MOMENT TENSOR AND SOURCE PROCESS OF EARTHQUAKES IN FIJI REGION OBTAINED BY WAVEFORM INVERSION

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ABSTRACT

We evaluated the quality of the local seismic waveform recorded at Yasawa station established by the Mineral Resources Department (MRD, Fiji), and tried to estimate moment tensor solution by using this waveform data. We also estimated moment tensor solution and seismic source process by using teleseismic body wave so as to investigate the faulting system in Fiji region. As for the evaluation of the quality of the waveform recorded at the Yasawa station, we found that EW and NS components were down frequently, and moment tensor solution obtained by 3 components of the Yasawa station is totally opposite to the Harvard CMT solution. This result may suggest that the polarity of the local seismometer components was in a reverse direction and magnification of the seismometer response information is not correct at this stage. We obtained a consistant result when we divided by -10 to observed waveform. Moment tensor inversion analysis was also carried out for 30 events by using teleseismic body-wave downloaded from the IRIS-DMC. Final results are well consistent to Harvard CMT solution. Rupture source process analysis was conducted for the two deep intraslab events that occurred respectively along the Tonga Kermedec subduction zone and two shallow depth events which occurred respectively along the transform fault zones. The rupture processes for the two deep earthquakes are characterized by the rupture propagating mainly along the strike of the fault plane. The two shallow events occurred along the transition zone also characterized by the rupture propagating along the strike of the Fiji Fracture Zone but are controlled by the geometry of the fault.

Keywords: Moment tensor inversion, Rupture process inversion, teleseismic data, near-source data.

INTRODUCTION

Earthquake focal mechanisms are basic and important information in seismology and have been utilized for understanding regional tectonic stress fields, source mechanisms of large earthquakes, simulation of strong motion, faulting systems, tsunami generation and so on. It is important to estimate focal mechanisms of earthquakes routinely as well as to make a homogenous catalogue of moment tensors (or focal mechanisms) from small to large earthquakes for future references. Moment tensor and rupture process inversion analysis has not so far being carried out in Fiji. Therefore in this study, we evaluated the quality of the local seismic waveform data obtained from the Yasawa broadband station established by Mineral Resources Department (MRD, Fiji), then we tried to estimate moment tensor solution by using this waveform data and as well as to estimate moment tensor solution and seismic source process using teleseismic body wave so as to investigate the faulting system in the Fiji region.

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DATA

We used both near-source data recorded at Yasawa broadband station established by Mineral Resources Department, Fiji with range from March 2003 to December 2005 as well as teleseismic body-wave (P-wave) data recorded at FDSN and GSN network stations collected by the Data Management Center of the Incorporated Research Institution for Seismology (IRIS-DMC).

Table 1: Shows the quality of Yasawa station components

Months	Year 2003			Year 2004			Year 2005		
	Components			Components			Components		
	UD	EW	NS	UD	EW	NS	UD	EW	NS
Jan	not yet being established			o	x	o	o	o	o
Feb				o	o	x	o	o	o
Mar	o	x	o	o	x	x	o	x	o
Apr	no data			o	o	x	o	o	o
May	o	x	o	o	x	x	o	o	o
June	o	x	o	o	o	o	o	o	o
July	no data			no data			o	o	o
Aug	no data			no data			o	o	o
Sept	o	x	o	o	o	o	o	o	o
Oct	o	x	x	o	o	x	o	o	o
Nov	o	o	o	x	o	o	o	o	o
Dec	o	x	o	o	o	o	o	o	o

o – Waveforms well recorded.
x – Component broken.

The raw continuous Yasawa waveform data was converted from nanometrics to seed format by makeseed software provided by Nanometrics Inc. Further, we obtained the waveform data in SAC format by using rdseed software which was available from the IRIS-DMC homepage. The broadband data were converted and numerically integrated from volts into the ground velocity cm/s and then band-passed between 0.01 and 0.1 Hz to reduce the effect of fine 3D structure and detailed source process. Table 1 shows the quality of waveforms recorded at the Yasawa station in each period. For teleseismic body-waves we retrieved and selected the IRIS-DMC stations from the viewpoint of good azimuthal coverage with the distance range from 30° to 90°. We referred to earthquake event list from the Harvard CMT catalogue from year 1990 to present. Thirty events with Mw > 6.5 occurred within Fiji region were analyzed for moment tensor inversion and 4 of these events were analyzed for their source rupture processes.

THEORY AND METHODOLOGY

Moment Tensor Inversion

To obtain moment tensor components of overall earthquake, we represented the seismic source process as point source model.

$$u_j(t) = \sum_{q=1}^{5} G_{jq}(t,\xi_c) * M_q^{'}(t,\xi_c) + e_o + e_m$$

$$= \sum_{q=1}^{5} M_q^{''}\left(G_{jq}(t,\xi_c) * T(t)\right) + e_o + e_m \qquad (1)$$

where $M_q^{'}$ and $M_q^{''}$ are moment tensor at centroid of source ξ_c, *T(t)* is source time function, and e_m is modeling error. For simplicity, the observation equation of (1) can be rewritten in vector form:

$$\mathbf{d}_j = \mathbf{H}(T(t),\xi_c)_j\,\mathbf{a} + \mathbf{e}_j \qquad (2)$$

where **d** and e are *N*-dimensional data and error vectors, respectively, **a** is a *5*-dimensional model parameter vector, **H** is a *N* x *5* coefficient matrix. The solution of the above matrix equation is obtained by using least square approach, if we assumed source time function and the centroid location. We determined the depth of centroid and the duration and shape of source time function by grid search method since these are needed for moment tensor inversion for the analysis of teleseismic body wave. For analyses of near-source data, we applied low pass filter to mitigate source time function effect and then estimated the depth of centroid by grid search method.

Rupture Process Inversion

To estimate rupture process, we basically followed the formulation by Yagi and Fukahata (2008). A vertical component of P-wave at a station *j* due to a shear dislocation source on a fault plane *S* is given by

$$u_j(t) = \sum_{q=1}^{2} \iint G_{jq}(t,\xi) * \dot{D}_q^{'}(t,\xi) dS + e_o, \tag{3}$$

where G_{jq} is a Green's function, $\dot{D}_q^{'}$ is a spatio-temporal slip-rate distribution, and * denotes the convolution operator in time domain. To formulate the inverse problem, we represent the spatio-temporal slip-rate distribution $\dot{D}_q^{'}$ by linear combination of a finite number of basis functions:

$$\dot{D}_q^{'}(t,\xi_c) = \sum_{k=1}^{K} \sum_{l=1}^{L} a_{klq} X_k(\xi) T(t) + \delta \dot{D}_q^{'}(t,\xi), \tag{4}$$

where a_{klq} are model parameters to be determined from observed data. $X_k(\xi)$ and $T_l(t)$ are the basis functions for space and time, respectively. We can rewrite in vector form:

$$\mathbf{d}_j = \mathbf{H}_j \mathbf{a} + \mathbf{e}_{mj}, \tag{5}$$

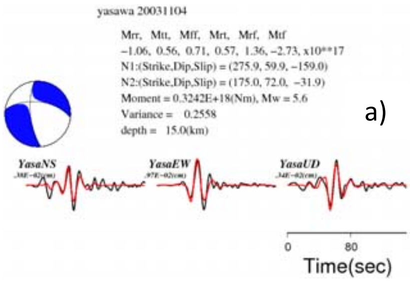
where $\mathbf{d}_j$ and $\mathbf{e}_{mj}$ are N_j-dimensional data and error vectors, respectively, **a** is a *M*-dimensional model parameter vector, and $\mathbf{H}_j$ is a $N_j \times M$ coefficient matrix.

RESULTS AND DISCUSSIONS

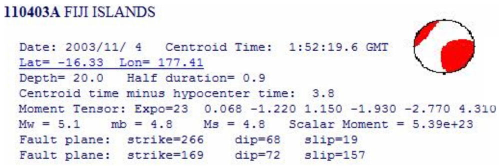
The results of this study are divided into three (3) main parts:

<u>Part I: Moment Tensor Inversion using near source data obtained by Local Seismic Station</u>

The local data set obtained for this study was from the period of its establishment in March, 2003 to December, 2005. We estimated the centroid moment tensor solution by using local seismic data which contains three components waveform. Green's function for near-field was calculated using program by Kohketsu (1985), and performed waveform inversion using program by Yagi (2006). To obtain the location of centroid, we applied the grid search method.



a)



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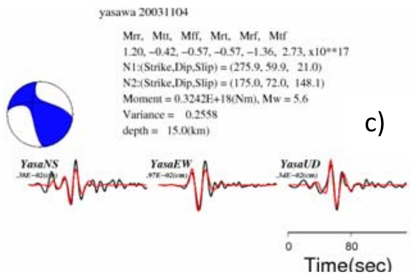

c)

We found the inconsistencies between this study solution (Figure 1a) and the Harvard CMT solution even if waveform fitting is good (Figure 1b). The result for this study is totally opposite to the Harvard CMT solution. One of the possibilities for this difference may be the polarity set up (EW and NS) components is in a reverse direction. If we divide by -1 to the waveform in our SAC program, the focal mechanism is well consistent with the result of Harvard CMT (Figure 1c). We should point out that our result (Figure 1c) is ten times larger in seismic moment than the Harvard result. This result implies that the magnification of the Yasawa seismometer information is not correct at this present time.

Figure 1. Moment tensor solutions. a) Result obtained by this study using local seismic data recorded at Yasawa station. b) Harvard CMT solution. c) Result for the reverse polarity waveform. The red curve is the theoretical waveform and the black curve is the observed waveform.

<u>Part II: Moment Tensor Inversion by using Teleseismic Body Waveforms.</u>

In Part II of this study, 30 events (Mw >6.5) that occurred within the Fiji region were analyzed by using teleseismic body waveforms downloaded from the Data Management Center of the Incorporated Research Institutions for Seismology (IRIS-DMC). We performed moment tensor inversion analysis for these local events by using moment tensor inversion programming coded by Yagi (2008). The depth of hypocenter, the seismic moment (Mo) and the final focal mechanism 'beachball' solutions of this study was computed with that of Harvard GMT solutions.

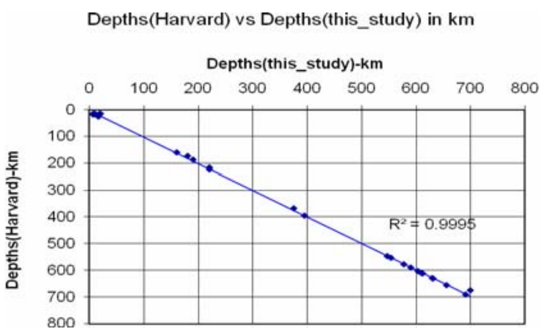

Figure 2. Graph of Depths (Harvard Solution)-km vs. Depths (this_study) in km.

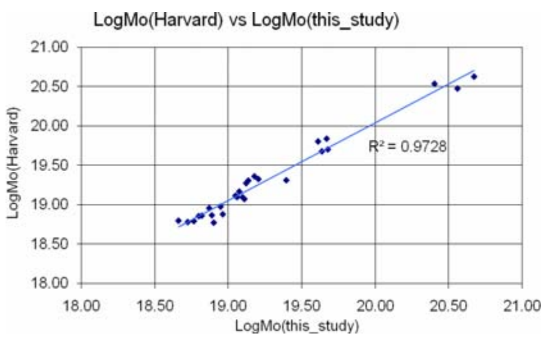

Figure 3. Graph of LogMo (Harvard Solution) vs. LogMo (this_study)

Our results reveal the consistencies with the depths of hypocenters (Figure 2) and logMo (Figure 3) in the two solutions. Such a difference observed is due to that the Harvard University routinely carried out the overall waveform picking in their moment tensor analysis, whereas in this study utilizes only the P-wave for such analysis of moment tensor.

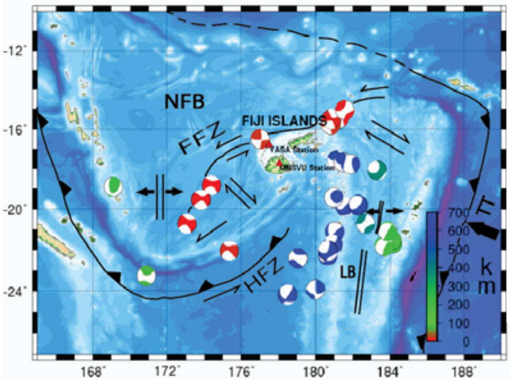

Figure 4 exhibits the final moment tensor solution of this_study plot as “beachballs” on the Fiji region map. Shallow depth events with strike-slip faulting type occurred mainly along the two Fracture zones, the Fiji Fracture Zone and the Hunter Fracture Zone. The rest are intermediate to deep intraslab earthquakes along the two subduction zones with mostly reverse and normal faulting type.

Figure 4. Focal mechanism plot of this study.

<u>Part III: Analysis of rupture source process</u>

Four earthquakes were analyzed for their rupture source processes during their occurrences. Two deep intraslab events which occurred along the Tonga subduction zone and two events were of shallow depths occurred along the Fiji Fracture Zone. We applied inversion code originally given by Yagi and Fukahata (2008) so that the constraints of smoothness and positivity were imposed on the solution used in this analysis. To detect actual fault plane, we found the fault plane and average slip direction which show best fitting using grid search method.

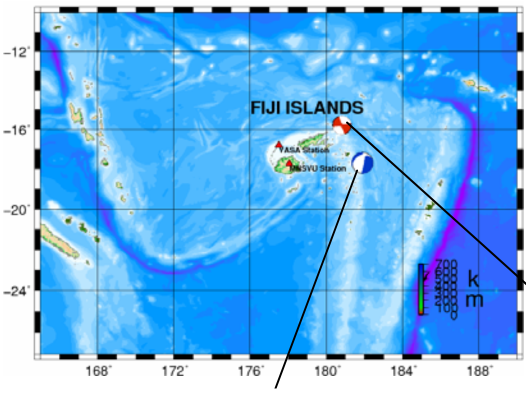

Figure 5. Indicates the location of the two events plotted as “beachballs” on Fiji map

In general, for deep earthquakes rupture propagates mainly along the strike direction due to the thinness of the seismogenic zones at deeper depths as proved by our results shown on Figure 6. As for shallow earthquakes along the Fiji Fracture Zone, the rupture propagates along the strike (NE and SW) direction and breaks some part of the fault, however the propagation of the rupture seems to be controlled by the geometry of the fault as proved by this study solution shown on Figure 7.

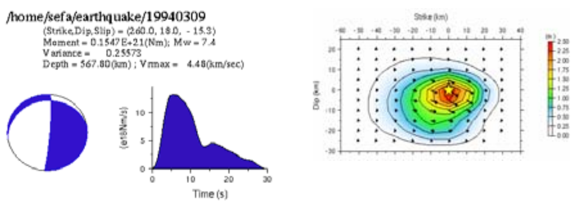

Figure 6. Shows the final results of inversion for one deep event 19940309. The star indicates the location of the initial break.

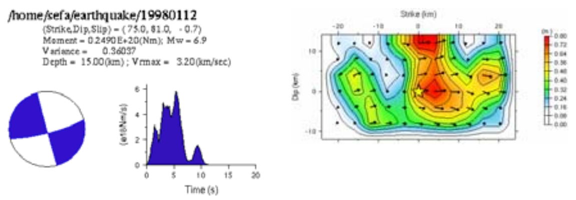

Figure 7. Shows the final results of inversion for one of the shallow depth earthquake 19980112. The star indicates the location of the initial break.

CONCLUSION

In this study, we first investigate the quality of waveforms recorded at Yasawa station which is operated by the Mineral Resources Department of Fiji. Using three components waveform recorded at Yasawa, we tried to estimate the centroid moment tensor solution so as to compare it with the result of Harvard CMT. We found that the solution by this study is not consistent with the Harvard CMT. If we divided by -10 to the observed waveform, we can obtain a consistent result as the Harvard CMT. On the other hand, moment tensor inversion analysis was carried out by using teleseismic body-waveforms for 30 past local earthquakes (Mw>6.5) retrieved from IRIS-DMC. We found that middle earthquake with shallow depth located along the two major fracture zones, the Fiji Fracture Zone (FFZ) and the Hunter Fracture Zone (HFZ) and intermediate and deep earthquakes located within the two subducting slab, the Tonga Kermedec subduction zone and the Vanuatu Trench. The focal mechanisms are well consistent with tectonic setting. In the final part of this study, source process inversion was performed for four events. As for deep earthquake, since thickness of seismogenic zones within the slab decreases with depths, the direction of rupture propagation during a large earthquake should be mainly along the strike of the slab. For shallow earthquake occurred within the Fiji Fracture Zone, rupture propagated along strike direction, NE and SW direction or parallel to the direction of the Fiji Fracture Zone. In general, for shallow earthquakes during such rupture, it breaks a part of the fault and the rupture propagation direction seems to be controlled by the orientation or the geometry of the fracture zone. Our results agree well to the theory.

RECOMMENDATION

Based upon the purpose of this study, the following recommendations are put forward.

1. To investigate and check the polarity of Yasawa broadband station as well as the magnification of the seismometer information and efforts should be made for our Mineral Resources Department (MRD) to monitor and maintain this station.
2. Also to check and maintain our CTBTO broadband station.
3. Moment tensor analysis to be carried out routinely for all medium-large size earthquakes that will occur within the Fiji region by using both near source data and teleseismic body-wave.
4. Database for this analysis should be compiled and accessed as references for future purposes.

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REFERENCES

Dregar, D., Ritsema, J. and Pasyanos, M., 1995, Geophys. Res. Lett., Vol. 22, 8, 997-1000.

Kohketsu, K., 1985, J. Phys. Earth, 33, 121-131.

Rognvaldsson, S. T. and Slunga, R., 1993, Bull Seis. Soc. Am. Vol. 83, 4, 1232-1247.

Tibi, R., Estabrook, C. H. and Bock G., 1999, Geophys. J. Int. (1999), 138, 625-642.

Yagi, Y., Kikuchi, M., 2000, Geophys. Res. Lett., Vol. 27, 13, 1969-1972.

Yagi, Y., Mikumo, T., Pacheco, J. and Reyes, G., 2004, Bull Seis. Soc. Am. Vol. 94, 5, 1795-1807.

Yagi, Y., 2007-2008, IISEE/BRI.