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A COMPREHENSIVE DEFORMATION MODEL OF MAKRAN REGION, FOR SEISMIC HAZARD STUDIES

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The Makran subduction zone is one of the last convergent margins that formed by the subduction of the Arabian plate beneath the southern coasts of Iran and Pakistan. The Makran convergence zone accommodates 3 cm/yr of convergence between Arabia and Eurasia. Despite this rapid relative plate motion, seismic activity in this region is low with only two significant historic earthquakes. The largest instrumentally recorded event is the 1945 Mw 8.1 Makran earthquake (Byrne et al., 1992); that shows the eastern Makran is locked and can produce large earthquakes. In contrast, the western Makran shows an almost total absence of shallow thrust earthquakes in both the instrumental and historical periods, with reports of only a single possible megathrust earthquake in 1483, for which the source region is poorly constrained (Musson, 2009). Therefore, we defined two models to evaluate the possibility of creep in the western part of Makran subduction zone. In the first model we assume that both part of Makran are temporarily locked (called the SDM); and the second model assumes the western Makran as a steady creeping subduction (called the HCDM).

In this study, we combine three independent data sets (geologic slip rate, geodetic velocity, and principal stress direction) using a kinematic finite-element model, based on iterated weighted least squares fits to data, to better understand regional geodynamics of the Makran region. The newest regional joint solution of GPS data, azimuth of the most compressive principal stress, and geometry and kinematics of the potentially active faults mapped in prior geological studies, is included in the models. Model provides long-term fault slip rates, velocity, and distributed permanent strain rates between faults in the Makran region from all available kinematic data. This model allows us to better constrain the fault slip rates and distributed deformations and finally assess the seismic hazard and also can be used to produce long-term seismicity maps which are independent of historic and instrumental catalogs.

The kinematic finite-element program (NeoKinema) was developed to combine all kinematic data including geological offset rates, GPS measurements, and principal stress directions by Bird and Liu (2007), which was used by Liu and Bird (2008); Khodaverdian et al. (2015) and UCERF3 (2013). The primary purpose of this modeling is to estimate long-term fault slip rates and distributed anelastic strain rates by combining all kinematic data including geological slip rates, geodetic velocities, and stress directions. The equations underlying the program are available from http://peterbird.name/oldFTP/NeoKinema.

In the modeling program, the domain is divided into 2-D spherical-triangle finite elements (Kong and Bird, 1995). Differentiation of long-term average velocity within each triangle gives the permanent (not elastic) 2-D strain rate tensor. Nodal horizontal velocities are calculated by optimizing a weighted least squares objective function, while velocity boundary conditions computed from a global model are imposed on a system of linear equations. Geodetic benchmarks are also considered as internal point constraints on the velocity field. However, the GPS data should be corrected before being used to estimate long-term velocity field since velocities at geodetic benchmark located near the faults are influenced by elastic fault locking effect. These correction processes are done based on analytical solutions for dislocation rectangular patches in a homogeneous half-space media, using estimated fault slip rates and interseismic locking depth. These processes are handled by iteration since long-term average velocities are obtained by adding rates of coseismic displacement based on the previous step estimates of fault slip rates. Fault offset rates and their uncertainties contribute, respectively, to target strain rate tensor and its uncertainty of all elements that faults cut through. Vertical slip rates are converted into horizontal slip rates using assumed fault dips (Bird and Kagan, 2004).

In order to verify the models, the estimates of fault slip rates are compared to slip rates from merely analyzing geodetic benchmark velocities or paleo-seismological studies or published geological rates which have not been used in the model. Our estimated rates are all in the range of geodetic rates and are even more consistent with geological rates than previous GPS-based estimates.

Another verification for the model is *comparison of* the computed interseismic velocities at GPS benchmarks to GPS measurements. Figure 2 shows the computed interseismic velocities at GPS benchmarks. While neither model accurately predicts these interseismic velocities at benchmarks, the HCDM is more accurate for CHBR station than the SDM. These results have important earthquake and tsunami hazard implications.

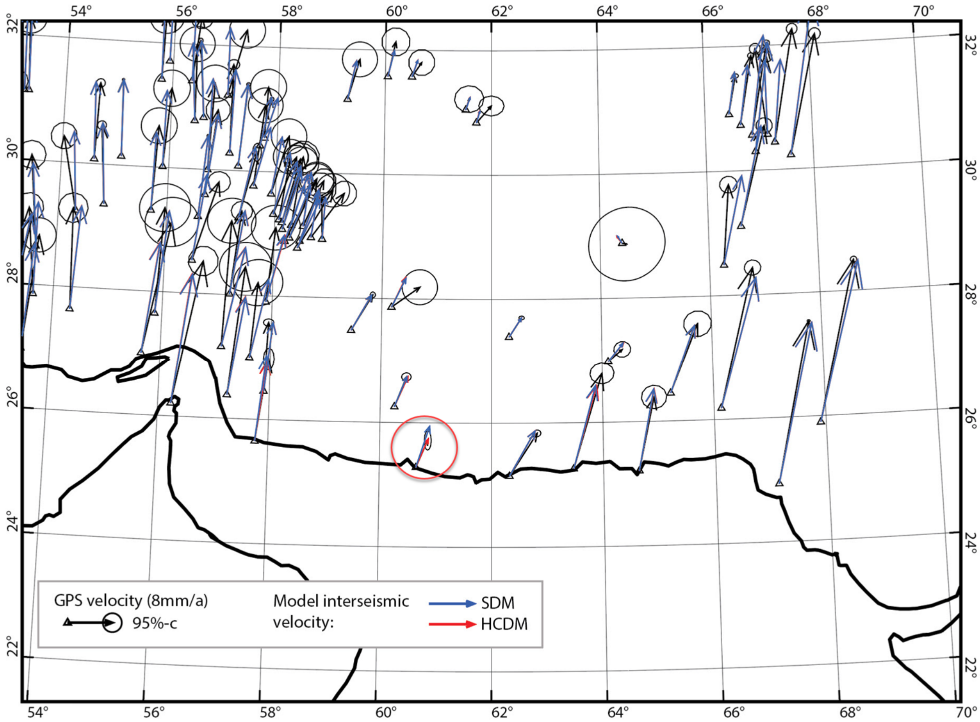

Figure 2. Computed interseismic velocities at GPS benchmarks, compared to GPS measurements (black arrows).

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