Bell-network states are loop-quantum-gravity states that glue quantum polyhedra with entanglement. We present an algorithm and a code that evaluates the reduced density matrix of a Bell-network state and computes its entanglement entropy. In particular, we use our code for simple graphs to study properties of Bell-network states and to show that they are non-typical in the Hilbert space. Moreover, we investigate analytically Bell-network states on arbitrary finite graphs. We develop methods to compute the Renyi entropy of order p for a restriction of the state to an arbitrary region. In the uniform large-spin regime, we determine bounds on the entanglement entropy and show that it obeys an area law. Finally, we discuss the implications of our results for correlations of geometric observables.