1. **Introduction**
   
   The Japan (Tohoku) earthquake that occurred on the 11th of March 2011 was the second one after the 2010 Chile earthquake (M 8.8) of the series of big earthquakes that followed the 2004 Sumatra earthquake (M 9.2) [Zollo A., 2011]. The USGS has updated the magnitude of the Tohoku earthquake in Northern Honshu, Japan, to 9.0 from the previous estimate of 8.9. Independently, Japanese seismologists have also updated their estimate of the earthquake’s magnitude to 9.0. This magnitude places the earthquake as the fourth largest in the world since 1900 and the largest in Japan since modern instrumental recordings began 130 years ago [USGS, 2011].

   Records from the main shock of the event have been released few hours later by different networks on the web, herein it is proposed a selection of station recordings that have been employed for the evaluation of peak and cyclic parameters and the elastic acceleration spectra. The selection of the stations was made on the basis of the maximum peak ground acceleration recorded.

2. **Event**
   
   The event time is 05:46:23 UTC, and the epicentre coordinates are 38.322 N, 142.368 E, 129 km from Sendai, Honshu, Japan, [USGS, 2011]. The depth of the event was 24 km. Fault area is estimated in about 500x200 km². In Figure 1 is reported the shake map of the event according to USGS.
3. **Selected Recording Stations’ Information**

The stations considered are shown in Figure 2 and station details are shown in Table 1. The stations selected belong to three different networks: four stations are from K-Net network [http://www.k-net.bosai.go.jp/], four stations are from Kik-Net network [http://www.kik.bosai.go.jp/], two stations are from BRI strong motion observation network¹ [http://smo.kenken.go.jp/weblinks]. Records from K-Net are registered on surface, and the site soil profiles are available for all the station considered for at least 10 m (Table 2), all the three components have been considered (NS, EW, UD). Records from Kik-Net are registered on both surface and underground², for both conditions three components have been considered (NS, EW, UD) and difference in meters between surface and underground registration is also reported in Table 1. Records form BRI strong motion observation are placed on buildings at different levels, two station have been considered, Sendai Government Office#2 at basement level (BF2) and Annex, Hachinohe City Hall at ground level (GL), for each record the three components have been considered, the direction is the clockwise angle in degree from North (azimuth) for the horizontal components and up down for the third vertical component.

Records from K-Net and Kik-Net networks have been corrected employing a linear baseline correction and a Buttereworth bandpass filter (Freq1=0.1, Freq2=25, Order 4). BRI records have not been corrected since it was not necessary. Figure 2 shows epicentre location and the stations considered according to a colour legend to distinguish the networks.

¹ This network is explicitly devoted to dynamic monitoring of buildings.
² Height in meters is considered with respect to the sea level.
### Table 1. Station location

<table>
<thead>
<tr>
<th>Network</th>
<th>Station Code</th>
<th>Site Name</th>
<th>Lat</th>
<th>Lon</th>
<th>Surface m</th>
<th>Underground m</th>
<th>Difference m</th>
</tr>
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<tbody>
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<td>37.1585</td>
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<td>140.7261</td>
<td>510</td>
<td>410</td>
<td>100</td>
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<td>140.0784</td>
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<td>Hitachi</td>
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<td>140.6453</td>
<td>57.5</td>
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<td>/</td>
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<td>Tsukidate</td>
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<td>/</td>
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<td>Annex, Hachinohe</td>
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<td>141.4889</td>
<td>GL</td>
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</tr>
</tbody>
</table>

**Figure 2.** Selected stations from different networks, (green – K-net), (violet – Kik-net), (yellow, BRI strong motion observation), and epicentre localization, Google Earth.
4. Peak and Cyclic Parameters

Peak and cyclic parameters of ground motion have been evaluated for each record component. Peak parameters evaluated are the peak ground acceleration (PGA) and the peak ground velocity (PGV). The latter was evaluated only on the corrected records because of the necessity of baseline correction. Cyclic parameters considered are the Arias intensity (IA), the Cosenza and Manfredi index (ID) [Cosenza et al., 1993], defined in equation (1), and the significant duration (SD), evaluated as the interval of time over which 5% to 95% of the total Arias intensity is accumulated.

\[ I_D = \frac{2 \cdot g}{\pi} \cdot \frac{I_A}{PGA \cdot PGV} \]  

(1)

For uncorrected records from Kik-Net and K-Net (see Table 3 and Table 4), three values of peak ground acceleration are reported: PGA, evaluated from our own processing of the record; PGAk, evaluated from our own processing according to the standard of K-Net and Kik-Net, considering the peak value minus the average of the acceleration of the record; and PGAr, that reported in the

\(^3\) Since ID is affected by PGV it was evaluated only for corrected waveforms.
record file. For corrected records from Kik-Net and K-Net and records from BRI network (see Table 5, Table 6 and Table 7), the PGAk is not evaluated and PGV and I_D value are shown.

Table 3. Kik-Net stations: peak and cyclic parameters (as provided records)

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Dir</th>
<th>Level</th>
<th>Epicentral Distance</th>
<th>R_Pjb Distance</th>
<th>PGA</th>
<th>PGAr</th>
<th>PGAk</th>
<th>I_α</th>
<th>S_d</th>
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<td>km</td>
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<td>cm/s²</td>
<td>cm/s²</td>
<td>s</td>
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Table 4. K-Net stations: peak and cyclic parameters (as provided records)

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<th>Epicentral Distance</th>
<th>R_Pjb Distance</th>
<th>PGA</th>
<th>PGAr</th>
<th>PGAk</th>
<th>I_α</th>
<th>S_d</th>
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<td>km</td>
<td>cm/s²</td>
<td>cm/s²</td>
<td>cm/s²</td>
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4 The Joyner and Boore distance has been computed considered the following coordinates for the projection of the fault \{142.2, 39.9; 144.3, 39.8; 143.3, 36; 141, 36.5\} in terms of longitude and latitude for each vertex.
### Table 5. Kik-Net stations: peak and cyclic parameters (corrected records)

<table>
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<th>Station Code</th>
<th>Dir</th>
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<th>Epicentral Distance</th>
<th>Rjb Distance</th>
<th>PGA</th>
<th>PGAr</th>
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<td>km</td>
<td>g</td>
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### Table 6. K-Net stations: peak and cyclic parameters (corrected records)

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Table 7. BRI stations: peak and cyclic parameters (as provided records)

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5. Elastic Spectra

The elastic acceleration spectra have been evaluated at 25 periods, the smallest is 0.03 seconds, and the highest is 4.0 seconds. The elastic spectra are investigated employing Kik-Net and K-Net corrected records and uncorrected BRI records. Figure 3 and Figure 4 shows the spectra for Kik-Net stations surface and underground records respectively, both horizontal and vertical spectra are considered. Figure 5 shows the spectra for K-Net stations and Figure 6 for BRI stations.

It has to be noted that records from K-Net network are characterized by specific high spectral value that cannot be recognized in Figure 5 because of the 5g scale adopted for all the acceleration spectra allowing a better comparison between all the records selected. MYG004 registration have a peak in the NS component, among the 25 periods investigated here, at 0.25 seconds equal to 11.98 g while the peak spectral value in EW component is significantly lower, 4.31 g at 0.2 seconds. MYG004 vertical component is characterized by a single spectral value equal to 6.15 g at 0.1 seconds that as well cannot be recognized because of the scale adopted in Figure 5.

Figure 3. Elastic spectra of horizontal (left) and vertical (right) components Kik-net, (surface)
Figure 4. Elastic spectra of horizontal (left) and vertical (right) components, Kik-net (underground)

Figure 5. Elastic spectra of horizontal (left) and vertical (right) components, K-net

Figure 6. Elastic spectra of horizontal (left) and vertical (right) components, BRI.
6. Fault-Normal and fault-parallel components

A report of National Research Institute for Earth Science and Disaster Prevention (NIED, 2011) provided some preliminary information about the rupture fault model; such data, in particular the suggested strike angle, equal to 195°, allowed rotating to fault-normal (FN) and fault-parallel (FP) the corrected components of the selected records, from K-Net and Kik-NET (surface records). This means to get strike-normal and strike-parallel components, respectively. The same peak and integral parameters of the previous section have been evaluated for the rotated components. Table 7 and 8 show the results for Kik-Net and K-Net respectively.

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Rupture directivity effects may interest near-source records resulting in peculiar velocity signals characterized by a large pulse in the beginning of the record. Usually such effects are studied in FN and FP directions: in fact FN is the direction in which they are supposed to be higher (Somerville, 2005). Due to the rupture dimensions, all the considered stations are within the near-source area but analyzing rotated components with a quantitative algorithm, proposed by Baker (Baker, 2007), no record has been classified as pulse-like. It is worth to note that, referring to the direction of surface
displacement, all the stations are seems to be in conditions not favourable to observe forward directivity.

7. **Comments**

MYG stations from both K-net and Kik-net and Sendai government building (SND) are close to each other (see Figure 2) and they are the closest to the epicentre among those considered. This area was also stroked by the tsunami event following the earthquake and produced catastrophic effects. MYG stations are located within 200 km from the epicentre. If these data will be confirmed, the most peculiar result is the PGA of the NS component of MYG004 station (169 km) belonging to K-Net network; this PGA is equal to 2.91 g, while the PGA of the same record in the EW direction is approximately half this value (1.45 g).

The other MYG signals are equally close to the epicentre. MYGH10 record (surface), which belongs to Kik-Net network, (176 km) do not show any evident discrepancy between the PGA of the NS and EW components (0.89 g versus 0.87 g).

MYG012 record, which belongs to K-Net, as well as MYG004 record, shows a similar effect to the one observed in MYG004 in EW component even if the value of the maximum PGA is significantly lower. In fact, the PGA of the EW component of MYG012 is equal to 1.90 g, more than double of the 0.68 g found in the NS component. Aimed at a better comparison of these results, in Figure 7 and Figure 8 the acceleration and velocity time-histories of MYG004 MYG012 and MYGH10 (surface) are shown together considering the corrected waveforms. The comparison of acceleration and velocities time-histories does not suggest any evident atypical trend in the signals, these plots help emphasizing that the NS component of MYG004 record is significantly higher with respect to all the other components of the three records registered close to each other. Further investigations are needed for these records.

![Figure 7. Comparison between acceleration time-histories of MYG004, MYG012 and MYGH10 records for NS, EW and UD components (corrected records).](image-url)
In this comparison SND signal from BRI network was not included even if it was registered very close to the other three stations (epicentral distance equal to 175 km). SND showed a very low value of PGA respect to the others in both components (0.26 g and 0.16 g) but it was registered in a building and no information are available regarding the structure and the placement of the sensors that certainly had a strong effect on the registration.

Another peculiar effect that can be observed in the results showed in the previous sections is the significant difference between elastic spectra of surface and underground records (see Figure 3 and Figure 4). Underground records have been registered between 100 to 200 meters under the surface registration (see Table 1) and they come from the same network, Kik-net, so they are characterized by the employment of the same kind of instruments. The amplification appears always very significant. Unfortunately, Kik-Net network does not provide the velocity profile and soil columns of the stations that could have helped in a straightforward interpretation of the amplification effect due to geotechnical characteristics of the soil; on the other hand the underground registrations are obtained at significant depth, larger than the average column depth employed for geotechnical characterization of the station (approximately equal to 30 meters).

Elastic spectra in Figure 3 and Figure 4 show that the most of the amplifications occur in the last 100-200 meters, and PGA of the underground signal can be considered comparatively low. It is worth to note that underground record peak values and their elastic spectra are comparable with the values registered on buildings (from BRI network). As in the previous case for SND registration compared with the other close registration, it is not easy to explain this deamplification effects registered on the two buildings considered, since no information are available regarding the structural systems of the buildings.

In the case of the four K-Net stations the soil columns and the velocity profiles are known (Table 2). IBR003 station is characterized by the lowest velocity profile between the four stations compared, so an higher spectral amplification is expected and confirmed by the results shown in Figure 5 (also considering that this station is characterized by an epicentral distance of 254 km).
MYG004 station, that registered the highest peak of acceleration (2.73 g), is characterized by high values of velocity in the profile and rock, very stiff, soil is found at less than 5 meters from the surface. The clay layer, less than 5 meters thick, can suggest the presence of an S1 or S2 soil according to the definition of Eurocode 8 [CEN, 2003], but this needs further investigations.

The information provided herein are very preliminary, therefore the above comments represents simply guidance for further investigations and are not meant to be conclusions regarding this earthquake which requires much deeper analyses.

References


