第 14 卷 第 1 期 CT 理论与应用研究 Vol.14 No1
2005 年 2 月（57~63） CT Theory and Applications Feb.,2005
文章编号：1004-4140（2005）01-0057-07

A New Method of Detecting Landslides: A Case for SNMR

LI Zhen-yu, LI Jun-li, TANG Hui-ming , PAN Yu-ling ,ZHANG Bing, QU Zan
(China University of Geosciences, Wuhan 430074,China; E-mail: zhenyuli626@sohu.com)

Abstract: After the Three Gorges Reservoir impounded, due to the rise of ground water, the flabbiness layers in landslides will become soft and collapse when they meet water. During the running of the reservoir, the change of water level will bring huge dynamic water pressure, which leads to slides, especially when the water level approaches sliding surface. It is a brand-new ideal research on ground water change characteristics and stability of landslides to use SNMR（surface nuclear magnetic resonance）. Except that a few papers have been published in our research group, there is no other reports or papers in or out of China. We take Zhaoshuling landslides in The Three Gorges Reservoir as an example to study ground water characteristics and stability of the landslides. Applying SNMR to research on landslides is a new method, and its success will not only pioneer a new way to study landslides and expand the application of NMR, but also promote the economic construction of our country. Therefore, it has both scientific significance and great practicality.

Keywords: SNMR（surface nuclear MR）, landslide, detection, stability, water content, permeability
CLC number: TP 391.41 **Document code:** A

一种应用于三峡滑坡探测的新方法—SNMR 法

李振宇，李俊丽，唐辉明，潘玉玲，张兵，曲赞
（中国地质大学，武汉 430074）

摘 要：三峡库区蓄水后，由于水位上升滑坡地区的软弱层遇到水就会变软并引起滑塌。核磁共振是当今世界尖端技术之一，我们首先将该技术应用于滑坡探查。本文探讨了用 SNMR 探查滑坡的方法技术以及通过 SNMR 实测数据求取与滑坡稳定性有关的水文地质参数，通过一个三峡的实例说明了该方法是一种快速有效的探测滑坡的方法。

关键词：地面核磁共振；滑坡；探查；含水性；渗透系数

1. Introduction

Landslides are a sort of familiar geological disaster, which can bury villages, destroy factories, railways, highways, and block up rivers and shatter farmlands and forest frequently. Accordingly，lives and properties of human beings，economy and constructions of nations will suffer from severe loss. The natural water level in The Three Gorges of Yangtze River was from 70m to 100m, and the reservoir water level will reach to 145m at first period and then reach to 175m at second period. The water level will periodically fluctuate between 145m and 175m,which must lead to the fluctuation of under groundwater, especially when the water level fluctuation is sharp, and which will affect the stability of landslides in the Three Gorges Reservoir. It connects the construction and safety in the Three Gorges reservoir.

It is a brand-new ideal research on ground water change characteristic and stability of landslides to use SNMR（surface nuclear magnetic resonance）. Except that a few papers have been published in our research group, there is no other reports or papers in or out of China. We take Zhaoshuling landslides in The Three Gorges Reservoir as an example to study ground water characteristics and stability of the landslides. Applying SNMR to research on landslides is a new method, and its success will not only pioneer a new way to study landslides and expand the application of NMR, but also promote the economic construction of our country. Therefore, it has

*Received date:2004-12-18.**本文得到国家自然科学基金（40072085）资助**

both scientific significance and great practicality.

NMR technique is one of the greatest results in advanced physics study. NMR phenomenon was simultaneously discovered in 1946 by American physicians E.M Burcell (Harvard University) and F Bloch (Stafford University), both of whom have been awarded the Nobel Prize of physics in 1952.As present, NMR have been widely used in certain fields, such as physics, chemistry, biology, medicine and petroleum-chemistry as well as earth science.

The application of NMR in earth science began as early as in 1954,M Packard (Member of F Bloch group in Stafford) and R H Varian had successfully observed free nuclear induction caused by water proton in geomagnetic field, that is FID signals. From which high accuracy, stability in performance proton precession magnetometers have been prepared, including ground and aero-proton magnetometers which were mainly used in geological and mineral resources investigation.

The second application of NMR in earth science is nuclear magnetic logging (NML) and its related rock core testing and analysis in lab. Having been developed for nearly 40 years, NML technique could possibly assess the permeability and porous structures in sandy rock and complex reservoir strata, stored deposits, residual oil distribution and fluid saturation as well as its viscosity, which has become a highlight in oil well logging techniques.

The third application in earth science is water finding.

The causes of landslide and its evolution are closely related to groundwater activity, rainfall and seepage of surface water. Because of the water action, there exist some obvious differences in conductivity, permeability, electric-chemistry activity, relaxation, radioactivity and wave velocity between physical properties caused by integrated rocks and damaged rocks, both are in landslide body. So far, the methods for investigating landslides are: resistively methods, VLF, Shallow seismic, GPR, natural acoustic radiation, electromagnetic radiation, radioactive survey and radio penetrating, etc.

The methods above respectively reflect the variation of physical property of landslide body from various aspects, it is, however, not a direct method to detect the distribution and variation of groundwater closely associated with landslide. Then, the surface nuclear magnetic resonance (SNMR for short) is the only one to directly detect groundwater, which can give the occurrence of groundwater about the studied section directly. With the help of National Natural Science Foundation of China, we began to study landslide problem with SNMR system for the first time, and did some tests, monitoring in Zhaoshuling, Badong County, Hubei province, and preliminary results have been obtained.

2. Feasibility of studying landslide and SNMR principle

2.1 SNMR principle

NMR is a phenomenon of physics based on atomic nucleus property, which means the matter with nuclear paramagnetic absorbs selectively electromagnetic energy [4]. On theory, the unique condition of NMR application is the magnetic moment of atomic nucleus, which is not zero. The Hydrogen atomic nucleus has paramagnetic, and its magnetic moment is not zero. As the hydrogen nucleus is the proton with highest abundance and largest gyromagnetic ratio of paramagnetic nucleus in the strata. Under the action of stable geomagnetic field, hydrogen proton processes along the geomagnetic direction, just like a top processes along the earth's gravitation, its procession frequency (Larmor angular frequency) is dependent on geomagnetic field intensity $\boldsymbol{B}_0$ and hydrogen proton gyromagnetic ratio γ

$$w_0 = g * B_0 \qquad (2\text{-}1)$$

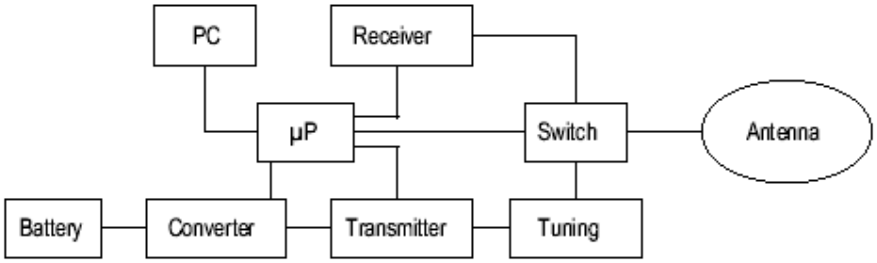
Under the action of geomagnetic, hydrogen proton is at certain energy levels. If the protons in groundwater are excided by alternative magnetic field $B_1(\omega_0)$ with Larmor frequency , making them to transit in energy levels, that NMR is generated.

In general, the alternating field pulses with Larmor frequency are introduced in surface loop (transmitting/receiving coil), the envelope curve of alternating current pulses is rectangular. Under excitation of alternating magnetic field caused by alternating current in earth, the macro-magnetic moments of hydrogen protons in underground water are formed. This macro-magnetic moment produce procession in geomagnetic field, its processing frequency is the behavior of hydrogen protons. After switching off the current pulses, the NMR signals caused by different exciting pulses are picked –up

with the same loop, the envelope of the signals attenuates as exponential curve. The intensity and decay speed of the signals are directly related to the quantity of proton in water, that is, the amplitude of signal is in direct proportion to free water content which is being investigated, from which a direct water finder method, SNMR, is introduced.

2.2 SNMR survey system and parameters

The device we used is NUMIS equipment from France. Which is the advanced direct waterfinder with high output power and high receiving sensitivity controlled with PC. The whole system consists of DC battery (2 vehicle batteries), DC/DC converter, and transmitter transmitting/receiving antenna, tuning units, receiver, portable PC and some accessory connecter, the connecting scheme in the field is given by Fig 1.



(a)

Fig. 1 (a) Components of NUMIS and diagram of interconnections ,

The survey parameter reads as follows:

(1) The initial amplitude of NMR signal Eo: Eo is in direct proportion to water content in water-bearing strata.

(2) The averaged relaxation time of NMR signal.

(3)The initial phase of NMR signal.

The useful parameters related to hydrological geology and engineering geology through interpretation to the raw data could be obtained: the depth of water-bearing strata, the thickness, the water content and water-bearing strata category (mean porosity and the conductivity of the strata).

2.3 The feasibility of detecting landslide with SNMR

It is indicated that over 80% landslides events have something to do with underground water （Guangzhong Sun）. SNMR could obtain the information about underground water, so SNMR could play an important role in the study of landslide to determine the sliding boundary layers and recognize the water-bearing strata:

(1) Near sliding surface, the mechanics property of rocks has changed, water-bearing saturation is much higher than integrated rock, and thus the permeability is largely enhanced. From SNMR, the water-bearing volume percent in aqueous strata could be obtained, or the permeable coefficients between strata could be calculated. In comparison with normal mean value of aqueous property, it is possible to deduce the existence of the landslides.

(2) With SNMR direct inversion, the histogram of variation of water content with depth could be obtained to deduce the number of landslide boundary and the depth of each sliding surface. From certain SNMR survey, it is possible to obtain the space distribution of landslide surfaces and to decrease the drilling quantity.

(3) From two monitoring in flood and drought periods at a landslide during the course of one year, it could provide some important parameters for qualitative analysis to landslide stability.

(4) From different period monitoring in several year at a landslide, it could provide real data for further creating landslide geological models, assessment of stability and prediction.

As analyzed above, it is feasible to detect landslide with SNMR, and to create models of stability analysis and prediction with measured SNMR data.

2.4 The application in studying landslides at the Three Gorges with SNMR

Zhaoshuling landslide is a large typical in Three Gorges area, its stability directly relates the safety of Badong county, Three Gorges power station and the smooth of transportation. For the correct assessment of Zhaoshuling landslide the rock and soil structures of landslide and the property of underground water should be determined, for the purpose of authenticity of the landslide models. We applied NUMIS system made in France to monitor the landslide for three years and get some successful results. The preliminary analysis of the surveyed data is as follows.

Fig. 1 (b)NUMIS in the feild

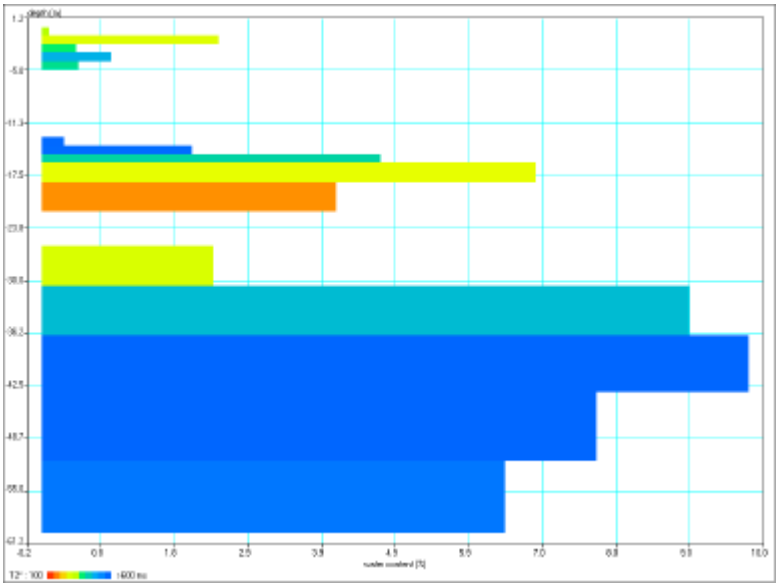


Fig. 2 An inversion result of SNMR on the landslide in Zhaoshulin

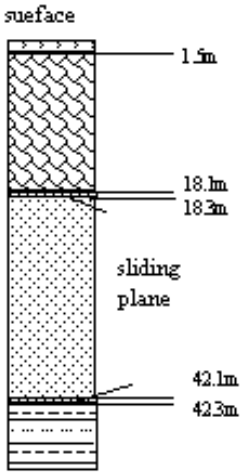


Fig.3 Drill column of Zhaoshuling landslide

3. The comparison result of one SNMR point result and drilling data

Fig .2 is the inversion result of SNMR on landslide in Zhaoshuling at Badong county. It is can be seen from the result, (1) there exists a aqueous strata at shallow surface with less water content, so it is not the target strata for our study; at the depth of 18m, an aqueous strata with large water content occurs; at depth of about 40m, there is a obvious water-bearing strata which water-bearing content is relatively large, (2) the aqueous strata near about 18m in depth has large seepage coefficient, near about 40m has relatively large seepage coefficient, (3) the water content between two strata is small, which is water-resisting layer. From which we deduced that there is a landslide boundary near about 18m; near about 40m a landslide boundary surface. Drilling data （Fig.3） evidence that a landslide boundary is at 18.2m in depth and another at 42m in depth. So it is evidenced that SNMR technique is feasible, effective, inexpensive and rapid in recognizing landslide surface with its measured data.

3.1 The comparison analysis of SNMR result in flood periods and the comparison analysis of SNMR result in drought periods

Six real measurements have been carried out in Zhaoshuling landslide, Badong. Three comparison results in drought periods indicate (1) the variation of water content at shallow water-bearing strata is violent; (2) water content at 18m has certain non-violent variation, basically, the depth of the strata keeps stable; (3) the water-bearing at 40m aqueous strata has certain variation, which is still stable and non-violent, the depth of aqueous strata is basically unchangeable. The three comparison results in flood periods have the same similar rules.

3.2 The comparison analysis of flood and drought periods results

The comparison between flood and drought period has the following rules: (1) the results of SNMR indicate that the depths of two landslide boundaries, at 18m and 40m,are basically unchangeable during the course of flood and drought periods;(2) the results of SNMR indicate that water content, at 18m and 40m surface, has certain variation, water content in flood period is larger than that in drought period. From the result analyzed above, the underground water distribution, and the information of season variation as well as useful reality measured data of landslide in Zhaoshuling, Badong county have been obtained, providing evident basis for further stability evaluation and landslide model in accordance with reality condition.

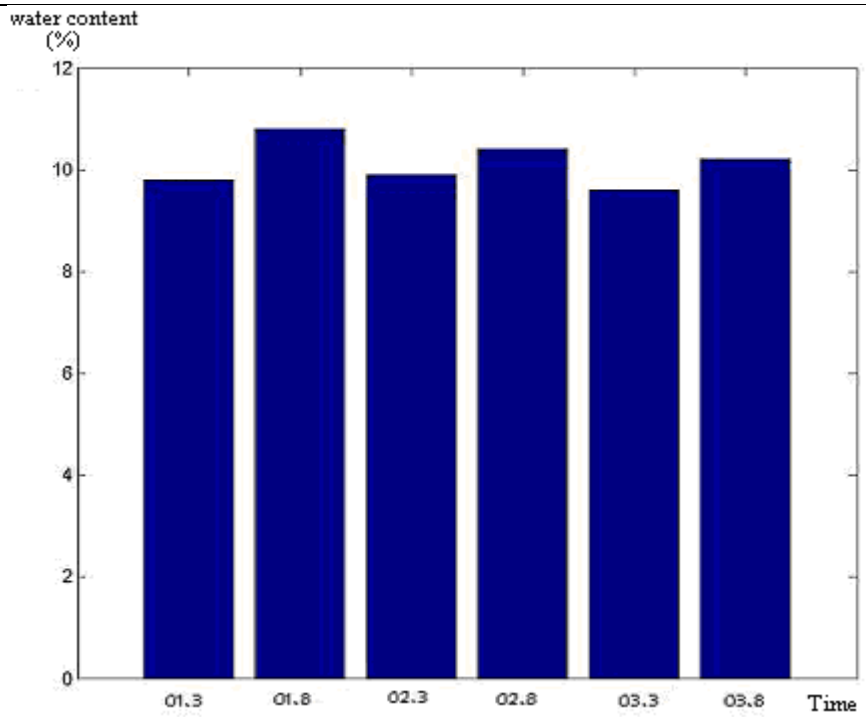


Fig.4.The water content-time change of Zhaoshuling landslide with SNMR in depth about 40m.

4. Conclusion and discussion

The conclusions obtained with SNMR to the problems of landslides are as follows:(1) To study landslide with SNMR technique is the first attempt, which is an applicable method through our investigation and practice;(2) From some parameters, such as depth of water-bearing strata, thickness, water content, the variation of permeability etc, the landslide boundary existing and space distribution could be correctly determined, which is identical to the bore hole data; (3) Through the monitoring result from different seasons at landslide body, the geologic model of landslide could be created with the help of SNMR result to provide basis for further assessing the stability;(4) Compared with other methods, SNMR method has such advantages as advanced theoretical basis, rapidity, accuracy and being inexpensive.

For the first time to study landslide with SNMR, some problems should be settled in the future, so that I put forward some suggestions as follows:（1）To study landslides with SNMR, because the signals are very faint and are influenced by noises, we have to enhance research on suppressing noises for the purpose of improving observation results of SNMR.（2） More sorts landslides should be studied with SNMR, the method and technology should be perfected, and the correct work program should be built up.（3） At present, there are no specialized instruments in detecting landslides with SNMR, as a result, research on the specialized instruments should be improved, so as to promote detecting landslides with SNMR more quickly and accurately.（4） We should do further study on building relationship between SNMR data and hydrology parameters, and provide more accurate SNMR data for the stability estimation and prediction of landslides. For the first time to study landslide with SNMR, some faults may exist in the paper. We authors wish to express our hearty welcome to any criticism and suggestions for the purpose of enhancing application effect with SNMR in landslide investigation.

References:

[1] Semenov A G ,Burshtein J F .Groundwater Survey Method and Apparatus[P].1968,US Patent 3398355.

[2]潘玉玲，张昌达等. 地面核磁共振找水理论和方法[M].武汉:中国地质大学出版社, 2000.

[3] Legchenko A V ,Baltassat J M ,Beauce A , Makki M A and AL-Gaydi B A. Application of the surface proton magnetic resonance method for the detection of fractured granite aquifers[C]. EEGS (European Section) Meeting ,Barcelona, 1998.

[4] Legchenko A and Valla P. A review of the basic principles for proton magnetic resonance sounding measurements [J]. Journal of Applied Geophysics, 2002.

[5] Roy J , Marques da Costs A , Lubczynsky M and Owuor C. Tests of the SGW-NMR technique within two aquifer characterization projects in the Iberian Peninsula[C]. EEGS (European Section) Meeting , Barcelona, ,1998, 14 ～17.

[6] A. Legchenko, J.-M. Baltassat, Beauce A and. Bernard I. Nuclear magnetic resonance as a geophysical tool for hydrogeologists [J]. Journal of Applied Geophysics, 2002.

[7] Yaramanci U, Lange G and Hertrich M. Aquifer characterisation using Surface NMR jointly with other geophysical techniques at the Nauen/Berlin test site [J]. Journal of Applied Geophysics, 2002.

[8] Vouillamoz J M, Descloitres M, Bernard J, Fourcassier P and Romagny L. Application of integrated magnetic resonance sounding and resistivity methods for borehole implementation. A case study in Cambodia [J]. Journal of Applied Geophysics, 2002.

[9] Plata J and Rubio F. MRS experiments in a noisy area of a detrital aquifer in the south of Spain [J]. Journal of Applied Geophysics , 2002.

[10] Meju M A, Denton P and Fenning P. Surface NMR sounding and inversion to detect groundwater in key aquifers in England: comparisons with VES-TEM methods [J]. Journal of Applied Geophysics, v.50(2002)

[11] Supper R, Jochum B, Hübl G, Römer A and Arndt R. SNMR test measurements in Austria [J]. Journal of Applied Geophysics, v.50(2002).

[12] Portselan A A and Treshchenkov V V. 2002, Application of the NMR-tomography technique for groundwater investigations in Equatorial Africa: a case-history in Guinea [J]. Journal of Applied Geophysics .

[13] PAN Yu-ling, LI Zhen-yu, DENG Jing-u, ZHANG Bing. Application Examples of SNMR Detection Groundwater Method in Hydrogeological Investigations in China[C]. MRS – 2nd International Workshop, Orléans,France, 2003.

[14] LI Zhen-yu , PAN Yu-ling ,TANG Hui-ming , ZHANG Bing , ZAN Qu. Application of SNMR Method in engineering geology[C]. MRS – 2 ND International workshop , Orléans, France, 2003.

[15] Roy J. MRS-Determined aquifer pore-size distribution – Multi-exponential decay analysis[C]. In:Orléans, MRS – 2 ND International workshop , Orléans, France, 2003.

[16] Félix M. Rubio and Juan Luis Plata. MRS (Magnetic resonance sounding) survey in a detrital coastal aquifer incastellon[C]. MRS – 2nd International workshop, In: Orléans,France SPAIN, 2003.

Editor remark: This article is the winner of "The Honor Prize Cup for New Advanced CT & 3D Imaging, 2004", in the academic conference for CT & 3D Imaging,October,2004, Beijing.

本刊编者注：本文的项目，被评为"2004年度ＣＴ和三维成像新进展荣誉奖杯"获得者，为授予项目第二名（该奖杯是由中国体视学学会设立，为中国科学技术奖励工作办公室承认的）。

Biography of author: LI Zhen-yu, male, born in 1962. Senior engineer, engaged with geophysical research and MR-detection in Geosciences, in. China University of Geosciences.

E-mail: zhenyuli626@sohu.com