短文

大岗山水电站地震台网的地震监测能力研究①

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摘要:采用地脉动噪声法和 b 值曲线拟合法对四川大岗山水电站地震台网的最小监测能力进行了研究和对比,结果表明在重点监视区理论监测能力达到了 $M_L0.5$ 的要求,实际记录重点监视区完整性震级下限为 $M_L0.5$,达到了地震台网设计目标。

关键词: 大岗山水电站; 地震台网; 理论监测能力; 实际监测能力
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Study on the Monitoring Capability of the Seismic Network at the Dagangshan Hydropower Station

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Abstract: Located at the northern section of the NS-trending seismic tectonic zone at the border between Sichuan and Yunnan, the reservoir of the Dagangshan hydropower station is at the intersection of three seismic belts, Xianshuihe, Longmenshan, and Anninghe, which present a complex geological environment. The earthquake seismic network at the Dagangshan hydropower station is a dedicated small diameter minor earthquake monitoring network for hydropower station projects and consists of eight stationary monitoring sites located across the Luding county of Ganzi and the Shimian county of Yaan, Sichuan province. The monitoring sites are located at both sides of the Dadu river, around the dam, at the main reservoir area, and at the fault zones, in accordance with the identified key fault zones to monitor reservoir induced earthquakes, increase the precision of locating seismic events, and decrease the lower limit of seismic magnitudes detectable in the area. The theoretical minimum monitoring capability of the designed seismic network in the focused monitoring area is $M_L0.5$. Based on the velocity records, the displacements recorded by the W-A short period seismometer are emulated, and then the max. P-P and the corresponding period on the displacement waveform emulated are substituted into the formula for near earthquake magnitude to calculate the earthquake magnitude. For validation of the background noise of earth motion, the PSD per hour at each station and the *RMS* values in the range of 1～20 Hz are calculated based on the noise data randomly selected from the background noise of earth motion recorded in a 48-hr interval at the Dagangshan earthquake monitoring network and the mean *RMS* value is taken as the average background noise of earth motion. Taking the ratio of the maximum magnitude of the S wave to the background noise as the minimum lower limit for seismic velocity detection by the system, the calibration function value $R(\Delta)$ is calculated using the earthquake magnitude formula. The minimum earthquake magnitude recordable at each site for various epicentral distances is determined based on the $R(\Delta)$. For validation using the b-value curve fitting, the data for the earthquakes, recorded in the monitoring area for which the seismic sources have been determined, and the Gutenberg-Richter law are used, and the monitoring capability of the earthquake seismic network is validated using the deviation from the linear relationship between $\lg N(M)$ and M. A b-value curve is plotted on

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the basis of 585 located earthquakes in the range of $M_L = 0.0 \sim 4.0$ recorded from Mar to Sep, 2013 in the specified area. When the magnitude is below a certain value, the actual number of earthquakes recorded significantly deviates from the reference line, i.e, the total number of earthquakes recorded is less than the number indicated by the fitting curve, implying that the system doesn't record all the minor earthquakes that have a magnitude below that value, and the deviation value is established as the lower limit of the magnitude detectable by the monitoring system. The statistical analysis of the seismic data recorded indicates that when $M_L < 0.5$, the recorded value is significantly below the fitting line. Therefore, the lower limit of detection at the earthquake seismic network at the Dagangshan hydropower station is $M_L = 0.5$. The theoretical monitoring capability of the earthquake seismic network at the Dagangshan hydropower station is calculated based on the near earthquake magnitude formula and the Gutenberg-Richter law. The calculations show that the theoretical monitoring capability in the focused monitoring areas is in compliance with the $M_L 0.5$ requirements. The practical minimum magnitudes of completeness at $M_L 0.5$ are validated by the actual record, which fulfills the design objectives of the reservoir induced earthquake seismic network at the Dagangshan hydropower station.

Key words: Dagangshan hydropower station; seismic network; theoretical monitoring capability; practical monitoring capability

0　前言

大岗山水电站为大渡河干流规划 22 级方案的第 14 个梯级电站，上游与硬梁包电站（引水式）尾水相接，下游与龙头石电站水库相接，是典型的高山峡谷型高坝大库容水库。库区位于川滇南北向构造带北段，为 NS 向与 NW 向、NE 向等多组构造的交汇复合部位，新构造活动较强烈，地震地质背景复杂。为监测大岗山水电站的水库诱发地震，在库区建立了微震监测台网，本文对该地震台网的监测能力采用地脉动噪声法和 b 值曲线拟合进行研究。

1　大岗山水电站地质构造背景和地震台网监测范围

大岗山水电台库区位于扬子准地台和松潘—甘孜褶皱系两个一级大地构造单元的边界附近，坝址距磨西断裂约 4.5 km、距大渡河断裂约 4 km。水电站坝址区和库首段处于由磨西断裂、大渡河断裂和金坪断裂所切割的黄草山断块上，又在川滇菱形断块的东部活动边界上，同时坝区又处于鲜水河、龙门山、安宁河三大地震带的交汇部。磨西断裂与大渡河断裂是控制水库诱发地震的关键性断裂。磨西断裂由磨西经湾东到田湾一线分布在坝右岸，大渡河断裂由得妥加郡到挖角一带顺大渡河穿过库区。库区构造稳定性主要受磨西断裂影响，地震危险性主要受康定—磨西间 8 级潜在震源区和石棉 7 级潜在震源区的影响。在坝右岸的西油房断裂、庙子坎断裂、草科、田湾河什月河一带也是可能的诱发地震震中。

大岗山水库诱发地震台网分布在北纬 29.3°～29.9°，东经 101.9°～102.5°，涉及四川省甘孜州泸定县、雅安市石棉县境内 8 个固定监测台站，为水利水电工程专用小孔径微震监测台网。大岗山水库遥测地震台网重点监测的区域是：坝区附近以坝址为中心，向上游约 6 km 到雨洒河支库北西侧，向下游延伸约 5 km 到沙达子沟口一带；大渡河左岸由雨洒河口沿大渡河主库向北到库尾桃子坪一带长约28 km的河段；大渡河右岸由田湾河口到田湾河支库库尾的大发沟西侧，宽约 3 km，呈带状向北，沿磨西断裂经田湾乡、什月河坝，到湾东的银沟一带，向南至大石包，长约 18 km 的地段。

按照确定的水库诱发地震的关键性断裂和重点监视区，监测系统台站围绕大坝、主库区和上述断裂带在大渡河两侧展布，较为均匀地展布在这三个监视区中，以便在区域中有较高的定位精度和较低的震级下限，基本监测的目标是上述三区域 $M_L 0.5$ 以上地震。

2　大岗山水电站地震台网微震监测能力验证方法

台网微震监测能力是台网一项最重要的技术指标。这里采用了两种方式进行验证，一种方法是台网建成并投入观测后，使用台网较长时段的观测数据进行计算，并绘制出微震监测能力图；另一种方法是利用地震学家古登堡关于震级与频度的关系通过统计得出的结论予以验证[1-3]。震级测定采用将速度记录仿真成 W-A 短周期地震仪位移记录的方法，仿真后在位移记录波形上量取最大记录双振幅和相应的周期。使用近震震级公式计算 M_L 震级，式中 $R(\Delta)$ 为短周期地震仪使用的量规函数，大岗山水电站地震台网无台基改正值 C：

$$M_L = \lg \frac{A_{\mu EW} + A_{\mu NS}}{2} + R(\Delta) + C$$

2.1　地脉动噪声法验证监测能力

抽取连续大岗山地震台网 48 小时记录的地噪声观测数据，分别计算各台站每小时的噪声功率谱密度（PSD），在 1～20 Hz 范围内计算出 RMS 值，再取 RMS 平均值来表示台站的平均地噪声水平。以台站所配置设备的相关参数，计算出每个台站的实际观测动态范围。大岗山水电站地震监测台站的环境地噪声水平如表 1 所示。

台网地震监测能力取决于台网台站的台基噪声水平、台站布局和仪器系统灵敏度三个因素。当仪器系统确定后，台网理论地震监测能力依据台站实际记录的环境地噪声水平与台站布局来进行计算[4-5]。

选取最大 S 波振幅值与环境地噪声水平的比值作为系统观测的最低下限地动速度，利用震级计算公式求出量规函

数值 $R(\Delta)$。通过 $R(\Delta)$求出单台在不同震中距时可观测到的最小震级。以 4 个以上台站可同时观测到某一震级地震为标准，划定台网对该震级地震的监测区域。若区域内有 4 个以上台站能同时监测到某一震级地震，则该区域属于台网的该震级可观测范围[6-7]。利用表 1 的数据，通过计算、绘制出大岗山水电站水库诱发地震监测系统地震监测能力图(图 1)。

表 1 大岗山水电站地震台站地噪声表

Table1 Ground noise of the earthquake monitoring net on the Dagangshan hydropower station

序号	台站名称	UD/(m·s^{-1})	EW/(m·s^{-1})	NS/(m·s^{-1})	平均值/(m·s^{-1})
1	小马场	3.99E-08	5.86E-08	3.86E-08	4.57E-08
2	扁路岗	7.53E-09	9.92E-09	7.41E-09	8.29E-09
3	火草坪	5.48E-08	6.27E-08	9.41E-08	7.05E-08
4	草科	1.39E-08	2.08E-08	1.78E-08	1.75E-08
5	安家湾	3.31E-08	6.10E-08	5.78E-08	5.06E-08
6	竹麻场	6.49E-08	8.39E-08	7.34E-08	7.41E-08
7	新兴	2.81E-08	4.55E-08	2.85E-08	3.40E-08
8	难田湾	3.52E-08	4.46E-08	3.90E-08	3.96E-08

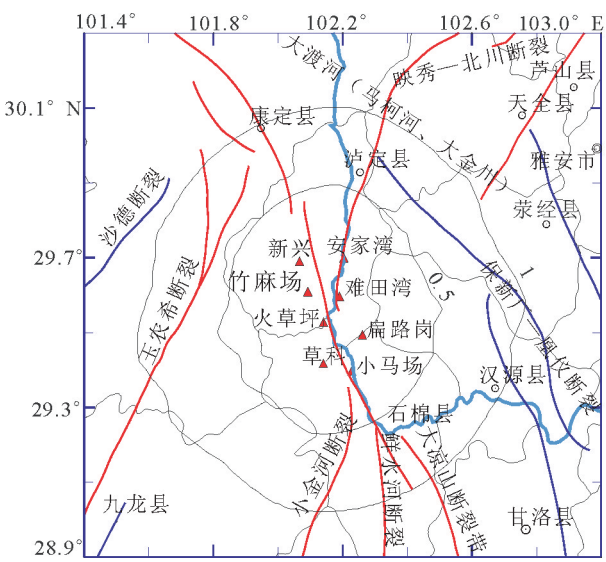

图 1 大岗山水电站地震台网监测能力图

Fig.1 Monitoring capability of the earthquake monitoring net for the Dagangshan hydropower station

2.2 *b* 值曲线拟合法验证监测能力

大岗山水电站地震台网的实际微震监测能力是否达到可定位震级下限为 $M_L \geqslant 0.5$ 的预期设计值，可利用台网监测区域实际观测到的已定位地震，引用古登堡—里克特公式来验证：

$$\lg N(M) = a - bM$$

式中 $N(M)$为某一地区指定时段内已发生地震的某个震级 M 分段内的地震数目。该公式表明，在自然界所发生地震中，小于某震级的地震事件数的自然对数与震级呈线性关系。b 值可能因地区不同而不同，也可能因是前震序列或余震系列而不同。

这里利用 $\lg N(M)$与 M 的线性关系的偏离来验证台网监测能力。使用台网对指定地区内实际的已定位地震来绘制该曲线，当震级低于某个值时，实际观测记录的地震数目与拟合直线发生明显偏离，即实际观测记录的地震数目低于拟合直线应有的地震数目，这表明台网不能完全观测到该区域内低于此震级的小震而有所遗漏，此偏离点则定为台网可定位震级的下限。大岗山水电站地震台网在 2013 年 3 月至 9 月期间记录到的 0.0～4.0 级 585 次地震 *M-T* 图见图 2，震中分布见图 3。

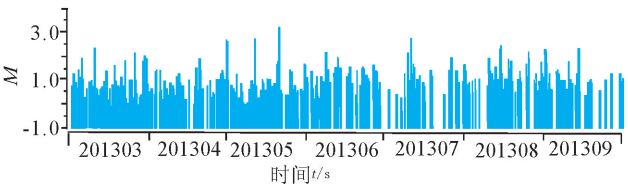

图 2 大岗山台网 2013 年 3 月至 9 月 *M-T* 图

Fig.2 *M-T* diagram from March to September, 2013, recorded by the Dagangshan net

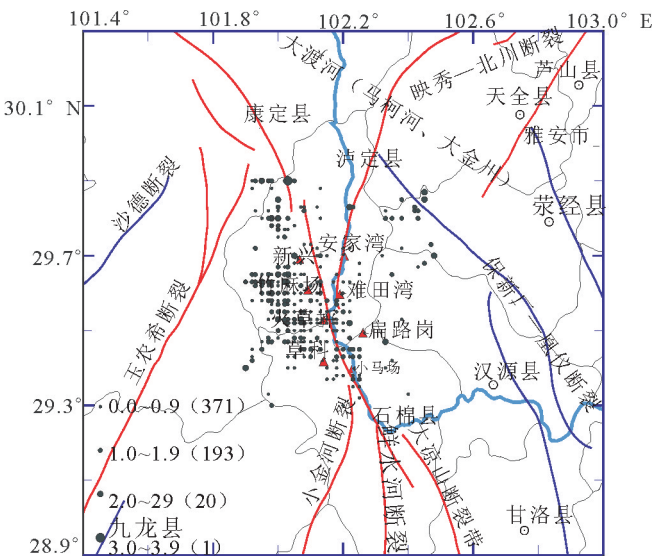

图 3 库区 2013 年 3 月至 9 月震中分布图

Fig.3 Epicenter distribution from March to September, 2013, in the power station area

当 $a = 3.133\ 1$，$b = 0.956\ 7$ 时，$\lg N = 3.133\ 1 - 0.956\ 7\ M$。拟合的 $\lg N$-M 直线见图 4 所示。可见当 $M_L \geqslant 0.5$ 时观测值以直线为轴心分散在其两侧，而 $M_L < 0.5$ 时观测值明显低于拟合直线。由此可以判定大岗山水电站地震台网重点监视区域可定位地震震级下限已达到 $M_L = 0.5$。

3 结论

从采用台网实际观测噪声计算和 b 值曲线拟合两种方法，对大岗山台网的监测能力进行计算和研究的结果来看，在重点监测区域内可定位地震震级下限满足 $M_L 0.5$ 的指标，达到总体设计要求。

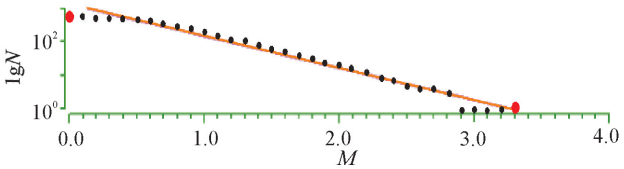

图 4　大岗山地震台网监测区域 lg*N*-*M* 图

Fig.4　lg*N*-*M* diagram in the Dagangshan hydropower station area recorded by the Dagangshan seismic monitoring net

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