INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

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OPEN ACCESS

Received: 23-01-2023

Accepted: 09-06-2023

Published: 13-09-2023

Citation: Ralte Z, Lalhmingsangi , Saitluanga , Vanthangliana V, Lawmkima H, Laldinpuia , Lalruatpuia (2023) Earthquake Source Mechanism and Source Parameters Determination Using Broadband Seismometer. Indian Journal of Science and Technology 16(SP1): 192-199. https://doi.org/10.17485/IJST/v16sp1.msc26

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Earthquake Source Mechanism and Source Parameters Determination Using Broadband Seismometer

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Abstract

Objective: The main objective of the study is to obtain precise and accurate sources and mechanisms of earthquakes which is a prerequisite for understanding physical processes with the associated fault generating an earthquake. **Methods:** The technique of waveform inversion and Seisan software are used for the study of source mechanism and hypocentral parameters. Spectral parameters for estimation of earthquake source parameters can be achieved through the software EQK_SRC_PARA. **Findings:** The obtained spectral parameters have been used to estimate source parameters such as seismic moment (Mo), Spectral corner frequencies (fc), Source radii (r), and stress drops ($\Delta\sigma$). From this study, the earthquake was a shallow focus earthquake at a depth of 40km and duration magnitude Md 4.3. Spectral analysis of the S-phase results in the average moment magnitude 4.2Mw which is different from the magnitude recorded by USGS which is 4.7Mb, stress drop $\Delta\sigma$ 0.75MPa, average source radius (r)1697.6m, and average corner frequency (fc) 0.75Hz. Waveform inversion results in moment magnitude Mw 2.7 from the combined stations whereas single seismic waveform inversion from the PUC station results in a moment magnitude of 3.6Mw. **Novelty:** Determination of earthquake source parameters and mechanisms with more seismic data is significant for improving the current understanding of the dynamic processes governing earthquakes.

Keywords: Spectral Analysis; Waveform Inversion; Source parameters; Synthetic Seismogram; Stress Drop

1 Introduction

The study of earthquakes has a high societal impact both in assessing and reducing the effect of an earthquake and in understanding the dynamic processes, physical structure, and seismotectonic of the regions. An earthquake of Mw 5.5 occurred on June 22, 2020, in the vicinity of the Indo Burma Region, it was associated with several swarm- type earthquakes felt within different parts of Mizoram[1]. These earthquakes occurred at a shallow depth and caused moderate damage of an intensity scale of VIII on the MSK scale and were related to Churachandpur Mao Fault (CMF) in the Indo Burma Region[2]. Accurate and precise source parameters are necessary for understanding the mechanism of an earthquake[3]. In this study earthquake in the Indo Burma Region (IBR) on 27-12-2021 with a duration magnitude of Md 4.3 recorded by three Broadband Seismic Stations located at Aizawl (N23°43'25.20" E092°43'54.57"), Lunglei (N22°53'25.11" E092°44'35.94") and Khawbung (N23°09'52.39" E09313'07.45") was used. The Broadband seismometer was Trillium (T40) recorded earthquake events at a sampling rate of 100Hz. The Northeastern regions are highly seismically active and are in Zone V of the seismic zoning map of India indicating that NE India is in the highest risk zone[4]. The Broadband seismic station installed within Mizoram is very significant for contributing to acquiring earthquake events up to a small tremor that occurs around the Indo-Burma regions. Spectral analysis and waveform inversion technique were used to determine the source parameters of the 28th April Kopili fault earthquake Mw 6.1 in Assam Valley of Northeast India[4]. The estimation of stress before and after an earthquake is a crucial parameter for understanding the accumulated stress over the fault regions which determines the size of an earthquake[5]. The data from the 2011 earthquake of Mw 6.9 in Sikkim Himalaya was used to study the source parameters using spectral analysis and waveform inversion[6]. Since the Indo-Burma region is a highly active tectonic area, many works have been done to study the source parameters and mechanism of an earthquake, the present study will contribute to understanding more insight into the earthquake in this region using the three Broadband Seismic Stations Figure 1.

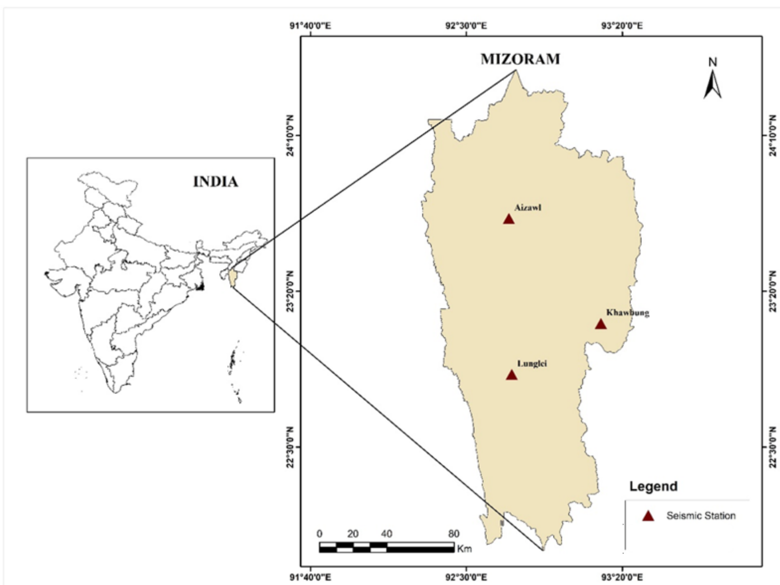

Fig 1. Location of Broadband Seismic Station

2 Methodology

A waveform that was recorded at three Broadband Seismic stations Aizawl (N23°43'25.20" E092°43'54.57), Lunglei (N22°53'25.11" E092°44'35.94"), and Khawbung (N23°09'52.39" E09313'07.45") was used for the present study. Different techniques and methods were adopted to determine the earthquake source mechanism and parameters.

2.1 Determination of Hypocentral Parameters

Three-component waveform data from the three stations were used to determine the Hypocentral parameters using Seisan v10.3 software. The epicenter, duration magnitude (Md), and depth of an earthquake were determined using this software.

2.2 Spectral Analysis

Spectral parameters for determination of source parameters using EQK_SRC_PARA software were used for the estimation of source parameters such as seismic moment (Mo), Spectral corner frequencies (fc), Source radii (r), stress drops ($\Delta\sigma$), nearsurface attenuation factor (κ)[7,8]. The spectral parameters were determined using MATLAB software for the estimation of spectral source parameters[8]. The Fast Fourier Transform (FFT) of the selected SH- component of time history is performed to obtain a spectrum of the SH component. The seismic moment for a homogeneous and isotropic medium was given by Aki (1966)[9]:

$$M_o = \mu DA$$

Where μ = rigidity or shear modulus of the medium

D = Average slip (Displacement offset between the two sides of fault)

A = The surface area of rupture

The value of μ is normally taken as $3x10^{11}$ dyne cm^{-2} for the crustal rocks.

For computing seismic moments from spectra of seismic waves, Kellis Borok (1959)[10] has given the following relationship for a homogeneous half-space as

$$M_o = \frac{4\pi\rho R\beta^3\Omega_o}{R_{\theta\varnothing}S_a}$$

Where R = hypocentral distance from the earthquake source to the seismic station;

ρ = average density of the medium around the source;

β = S-wave velocity of the medium around the source;

$R_{\theta\ \varphi}$ = a correction to be applied to the observed seismic amplitudes to account for the direct variation of the radiation pattern of seismic waves.

Ω_o = amplitude at the low frequencies measured from the S wave spectrum after correcting for the instrument response and attenuation of the medium;

S_a = a correction for amplification due to surface effect.

Source parameters determination for microearthquake was carried out in High Dam Lake, Aswan region Egypt using the vertical component[11]. In the present work, the source parameters were determined using the horizontal component or S-wave spectra.

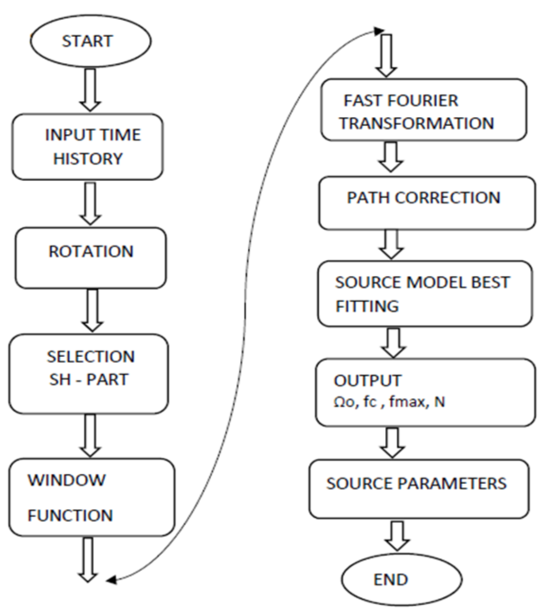

Fig 2. Flowchart procedure for estimation of earthquake source parameters

2.3 Waveform Inversion

Seismic Waveform modeling or inversion tool is used for determining the characteristic of earthquakes and their associated fault[12]. Fortran MATLAB-based ISOLA-GUI developed by Sokos et al is used in the present study for source characterization and the displacement waveform was created from the three-component and filtered by Butterworth filters[13]. The waveform recorded in the three seismic stations South Khawbung (SKH), Lunglei Station (LLI), and Aizawl Station (PUC) was used for the study. The amplitude difference of various phases of an earthquake is crucial for the determination of the earthquake sources. The errors are normalized by the data and synthetics in some waveform inversions. Then resampled from 100 to 33Hz, followed by DC and trend removal. Green's function was computed and the crustal 1D velocity model[Figure 7] was used for waveform modeling. The best fit between the observed and synthetic seismograms was selected for the three seismic stations [8]. The advantage of this technique is that the complete seismogram was utilized for the analysis which can be used for both fault plane solution as well as source time history. This technique allows using of single stations or stations with poor azimuthal coverage with accurate solutions [8].

3 Results and Discussion

3.1 Spectral Analysis

Source parameters determined from the study were shown in Table 1, the analysis was done for three different stations, PUC SKH, and LLI. Each station shows a small difference in the source parameters. From this study, the depth of the earthquake was 11km, duration magnitude or coda magnitude Md=4.3. Spectral analysis of the S-phase of PUC [Figure 4], SKH [Figure 5], and LLI [Figure 6] shows the average moment magnitude of 4.2 Mw, average stress drop $\Delta\sigma$ 0.75MPa, the low average source radius (r) of 1697.6m, and a corner frequency of 0.75HZ. The attenuation factor for the calculation of spectral parameters makes a difference in the moment magnitude estimated from spectral analysis and the waveform inversion [4]. The stress drop study of the Ladakh-Karakoram zone from the spectral analysis showed the overall low-stress drop in the region which is significant in understanding the tectonic in the region [5].

Table 1. Spectral source parameters using Spectral analysis

Spectral analysis of S-Phase					
Station Name	**Seismic Moment (Mo)**	**Moment Magnitude (Mw)**	**Stress Drop $\Delta\sigma$ (Mpa)**	**Source Radius (r)m**	**Corner Frequency (fc)**
PUC	1.3e +15Nm	4	0.083	1888.7	0.7Hz
LLI	2.5e +15Nm	4.2	0.248	1643	0.8Hz
SKH	3.7e +15Nm	4.3	0.421	1561.2	0.8Hz

3.2 Waveform Inversion

A full seismogram from three stations PUC, SKH, and LLI was used for inversion, which gives the result of the moment magnitude Mw and the characteristic of the associated fault. The advantage of this method is that the complete seismic waveform is used for source characterization. Single seismic waveform inversion was done for the PUC station [Figure 8] the observed and synthetic seismogram shows a good matching resulting in a moment magnitude Mw 3.6, seismic moment Mo 2.998410E + 14. The percentage of the Double Couple (DC) was 97.6%. The combined waveform for all three stations shows a good matching of the synthetic and observed seismogram [Figure 9]. The combined inversion shows a moment magnitude of Mw 2.7 and a seismic moment of 1.47675E +13. The source characteristic and source parameters from the combined waveform inversion as shown in Table 2.

Table 2. Source characteristics and parameters using Waveform Inversion

YYYY-MM-DD	**hh:mm:ss**	**Lat (°N)**	**Long (°E)**	**Mag (Mw)**	**Depth (Km)**	**Strike (°)**	**Dip (°)**	**Rake (°)**
27-12-2021	12:43:13	22.9337	94.1653	3.6	11	115	12	74

Kabaw fault is not only a reverse fault but a strike-slip component, which has an important role in understanding the seismotectonic of the IBR regions [14]. The focal mechanism and fault plane solution using the three broadband seismic station showed a reverse fault with a strike-slip component (Figure 3) which correlates well with the Kabaw-fault in the Indo-Burma region.

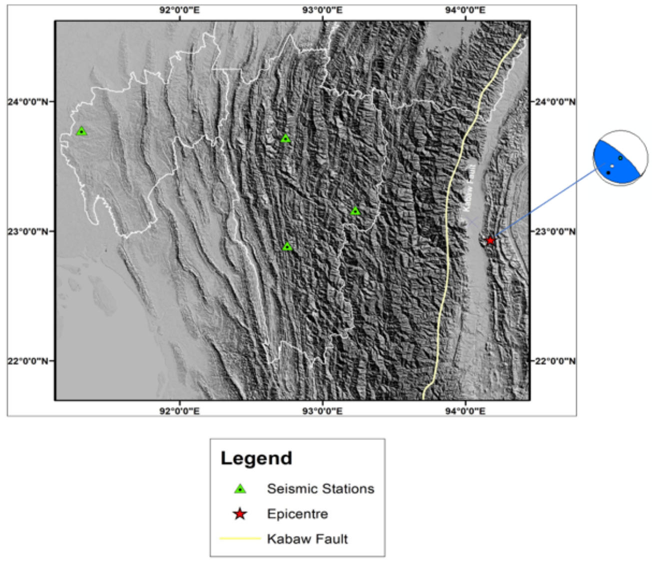

Fig 3. Focal Mechanism solutions of the 27th Dec 2021 earthquake at the Kabaw Fault

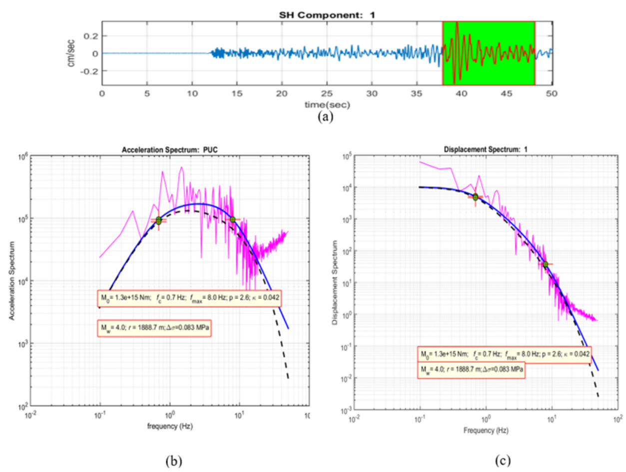

Fig 4. Spectral analysis of PUC Station (a) SH-Component (b) Acceleration spectrum (c) Displacement Spectrum

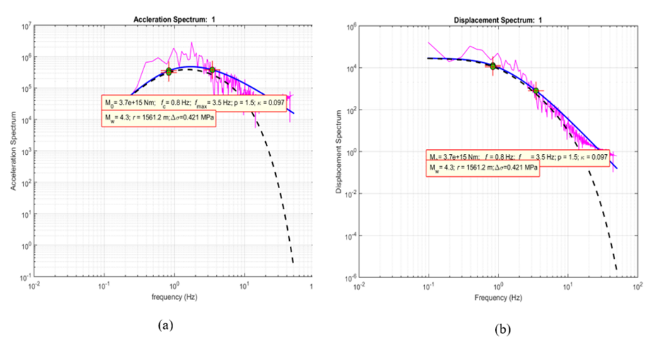

Fig 5. Spectral analysis of SKH Station (a) Acceleration spectrum (b) Displacement spectrum

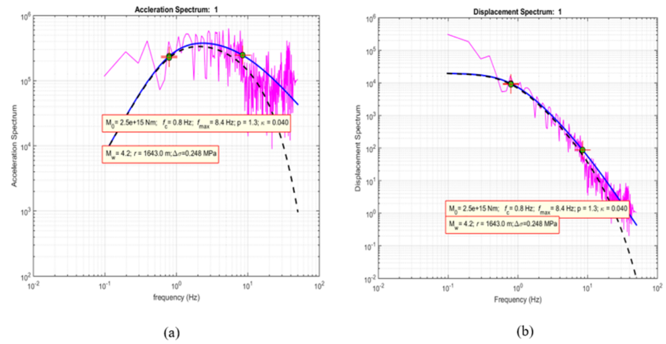

Fig 6. Spectral analysis of LLI Station (a) Acceleration spectrum (b) Displacement spectrum

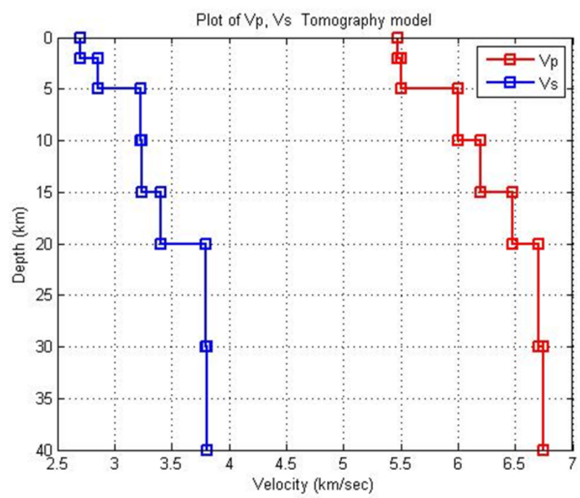

Fig 7. 1D Crustal velocity model Bhattacharya (2005)

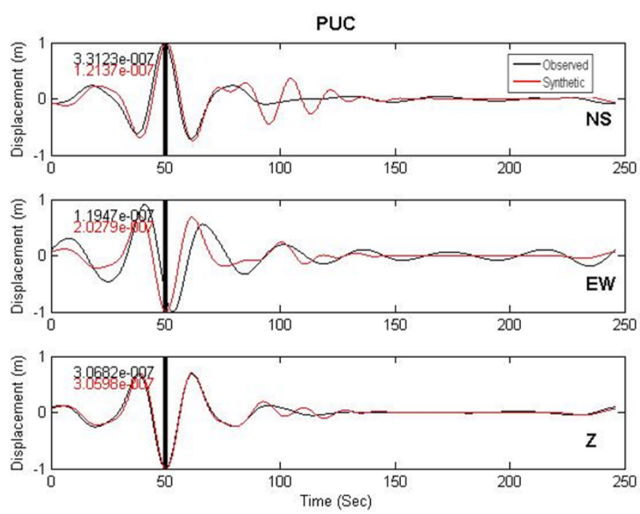

Fig 8. Synthetic and Observed Data of Single Station waveform inversion (PUC)

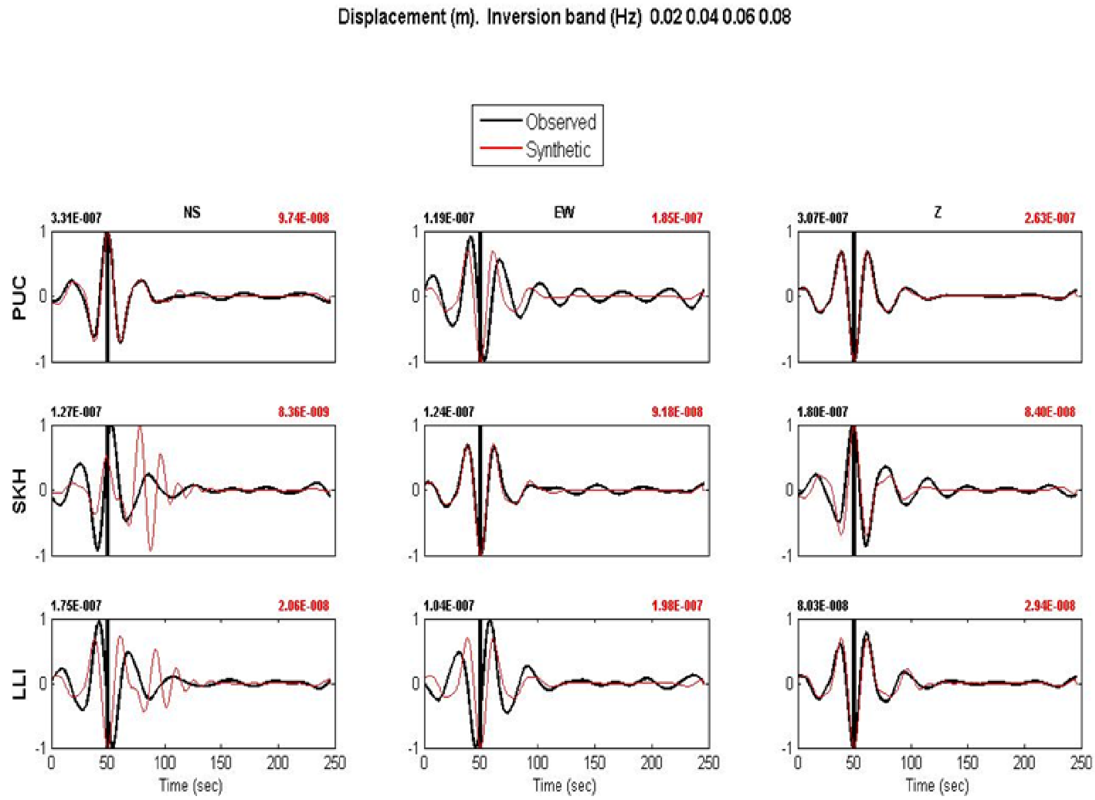

Fig 9. Synthetic and Observed Seismogram Combined from three seismic stations

4 Conclusion

The source parameters of the earthquake which occur on 27:12:2021 at 12hrs 43min 13sec resulted in different values of moment magnitude (Mw) for each station from spectral analysis. The duration magnitude Md 4.3 was observed to be higher than the moment magnitude determined from waveform inversion. The epicenter and fault plane solution from waveform inversion is related to reverse fault with the strike-slip fault component of the KF in the Indo-Burma region. The stress before and after the earthquake determined using spectral analysis was 0.75MPa and the average source dimension is 1697.6m. The study showed a low-stress drop, which could be due to the low energy release and reactivation of the fault. The same has been observed for the Kopili Fault which showed a low-stress drop due to the reactivation of the fault and pre-existing fault at greater depth[(4)].

5 Declaration

Presented in 4th Mizoram Science Congress (MSC 2022) during 20th & 21st October 2022, organized by Mizoram Science, Technology and Innovation Council (MISTIC), Directorate of Science and Technology (DST) Mizoram, Govt. of Mizoram in collaboration with science NGOs in Mizoram such as Mizo Academy of Sciences (MAS), Mizoram Science Society (MSS), Science Teachers' Association, Mizoram (STAM), Geological Society of Mizoram (GSM), Mizoram Mathematics Society (MMS), Biodiversity and Nature ConservationNetwork (BIOCONE) and Mizoram Information & Technology Society (MITS). The Organizers claim the peer review responsibility.

References

1) Bharali B, Rakshit R, Dinpuia L, Saikia S, Baruah S. The 2020 Mw 5.5 Mizoram earthquake and associated swarm activity in the junction of the Surma Basin and Indo-Myanmar Subduction Region. *Natural Hazards*. 2021;109:2381–2398. Available from: https://doi.org/10.1007/s11069-021-04924-1.

2) Malsawma J, Lalnuntluanga P, Sailo S, Vanthangliana V, Tiwari RP, Gahalaut VK. The 22 June 2020 Mizoram, India earthquake (Mw 5.5): an unusual intra-wedge shallow earthquake in the Indo-Burmese Wedge. *Current Science*. 2021;120(9):1514–1516. Available from: https://doi.org/10.18520/cs/v120/i9/1514-1516.
3) Baruah S, Saikia S, Baruah S, Bora PK, Tatevossian R, Kayal JR. The September 2011 Sikkim Himalaya earthquake Mw 6.9: is it a plane of detachment earthquake? *Geomatics, Natural Hazards and Risk*. 2016;7(1):248–263. Available from: https://doi.org/10.1080/19475705.2014.895963.
4) Dey C, Baruah S, Abdelwahed MF, Saikia S, Molia N, Borthakur P, et al. The 28 April 2021 Kopili Fault Earthquake (Mw 6.1) in Assam Valley of North East India: Seismotectonic Appraisal. *Pure and Applied Geophysics*. 2022;179:2167–2182. Available from: https://doi.org/10.1007/s00024-022-03072-2.
5) Paul A, Hazarika D. Occurrences of low-stress drop earthquakes in the eastern Ladakh-Karakoram zone of the Trans Himalaya and their tectonic implications. *Journal of Asian Earth Sciences: X*. 2022;7:1–10. Available from: https://doi.org/10.1016/j.jaesx.2022.100080.
6) Baruah S, D'amico S, Saikia S, Gautam J, Devi RK, Boruah GM, et al. Study of fault plane solutions and stress drop using local broadband network data: The 2011 Sikkim Himalaya earthquake Mw 6.9 and its aftershocks. *Annals of Geophysics*. 2018;61(1):1–22. Available from: https://doi.org/10.4401/ag-7367.
7) Kumar A, Kumar A, Gupta SC, Mittal H, Kumar R. Source parameters and fmax in Kameng region of Arunachal Lesser Himalaya. *Journal of Asian Earth Sciences*. 2013;70-71:35–44. Available from: https://doi.org/10.1016/j.jseaes.2013.02.030.
8) Elhadidy M, Alarab ME, Salam M, Faried A. Source parameters and moment tensor inversion of April 11, 2020 (mb=4.4), the significant El-Negalah Earthquake, Matrouh, Egypt. *NRIAG Journal of Astronomy and Geophysics* . 2023;12(1):58–71. Available from: https://doi.org/10.1080/20909977.2023.2169133.
9) Aki K. Generation and Propagation of G Waves from the Niigata Earthquake of June 16, 1964. : Part 2. Estimation of earthquake moment, released energy, and stress-strain drop from the G wave spectrum. *Bulletin of the Earthquake Research Institute*. 1966;44:73–88. Available from: https://doi.org/10.15083/0000033586.
10) Keilis-Borok VI. On the estimation of the displacement in an earthquake source and of source dimensions. *Annals of Geophysics*. 1959;12(2):205–214. Available from: https://www.researchgate.net/publication/247004297_On_estimation_of_displacement_in_an_earthquake_source_and_of_source_dimension.
11) Saadalla H, –aal AEAKAE, Mohamed A, El-Faragawy K. Determination of earthquake source parameters using the inversion of waveform data: A case of small earthquakes around High Dam Lake, Aswan region, Egypt. *Journal of African Earth Sciences*. 2019;151:403–416. Available from: https://doi.org/10.1016/j.jafrearsci.2019.01.001.
12) Sokos EN, Zahradnik J. ISOLA a Fortran code and a Matlab GUI to perform multiple-point source inversion of seismic data. *Computers & Geosciences*. 2008;34(8):967–977. Available from: https://doi.org/10.1016/j.cageo.2007.07.005.
13) Zahradník J, Sokos E. ISOLA Code for Multiple-Point Source Modeling—Review. In: D'Amico S, editor. Moment Tensor Solutions. Springer Natural Hazards;Springer, Cham. 2018;p. 1–28. Available from: https://doi.org/10.1007/978-3-319-77359-9_1.
14) Khin K, Moe A, Aung KP, Zaw T. Structural and tectonic evolution between Indo-Myanmar ranges and central Myanmar basin: Insights from the Kabaw Fault. *Geosystems and Geoenvironment*. 2023;2(2):1–19. Available from: https://doi.org/10.1016/j.geogeo.2022.100176.