Broadband earthquake ground motion simulations represent a promising approach to seismic hazard analysis. After validation of synthetics against recordings, it provides us the possibility to dense up the information needed to prepare accurate ground motion models. Here we develop broadband (0–10 Hz) kinematic source models of two disastrous events: 2016 Mw6.2 Amatrice in Italy and 2023 Mw7.8 Kahramanmaraş in Türkiye. The model utilizes integral and composite approaches to model rupture propagation at low and high frequencies, respectively. We adopt slip distribution, fault dimensions, and rupture velocity from available source inversions. First, we optimize those parameters by minimizing the spectral acceleration bias between modeled and recorded data at stations in the studied area. Then, we expand our models beyond the real stations by simulating ground motions at a grid of virtual stations and we test the robustness of the optimal model against a (nonergodic) ground motion model. For the Kahramanmaraş earthquake, we demonstrate that even a very rough estimate of major rupture parameters makes the ground motion simulations of such large events possible and may thus improve the efficiency of rapid, physics-based shaking estimation for emergency response and seismic hazard assessment. For the Amatrice earthquake, we use the set of virtual stations to model various scenarios of the event and study the ground motion variability by applying mixed-model analysis. Comparison with an empirical ground motion model (GMM) shows that the synthetic between-event variability exceeds the empirical value. We propose a way to restrict the scenario variability to conform with the empirical nonergodic GMM. The presented validation of the scenario variability can be generally utilized in scenario modeling for more realistic physics-based seismic hazard assessment.