Digitizing analog seismograms of Iranian seismic stations - preserving records for strong earthquakes in Iran 1960-1990

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Research Article

Keywords: Analog Seismograms, Digitization, Historical Earthquakes, Major Earthquake of Iran, Instrumental seismology.

Posted Date: November 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2179679/v1

Version of Record: A version of this preprint was published at Journal of Seismology on July 11th, 2023. See the published version at https://doi.org/10.1007/s10950-023-10158-4.

Abstract

To preserve the analog records of historical earthquakes which occurred in and around Iran in digital form and to make them available for modern analyses techniques that require waveforms, we decided to scan seismograms of destructive earthquakes that occurred between 1960 and 1990. The seismograms have been recorded in five seismic stations deployed in Tehran, Mashhad, Kermanshah, Tabriz, and Shiraz by the Institute of Geophysics of the University of Tehran (IGUT). The restoration project of the old analog seismograms archived in the IGUT started in 2018. Seismograms were sorted by station and date to create a hardcopy data bank, and then those from large earthquakes with significant damage and casualties, and their larger aftershocks, were chosen to scan. At present, over 600 scanned seismograms from 52 major earthquakes, and their aftershocks larger than M_W = 5.0 that occurred in and around Iran and some major and great tele-seismic earthquakes from abroad are available. The current digitization process in IGUT is done manually and is based on waveform vectorization. The provided databank is one of the most important sources of information for researchers in seismology and active tectonics in and around Iran.

Article Highlights

- Reliability of manual digitization against automated for large earthquakes and converting scanned image to statistic table in MATLAB
- Applying curvature correction in account of analog nature of instrument.
- Creating a manual digitization algorithm to eliminate crossing in large earthquakes.

Introduction

The Plateau of Iran is a part of the Alpine-Himalayan belt in between converging Eurasian and Arabian plates. Therefore, Iran is one of the most seismically active countries in western Asia, so that, on average, the Iranian Seismographic Network (IRSC) locates more than 11,000 earthquakes per year during the last decade (see IRSC website at http://irsc.ut.ac.ir) (Fig. 1). Concerning major, potentially damaging earthquakes, it would be interesting to provide the number of earthquakes larger than M_W = 5 observed from 1959 to 1990, prior to the generalization of the digital record in Iran. The total number is surpassing largely 400.

Following some of these earthquakes, terrible fatalities and destruction have been reported. For example, on September 16, 1978, $Mw 7.3$, Tabas-e Golshan earthquake killed more than 20,000 people (more than 80% of inhabitants), destroyed or severely damaged about 90 villages, and completely demolished the evergreen oasis town of Tabas-e Golshan (Berberian, 1979, 1982, 2014; Niazi and Kanamori, 1981; Silver and Jordan, 1983; Shoja-Taheri and Anderson, 1988; Walker et al., 2003, 2013). The Manjil-Rudbar earthquake of 1990 June 20 (*Mw 7.3*) is one of Iran's largest and most deadly earthquakes that affected both urban and rural regions, killed 13000–40000 people, and made more than 500000 homeless (Berberian and Walker, 2010). The IGUT's analog seismographic stations recorded the majority of such destructive earthquakes. Analog seismograms contain a wealth of information for seismological studies, but modern analysis techniques have yet to be applied due to their analog nature. For these reasons, the IGUT is devoting important efforts on scanning and digitizing the seismograms of these focus events.

Here, we describe ongoing efforts to scan and digitize the key seismograms associated with the large earthquakes in Iran from 1960 to 1990. In the following, we will explain the method and introduce scanning and digitizing procedure with pros and cons. Also, an optimized digitization technique is introduced with the essential corrections related to analog nature of records and recording instruments.

Considering the importance of geophysical sciences, the International Council of Scientific Unions (ICSU) announced 1957–1958 the International Geophysical Year (IGY) and asked for global cooperation to develop and promote this field of science (Annals, 1959; Korsmo, 2007). In this regard, the IGUT was established in 1958. Until 1995 the IGUT deployed five main analog seismic stations in Tehran (1958), Shiraz (1963), Tabriz (1965), Kermanshah (1965) and Mashhad (1967) (Table 1), and some temporary stations (in Brojen (BRJ), Minoodasht (MND), Qamsar-Kashan (QAMS), Ghale-Ghazi (GHG), Sefidrood (SRI, 1965), and Mahabad (MAH) to record earthquakes and provide informative reports to the government and public. The IGUT archive includes more than 150000 analog seismograms. Three stations in Shiraz (SHI), Tabriz (TAB), and Mashhad (MSH) were equipped with WWSSN instruments. Each WWSSN station consisted of three short-period seismographs, three long-period seismographs, a timing and power console, and various support equipment that ordered by Coast and Geodetic Survey (CGS) and made by Geotechnical Corporation of Garland, Texas (GCP) (Peterson and Hutt, 2014; Aghajani and Mirzaei, 2020). In 1975, the Iranian long-period Array (ILPA), a circular array with seven borehole digital seismic stations (Fig. 2), was established in the southwest of Tehran. The records of ILPA are mostly available for a time period from 1978 to 1995.

Table 1
List of selected electromagnetic seismograms with the collected instrument constants of the recording instruments.

Station Code	Opened	Coordinate Lat .(N), Lon. (E)	[1]Elv. (m)	Instrument	[2]Comp.	Free period of Seismometer	Free period of Galvanometer	[3]Mag.
TEH	1959	35.73, 51.38	1462	Stuttgart-Hiller ([4]SP)	N, E, Z	1.1 s for all	0.25 s for all	10.000
				Gallitzin ([5]LP)	N, E, Z	11.0 s in N & E, 10.8 s in Z	12.3 s in N& E, 11.1 s in Z	492 in N 600 in E 340 in Z
MSH*	1967	36.31, 59.58	987	WWSSN (SP)	N, E, Z	1.0 s for all	0.75 s for all	12.500
				WWSSN (LP)	N, E, Z	15 s for all	100.0 s for all	1500
TAB	1965	38.06, 46.32	1430	WWSSN (SP)	N, E, Z	1.0 s for all	0.75 s for all	12.500
				WWSSN (LP)	N, E, Z	15 s for all	100.0 s for all	1500
SHI	1963	29.64, 52.51	1595	WWSSN (SP)	N, E, Z	1.0 s for all	0.75 s for all	100.000
				WWSSN (LP)	N, E, Z	15 s for all	100.0 s for all	1500
KER	1967	34.38, 47.13	1330	Stuttgart-Hiller (SP)	N, E, Z	1.1 s for all	0.25 s for all	6.000

** The MSH station was transformed to a new location in 1975, and the station code changed to MHI.*

1. Elevation. 2. Component. 3. Magnification. 4. Short period. 5. Long period

SEISMOGRAMS

If the seismicity history of a region is reviewed using the information preserved in analog seismograms, new understandings may be obtained. The analog seismic data have a longer time span and are essential for seismological research. (Kanamori, 1988).

Different types of seismographs were used in seismographic stations in Iran from 1958 to 1980, e.g., Stuttgart-Hiller, Gallitzin, WWSSN instruments, etc. The seismograms have been recorded on photographic papers and also on smoked papers (mainly in Stuttgart-Hiller seismographs). Most of the papers have dimensions 100 centimeters long and 40 centimeters in width (with some exceptions). Each seismogram contains one component of ground motion; therefore, usually, there are three seismograms for three components of ground motions for each event in a single station. A fully recorded short-period seismogram typically includes about 96 lines for 24 hours; each corresponds to about 15 minutes, and long-period seismograms include 24 lines for 24 hours. A simple mark time determine minutes, and the distance between two continuous mark times is 60 millimeters for a short period, equal to 60 seconds (Fig. 3), and 15 millimeters for a long period. The analog seismograms had been kept in special nylon packages to prevent humidity penetration.

It is challenging to analyze analog seismograms because of the vulnerability of old smoked papers and photographic papers on one hand and lack of expert people who can work with such kind of records on the other hand. Besides, converting analog records into digital confronts complex problems related to the instrument's physical characteristics, such as varying rotation speed of the drum and unknown physical or electrical characteristics of the seismographs.

DIGITIZATION

Nowadays, many institutions in different countries are trying to scan or digitize analog records using innovative techniques that correspond to records. Some of the most recent projects are: the India (Shulka et al., 2015) and Romania (Paulescu et al., 2016) projects, Harvard Seismogram Archival Project (HRV; Lee et al., 2019), the Spanish Archive of Geophysical Data (Instituto Geográfico Nacional, IGN) (Muga et al., 2019), the database of scanned seismograms at the Institut Cartogràfic i Geològic de Catalunya (ICGC) (Batlló et al., 2021), the SISMOS project in Italy (Michelini et al., 2005), the SISMOMET in Mexico (Pérez-Campos et al., 2019), Albuquerque Seismological Lab (Alejandro et al., 2019) or the Central Asia project led by Michigan State University (Burk et al., 2019).

The digitizing procedure starts with scanning the seismograms for an acceptable resolution, then obtaining the technical specification of each instrument, instrumental correction, and calculating the response file (namely Poles & Zeros).

Digitization software

The wider possibilities and enhanced results offered through the processing of digital seismograms have been recognized since technical progress allowed such analysis techniques. Allen and Adams (1961) used a device to digitize analog seismograms, which was previously applied to digitize the meteorological and weather maps. As computer technology and scanning and image processing techniques advanced the preferred procedure became to convert seismograms to scanned raster images and then their traces vectorized using different software developments. Raster images are made up of pixels and colors whereas the vector image is made up of vectors and equations. Trifunac et al. (1999) presented and discussed the issues associated with semi-automatic vectorization of accelerograms based on raster images scanned from photographic records. Teves-Costa et al. (1999) manually vectorized the raster image before converting it to ASCII files with CADcore. The method is presented as without zoom limitation. On the last years several software packages have been developed with the goal of speeding the seismogram analog/digital conversion process. They are optimized for specific research goals. Among them, we may cite applications as the Seisdig software, which vectorizes scanned analog seismograms. It was developed based on MATLAB by Bromirski and Chuang (2003). In 2005, the TESEO was developed as a plug-in for GIMP (a powerful graphic software). The TESEO, which is based on neural networks and the Bezier fitting algorithm, provides manual and automatic seismogram trace vectorizations. (Pintore et al., 2005). Recently a new version has been released (https://teseo.rm.ingv.it). Bogiatzis and Miaki (2016) developed the DigitSeis software, based on MATLAB, as an HRV (Harvard-Adam Dziewoński observatory) project.

With all efforts to develop digitization software since the early 21st century, automated digitization faces some complex problems, and automatic digitization is not reliable for dealing with records of major earthquakes, with large amplitudes, many crossings, and so on (Batllo et al., 2008). The complication in these seismic records involves the interruption of lines, the breakup of lines, the specific characteristics of different recorders, and other problems not easy to identify, leading automated digitization to unacceptable results. Therefore, in this project, dealing mainly with large earthquakes recorded at regional distances with tangled lines, the manual digitization is considered to be the best choice. For this purpose, we developed a procedure using two spread software packages, GIMP and MATLAB. Our work method for manual digitization was as follows:

The procedure of manual digitizing starts with selecting the target earthquakes and their related aftershocks in terms of magnitude, casualties, and damages. After scanning the seismograms at 1200 dpi, we used the GIMP software to digitize the records based on color differences between earthquake signals and background. Therefore, the contrast of the scanned seismograms must be high. In addition, the RGB image must be converted to a grayscale image. Next step is the vectorization of the raster image. As a result, the vector image is pixel-free and will be used to calculate sample rate in the following step. The scanned image was converted to vector format by drawing lines on the waveform with the Path tools in GIMP.

Our experience is that using a curved line to obtain the best points for coverage on the waveform and eliminate mismatches in pick points is preferable. To a large extent, the cubic Bezier equation in the GIMP Path tools makes it possible. Furthermore, because there are no dimension constraints, a single vector is assigned to fit a Bezier curve with two control points on the seismic line of the scanned seismogram. Following this, the scanned seismogram will be converted to a vector setup (Fig. 5).

The GIMP output is a vector setup that includes the coefficients of the cubic Bezier equation (Eq. 1), which are defined as inputs to the MATLAB program. By transforming the output of GIMP with a MATLAB program, a series of (x, y) set down points can be extracted samples rate is 50 per second in the following step.

$$B(t) = (1-t)^3 K_0 + 3(1-t)^2 t K_1 + 3(1-t)\, t^2 K_2 + t^3 K_3 \ , \quad 0 \le t \le 1 \qquad (1)$$

Where K_0 is beginning point, K_1 and K_2 are control points, and K_3 is end point of Bezier curve. The series of set down points contains just one event, which consists of a series of pixel values ranging from 0 to 255 assigning black and white respectively. The MATLAB set of (x, y) points is a matrix that depicts time (horizontal axis) and amplitude (vertical axis). The amplitude is represented by the black pixels. The series of set down point is plotted as a waveform of the event that is needing further corrections.

Correction

The image scanning cause rotation error due to the position of the seismogram in the scanner, which is a deviation angle. Although this little angle deviation occurs for all scanned images and is noticeable in handy scanners, it can be removed easily using the GIMP Rotation tool (Fig.6).

The needle on the recording arm moves in an arched line over the recording drum. (Batllo et al, 2008). The geometry of the recorder, such as the drum, pen, and arm (Fig 7), causes a mismatch between time and amplitude. The time displacement in X-axis was corrected using the Cadek formula (Cadek, 1987):

$$t(i) = \frac{60}{d_1}\left\{x(i) - r\frac{arcsin\{r^2 + {d_0}^2 + L^2 + [y(i) - b]^2\} + arcsin\,(r^2 + a^2 - L^2 + b^2)}{2ar}\right\} \quad (2)$$

In this equation L represents the length of the writing arm, which is distance from rotating axis to the tip of the stylus, r = radius of the cylinderal smoke paper-bearing drive, d_0 = access distance of the rotating arm to the driving cylinder axis, b = shift of the arm access in millimeters to the baseline on the smoke paper, d_1 = millimeters between two minutes time marks, x(i) = not corrected time recorded, and y(i) = The amplitude recorded in millimeters that was not corrected.

The MATLAB GUI is used to apply formula 1 (curvature correction) to precisely set down points and generate as coherently accurate waveforms as possible. In addition, the moving velocity of the recorder's pen (short or long period), the start and end time of the event, the pixels of a raster image, the real-time, and the amplitude are all defined in the MATLAB GUI. Finally, all output is saved in SAC format.

An example of smoked seismogram curvature correction shows respectively in figure 8.

free period, damping, and friction are the characteristics of a mechanical seismograph, whereas galvanometric seismographs have mass, galvanometer free period, coupling, and galvanometer damping. Driving pole and zero from analog seismometers is a critical feature for converting analog to digital records. Galvanometric seismographs have two oscillation systems: electromagnetic sensors and galvanometers. The pole and zero for galvanometric seismometers were calculated using the method proposed by Batllo and Bormann (2000). Assuming that the coupling between the sensor and the galvanometer is zero, the system transfer function is as follows (Aki,1980):

$$T(s) = \frac{A_m S^3}{(s^2 - 2w_g h_g s + w_g^2)(s^2 - 2w_s h_s s + w_s^2)} \quad (3)$$

Where, w_s is the natural frequency of the sensor, and w_g is the natural frequency of the galvanometer; h_s and h_g are the sensor and galvanometer damping coefficients; and A_m is a constant that fits the magnification curve to the true values.

The formula to obtain pole and zero is (Batllo and Bormann, 2000):

$$\begin{cases} p_{1,2} = w_s(-h_s \pm j\sqrt{1 - h_s^2}) \\ p_{3,4} = w_g(-h_g \pm j\sqrt{1 - h_g^2}) \end{cases} \quad (4)$$

We need hg to calculate the Poles & Zeroes, which is not listed in any catalog. The ideal value of h_g according to the concept of designing a galvanometer, is 1, but the real value is not exactly 1 because if h_g was assumed 1 in the Eq. 4, we would only have two pairs of poles instead of four different poles. As a result, different values ranging from 0.5 to 1 with a specific step were inserted, and the transform function for each one was drawn. Following that, each diagram was compared to the original amplitude response diagram, which is absolute value of the complex frequency response, provided in an old supplement report produced by IGUT as an end user of the equipment, and the best coverage was determined to be h_g = 0.95.

Table 2 The METADATA of each seismogram for the electromagnetic instrument.

Metadata Item	Description	Units or Format
Start time of the event	The time of the image's first sample	YYYMMDDTHH:MM:SS
End time of the event	The time of the image's last sample	YYYMMDDTHH:MM:SS
Time Correction	Any time correction that has been applied to the data.	YYYMMDDTHH:MM:SS
IR Station Code	In the International Registry, the station's code.	Text
Location	Latitude, Longitude, Elevation	Real
Vertical pixels	The number of pixels along the vertical axis.	Integer
horizontal pixels	The number of pixels along the horizental axis.	Integer
Damping of galvanometer	The galvanometer's damping constant	Real
Damping of Seismometer	Electromagnetic magnification of seismograph	Real
Name of the network	the network to which the station is connected	Text
Network code	Site name	Text
Component	Channel code	Text
Open date	Date when the station was opened	YYYMMDDTHH:MM:SS
Close date	Date when the station was closed	YYYMMDDTHH:MM:SS
Registration	Kind of recording paper	Smoked or photographic paper
Seismometer	type of sensing instrument (e.g., Stuttgart Hiller, WWSSN, Gallitzin)	Text
The pendulum's free period	The instrument's free period	Second
Free period of galvanometer	The instrument's free period	Second
System type of recording (drum and seismometer)	The manufacture of the recording system (e.g., Teledyne, Gallitzin, Stuttgart).	Text
Scale/Gain/Amplification	Gain or scale factor	Real dimensionless
Resolution	The resolution of the scanned image	Pixels per mm
Length of the analog image	The original document's length	Centimeter
Width of the analog image	The original document's width	Centimeter
The original record's location	A country, a state or province, a city, or an institution	Text
Motor constant	Characteristics of electrical motors (transform electrical power into mechanical power)	Newton-meters/ampere

Type of damper	Electromagnetic for all	Text
Mass of pendulum	Mass of pendulum for different component	Integer
Paper speed	Turning recorder drum speed	Millimeter per second

Preliminary results

Calculating Poles & Zeroes for analog instruments is required for modern techniques. The technique presented in the Poles & Zeroes section can be used to obtain the true value of h_g. One of the project's first accomplishments was digitizing the aftershocks of the July 30, 1970, earthquake in Maraveh-Tappeh at 00:52 GMT and 04:22 local time. Several Maraveh-Tappeh earthquake aftershocks have been digitized (Figs 9 to 11). The P&S arrival phase time is as precise as possible when digitizing seismograms, whereas the S-phase has never been published before.

Relocation of the Maraveh_Tappeh 1970 earthquake and aftershocks based on digitized seismograms is shown in figure 12. Digitized seismograms allow using full-waveform and amplitude values to locate older earthquakes precisely. The earthquakes have been relocated using the IGUT present procedures (software, regional velocity model, etc.) and they may be compared in a homogeneous way with the present regional seismicity.

Conclusion

IGUT holds a large number of historical seismograms. A project to recover the waveforms of main earthquakes occurred in Iran in digital form has been started. A procedure allowing the acquisition of the desired waveforms from the raster images of the analog seismograms recorded in smoked or photographic paper has been developed. The developed procedure uses spread software packages and open-source software making it easily available to anybody interested in their use. Digitization of analog seismograms recorded by the IGUT's Iranian seismographic stations demonstrates the benefit of manual digitizing, which may face crossings and time gaps due to large earthquakes with large amplitudes present in the digitized seismograms. This method avoids common problems like line interruption, errors caused by recorder geometry, and the inherent nature of analog instruments. Once digital waveforms are obtained, they are identified with a set of metadata intended to make them easily accessible through FAIR principles.

Because of the digitization project, the IGUT's digital seismic data bank is growing. Now, the full waveforms of recorded earthquakes (main-shocks) and their aftershocks are available for various types of seismological researches and they are used to enhance the homogeneity of the Iranian seismicity catalogue from 1958 onwards.

Declarations

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual

property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). Mahdy Aghajani is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

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Ethics approval

Hereby, I, Mahdy Aghajani, consciously assure that for the manuscript "Digitizing analog seismograms of Iranian seismic stations - preserving records for strong earthquakes in Iran 1960-1990" that this manuscript does not involve the use of animal or human data or tissue and the following is fulfilled:

1) This study is the authors' own original work, which has not been previously published elsewhere.

2) The paper is not currently being considered for publication elsewhere.

3) The paper reflects the authors' own research and analysis in a truthful and complete manner.

4) The paper properly credits the meaningful contributions of co-authors and co-researchers.

5) The results are appropriately placed in the context of prior and existing research.

6) All sources used are properly disclosed.

7) All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Consent for publication

Not applicable

Availability of data and material

The seismograms that support the finding of this study are freely available on demand at seismology division of Institute of Geophysics of University of Tehran, https://geophysics.ut.ac.ir/en/%D8%A8%D8%AE%D8%B4-%D9%BE%DA%98%D9%88%D9%87%D8%B4%DB%8C-%D8%B2%D9%84%D8%B2%D9%84%D9%87-%D8%B4%D9%86%D8%A7%D8%B3%DB%8C.

In addition, The source codes used in this study are available for downloading at the link: https://github.com/hosseinahmadi1/digitizing-seismograms, and the name of the code/library is: digitizing-seismograms. Program language: MATLAB, Software required: Windows 10 and MATLAB 2015 and upper, Program size: 64 KB.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This study received no specific funding from public, commercial, or not-for-profit funding agencies.

Authors' contributions

Mahdy Aghajani: Author 1 designer and coordinator the project, makes main contributions to the development of ideas, wrote the manuscript.

Hossein Ahmadi: Author 1 the implementation of ideas, designed the computational framework and analyzed the data and performed the calculations, the conception of experiments.

Noorbakhsh Mirzaei: Author 2 participate in drafting and critically revisiting the manuscript and take intellectual responsibility for its content.

Josep Batllo: Author 2 verified the analytical methods and critically revisiting the manuscript and take intellectual responsibility for its content.

Acknowledgements

The authors would like to thank the seismology research division of IGUT for their technical assistance, and Dr. Jochen Braunmiller of the University of South Florida for his helpful suggestions and thorough review of the manuscript.

References

1. Adams, W.M. and Allen, D.C., 1961. Reading seismograms with digital computers. Bulletin of the Seismological Society of America, 51(1), pp.61-67.
2. Aghajani, M., Mirzaei, N., 2020. Instrumental Seismology in Iran., 154 p., Hardcover ISBN 978-622-214-626-9, Doi: 551/220287
3. Aki, K., and Richards, PG, 1980. Quantitative Seismology Theory and Methods (Vol. 2): San Francisco (WH Freeman).
4. Alejandro, A.C.B., Hutt, C.R., Ringler, A.T., Moore, S.V., Anthony, R.E. and Wilson, D.C., 2019. The Albuquerque Seismological Lab WWSSN film chip preservation project. Seismological Research Letters, 90(1), pp.401-408.
5. Annals, 1959. Annals of the International Geophysical Year, Pergamon, Press, London, volume I.
6. Batlló, J., Stich, D. and Macià, R., 2008. Quantitative analysis of early seismograph recordings. In Historical seismology (pp. 385-402). Springer, Dordrecht.

7. Batlló, J. and Bormann, P., 2000. A catalog of old Spanish seismographs. Seismological Research Letters, 71(5), pp.570-582.
8. Batlló, J., Villaseñor, A., Jara, J. A., Merino, M., Solé, G., Unamuno, J. (2021). Digital Preservation of Analogue Seismograms and Other Documents at Institut Cartogràfic i Geològic de Catalunya (ICGC). XXVII IAGA-IASPEI General Assembly Abstract Book, Hyderabad, India, pp. 86.
9. Berberian, M. and Walker, R., 2010. The Rudbār M w 7.3 earthquake of 1990 June 20; seismotectonics, coseismic and geomorphic displacements, and historic earthquakes of the western 'High-Alborz', Iran. Geophysical Journal International, 182(3), pp.1577-1602.
10. Berberian, M., 2014. Earthquakes and Coseismic Faulting on the Iranian Plateau: A Historical, Social and Physical Approach, Elsevier Series Development in Earth Surface Processes 17, Amsterdam, The Netherlands, 776 pp.
11. Berberian, M., 1979. Earthquake faulting and bedding thrust associated with the Tabas-e-Golshan (Iran) earthquake of September 16, 1978. Bulletin of the Seismological Society of America, 69(6), pp.1861-1887.
12. Berberian, M., 1982. Aftershock tectonics of the 1978 Tabas-e Golshan (Iran) earthquake
13. sequence: a documented active 'thin-and thick-skinned tectonic' case. Geophys. J. R. Astron.
14. Soc. Lond. 68, 499–530.
15. Bogiatzis, P. and Ishii, M., 2016. DigitSeis: A new digitization software for analog seismograms. Seismological Research Letters, 87(3), pp.726-736.
16. Bromirski, P.D., and Chuang, S., 2003. SeisDig: Software to digitize scanned analog seismogram images, User's Manual.
17. Burk, D., Mackey, K., Burkhart, K., Abrams, K., Sokolova, I., 2019a. Restoration and Recovery of Historical Seismic Records from the Former Soviet Union, WORKSHOP REPORT: Securing Legacy Seismic Data to Enable Future Discoveries September 18-19, 2019 Albuquerque, New Mexico.
18. Cadek, O., 1987. Studying earthquake ground motion in Prague from Wiechert seismograph records. Gerl. Beitr. Geophs. 96, 438–447.
19. Hwang, L.J., Ahern, T., Ebinger, C., Ellsworth, W., Euler, G., Okal, E., Okubo, P. and Walter, W., 2020. WORKSHOP REPORT: Securing Legacy Seismic Data to Enable Future Discoveries September 18-19, 2019 Albuquerque, New Mexico.
20. Kanamori, H., 1988. Importance of historical seismograms for geophysical research, Historical Seismograms and Earthquakes of the World, pp. 16–33.
21. Korsmo, F. L., 2007. The Genesis of the International Geophysical Year, Phys Today, 60, 38–43.
22. Lee, T. A., Ishii, M., Ishii, H., Morinaga, T., 2019. The Potential of Analog Seismograms for Science and Education, WORKSHOP REPORT: Securing Legacy Seismic Data to Enable Future Discoveries September 18-19, 2019 Albuquerque, New Mexico.
23. Michelini A., De Simoni B., Amato A. and Boschi E. (2005), "Collecting, digitizing and distributing historical seismological data", EOS Transactions AGU, 12 July 2005, Vol. 86, no. 28.
24. Muga, M.L., Benayas, I. and Tordesillas, J.M., 2019. Seismic Information at the Spanish Geophysical Data National Archive. Example: the Earthquake of February 28, 1969. Pure and Applied Geophysics, pp.1-13.
25. Niazi, M., Kanamori, H., 1981. Source parameters of 1978 tabas and 1979 Qainat, Iran, earthquakes from long-period surface waves. *Bulletin of the Seismological Society of America* 1981, 71 (4): 1201–1213.

26. Paulescu, D., M. Rogozea, M. Popa and M. Radulian, 2016. Digitized Database of Old Seismograms Recorder in Romania, Acta Geophys., 64(4), 963-977, Doi: 10.1515/acgeo-2016-0039.
27. Pérez-Campos, X., Armendáriz-Sánchez, S., Espíndola, V.H., Castro-Escamilla, M., Perez, J., Casiano, L.M., Rodriguez Rasilla, I., Cárdenas Monroy, C. and Cárdenas, A., 2020. Preservation and reuse of historical seismic data in Mexico: SISMOMex and the online "National Seismogram Library". Seismological Research Letters, 91(3), pp. 1482-1487.
28. Peterson, J. and Hutt, C.R., 2014. World-wide standardized seismograph network: a data users guide (p. 82). US Department of the Interior, US Geological Survey.
29. Pintore, S., Quintiliani, M. and Franceschi, D., 2005. Teseo: A vectoriser of historical seismograms. Computers & geosciences, 31(10), pp.1277-1285.
30. Shoja-Taheri, J. and Anderson, J.G., 1988. The 1978 Tabas, Iran, earthquake: an interpretation of the strong motion records. Bulletin of the Seismological Society of America, 78(1), pp.142-171.
31. Shukla, H. P. and Dattatrayam, R. S., 2015. VECTOR DIGITIZATION OF HISTORICAL SEISMOGRAMS. International Research Journal of Natural and Applied Sciences, 2(8), pp. 112-130.
32. Silver, P. G., Jordan, T. H., 1983, Total-Moment Spectra of Fourteen Large Earthquakes, Journal of Geophysical Re- search, Vol. 88, No. B4, 1983, pp. 3273-3293.
33. Teves-Costa, P., Borges, J.F., Rio, I., Ribeiro, R. and Marreiros, C., 1999. Source parameters of old earthquakes: semi-automatic digitization of analog records and seismic moment assessment. Natural Hazards, 19(2), pp.205-220.
34. Trifunac, M.D., Lee, V.W. and Todorovska, M.I., 1999. Common problems in automatic digitization of strong motion accelerograms. Soil Dynamics and Earthquake Engineering, 18(7), pp.519-530.
35. Walker, R., Jackson, J. and Baker, C., 2003. Surface expression of thrust faulting in eastern Iran: source parameters and surface deformation of the 1978 Tabas and 1968 Ferdows earthquake sequences. Geophysical Journal International, 152(3), pp.749-765.
36. Walker, R.T., Khatib, M.M., Bahroudi, A., Rodés, A., Schnabel, C., Fattahi, M., Talebian, M. and Bergman, E., 2015. Co-seismic, geomorphic, and geologic fold growth associated with the 1978 Tabas-e-Golshan earthquake fault in eastern Iran. Geomorphology, 237, pp.98-118.
37. Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.W., Santos, L.B.D.S., Bourne, P.E. and Bouwman, J., 2016. Addendum: The FAIR Guiding Principles for scientific data management and stewardship. Scientific data, 6, p.6.

Figures

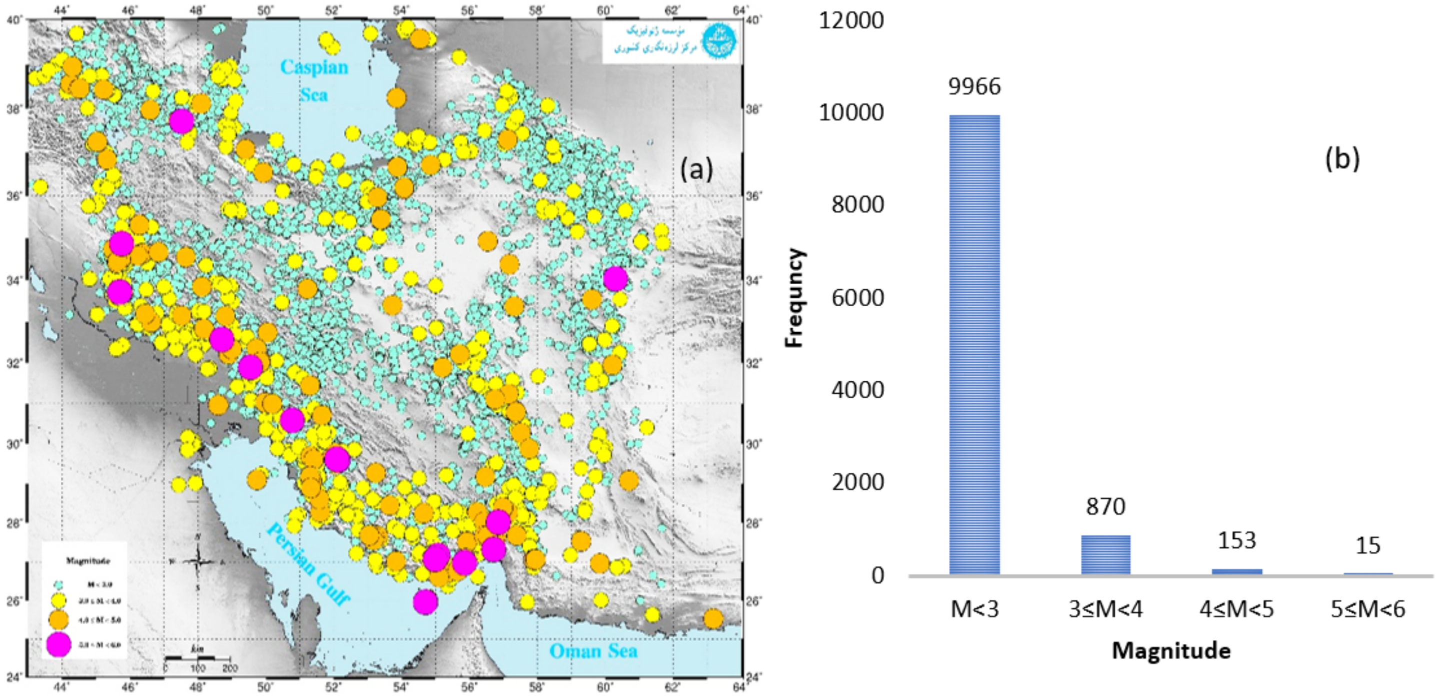

Figure 1

a) Earthquake epicenter map of more than 11,000 earthquakes recorded during a period of one year from 21 March 2018 to 20 March 2019 (Annual report of recorded earthquakes in Iran, see IRSC website at http://irsc.ut.ac.ir), b) Histogram of earthquake magnitudes versus number of events from 21 March 2018 to 20 March 2019.

Image not available with this version

Figure 2

Map of analog seismic stations in Iran Till 1995 (Aghajani and Mirzaei, 2020).

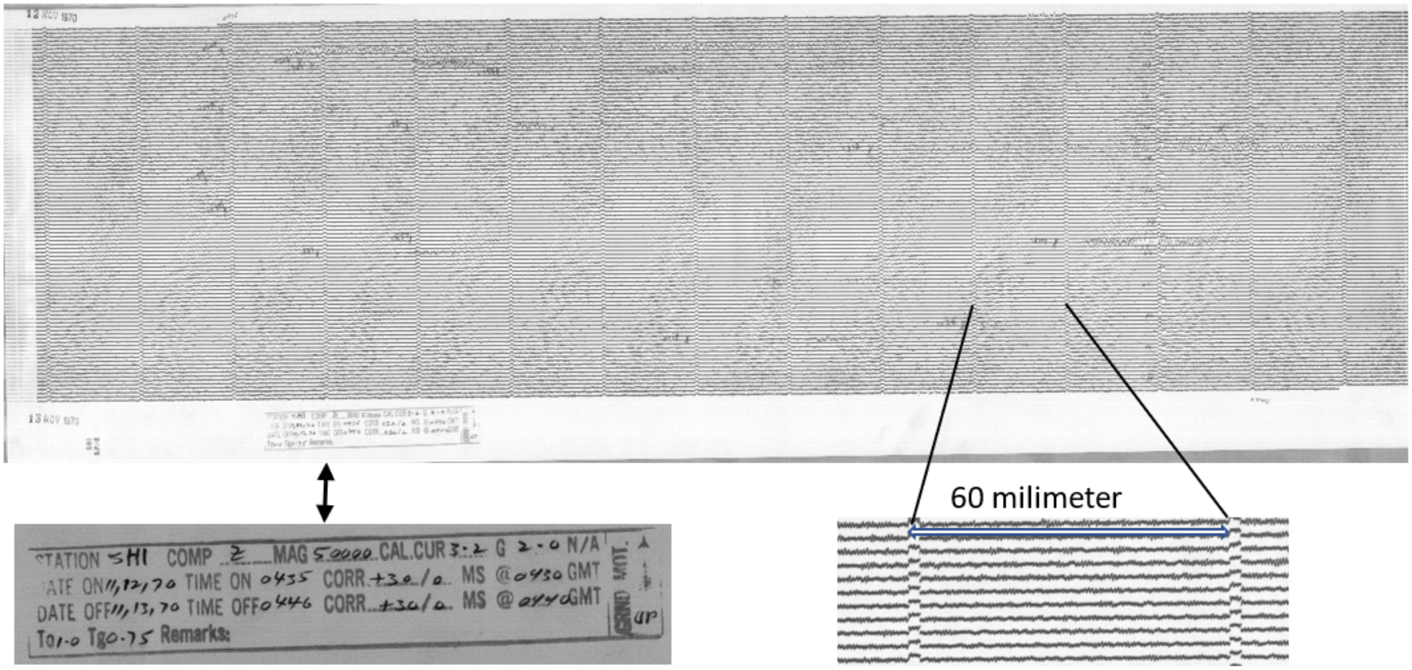

Figure 3

An example of a seismogram recorded on photographic paper, representing a 60-millimeter distance between two continuous mark-times. Each record contains some specific information on the front left corner that indicates start time, end time, date, component, type of seismometer, short-period or long period, station name, time correction, and magnification.

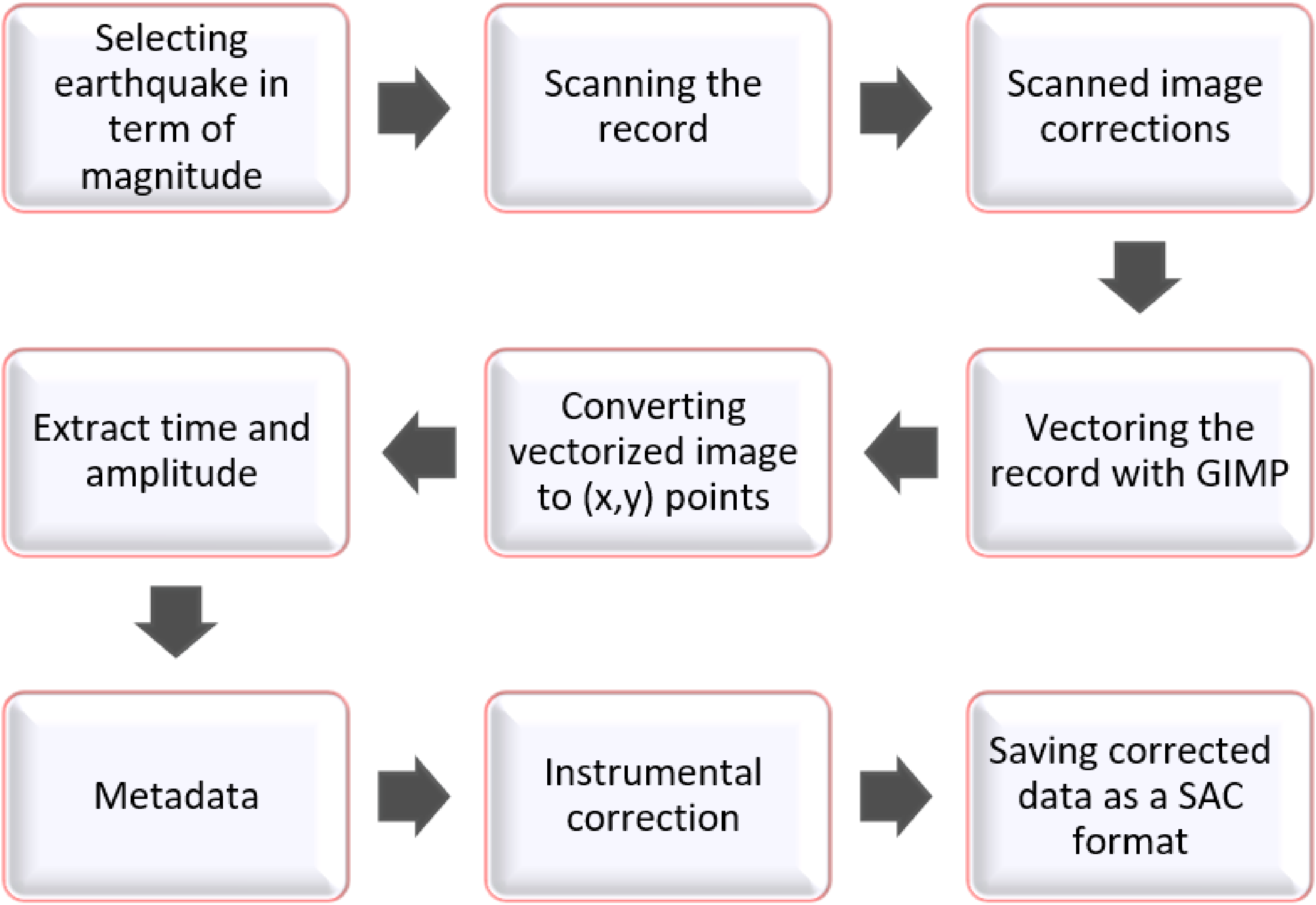

Figure 4

The flowchart of digitization of the analog seismograms in IGUT

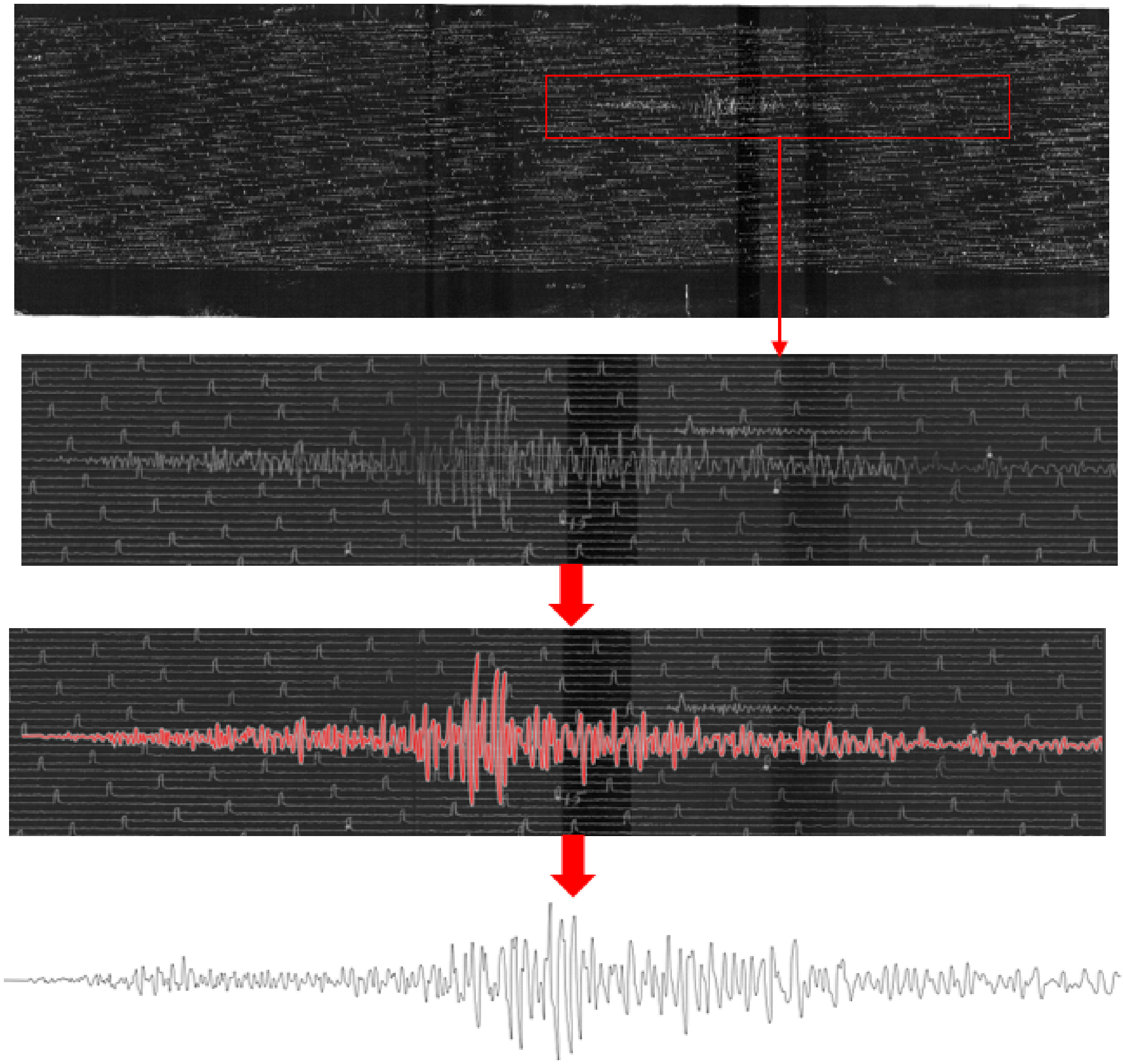

Figure 5

Conversion of raster-scanned image to vector image with curvature correction for an aftershock, MW=4.7 at 13:10 GMT, of July 30, 1970 Maraveh-Tappeh earthquake. Seismogram recorded by Stuttgart-Hiller instrument in Tehran (TEH) on Nov 12, 1970.

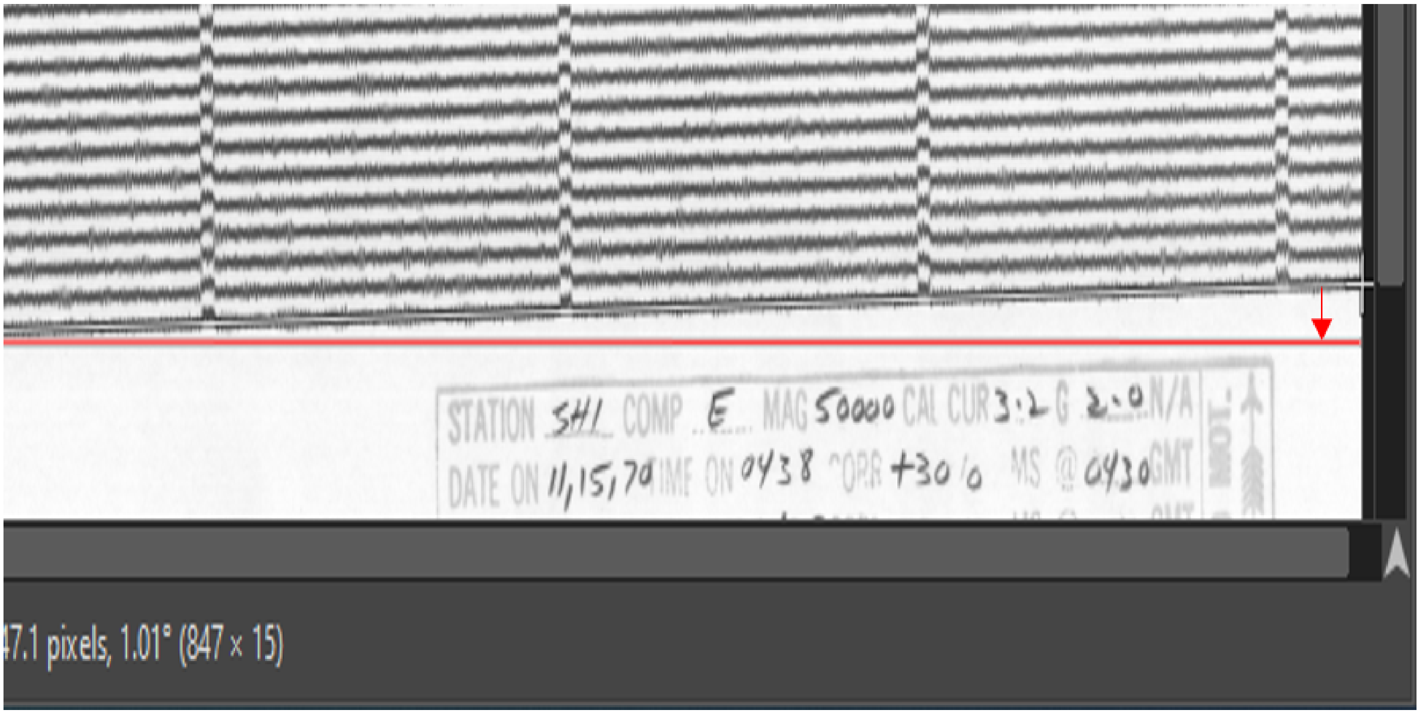

Figure 6

A mere deviation from horizontal axis is 1.01° in GIMP, which is 1200dpi resolution.

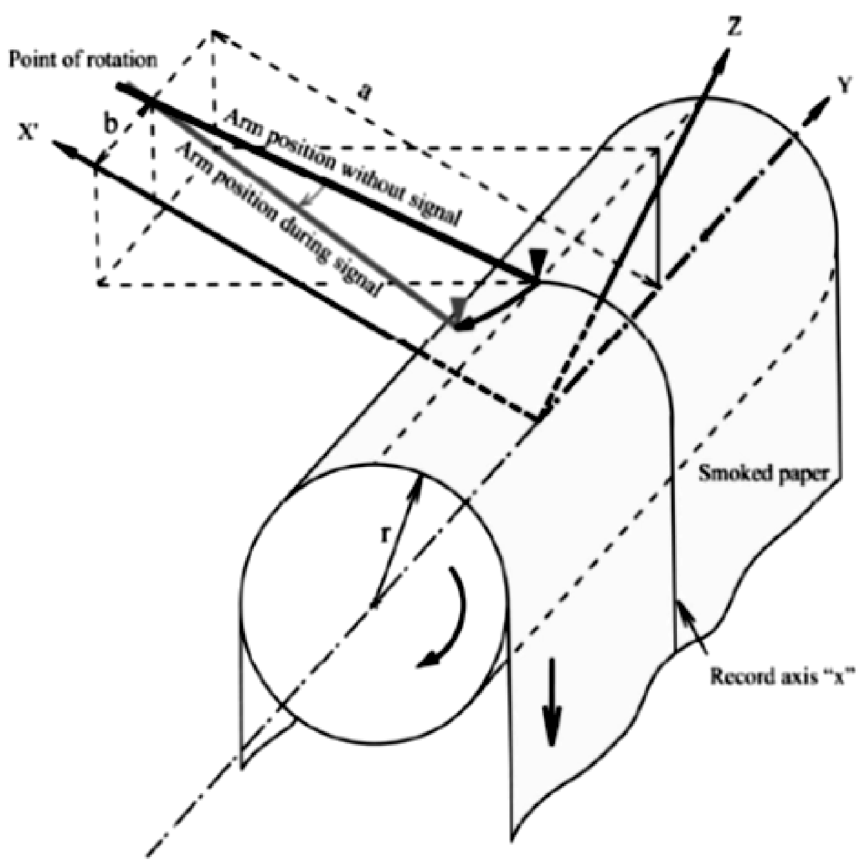

Figure 7

The drum, pen, and lever of the mechanical recorder shows angle deviation and curved recorded seismic signal (Pintore, 2005).

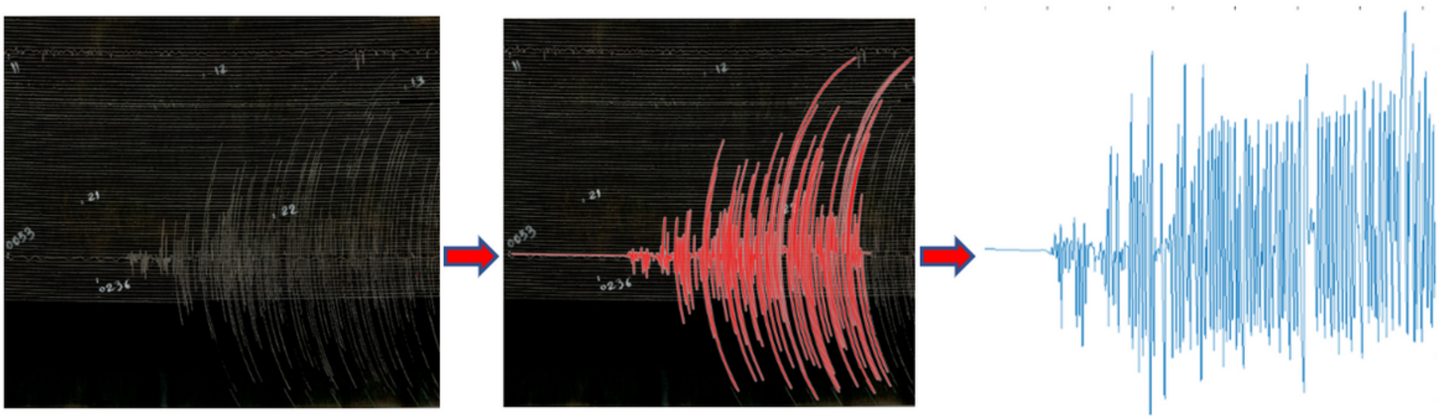

Figure 8

A procedure for correcting the curvature of a horizontal N-S component seismogram of the Maraveh-Tappeh 1970 earthquake recorded by the Stuttgart-Hiller short period in Kermanshah (KER) on July 30, 1970. From left to right, the original waveform, digitized waveform, and curvature corrected waveform are shown.

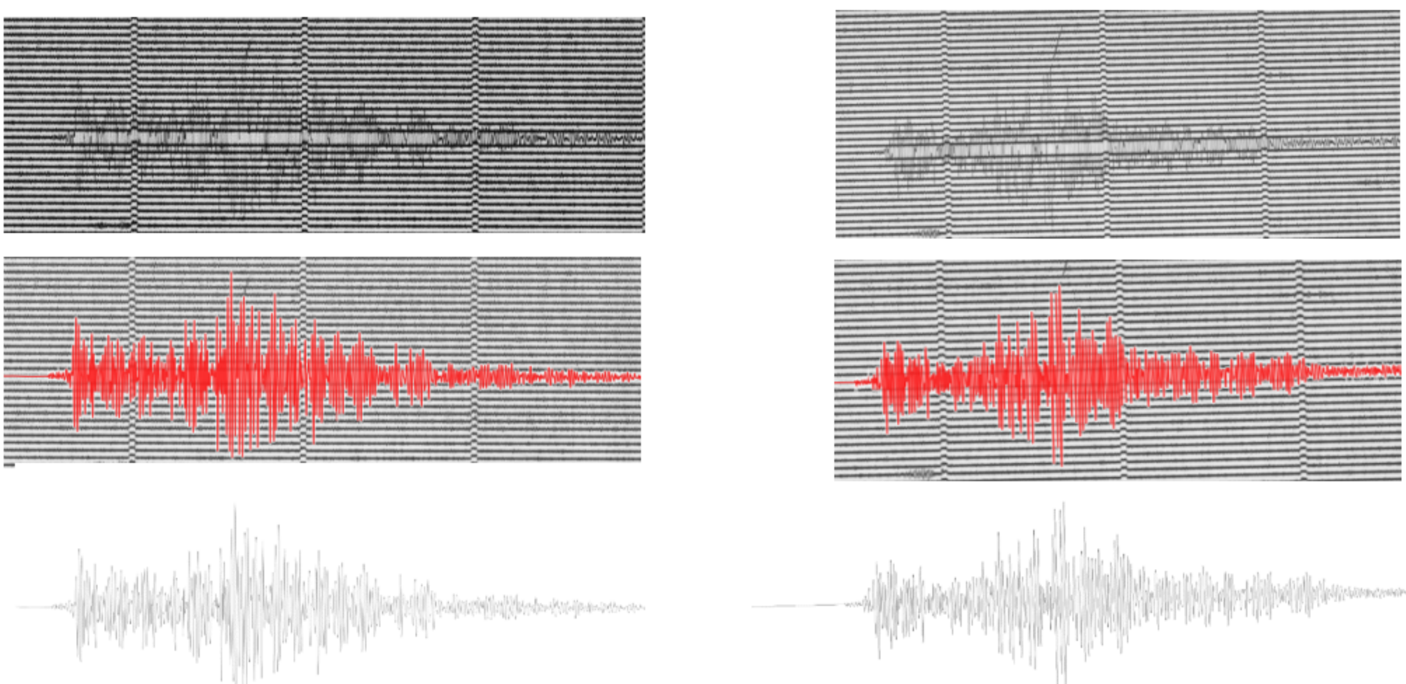

Figure 9

Digitized seismograms of Maraveh_Tappeh 1970 earthquake at 11:40:37 GMT, seismogram recorded by WWSSN short_period in Mashhad (MSH) on Aug 1, 1970. Left: E-component, and right: N-component.

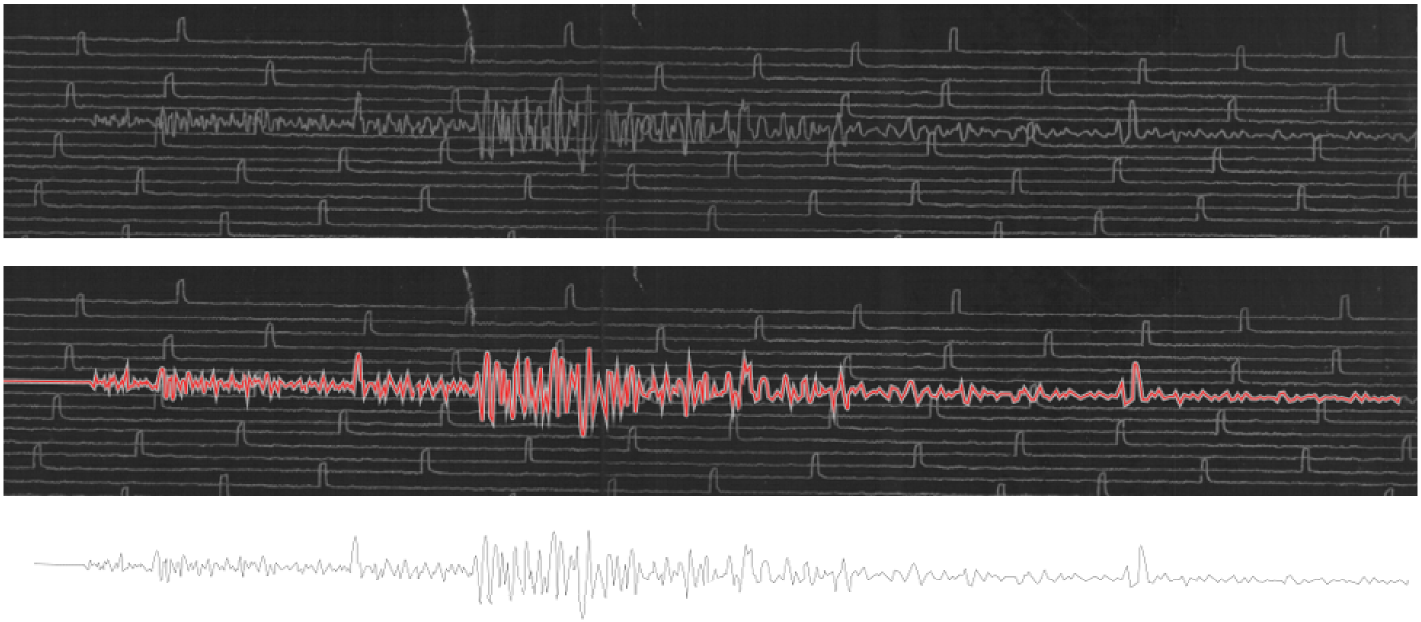

Figure 10

Digitized N-component of Maraveh-Tappeh 1970 earthquake at 8:16:02 GMT, seismogram recorded by Stuttgart-Hiller in Tehran (TEH) on Nov 6, 1970.

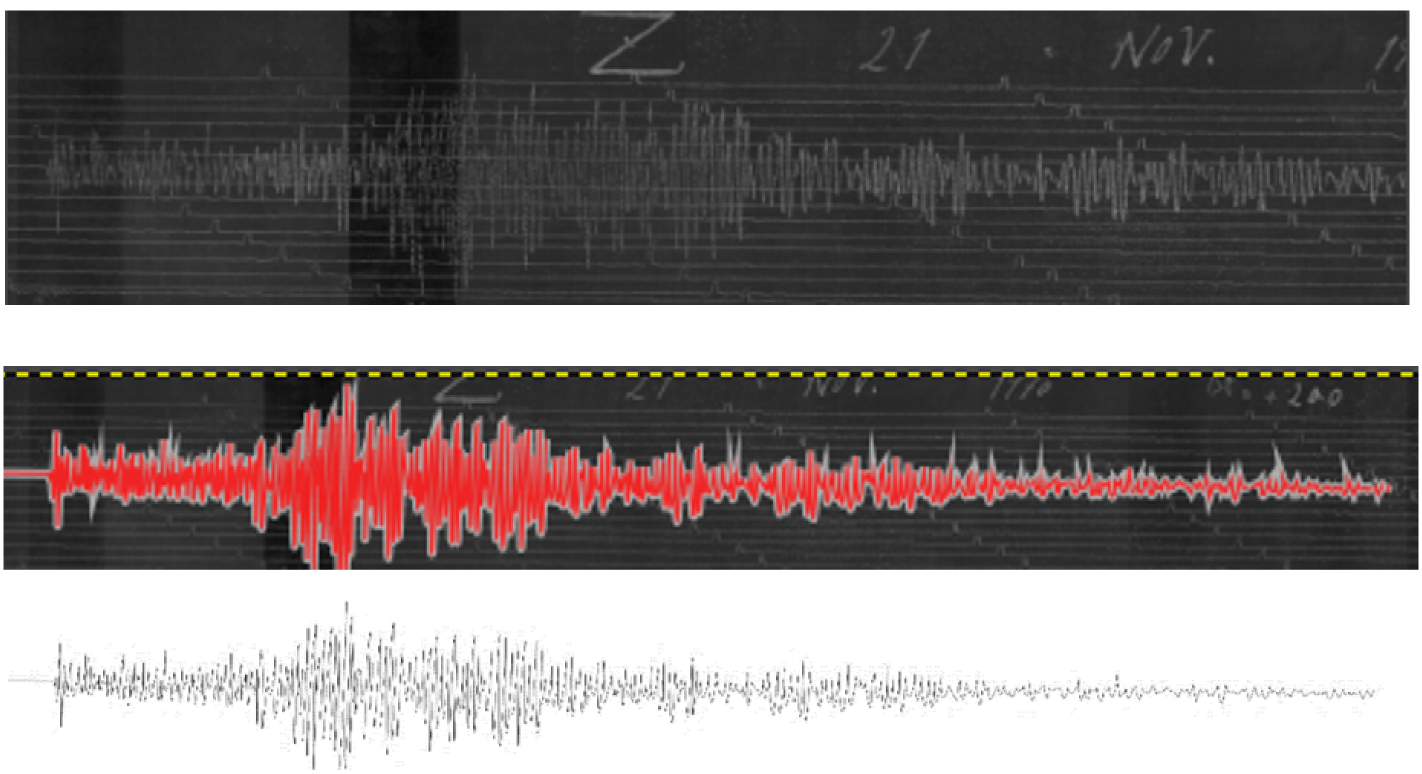

Figure 11

Digitized Z-component of Maraveh_Tappeh 1970 earthquake at 11:57:10 GMT, seismogram recorded by Stuttgart-Hiller in Tehran (TEH) on Nov 21, 1970.

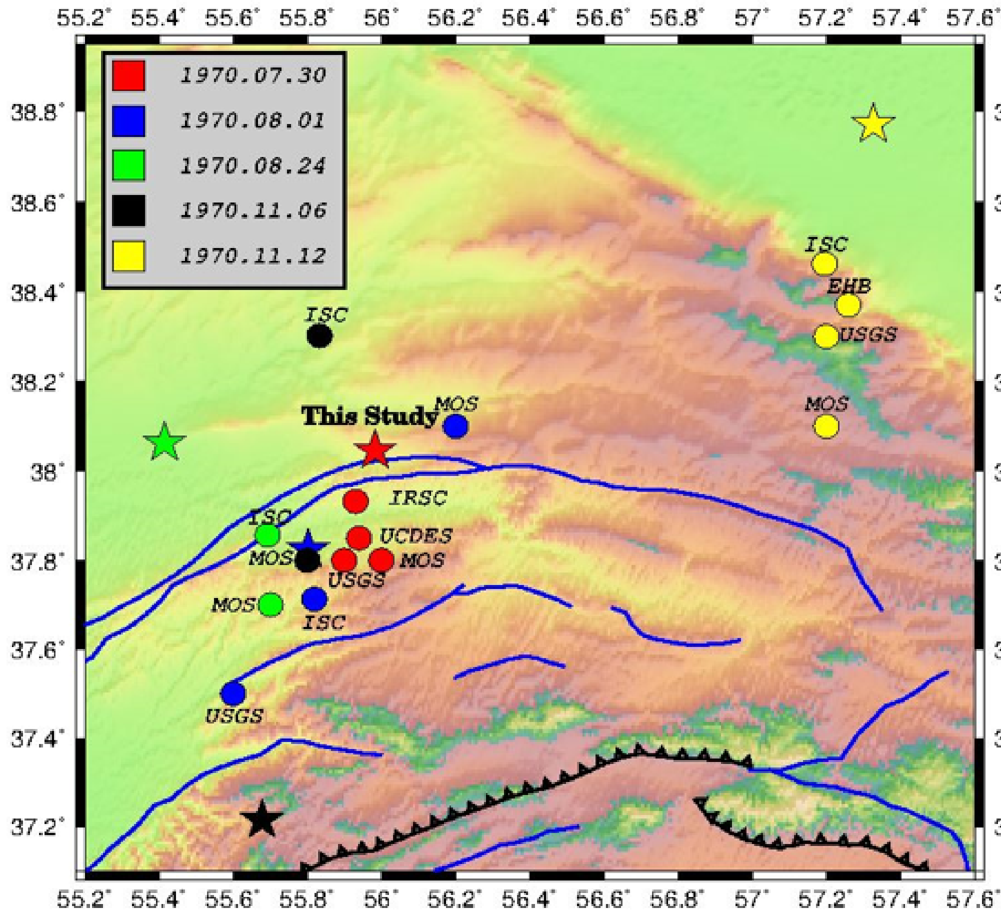

Figure 12

Location of Maravveh-Tappeh Aug 1970 earthquake and aftershocks. The circles reported by IRSC, ISC, MOS (Geophysical Survey of Russian Academy of Sciences), USGS, and UCDES. The stars in all colors result from relocation based on digitized analog records of the Institute of Geophysics of Tehran University.