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# VECTOR DIGITIZATION OF HISTORICAL SEISMOGRAMS

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## ABSTRACT

*In the past few decades' historical recordings of a scientific nature has taken up a critical importance in the different sectors of seismology: historical seismology and historical seismometry. Modern technologies now offer unique opportunities to catalog and efficiently distribute the reproductions into digital versions of scientific records. In order to mitigate earthquake hazards, it is important to study and learn from the past earthquakes. Seismograms contain the basic observational data for earthquake studies and must be archived properly and made available to the seismologists for further research. Seismologists normally prefer to work with digital seismograms that can be processed and analyzed easily and quickly. Old seismograms contain a lot of information useful for the study of historical earthquakes as correctly stated Ferrari, (1997). It is necessary to extract this information by digitizing the analog seismograms by using modern analysis tools. There are a few application software available on public domain for digitization of seismograms and one of these is 'Teseo' of INGV, Italy. 'Teseo' (Teseo$^2$, new version) was developed by a team (Pintore et al., 2005) in the framework of the Sismos project (Michelini et al, 2005). Teseo is a plug–in for GIMP, an image processing tool (Gimp, V: 2.6.10) that extends its functionalities for seismological studies. IMD customized Teseo for quick and accurate digitization of historical seismograms. The main process involved is to raster scan of the seismograms, select earthquake traces of desired nature, processing of raster scans and vector digitization of these traces applying piecewise cubic B'ezier curves. Under present program, raster scanning of 100,000 seismograms and vector digitization of 5,000 historical earthquakes have been completed for pursuing further research.*

**Keywords:** Historical seismogram, Raster Scanning, Vectorisation, Digitization

# 1. Introduction

India Meteorological Department (IMD), the nodal agency for seismic monitoring in the country, has been preserving a huge number of analog seismograms from the pre-digital era. Most of the seismograms are in good condition but some seismograms are fading out due to aging effect.

The analog seismograms recorded on paper result from the response of a seismometer and a recording system to the ground motion. These charts, containing the short period and long period ground motion records, are made on photographic, heat-sensitive and smoke recording papers. These analog seismograms require to be archived properly in a suitable electronic media. In this direction, IMD has taken up a vital project "Archival and digitization of seismic analog charts" to preserve the historical seismograms in electronic form.

The present study describes creation of facilities for the following:

(i) Preparing analog seismograms to be scanned.
(ii) Gathering information on metadata of the seismograms.
(iii) Scanning and editing the image files in Pro View and GIMP.
(iv) Extraction of the event directly from the raster image, in a manual or automatic way.
(v) Digitizing the image files into digital waveform files without losing any information contained in original seismograms.
(vi) Correct mapping from the (x, y) image coordinates to time and amplitude of the event
(vii) Creation of an appropriate database.

The use of modern techniques of vector digitization is to recover seismological information contained in historical seismograms that can supply additional knowledge on past seismicity and ongoing tectonic processes. The important of this goal is widely acknowledged (Kanamori, 1988), but it presents some difficulties, since data recorded by early instruments on paper media must be properly processed to obtain numerical data usable for modern analysis. In this direction, a new system for scanning, vector digitization of analog seismograms and creation of its database in active electronic media has been installed.

## 2. Objective

Long term preservation of seismic analog charts in electronic media for use by research community for understanding of earthquake phenomena for better preparedness and mitigative measures to reduce damage to property and loss of life in future earthquakes.

## 3. System Detail:

The present system installed in India Meteorological Department (IMD) have successfully achieved the target of raster scanning of selected **100,000** seismograms and vector digitization of **5,000** significant events. To achieve this target, a fast and accurate digitization procedure was created for transforming images of large dimensions and independent type on original paper or recording instrument.

### 3.1 Hardware

The system comprises of the following hardware:

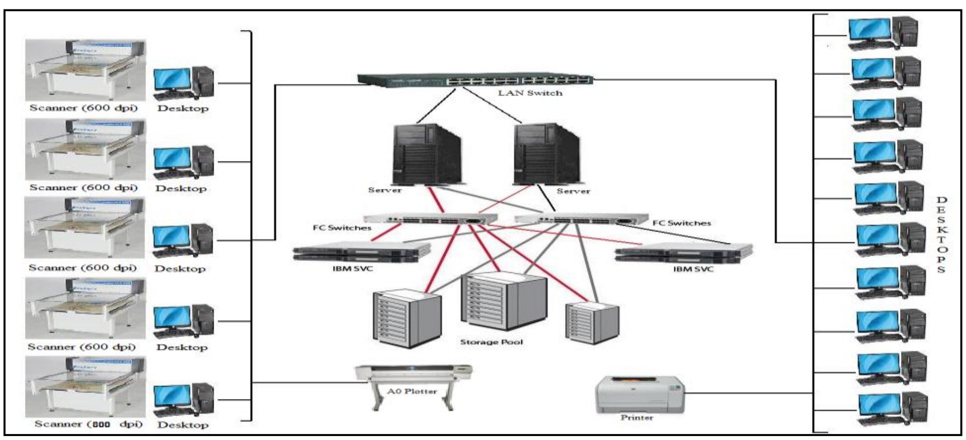



Fig.1: System hardware

For digitization process, 5-scanners (**600**dpi/**800**dpi), a storage system (84 TB), 2 servers and 15 desktops were connected each other through LAN to facilitate smooth processing of raster scanning, vector digitization and their archival in suitable electronic media (Fig.1).

### 3.2 Software

The work on digitization of seismograms primarily started by Samardjieva et al. (1998), who created a digital database for historical earthquakes using a manual digitization process whereby the original records were enlarged by a projector on a screen. Teves-Costa et al. (1999) made an effort to recover source parameters from historical records and developed a semi-automatic method using commercial software on images of 200 dpi Istituto Nazionale di Geofisica e Vulcanologia resolution. Baskoutas et al. (2000) digitised 1852 seismograms obtained from the Mainka and Wiechert seismographs in the National Observatory of Athens during the period 1911–1960. They developed software usable on black and white images with 1600 dpi, or 500 dpi if the image was too large.

There is few more software available for digitizing seismograms, namely, SeisDig (Bromirski and Chuang, 2003) and Teseo (Michelini et al, 2005). The key element of the approach made use of mathematical statistics to automatically determine specified tuning parameters in order to develop spatially adaptive threshold parameters, accurate timing and calibration information, and signal reconstruction that maintain waveform fidelity. Implementation of some of the statistics algorithms have successfully applied to digitize some WWSSN LP recordings of NTS explosions.

After exploring all possibility of digitization of analog seismograms on international and national levels, it was found that **Teseo (Teseo2, new version)** developed by a group under Sismos Project of Istituto Nazionale di Geofisica e Vulcanologia (INGV) Via di Vigna Murata 605, 00143 Roma, Italy. In IMD, web browser was developed as shown in Fig.2 in IMD to upload/retrieve of scans/vector files using GIMP and Teseo.

Further, Teseo was customized as per requirements and made available on both Linux and Windows platforms. A SQL data base was created to store raster scans/vector files generated under the project and handle data flow.

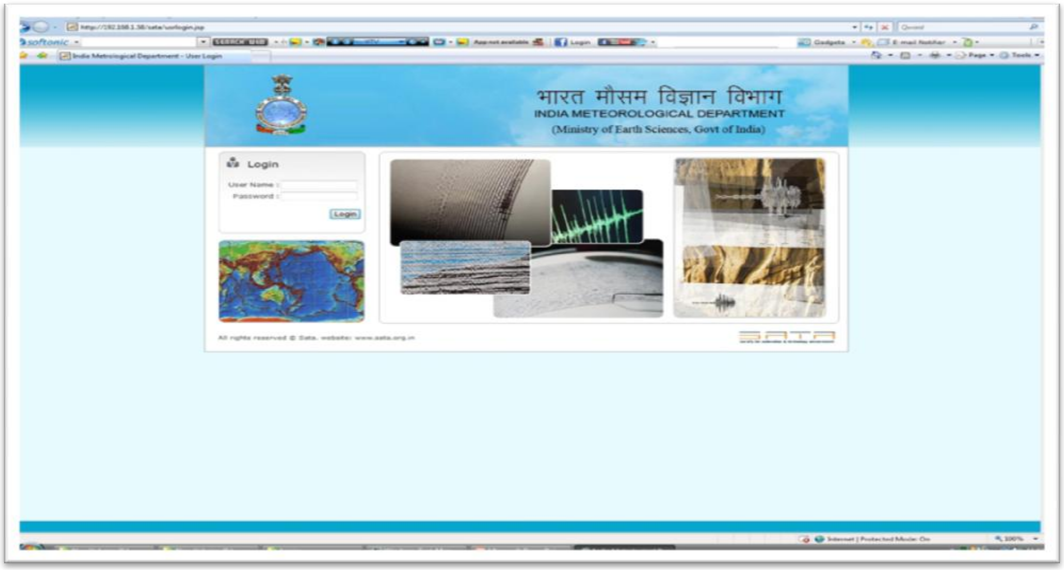



Fig. 2: A web browser developed in IMD

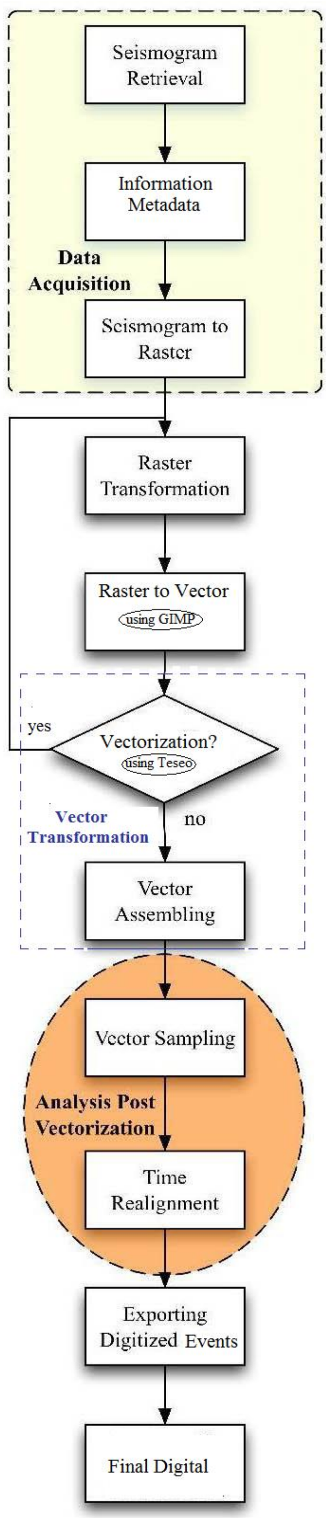
In the digitization process, seismograms are classified in a lot broadly based on the similarity of the seismograms. The seismograms of a lot are raster scanned and vector digitized using the tool of 'Teseo plugged in Gimp'. The output is created in plane ASCII/SAC2000 and subsequently SAC2000 is converted into SEISAN format for locating an historical earthquake. Finally, raster scans, vector digitized images (.Xcf) and waveform data in SEISAN formats are archived in a suitable database.

## 4. Collection of data

Analog seismograms recorded on paper result from the response of a seismometer and a recording system to ground motion. The main classes of old seismometers include short, intermediate and long-period instruments. The recording system for analog instruments is smoked, photographic and thermal type of paper with tracing device such as needle, light beam and significant mechanism of paper speed.

The seismograms are retrieved event-wise and made ready for scanning after applying cleaning and annotating process. Raster scanning is the first crucial steps for conversion of analog information into digital image form. Therefore, a sufficient care was taken during selection of charts and its transformation to raster scans to achieve the objective. The main focus was on vector digitization of earthquake traces available in historical seismograms without losing any information contained in the charts during the process of raster scanning, image processing and vector digitization.

## 5. Technique (work flow)




To achieve, raster scaning of seismograms are taken at an optical resolution of 600 or 800 dpi, as the case may be, in 256 gray levels. The standard format used to store raster scans was TIFF (Autodesk, 1992). This produces approximately 150–250 MB for seismograms of size 90x30/60x30/48x23cm with confirmation on the information contained in original seismograms be present in the raster image. Teseo software is designed and customized to offer a tool for vectorization of all types of seismograms preserved in IMD. The complete digitization workflow that produces a very good quality of data, is given below:

(i) *Seismogram Retrieval*: Collecting analog seismograms.

(ii) *Information Metadata*: Gathering information on metadata e.g. name of station, time on/off, instrumental parameters etc.

(iii) *Seismogram to Raster*: In order to preserve the information contained in the analog seismograms, used high–quality A0 flat bed scanners (600 or 800 dpi).

(iv) *Raster Transformation*: To enhance 'readability' of a seismogram powerful and useful filters in Teseo were applied to increase the brightness and contrast of the raster image under image processing.

(v) *Raster to Vector*: The intermediate step in digitization process allows to reproduce the shape of the earthquake traces using a vectorial representation in GIMP. Usually there are discontinuities in the signal trace recorded on the image that force the user to create iteratively multiple vector pieces.

(vi) *Vectorization*: Converting analog signals into digital using Teseo in-built GIMP.

(vii) *Vector Assembling*: Ordering vector pieces and filling gaps.

(viii) *Vector Sampling*: Extraction of the points sequence belonging to the vector.

(ix) *Time Realignment*: Assignment of the right time and amplitude to each point along with required curvature correction.

(x) *Exporting Digitized Trace*: Saving the sequence of samples choosing an appropriate file format.

(xi) *Final Digital (Consolidation Process)*: Saving all the information related to the digitization process in a single place. This permits to achieve a good quality of data and obtaining *final digital* in formats such as ASCII, SAC etc.

Fig.3: Flowchart of digitization process

The Image processes produce a pixel coordinate sequence for the trace (rough digital) and the correction process transforms it in a time domain to a seismic signal (final digital). This latter stage needs some instrumental parameters, either available from the seismograms or from known sources. During image process, an intermediate step was developed (raster to vector) that produces a vectorial representation of the seismic traces on the image.

## 6. Implementation plan

The data acquisition is exhaustive work in terms of time spent to search out seismograms and gathering its associated information such as metadata. To achieve high–quality of raster scanning, A0 size flat bed scanners along with high end server, workstations/desktops and high capacity storage system are used. The infrastructure was created for implementation of the project entitled "Archival and digitization of seismic analog charts".

In order to implement digitization workflow (Fig: 3), developed/customized Teseo software, plug–in for GIMP was used. The GIMP offers many features and capabilities for image processing. Teseo relies on GIMP only for the raster to vector transformation, vectorial representation of the seismic trace and the consolidation of the digitization process. This last step is achieved by putting all information related to the digitization process into an xcf file (Fig.4). The xcf format is a GIMP proprietary format that saves different raster layers and vectors produced as well as arbitrary pieces of data. Also, xcf supports gzip and bzip2 compression.

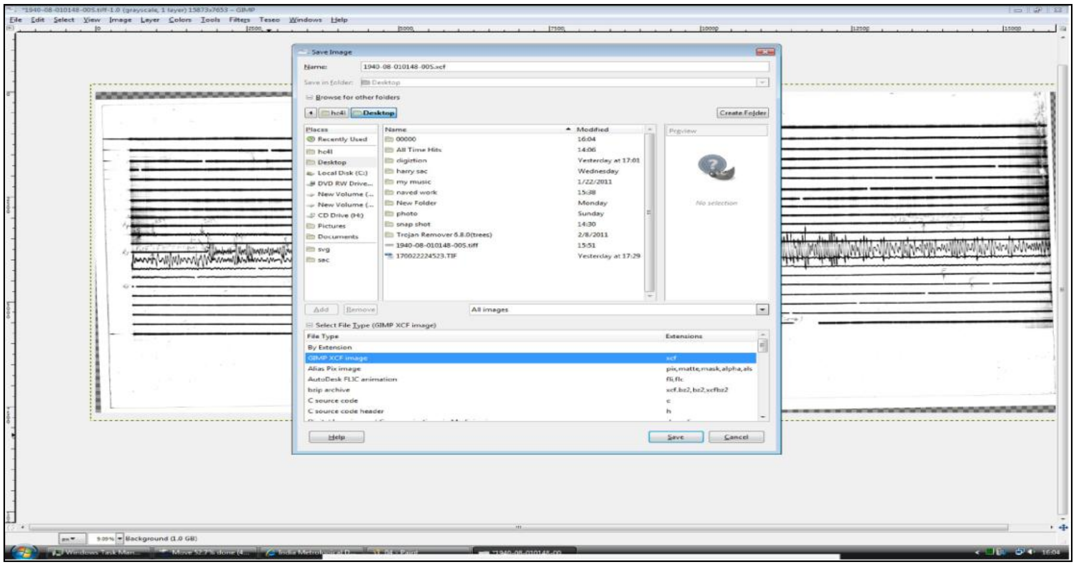


Fig.4: Snap shot of scanned image converted from TIFF to xcf format and saved on GIMP platform.

### 6.1 Teseo, an application software

Teseo has the facility for:

• Additional operations on the vectorised events (i.e. resampling and alignment of traces)

• A vectorization algorithms (color weighted mean)

• Processing after event vectorization, such as curvature correction and time realignment.

• Event import/export in various formats (such as SAC, SVG, ASCII, DXF).

In order to keep track of the stages and parameters of a seismogram vectorization, Teseo is able to write this information into the image saved in *xcf* format. Te main window of Teseo is shown in Fig.5, where an image has been displayed on GIMP platform for processing.

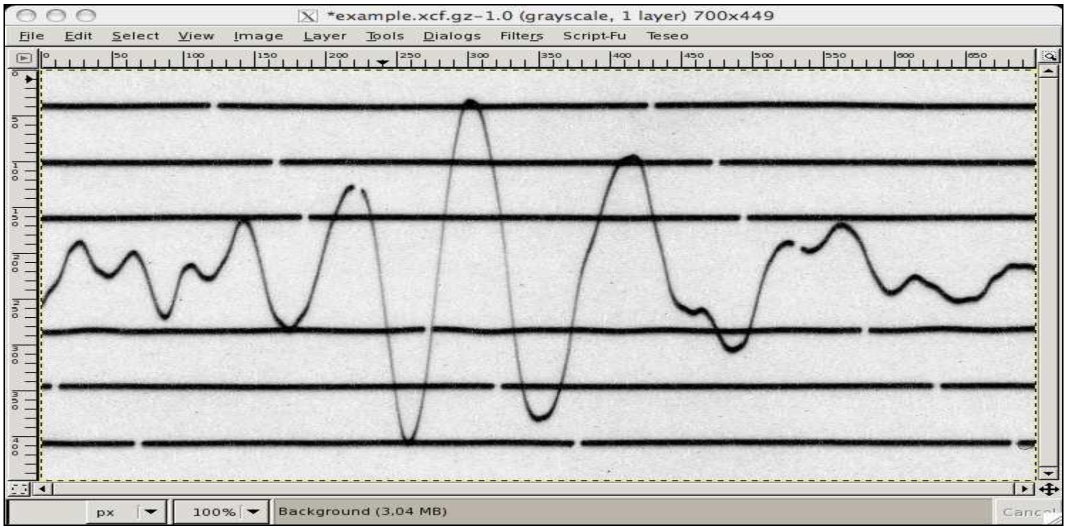



Fig.5: Window of Teseo

### 6.2 Raster Transformation

GIMP provides facility for variety of filters and instruments to manipulate and process the raster images. However, Teseo provides a graphical filter useful to 'clean' a seismogram before moving to vectorization. It is advantageous to remove horizontal lines to achieve event continuity. A particular of an event before and after applying the 'clean' filter is shown in Fig.6 and Fig.7 respectively.

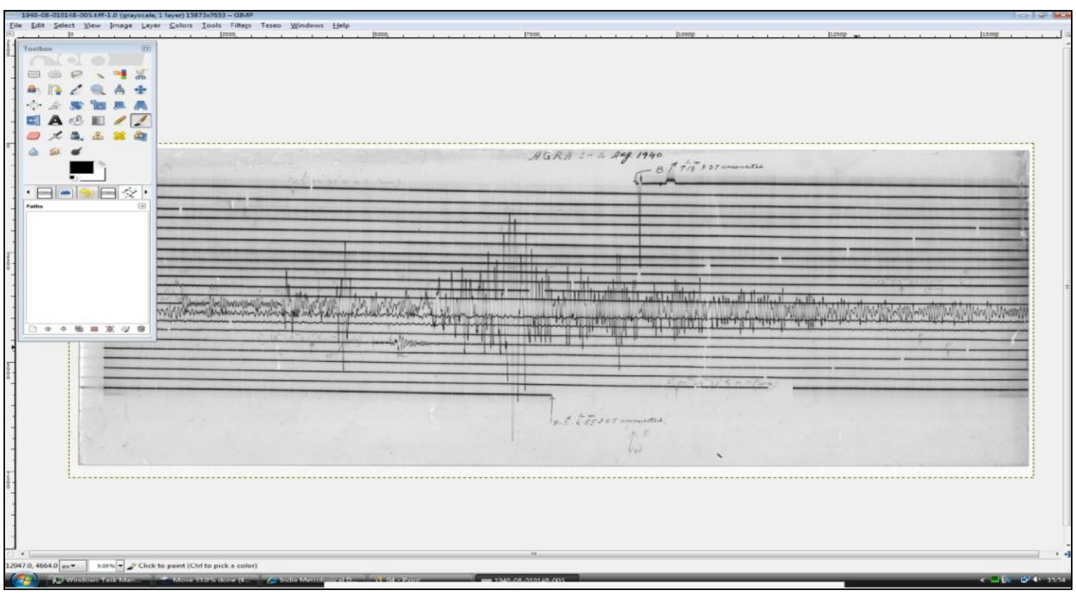


Fig. 6: Raw scanned (TIFF) image before applying 'clean' filter

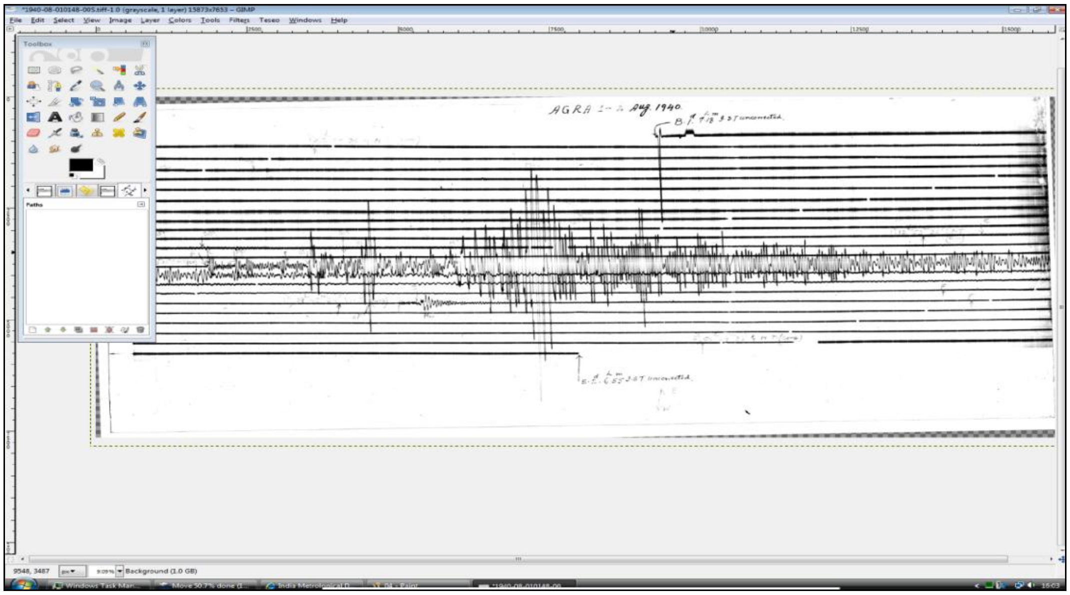


Fig. 7: Raw scanned (TIFF) image after applying 'clean' filter

### 6.3 Raster to Vector

One can manually vectorize the events by GIMP Path tool creating several piecewise cubic B′ezier curves or polylines. However, Teseo is designed to easily add algorithms for automatic seismogram vectorization. An iterative procedure takes place whereby at each step of the algorithm is executed providing it with a rectangular portion of the image centered at the last point of the current path;

- Information regarding the closest previous points;
- A preferred direction suggested by the user clicking on the arrow buttons showed in figure 5; in order to find the next point.

The seismic traces can be represented by a piecewise cubic B′ezier curve, that is, a sequence of cubic B′ezier segments. This vectorial description of the curve requires the definition of four points for each B′ezier curve. It also allows an unlimited level of detail in re-sampling. Using B′ezier curves to vectorise images is quite common, e.g. for shape description or vectorization of hand-drawn images (Chang et al, 1998). Presently, Teseo uses an algorithm based on a weighted mean of the event gray levels/color that is described in (Pintore et al., 2005). A very common problem in seismogram images is the lack of proper traces of an event, but B′ezier curves are well fitted to solve this issue as shown in Fig.8. Usually raster scanned seismogram needs some enhancement, such as contrast adjustment or filtering. For this purpose, vectorisation of seismograms needs a software tool for processing large seismogram images and apply desired filter and cubic B′ezier curves (Cinque et.al.1998). This lead to use of a powerful graphics software developed by Spencer Kimball, Peter Mattis et al. named GIMP (Kylander et al, 1999; Bunks, 2000). For vector digitisation, the Teseo vectoriser system was chosen to vectorize seismic event traces on a raster image while featuring different levels of automation.

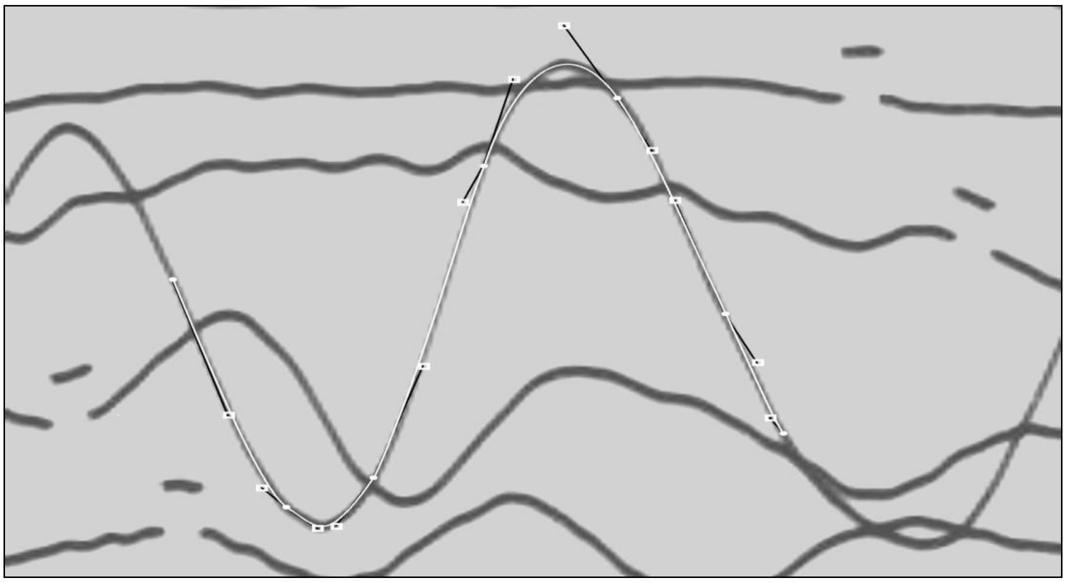


Fig. 8: Example of choosing cubic B′ezier points cubic during manual vectorization using Teseo. Note that with a few B′ezier points it is possible to represent a long trace segment.

The Earthquake trace vectorization methods implemented are: manual, semi-automatic and automatic.

### 6.3.1 Manual vectorization

The simplest method of vectorization is manual mode of Teseo. In this mode, the user picks up a sequence of points connected by straight lines or curves and create the curve directly on the seismogram image using the mouse pointer to reproduce the shape of the trace by choosing the position of the control and the anchor points. The accuracy of the vectorization entirely depends on the skill of the operator. If this work is extended to a long digitizing sessions, the overall quality tends to decrease. However, Teseo offers some vectorizing modalities whereby the operator has only a controlling function on the results obtained from the automatic procedure adopted.

### 6.3.2 Semiautomatic vectorization

The most simple and useful method of vectorization is semiautomatic mode of Teseo. In this mode, the user picks up a sequence of points connected by straight lines or curves by running Teseo in automatic mode and create the curve on the seismogram image using the mouse pointer to reproduce the shape of the trace in manual mode by choosing the position of the control and the anchor points wherever it is wrong. In this mode, the operator can accept, modify or reject the solution evaluated by the automatic method. This method is more users friendly and takes less time and more accurate in comparison to manual mode.

### 6.3.3 Automatic vectorization

The automatic method determines a polygonal line or a piecewise cubic B′ezier curve that starts from the last point of a pre-existing curve. The latter is the output of either the manual or the semiautomatic method applied previously. In this mode, the operator can accept, modify or reject the solution suggested by the automatic method. What effectively takes place is an iterative procedure, whereby at each single iteration step the next point is found by submitting to an "oracle" a rectangular portion of the image centered at the current point and the information regarding the closest previous points. The operator can either set automatic B′ezier fitting of the point sequence produced by the last n iterations, or refine the whole final digital trace at the end (Schneider, 1990). Two different algorithms have been adopted here to evaluate the next digitization point. The first is based on color/gray level selection, while the second is based on neural networks. Color trace weighted mean vectorization is based on the color weighted mean applies to gray-scale images, where the values of the pixel color are between Black, the lowermost bound value, and White, the uppermost bound value. We define a pixel array as a linear array in which each item contains a value for pixel color. Two pixel arrays are used in this algorithm. The neural networks method still needs more development to get fitted with our requirements. When signal shows gentle variations, Teseo provides a powerful automatic vectorization procedure. However, problems encountered in automatic digitisation of seismic traces were described in detail by Trifunac et al. (1999).

### 6.3.4 Refinement of the output

The use of three types of vectorization procedures for a trace results in a path consisting of a mixed sequence of B′ezier curves and a succession of unevenly spaced samples. For this purpose the operator can fit the sequence of samples with piecewise cubic B′ezier curves (1974) using the B′ezier fitting algorithm in Teseo. The main objective of the curve fitting algorithm is to use a minimum number of cubic curve pieces to approximate the data with minimum distortion. As described, there are several ways to identify the anchor and control points reported in the literature (Huang et al, 2000). We select the anchor points at the maximum and minimum of the sample sequence and made fitted to a single cubic B′ezier curve, thus leading to the control points. For most fitting, we use least-squares fitting functions. A single piecewise cubic B′ezier curve is then created, sequencing the various segments. It is still possible to interactively alter the curve once the operation has been completed, because the curve is already in vectorial format.

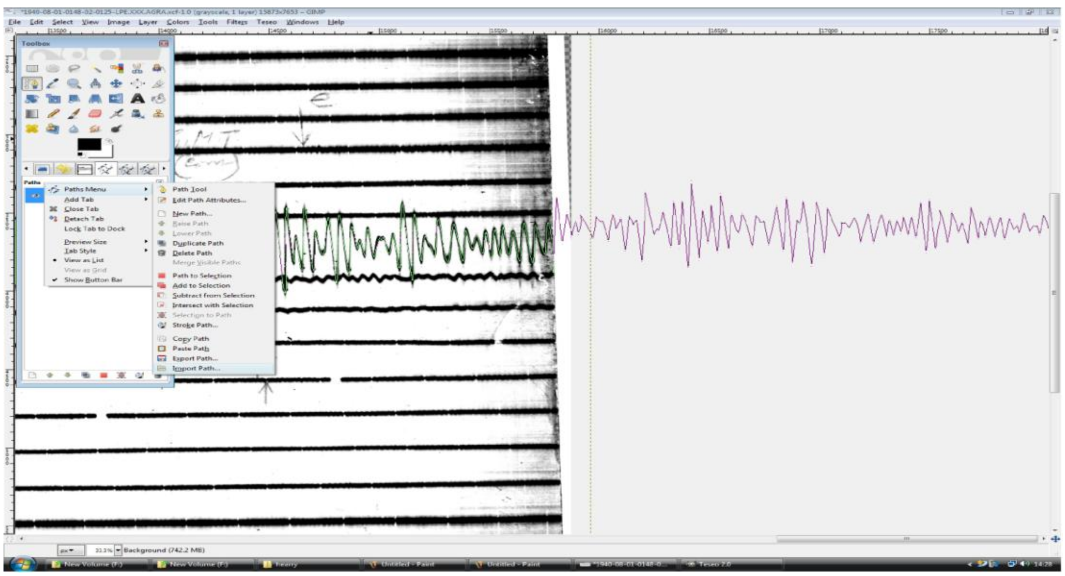


Fig.9: Resampled and aligned image of an event

Once the suitable results is achieved as shown in Fig.9 resample the curve and the sequence of samples are saved in various standard formats, such as DXF4 polylines (Autodesk, 1992), SAC5 (Goldstein et al., 2003), or in plain ASCII as presented in Fig:10. Although B′ezier curves allow an unlimited level of detail in re-sampling, we generally limit the sample rate to one sample per pixel.

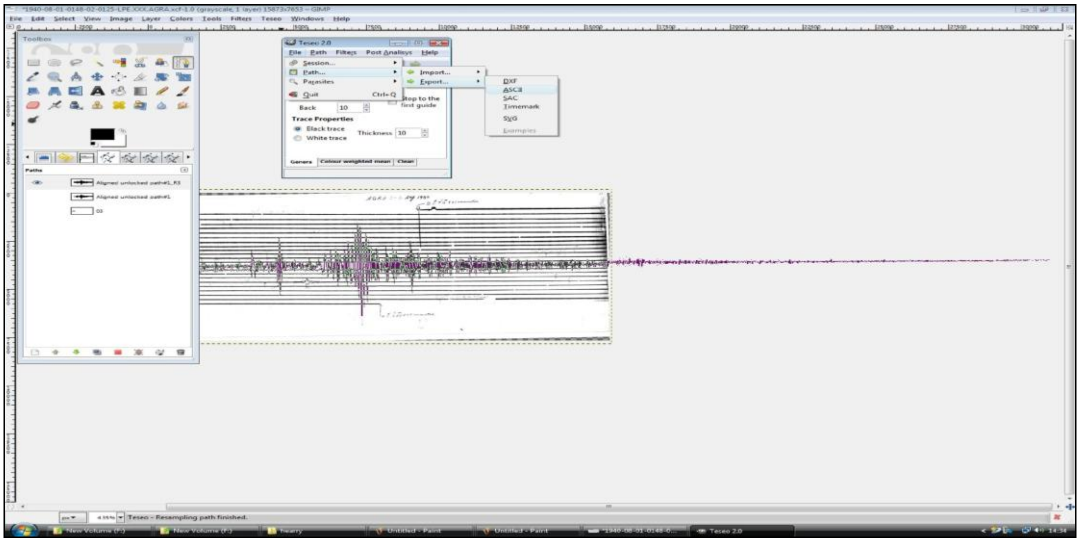


Fig.10: Saved sequence of samples and exported in different standard formats.

In fact, digitization systems based only on the determination of event graylevel/colour and thus not able to distinguish between points belonging to one trace to other. Sometimes this task can be very difficult, even for a seismologist. When digitizing, it is also important to consider the thickness of the traces in relation to the frequency of the signal. In a blurred trace, it is hard to determine the middle of the trace because of the overall lack of contrast. The curvature of the trace resulting from the needle mechanism is evident. In this case, there is a loss of correspondence between the abscissa and time, because the trace at its maximum amplitude is somewhat ahead of the zero crossing at the same time. This justifies the use of a parametric representation of the seismogram trace.

### 6.4 Time realignment

The seismogram curve on the image is to be corrected to get a best seismic data with right amplitude and time. There are many errors that might be introduced during the digitization and that must be taken into account.

### 6.5 Exporting Digitized Trace

The output is exported and saved into different formats such as DXF4 polylines (Autodesk, 1992), SAC5 (Goldstein et al., 2003), or in plain ASCII. An example of plain ASCII is presented in Fig.11.

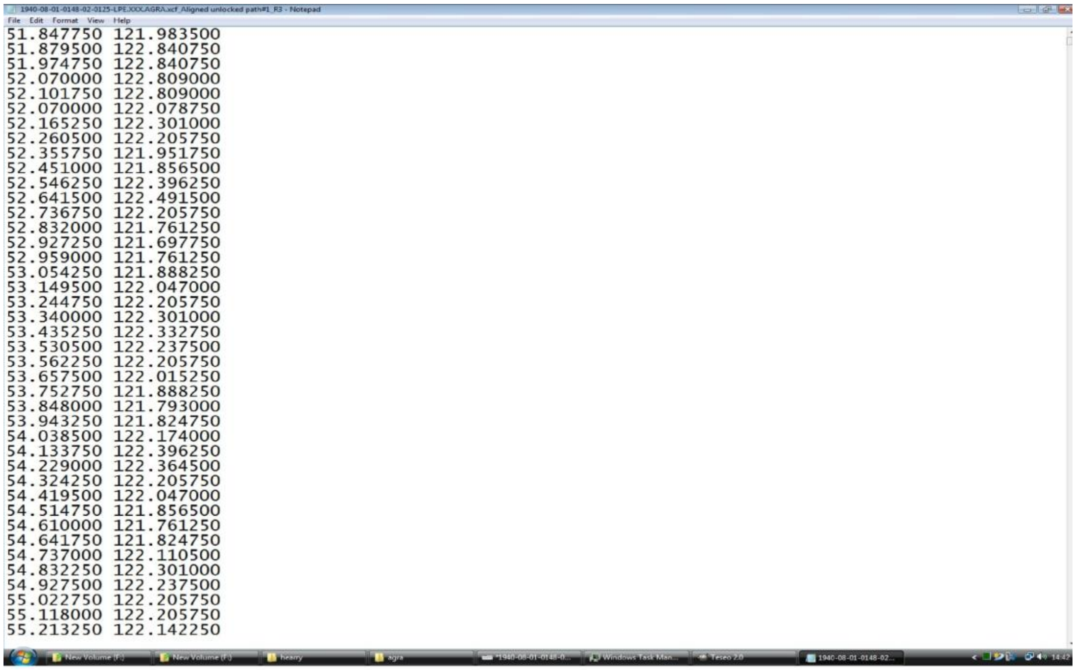



Fig.11: Exported samples (events) in ASCII formats.

As an example of a significant historical earthquake, an analog seismogram of Anjar Earthquake (station: Pune) has been taken up for vector digitization. The raster scans of seismogram in TIFF format is shown in Fig.12 and earthquake event is digitised using vectoriser, a customized Teseoas shown in Fig.13. Finally, the exported data in ASCII format is converted into SEISAN format and plotted as in Fig.14 for further evaluation of epicentral parameters of an Anjar earthquake dated 21.07.1956 (Magnitude:7.1).

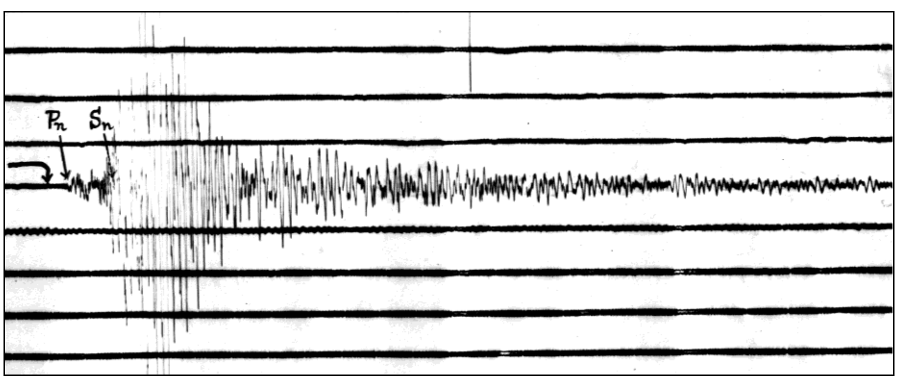



Fig.12: Analog seismogram of Anjar Earthquake, 1956 (Station: Pune)

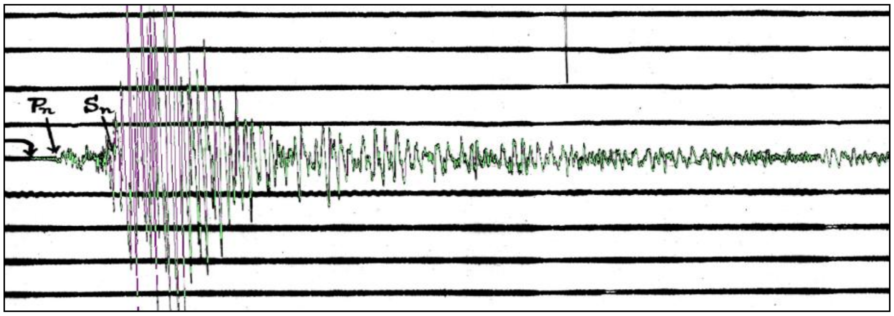



Fig.13: Digitised seismogram of Anjar Earthquake, 1956 (Station: Pune)

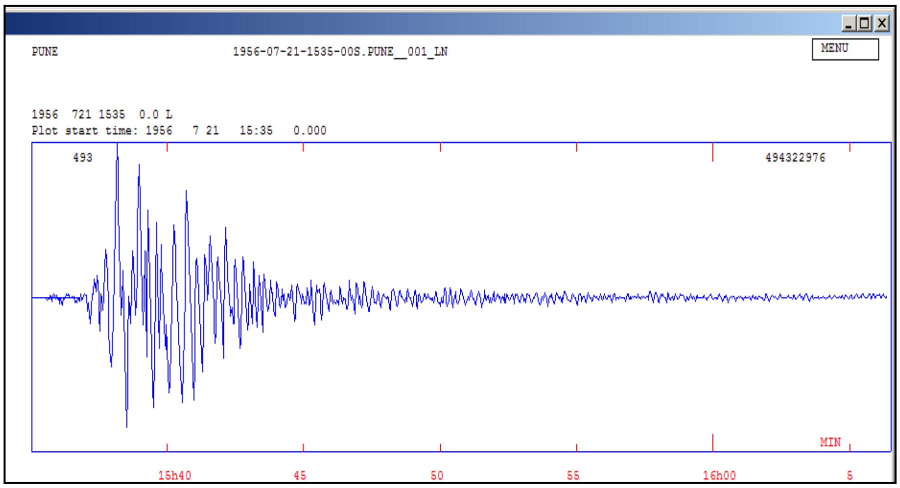



Fig.14: SEISAN plot of Anjar Earthquake, 1956 (Station: Pune)

However, analog seismograms of 6 stations have been retrieved for vector digitization and subsequently evaluation source parameters of the Anjar Earthquake 1956 in forthcoming paper. The digitized wave forms generated under the project have been subsequently utilized for evaluation of epicenter, depth and magnitude of Delhi (1960) earthquake and a paper was published in current science (Singh et al, 2013). Also, more than **100** historical earthquakes of India and neighborhood were evaluated for source parameters by utilizing vector digitizing events contained in seismograms.

**Connclusions:**

**Teseo, is a open source license software, available on the Sismos site at http://sismos.ingv.it. Teseo has been customized in IMD to best fit in our environment. Based upon experience and customization of Teseo by IMD, the Sismos team released a new version of 'Teseo 2.1.0' on 31.01.2011 in a coordinated manner and the same is available on** web site **http://teseo.rm.ingv.it/**

**with an acknowledgement. A web browser was developed in-house IMD for creating user friendly environment and smooth image processing and upload/retrieval of scans/vector files from storage system. A SQL data base was created to handle the data from data base though front end servers. A flow chart of vector digitization of analog seismic records, is presented in figure-1, together with image processing software inbuilt application software Teseo. It implies use of higher optical resolution usually 600 or 800 dpi as the case may be, for analog seismograms with long grayscale depths. The vectorisation output is a re-sampled piecewise cubic B´ezier curve. Manual, semi-automatic and automatic vectorisation methods are being adopted. Manual vectorisation is found to be accurate but time-consuming. The colour trace algorithm for semi-automatic, is suited in several cases, but requires operators intervention at certain points for example at the crossing of traces.**

**Thus, the technique followed for raster scanning of seismograms, vector digitization of earthquake events contained in seismograms using 'Teseo inbuilt GIMP' found very successful and meeting IMD requirements. The techniques used of vector digitization, encourages study of historical scientific records (seismograms) seeking to bring together scholars and research groups within a new disciplinary community dedicated to studying the history of earth sciences. The digitized data of Koyna (1967) earthquake, its aftershocks, Delhi (1960) and Moradabad (1966) earthquakes are currently under use by researcher. A research paper has already been published after utilizing digitized data on Delhi (1960) earthquake (Singh et al, 2013).**

## 8. Acknowledgements

The authors would like to acknowledge the developments of application software, Teseo in open domain and thank its developers Mr. Stefano Pintore and Mr. Matteo Quintiliani of INGV, Italy. The authors also thank the developer of the open domain Gimp 2.6, image processing software. The author is thankful to the IMD authorities, allowed to use and work on customization of Teseo for best-fit use on historical seismograms preserved in IMD.

## 9. References


1. B´ezier, P. E., 1974. Mathematical and practical possibilities of unisurf. In: Barnhill, R. E., Riesen- feld, R. F. (Eds.), Computer Aided Geometric Design. Academic Press, New York, pp. 127–152.
2. KANAMORI, H. (1988): Importance of historical seismograms for geophysical research, in *Historical Seismograms and earthquakes of the world*, edited by W.H.K. LEE (1988), H. MEYERS and K. SHIMAZAKI, (Academic Press), 16-36.
3. Schneider, P. J., 1990. An algorithm for automatically fitting digitized curves. In: Glassner, A. S. (Ed.), Graphics Gems. Academic Press, Inc., San Diego, CA, pp. 612–625.
4. Autodesk, 1992, Auto CAD Release 12 DXF Format, Adobe Systems Incorporated - 1585 Charleston Road - P.O. Box 7900 - Mountain View, CA 94039-7900, Drawing Interchange and File Formats Release 12.
5. FERRARI, G. (1997): Cultural and scientific value of seismology's heritage in Europe: why and how to preserve, *Proceeding of the Workshop: Historical Seismic Instruments and Documents: a Heritage of Great Scientific and Cultural Value*, edited by G. FERRARI, May 16th to 18th, 1994 Walferdange (Grand-Duchy of Luxembourg), Conseil de l'Europe, Cahiers du Centre Européen de Géodynamique et de Séismologie, vol. 13, 1-30.
6. Chang, H., Yan, H., November 1998. Vectorization of hand-drawn image using piecewise cubic B´ezier curves fitting. Pattern Recognition 31 (11), 1747–1755.
7. Cinque, L., Levialdi, S., Malizia, A., July 1998. Shape description using cubic polynomial Bezi´er curves. Pattern Recognition Letters 19 (9), 821–828.
8. Samardjieva, E., Payo, G., Badal, J., Lopez, C., 1998. Creation of a digital database for XXth century historical earthquakes occurred in the Iberian area. Pure and Applied Geophysics 152, 139–163.
9. Kylander, O., Kylander, K., 1999. Gimp the Official Handbook with Cdrom. Coriolis Value, 895pp.
10. Teves-Costa, P., Borges, J. F., Rio, I., Ribeiro, R., Marreiros, C., 1999. Source parameters of old earthquakes: semi-automatic digitization of analog records and seismic moment assessment.Natural Hazards 19, 205–220.
11. Trifunac, M. D., Lee, V., Todorovska, M., October 1999. Common problems in automatic digitization of strong motion accelerograms. Soil Dynamics and Earthquake Engineering 18 (7), 519–530.

12. Baskoutas, I. G., Kalogeras, I. S., Kourouzidis, M., Panopoulou, G., January 2000. A modern technique for the retrieval and processing of historical seismograms in Greece. Natural Hazards 21 (1), 55–64.
13. Bunks, C., 2000. Grokking the GIMP. New Riders Publishing, Thousand Oaks, CA, 352pp.
14. Huang, M., Tai, C., 2000. The pre-processing of data points for curve fitting in reverse engineering. International Journal of Advanced Manufacturing Technology 16, 635–642.
15. Goldstein, P., Dodge, D., Firpo, M., 2003. SAC2000: Signal processing and analysis tools for seismologists and engineers. In: Lee, W., Kanamori, H., Jennings, P., Kisslinger, C. (Eds.),
16. Peter D. Bromirski and Steve Chuang (2003), SeisDig, Software to digitize Scanned Analog Seismogram Images, Scripps institution of Oceanography, University of California, San Diago.
17. MICHELINI, A., B. DE SIMONI, A. AMATO and E. BOSCHI (2005): Collecting, igitizing, and Distributing Historical Seismological Data, *Eos Trans. AGU,* 12 July 2005, **86** (28).
18. PINTORE, S., M. QUINTILIANI and D. FRANCESCHI (2005):Teseo: A vectoriser of historical seismograms, *Computers & Geosciences*, **31**, 1277-1285.
19. Singh, S. K, Suresh, G., Dattatrayam, R. S., Shukla, H. P., Martin, S., Havskov, J., Pérez-Campos X. and Iglesias A. (2013):The Delhi 1960 earthquake: epicentre, depth and magnitude, CURRENT SCIENCE, VOL. 105, NO. 8, 25 OCTOBER 2013.