**The East Anatolian fault earthquake sequence of 6 February 2023: epicentral afterslip and anticipated future rupture propagation**

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On occasion, some of the data listed in this 1.3 Gbyte archive were retrieved by investigators supported Tubitak funding.

**Summary**

Fourteen carbon-rod extensometers (creepmeters constructed in the University of Colorado) were placed across surface ruptures of the Mw7.8 and Mw7.6 ruptures of the Kahramanmaraş earthquake sequence of 6 February 2023 to record potential afterslip (Ayruk et al., 2024). Their data are depicted graphically as time series in the attached annual report for the NSF research grant. The location and length of each extensometer are listed in Table 1. Data from 2023 and early 2024 are included in this report. Each instrument consists of a carbon rod extensometer with a rotary Hall sensor, which has a full-scale wrap of ≈10 mm measured to 12-bit-precision (~2.5 µm), and a concatenated range of 1.6 m (after the data are unwrapped). The instrument is described briefly in Bilham and Castillo, 2020 and Langbein et al., (2024). Most of the data were recorded at a rate of 1 sample per minute. At two sites (Karakose and Goksun (1Dec2023) biaxial creepmeters were installed, the orthogonal component permitting fault dilatation to be quantified.

After editing to remove measurement artifacts, cumulative data have been incrementally archived in the NSF GAGE facility creep data base. The digital data archived here describe uninterpreted data edited to mid 2024 compiled by the authors of this "read-me" file.

**Timing**

Although some data were telemetered (providing synchronous common UTC corrected timing) a new law was introduced in Turkey during the measurements that denied cell use to foreign IMEI serial numbers after two months of operation. This resulted in a number of gaps in the data (days or weeks) as we responded to instruments going down at apparently random times. After the problem was diagnosed the data were all recorded by local data loggers and download manually. At some sites where the afterslip signal was considered uninformative, instruments were removed and redeployed. The telemetered data have a time stamp accurate to 1 second. The autonomous data loggers may have timing errors of up to one minute after corrections for linear clock drift between data launch and retrieval.

**Afterslip**

For most of the sites no significant afterslip occurred. Instead of conventional afterslip, which consists of continued slip at a decaying rate, at locations that slipped 2-5 m the massive open fissures (push-ups or "pull-aparts") along the fault were measured to be apparently collapsing in response to local potential energy (gravity-slumping) or by lateral flow during or following heavy rain and saturation and weakening of surface soils. These signals were mostly contractional in nature, and at these sites, measurements have largely been discontinued.

In contrast to these local fault-zone-collapse signals, afterslip continues at three locations. The eastern and western tips of the second rupture (creepmeters at Gozene and Goksun) and the eastern end of the first rupture. Few measurements were made at the SW end of the first mainshock. The eastern end of the first mainshock terminates in a creeping segment of the fault known as the Puturge gap that separates the Sivrice 2020 and Kahramanmaraş 2023 ruptures (creepmeters at Tasmis, Sivrice, Yazica east and Yazica west). The creepmeter at Ormanici was accidently destroyed by ploughing in 2024.

**Calibration**

// the data are stored as extension in mm with a nominal full-scale wrap of 10 mm. To convert to sinistral slip, multiply the listed values by 1.218 (this includes an instrument calibration and a 30° obliquity correction).

The reason for this correction is that although each sensor was calibrated for its voltage wrap threshold, a generic (10 mm) circumference for the 1/8" diameter measurement shaft was assigned to data loggers, ignoring the 30° obliquity of the fault and its precise path around the measurement shaft. Subsequent experiments show that the value above provides an appropriate conversion of listed values to sinistral fault slip.

Typically, actual fault slip is always larger than captured by the span of the creepmeter due to the finite width of the shear zone in surface materials above an active fault.

**Data Format:**

Downloaded data inevitably include gaps between contiguous files, either for a few minutes associated with downloading, or occasionally for long intervals if, for example, a power-supply malfunction occurred. For this reason, each data point is assigned a time stamp. Data are archived as comma-separated-text files using the long UTC (≈GMT) date format MM/DD/YYYY hh:mm:ss. Users should be aware that gaps in the data should be interpolated with intervening points, and where necessary corrected for unequal sampling, prior to spectral analysis or smoothing operations.

**Excel issues?**

Current versions of Microsoft Excel will truncate files longer than 1 million lines. Hence, these longer files should be opened in a text editor, Matlab or Wavemetrics Igor (the latter program was used to edit and compile incoming data). A text editor can be used to segment the data into chunks fewer than 1 million lines if excel is chosen to manipulate the data further. If the data are opened in Microsoft Excel the long date format is typically not displayed unless the user manually assigns this date format in the Format->Custom menu, and then modifies one of the provided formats (e.g. MM/DD/YY hh:mm) to MM/DD/YYYY hh:mm:ss. For most users this will not be necessary, and the automatically displayed format should be sufficient.

**Igor files**

Some users will find the Wavemetrics time-series analysis program "Igor" to be a more convenient tool to manipulate and edit creep data. Each site folder includes an Igor file (.pxp), a plot (.pdf) in addition to a comma-separated text file of the data (.txt). In some cases, a "narrative word document (.doc) explains site information and operational or editing details.

**Filling gaps in the data.**

Most gaps persist for fewer than several minutes and arise from the time taken to download and launch manual data loggers. However, in a few cases a several-week segment of data was lost due to a faulty battery pack, or because data were overwritten when a data retrieval visit was not possible before data-logger memory filled. For short gaps, no datum loss occurs, and missing data can be interpolated as a straight line between the two segments. For large gaps it is possible that an unrecorded wrap (equivalent to a GPS cycle-slip) may have occurred, with a consequent ±10 mm ambiguity in cumulative slip (the precise wrap is instrument-specific). Such gaps occur at Goksun in 2023 and Sivrice in 2020.

**Occasional severe editing: noise suppression in the recorded data**

A number of sites recorded extended periods of noisy data (attributable to poor battery D-cell contacts in high humidity environments underground). Noise in such cases takes the form of prolonged periods (several days) of intermittent zero values interspersed with true values. In these cases, the envelope of maximum values was estimated using a maximum filter with a sampling aperture of 1 hour (60 points) to 1 day (1440 points). Since the maximum filter adopts the maximum value in the chosen sampling interval it yields data manifest as a series of steps. To provide more realistic estimates of the contaminated data, the resulting time series are interpolated using a smoothing spline to obtain an approximation to uncontaminated data. These interpolated data were used to replace noisy data.

*Table 1 Coordinates of East Anatolian Fault creepmeters*

| *Location* | *Lines* | *latitude* | *longitude* | *length* | *obliquity* | *span* |
| --- | --- | --- | --- | --- | --- | --- |
| Balikburnu | 255904 | 37.9903 | 38.1990 | 5 m | 30° | Mar-Jul'23 |
| Goksun oblique  Goksun ortho | 379698 | 38.0060 | 36.5267 | 6 m  5 m | 30° | Mar23-Oct24  Sep23-Oct24 |
| Gozene | e33.36 | 38.1759 | 38.0103 | 5 m | 30° | Mar23-Oct24 |
| Hassa | e32.37 | 36.8006 | 36.5185 | 5 m | 30° | Mar-Aug'23 |
| Hatay | e33.39 | 38.3870 | 36.2803 | 26 m | 30° | Mar-Jul'23 |
| Karakose ortho |  | 38.0697 | 38.4983 | 6 m | 30° | 4 June |
| Karakose oblique |  |  | 38.4983 | 12.5m | 90° | 4 June |
| Kirikhan | e33.38 | 36.4791 | 36.3339 | 5 m | 30° | 4 Mar |
| Ormanici | e31.40 | 38.2113 | 38.7732 | 16 m | 30° | 2020 |
| Palu North | d23 | 38.6990 | 39.9537 | 8 m | 30° | 2014 |
| Sivrice | 5575687 | 38.3880 | 39.1873 | 16 m | 30° | Feb20-Oct24 |
| Tasmis | e33.42 | 38.2049 | 38.7872 | 52 m† | 30° | 23 Mar |
| Yazica East | e33.47 | 38.1791 | 38.7426 | 20 m | 30° | 6 Sept |
| Yazica West | e31.41 | 38.1806 | 38.7361 | 5 m | 35° | 22 Mar |

*Coordinates of North Anatolian Fault creepmeters near Ismetpasa*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Cerkes | vertical | 40.8947 | 32.7773 | 20 m | 30° | 2017 |
| Hamamli | d25 | 40.8729 | 32.6603 | 13 m | 30° | 2017 |
| IsmetpasaN | LVDT | 40.8698 | 32.6258 | 16.5 m | 30° | 2014 |
| IsmetpasaS | d14 | 40.8697 | 32.6258 | 20 m | 30° | 2017 |
| West Sazlik | vertical | 40.8692 | 32.6194 | 30 m | 30° | 2017 |

*†Tasmis was originally 9 m but in mid 2023 was shifted 30 m to the SE and lengthened to 52 m. Data for a few months after this shift trended briefly dextral due to settlement following its >1 m depth of burial. The East Yasica site also shows initial settlement due to this too being installed in a deep, backhoe-excavated trench.*

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Figure 1 Graphical summary of creep signals measured at the sites mentioned in this report. Ortho indicates an extensometer installed normal to the fault, close to the observed oblique component monitoring sinistral slip. Data from the North Anatolian fault (viz. Ismetpasa, are archived elsewhere (NSF Gage facility).

**References**

Ayruk, Efe T., Muhammed Turǧut, İlay Farımaz, Mehmet Köküm, Roger Bilham, Uǧur Doǧan (2024), Afterslip of 6 February 2023 Kahramanmaras Earthquake Sequence: Preliminary Results, EGU General Assembly Conference Abstracts, 2024

Bilham, R., (2024). Kahramanmaras Afterslip Final Report 2024 *NSF RAPID EAR 2318733*

Bilham, R., and B. Castillo, (2020) The July 2019 Ridgecrest, California, earthquake sequence recorded by creepmeters: negligible epicentral afterslip and prolonged triggered slip at teleseismic distances, *Seismological Research Letters,* 91 (2A): 707–720 doi: 10.1785/0220190293.

Langbein, J., R. Bilham, H. A. Snyder, and T. Ericksen (2024). Summary of Creepmeter data from 1980 to 2020; measurements spanning the Hayward, Calaveras, and San Andreas faults in northern and central California, *U.S. Geological Survey Open File Report* 2024-1011.  110 p., <https://doi.org/10.3133/ofr20241011>.