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Near field domain effects and their consideration in the international and Italian seismic codes

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ABSTRACT It is widely proven that in the field area near a seismic source the characteristics of the seismic ground motion (near field) could be meaningfully different from those far from the source (far field), not only in terms of intensity but also in terms of nature and typology. Nevertheless, structures are usually designed on the base of accelerations derived from ordinary probabilistic seismic hazard analyses (PSHA) under the hypothesis of far-field conditions, and further modified taking into account the local seismic response. As a consequence, a structure might not have proper safety levels if it is located close to an earthquake source (i.e., in a potential near-field domain). The purpose of this paper is to analyse the near-field effects on the seismic hazard, focusing in particular on the Italian case. For this aim, an essential bibliographic overview is presented, showing the specific seismic effects in the proximity of an earthquake source and the related consequences on the structures. Furthermore, the paper presents a brief analysis on how some international seismic building codes consider the near-field effects, underlining the fact that, nowadays, the near field effects are not considered in the Italian codes. For this reason, the authors suggest to consider the increase of the seismic demand in the potential near-field domains, introducing the concept of "potential epicentral area contribution to hazard – PEACH", directly associated to the specific characteristics of the seismogenic source. Finally, the limits of the proposed approach and the prospective of its application in Italy are outlined.

Key words: near field, hazard, seismic code, epicentral area.

1. Introduction

In the case of an earthquake, the seismic motion spreads from the seismic source and its characteristics at the field surface vary depending on several different factors: source mechanism, distance from the source, radiation pattern, site effects, etc. In an area around the epicentre, the seismic ground motion could be substantially different from the ground motion in the far field. Depending on fault dimension and mechanism, the area within some tens of kilometres from a seismic source could be subject to specific ground motion effects (Housner and Trifunac, 1967; Bozorgnia *et al.*, 1995; Abrahamson and Somerville, 1996; Teisseyre *et al.*, 2006).

Bibliographic studies on seismic ground motion effects close to the seismic source evidence that researchers use different names in order to address the zone in which these effects are observed: near fault, near source, near field or epicentral area. On the other hand, all researchers use always “far field” to refer to seismic ground motion recorded far away from source. In this paper, the term “near-field domain” will be used in order to refer to the zone characterized by ground motion effects that have an intensity decreasing rather rapidly with the distance from the earthquake source and that are not evident in far-field ground motion.

The purposes of this paper are:

a) to describe the most meaningful seismic effects in the near-field domain and the potential consequences on structures;
b) to examine how different seismic codes take into account the near-field domain effects;
c) to focus on the Italian case and to formulate a proposal for including the potential near-field domain effects in the Italian seismic code.

2. Near-field domain effects and consequences on structures

The study of seismic records in the near-field domain and the recognition of specific effects was started in the second half of the twentieth century, and particularly with the paper of Housner and Trifunac (1967), but the developments boomed over the last few decades when more in depth studies have been conducted, especially considering the effects of the seismic ground motion on structures. It has been recognized that the seismic motion in the near-field domain can expose structures to seismic demands different from the design ones, both for intensity and, especially, for nature of ground motion.

The seismic ground motion in near-field domain is mainly influenced by the fault type (e.g., strike-slip, dip-slip), by the rupture mechanism (e.g., dislocation instead of crack-like rupture) and by the magnitude. Furthermore, it can change also according to the relative position with respect to the strike direction of the causative fault.

Examining the existing literature, the ground motion effects that can discriminate the near -field domain from the far field (strictly related to the fault mechanism and its characteristics) are:

- vertical seismic component;
- hanging-wall;
- fling-step;
- directivity;
- velocity pulse;
- rotational seismic components.

In the following a brief overview on each effect, as derived from literature analysis, is presented.

2.1. Vertical seismic component

The presence of a relevant vertical component can characterize the seismic ground motion in the near-field domain. The features of the vertical seismic component in the near field are the following:

1) the ratio between the peak of the vertical and the horizontal ground acceleration can exceed the unity; this has been verified in many seismic records (Elgamal and He, 2004; Shreshta, 2009; Kim *et al.*, 2011);

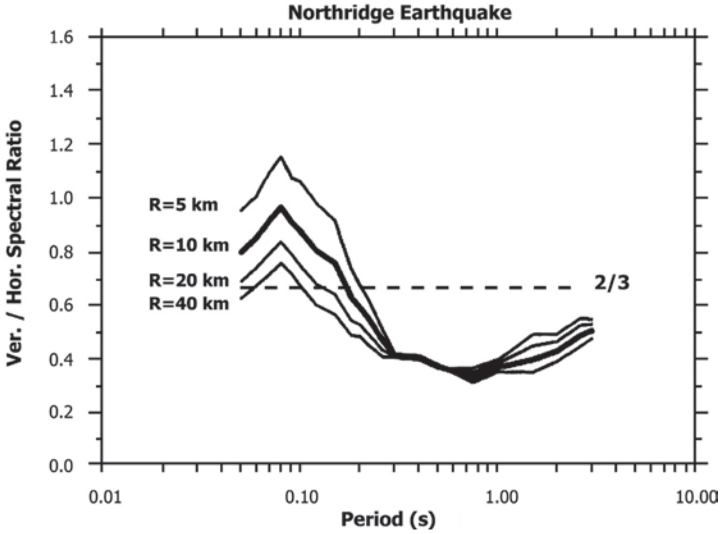

Fig. 1 - Vertical to horizontal spectral ratio for the Northridge earthquake, at distances 5, 10, 20 and 40 km from surface projection of fault plane (from Bozorgnia *et al*., 1995).

2) the ratio between the spectra of vertical and horizontal components depends on period: the vertical ground acceleration usually has higher frequency content than the horizontal component (Fig. 1);
3) the vertical ground motion presents most of its energy in a narrow high-frequency band (Collier and Elnashai, 2001);
4) in the near-field domain, the peak of the vertical component occurs slightly before the horizontal one; the time-lag among the two peaks generally increases with distance (Collier and Elnashai, 2001; Shreshta, 2009).

The measured values of vertical to horizontal PGA (peak ground acceleration) ratios in near-field domain are often higher than the value of circa 2/3 originally proposed by Newmark *et al*. (1973), while in far field they can be lower. Ambraseys *et al*. (1996) show that, for the European dataset and far from the earthquake source, the vertical PGAs vary between 1/2 and 1/4 of their corresponding horizontal values. However, seismic codes often assume the value of two thirds [sometime rounded as 0.7, see for example NZS (2004)]; that means that the seismic design of structures with low period can be under-conservative in near field and over-conservative in far field (Elgamal and He, 2004).

The presence of a relevant vertical component in near field has been proven also by the observation of the upthrow of objects in earthquakes (Newmark, 1973; Bolt and Hansen, 1977) and by the presence of freshly fractured and broken rocks and stones in the near-field domain caused by the upthrow of stones due to vertical acceleration greater than gravity (Bouchon *et al*., 2000).

All these aspects have been recognized also after the recent Italian earthquakes. In particular, Di Sarno *et al*. (2010) showed the relevance of the vertical component of seismic ground motion of the L'Aquila 2009 earthquake; Fig. 2 shows the ratios between vertical and horizontal PGA as function of epicentral distance and the time-lag between the vertical and horizontal peak acceleration.

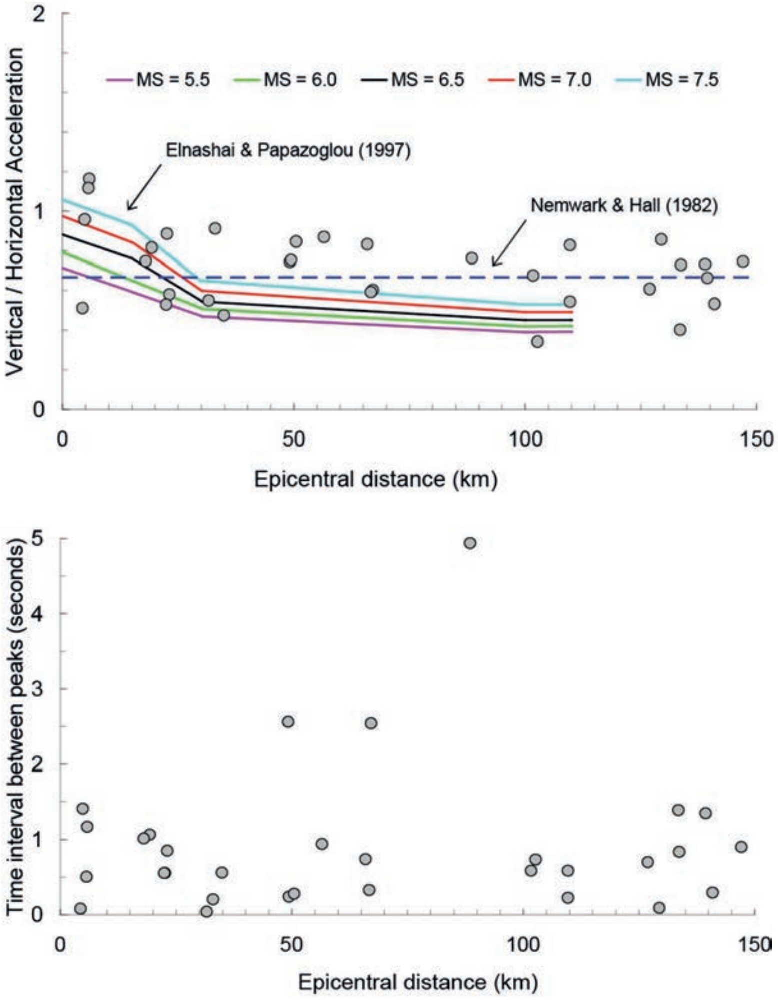

Fig. 2 - Vertical/horizontal acceleration ratios as a function of the epicentral distance for the recording stations (up to 150 km away from the fault) (top) and time interval between peaks (bottom) for the recording stations (up to 150 km away from the fault) of the April 6, 2009 L'Aquila earthquake. The dotted line corresponds to the 2/3 ratio proposed by Newmark and Hall (1982) (from Di Sarno *et al*., 2010).

The presence of a relevant vertical component can induce meaningful changes in the seismic dynamical behaviour of structures (especially if it acts combined with the horizontal component): the vertical component focuses its energy in a high frequency band (commonly, above 5 Hz), that usually coincides with the period of the first mode of vertical respons [both reinforced concrete (RC), masonry and precast system structures]; this implies a significant response amplification and a consequent possible increase of damage. Furthermore, it can reduce the shear and flexure strength capacity of columns in RC buildings, also considering a possible reduction of axial loads: a decrease of axial forces results in a decrease of the shear capacity. The vertical ground motion can also increase the axial force on vertical structures (e.g., columns); for this reason particular effects are expected [and have been observed, e.g., Papazoglou and Elnashai (1996)] on inner columns instead of external ones, since they have, generally, a greater load. If both vertical and horizontal seismic ground motions in the near field domain are considered jointly, the behaviour factor for RC building can be reduced up to 30% (Papazoglou and Elnashai, 1996). Mwfay (2012) presents a deep investigation on the response of RC buildings designed according to modern capacity design principles and subject to both horizontal and vertical ground motions in near field. Mwfay (2012) underlines the necessity to consider jointly both vertical and horizontal seismic action for the evaluation of the seismic design of structures located near active faults. Furthermore, within 5 km from source, it is suggested to consider the peaks of vertical and horizontal components as almost coincident in time and therefore to consider jointly the two motions in the seismic evaluations (see e.g., Papazoglou and Elnashai, 1996; Elgamal and He, 2004; Kim and Elnashai, 2008). Other effects on structures connected with the presence of a relevant vertical component could be: the amplification of plastic deformation; the extension of the plastic hinge formation; the decreasing of the ductility capacity of vertical structural component. The relevance of the vertical component is fundamental also for steel structures, in particular for the connections, where many problems are caused by a large number of cycles closed and/or exciding yield (this occurs as a consequence of the vertical component) and for the buckling of columns or of compressed members in truss beams. Furthermore, in case of poor masonry structures with low compressive strength, a relevant vertical component in the seismic ground motion could favour the structural damage and/or collapse. Similar considerations hold for arches, vaults and roofs. In precast structures, uplift can favour the fall of horizontal structures. Finally, the vertical motion favours also the collapse of bridge piers by reducing the shear strength (Papazoglou and Elnashai, 1996).

In the Italian seismic code (Ministero delle Infrastrutture, 2008), in case of linear static analysis, the three seismic ground components are considered independently; the vertical component has to be considered only in few (defined) cases. The vertical elastic response spectrum is defined with almost the same formulas of the horizontal elastic response spectrum, but with different (lower) period values for each segment of the spectrum, and in addition, the maximum amplification of the vertical spectrum is defined by the parameter Fv expressed as a function of Fo and a_g:

$$Fv = 1.35 \cdot Fo \cdot (a_g/\mathrm{g})^{0.5}. \qquad (1)$$

For the return period $T_R = 475$ years in Italy the minimum a_g/g value is about 0.037 and the maximum is about 0.283; if we apply these values, it can be noticed that the maximum value of the vertical elastic spectra is almost 0.26 and 0.72 times the maximum value of the horizontal elastic spectra, respectively.

2.2. Hanging-wall effect

The hanging-wall effect is strictly connected with the fault mechanism and it is potentially present in case of dipping fault, where it is possible to recognize the hanging-wall and the footwall sides with respect to fault plane (Fig. 3).

The hanging-wall effect has the following features:

1) the ground motion on the hanging-wall shows systematically higher values than that on the footwall sites. Shabestari and Yamazaky (2003) report that for the hanging-wall effect higher values are found for horizontal peak ground acceleration, and they propose a

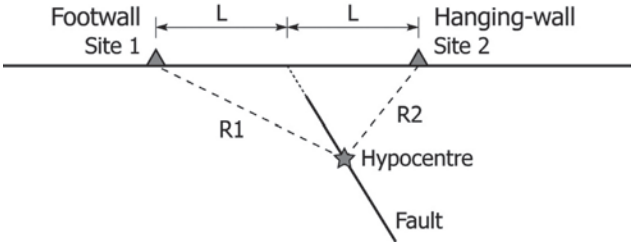

Fig. 3 - Hanging-wall and footwall (from Li and Xie, 2007).

new empirical model for the PGA on the hanging-wall that indicates values 46% to 50% higher than the mean predicted over the near field range of 5 to 25 km. The suggested empirical hanging-wall model was in agreement with the results of Abrahamson and Somerville (1996);

2) the hanging-wall effect causes larger short period ground motions on the hanging-wall than on the footwall at the same closest distance (Somerville, 2000): sites on the hanging-wall of a dipping fault are closer to the fault than sites at the same surface distance but on the footwall side (Fig. 3).

The effects of the hanging-wall on structures are strictly related to the demand increase and to the short ground motion pulse; the effects of the ground motion pulse are analysed in a specific paragraph in the following. Finally, ground permanent deformation (open cracking, bending, folding and tilting of the ground) in the proximity of the fault can affect structures; in this case, the best solution is to define an area (if possible) in which no construction can be built, otherwise (for example, in case of roads, railways, or pipe-lines) proper specific solutions should be found (Lee *et al.*, 2000).

2.3. Fling-step effect

The fling-step effect is associated to:

1) permanent displacement of the ground;
2) a unidirectional large-amplitude velocity pulse. The fling-step effect arises in strike-slip faults in the fault-parallel (or strike-parallel) direction or in dip-slip faults in the fault-normal (or strike-normal) direction (Fig. 4).

The fling-step occurs because of the permanent displacement caused by a fault; it is not strongly coupled with the strike direction, although it is usually more powerful in the forward-directivity (Abrahamson, 2001). The fling-step effect is strictly connected with the velocity pulse effect (Abrahamson, 2001) as it causes a “one-sided” velocity pulse (see Fig. 5a).

A literature survey highlights the analysis of the effects of fling-step on tall buildings; Kalkan and Kunnath (2006) investigate steel moment frames buildings, concluding that the presence of fling-step effects in ground motion can be more damaging than far-fault records, but they tend to accentuate the first-mode behaviour. Ventura *et al.* (2011) illustrate the effects of fling-step on tall RC buildings through a parametric study on SDOF (Single Degree Of Freedom) systems; their study confirms that the motion with fling effects generates much larger response than those without fling (and therefore a potential higher damage). Furthermore, the ratio of the structural period to the rise time confirms to be one of the most important variable

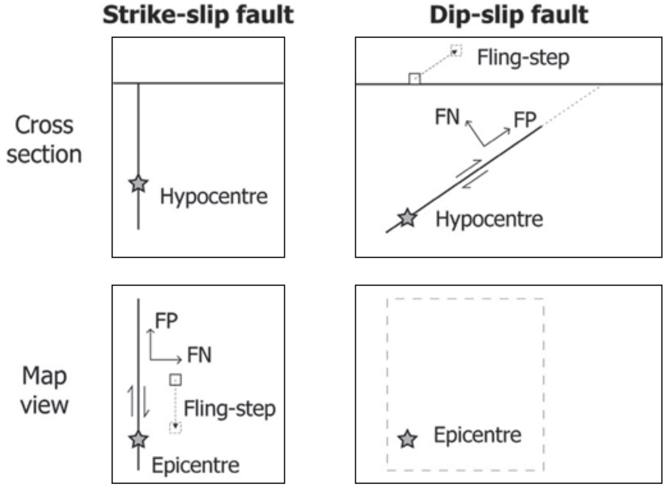

Fig. 4 - Directions of fault normal (FN) and fault parallel (FP) in case of strike-slip and dip-slip faults, and fling-step permanent displacement for strike-slip and dip-slip faults [from Somerville (2005) and Chioccarelli (2010)].

controlling the level of structural displacements. Conversely, Hamidi Jamnani *et al.* (2013) investigate the effect of fling-step on the response of high-rise buildings during the Christchurch 2011 earthquake (using a record with fling-step effect, with a fling-pulse period of 2.75 s). In their study, Hamidi Jamnani *et al.* (2013) compare the displacement ductility demand in the SDOF systems in the cases in which the fling-step effect is present or it has been removed from the seismic ground motion. For SDOF systems with small natural period values ($T < 2.5$ s) and low reduction factors (R =5 or 6), the analyses show an increase in the seismic demand when the effect of fling-step is removed from the ground motion.

The fling-step effect implies generally the presence of a large amplitude velocity pulse; the related effects are illustrated in a specific paragraph in the following.

2.4. Directivity effect

The directivity effect depends on the direction of the rupture front in case of an earthquake. If the rupture arises towards the site it is called forward directivity, if it is in the opposite direction it is called backwards directivity (Fig. 6). The directivity effect can produce a “two-sided” velocity pulse (Fig. 5b).

The forward-directivity effect can increase significantly the ground motion [see for example Champion and Liel (2012) and Garini and Gazetas (2013)]. The greater effect occurs in forward directivity when:

1) the rupture front propagates toward the site (Somerville, 2005);
2) the velocity of the rupture front is comparable with the shear wave velocity of the site (Somerville, 2000);
3) the direction of slip on the fault is aligned with the site (Somerville *et al.*, 1997);
4) the site is close to the fault but away from the epicentre (Abrahamson, 2001).

The directivity effect has the following features:

1) it has different values for the fault-normal and the fault-parallel directions (in particular, it is maximum along the fault-normal direction, both for strike-slip and dip-slip faults);

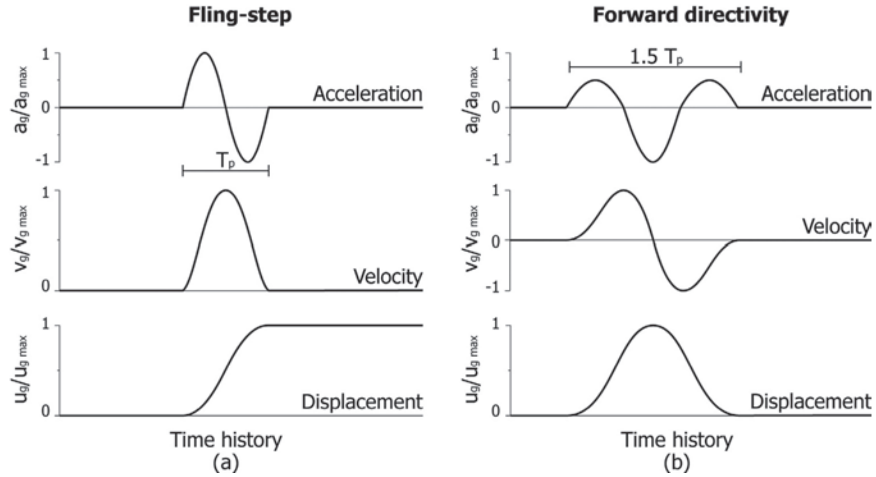

Fig. 5 - Idealized sinusoidal pulses: a) fling-step and b) forward-directivity. Note: curves are normalized by maximum acceleration, velocity and displacement (modified from Kalkan and Kunnath, 2006).

2) it can cause an increase in the amplitude of the ground motion for long periods in case of forward directivity;
3) it can cause a decrease in the amplitude of long period ground motion away from the site.

The effects connected to forward directivity can be recognized at distances less than 50 km from the fault, with the size of the effect depending on the earthquake magnitude and on the geometry of the site in relation to the fault (Somerville, 2000).

Since the directivity effect implies the presence of a relevant velocity pulse in the ground motion, its effects on structures will be analysed in the paragraph discussing the effects of velocity pulse.

2.5. Velocity pulse

Fling-step and directivity effects can cause a long-period and high-value velocity pulse-like ground motion (with one or more pulses). The pulses have the following features (Moustafa and Takewaki, 2010):

1) large amplitudes and long period;
2) high PGV/PGA and PGD/PGA ratios;
3) unusual response spectra shapes;
4) energy contained in a single or a few pulses.

The pulse-like motion is characterized by its period (commonly named T_p) that can be recognized using different signal analyses [for example, the wavelet analysis: Baker (2007)]; the period T_p increases with earthquake magnitude: ground motions in the near field domain from moderate magnitude earthquakes may exceed those of larger earthquakes at intermediate periods (around 1 s) (Somerville, 2005). The ground velocity can reach values of the order of 1 m/s (Hall, 1998) usually at the beginning of the seismogram. Furthermore, fault-normal and fault-parallel components present two different amplitudes, being the fault-parallel usually slower than the fault-normal; non-pulse-like motions present instead comparable components in the two directions (Iervolino *et al.*, 2012). The velocity pulses are not present in far-field ground motion and unless specific evaluations [see, for example, Iervolino and Cornell (2008)] they are

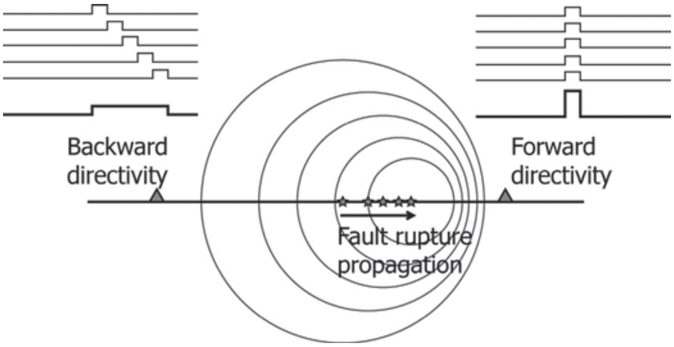

Fig. 6 - Forward and backward directivity effects (modified from Chioccarelli, 2010).

not considered in the probabilistic seismic hazard analyses (PSHA) that usually refers to far-field conditions.

The pulse period T_p is a relevant parameter for assessing the effects of velocity pulses on dynamical structural response: if it has almost the same value as the fundamental period of a structure, the damage on constructions will be emphasized. Furthermore, considering the possible presence of long-period pulses in the near-field domain, structures with a high fundamental period could suffer an increased damage due to resonance effects (Hall, 1998; Champion and Liel, 2012). The maximum story ductility demand of a structure occurs at different building heights depending on the relationship between the period of structure (T_s) and pulse (T_p): if $T_s \leq T_p$ the maximum story ductility demand occurs in the bottom stories, while for $Ts > Tp$ and relatively strong structures (high ratio between base shear strength and structure weight), the maximum story ductility demand occur in the upper stories, while for relatively weak stories the ductility demand migrates to the bottom of the structure (Alavi and Krawinkler, 2004a, 2004b). Even steel framed code-compliant structures are vulnerable to near-field pulse-like ground motions: Hall (1998) showed that existing code-compliant steel buildings in near- field domains in the U.S. could be subject to widespread damage, including collapse (especially for the larger earthquake). The velocity pulse-like ground motion may generate high demands that force the structures to dissipate this input energy with few large displacement excursions. Consequently, the risk of brittle failure for poorly detailed systems is considerably enhanced (Manfredi *et al.*, 2003). Few studies have been developed in order to assess the effect of the velocity pulse on buildings with shear walls; Mortezaei and Ronagh (2012) studied the effect of velocity pulse on flanged shear wall buildings and the analysis underlines how medium- and high-rise buildings subject to near-fault earthquakes with velocity pulse suffer slightly less damage than buildings in the far-field. Brun *et al.* (2004) also highlighted the fact that, in the case of low-rise buildings with shear walls, low-magnitude near-field earthquakes are less damaging than earthquakes with the same PGA values but with larger magnitudes at larger distances.

2.6. Rotational seismic component

The study of rotational seismic effects has received increasing attention in recent times, whereas the observation of rotated objects date back to few centuries ago [see for example Mallet (1862)]. Recently, the most significant publications are reported in a book (Teisseyre

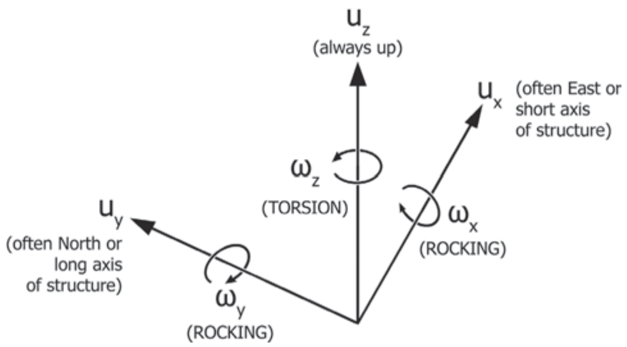

Fig. 7 - Nomenclature and sign convention for the 3 translational and the 3 rotational ground motions (from Guidotti, 2012).

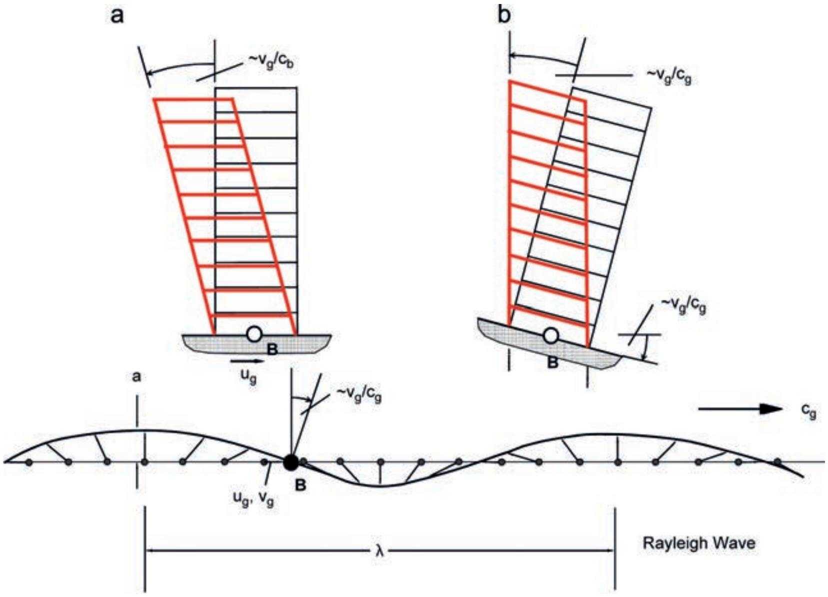

Fig. 8 - Geometric interpretation of how horizontal translation and rocking can contribute to the total drift in a simple building during passage of a Rayleigh wave (from Trifunac, 2009).

et al., 2006), in a special volume of the Bulletin of the Seismological Society of America (Lee *et al.*, 2009), in a special number of the Journal of Seismology (Igel *et al.*, 2012) and in a web-site (www.rotational-seismology.org).

The analysis of the ground motion should not be limited to the 3 translations (u_x, u_y, and u_z) but it should also include the three rotations (ω_x, ω_y and ω: see Fig. 7 for the common assumptions on the directions). The rotation around horizontal components (ω_x and ω_y) are usually called rocking while the rotation along the vertical component (ω_z) is called torsion (Zembaty, 2006).

It has been recognized that the rotational seismic motion can play a meaningful role in the seismic ground motion, and it has several implications; for example it can contaminate the translational seismometers records (Trifunac and Todorovska, 2001; Graizer, 2005; Guidotti, 2012; Igel *et al.*, 2012) and it can impose centrifugal acceleration and gravity effects (Kozák, 2006; Chiu *et al.*, 2012).

The rotational effects are relevant when the horizontal and the vertical seismic motion have a comparable importance; they depend on the amplitude of the response spectrum of the vertical component in the long period range (Castellani *et al.*, 2012). For this reason, they can play a significant role in the ground motion of the near field domain, where the vertical ground motion is relevant and where many evidences of their effect on structures have been recognized (Grimaz, 2012). Trifunac (2009) also underlines the importance of considering the rocking effect as it can result in a meaningful increment of drifts in structures also by factors approaching two (Fig. 8). There is anyway a lack of experimental data (i.e., seismic ground motion measurements) especially in the near field domains.

The analysis of objects rotated around the vertical component during an earthquake has been developed by many studies and it has captured the attention of many seismologists in the last centuries. The torsions can be due both to the presence of irregular asperities or asymmetrical geometries and to seismic rotations (torsions) of the ground. Hinzen (2012) showed how the torsion of vertically oriented objects can be due to a rocking together with a translation motion.

Finally, the relevance of rotational effects on buildings is still under debate by the scientific community, but recent recognitions show that it could significantly contribute to the overall structural response, especially in near-field domain (Castellani *et al.*, 2012).

3. Near-field domain effects in recent Italian earthquakes

After the earthquakes of M_W=6.3 L'Aquila (Italy, 2009) and M_W=5.8 Emilia (Italy, 2012), many pieces of evidence (such as ground motion records, effects on structures and on environment) pointed the attention on near-field effects also in the Italian territory (Di Sarno *et al.*, 2010; Carydis *et al.*, 2012; Grimaz, 2014).

In L'Aquila, the affected structures where mainly old stone masonry buildings, RC buildings, some pre-cast and steel buildings and lifelines (Grimaz and Maiolo, 2010). In the area hit by the Emilia earthquake, the structures where mainly brick masonry buildings (both for cultural heritage and civil buildings) and precast system structures (for factories); these typologies of structures behave mainly on the basis of friction effects among different structural parts and these are very vulnerable to vertical ground motion. In the Emilia and L'Aquila earthquakes, the damage observed on precast structures (Fig. 10a) could be, at a first glance, considered as an evidence of a relevant vertical ground motion (Decanini *et al.*, 2012). The sharp cut of the cusp of the tower bells (Fig. 10b) could also be due to rotational component, even if this hypothesis has to be proven through specific analysis. Furthermore, evidence of the presence of rotational (torsional) component (Fig. 10c) was recorded (Cucci and Tertulliani, 2011). It is not a purpose of this paper to demonstrate if and how the presented evidence can be associated to specific near-field effects; deeper studies and careful analysis are needed to connect evidence to near-field effects. Anyway, the damage observed after recent Italian earthquakes evidences the presence of near-field domain effects in the epicentral areas.

Fig. 10 - a) Precast building in L'Aquila (Monticchio, Italy). The damage could be ascribed to joint presence of vertical and horizontal ground motion in a friction based-system. b) Bell towers showing a clear cut at the cusp: bell tower of the church of S. Martino in Buonacompra – Cento (FE, Italy) (date of the photo: May 21, 2012). c) Rotation of a symmetrical obelisk (Mirandola, Emilia, Italy 2012).

4. Near-field domain effects in international seismic codes

Although the ground motion effects in near field have been studied for many decades, only some seismic codes have started to consider them in their prescriptions. In the following, a short analysis on how some national and international seismic codes consider the near-field effects is presented. The terminology of each seismic code is used in the description, so the original terms "near source", "near fault" and "near field" are used. Note that the references are done with regard to paragraphs, figures and tables of each seismic code. The following seismic codes are analysed:

- European seismic code: EN 1998-1:2004: Eurocode 8 – part 1 (CEN, 2003);
- American seismic codes: Uniform Building Code 1997 (ICBO, 1997); ATC-40 (ATC, 1996); ASCE/SEI 7-10 (ASCE, 2010);
- National Standard of the People's Republic of China: GB 50011-2010 (Ministry of Construction, 2010);
- New-Zealand seismic code: NZS 1170-5 (NZS, 2004).

4.1. EN 1998-1:2004: Eurocode 8 – part 1 (CEN, 2003)

The near-source effects are considered by the code only for buildings of importance class IV (buildings whose integrity during earthquakes is of vital importance for civil protection, e.g., hospitals, fire stations, power plants, etc.). For these buildings, site-specific spectra including near-source effects should also be taken into account, if the building is located at a distance less than 15 km from the nearest potentially active fault with a magnitude $M_s \geq 6.5$ (CEN, 2003, Par. 10.6).

4.2. Uniform Building Code 1997 (ICBO, 1997)

It considers two near-source factors N_a and N_v that depend on the seismic source type and the closest distance to known seismic sources; these factors are defined in ICBO (1997) Table 16-S and 16-T of the code respectively (the tables are reported in Fig. 9). The near-source factors N_a and N_v are applied to the seismic coefficients C_a and C_v (respectively) only for zones with a seismic zone factor Z = 0.4 (i.e., seismic zone 4).

It is possible to define the vertical component of ground motion by scaling the corresponding horizontal accelerations by a factor of two-thirds. Alternative factors may be used when substantiated by site-specific data. Where the near source factor, N_a, is greater than 1.0, site-specific vertical response spectra shall be used in lieu of the factor of two-thirds (ICBO, 1997, par. 1631.2).

4.3. ATC-40 (ATC, 1996)

Near-fault effects are taken into account as a site characteristic that it is necessary to identify in a seismic design checklist to be compiled in order to highlight the issues pertinent to the rehabilitation and retrofit process (ATC, 1996, table 2-2). The values assigned for near-fault factor are the same of Uniform Building Code 1997 (ATC, 1996, par. 4.4.2.3); in the commentary of the paragraph it is underlined that in case of fault-normal action the ground shaking may be as much as 50% greater than that predicted using the near-source factors suggested in the tables. Anyway, site specific studies should also be performed for certain buildings situated near active sources and for buildings with special design requirements (ATC, 1996, par. 4.4.3.2).

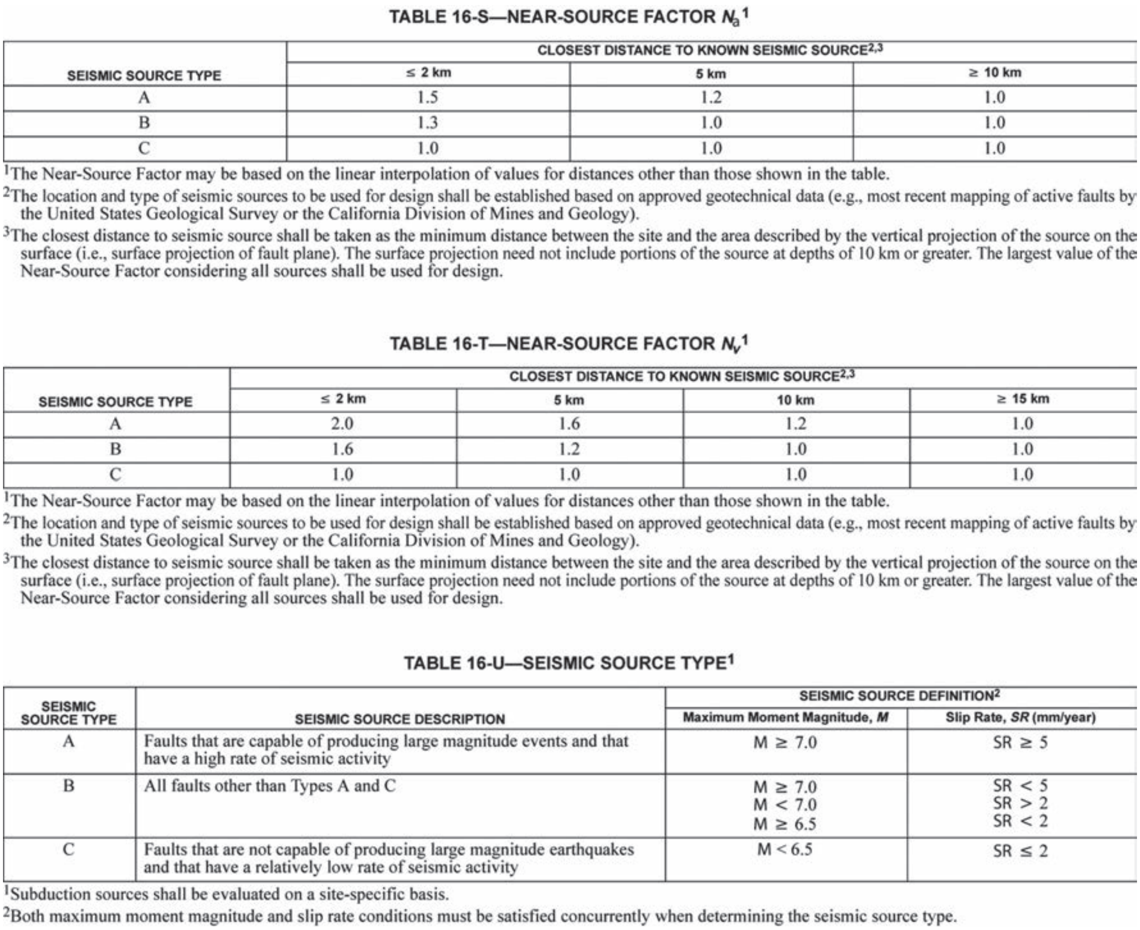

TABLE 16-S—NEAR-SOURCE FACTOR N_a[1]

SEISMIC SOURCE TYPE	CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE[2,3]		
	≤ 2 km	5 km	≥ 10 km
A	1.5	1.2	1.0
B	1.3	1.0	1.0
C	1.0	1.0	1.0

[1] The Near-Source Factor may be based on the linear interpolation of values for distances other than those shown in the table.

[2] The location and type of seismic sources to be used for design shall be established based on approved geotechnical data (e.g., most recent mapping of active faults by the United States Geological Survey or the California Division of Mines and Geology).

[3] The closest distance to seismic source shall be taken as the minimum distance between the site and the area described by the vertical projection of the source on the surface (i.e., surface projection of fault plane). The surface projection need not include portions of the source at depths of 10 km or greater. The largest value of the Near-Source Factor considering all sources shall be used for design.

TABLE 16-T—NEAR-SOURCE FACTOR N_v[1]

SEISMIC SOURCE TYPE	CLOSEST DISTANCE TO KNOWN SEISMIC SOURCE[2,3]			
	≤ 2 km	5 km	10 km	≥ 15 km
A	2.0	1.6	1.2	1.0
B	1.6	1.2	1.0	1.0
C	1.0	1.0	1.0	1.0

[1] The Near-Source Factor may be based on the linear interpolation of values for distances other than those shown in the table.

[2] The location and type of seismic sources to be used for design shall be established based on approved geotechnical data (e.g., most recent mapping of active faults by the United States Geological Survey or the California Division of Mines and Geology).

[3] The closest distance to seismic source shall be taken as the minimum distance between the site and the area described by the vertical projection of the source on the surface (i.e., surface projection of fault plane). The surface projection need not include portions of the source at depths of 10 km or greater. The largest value of the Near-Source Factor considering all sources shall be used for design.

TABLE 16-U—SEISMIC SOURCE TYPE[1]

SEISMIC SOURCE TYPE	SEISMIC SOURCE DESCRIPTION	SEISMIC SOURCE DEFINITION[2]	
		Maximum Moment Magnitude, *M*	Slip Rate, *SR* (mm/year)
A	Faults that are capable of producing large magnitude events and that have a high rate of seismic activity	M ≥ 7.0	SR ≥ 5
B	All faults other than Types A and C	M ≥ 7.0 M < 7.0 M ≥ 6.5	SR < 5 SR > 2 SR < 2
C	Faults that are not capable of producing large magnitude earthquakes and that have a relatively low rate of seismic activity	M < 6.5	SR ≤ 2

[1] Subduction sources shall be evaluated on a site-specific basis.

[2] Both maximum moment magnitude and slip rate conditions must be satisfied concurrently when determining the seismic source type.

Fig. 9 - Tables 16-S, 16-T and 16-U from the UBC 1997 (ICBO, 1997).

4.4. ASCE/SEI 7-10 (ASCE, 2010)

In the cases in which a ground motion analysis is performed or required, par. 21.2 (ASCE, 2010) underlines the necessity to take into account also the near-source effects. Further in par. 16.1.3.2 (ASCE, 2010, three dimensional analysis) it is stated that at sites within 5 km of the active fault that controls the hazard, each pair of components shall be rotated to the fault-normal and fault-parallel directions of the causative fault and shall be scaled so that the average of the fault-normal components is not less than the MCE_R (Risk-targeted Maximum Considered Earthquake) response spectrum for the period range from 0.2 T to 1.5 T, where T is the natural period of the structure in the fundamental mode for the direction of response being analysed.

4.5. GB 50011-2010 (Ministry of Construction; 2010)

In the National Standard of the People's Republic of China - Code for Seismic Design of Buildings, the near field effects are considered for the structures within 10 km on both sides of the shock fracture. The near-field effects are considered by multiplying the horizontal and vertical ground motion parameter by an enhancement coefficient of 1.5 for distances within 5 km; for the structures outside of 5 km (and within 10 km) the ground motion parameter should be multiplied by an enhancement coefficient of no less than 1.25 (par. 3.10.3 clause 1). No modifications are done on the periods of the spectrum.

4.6. New Zealand NZS 1170 – part 5 and commentary (NZS, 2004): Near-fault factor (NZS, 2004, Clause 3.1.6, C3.1.6)

The near-fault factor defined in the NZS 1170.5 code takes into account the effects of forward-directivity and polarization of the long period motions in the near-source region (NZS 1170.5 – Commentary). The hanging-wall effect is neglected as no dip-slip fault satisfy the criteria for consideration. In the NZS 1170.5 – Commentary specific information are given on the forward and backward directivity effects; furthermore, the differences between strike-parallel and strike-normal components are highlighted. The near-fault factor is one of the components of the elastic site spectra (NZS, 2004, Clause 3.1.1) together with a spectral shape factor [determined from NZS (2004), Clause 3.1.2], a hazard factor (NZS, 2004, Clause 3.1.4) and a return period factor (NZS, 2004, Clause 3.1.5). The near-fault factor, $N(T,D)$, shall be determined depending on the value of the annual probability of exceedance for locations of shortest distance, D, of less than 20 km from the nearest major fault listed in Table 3.6 (Clause 3.1.6). For location at distances greater than 20 km from the major faults, the near-fault factor is assumed as 1.0. The near-fault factors change with period; they are equal to 1.0 for periods lower than 1.5 seconds, while the maximum value is 1.72 for periods higher than 5 seconds.

4.6.1. Site hazard spectra for vertical loading (NZS, 2004, Clause 3.2, C3.2)

It is considered as 0.7 times the elastic site hazard spectrum for horizontal loading, determined from Clause 3.1.1 for the modal or time history method of analyses. But in the commentary it is highlighted that at near-source locations, the short-period part of the vertical spectrum may be equal to, or exceed, the horizontal spectrum. At locations where the seismic hazard is dominated by a fault at a distance of less than 10 km, it may be more appropriate to assume that the vertical spectrum equals the horizontal spectrum for periods of 0.3 s and less.

4.7. Considerations

The analysis of the international codes shows that all of them take into account some near -field effects in the definition of seismic action for structure design. Even if the codes define the near-field effects in different ways, it is possible to make the follow considerations:

a. usually near-field effects are considered within zones with boundaries identified considering one or more defined distance values from a potentially seismogenetic fault;
b. the effects are considered if the magnitude is greater than a defined threshold value (usually above 6.5);
c. the vertical acceleration is considered in the near field in almost all the international codes analysed, while directivity effects are explicitly considered only in the NZS (2004);
d. in the NZS (2004), the nature and intensity of near field effects are related to the fault mechanisms and their magnitude depends on the spectral period and distance from the fault source.

5. Near-field domain effects in the Italian seismic code: actual situation and hypothesis of work

It is worth highlighting that, nowadays, the Italian seismic code (Ministero delle Infrastruttre, 2008) does not consider near-field effects in the seismic design of structures located in the near-field domain. On the other hand, the outcomes of literature review and the evidence of near-field effects observed after Italian medium-magnitude earthquakes suggest a specific evaluation on the opportunity to include the near-field domain effects in the seismic design of structures. Although deeper analysis are necessary before the implementation of new rules in the Italian seismic code, in the following, the authors formulate a hypothesis of work for considering near -field effects also in Italian seismic code.

The hypothesis is based on some preliminary considerations:

a) in order to define provisions it is necessary to simplify as much as possible the regulations; the developed studies show that usually tall buildings are more affected by near-field effects, and the suggestion is to prescribe specific analysis on near-field effects for relevant and strategic structures;
b) the near-field effects depend strictly on the characterization of the faults, and this is a relevant problem in Italy, as there are large uncertainties in the knowledge of single faults and faults systems;
c) the seismic behaviour of structures subject to near-field effects is still a matter of studies, and further research is needed, especially for masonry and low-rise buildings.

Taking into account that the features of areas with potential near-field effects depend mainly on the fault characteristics and on the focal mechanism, for the Italian case, a first definition of the potential near-field domains might be derived from the Database of the Individual Seismic Sources – DISS (Basili *et al.*, 2008). More in detail, the hypothesis of work could be to define, for each seismogenic source of the DISS, a Potential Epicentral Area Contribution to Hazard - PEACH chart (Fig. 11), where the definition of epicentral area considers all the area where potential near-field effects could be present and relevant. For each PEACH it should be necessary to characterize:

- the features of the seismogenic source;
- the features of the area characterized by an increase of the seismic action due to epicentral area effects (“PEACH shape”, without specific information an ellipse can be used);
- the characteristics of the potential epicentral area effects related to the specific seismic source.

The PEACH seismic actions should be taken into account in the seismic design, playing a role of “extra seismic action” that have to be considered jointly with PHSA and/or as site effects.

In this way an additional layer, defining the areas in which the near-field ground motion effects are characterized, could be associated to the hazard map and used for the aim of seismic design of structures (Fig. 11). Nowadays, the seismogenic areas in the DISS database are not still precisely characterized, therefore the proposal above formulated has to be considered as a first hypothesis of work to evaluate if, where and how to take into account the near-field domain effects in the seismic design of buildings located in potential epicentral areas, in order to ensure the same safety level as in the far field zones, in the whole Italian territory.

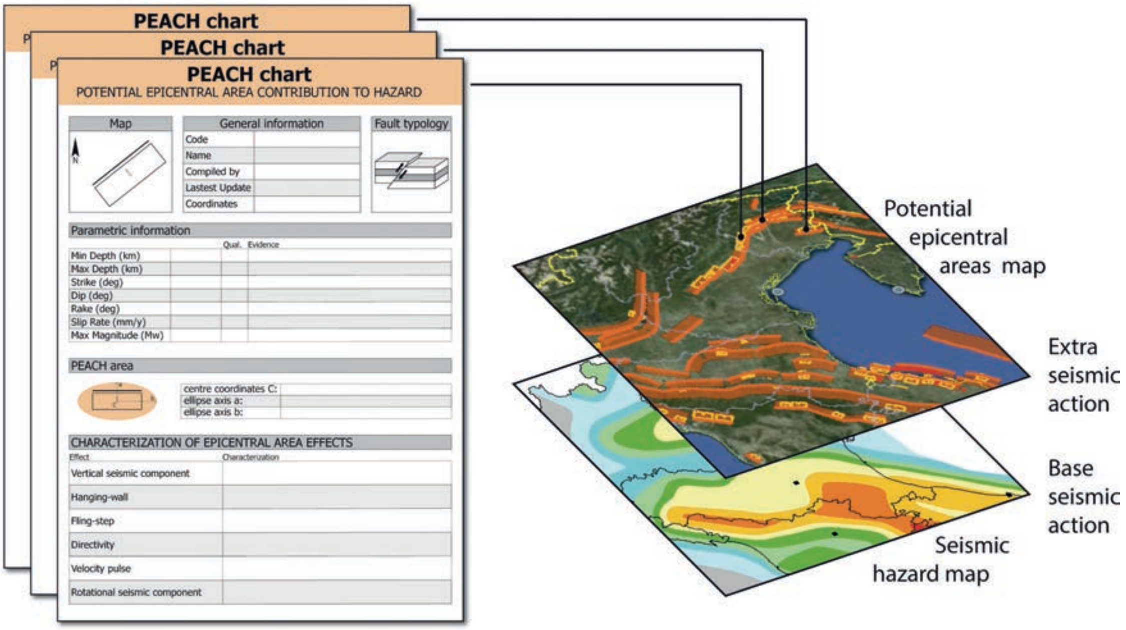

Fig. 11 - The near-field domain effects should be considered taking into account the contribution of the potentially epicentral areas to seismic hazard (PEACH area). In the example, potential epicentral areas have been gathered from DISS 3.1 project (Basili *et al.*, 2008); for each seismogenic area a PEACH chart should be compiled, reporting fault features together with the features of the PEACH area and the characteristics of the potential epicentral area effects related to the specific seismic source.

6. Discussion

In the near-field domain, the ground motion effects of a moderate-large earthquake substantially differ from the effects recorded far from the earthquake source. These effects have become a matter of study only on the last decades, and it has been proven that they can impose to structures stronger seismic demands. In particular, in the near-field domain it is possible to observe the presence of vertical ground motion, the high-value velocity pulse-like ground motion, the presence and the effects of permanent displacements and rotational ground motion effects. The consequences on buildings have been widely examined in the last years, but the studies focused mainly on RC and steel buildings, bridges and dams. There is, however, a lack of studies regarding old-masonry building and precast system structures; these studies are really necessary and important, especially in countries where old heritage buildings are present in potential near-field domains, such as in Italy. In fact, the dynamical behaviour of these structures is mainly based on friction and therefore the presence of a meaningful vertical component of ground motion, jointly with a horizontal one, can increase the expected damage. The experimental test done on a typical Mexican colonial temple (Chávez and Meli, 2012) highlighed the importance of considering the vertical component of the seismic motion for stone masonry structures, demonstrating that the effects on structures can be more severe than expected. This should be taken particularly into account when seismic structural improvements are planned.

Furthermore, it is important to underline that different near-field effects might coexist in the seismic ground motion (depending on fault characteristics): this implies that they have to be considered jointly for a correct and comprehensive structural design in near-field domain.

Finally, even if the effects of moderate to large earthquake in the near-field domain are known, not all the seismic codes take them into account; in particular near-field effects are usually considered, in seismic codes, for earthquakes with magnitude greater than 6.5. Furthermore, seismic codes that consider near-field effects always define a distance (from faults or known seismic sources) within that near-field effects should be taken into account.

Evidence of near-field effects has been observed also after earthquakes with magnitudes lower than 6.5 (as for the M_W 6.3 L'Aquila and M_W 5.9 Emilia earthquakes). Although many urban sites are located very near (or even above) seismic active faults that could generate magnitude greater 5.5, the Italian seismic code does not explicitly consider the near-field effects in the structural design.

In order to propose a correct approach to seismic design of structures, it will be necessary to define jointly both the far-field and near-field effects of seismic ground motion. The assessment of near-field ground motion should consider the features proper of the different effects, and not only change the intensity as the actual hazard maps do. Indeed, the definition of the hazard values considers the historical macroseismic records, which also include near-field effects, but the peculiarities of the seismic ground motion in the near-field domain are not enhanced in the results.

A proper approach for computing the seismic hazard requires the joint evaluation of near-field and far-field ground motion; this implies specific efforts to consider the two effects in the hazard map but this appears difficult to apply in the immediate future. Indeed, nowadays, there are still difficulties in identifying the seismogenic faults potentially active and uncertainties in the definition of the seismogenic areas.

The above evaluations lead the authors to hypothesize a preliminary proposal for considering the near-field domain effects as a layer over the current Italian seismic hazard map (identification and characterization of PEACH areas). The boundaries of the PEACH areas and the effects associated to each area should be analysed in depth through specific studies. Furthermore, it is necessary to define proper provisions capable of taking into account the most dangerous effects in the area that should be, at the same time, conceptually correct and as simple as possible to apply. Considering that different seismic codes take into account for near-field effects adopting simplified rules, the authors believe that, despite the uncertainties in the characterization of the seismogenic areas, similar approaches could be adopted also in Italian provisions in order to provide a proper safety level in the whole country.

7. Conclusions

The aims of this paper were to present the state of the art regarding the main possible seismic effects in near-field domains as seismic actions on built environment, and, at the same time, to analyse how those effects are taken into account in the seismic codes at international level and in Italy in particular. The conducted analyses highlight that there could be a deficiency of seismic safety in near-field domains if the near-field seismic effects are not considered in the seismic design, as is the case of the Italian seismic code.

A hypothesis of work for including the near-field effects in the Italian seismic code was presented. In order to consider adequately the ground motion in the seismic design of structures, the authors hypothesize a multi-layer hazard approach, in which the specific contribution of seismic effects within potential epicentral areas (PEACH – Potential Epicentral Area Contribution to Hazard) is defined on the bases of the fault-source characterization derivable from DISS (Database of the Individual Seismic Sources).

The proposal has to be necessarily submitted to the scientific debate; anyway, the results of the analyses highlight that, in order to guarantee an adequate safety level also for people living within potential near-field domains, it is opportune to evaluate if, where and how to include the near-field effects in the Italian seismic design provisions.

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REFERENCES

Abrahamson N.A.; 2001: *Incorporating effects of near fault tectonic deformation into design ground motions*. Presentation sponsored by the Earthquake Engineering Research Institute Visiting Professional Program, hosted by the State University of New York at Buffalo, 26 Oct. 2001, available at http://mceer.buffalo.edu/outreach/pr/abrahamson.asp.

Abrahamson N.A., Somerville P.G.; 1996: *Effects of the hanging wall and footwall on ground motions recorded during the Northridge earthquake*. Bull. Seism. Soc. Am., **86**, S93–S99.

Alavi B. and Krawinkler H.; 2004a: *Behavior of moment-resisting frame structures subjected to near-fault ground motions*. Earthq. Eng. Struct. Dyn., **33**, 687-706.

Alavi B. and Krawinkler H.; 2004b: *Strengthening of moment-resisting frame structures against near-fault ground motion effects*. Earthq. Eng. Struct. Dyn., **33**, 707-722.

Ambraseys N.N., Simpson K.A. and Bommer J.J.; 1996: *Prediction of horizontal response spectra in Europe*. Earthq. Eng. Struct. Dyn., **25**, 371-400.

ASCE; 2010: *Minimum design loads for buildings and other structures*. American Society of Civil Engineers ASCE-7.10.

ATC; 1996: *Seismic evaluation and retrofit of concrete buildings*. Report ATC-40, Applied Technology Council, Redwood City, U.S.A. (also Report SSC 96-01, Seismic Safety Commission, State of California, Sacramento, U.S.A.).

Baker J.W.; 2007: *Quantitative classification of near-fault ground motions using wavelet analysis*. Bull. Seism. Soc. Am., **97**, 1486-1501.

Basili R., Valensise G., Vannoli P., Burrato P., Fracassi U., Mariano S., Tiberti M.M. and Boschi E.; 2008: *The Database of Individual Seismogenic Sources (DISS), version 3: summarizing 20 years of research on Italy's earthquake geology*. Tectonophysics, **453**, 20–43.

Bolt B.A. and Hansen R.A.; 1977: *The upthrow of objects in earthquakes*. Bull. Seism. Soc. Am., **67**, 1415-1427.

Bouchon M., Gaffet S., Cornou C., Dietrich M., Glot J.P., Courboulex F., Caserta A., Cultrera G., Marra F. and Guiguet R.; 2000: *Observations of vertical ground accelerations exceeding gravity during the 1997 Umbria-Marche (central Italy) earthquakes*. J. Seismol., **4**, 517-523.

Bozorgnia Y., Niazi M. and Campbell K.W.; 1995: *Characteristics of free field vertical ground motion during the Northridge earthquake*. Earthquake Spectra, **11**, 515-525.

Brun M., Reynouard J.M., Jezequel L. and Ile N.; 2004: *Damaging potential of low-magnitude near-field earthquakes on low-rise shear walls*. Soil Dyn. Earthq. Eng., **24**, 587–603.

Carydis P., Castiglioni C.A., Lekkas E., Kostaki I., Lebesis N and Drei A.; 2012: *The Emilia Romagna, May 2012 earthquake sequence: the influence of the vertical earthquake component and related geoscientific and engineering aspects*. Ingegneria Sismica, **2-3**, July 2012.

Castellani A., Stupazzini M. and Guidotti R; 2012: *Free field rotations during earthquakes: relevance on buildings*. Earthq. Eng. Struct. Dyn., **41**, 875-891.

CEN; 2003: *Eurocode 8: design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings*. Final Draft prEN 1998, European Committee for Standardization, Brussels, Belgium.

Champion C. and Liel A.; 2012: *The effect of near-fault directivity on building seismic collapse risk*. Earthq. Eng. Struct. Dyn., **41**, 1391-1409.

Chávez M. and Meli R.; 2012: *Shaking table testing and numerical simulation of the seismic response of a typical Mexican colonial temple*. Earthq. Eng. Struct. Dyn., **41**, 233-253.

Chiu H.C., Wu F. J., Lin C.J., Huang H.C. and Liu C.C.; 2012: *Effects of rotation motions on strong-motion data*. J. Seismol., **16**, 829-838.

Chioccarelli E.; 2010: *Design earthquakes for PBEE in far-field and near-source conditions*. PhD Thesis, Dipartimento di ingegneria Strutturale, Università degli Studi di Napoli Federico II, Italy, available at: http://www.dist.unina.it/doc/tesidott/PhD2010.Chioccarelli.pdf.

Collier C.J. and Elnashai A.S.; 2001: *A procedure for combining vertical and horizontal seismic action effects*. J. Earthq. Eng., **5**, 521-539.

Cucci L. and Tertulliani A.; 2011: *Clues for a relation between rotational effects Induced by the 2009 Mw 6.3 L'Aquila (Central Italy) earthquake and site and source effects*. Bull. Seism. Soc. Am., **101**, 1109–1120.

Decanini L.D., Liberatore D., Liberatore L. and Sorrentino L.; 2012: *Preliminary report on the 2012, May 20, Emilia earthquake*. http://www.eqclearinghouse.org/2012-05-20-italy-it/ .

Di Sarno L., Elnashai A.S. and Manfredi G.; 2010: *Seismic response of RC members subjected to the 2009 L'Aquila (Italy) near-field earthquake ground motions*. Report No.01-2010. Mid-America Earthquake Center, University of Illinois at Urbana-Champaign, U.S.A.

Elgamal A. and He L.C.; 2004: *Vertical earthquake ground motion records: An overview*. J. Earthq. Eng., **8**, 663-697.

Elnashai A.S. and Papazoglou A.J.; 1997: *Procedure and spectra for analysis of RC structures subjected to strong vertical earthquake loads*. J. Earthq. Eng., **1**, 121–155.

Garini E. and Gazetas G.; 2013: *Damage potential of near-fault records: sliding displacement against conventional "Intensity Measures"*. Bull. Earth. Eng., **11**, 455-480.

Graizer V. M.; 2005: *Effect of tilt on strong motion data processing*. Soil Dyn. Earthq. Eng., **25**, 197-204.

Grimaz S.; 2012: *Fenomeni near-field come effetti di sito? Un'ipotesi di lavoro che trova riscontri anche nelle osservazioni sul campo in occasione dei recenti terremoti distruttivi italiani*. In: Atti del 31° Convegno Nazionale Gruppo Nazionale di Geofisica della Terra Solida, Potenza, 20-22 November 2012, ISBN: 978-88-902101-2-9.

Grimaz S.; 2014: *Can earthquakes trigger serious industrial accidents in Italy? Some considerations following the experiences of 2009 L'Aquila (Italy) and 2012 Emilia (Italy) earthquakes*. Boll. Geof. Teor. Appl., **55**, 227-237.

Grimaz S. and Maiolo A.; 2010: *The impact of 6th April 2009 L'Aquila earthquake (Italy) on the industrial facilities and lifelines. Consideration in terms of NaTech risk*. Chem. Eng. Trans., **19**, 279-284.

Guidotti R.; 2012: *Near-field earthquake ground motion rotations and relevance on civil engineering structures*. PhD thesis, Department of Structural Engineering Doctoral School in Structural, Earthquake and Geotechnical Engineering, XXIV Cycle.

Hall J.F.; 1998: *Seismic response of steel frame buildings to near-source ground motions*. Earthq. Eng. Struct. Dyn., **27**, 1445-1464

Hamidi Jamnani H., Karbassi A. and Lestuzzi P.; 2013: *Fling-step effect on the seismic behavior of high-rise RC buildings during the Christchurch earthquake*. In: New Zealand Society for Earthquake Engineering conference, Wellington, New Zealand.

Hinzen K.G.; 2012: *Rotation of vertically oriented objects during earthquakes*. J. Seismol., **16**, 797-814.

Housner G.W. and Trifunac M.D.; 1967: *Analysis of accelerograms – Parkfield earthquake*. Bull. Seism. Soc. Am., **57**, 1193-1220.

ICBO; 1997: *1997 Uniform Building Code: Vol.2*. Whittier, California: International Conference of Building Official (ICBO), 2: 34-35.

Iervolino I. and Cornell C.A.; 2008: *Probability of occurrence of velocity pulses in near-source ground motions*. Bull. Seism. Soc. Am., **98**, 2262-2277.

Iervolino I., Chioccarelli E. and Baltzopoulos G.; 2012: *Inelastic displacement ratio of near-source pulse-like ground motions*. Earthq. Eng. Struct. Dyn., **41**, 2351-2357.

Igel H., Brokesova J., Evans J. and Zembaty Z.; 2012: *Preface to the special issue on "Advances in rotational seismology: instrumentation, theory, observations, and engineering"*. J. Seismol., **16**, 571-572.

Kalkan E. and Kunnath S.K.; 2006: *Effects of fling step and forward directivity on seismic response of buildings*. Earthquake Spectra, **22**, 367-390.

Kim S.J. and Elnashai A.S.; 2008; *Seismic assessment of RC structures considering vertical ground motion*. MAE Center Report No.08-03, University of Illinois at Urbana-Champaign, U.S.A.

Kim S.J., Holub C.J. and Elnashai A.S.; 2011: *Analytical assessment of the effect of vertical earthquake motion on RC bridge piers*. J. Struct. Eng., **137**, 252-260.

Kozák J.T.; 2006: *Development of earthquake rotational effect study*. In: Teisseyre R., Takeo M. and Majewski E. (eds), Earthquake source asymmetry, structural media and rotation effects, Springer, Berlin, pp. 3-10, ISBN 3-540-31336-2.

Lee C.T., Kelson K.I. and Kang K.H.; 2000: *Hangingwall deformation and its effects to buildings and structures as learned from the Chelungpu faulting in the 1999 Chi-Chi, Taiwan earthquake*. In: International workshop on Annual Commemoration of Chi-Chi earthquake, September 18-20, 2000, Taipei, pp. 93-104.

Lee W.H.K., Çelebi M., Todorovska M.I. and Igel H.; 2009: *Introduction to the special issue on rotational seismology and engineering applications*. Bull. Seism. Soc. Am., **99**, 945-957.

Li S. and Xie L.-L.; 2007: *Progress and trend on near-field problems in civil engineering*. Acta Seismologica Sinica English edition, **20**, 105-114.

Mallet R.; 1862. *Great Neapolitanian earthquake of 1857, the first principles of observational seismology*. Vol. 2. Chapman and Hall, London, 1600 pp.

Manfredi G., Polese M. and Cosenza E.; 2003: *Cumulative demand of the earthquake ground motions in the near source*. Earthq. Eng. Struct. Dyn., **32**, 1853-1865.

Ministero delle Infrastrutture; 2008: *DM 14 gennaio 2008, Norme tecniche per le costruzioni*. Suppl. or. n. 30 alla G.U. n.29 del 4/2/2008 (in Italian).

Ministry of Construction; 2010: *Code for seismic design of building GB50011-2010*. Architecture & Building Press, Beijing, China.

Mortezaei A. and Ronagh H.R.; *Plastic hinge length of FRP strengthened reinforced concrete columns subjected to both far-fault and near-fault ground motions*. Scientia Iranica, **9**, 1365-1378.

Moustafa A. and Takewaki I.; 2010: *Characterization and modelling of near-fault pulse-like strong ground motion via damage-based critical excitation method*. Struct. Eng. and Mechanics, **34**, 755-778.

Mwafy A.F.; 2012: *Effect of bidirectional excitations on seismic response of RC buildings*. J. Earthquakes and Tsunami, **6**, doi: 10.1142/S1793431112500194.

Newmark N.M.; 1973: *Interpretation of apparent upthrow of objects in earthquakes*. In: Proc. 5th World Conf. Earthquake Eng., Intl. Assoc. Earthquake Eng., Rome 1973, vol. 2, pp. 2338-2343.

Newmark N.M. and Hall W.J.; 1982: *Earthquake spectra and design*. EERI Monograph Series, EERI, Oakland, California.

Newmark N. M., Blume J. A. and Kapur K.K.; 1973: *Seismic design spectra for nuclear power plants*. J. Power Div., **99**, 287–303.

NZS; 2004: *NZS 1170:5: 2004 Structural design actions, Part 5: Earthquake actions – New Zealand*. New Zealand Standards, Wellington, IABN 1-86975-018-7.

Papazoglou A.J. and Elnashai A.S.; 1996: *Analytical and field evidence of the damaging effect of vertical earthquake ground motion*. Earthq. Eng. Struct. Dyn., **25**, 1109-1137.

Shabestari K.T. and Yamazaki F.; 2003: *Near-fault spatial variation in strong ground motion due to rupture directivity and hanging wall effects from the Chi-Chi, Taiwan earthquake*. Earthq. Eng. Struct. Dyn., **32**, 2197-2219.

Shrestha S.; 2009: *Vertical ground motions and its effect on engineering structures: a state-of-the-art review*. In: Proceeding of International Seminar on Hazard Management for Sustainable Development in Kathmandu, Nepal, 29-30 November 2009.

Somerville P.G.; 2000: *Seismic hazard evaluation*. Bull. New Zealand Soc. Earthq. Eng., **33**, 371-386.

Somerville P.G.; 2005: *Engineering characterization of near-fault ground motions*. In: Proceedings of 2005 NZSEE Conference, Wairakei, NZ, 2005.

Somerville P.G., Smith N.F., Graves R.W. and Abrahamson N.A.; 1997: *Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity.* Seismol. Res. Letts., **68**, 199-222.

Teisseyre R., Takeo M. and Majewski E. (eds); 2006: *Earthquake source asymmetry, structural media and rotation effects*. Springer-Verlag, Berlin Heidelberg, 582 pp.

Trifunac M.D.; 2009: *The role of strong motion rotations in the response of structures near earthquake faults*. Soil Dyn. Earthq. Eng., **29**, 382-393.

Trifunac M.D. and Todorovska M.I.; 2001: *A note on the usable dynamic range of accelerographs recording translation*. Soil Dyn. Earthq. Eng., **21**, 275-286.

Ventura C.E., Archila M., Bebamzadeh A. and Liam Finn W.D.; 2011: *Large coseismic displacements and tall buildings*. In: The Structural Design of Tall and Special Buildings, **20**, pp. 85–99.

Zembaty Z.; 2006: *Deriving seismic surface rotations for engineering purposes*. In: Teisseyre R., Takeo M. and Majewski E. (eds), Earthquake source asymmetry, structural media and rotation effects, Springer-Verlag, Berlin Heidelberg, pp. 549-568.

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