Abstract: As a non-linear theory of space-time, general relativity deals with interesting dynamical systems which can be expected more prone to chaos than their Newtonian counter-parts. In this thesis, we study the dynamics of time-like geodesics in the static and axisymmetric field of a Schwarzschild black hole surrounded, in a concentric way, by a massive thin disc or ring. We reveal the rise (and/or decline) of geodesic chaos in dependence on parameters of the system (the disc/ring mass and position and the test-particle energy and angular momentum), (i) on Poincaré sections, (ii) on time series of position and their power spectra, (iii) by applying two simple yet powerful recurrence methods, and (iv) by computing Lyapunov exponents and two other related quantifiers of orbital divergence. We mainly focus on "sticky" orbits whose different parts show different degrees of chaoticity and which offer the best possibility to test and compare different methods. We also add a treatment of classical but dissipative system, namely the evolution of a class of mechanical oscillators described by non-standard constitutive relations.