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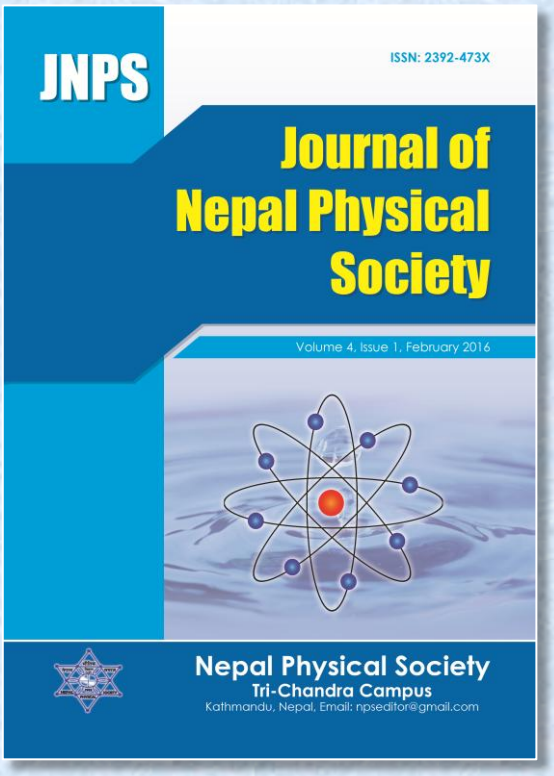

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Research Article

Features of Ground Flashes before and after the Massive Earthquake Observed from Kathmandu, Nepal

Pitri Bhakta Adhikari
Central Department of Physics, Tribhuvan University, Kirtipur, Nepal
Corresponding Email: pitribhakta_adhikari@hotmail.com

ABSTRACT

Lightning electric field signatures pertinent to the subtropical thunderstorms occuring over the rugged terrain have been measured and recorded at a hilly station Kathmandu, Nepal. In the present work signatures of the ground flashes have been selected from all the records before and after the massive earthquake and were analyzed. It is the first time that such signatures were analyzed and presented. Two hundred and eight flashes (208) of the totals of six hundred and forty–five (645) flashes were selected from about eight thunderstorm days before and after the massive earthquake and analyzed. Majority of the positive ground flashes were found to be single stroke ones whereas the average number of strokes per flash is found to be 1.13 with a maximum value of 4, after the massive earthquake.

Keywords: Positive and negative lightning, Massive earthquake, Electric field signatures of Lightning.

INTRODUCTION

Lightning positive ground flashes, that in general transport the positive charge from the cloud to the ground, occur very rarely. Of all the cloud to ground flashes, the positive ground flashes account for about 10% (Rakov and Uman, 2003). Considering the tripole structure of a thundercloud, the paucity of the positive ground flashes can easily be justified. However, the charge structure of the cloud still remains a mystery. Because of the paucity of their occurrence, positive ground flashes are considerably less studied and hence less understood as compared to their negative counterparts (Nag and Rakov, 2012).

According to Williams (1989), the lightning activity itself follows a specific pattern with the intracloud (IC) lightning normally appearing in the developing stage followed by the cloud-to-ground (CG) lightning during the mature stage, whereas, both types of lightning can occur in the decaying stage of thunderstorms. Lightning in thunderstorms is strongly linked to the microphysics and dynamics of thunderstorms and, hence, changes in the lightning activity can tell us about changes in the internal processes within the thunderstorms (Price, 2008; Qie *et al.*, 2013). Positive ground flashes are of much interest to the lightning community because of their possible association with the upper atmospheric discharges, such as sprites, and due to the magnitude of current possessed by them. The positive ground flashes may also be related to the severe weather phenomena such as tornadoes, hails, derecho etc.

The atmospheric structure and hydrometeorological processes along the south slopes of the Himalayas are not well known or well documented mainly because of the rugged and remote terrain (Barros and Lang, 2003). The hydrometeoroloical processes over the rugged terrain, development of the thundercloud, its charge structure and the signatures of lightning flashes are of much interest to the scientific community. Monitoring the lightning activity over Kathmandu and its vicinity for 21 months, Baral and Mackerras (1993), found the average proportion of positive ground flashes to the total ground flashes to be 0.28.

Signatures of the lightning electromagnetic field pertinent to the subtropical mountainous country Nepal are of much interest to the scientific community as the rugged terrain and high hills may influence the occurrence and the nature of the lightning strikes on the period of before and after the massive earthquake.

EXPERIMENTAL SETUP (INSTRUMENTATION AND MEASUREMENT)

The lightning electric fields were recorded at a measuring station in Kathmandu, Nepal, which is situated at $27^0$44'N; and $85^0$19'E; and about 1300 m height above the sea level. Two hundred thirty-

six positive and sixteen negative strokes have been recorded from the measuring station and analysed. The vertical electric fields of the flashes were sensed by the flat plate antenna fixed on a 1.5 m high post and was placed on the rooftop of a house at a physical height of about 12 m from ground. The parallel plate of capacitance 60 pF was connected to a buffer circuit through a 60 cm long RG 58 coaxial cable. The signal passing through buffer amplifier was fed to the digital storage oscilloscope (Pico-scope 6404D) through a 20 m long RG 58coaxial cable. The signals so received were recorded by the pico-scope whose window size was varied from 200 – 500 ms at different sampling rate of 40 – 312 MS/seconds. A schematic diagram of the antenna and recording system that has been used in this study is adopted from Sharma *et al*. (2008).

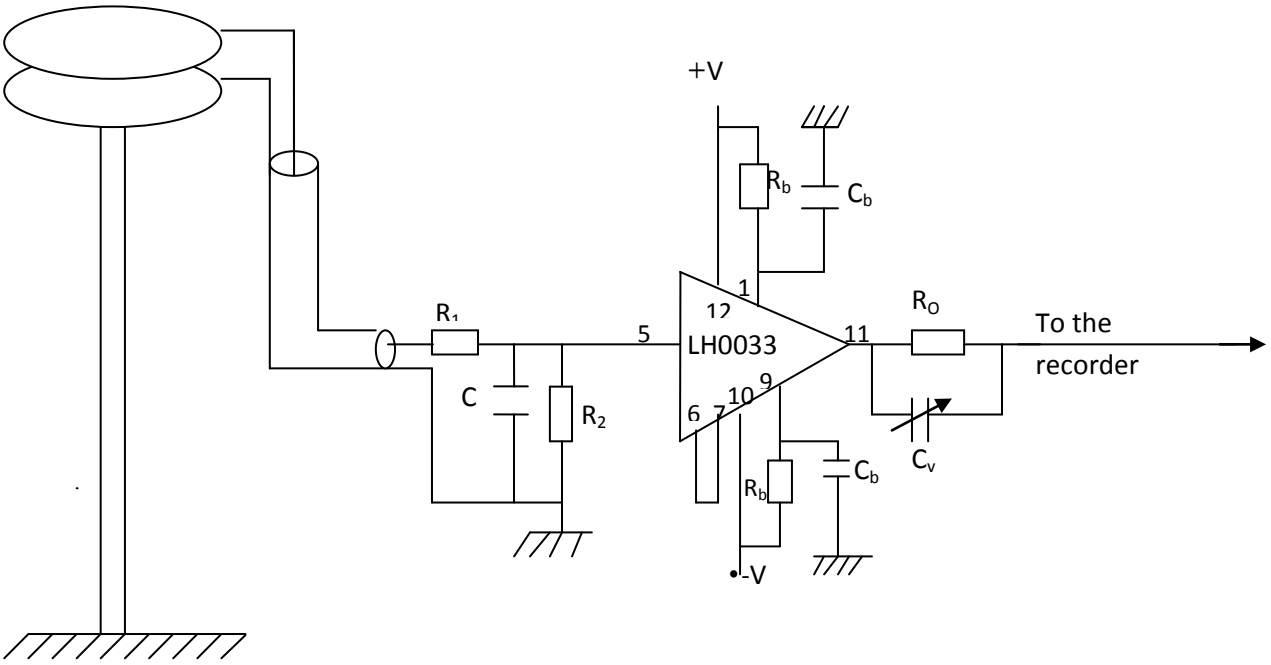


Fig. 1. The parallel plate antenna and the buffer circuit used for the electric field.

OBSERVATION

Electric fields generated by the lightning flashes were recorded during the pre – monsoon 2015. A total of two hundred and eight positive and sixteen negative ground flashes were recorded and analyzed. Most of the positive ground flashes were found to have single strokes, however, some of the positive ground flashes consisted of two or more than two return strokes but in negative ground flashes have only single strokes. The data acquired on the different days of March, April and May 2015, and analysed in the study are depicted in the table 1. As is depicted in table 1, a total of six hundred and forty-five lightning flashes were recorded on different eight days of pre-monsoon, out of which two hundred and eight strokes were observed to be positive where as sixteen only observed to be negative ground flashes.

We have studied the various conceptual cloud charges leading to production of positive lightning with a view towards an explanation of its observed properties. Data for fifty-seven (57) cloud to ground flashes in which sixty-four (64) positive strokes were observed within the month of March and April before the earthquake. One hundred fifty-one cloud to ground flashes in which one hundred seventy two positive strokes were recorded after the earthquake of large magnitude of 7.6 rector scale on 25th April, magnitude of 6.8 rector scale on 26th April, magnitude of 6.9 rector scale on 12th may. Within the period of twenty-four (24) days,(April 25 to may 18) two hundred forty two (242) times recorded the earthquake of magnitude above four rector scale. The data of one hundred seventy-two positive strokes within the period of earthquake were recorded on the date 2015-05-11 and 16 as shown in Table 1.

We measured the electric field, rise time, zero-crossing time and field width at half maximum (FWHM) of the data presented here in Kathmandu, Nepal. The electric field sensor consisted of a circular flat-plate antenna followed by a buffer circuit. We have recorded cloud to ground flashes on the different day of March, April and May 2015 as shown in Table 1 below.

Table 1: Cloud to ground flashes on the different day of March, April and May 2015.

Before Earth quake	Total recorded flash	Total Flash containing Return Stroke		Cloud and other flashes	Total positive R.S
		Positive	Negative		
2015-03-30	50	26	5	19	29
2015-03-31	1	1	0	0	1
2015-04-12	20	13	0	7	14
2015-04-15	48	1	8	39	1
2015-04-16	104	6	3	95	8
2015-04-17	70	10	0	60	11
Total	293	57	16	220	64
After Earth quake					
2015-05-11	132	76	0	56	82
2015 -05-16	220	75	0	145	90
Total	352	151	0	201	172
Grand total	645	208	16	421	236

Out of two hundred and eight positive ground flashes, one hundred and eighty five flashes were found to have single strokes where as nineteen flashes have two strokes, three flashes have three strokes, and single flash have four strokes. Table 2 depicts the occurrence of the positive ground flashes on different days along with their multiplicity.

Table 2: Occurrence of positive ground flashes on different thunderstorm days along with their multiplicity.

Date of flash	3-30	3-31	4-12	4-15	4-16	4-17	5-11	5-16	Total
No of flash	26	1	13	1	6	10	76	75	208
Flash containing									
1 RS	23	1	12	1	4	9	72	63	185
2 RS	3	0	1	0	2	1	3	9	19
3 RS	0	0	0	0	0	0	0	3	3
4 RS	0	0	0	0	0	0	1	0	1
Total no of strokes	29	1	14	1	8	11	82	90	236

BEFORE EARTHQUAKE

We have recorded two hundred ninety three total flashes within the month of the March and April 2015, before earthquake. Among them the fifty seven cloud flash were taken in which sixty-four positive return strokes and sixteen negative return strokes were recorded. We have measured the rise time (t_r), Zero crossing time (t_z), field width at the half –maximum (FWHM) and amplitude of the waves which are the basic parameter of the waves. Before the Earth-quake, fifty seven positive ground flashes were recorded in which sixty four positive

strokes and sixteen flashes containing sixteen negative strokes were analyzed. These are expressed also in the Table 1.

On these fifty Seven Ground flashes containing sixty four positive strokes, the analysis has been done. For the analysis the arithmetic mean, Geometric mean, Median, Maximum value, Minimum value, Range, correlation coefficient, Standard Deviation, Variance of the parameter etc. of the parameter rise time, Zero crossing time, FWHM, amplitudes of the waves were found. The average of the rise time is 10.15 μs, in which G. M. is 7.96 μs. The average of zero-crossing time is 32.30 μs and G. M. is only 24.31 μs. The average of FWHM is 15.38 μs but G. M. is only 11.82 μs. Similarly, the mean amplitude of the wave is 567.32 mV but the G.M. is only 448.75 mV.

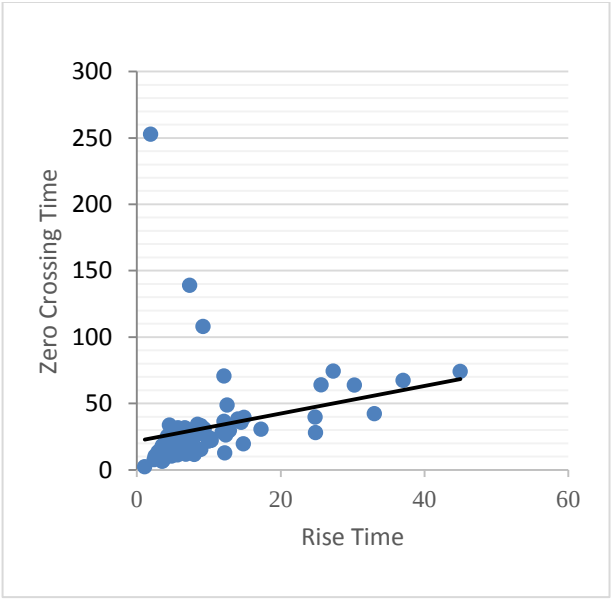
On these data, the rise time varies from 1.08 μs to 44.97 μs. So the range is 43.89 μs. Similarly, the zero-crossing time varies from 2.35 μs to 252.8 μs whose range is 250.45 μs. The FWHM varies from 1.3 μs to 63.70 μs, so the range is 62.40 μs. The amplitude of the waves varies from 103.1 mV to 2949 mV having range 2845.9 mV. The standard deviation of the rise time is 8.28 μs and the standard deviation of zero-crossing time, FWHM and amplitude are 34.13 μs, 12.35 μs and 491.76 mV respectively. These data are summarized in the following table 3.

Table 3: Statistics of different parameters for positive return strokes before the earthquake.

	Rise time(t_r)	**Zero-crossing time(t_z)**	**FWHM**	**Amplitude**
Average	10.15	32.30	15.38	567.32
G. M.	7.96	24.31	11.82	448.75
Max	44.97	252.8	63.70	2949
Min	1.08	2.35	1.30	103.1
Range	43.89	250.45	62.40	2845.9
Median	7.48	24.85	12.45	406.7
S. D.	8.28	34.13	12.35	491.76
Correlation Coefficient	R_{12} R_{13} R_{14}	0.25	0.52	0.15
	R_{23} R_{24}		0.52	0.04
	R_{34}			0.03

The correlation coefficient between the rise time and zero-crossing time is 0.25. The correlation coefficient between rise time and FWHM is 0.52 and correlation coefficient of rise time and amplitude is 0.15. The correlation coefficient between zero-crossing time and FWHM is 0.52 which is the same as the correlation coefficient between rise time and FWHM. The correlation coefficient of amplitude with zero-crossing time and FWHM are 0.04 and 0.03 respectively. This relation of amplitude is very weak with zero-crossing time and FWHM.

From the above data, the relation of amplitude with zero-crossing time and FWHM is very poor. The relation of FWHM with zero-crossing time and rise time is same. These relations of the parameters are also shown in figure 2 below.



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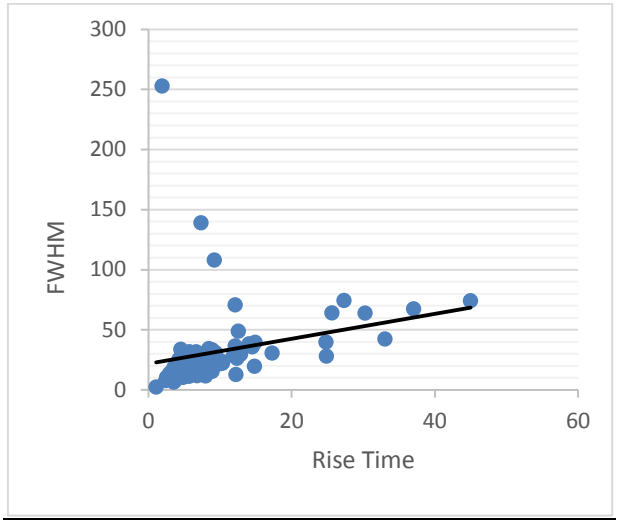

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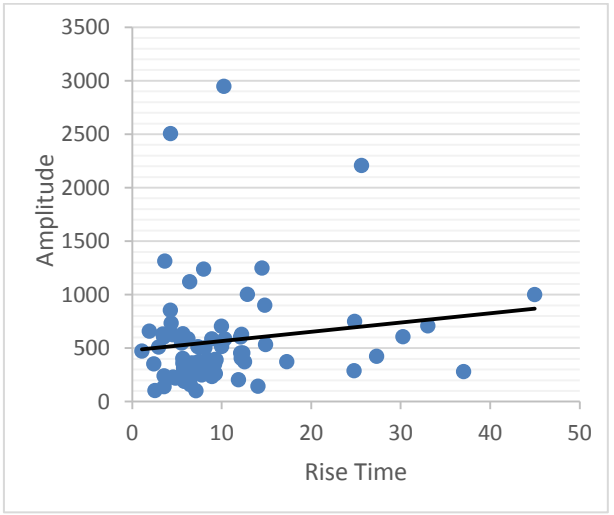

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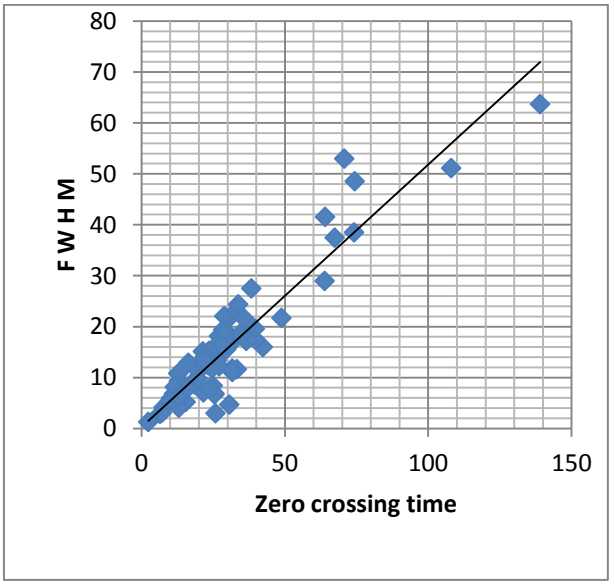

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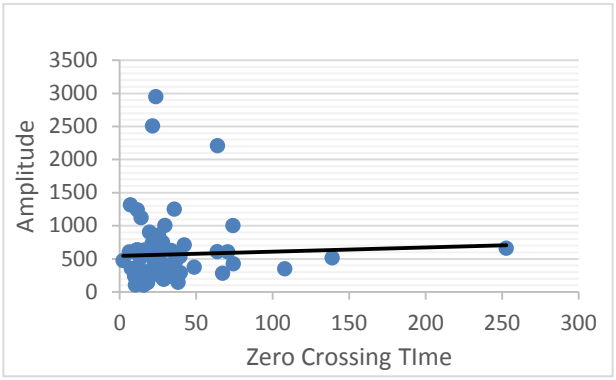

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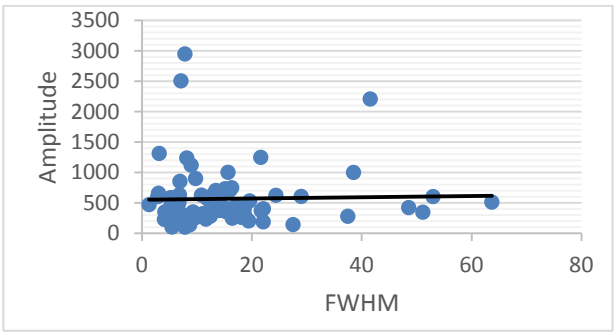


(f)

Fig. 2. Graph of the parameters of positive flashes before the earthquake (a) Rise time vs zero-crossing time (b) Rise time vs FWHM (c) Rise time vs Amplitude (d) Zero-crossing time vs FWHM (e) Zero-crossing time vs Amplitude (f) FWHM vs Amplitude.

***(Note:** The value of correlation coefficient(r) is interpreted as, if r is less than 0.2, the correlation is very weak. If r is greater than and equal to 0.2 and less than 0.4, the correlation coefficient is weak. If r is greater than and equal to 0.4 and less than 0.6, the correlation coefficient is moderate. If r is greater than and equal to 0.6 and less than 0.8, the correlation coefficient is good. If r is greater than 0.8, the correlation is very good. However, the value of r^2 is preferred for more precise analysis and is called coefficient of determination.)*

Similarly, for the negative strokes of 16, the same rise time, zero-crossing time, FWHM and amplitudes were taken and average, G.M., median, standard deviation etc. of them are calculated.

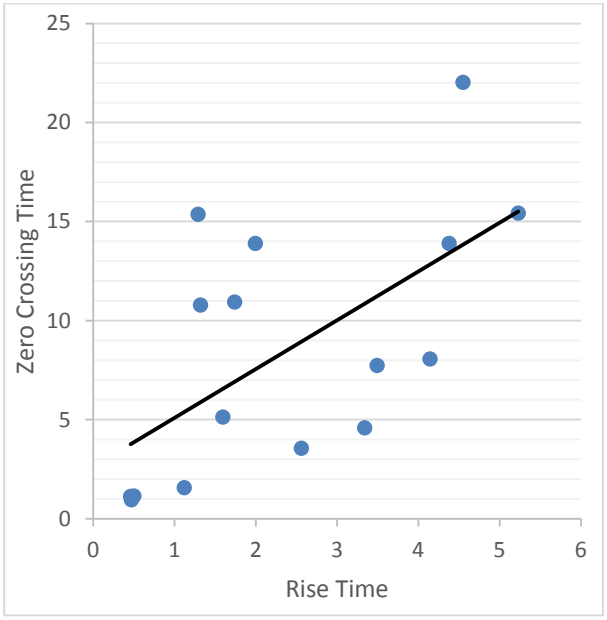
The average of the rise time is 2.39 μs, in which G.M. is 1.82 μs. The average of zero-crossing time is 8.51 μs and G.M. is only 5.68μs. The average of FWHM is 4.94 μs but G.M. is only 2.54μs. Similarly, the mean amplitude of the wave is 179.2 mV but the G.M. is only 136.04 mV.

The standard deviation of the rise time is 1.54μs and the standard deviation of zero-crossing time, FWHM and amplitude are 6.19 μs, 4.26 μs and 137.56 mV respectively. These data were depicted in the following table 4.

Table 4: Statistics of different parameters for negative return strokes.

	Rise time(t_r)	**Zero-crossing time(t_z)**	**FWHM**	**Amplitude**
No. of strokes	16	16	16	16
Average	2.39	8.51	4.94	179.2
G.M.	1.82	5.68	2.54	136.04
Median	1.87	7.89	4.42	127.85
Standard Deviation	1.54	6.19	4.26	137.56
Correlation coefficient		0.61	0.58	0.20
			0.84	0.59
				0.23

The correlation coefficient between the rise time and zero-crossing time is 0.61. The correlation coefficient between rise time and FWHM is 0.58 and correlation coefficient of rise time and amplitude is 0.2. The correlation coefficient between zero-crossing time and FWHM is 0.84 which is very strong. The correlation coefficient of amplitude with zero-crossing time and FWHM are 0.59 and 0.23 respectively. From the above data, the relation of amplitude with rise time and FWHM is very poor. These relations of the parameters are also shown in figure 3.



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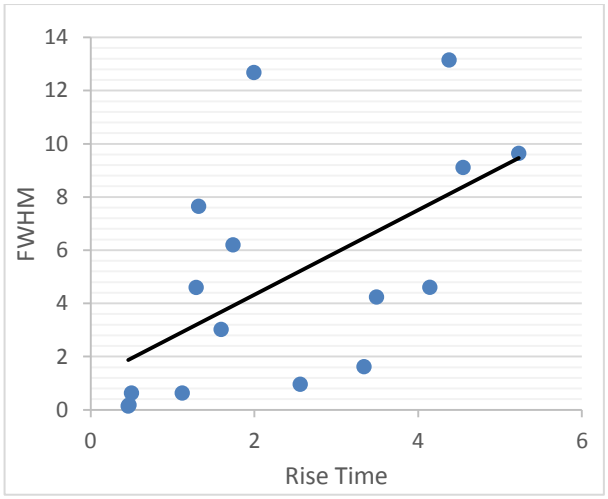

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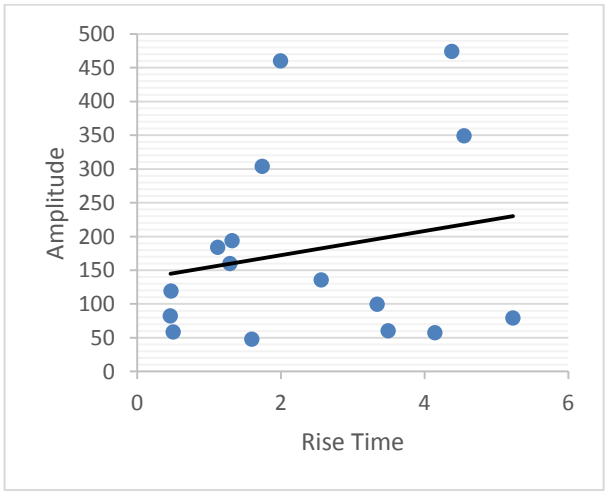

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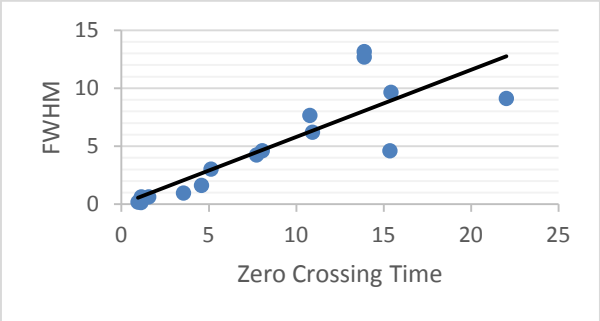

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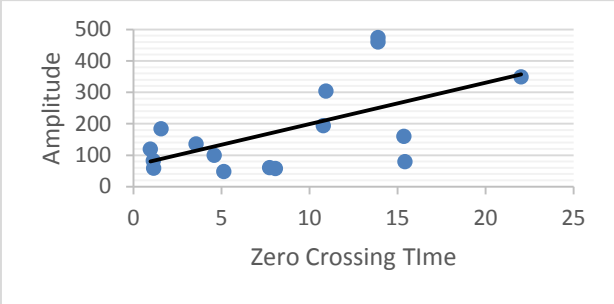

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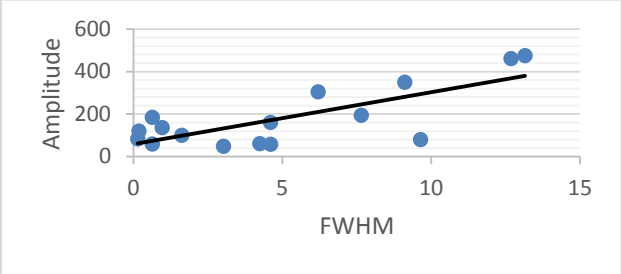


(f)

Fig. 3. Graph of the parameters: (a) Rise time vs zero-crossing time (b) Rise time vs FWHM (c) Rise time vs Amplitude (d) Zero-crossing time vs FWHM (e) Zero-crossing time vs Amplitude (f) FWHM vs Amplitude.

AFTER EARTHQUAKE (DURING EARTHQUAKE)

We have recorded three hundred fifty-two total flashes on the 11th and 16th of the May 2015, after the massive earthquake. Among them one hundred fifty one flashes were taken in which one hundred seventy-two positive return strokes were recorded. The multiplicities of the strokes are mentioned in table 2. We have measured the rise time (tr), Zero crossing time (t_z), field width at the half –maximum (FWHM) and amplitude of the waves which are the basic parameter of the waves. After the Earth-quake, these one hundred fifty one flashes were taken in which one hundred seventy-two positive return strokes were analyzed. These are expressed also in the Table-1. For the analysis the arithmetic mean, Geometric mean, Median, Maximum value, Minimum value, Range, correlation coefficient, Standard Deviation, Variance of the parameter etc. of the parameter rise time, Zero crossing time, FWHM, amplitudes of the waves were found. The average of the rise time is 7.14 μs, in which G.M. is 5.42 μs. The average of zero-crossing time is 29.97 μs and G.M. is only 20.46 μs. The average of FWHM is 10.36 μs but G.M. is only 7.56 μs. Similarly, the mean amplitude of the wave is 424.91 mV but the G.M. is only 258.6 mV.

On these data, the rise time varies from 0.12 μs to 31.17 μs. So the range is 31.05 μs. Similarly, the zero-crossing time varies from 0.28 μs to 360 μs whose range is 359.72μs. The FWHM varies from 0.17μs to 42.96μs, so the range is 42.79μs. The amplitude of the waves varies from 79.05 mV to 3452 mV having range 3372.95 mV. The standard deviation of the rise time is 4.57 μs and the standard deviation of zero-crossing time, FWHM and amplitude are 31.48 μs, 6.55μs and 430.5 mV respectively. These data are summarized in the following table 5.

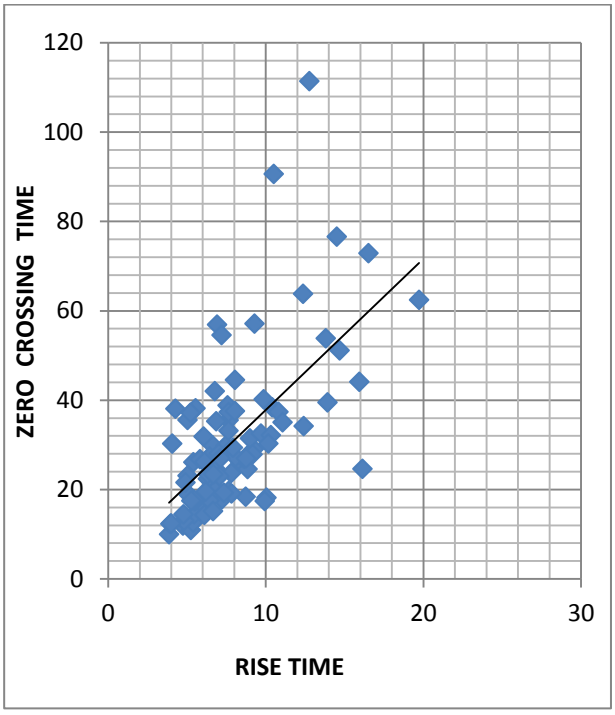
Table 5: Statistics of different parameters for positive return strokes after earthquake.

	Rise time(tr)	Zero-crossing time(tz)	FWHM	Amplitude
Number	179.00	179.00	179.00	179.00
AVERAGE	7.14	29.97	10.36	424.91
G MEAN	5.42	20.46	7.56	258.60
MEDIAN	6.48	25.88	9.87	346.40
MAXIMUM	31.17	360.00	42.96	3452.00
MINIMUM	0.12	0.28	0.17	79.05
RANGE	31.05	359.72	42.79	3372.95

STD	4.57	31.48	6.55	430.50
VARIANCE	21.00	996.85	43.17	186370.93
CORRELATION R12,R13,R14		0.48	0.63	0.33
Correlation R23,R24			0.68	0.30
Correlation R34				0.21

Fine structures of each stroke were analyzed and different parameters were studied. Possible relation among those parameters was sought. The flashes were analyzed for duration of the stroke, rise time, FWHM, relative amplitude, etc. The correlation coefficient between rise time and zero-crossing time isfound to be .048 means that the correlation coefficient between rise time and zero-crossing time is moderate. Similarly, correlation coefficient between rise time and FWHM is found to be 0.63 which is good. Furthermore, the correlation coefficient between rise time and amplitude is found to be 0.33 which is moderate. However, the correlation coefficient between zero-crossing time and FWHM is found to be .068 which is good, but, the correlation coefficient between amplitude and zero-crossing time is found to be 0.3 which is again moderate whereas the correlation coefficient between amplitude and FWHM is found to be .021 which is poor given in figure 4 below.

These relations of the parameters are also shown in graph:



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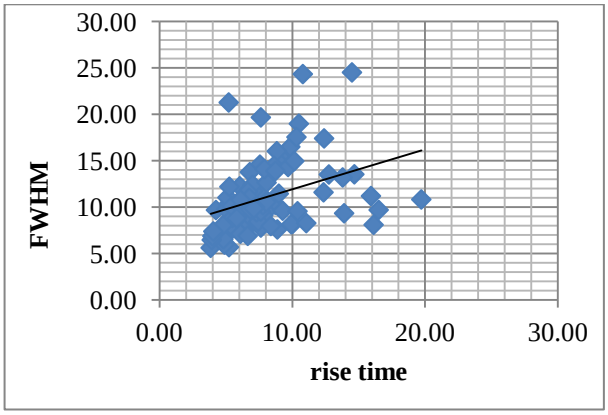

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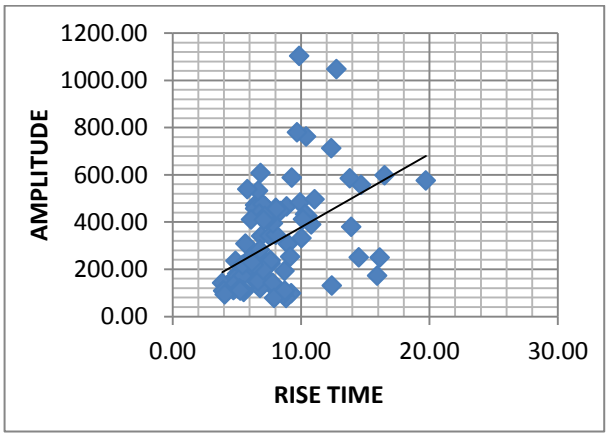

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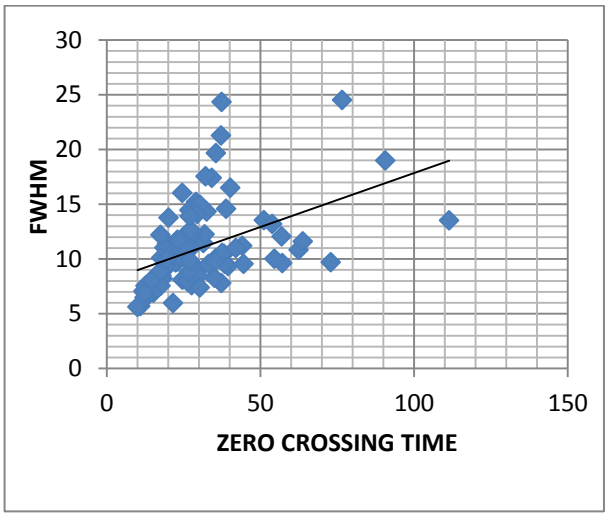

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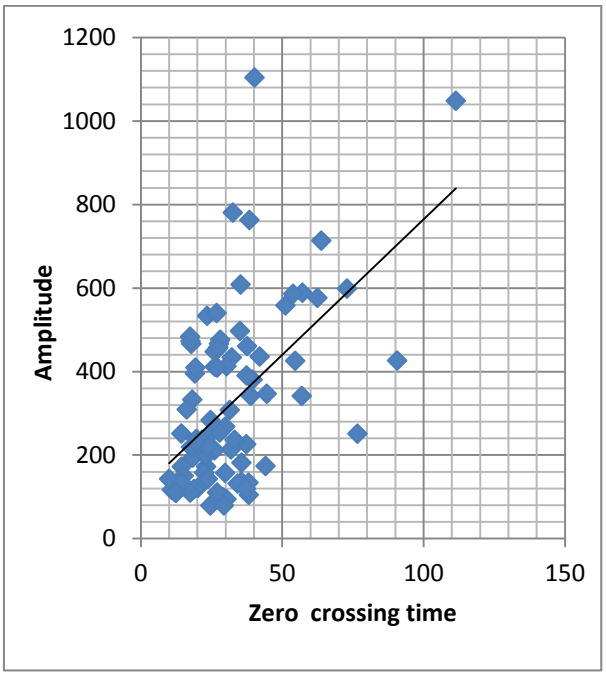

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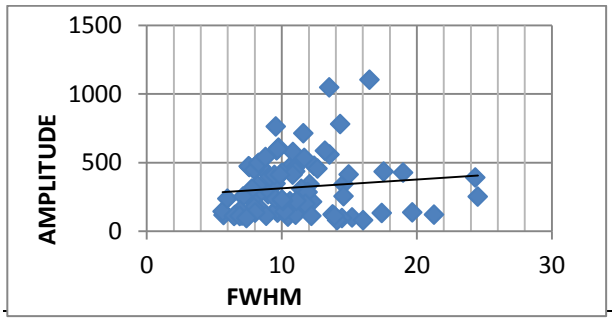

(f)

Fig. 4. Graph of the parameters: (a) Rise time vs zero-crossing time (b) Rise time vs FWHM (c) Rise time vs Amplitude (d) Zero-crossing time vs FWHM (e) Zero-crossing time vs Amplitude (f) FWHM vs Amplitude.

The examples of occurrence of lightning activity which is taken from the Google map is shown in figure 5 below.

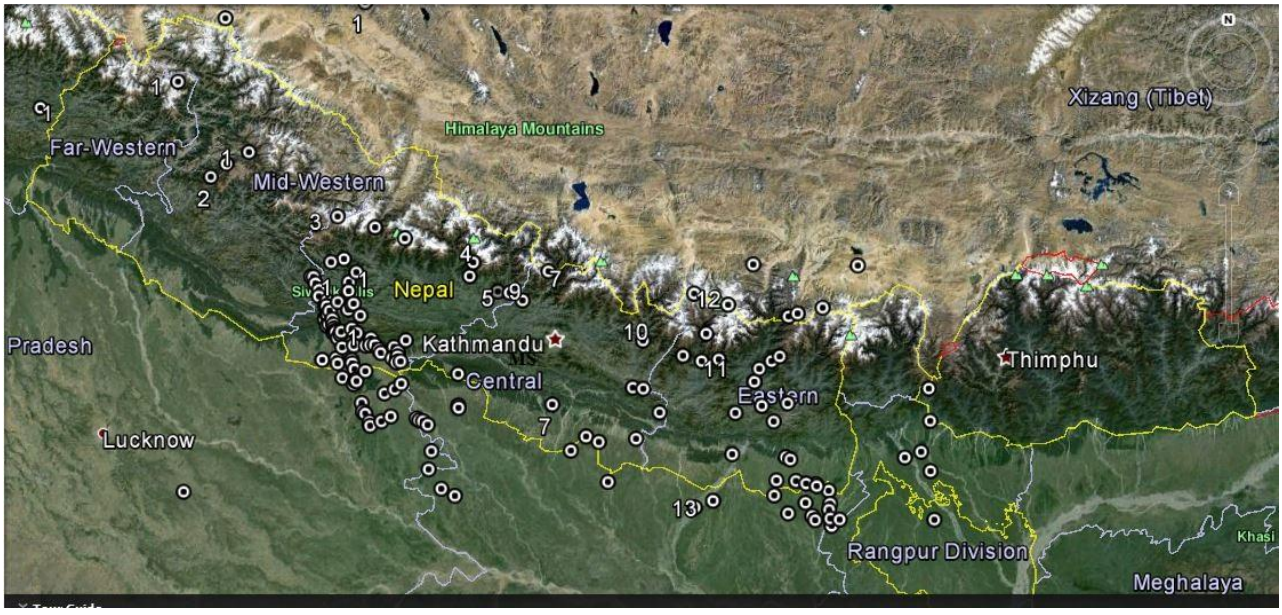

Fig. 5. Example of occurrence of lightning activity.

RESULTS AND DISCUSSION

In this present work six hundred forty-five flashes were recorded on eight thunderstorm days, in which two hundred and ninety three flashes were recorded before the earthquake and three hundred fifty-two flashes were recorded after the massive earthquake. Among them fifty seven flashes were positive and sixteen flashes were negative ground flashes before the earthquake but one hundred fifty one flashes were only positive flashes after the massive earthquake. Before the earthquake there were sixty four strokes of the fifty seven flashes having multiplicity 1.12 for positive ground flashes but for negative ground flashes, multiplicity is unity (i.e. sixteen strokes of sixteen flashes). After the massive earthquake there were one hundred seventy two strokes of the one hundred fifty one flashes having multiplicity 1.14 for positive ground flashes and there were no negative ground flashes recoded from this

measuring station Kathmandu, Nepal. These recorded data were mentioned in the table 1 and multiplicity were mentioned in table 2.These sixty four positive strokes before the earthquake and one hundred seventy-two positive strokes after the massive earthquake were recorded from Kathmandu, at an elevation 1300 m above the average sea level and these data were analyzed separately and mentioned in tables 3, 4, and 5.

Before the earthquake, fifty flashes were single strokes flashes and seven flashes were two strokes flashes where as one hundred thirty five flashes were single strokes flashes, twelve flashes were two strokes flashes, three flashes were three strokes flashes and single flash contain four strokes flash after the massive earthquake. These data are depicted in the following table 6 and compared in percentage.

Table 6: comparison of multiplicity before and after earthquake.

Flashes contain	**Before earthquake**		**After earthquake**	
	In number	**In percentage**	**In number**	**In percentage**
Single strokes	50	87.7	135	89.4
Two strokes	7	12.3	12	7.9
Three strokes	0	-	3	2
Four strokes	0	-	1	0.7
Total	**57**	**100**	**151**	**100**

The correlation coefficient between the rise time and zero-crossing time is 0.25 and 0.48 before and after the earthquake whereas the correlation coefficient between rise time and FWHM is 0.52 and 0.63 respectively. Similarly the correlation coefficient of rise time and amplitude is 0.15 and 0.33 before and after the earthquake whereas the correlation coefficient between zero-crossing time and FWHM is 0.52 and 0.68 which is good. The correlation coefficient of amplitude with zero-crossing time and FWHM are 0.04 and 0.03 respectively before the earthquake where as the values 0.3 and 0.21 respectively after the earthquake. This relation of amplitude is very weak with zero-crossing time and FWHM before the earthquake. These data are depicted in the table – 7.

Table 7: comparison of correlation coefficient of different parameters before and after earthquake

Correlation coefficient	R12	R13	R14	R23	R24	R34
Before earthquake	0.25	0.52	0.15	0.52	0.04	0.03
After earthquake	0.48	0.63	0.33	0.68	0.3	0.21

The average of the rise time is 10.15 μs before the earthquake but 7.14 μs after the earthquake.

Similarly average of zero-crossing time is 32.30 μs and 29.97 μs respectively before and after the earthquake. The average of FWHM is 15.38 μs and 10.36 μs respectively before and after the earthquake and similarly, the mean amplitude of the wave is 567.32 mV and 424.91 mV respectively before and after the earthquake. In this case average of all the values of rise time, Zero crossing time, FWHM and amplitudes are higher before the earthquake than after the earthquake. Similarly the standard deviations of the parameter before the earthquake are greater than the standard deviation of the parameter after the earthquake. The standard deviation of the rise time is 8.28 μs and 4.57 μs respectively before and after the earthquake the standard deviation of zero-crossing time, FWHM and amplitude are 34.13 μs, 12.35 μs and 491.76 mV respectively before and 31.48 μs , 6.55 μs, and 430.5 mV after the earthquake. These are depicted in the table – 8 below.

Table 8: Comparison of average and standard deviation of different parameter before and after earthquake

Average of	**Rise time**	**Zero crossing time**	**FWHM**	**Amplitude**
Before earthquake	10.15μs	32.3 μs	15.38 μs	567.32mV
After earthquake	7.14 μs	29.97 μs	10.36 μs	424.91 mV
S.D. of	Rise time	Zero crossing time	FWHM	Amplitude
Before earthquake	8.28 μs	34.13 μs	12.35 μs	491.76 mV
After earthquake	4.57 μs	31.48 μs	6.55 μs	430.5 mV

The examples of the signature for the positive and negative flashes are given in the following figure 6 and 7 respectively.

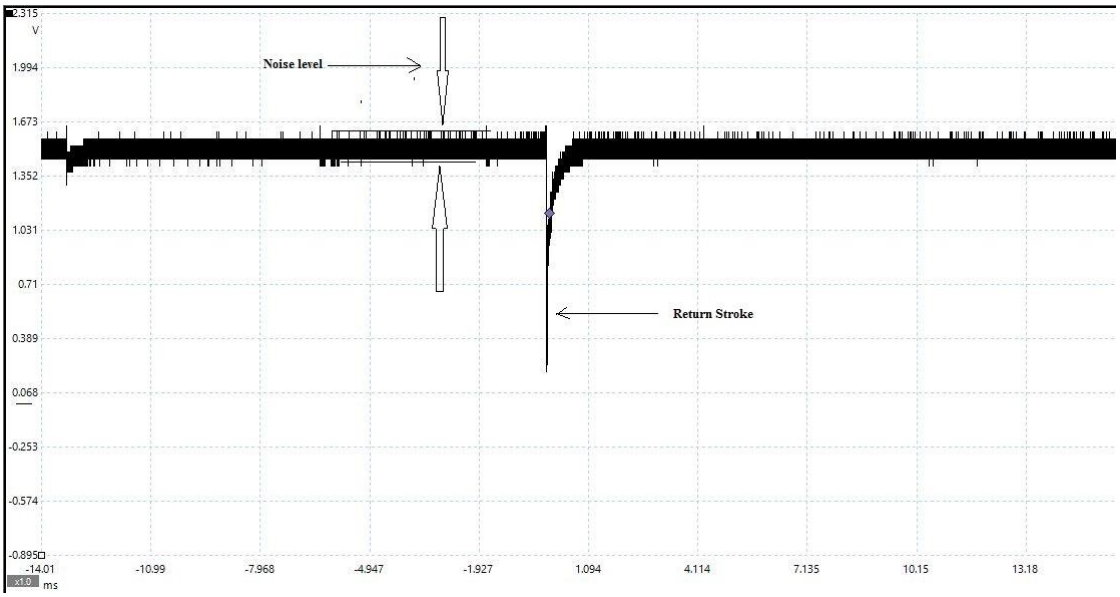

Fig. 6. Example of wave - signature for the positive flashes.

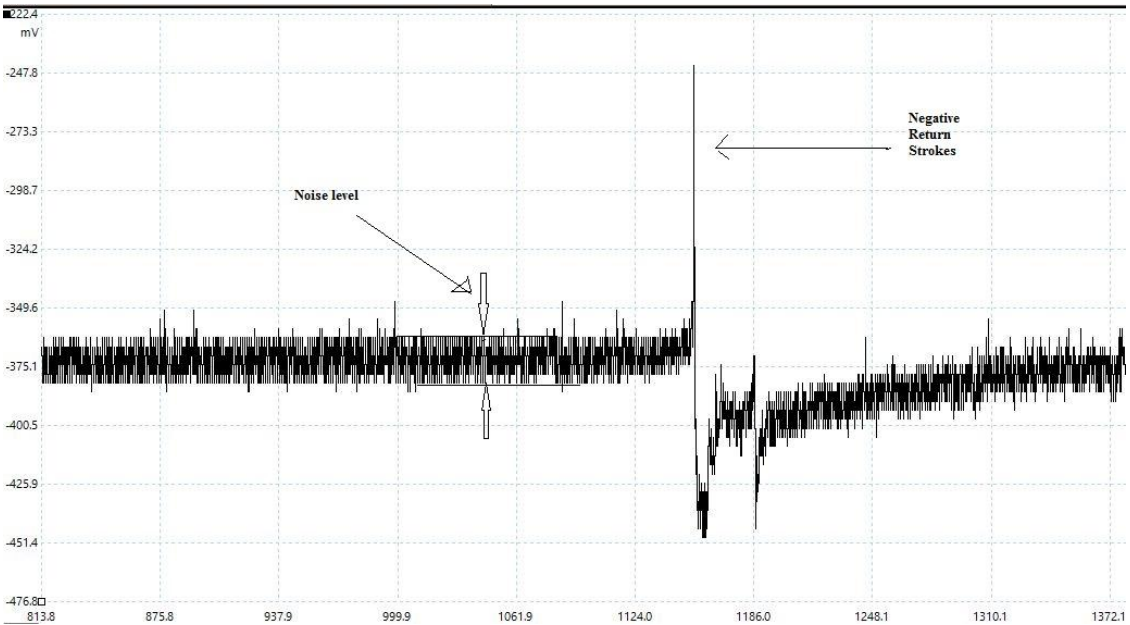

Fig.7. Wave - signature for the negative flashes.

CONCLUSION

The characteristics of fifty seven positive flashes and sixteen negative flashes before the earthquake and one hundred fifty one positive flashes after the massive earthquake were recorded at a measuring station in Kathmandu, (27^0 44'N, and $85^0$19'E) Nepal. The numbers of strokes per flash are 1.12 and 1.14 before and after the massive earthquake. Majority of the positive ground flashes were found to be single stroke ones whereas the average number of strokes per flash is found to be 1.13. The features of such flashes that occurred before and after the massive earthquake were separately analyzed and compared, however no significant difference could be observed.

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