INDUCED SEISMICITY AT MIRANDA RESERVOIR - A fine example of immediate seismic response

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Abstract

This paper shows that Reservoir Induced Seismicity (RIS) at Miranda (Minas Gerais State) is a very clear example of immediate seismic response. The first induced earthquakes happened immediately after the beginning of the lake's impoundment (August, 1997). It is also shown that the reservoir responded promptly to a sudden water level variation, producing a magnitude 3,3 (m_R) earthquake, with a maximum intensity of VI (MM).

It will be showed that a very low magnitude induced earthquake can produce substantial damage to poor quality constructions, increasing the hazard of RIS due to its shallow focus characteristics. Miranda main shock of May 06 also shows that sometimes microseismic survey can produce better epicentral location than the instrumental data analysis.

Introduction

Seventeen proven cases of RIS have already been identified in Brazil [Marza et al. (1999), Assumpção et al. (2001)]. Of those, 71% were considered of the initial type of RIS, i. é., the induced earthquakes happen a few years (maximum three years later) after the reservoir impoundment.

The Miranda Reservoir area was monitored, during the six first years that preceded the impoundment, by the neighboring Nova Ponte reservoir seismographic network whose stations are situated between 30 and 50 km away and had not detected any event until the concernment of impoundment in August of 1997(Fig. 1). The first earthquakes happened immediately after the lake's formation in August of 1997, when one local seismographic station (MIR1) was quickly installed close to the dam structure (Fig. 2).

With the increase of the seismic activity in the area, the Seismological Observatory (SIS) of the University of Brasilia (UnB) increased the number of stations and, jointly with IAG-USP, operated up to seven digital three components stations around the reservoir's area.

Reservoir Induced Seismicity phenomenon

RIS is related with various factors [Simpson (1976)], such as: size and weight of the reservoir water mass, pre-existent tectonics stresses, geologic and hydromechanics conditions present in the area, constructive interaction between the orientation of pre-existing tectonic stress and the additional stresses due to the lake and it's water level dynamics. RIS results, then, from rupture process caused by one or more of aforementioned factors, presented in an area where the state of the stress is close to rupture.

The reservoir's seismic response was classified by Simpson et al. (1998) or Talwani (1995) in two categories:

i) Initial response - the events occur immediately after lake's impoundment or are caused due to sudden variations in reservoir water level and generally, decrease after a few years; and

ii) Delayed response - the events occur a long period after the reservoir impoundment within various fluctuations of the reservoir water level.

The first type response is the most common. From the seventeen proven RIS cases in Brazil, twelve are of initial type (Marza et al. 1999).

The second type response, with five occurrences in Brazilian reservoirs, has as a classical example of the Carmo do Cajuru/MG UHE, whose seismic response occurred seventeen years after the impoundment, with an event of 3,3 m_R [Vioti et al. (1995), Veloso et al (1995), Vioti et al. (1997), Gomide (1998), Marza et al. (1999)].

That reservoir, despite of its short dimension (maxim height of water blade of 20m and volume of 0,2 km^3), is still presenting seismicity, more than 30 years after the RIS has begun in 08/08/1971 (m_b = 3.5). Nowadays, Cajuru RIS passes by a reactivation period, which restarted on Feb/03, with an event of 3.0 m_b on 05/04/2003. It proves that not only the reservoir dimensions are the determinant factors to initiate RIS. Itaipu reservoir, with a volume 145 times larger and almost ten times higher than Cajuru reservoir, had never presented seismicity, in spite of 25 years of uninterrupted and efficient seismographic monitoring of the reservoir area. These two facts explain the necessity of the existence of a conjunction of tectonics, geological and hydromechanical factors at the reservoir area and the additional effects created by reservoir, i. e, it is necessary that the mechanical and hydraulic effects of the reservoir sum itself positively at the tectonic stress present in the reservoir area and, most important, is necessary that the state of the tectonic stress before the lake impoundment is closed to its rupture limit. The reservoir itself does not cause seismicity. It only speeds up a process that was running before its impoundment. For this reason, it is said that induced earthquake anticipates an earthquake that would occur in the future.

Location of Miranda Reservoir

Miranda Reservoir is located at Parana Basin boundary, close to the seismic Nova Ponte Reservoir, with repetitious circle of RIS (4/21/1995, m_b = 3,5 and 5/22/1998, m_b = 4.0). In Figure 1 are showed seven reservoir that presented RIS in Brazil: Miranda, Nova Ponte, Emborcação, Marimbondo, Porto Colômbia/Volta Grande, Carmo do Cajuru and Furnas, and one doubtful case: Três Marias.

Coincidently, the two largest RIS cases in Brazil are among those seismic reservoirs, the largest magnitude ever observed occurred between closed reservoirs of Porto Colombia and Volta Grande (m_b = 4,2, on 02/24/1974) and the second largest magnitude occurred at Nova Ponte Reservoir (m_b = 4,0, on 05/22/1995). As it can be noted in Figure 1, the great majority of the RIS cases in Brazil, from seventeen cases, is located at Parana Basin boundary, suggesting that exists some correlation between the location of those reservoirs and the existence of favorable conditions to RIS phenomena in this area. Assumpção et al. (2002) mention the existence of a concentration of RIS cases at Parana Basin boundary, but these cases do not coincide with the natural seismicity. Yamabe (1999) identified three cases of seismicity induced by artesian wells in that region. Thus, the Parana Basin boundary is a very favorable region for RIS occurrences.

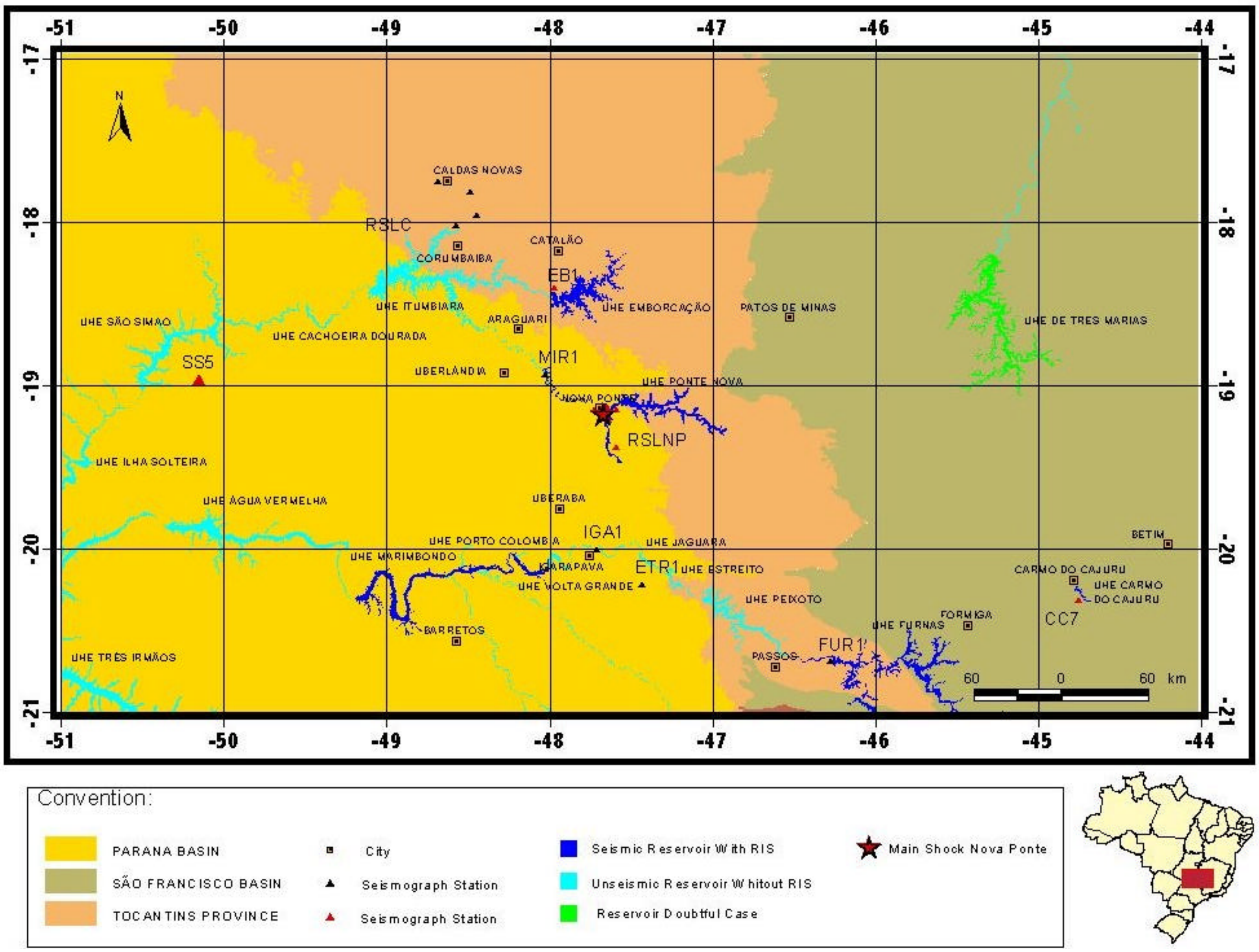

Figure 1 - Location map of Miranda/MG Reservoir showing six other cases of RIS in the region. The seismographic stations that detected the seismo of 05/06/2000 are showed as a red triangle. The seismic reservoirs are painted of different color, according to the presence of RIS or not. Três Marias reservoir is a doubtful case of RIS.

Miranda's RIS

The Miranda Reservoir, with a maximum water depth of 85m and a volume of 1,14 billion m^3, is located in a region with predominance of basaltic mesozoic rocks of the Serra Geral Formation that overlays proterozoic gneisse (Assumpção et al. 2001).

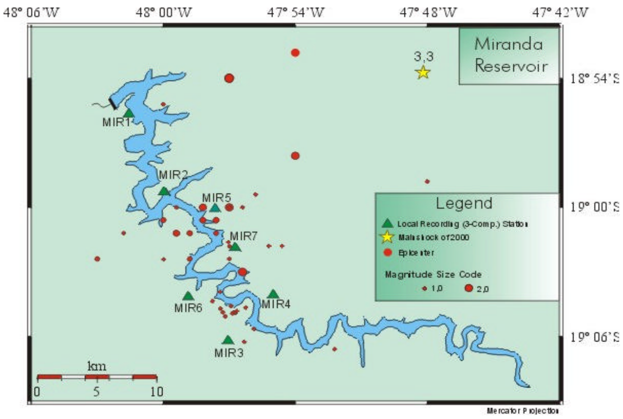

Figure 2 - Map of Miranda's Reservoir indicating the location of main events and of the local seismographic network. Note that the star represents the instrumental location of the May 06 mainshock.

The induced microtremors at Miranda Reservoir appeared soon after the lake's impoundment (August, 1997) and was monitored by a vertical component station code (MIR1) installed around the dam axis, almost simultaneously with the reservoir impoundment (Fig. 2).

During August and September of 1997, the MIR1 Station detected up to 420 microtremors with magnitudes ranging from 0,3 to 2,1 (m_D) (Fig. 3). This seismicity decreased soon after September and was reactivated in April of 1998, when the most significant event until then occurred (magnitude of 2,4 m_D). In the following months a long quiescent period occurred, with only some minor background micro activity between April 1998 and May 6, 2000, when a mainshock (m_R = 3,3) occurred (Fig. 3). At that time, Miranda Reservoir was being monitored only by the MIR1 Station, which, unfortunately, due to several technical and maintenance problems, did not register that event. The absence of seismicity during the referred quiet period and some needs for redistribution of the instruments resulted in disablement of the Miranda temporary seismographic network, with only MIR1 Station remaining for monitoring.

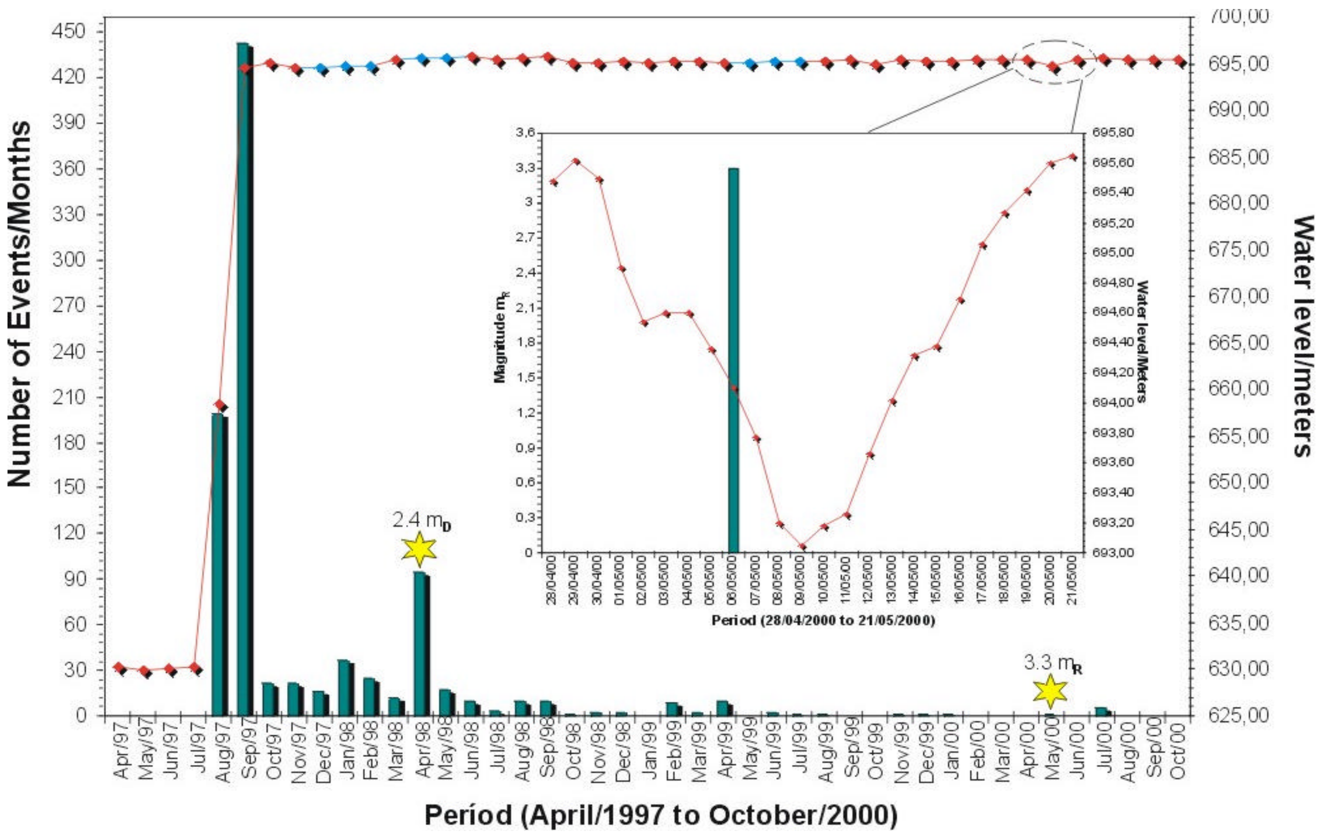

Figure 3 - Seismicity at Miranda's Reservoir showing the water level variations with the occurrence of the main event of 2000/05/06.

After the occurrence of May, 2000 mainshock, the SIS/UnB re-installed three new triaxial seismographic digital stations (MIR2, MIR6 and MIR7) that, together with MIR1 Station, constituted a local network of four stations. However, it did not detect any aftershock activity between May 6 and July 2000!

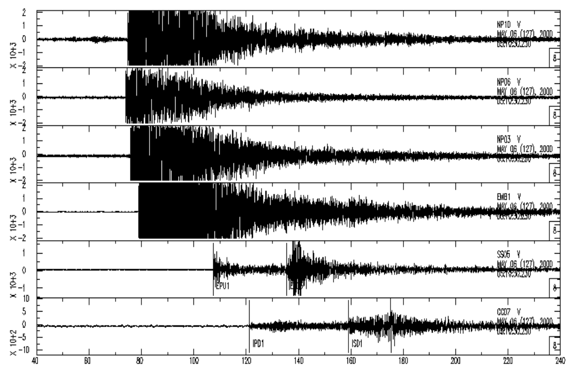

Figure 4 - Register of the 06/05/2000 event at CEMIG's Seismographic Network [Nova Ponte (three first channels) Emborcação, São Simão and Carmo do Cajuru]. All these stations are in Minas Gerais State.

The event of May 6, 2000 was registered by most of the stations of CEMIG's Seimographic Network (located in the Minas Gerais State) (Fig. 4) and by the Brasilia Seismographic Array. Unfortunately, due to one large azimuthal gap regarding the distribution of the stations in relation to the epicenter it was not possible to obtain an accurate instrumental localization (Fig. 2). The results obtained, using various velocity models always, presented a high residual. However, a microseismic survey allowed a more accurate epicenter (Fig. 5) to be determined which was adopted as the preferred epicenter. This shows that, despite a good instrumental register of the earthquake (Fig. 5), it was preferable to adopt the microseismic epicenter as more accurate because the site survey was done accurately and the evidences showed that the epicenter was not located where the instrumental measurement was indicating. So, sometimes microseismic epicenters should be preferable than instrumental ones, especially when the seismographic station coverage is not uniform.

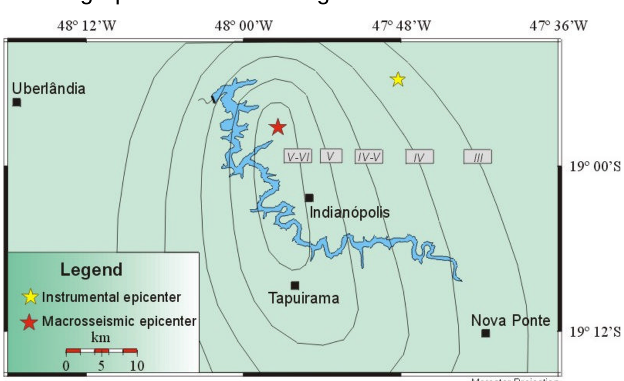

Figure 5 - Isossist map of mainshock - May 6, 2000.

This survey was made in two stages: the first, soon after the occurrence of the event and, the second, one month after it. At Indianópolis, almost everybody woke up and, being afraid, abandoned their houses. At approximately 10 km in the north of Indianópolis, at the Furnas Retiro Farm, which belongs to José Alves Pereira, the event was felt more strongly, with intensity VI (MM), causing trines and cracks (Fig. 6). That local was considered the macroseismic epicenter, seeming to be more reliable than the instrumental epicenter.

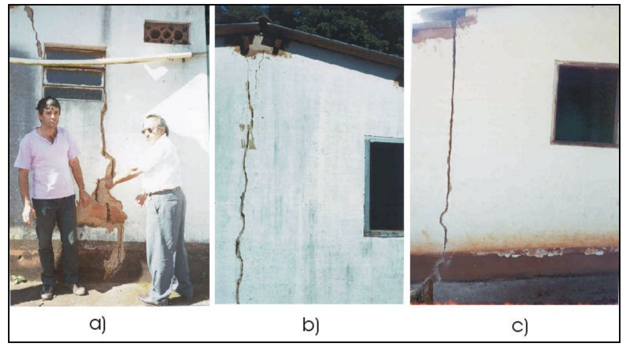

Figure 6 - Damages caused by mainshock of May 6, 2000 (3,3 m_R) at a house in Indianópolis region at Furnas Retiro Farm: a) cracks on side of house, b) cracks on front of house and c) lateral part showing that the cracks extends up to the ground.

Miranda's mainshock of May 06, 2000 represents a clear immediate seismic response caused by a sudden variation in reservoir water level. A decrease of about 2 m in the reservoir's water level and the 3,3 magnitude event occurred within a week time interval (see the insert in Fig. 3).

A very important aspect that should be considered is that a micro earthquake (magnitude 3.3) causes cracks on the wall and foundation of a house. It shows that if the magnitude of the earthquake had been one unit of magnitude larger, equal to the largest magnitude of induced earthquake ever observed in Brazil, certainly houses would fall and people would probably have died, because it was night and many people were sleeping.

It shows two important things: first, for an earthquake produce damaged, besides its magnitude, it should be take into account another factors, like the focus depth, the quality of the constructions, among others. The focus of the induced earthquakes are, normally, very shallow, like that one in Miranda Reservoir; the quality of the house construction was not very good as shown in Fig. 7; second, the risk of RIS magnitude in Brazil capable to causes damage it is not negligible. In seismology, there is a rule of thumb that says the following: "the largest induced earthquake in an area could be at least the same order of magnitude of the largest natural earthquake ever observed with epicenter in same area". The largest natural earthquake in the seismotectonic southern province had a magnitude of 5.1 (Berrocal et. al., 1984). So, as most of the seismic reservoir in Brazil are located in this province it should be considered such possibilities as a not negligible.

Conclusion

1. The induced seismicity presented by the Miranda Reservoir is a great example of immediate seismic response; the events happened soon after the lake's impoundment, later an abrupt variation in water level

of the reservoir caused a mainshock on May 06, 2000 (m_R = 3,3);

2. The mainshock of May 06, 2000 happened alone, without foreshock nor aftershock activity, showing a very uncommon seismicity behavior;

3. The magnitude of the main shock of May 06, 2000, in spite of not being large, produced a maximum intensity of VI (MM), suggesting a shallow hypocenter and showing that the IRIS has a great destructive potential; low magnitude with shallow focus can produce damage due to the cause of the IRIS great (Engineering Buildings). So, before the building of structures that may have potential to induce seismicity, it is necessary to evaluate the seismic hazard of the area.

4. The lack of a uniform seismographic stations coverage resulted in an instrumental unreliable epicenter determination, for this reason, the macro seismic epicenter was preferred, showing that, sometimes, the macroseismic location should be preferable than the instrumental location, depending on the epicentral area stations coverage, and how good is the microseismic survey.

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