The anomalous shear modulus behavior of fused silica glass has been a long-standing topic of investigation. Likewise, the anomalous pressure dependence of the strength of amorphous silica has also received considerable attention. In order to formulate a model of material behavior, we perform molecular dynamics (MD) calculations designed to data-mine information regarding the permanent deformation, both volumetric and in shear, of amorphous silica. Based on these observations, we formulate a critical-state constitutive model for fused silica and fit material parameters to the MD data. Remarkably, the MD data reveals that the limit yield surface is non-convex. The treatment of this non-convexity necessitates a fundamental extension of classical plasticity. We consider the implications of this extension and utilize tools from the Direct Methods in the Calculus of Variation to characterize explicitly the effective behavior at the macro-scale. The resulting effective model of plasticity, together with consideration of brittle fracture of fragmentation, provide the basis for the simulation of failure waves in glass rods impacting a rigid target. The calculations are carried out using the Optimal-Transportation Meshfree (OTM) method combined with the eigenerosion approach to fracture. This computational approach proves effective at predicting the experimentally observed failure wave speeds and complex fracture and fragmentation patterns, while simultaneously allowing for complex material behavior.