Rotations in Structural Response

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ABSTRACT

The first studies of earthquake strong motion began by assuming linear materials, and small deformations. The early researchers observed that under favorable conditions (long waves) the accompanying rotational motions would be small, and proceeded to neglect their effects. Another simplification, that the theory can be constructed on the basis of equivalent homogeneous representation of the medium, and in terms of homogeneous layers with different properties, in soil and in sediments, further contributed to proliferation of the studies, which designed experiments, and formulated the governing equations and their solutions by considered only the translational components of motion. Mathematically the dynamic response of structures can be formulated either by following D'Alemert's (1750 - wave propagation), or Bernoulli's (1755 – vibrational) method of solution. In his formulation of the response spectrum method in 1932, Biot opted for the vibrational approach, and this further lead in the conditions, which did not seem to require consideration of the rotations. The engineering profession was not prepared in 1930s and 1940s, and first had to learn the basic dynamics of structures, before it could question the wisdom, or influence the selection, of vibrational versus the wave propagation approaches to the solution. There were too many other concerns, caused by the modeling simplifications, which pushed the studies of the rotational motion further down to the lower levels of priority. Even today, 40 years after the arrival of digital computers, and emergence of powerful numerical computational capabilities, which uncovered unexpectedly large families of chaotic solutions, accompanying large deformation, and nonlinear response, we continue to ignore the role of rotations. Had Biot and von Kármán chosen the wave propagation approach for the solution of the earthquake engineering problems in 1932, the "progress" might have been faster. The wave can be differentiated with respect to a space coordinate, giving the rotations at a point. In contrast the lumped mass models in the vibrational approach do not make this possible, and the closest one comes to considering rotations, is in terms of average, per floor rotation, or drift.

In this paper I will review some elementary examples of structural deformation, which illustrate the presence of large rotations. I will show examples of how large rotations can be in the response of actual structures, and will suggest how we might proceed to study and to interpret their consequences. Whether we wish to understand why microtremors in metropolitan areas abound with high frequency Rayleigh waves, why buildings rock and even overturn during strong earthquake shaking, or why columns fail, we must consider the rotational components of ground and of structural motions. Only then will we be able to understand and to control the response to strong earthquake excitation.