Characteristics Analysis of Multi-Directional Geo-Electric Field Observation Data in FengNing Area

Rui Yan [1*], Lanwei Wang [1], Guiyun Song [2] and Shizhong Zhang [1]
[1]*Institute of Crustal Dynamics, China Earthquake Administration, Beijing 100085*
[2]*The Water Conservancy Bureau in the West Coast New Area of Qingdao, Qingdao 266400*
Email: yanxiaoxiao_best@163.com

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Abstract: Based on the experimental data of multi-directional geo-electric field observation in FengNing station, the time series trend, periodic characteristics and correlation of different direction data are carried out in this paper. The results show that: 1. There are not obvious regular temporal characteristics in different measurement directions. The temporal changes in different direction are anisotropy. 2. The value of spontaneous electric field in different directions is different and has not obvious seasonal characteristics. The value of telluric field is similar in different direction, which is higher in summer and lower in winter. 3. Frequency-spectrum analysis suggests that the dominant period of telluric field is mainly 12 hours, 8hours, 24hours or 6hours. There is no obvious period of spontaneous electric field. 4. For spontaneous electric field, the correlation between different directions is best, while there is a good correlation between two opposite directions for telluric field. With the increasing of observational data number, the correlation will be worse.

1 INTRODUCTION

In the process of earthquake preparation, the changes of crustal media and seismogenic stress can cause the electrical variations of the crustal, which can change geo-electric field. So developing the observation and research on geo-electric field and exploring the geo-electric field variation characteristics and mechanism in the process of earthquake preparation are meaningful (Mao et al., 1999).

In the past, the geo-electric field observations were mainly used to find minerals and explore earth structure. In these 40 years, it is applied to the study on seismic precursor (Sun and Wang, 1984; Li et al., 2014). Before 1980s, the single-pole direction observation method was used in geo-electric field, which measured potential difference between two electrodes on a certain direction near the earth surface. In 1981, Varotsos, Alexopoulous and Nomicos put forward a method of seismic electrical signals (SES) to predict earthquake and the multi-pole distance observation of geo-electric field began to be used (Varotsos and Alexopoulous, 1984a; Varotsos and Alexopoulous, 1984b). Afterwards, the geo-electric field which is used to forecast earthquake evoked great repercussions in international academia (Varotsos and Alexopoulous, 1984a; Varotsos and Alexopoulous, 1984b; Qian and Zhao, 2005). Since 1990s, the digital geo-electric field observation technology based on ZD9/ZD9A instruments has been developed in China. At present, there are more than 100 digital geo-electric field observation stations all over China, which has covered main structural belt, earthquake-prone area and key monitoring area (Ma, 2008; Xi et al., 2016).

According to different field sources, the geo-electric field can be divided into telluric field and spontaneous electric field. The telluric field is a varying field caused by various field sources outside the earth; the spontaneous electric field is a stable field formed by various physical and chemical interactions underground. The geo-electric field observed by ZD9A in fact has these two parts, namely the telluric electric field and spontaneous electric field (Qian and Lin, 1995). In most stations of 100 stations in China, there are only two (orthogonal) observation directions. This observation method cannot reflect accurately the characteristics of spontaneous electric field, such as its locality and anisotropy.

In order to have a better exploration on the characteristics of spontaneous electric field and

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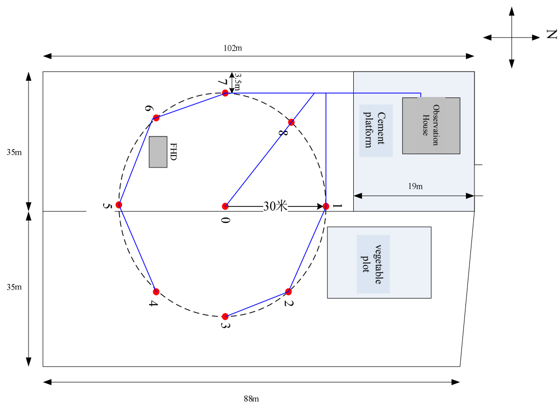
telluric field, researchers started to try multi-directional Geo-electrical field observation, that is, the electrodes are laid out in multi-direction. The gradient changes of spontaneous electric potential in each direction (at least 8 directions) can be recorded synchronously. The variation in each measuring direction with time changing is gathered. The preliminary characteristics such as diurnal and frequency spectrum are also studied using the data (Xi et al., 2013).

In this paper, the experiment data of geo-electric field in multi-direction observed in FengNing station is presented. The long time series trend, periodic characteristics and correlation of different direction data is studied, which help to further explore the characteristics of the spontaneous electric field and the telluric field observation data.

2 EXPERIMENTAL DATA

The multi-directional geo-electric field observation tests were carried out from 2012 using the GEF-1 observation system consisting of GEF-1 instrument and LGB-1 solid non-polarizable electrode. There are 26 measurement channels. The geo-electric field in multi-directional can be observed. The frequency band is 0~0.005Hz. There are 9 observation points including 8 observation directions and the central standard observation point (Figure 1). In the eight directions, three electrodes are buried in each electrode pit; each electrode is connected with the electrode 1 in electrode pit 0. Each direction has three measurement values, and the three measurement values can be inspected each other in order to ensure the accurate electrode observation. So there are measurement data from 24 channels. There are also three electrodes in pit 0. The electrode 1 is the main electrode, which is also linked with the other two electrodes in pit 0. Both potential differences between electrodes 1 and 2 and between electrodes 1 and3 are measured so as to test whether the central electrode1 in pit 0 works normally or not.

The sampling rate is 60s. One data file is obtained every day including 26 channels of data records where the former 24 channels of data are difference value between the three electrodes in each pit and electrode 1 in central pit 0; The 25th and 26th channels of data are the potential difference between electrodes 1 and 2 and between electrodes 1 and 3 in central electrode pit (pit 0), respectively.



electrode problems.

3 DATA ANALYSIS

3.1 Long Trend Characteristics of Time Series

At present, it is hard to distinguish the spontaneous electric field from the telluric field. According to the standard "The Method of Earthquake-related Geo-electrical Monitoring and Geo-electric Field Observation" and the tests to the various parameters, the method of 'five days' moving average is selected to get the spontaneous electric field data (Qian and Lin, 1995). Figure 2 shows the time series of original observation data in two consecutive years, the five days' moving average (spontaneous potential) and the telluric field observation data from the eight directions in the multi-directional geo-electrical field.

The data in directions of north and south, east and west, northeast and southwest, northwest and southeast of the original observation are all in the opposite directions. Their diurnal variations show the typical opposite trends, while the opposite trends are not found in their long time series. The possible reason may be that, in addition to the diurnal variations, many other elements have influenced the long time series. So, the general trend of long time would not be completely opposite and it is not like the diurnal variation curve, which has the simple elements and shows the opposite trend.

For the original observation data, the time series of the different observation directions show the different trends, but a similar fluctuation can be seen at the same time in each direction. There are many glitches in the observation data from the direction of north, south, southwest, southeast and northwest, which means that exist high frequency interference; while there are less glitches in the observation data from the direction of northwest, east-west and west, which means they have less high frequency interference. We think that the reason of these situations is related to the electrode embedment and the environment, such as some contamination to electrodes.

From the time series, the 'five days' moving average value, which is on behalf of the spontaneous electric field, show the same evolutionary trend with the original observation data. Due to the different position of electrode embedment, the spontaneous potential is different in each direction.

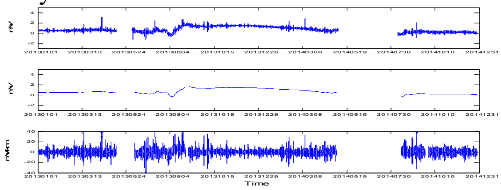
There are no obvious seasonal characteristics in original data and the spontaneous electric field. The values vary greatly in different directions. Figure 3 shows an azimuthal map of data gathered in the eight directions during two consecutive months, evidencing the anisotropy of the field. This is consistent with Mota et al.'s results (Mota et al., 2004), in which the authors used the same approach but with vertical electrical sounding to detect electrical anisotropy in 8 directions over a fractured rock mass.

As for the calculated telluric electricity field, the data in each direction are stable. The diurnal variation has higher values in the middle of the year while has the lower values in the beginning and in the end of the year (Cui, 2013).

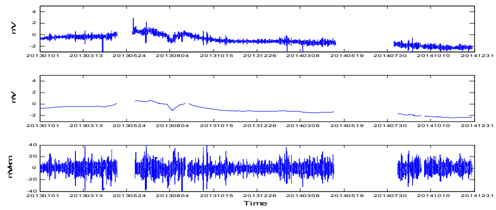
3.2 Periodic Characteristics

The periodic characteristics and amplitudes of the original data, the calculated telluric field and spontaneous electric field for two consecutive years were presented on Tables 1 to 3.

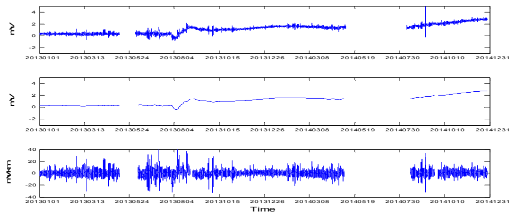
The telluric field in the eight directions display mostly a 12-hour period, followed by 8 hours period and 24 hour period (Table 1), which is consistent with previous studies (Du et al., 2006). The spectrum values of dominant periods in different direction are different. The telluric field data in the south, southwest and southeast directions have larger values which are influenced by the high frequency elements, while the values of other directions are relatively close.



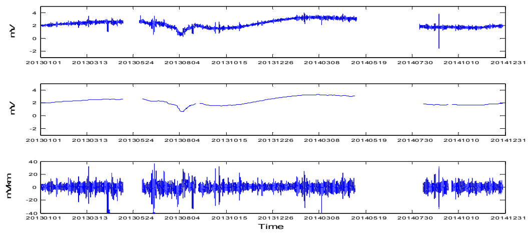
(a) North (Pit. 1)



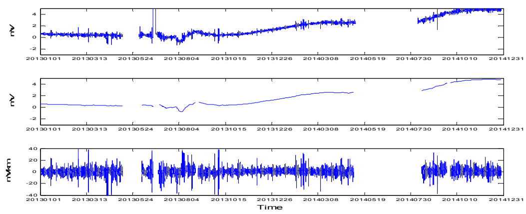
(b) South (Pit. 5)



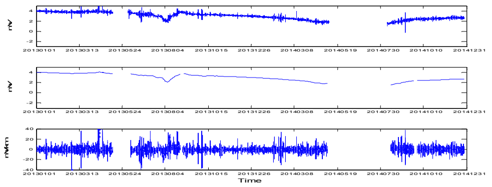
(c) Northeast (Pit. 2)



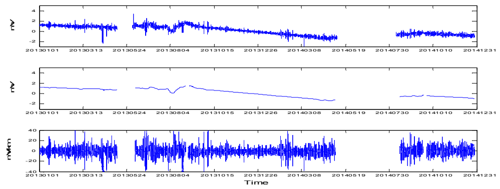
(d) Southwest (Pit. 6)



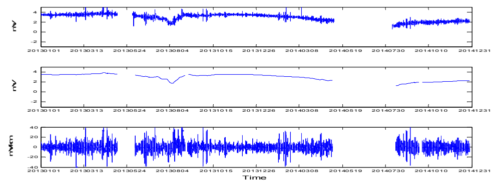
(e) East (Pit. 3)



(f) West (Pit. 7)



(g) Southeast (Pit. 4)



(h) Northwest (Pit. 8)

Figure 2: Results of the Spontaneous Electric Field and Telluric Field from the Eight Directions. (From the top to the bottom respectively are the original observation data, spontaneous potential and the telluric field).

The dominant periods of the original observation data are mainly 8 hours, followed by 12 hours, 24-hour and 6-hour period (Table 2). In addition, there are longer periods for the special directions such as 30 days and 19 days, which may be related to fluctuation of observation data or their long period elements. The observation directions with the long-period observation data have the larger amplitude of the dominant frequency.

In Table 3, the periods of calculated spontaneous electric field are mainly 580 days and 290 days, which are the close to one-year or two-year long period. However, the data are wrong during May, 2013 and May to August, 2014 due to the abnormal equipment. After eliminating the abnormal data, the number of the data which has been calculated is 580. Obviously, the calculated period of spontaneous electric field in Table 3 is related to the number of the data which has been calculated. The periodic result only is caused by the number of data calculated, not the real period. Therefore, it shouldn't be a correct period conclusion. From Figure 2, we can see that there is no obvious regular tendency in long time series. So, for the time series which have no tendency, it is no sense to calculate its period by FFT.

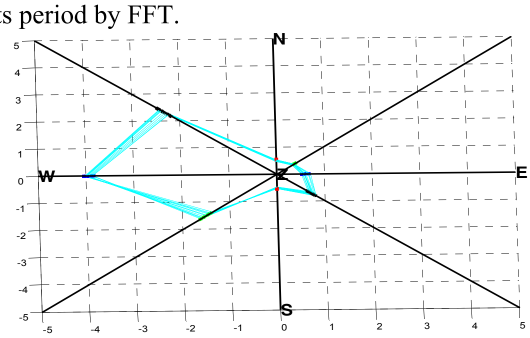


Figure 3: Spontaneous electric field data directions in **FengNing** station topological graph.

Table1. Observation data period and the dominant frequency amplitude of the telluric field.

Period (h)	N Pit 1	S Pit 5	NE Pit 2	SW Pit 6	E Pit 3	W Pit 7	SE Pit 4	NW Pit 8
1	8/0.80	12/1.51	12/0.96	12/1.04	12/0.79	12/0.64	24/1.17	8/0.73
2	12/0.77	24/1.19	8/0.77	8/0.9	12/0.73	8/0.61	12/1.04	12/0.72

Table2: Periodic characteristics of the original observation data and the dominant frequency amplitude.

Period (h)	N Pit 1	S Pit 5	NE Pit 2	SW Pit 6	E Pit 3	W Pit 7	SE Pit 4	NW Pit 8
1	8/0.022	**59d/0.033**	8/0.021	8/0.020	**30d/0.025**	8/0.015	8/0.019	30d/0.031
2	6/0.014	8/0.030	24/0.017	12/0.013	8/0.015	12/0.012	**19d/0.014**	8/0.021

Table3: Periodic characteristics of original observation data in spontaneous potential and the dominant frequency amplitude.

Period (h)	N Pit 1	S Pit 5	NE Pit 2	SW Pit 6	E Pit 3	W Pit 7	SE Pit 4	NW Pit 8
1	580/0.54	580/0.92	580/0.78	290/0.69	570/1.87	580/0.72	580/1.02	290/0.62
2	290/0.29	290/0.43	290/0.40	580/0.33	285/0.72	290/0.45	116/0.22	580/0.55

3.3 Correlation between Different Directions

The stable observation data are selected to calculate the telluric field and the spontaneous electric field. And the correlation between the different directions is analyzed, as shown in Table 4 to 6.

From Tables 4 to 6, the spontaneous electric field has the best correlation between each direction. Because, as it was already mentioned, the spontaneous electric field is a stable field formed on the earth surface by underground physical and chemical processes, which commonly has limitations (Qian and Lin, 1995). Therefore after removing most of the telluric field with periodic changes from original data, the spontaneous electric field accounts a large part, which is more influenced by the regional environment. This is the reason of best correlation between data in short time.

From Table 5, we can see that each two opposite directions of the 8 measurement directions, namely directions 1 (north) and 5 (south), directions 2 (north east) and 6 (south east), directions 3 (east) and 7 (west), and directions 4 (south east) and 8 (northwest), have the best correlation separately. This shows that the telluric field in the same direction is more consistent, the trend is closer.

With the increasing of data, the correlation of each pair of directions become weak, that shows that the long time series observational data of geo-electric field will be mixed with more and more other components. So, the correlation will be weak and the changes are anisotropy. This may also be one of the reasons why we cannot get the characteristics of long-time series of geo-electric field observational data.

Table 4. Correlation of spontaneous electric field data between different directions.

	1	2	3	4	5	6	7	8
1	1.0000	0.1602	-0.0045	-0.0393	-0.5052	-0.5411	0.7210	0.5676
2	0.1602	1	0.9578	0.8823	-0.8032	-0.7828	0.6133	0.7997
3	-0.0045	0.9578	1.0000	0.9588	-0.8069	-0.7855	0.5815	- 0.7190
4	-0.0393	0.8823	0.9588	1.0000	-0.8098	-0.7899	0.6289	0.5797
5	-0.5052	-0.8032	-0.8069	-0.8098	1.0000	0.9959	-0.9179	-0.8043
6	-0.5411	-0.7828	-0.7855	-0.7899	0.9959	1.0000	-0.9376	-0.8123
7	0.7210	0.6133	0.5815	0.6289	-0.9179	-0.9376	1.0000	0.7451
8	0.5676	0.7997	0.7190	0.5797	-0.8043	-0.8123	0.7451	1.0000

Table 5: Correlation of the telluric field data between different directions.

	1	2	3	4	5	6	7	8
1	1.0000	0.4063	-0.4722	-0.8424	-0.9211	-0.5990	0.5144	0.7592
2	0.4063	1.0000	0.5317	0.0528	-0.4513	-0.8229	-0.4281	-0.0965
3	-0.4722	0.5317	1.0000	0.8327	0.3750	-0.2796	-0.8978	-0.7906
4	-0.8424	0.0528	0.8327	1.0000	0.7724	0.2187	-0.7992	-0.909
5	-0.9211	-0.4513	0.3750	0.7724	1.0000	0.7255	-0.4343	-0.7169
6	-0.5990	-0.8229	-0.2796	0.2187	0.7255	1.0000	0.2509	-0.1179
7	0.5144	-0.4281	-0.8978	-0.7992	-0.4343	0.2509	1.0000	0.8867
8	0.7592	-0.0965	-0.7906	-0.9097	-0.7169	-0.1179	0.8867	1.0000

Table 6: Correlation of the original observation data between different directions.

	1	2	3	4	5	6	7	8
1	1.0000	0.4585	-0.4849	-0.8020	-0.7934	-0.5566	0.6116	0.7532
2	0.4585	1	0.4552	-0.0017	-0.5221	-0.7174	-0.1281	0.1045
3	-0.4849	0.4552	1.0000	0.8608	-0.1268	-0.3030	-0.6018	-0.5833
4	-0.8020	-0.0017	0.8608	1.0000	0.4494	0.0547	-0.6069	-0.7620
5	-0.7934	-0.5221	0.1268	0.4494	1.0000	0.8709	-0.6783	-0.7322
6	-0.5566	-0.7174	-0.3030	0.0547	0.8709	1.0000	-0.3170	-0.3673
7	0.6116	-0.1281	-0.6018	-0.6069	-0.6783	-0.3170	1.0000	0.8714
8	0.7532	0.1045	-0.5833	-0.7620	-0.7322	-0.3673	0.8714	1.0000

4 CONCLUSIONS AND DISCUSSION

The obvious regular long trends in all eight directions are not found in original data, calculated spontaneous electric field and calculated telluric field observed in FengNing station (Figure2). After quality inspection, all observation data can be classified as normal. They are the objective reflex of geo-electric field in FengNing area, and the time series long trend show anisotropy, which is consistent with results obtained by Mota et al. (Mota et al., 2004). About the geo-electric field characteristics during calm period, Mogi et al. (Mogi et al., 2000) have also studied the short-term and the long-time variation of electric field. Short-term electric field variations were found to correspond mainly to geomagnetic activity, while long-term variation was mostly gradual shift and was clearly uncorrelated to precipitation and to ground water level variations (Mogi et al., 2000).

From Figure 2 and 3, the amplitude of original data and spontaneous electric field in 8 directions is different. The telluric field in the middle of year is high and is low in the beginning and by the end of the year. The observation values in different directions are nearly the same. These results are consistent with the present research results (Qian and Lin, 1995; Xi et al., 2013). In addition, Zhang et al. (Zhang et al., 2012) think that the differences in electric field variation amplitude and shapes between different stations and among ground observing data reflect the different response process at stations with different underground electromagnetic structures and the response mechanism to current system in lithosphere. The direction of anomalies may be affected and controlled by regional stress state and the strikes of fault belts (Zhang et al., 2012). Li et al. (Li et al., 2014) researched the abnormal variations of geo-electric field observed at three stations in the Shanghai area and found that data in even very close three stations can vary greatly. They pointed that the huge differences of curve shape, amplitude and phase are caused by different electrical properties under the stations (Li et al., 2014). The different laying way of the electrode, and the different distance between the electrodes are other reasons, which is also mentioned by Mogi et al. (Mogi et al., 2000). So, the amplitude and shape of data in different stations may be different due to the local Earth's surface, the underground layer conductivity, and also the electrode. It is also why there is or is not annual variation in long time series of geo-electric field.

The regular diurnal variations of telluric field can be recorded using the multi-direction observation. The dominant period of the original data and telluric field is mainly 12, 24, 8 or 6 hours, which is in accordance with the results of the previous researches (Ye, 2006). Ye (Ye, 2006) studied the spectrum characteristics of geo-electric diurnal variation based on data from stations in China, which showed that in geo-electric diurnal variation, the amplitude of the 12 h semidiurnal wave is the largest, followed in turn by the 24~25h diurnal wave and the 8 h periodic wave (Ye, 2006). In general, the diurnal variation and its frequency represent the telluric electric field part in the data, which is homogenous with the ionospheric electric field and is correlated with the daily geomagnetic fluctuation (Qian and Lin, 1995 ; Mogi et al., 2000; Ye, 2006). However, the spontaneous electric field is in a slow evolutionary process, there is no obvious period found from two years data so far.

The spontaneous electric field is a stable electric field formed on the Earth's surface by the underground medium under the effect of physical and chemical processes, so the correlation is better between different directions. For the telluric field, there is a good correlation between two opposite directions. With the increasing of observational data amount, the correlation will be worse, showing that the long time series of all directions are gradually anisotropic.

The geo-electric field characteristics of experimental data in multi directions in FengNing station was presented in this paper. The results of calculated spontaneous electric field and the telluric field in FengNing station are basically consistent with the ones in theory. However, there are still some phenomena that are not very consistent with the theoretical basis, such as the telluric field that didn't display obvious seasonal variation, except on the amplitude, which has high value in summer and low value in winter. In fact, the telluric field is caused by Sq current system. The long-term seasonal and solar cycle variability and significant day-to-day variability in the Sq current system are found as early as 1960 (Hasegawa, 1960). The main reason may be that there are a variety of other components in the actual observation data, besides the spontaneous electric field and the telluric field, even undetected interference components in data quality assessment. Therefore, sometimes the objective processing result of the observation data cannot fully reflect the real characteristics of the spontaneous electric field and the telluric field. Further research is necessary in the following aspects: continue to accumulate reliable data, select further better quality data and eliminate more interference comprehensively. More statistical analysis and phenomenon accumulation are necessary and meaningful.

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