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Vibrational Source Analyzing of the Earthquake of Haiti

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Abstract

In the recent years, one of the main issues in seismology and geophysics science is the vibrational analysis of the earthquake. The main contribution of this paper is to analysis of the inter-station horizontal magnetic responses and the vertical magnetic data of Haiti earthquake. An earthquake trembled Haiti and the Dominican Republic (Hispaniola Island) on Monday 12 January of 2010 with extent of MW = 7.1. Hispaniola is located in an active tectonic zone and the North American and Caribbean sheets strike site. The Caribbean sheet moving toward North American sheet has occurrence high extent earthquakes in different periods. There are two active sills with eastern western procedure and approximately 1000 Km length in Haiti. The surface center of 12 January's earthquake was happened on southern sill and by strikes lip mechanism. Vibrational analysis results demonstrate that, by studding aftershocks, the western side of earthquake's surface center is more active than the eastern side. Finally the effects of adding aftershocks are evaluated on earthquake analysis accuracy.

Keywords: Haiti, earthquake, vibration analysis, aftershock

1. INTODUCTION

Seismic events which are episodes of release of accumulated stress in the earth's crust can result in surface deformation which may be manifested in the form of surface rupture, subsidence and/or upliftment, depending on the sense of movement along the source structure. On Monday of January 12, 2010 at 16:53:10 local time and 21:53:10 GMT, an earthquake with magnitude of M=7.1 occurred in 15 km away from the center of Haiti. Two hundred and thirty thousand people were killed and more than hundreds of thousands people were injured owing to the earthquake. This was not the first earthquake in Haiti and Hipaniola Island, However this country has witnessed natural disasters such as floods, storms, earth slips and earthquakes over period of time (Alexander, 2010). Haiti is located in Central America. An earthquake with magnitude of Mw=7/1 hit this country at 16:53:10 on January 12 and caused a lot of financial losses. Due to this earthquake, nearly two hundred and thirty thousand people died. Governmental and infrastructural facilities and houses were damaged. Aspects of seismology have been considered from various angles in this article [1, 2].
Miyagiet et al. [3] used ALOS PALSAR data to derive the co-seismic deformation of the Solomon islands earthquake (2007). They also used the Differential Synthetic Aperture Radar (DInSAR) derived displacement values to derive the fault plane solution using elastic dislocation modelling. Chini et al. [4] used on-linear and linear and derived deformation of the Sichuan earthquake (China, 2008) for deriving the geometry and position of the fault parameters. A swarm of micro earthquakes occurred on October 31, 2009 within 5 km of the Sunset Crater, Arizona, volcano. A detailed study of the swarm was warranted because of its location near a young volcanic construct and its proximity to the population center of Flagstaff, Arizona. Analysis presented in [5] included swarm duration, frequency of events, b-value, focal depths and epicentral pattern of the swarm. Gan et al. [6] evaluated the characteristics of deep earthquakes in the northwestern Pacific plate and focus on three isolated clusters, particularly one directly beneath the seismic gap and northeast China.

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Seismic time series of the four most active Chilean zones, the country with largest seismic activity, are analyzed in [7] in order to discover precursory patterns for large earthquakes. Their Results verging on 70% on average are reported, leading to conclude that the methodology proposed is suitable to be applied in other zones with similar seismicity. Stramondo et al. [8] applied DInSAR technique for the Izmit earthquake (Turkey, 1999) in analyzing the coseismic displacement along the North Anatolian fault system and also inverted the deformation to derive the source dislocation. Lohman et al. [9] studied the fault mechanism of the Little Skull Mountain earthquake (Yucca Mountain, Nevada, 1992) by using finite dislocation model. Atzori et al. [10] used defined the geometric and kinematic characteristics of the seismogenic fault of the L'Aquila earthquake (Italy, 2009) through non-linear and linear inversion.

2. TECTONIC STRUCTURE OF HAITI

Haiti is limited to Dominican Republic from the East, and Cuba and Jamaica from the West, and North American plate from the North and Caribbean Sea from the South and is located in Caribbean tectonic plate from the North. Haiti is located in the boundary of North American and Caribbean plates and by and large it is part of the Caribbean plate which in simple conditions is part of the Earth's crust with great faults which has caused changes in geological structure of the area (Calasis and colleagues).

3. METHODOLOGY

3.1 Locating the Earthquake

The earthquake of Haiti on January 12, 2010 that happened at a depth of 13 KM and 25 KM away from the center of Haiti was located by geological organization of the U.S.A. Locating by the organization and locating by GMT software are indicated in figures 1 and 2.

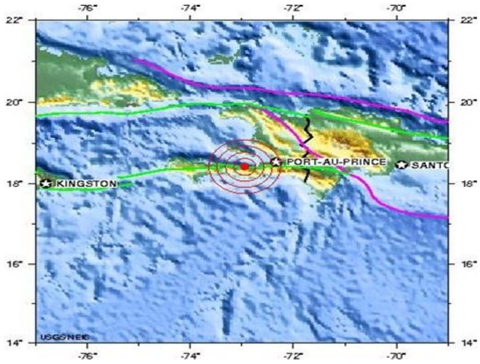

Fig. 1 Location of Haiti earthquake 12 usgs

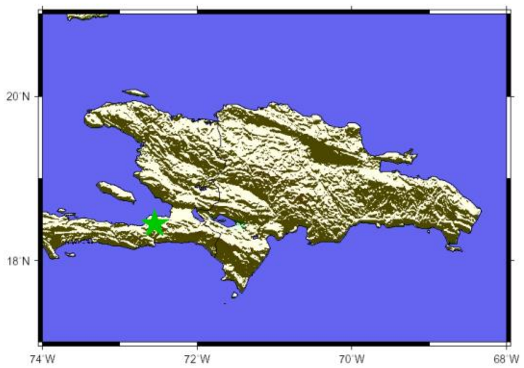

Fig. 2 Location of Haiti earthquake January 12 by GMT

3.6 Source Modeling

Seismic source modeling means modeling of seismographs to examine kinematic characteristics of an earthquake's source. However, current attempts to use other data (e.g. measurement of geodic deformations created due to the earthquake) and consider dynamics of the source in modeling make the abovementioned definition a bit difficult. An artificial seismograph is made by mathematical modeling of factors such as dispersion, source effects and seismograph characteristics.

By comparing an artificial and a real seismograph during repetition process, the difference between them can be minimized by adjustment of model parameters.

In this study, data of 14 stations were used for modeling based on Waren method. Characteristics of these stations are portrayed in table 1.

Table 1. Characteristics of stations data of which were used for studying the earthquake

Stn	shift	Inst	Mode	Comp	Az	B.Az	Del
II.ALE.00	0	1	1	1	1.5	-169.2	64.2
II.ASCN.00	0	1	1	1	109.4	-64.6	63.1
II.BFO.00	0	1	1	1	44.2	-84.0	70.5
II.BORG.00	0	1	1	1	23.3	-118.5	57.4
II.ESK.00	0	1	1	1	36.6	-96.1	63.3
II.FFC.00	0	1	1	1	-24.7	136.6	42.6
II.KDAK.00	0	1	1	1	-34.2	88.2	69.3
II.LVZ.00	0	1	1	1	21.5	-67.3	79.4
II.NNA.00	0	1	1	1	-171.8	7.9	30.5
II.OBN.00	0	1	1	1	32.8	-64.1	85.5
II.PFO.00	0	1	1	1	-59.9	99.9	41.9
II.RPN.00	0	1	1	1	-141.0	42.1	57.6
II.SACV.00	0	1	1	1	86.5	-78.6	46.9
II.SHEL.00	0	1	1	1	113.3	-65.0	74.1

In the first phase of source, we consider a point with triangular time function. After changing the time function variable, the failure time is 4 seconds, failure velocity is 3 km/h and raise time of 3 seconds gives the best fitting. An event presented in figure 9 happened in this phase and there is a good fitting between two wave forms.

Table 2. Performed modeling with a time event

```
                                 fort
 Hii earthquaker
 J-B model
   NT    DT      H0    Dip     Ne Type Shift
   160 0.500   15.0   85.0     1    1  -20
 Time Function : (Type,T1,T2) = 1   3.0   4.0
 Grid-search extent: V max =    4.0
 Time span at each iteration =  150.0
  # Time Location(r,phi,Y-axis)  Moment non.DC  Strike  Dip   Slip  Error
Step :  1
   1  17.5   30.0   90.0    0.0    9.749   0.000   86.2   20.0  141.4  0.7832
< Convergence >
        1  0.7832  ========================================
          Total                     9.75    0.00    86.2    20.0   141.4
          standard-deviation        0.96    0.91   -11.4    -0.1    -8.1
 Mw =    6.59
```

Stn	shift	Inst	Mode	Comp	Az	B.Az	Del	p	G	PV	fc
II.ALE.00	0	1	1	1	1.5	-169.2	64.2	0.059	5.980	0.38	1.00
II.ASCN.00	0	1	1	1	109.4	-64.6	63.1	0.059	6.060	0.38	1.00
II.BFO.00	0	1	1	1	44.2	-84.0	70.5	0.054	5.470	0.35	1.00
II.BORG.00	0	1	1	1	23.3	-118.5	57.4	0.064	6.500	0.42	1.00
II.ESK.00	0	1	1	1	36.6	-96.1	63.3	0.059	6.050	0.38	1.00
II.FFC.00	0	1	1	1	-24.7	136.6	42.6	0.073	7.610	0.47	1.00
II.KDAK.00	0	1	1	1	-34.2	88.2	69.3	0.055	5.540	0.36	1.00
II.LVZ.00	0	1	1	1	21.5	-67.3	79.4	0.049	4.760	0.32	1.00
II.NNA.00	0	1	1	1	-171.8	7.9	30.5	0.080	13.700	0.52	1.00
II.OBN.00	0	1	1	1	32.8	-64.1	85.5	0.045	4.020	0.29	1.00
II.PFO.00	0	1	1	1	-59.9	99.9	41.9	0.073	7.700	0.47	1.00
II.RPN.00	0	1	1	1	-141.0	42.1	57.6	0.064	6.490	0.42	1.00
II.SACV.00	0	1	1	1	86.5	-78.6	46.9	0.071	7.230	0.46	1.00
II.SHEL.00	0	1	1	1	113.3	-65.0	74.1	0.051	5.180	0.33	1.00

As can be seen, in a single-event modeling Mw=6/6 is calculated and measure of convergence is obtained as was expected.

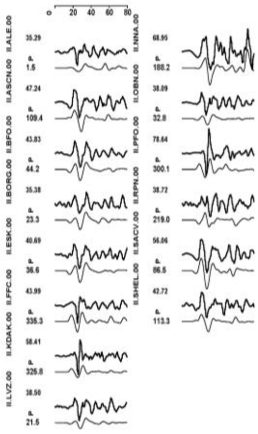

Fig. 8 Artificial and (high) real waves for single event source

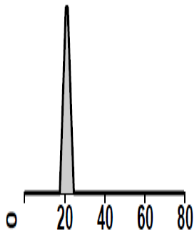

Fig. 9 Time function of the earthquake source with one event

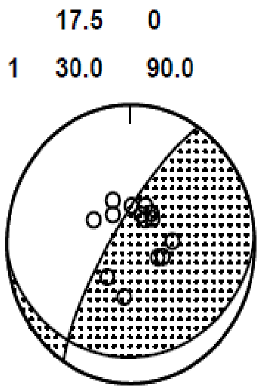

Fig. 10 Single event focal mechanism of Haiti earthquake

There is an acceptable fitting between recorded waves and modeling in two point sources. Therefore, when two events happened, the magnitude did not change in comparison to the first case and Mw was calculated as 6.6. Focal mechanism of the earthquake was obtained by reverse oblique slip. As shown in figures 11 and 12, the first event was recorded in the first 22 seconds and the second one occurred between 22 and 25 seconds.

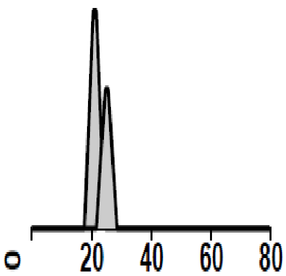

Fig. 11 Time function of the earthquake source with two events

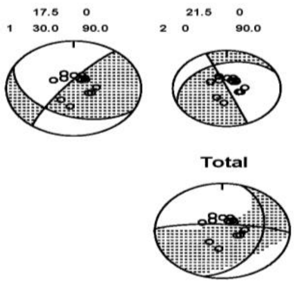

Fig. 12 Focal mechanisms of two events of Haiti earthquake

Table 3. Modeling with two time events

```
 Hii earthquaker
 J-B model
   NT     DT      HO     Dip     Ne Type Shift
   160 0.500   15.0   85.0    2    1  -20
 Time Function : (Type,T1,T2) = 1   3.0   4.0
 Grid-search extent: V max =    4.0
 Time span at each iteration =  150.0 150.0
  # Time Location(r,phi,Y-axis)  Moment non.DC  Strike  Dip   Slip  Error
Step :  1
   1  17.5   30.0   90.0    0.0    9.749    0.000   86.2   20.0  141.4  0.7832
   2  21.5    0.0   90.0    0.0    6.577    0.000  336.8   88.2   58.9  0.7058
Step :  2
   1  17.5   30.0   90.0    0.0   11.403    0.000  115.0   39.7  164.5  0.6993
   2  21.5    0.0   90.0    0.0    7.393    0.000  337.4   89.1   55.2  0.6984
Step :  3
   1  17.5   30.0   90.0    0.0   11.714    0.000  116.9   42.0  165.3  0.6983
   2  21.5    0.0   90.0    0.0    7.497    0.000  337.4   89.1   55.2  0.6983
< Convergence >
        1  0.7832  ========================================
        2  0.7058  ====================================
          Total                    9.61    2.19   16.0    40.1    17.7
          standard-deviation       1.67    0.61  265.7    46.7   126.6
 Mw =     6.59
 Stn            Inst Mode Comp    Az      B.Az    Del    p        G      PV      fc
shift
II.ALE.00         1    1    1    1.5 -169.2   64.2   0.059   5.980   0.38   1.00
  0
II.ASCN.00        1    1    1  109.4  -64.6   63.1   0.059   6.060   0.38   1.00
  0
II.BFO.00         1    1    1   44.2  -84.0   70.5   0.054   5.470   0.35   1.00
  0
II.BORG.00        1    1    1   23.3 -118.5   57.4   0.064   6.500   0.42   1.00
  0
II.ESK.00         1    1    1   36.6  -96.1   63.3   0.059   6.050   0.38   1.00
  0
II.FFC.00         1    1    1  -24.7  136.6   42.6   0.073   7.610   0.47   1.00
  0
II.KDAK.00        1    1    1  -34.2   88.2   69.3   0.055   5.540   0.36   1.00
  0
II.LVZ.00         1    1    1   21.5  -67.3   79.4   0.049   4.760   0.32   1.00
  0
II.NNA.00         1    1    1 -171.8    7.9   30.5   0.080  13.700   0.52   1.00
  0
II.OBN.00         1    1    1   32.8  -64.1   85.5   0.045   4.020   0.29   1.00
  0
II.PFO.00         1    1    1  -59.9   99.9   41.9   0.073   7.700   0.47   1.00
  0
II.RPN.00         1    1    1 -141.0   42.1   57.6   0.064   6.490   0.42   1.00
  0
II.SACV.00        1    1    1   86.5  -78.6   46.9   0.071   7.230   0.46   1.00
  0
II.SHEL.00        1    1    1  113.3  -65.0   74.1   0.051   5.180   0.33   1.00
  0
```

By adding the third event, a better answer can be obtained. Compared with the two previous phases, shapes of artificial and real waves have better fitting in this phase and the focal mechanism is strike slip, oblique-slip reverse component and strike slip, respectively which the mechanism of all of the three is approximately strike slip. The third event was recorded at 25 to 30 seconds of the earthquake. The magnitude of this phase is Mw=6/7.

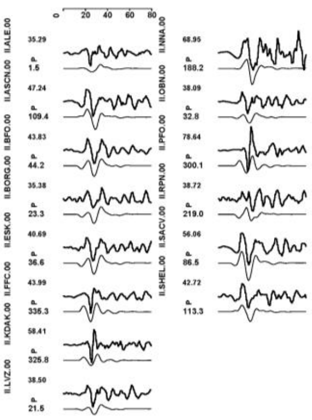

Fig. 13 Artificial and high real waves for three events

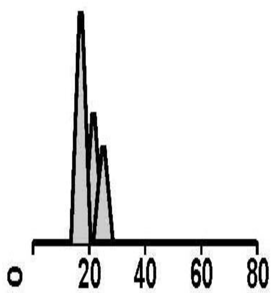

Fig. 14 Time function of the earthquake source with three events

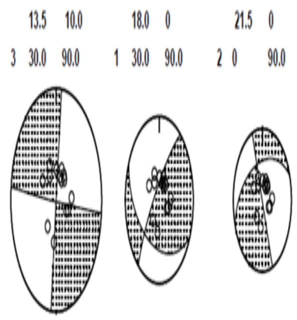

Fig. 15 Focal mechanism of three events of Haiti earthquake

The fourth event was recorded at 48 to 62 seconds of the earthquake. In this phase, four focal mechanisms were obtained including strike slip, oblique slip, oblique-slip reverse component and strike slip, respectively which the general conclusion is strike slip. In comparison with the three previous phases, shapes of artificial and real waves have better fitting in this phase and the magnitude of this phase is Mw=6/8.

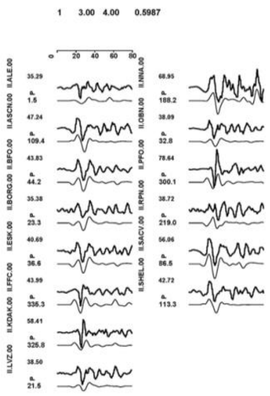

Fig. 16 Artificial and high real waves for four events

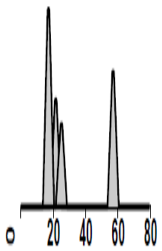

Fig. 17 Time function of the earthquake source with four events

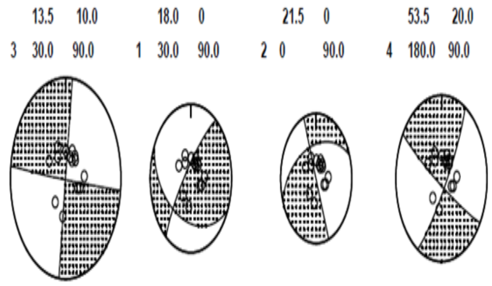

Fig. 18 Focal mechanisms of four events of Haiti earthquake

With the addition of the fifth event that was recorded at 62 to 70 seconds by seismograph, the final fitting between artificial and real waves were obtained in the best way. The obtained magnitude of this phase is Mw= 6/7 which has just 0/1 difference with the obtained magnitude by geological organization of the U.S.A. Five focal mechanisms were obtained in this phase that mechanisms of most of them were strike slip.

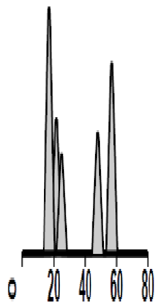

Fig. 19 Time function of the earthquake source with five events

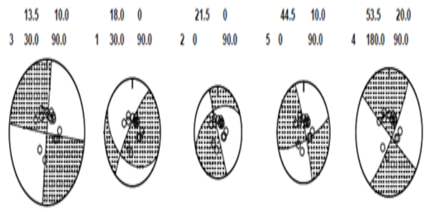

Fig. 20 Focal mechanisms of five events of Haiti earthquake

Table 4. Artificial and high real waves for five events

```
 Hii earthquaker
 J-B model
   NT    DT     H0    Dip    Ne Type Shift
   160 0.500   15.0   85.0    4    1  -20
 Time Function : (Type,T1,T2) = 1   3.0   4.0
 Grid-search extent: V max =    4.0
 Time span at each iteration =  150.0 150.0 150.0 150.0
  # Time Location(r,phi,Y-axis)  Moment non.DC  Strike  Dip   Slip  Error
Step :  1
   1  17.5   30.0   90.0    0.0    9.749    0.000   86.2   20.0  141.4  0.7832
   2  21.5    0.0   90.0    0.0    6.577    0.000  336.8   88.2   58.9  0.7058
   3  13.5   30.0   90.0   10.0   18.830    0.000   97.3   86.7    0.2  0.6579
   4  53.5  180.0   90.0   20.0   13.240    0.000  122.3   83.9    9.0  0.6101
Step :  2
   1  18.0   30.0   90.0    0.0   10.825    0.000  111.1   37.4  161.9  0.6047
   2  21.5    0.0   90.0    0.0    8.165    0.000  160.2   89.3  -46.2  0.6015
   3  13.5   30.0   90.0   10.0   20.016    0.000   97.0   88.8   -0.3  0.5996
   4  53.5  180.0   90.0   20.0   13.151    0.000  122.3   83.9    9.1  0.5996
Step :  3
   1  18.0   30.0   90.0    0.0   11.040    0.000  114.9   41.3  162.9  0.5991
   2  21.5    0.0   90.0    0.0    8.512    0.000  159.5   89.9  -42.2  0.5988
   3  13.5   30.0   90.0   10.0   20.431    0.000   97.0   88.8   -0.3  0.5988
   4  53.5  180.0   90.0   20.0   13.951    0.000  122.3   83.9    9.1  0.5987
< Convergence >
        1  0.7832  ========================================
        2  0.7058  ====================================
        3  0.6582  ==================================
        4  0.6130  ================================
          Total                   23.65    1.53   290.5    83.1     7.8
          standard-deviation       1.92    0.09    -0.2    -0.6    -0.1
 Mw =    6.85
 Stn           Inst Mode Comp    Az     B.Az    Del    p       G     PV     fc
shift
II.ALE.00        1    1    1    1.5 -169.2   64.2   0.059   5.980   0.38   1.00
  0
II.ASCN.00       1    1    1  109.4  -64.6   63.1   0.059   6.060   0.38   1.00
  0
II.BFO.00        1    1    1   44.2  -84.0   70.5   0.054   5.470   0.35   1.00
  0
II.BORG.00       1    1    1   23.3 -118.5   57.4   0.064   6.500   0.42   1.00
  0
II.ESK.00        1    1    1   36.6  -96.1   63.3   0.059   6.050   0.38   1.00
  0
II.FFC.00        1    1    1  -24.7  136.6   42.6   0.073   7.610   0.47   1.00
  0
II.KDAK.00       1    1    1  -34.2   88.2   69.3   0.055   5.540   0.36   1.00
  0
II.LVZ.00        1    1    1   21.5  -67.3   79.4   0.049   4.760   0.32   1.00
  0
II.NNA.00        1    1    1 -171.8    7.9   30.5   0.080  13.700   0.52   1.00
  0
II.OBN.00        1    1    1   32.8  -64.1   85.5   0.045   4.020   0.29   1.00
  0
II.PFO.00        1    1    1  -59.9   99.9   41.9   0.073   7.700   0.47   1.00
  0
II.RPN.00        1    1    1 -141.0   42.1   57.6   0.064   6.490   0.42   1.00
  0
II.SACV.00       1    1    1   86.5  -78.6   46.9   0.071   7.230   0.46   1.00
  0
II.SHEL.00       1    1    1  113.3  -65.0   74.1   0.051   5.180   0.33   1.00
  0
```

4. CONCLUSION

1. Haiti is tectonically complex and contains a lot of tectonic faults and plates and it has experienced a lot of great earthquakes.
2. A lot of historical earthquakes represent potential seismicity of the area.
3. Studying aftershocks of the earthquake of January 12 is indicator of high potentiality of the western part of the fault E.P.G.Z.F
4. More seismic energy was released in the first 20 seconds of the earthquake.
5. In a short time (less than 50 years) an earthquake with magnitude of more than 7 occurs in this country.
6. Haiti earthquake of January 12 contains 5 time events that amount of energy of the earthquake was released in each stage.
7. Earthquakes of January 12, 2010 occurred on the boundary of Caribbean and North American plates and its surface center was at 25 KM Southwest of Port-au-Prince.

Time function of this earthquake source is indicator of five events which follows a multi-source model. Focal mechanism of the main event and its aftershocks is mainly strike-slip which has been determined by the usage of polarization method of wave motion P in this study. Since this earthquake had a lot of aftershocks, it can be concluded that the area under study is highly heterogeneous. The focal mechanism of the earthquake is mostly strike slip.

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