Reservoir-Induced Seismicity at Castanhão (NE Brazil)

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Abstract

Reservoir-induced seismicity (RIS) has acquired great attention of geoscientists mostly because of big destructive potential in structures and human loss. This kind of seismic events has been reported since 1945 at lake Mead (USA). However, the largest induced earthquake (*M 6.3*) took place at Koyna (India) in 1967. In NE Brazil, at least two cases of RIS were reported: one at Açu reservoir (Ferreira, 1995; do Nascimento et al., 2004a, 2004b, 2004c) and another one at Castanhão reservoir. The latter is the subject of the present paper. Our study shows the results of a campaign done in the period from November 19th, 2009 to December 31th, 2010 at the Castanhão reservoir. We deployed six three-component digital seismographic station net work around one of the areas of the reservoir. These data were used to estimate the velocity model and its parameters, hypocenters, focal mechanism, and carry out a spatial-temporal. We recorded and analyzed a total of 526 which were registered in at least three stations. To determine hypocenters and time origin, we used HYPO71 program assuming a half-space model with following parameters: V_P (P-wave velocity) equal to 5.95 km/s and V_P/V_S equal to 1.73 – the later was estimated by the Wadati diagram. The earthquakes hypocentral distribution was observed in three main clusters activated in different periods and others spread over with depths varying up to 2kmwithin the network. The focal mechanism determination was made from a group of 8 selected earthquakes. The solution acquired with this polar distribution by visual was 217º for strike, 70º for dip and 45º for slip. A plane fit of hypocentral distribution from this 8 events suggests 257º for strike and 57º for the dip.

Introduction

Reservoir-induced seismicity (RIS) cases have acquired special attention since 1967, when a earthquake of *M 6.3* took place at Koyna (India), killing about 200 lives and damaging many structures (Gupta, 2002). Others damaging reservoir-induced events happened worldwide in the 1960's at Hsingfengkiang (China), Kariba (Zimbabwe) and Kremasta (Greece) (Gupta, 1992). Talwani (1997) classified these RIS cases in two categories:

- Initial seismicity: Associated to the initial impoundment or large lake-levels changes;
- Protracted seismicity: Occurs after the effect of initial filling has diminished.

Particulary in Brazil, Assumpção *et al.* (2002) has shown 19 cases of RIS, of which 16 have been confirmed and 3 are still uncertain. In NE, for instance, the Açu reservoir has received intensive attention and monitoring by researchers (Ferreira *et al.*, 1995; do Nascimento *et al.*, 2004a; 2004b; 2004c).

Our case study – the Castanhão reservoir –is located in NE Brazil which is located at Borborema Province. The Borborema Province is a major Proterozoic-Archean terrain (Figure 1). It was formed as a consequence of convergence and collision of the São Luis-West Africa craton and the São Francisco-Congo-Kasai cratons.The reservoir is an earth-filled dam, 60 m high, which can store up to 4.5 billion m³ of water. The construction begun in 1990 and finished in October 2003.The first identified reservoir-induced events occurred in 2003, when the water level was still low. The water reached the spillway for the first time in January 2004 and, after that, an increase in seismicity occurred (Figure 2).

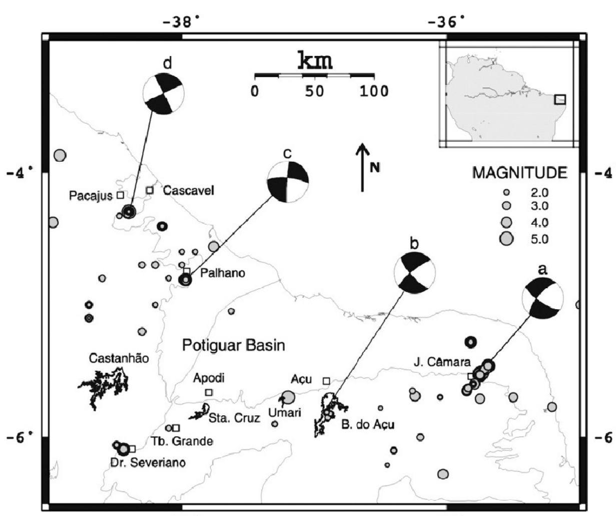

Figure 1: *Study area showing Castanhão Dam, Açu dam and other activities in Potiguar Basin and vicinity. Except for Açu Dam earthquakes, all other activities reflects natural events (m_b ≥ 2). Lower hemisphere focal mechanisms: (a) João Câmara (Ferreira et al., 1987); Açu Dam (Ferreira et al., 1995); (c) Palhano (Ferreira et al., 1998); Cascavel-Pacajus (Assumpção et al., 1985). (Modified from Ferreira et al., 2008).*

A previous research (campaign of March 2003 to June 2004) at Castanhão dam showed that seismicity in this reservoir appears to be an example of initial seismicity and an spatio-temporal analysis indicated that the seismicity occurs in clusters activated in different periods (Ferreira et al., 2008). Our study will show the results from a campaign made from November 19th, 2009 to December 31th, 2010.

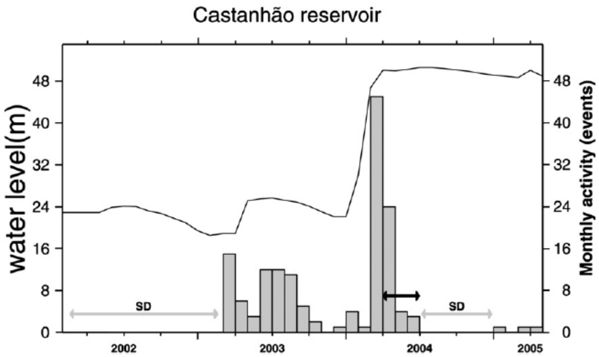

Figure 2: *Monthly variation of waterlevel (top line) and seismic activity (bottom line) in Castanhão reservoir. The black arrow denotes the four-station campaign in 2004. Gray arrows denote periods of no data (station down). Waterlevel data from DNOCS — Dpto. Nacional de Obras Contra a Seca, Brazil. (Ferreira, 2008).*

Methodology

During the campaign, we had six three-component digital stations network deployed around a branch of the reservoir (Figure3).The equipment utilized were granted from the "Pool de Equipamentos Geofísicos do Brasil" (PEGBr). We used seismographics stations with the DAS-120 (Reftek) recorded and andL4C3Dsensors. The sampling rate used was 250 samples/second..

From the collected data, we select a total of 526 to show the results of the spatio-temporal evolution, velocity model, hypocentral distribution and focal mechanism. All these events were recorded in at least three stations.

SAC program (Tapley & Tull, 1991) were used to carry out the reading of P and S-waves arrivals and polarities. Hypocenters were evaluated using HYPO71 (Lee & Lahr, 1975). We used a visual inspection for the determination to the solution of focal mechanism.

Velocity model, Hypocentral and epicentral distribution (spatial-temporal analysis)

The first step to proceed with a good hypocentral determination is determine the P-wave velocity (V_P) and P and S-waves velocity ratio ($k=V_P/V_S$). A half-space model was used to this study, because of it has been very successful in studies at NE Brazil (eg., Ferreira et al., 1987, 1995, 1998 and 2008).

A velocity model was acquired considering a Wadati diagram (Figure 4). For this diagram, we used 39 points each one representing readings from the best recorded events with maximum distance to CSMI station up to 2.0 km. These events showed the smaller horizontal and vertical errors (300 m) and residual mean square (RMS) in time (0.03 s). The linear regression gives the value of $k(=V_P/V_S) = 1.73$. The P-wave velocity value (equal to 5.95 km/s) was used from Palhano's velocity model, because of the proximity of the Castanhão region.

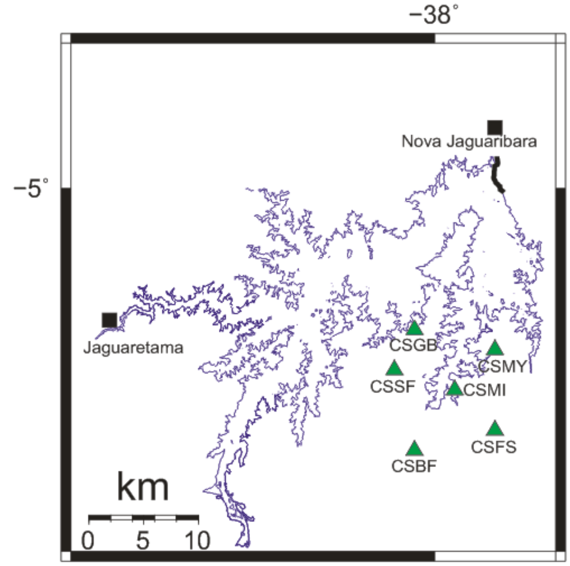

Figure 3: *The study area and distribution of seismographic stations at Castanhão dam. Two cities are represented in this figure: Nova Jaguaribara and Jaguaretama.*

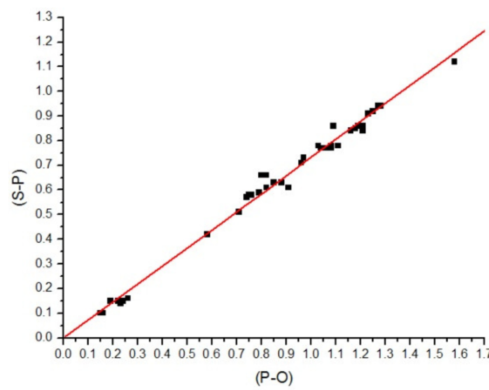

Figure 4: *Wadati diagram obtained from selected earthquakes for acquire a velocity model. (P-O) is the difference between P-wave arrival time and origin time. (S-P) is the difference between S-wave arrival time and P-wave arrival time.*

The preliminary results from a epicentral map with all these 526 events (Figure 5) shows that seismic activity at Castanhão occurs in three clusters (A, B and C) activated in different periods of time and other spread in area. The orientation obtained is NE and were best observed on cluster B and C. This agrees with a previous study from Camarão Junior (2001).

The cluster C is the most active, having earthquakes during all period, becoming deeper for longer observation time. Cluster A is activated in May 2010. This activity diminishes in the following months. Cluster B shows activities during principally the period between January, 2010 and March, 2010. This migration of activities is consistent with a fluid pressure diffusion on cracks and faults, modifying shear and normal stress on these faults, which confirms this RIS case.

The hypocentral distribution from the best recorded events (horizontal and vertical error up to 300 km, RMS up to 0.03 s and GAP up to 180º) shows a maximum depth equals to 2 km (Figure 7).

Focal Mechanism

To determine the focal mechanism we mapped all polarities in the projection and determine visually the fault plane and auxiliary plane. We chose 8 events with minimum horizontal and vertical errors (300 m), minimum RMS (0.03 s) and maximum distance from epicentral station (CSMI) equals to 2.0 km. All these events were in cluster C. The plane solution obtained gives a strike of217º, dip of 70º and slip around to 45º (Figure 6).Fitting a plane by using least squares on these epicenters, we obtain a strike equals to 257º and dip equals to 57º (Figure 7).The interchange of polarities in some stations are due to their position in respect to a nodal plane and the depth of these events.

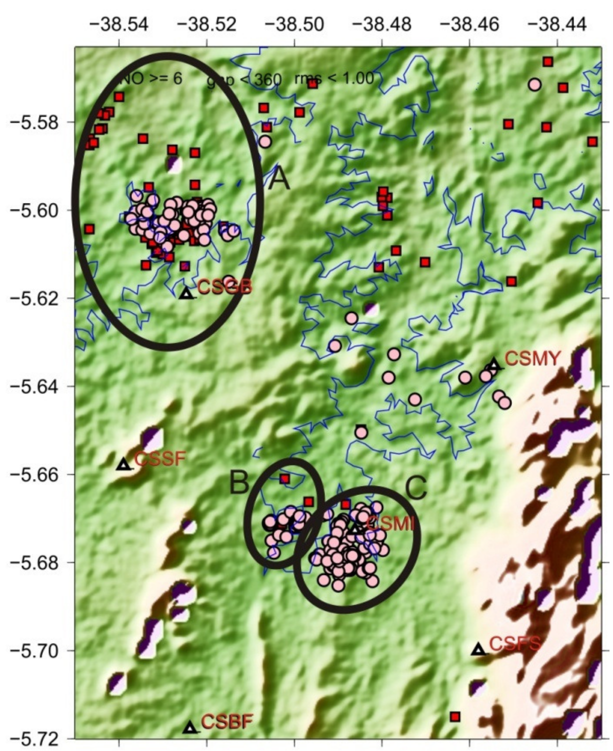

Figure 5: *All recorded epicenters in our study area. This figure shows that seismicity in Castanhão occurs in clusters (A, B and C) activated in different periods and others spread in the area. The pink circles are events with depth up to 1.3 km and the red squares are events with depth greater than 1.3 km.*

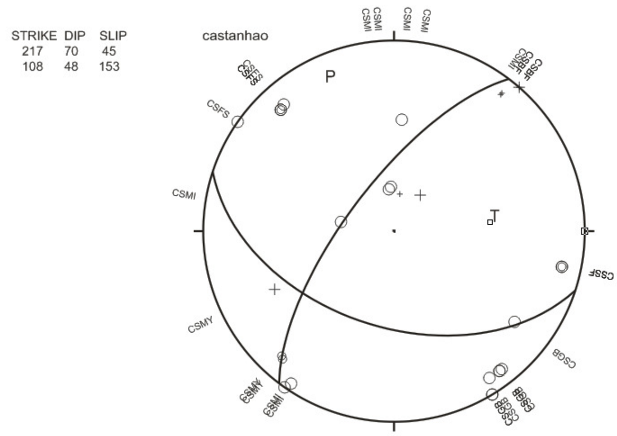

Figure 6: *Focal mechanism obtained from best recorded events in cluster C.*

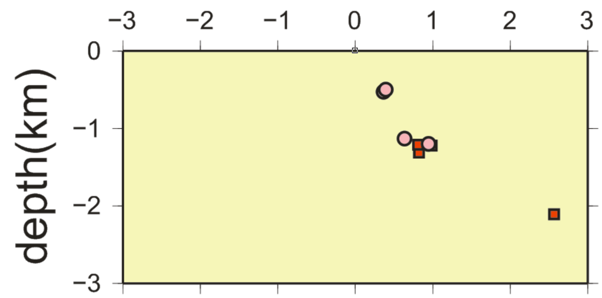

Figure 7: *Hypocentral distribution in the area right down of CSMI station. Pink circles represents hypocenters with depth up to 1 km and red squares represents hypocenters greater than 1 km.*

Discussions and conclusions

The first earthquake was observed still in 2003, during impoundment when a sudden increase in the activity occurred shortly after the dam reached its spillway.

A previous study from Ferreira (2008) showed the seismicity at Castanhão dam as a case of RIS because its epicenters were founded concentrated in three different clusters. He used a velocity model from Palhano to evaluate epicenters.

A epicentral and hipocentral distribution made here shows the migration in other three more clusters, confirming the migration (There are at least six). The best registered events confirms the velocity model used by Ferreira (2008). The position of epicenter (NE) and the hypocentral distribution (57º)agrees with agrees with faults mapped by Camarão Junior (2002).

We found a solution to focal mechanism based on distribution of polarities and visually determined. Because the depth of our selected events and this little quantity, we found a divergent values of strike and dip.

There is no magnitudes, measurements yet. In the future we will investigate if there is any relationship between magnitude clustering with depth, or cluster.

Acknowledgments

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