This paper presents a numerical study of the boundary layer flow and properties induced by tsunami-scale waves. For this purpose, an existing one-dimensional vertical (1DV) boundary layer model, based on the horizontal component of the incompressible Reynolds-averaged Navier–Stokes (RANS) equations, is newly extended to incorporate a transitional variant of the standard two-equation k–ω turbulence closure. The developed numerical model is successfully validated against recent experimental measurements involving transient solitary wave boundary layers as well as for oscillatory flows, collectively demonstrating the ability to reproduce accurate velocity profiles, turbulence, and bed shear stresses on both smooth and rough beds. The validated model is then employed for the study of transient wave boundary layers at full tsunami scales, covering a wide and realistic geophysical range in terms of the flow duration, bottom roughness, and associated Reynolds numbers. For this purpose, three different “synthetic” (idealised) tsunami wave descriptions are considered i.e., invoking: (1) single wave (solitary-like, but with independent period and wave height), (2) sinusoidal, and (3) N-wave descriptions. The flow, boundary layer thickness, turbulence, and bed shear stresses induced are systematically monitored and parameterised, under both hydraulically smooth and roughbed conditions. The results generally support a notion that the boundary layers induced by tsunami-scale waves are both current-like, due to their long durations, as well as wave-like, in the sense that the boundary layer will not necessarily span the entirety of the water column. The results likewise suggest that there is a continuum connecting wind-wave and tsunami-wave scales, as existing expressions commonly used for characterising boundary layer properties beneath wind-waves maintain reasonable accuracy when extrapolated to full tsunami scales. Boundary layers driven by actual field-measured tsunami signals are likewise simulated, stemming from both the 2004 Indian Ocean as well as the 2011 Tohoku events. These results are reconciled with the various synthetic tsunami signals considered, generally confirming their usefulness as idealised tsunami waves.