthquake engineering. After he formulated the concept of the RSM, he extended it to other vibrational problems, such as the analysis of aircraft landing gear. Biot briefly returned to the subject of earthquake engineering almost ten years later, presenting response spectral amplitudes of several earthquakes, which he calculated using the torsional pendulum at the Columbia University (Biot, 1941). In 1942, he presented a review of RMS, discussed the effects of flexible soil on the rocking period of a rigid block (Biot, 2006), and described the spectrum superposition method based on the sum of absolute modal maxima (Biot, 1942). After 1942, Biot moved on to other subjects, making fundamental contributions to many other fields. He did not write papers on earthquake engineering (Trifunac, 2005), but he followed closely and with interest the work of others.

The principal areas of Biot's opus and his exceptional talent and technical views have been described by Mindlin (1989) and Tolstoy (2006), who wrote: "While Biot's contributions to science owed much to his command of the sophisticated mathematical tools of theoretical mechanics, they were always rooted in concrete problems of engineering and geophysics. His solutions were firmly based on physical insight. He understood the pitfalls of formalism, but at the same time he appreciated the creative role of mathematical elegance upon which he laid much stress. He was one of the twentieth century's true masters of Lagrangian techniques". A complete list of Biot's publications can be found in Trifunac (2006), and of his patents and awards in the introduction to Volume 14 of the Journal of Mathematical and Physical Sciences, published in Madras, India, in 1980, on the occasion of his 70th birthday anniversary.

Theodor von Karman (left) and Maurice A. Biot (right) at Professor von Karman's house in Pasadena, California (circa 1932)

RSM remained in the academic sphere of research for almost 40 years, gaining engineering acceptance during the early 1970s. There were two main reasons for this. First, the computation of response to earthquake ground motion led to "certain rather formidable difficulties" (Housner, 1947), and, second, there were only a few well-recorded accelerograms that could be used for response studies. This started to change in the 1960s with the arrival of digital computers and with the commercial availability of strong-motion accelerographs. Before the digital computer age, the computation of response was time-consuming, and the results were unreliable (Trifunac, 2003). By the late 1960s and early 1970s, the digitization of analog accelerograph records and the digital computation of ground motion and of the response spectra were developed completely and tested for accuracy. Then, in 1971, with the occurrence of the San Fernando, California, earthquake, the modern era of RSM was launched. This earthquake was recorded by 241 accelerographs. By combining the data from the San Fernando earthquake with all previous strong-motion records, it become possible to launch the first comprehensive empirical scaling analyses of response spectral amplitudes (Lee, 2002, 2007).

This special issue of the ISET Journal presents examples of the use and extensions of RSM in earthquake engineering. It begins with a historical review of the early studies of dynamic response, following the Messina-Reggio earthquake of 1908 in Italy, and it includes the period that preceded the formulation of the concept of RSM in 1932. Sorrentino describes the pioneering work of Arturo Danusso, who recognized the need to account for the dynamic properties of the building responding to earthquake shaking and to understand how the linear elastic n-degree of freedom can be considered as equivalent to n single-degree-of-freedom oscillators. Arturo Danusso presented a paper in Liege, Belgium at the first international conference on concrete and reinforced concrete (1–6 September 1930), at the time when Biot was a student at Louvain and von Karman was in the process of moving from Germany to Pasadena. In his last paper on earthquake-resistant structures in 1946, Danusso reviews the results he had obtained previously and references the works of Levi-Civita and Rayleigh, but he was apparently not aware of Biot's papers on RSM written in 1933 and 1934.

The paper by Freeman in this issue outlines the design aspects of RSM. Freeman describes the role Biot's standard acceleration spectrum played in the proposed design curve, $C = K/T$, in the seismic codes in California.

Papers by Lee, Douglas, and Kawakami et al. describe empirical scaling of spectral amplitudes and the regional differences in attenuation. The paper by Ventura and Blázquez reminds us of the effect of the initial ground velocity on the RMS amplitudes.

Different uses of spectral amplitudes in mapping the geographical distribution of seismic hazard are reviewed by Gupta, and the paper by Aydınoğlu describes the use of push-over analyses in earthquake-resistant design. The response of secondary structures and the estimation of the peak floor accelerations are addressed in the papers by Muscolino and Palmeri, and Kumari and Gupta.

The last four papers explore the possibilities for extending RSM to more complex excitations and describe the nature of the strength-reduction factors for impulsive and large near-fault strong-motion pulses. Zembaty reviews the role of differential motions and describes extensions of RSM that incorporate those additional effects. Kalkan and Graizer describe the role of rotational excitations, and Jalali and Trifunac examine the behavior of the response-reduction factors for an extreme excitation at the earthquake source.

Finally, Gicev and Trifunac discuss limitations of Biot's RSM, which is based on the vibrational solution of the linear differential equations of motion, and which does not explicitly consider the duration of the forcing function. They describe the power of strong-motion waves in a building, in search of a new design tool in the near-field of strong earthquakes.

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