IDENTIFICATION OF NEAR-FAULT EARTHQUAKE RECORD CHARACTERISTICS

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ABSTRACT:

This paper compares the characteristics of earthquake ground-motion records obtained in near-fault regions of Greece with well known international near-fault records and simple wavelets. Several parameters of strong motion are evaluated and discussed. Emphasis is given on records from small-to-moderate magnitude earthquake events with M<6.0 which are found to satisfy several damage potential criteria, when recorded at small distances from the source. These records are characterized by pulses of shorter duration and smaller peak ground velocity, *PGV*, than records of greater earthquake magnitude, while representing forward directivity phenomena. Such events can cause extensive damage to medium period structures with fundamental period less than 1 sec which are located close to active faults. A simple expression, based on the ratio of spectral velocity (*SV*) to peak ground velocity (*PGV*), is proposed as a criterion to identify the velocity pulse type of near-source records.

KEYWORDS: strong-motion characteristics, near-fault records, velocity pulse ground motion

1. INTRODUCTION

The importance of the near-source motion characteristics on the elastic and inelastic behaviour of engineered structures has been noted by several researchers, i.e. Naeim (1995), Chopra and Chintanapakdee (2001). The sensitivity of flexible or base isolated structures accommodating the deformation demands of impulsive motion in the near-source region has also been addressed in several studies, e.g., Hall *et al.* (1995). Using simplified mathematical models, a quite extended range of wavelets has been proposed to examine impulsive ground-motion, e.g., Mavroeidis and Papageorgiou (2003). It is broadly accepted that the most severe damage from earthquake activity is localized in a region close to the causative fault, known as the ‘‘near-source’’ region. The expected acceleration amplitude of the ground motion is strongly related to the focal depth of small-to-moderate magnitude earthquakes in short distances from the source (Hall *et al.*, 1995).

Also, significant vertical accelerations are expected to develop, a parameter that increases the possibility of severe damage, a remark made by several researchers, e.g., Elnashai and Papazoglou (1997). Somerville *et al.* (1997) indicated that the damage potential in the near –source region is greatly affected by phenomena related with the propagation of the fault rupture, such as polarization and directivity effects. Velocity pulses of significant amplitude have been related with the hazard induced by strong motion, specially when combined by large displacement demands.

Rupture directivity is found to increase the low frequency content of ground motion at distances within 20km from the focus (Rathje *et al.*, 2004). From the performance-based design point of view, the impulsive motion induced by forward rupture directivity is found to amplify the spectral scaling factors of displacement specified by current codes for a wide range of frequencies (Bommer and Mendis, 2005). Study of the effects of rupture directivity on ground-motion attenuation relationships has led to the conclusion that the period of the pulse increases with magnitude, a parameter related with fault dimensions and source parameters (Somerville, 2003). Therefore, the amplification effect of impulsive motion is limited to a narrow region near the prominent period of the pulse. Small-to-moderate earthquakes are expected to have peaks in their elastic response spectra at frequencies affecting structures with a medium fundamental period as compared with earthquakes of greater magnitude with long period pulses in their near-source records. Although the directivity effect has been thought as limited to earthquake magnitudes greater than M=6.0, it has been ascertained that it can play a significant role in seismic events of smaller magnitude (Bray and Rodriguez-Marek, 2004].

In this study the impulsive character of near-source earthquake records of small-to-moderate magnitude in Greece identified in a previous work of the authors (Spyrakos *et al.*, 2005) is studied, and comparisons are made with international seismic near-source records and simple wavelets. The accelerograms from Greece are obtained from the unified database of GI-NOA and the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) (Theodulidis *et al.*, 2004). Records of international seismic events have been downloaded from PEER, COSMOS Virtual Data Center and NGDC strong motion databases.

2. CRITERIA FOR NEAR-SOURCE RECORDS

Martinez-Pereira and Bommer (1998) examined several definitions of the near-source region by demanding the satisfaction of several criteria at specific lower bound values that are statistically correlated with ground motion intensities greater than or equal to VIII in the Modified Mercalli scale (*MMI*). From the magnitude-distance relation of the records that satisfy all criteria the applicability of Krinitzky and Chang's curve (1987) is confirmed. The criteria define the near-source region in which even well engineered structures could suffer significant damage. The parameters used to select the records attempt to address the complexity of strong seismic motion, such as frequency content, amplitude and duration, given the fact that it is impossible to characterize strong motion accurately using any single parameter (Jennings, 1985).

This procedure has been applied in the available strong motion data of earthquake events from Greece for the period from 1975 to 1999 in order to identify near-source records. The following parameters have been selected:

i) peak horizontal ground acceleration (*PHGA*) or (*PGA*)

ii) cumulative absolute velocity (*CAV*), defined as

$$CAV = \int_0^{t_r} \left| a_g(t) \right| dt \qquad (2.1)$$

where t_r is the total duration of the acceleration trace.

iii) peak horizontal ground velocity (*PHGV*) or (*PGV*) which has been found to be a better indicator of damage potential than *PGA* (Akkar and Özen, 2005) for structures with fundamental frequency in the intermediate range

iv) Arias intensity (I_A) (1970), defined as

$$I_A = \frac{\pi}{2g} \int_0^{t_r} a_g^2(t) dt = \frac{\pi}{2g} \cdot I_E \qquad (2.2)$$

where a_g(t), is the ground acceleration and I_E the integral of the squared ground acceleration.

v) The damage potential parameter proposed by Fajfar *et al.* (1990), (*I*), defined as

$$I = PGV \cdot t_D^{0.25} \qquad (2.3)$$

where t_D is the duration of strong motion, according to Trifunac and Brady (1975). The index incorporates the effects of strong motion duration on the response of medium-rise buildings

vi) The root mean square acceleration (a_{rms}), defined as

$$a_{rms} = \sqrt{\frac{1}{t_D} \int_{t_D} a_g^2(t)dt} \tag{2.4}$$

This index accounts for the effects of amplitude and frequency content of a strong-motion record and is directly proportional to the square root of the gradient of the specified interval of Arias Intensity.

Table 1 presents the lower bounds for the parameters listed above that serve as criteria to identify records that correspond to seismic intensities $MMI \geq$VIII.

Table 1.1 Ground motion parameters, measured characteristics and lower-bound values

Ground Motion Parameters	*Ground Motion Characteristics*				*Lower-Bound*
	Amplitude	*Frequency Content*	*Duration*	*Energy*	
PGA	✓				0.2 g
CAV	✓			✓	0.30 g sec
PGV	✓			✓	20 cm/sec
I_A	✓		✓	✓	0.4 m/sec
I	✓		✓		30 cm sec$^{-0.75}$
a_{rms}	✓	✓	✓		0.5 m/sec^2

Figure 1 presents the results for the simultaneous application of all criteria. The space defined from the lower limits of the strong motion parameters is very similar to that defined by Krinitzky and Chang (1987), an observation originally made by Martinez-Pereira and Bommer (1998). The velocity time histories of the records that are characterized by pulses of significant amplitude and small duration are shown in figure 2.

3. IMPULSE TYPE CLASSIFICATION FOR NEAR-SOURCE GROUND MOTIONS

The effect of near-source ground excitations on earthquake design has been associated with characteristics of the impulsive nature of this kind of motion (Mavroeidis *et al.*, 2004). In the literature, there is a substantial number of simplified representations, used mostly in seismology, in the form of "pulse" shapes that attempt to capture the salient features of near-source ground motions, e.g., Mavroeidis and Papageorgiou (2003). In the present study the velocity pulses are distinguished as type-*A*, type-*B* and type-C_n (Makris, 1997), as shown in figure 3. An evaluation of the eleven near-fault records shown in figure 2 revealed that five records present a single dominant velocity pulse and can be characterized as impulsive motions of type-*B*. The other six records can be characterized as type-*Cn* impulsive motions. It should be noted that type-*A* impulsive motions that are capable to induce significant *MMI* intensities have not been identified from the strong ground-motion records in Greece examined in this study. In order to evaluate and categorize the impulsive types, the following parameters are calculated:

- The predominant period T_p that corresponds to the maximum spectral velocity (*SV*) for ξ=0.05, as defined by Krawinkler and Alavi (1998). According to Bray and Rodriguez-Marek (2004), the period of the velocity pulse T_p is expected to be a function of the moment magnitude, related with the duration of the velocity pulse with the largest amplitude. Also it is ascertained that lower magnitude earthquakes are expected to have lower pulse periods.

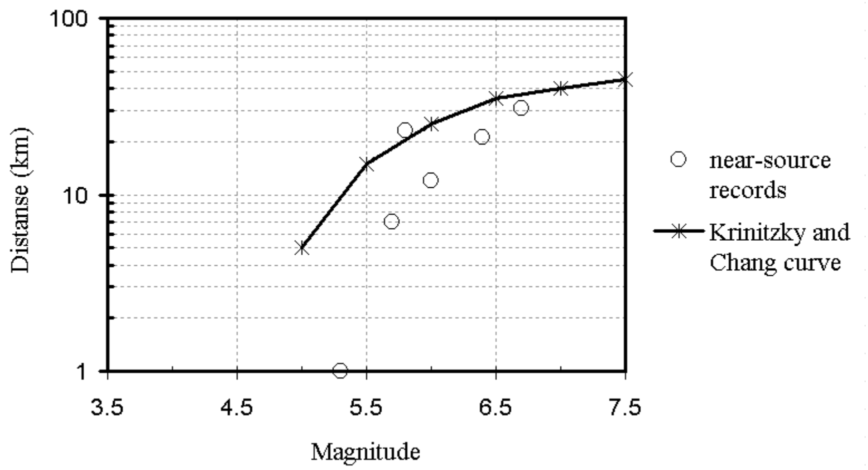


Figure 1 Confirmation of the applicability of Krinitzky and Chang's definition for the near source space with the near-source records from Greece that simultaneously satisfy all the proposed criteria

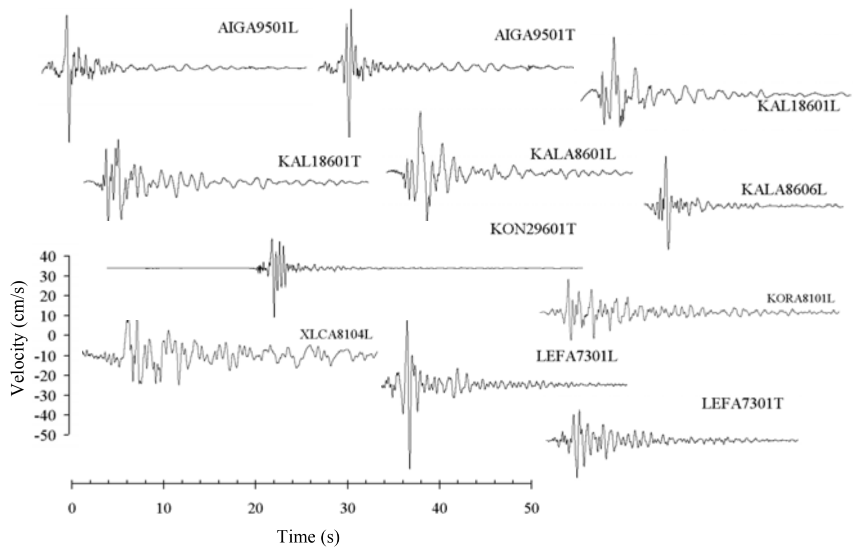


Figure 2 Velocity time histories for the near-source earthquake events from Greece

- The maximum ratio of spectral velocity to peak ground velocity for ξ=0.05 $(SV_{max}/\ v_{go})_{\xi=0,05}$[1]. This normalized index is used in order to facilitate the correlation between the recorded strong motion and the type-*A*, -*B* and -C_n pulses. The number of half-sine cycles in the velocity time history has been related with the fault characteristics and the fault slip distribution (Somerville *et al.*, 1997; Bray and Rodriguez-Marek, 2004).

In figure 4 the results are shown for the parameters calculated for the simple theoretical pulses and the real records. Notice that records of the same earthquake that are obtained at the same hypocentral distance have practically the same value of the SV_{max}/v_{go} ratio, independently of the direction. This similarity is observed, for example, in the Korinthos 1981 and Kalamata 1986 mainshock records, as shown in figure 4.1(a).

The Greek near-source velocity pulses seem to belong to one or one and a half sinusoidal impulsive motion, that

[1] v_{go} symbol is used as an alternative of *PGV*

is type-*B* and type-C_1 pulses, respectively. The type-*A* pulses represented by the continuous line in figure 4.1(a) appear to have the smallest values of the SV_{max}/v_{go} ratio. Even though velocity records with an SV_{max}/v_{go} ratio of about 1.3, which characterizes type-*A* pulses, are not found, it cannot be excluded that type-*A* velocity pulses may be identified in the future. It is also possible that type-*A* velocity pulses have occurred but have either not been recorded or have been distorted by filtering procedures. However, significant permanent displacement phenomena induced by Greek earthquakes that are related with type-*A* velocity pulses have not been reported in the literature (Papazachos and Papazachou, 1997). The absence of this type of pulse is possibly related to the fault characteristics of the Greek region. The role of the type of fault mechanism in affecting the shape and the direction of the predominant pulse is acknowledged in the literature. In the Greek region, which is characterized by dip-slip faulting, a combination of directivity-pulse and fling-step is expected to take place in a horizontal direction (Stewart *et al.*, 2001).

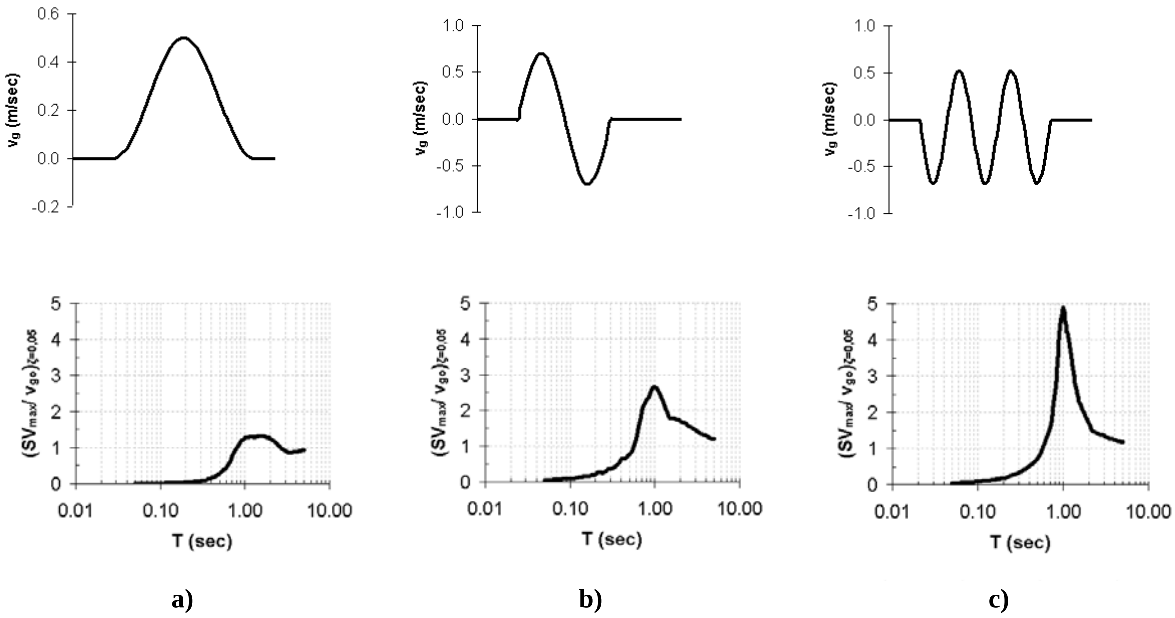


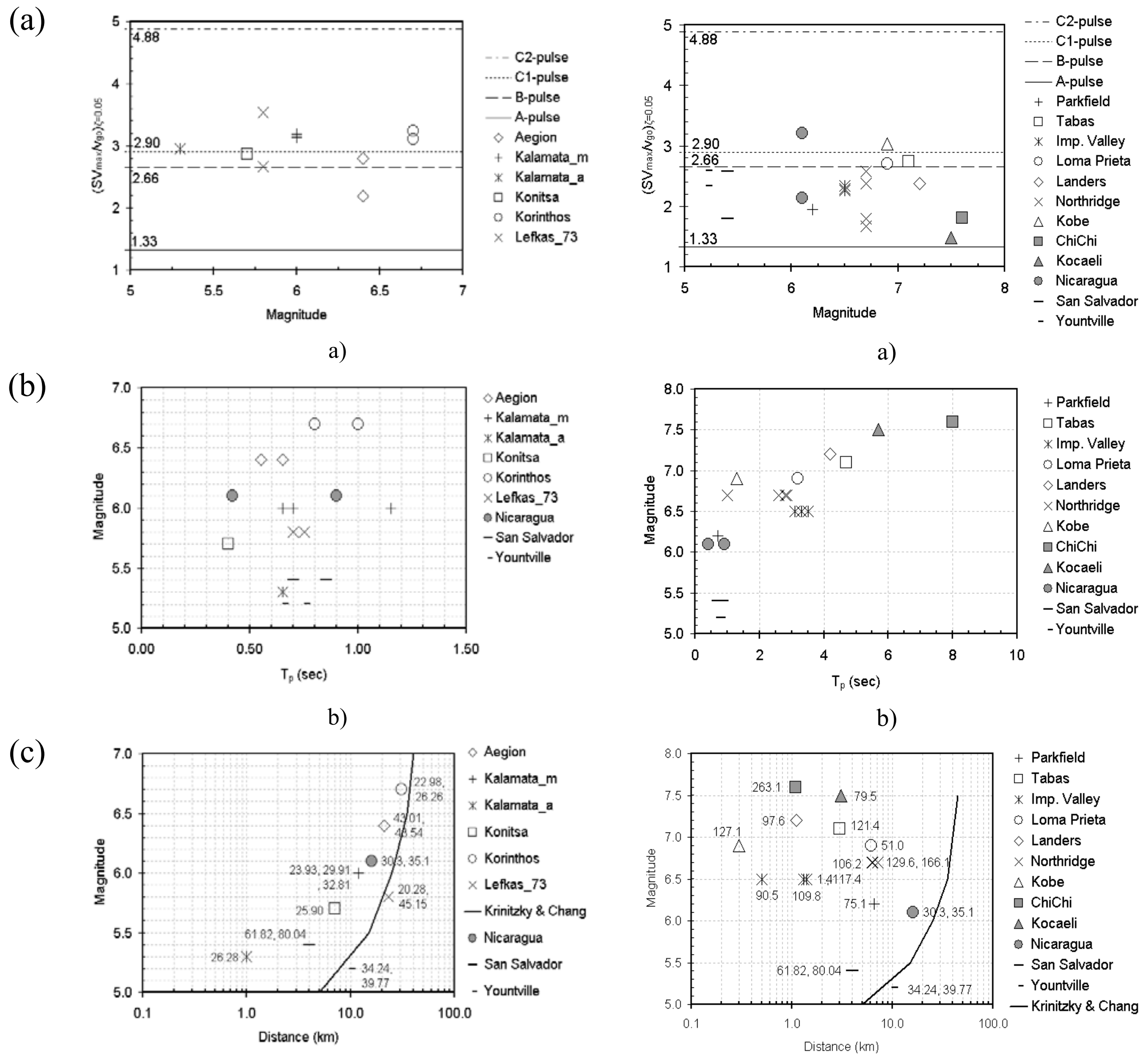
Figure 3 Schematic representation of velocity time history and spectral amplification for: a) Pulse Type-*A*; b) Pulse Type-*B*; and c) Pulse Type-C_2

Figure 4.1(b) presents the predominant periods T_p of the Greek records as related to magnitude, while the relation of the peak ground velocity (*PGV*) with the earthquake magnitude and distance from the source is presented in figure 4.1(c). Notice that *PGV* varies from 20 to 45 cm/s for the Greek records. Since all the T_p values are between 0.4 and 1.15 s (0.87~2.5 Hz), it is expected that the filters used for processing have not distorted the significant part of the strong motion.

4. COMPARISON WITH INTERNATIONAL NEAR-SOURCE RECORDS

The characteristics of the Greek near-source earthquake records are compared with several accelerograms of international seismic events recorded in the near-source region. Representative near-fault records were selected from the Parkfield (1966), Tabas (1978), Imperial Valley (1979), Loma Prieta (1989), Landers (1992), Northridge (1994), Kobe (1995), Chichi (1999) and Kocaeli (1999) earthquakes. These records correspond to great and large earthquakes and have strong impulsive character in their velocity traces. The ground accelerations range between 0.296g and 0.852g. These accelerograms are selected in order to satisfy the criteria of table 1.1 as the records of the Greek region (Spyrakos *et al.*, 2008). Also records of small-to-moderate magnitude earthquakes presenting near-source characteristics are selected from the Nicaragua (1972), San Salvador (1986) and Yountville, CA (2000) earthquakes.

All records satisfy the criteria listed in Table 1.1; thus, they can be characterized as near-source. The great majority of the predominant periods of great and large earthquakes varies between 2 and 8 s, as shown in figure 4.2(b) and are clearly greater than the periods of the Greek pulses shown in figure 4.1(b). It is observed that the predominant period of a pulse tends to increase with magnitude, a fact that agrees with the study of Bray and Rodriguez-Marek (2004). From figures 4.1(c) and 4.2(c) it is shown that *PGV* increases with magnitude and decreases with distance. The $(SV_{max}/ v_{go})_{\zeta=0,05}$ ratio is calculated for the international records and plotted in figure 4.2(a). As shown in figure 4.1(a), velocity traces with prominent type-*A* pulse, like the Chi-Chi and Kocaeli records, present the smallest amplification of spectral velocity.



4.1 **4.2**

Kalamata_m: *Kalamata mainshock* Kalamata_a: *Kalamata aftershock*

Figure 4 Impulsive motion parameters of small-to-moderate Greek and international earthquakes (4.1) and international records obtained at relatively small distances from the source (4.2): (a) $(SV_{max}/ v_{go})_{\zeta=0,05}$ versus magnitude, (b) Magnitude versus T_p, (c) PGV for distance from the source versus magnitude.

The diagrams for the Greek records in figures 4.1(b) and 4.1(c) include only the records of small-to-moderate magnitude international earthquakes, such as the San Salvador 1986 earthquake, that seem to have about the same T_p as the Greek records. Since T_p varies between 0.4 and 1.15 s as shown in figure 4.1(b), medium period structures with fundamental period less than 1s at sites located close to active faults may be subjected to a more damaging motion for earthquakes of lower magnitude. Medium-rise buildings, common to urban areas, with fundamental periods near the predominant period of the velocity pulse induced by a small-to-moderate earthquake, are expected to experience larger earthquake demand than the one caused by seismic events of greater magnitude (Bray and Rodriguez-Marek, 2004). This difference in T_p is more distinct for earthquake magnitudes M_w>6.5 and records obtained at distance less than 7 km from the fault, where the larger values of T_p and *PGV* are recorded, as shown in Figures 4.2(b) and 4.2(c**)**.

5. CONCLUSIONS

The work presents a comparison between Greek records and well-known international near-source records from small, moderate and strong earthquakes. For a rational quantitative selection of near-source records a procedure is applied using several parameters of ground motion to identify records capable to cause intensities greater than VII or VIII on the Modified Mercalli scale (*MMI*).

The predominant period of the velocity pulse, T_p, and the maximum ratio of spectral velocity to peak ground velocity, $(SV_{max}/\ v_{go})_{\xi=0,05}$, are calculated and compared with the corresponding values of the international near-source records and simple wavelets. Since the records identified by the parametric study of the Greek strong-motion databases are obtained in regions in which directivity phenomena have occurred, there is a strong indication that the damage criteria can be successfully used to identify records with near-source characteristics.

Near-source records of small-to-moderate magnitude are found to belong to the upper bound of the near-source region and are characterized by velocity pulses of significantly smaller T_p and peak ground velocity, *PGV*, than records of greater earthquake magnitude, yet capable to threaten medium period structures. The opinion that earthquakes of magnitude smaller than *M*=6.0 could present near-source characteristics is strengthened.

The ratio of spectral velocity (*SV*) to peak ground velocity (v_{go}) for a damping ratio ζ=5% is found to be a good indicator of the velocity pulse type. According to this criterion two or three half-cycles characterize the Greek records velocity traces, classifying them as type-*B* and -C_1 pulse types. It is found that pulse type-*A* related with permanent displacement phenomena does not characterize the available Greek records.

The possibility of severe damage potential to be related with near-source characteristics (forward directivity, polarization) of earthquakes with small-to-moderate magnitude necessitates their inclusion in earthquake engineering design and urges for further research related to near-source effects on medium-period structures.

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REFERENCES

Akkar, S. and Özen, Ö. (2005). Effects of peak ground velocity on deformation demands for SDOF systems. *Earthquake Engineering and Structural Dynamics* **34:13**, 1551-1571.

Arias, A. (1970). A measure of earthquake intensity. In: Hansen RJ, editor. Seismic Design for Nuclear Power Plants, pp. 438-483. Cambridge, Massachusetts: MIT Press. 23.

Bommer, J.J. and. Mendis, R. (2005) Scaling of spectral displacement ordinates with damping ratios. *Earthquake Engineering and Structural Dynamics* **34:2**, 145-165.

Bray, J.D. and Rodriguez-Marek, A. (2004). Characterisation of forward-directivity ground motions in the near-fault region. *Journal of Soil Dynamics and Earthquake Engineering* **24**, 815-828.
Chopra, A.K. and Chintanapakdee, C. (2001). Comparing response of SDF systems to near-fault and far-fault earthquake motions in the context of spectral regions. *Earthquake Engineering and Structural Dynamics* **30**, 1769-1789.
COSMOS Virtual Data center, http://db.cosmos-eq.org/scripts/default.plx.
Elnashai, A.S. and Papazoglou, A.J. (1997). Procedure and spectra for analysis of RC structures subjected to vertical earthquake loads. *Journal of Earthquake Engineering* **1**, 121-155.
Fajfar, P., Vidic, T. and Fischinger, M. (1990). A measure of earthquake motion capacity to damage medium-period structures. *Soil Dynamics and Earthquake Engineering* **9**, 236-242.
Hall, J.F., Heaton, T.H., Halling, M.W. and Wald, D.J. (1995). Near-source ground motion and its effects on flexible buildings. *Earthquake Spectra* **11:4**, 569-605.
Jennings, P.C. (1985) Ground motion parameters that influence structural damage. In: Scholl RE, King JL, editors. Strong Ground Motion Simulation and Engineering Applications, EERI Publication 85-02. Earthquake Engineering Research Institute, Berkeley, California, USA.
Krawinkler, H. and Alavi, B. (1998). Development of improved design procedures for near-fault ground motions. In: SMIP98, Seminar on Utilization of Strong Motion Data. Oakland, CA, USA.
Krinitzky, E.L. and Chang, F.K. (1987). State of the art for assessing earthquake hazards in the United States: Parameters for specifying intensity related earthquake ground motions, US Army Corps of Engineering Waterways Experiment Station, Report 25.
Makris, N. (1997). Rigidity-plasticity-viscocity: can electrorheological dampers protect base-isolated structures from near-source ground motions. *Earthquake Engineering and Structural Dynamics* **26**, 571-591.
Martinez-Pereira, A. and Bommer J.J. (1998). What is the near-field? In: Seismic Design Practice into the Next Century, pp. 245-252. Rotterdam: Booth editions.
Mavroeidis, G. and Papageorgiou, A. (2003) A mathematical representation of near-fault ground motions. *Bulletin of the Seismological Society of America* **93:3**, 1099-1131.
Naeim, F. (1995). On seismic design implications of the 1994 Northridge earthquake record. *Earthquake Spectra* **11:1**, 91-109.
National Geophysical Data Center (NGDC), http://www.ngdc.noaa.gov.
Papazachos, B. and Papazachou, C. (1997). The earthquakes of Greece, Thessaloniki, Ziti editions, Greece.
PEER Strong Motion Database, http://www.peer.berkeley.edu.
Rathje, E.M., Faraj, F., Russell, S. and Bray, J.D. (2004). Empirical relationships for frequency content parameters of earthquake ground motions. *Earthquake Spectra* **20:1**, 119-144.
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. *Seismological Research Letters* **68:1**, 199-222.
Somerville, P.G. (2003). Magnitude scaling of the near fault rupture directivity pulse. *Physics of the Earth and Planetary Interiors* **137**, 201-212.
Spyrakos, C.C., Maniatakis, Ch.A. and Taflambas, J. (2005). Critical evaluation of near-field seismic records in Greece. In: Brebbia CA, Beskos DE, Manolis GD, Spyrakos CC, editors. Earthquake Resistant Engineering Structures, pp. 53-62. WIT Press.
Spyrakos, C.C., Maniatakis, Ch. A. and Taflambas, J. (2008). Evaluation of near source seismic records based on damage potential parameters. Case study: Greece. *Soil Dynamics & Earthquake Engineering* **28**, 738-753.
Stewart, J.P., Chiou, S.J., Bray, J.D., Graves, R.W., Somerville, P.G. and Abrahamson, N.A. (2001). Ground motion evaluation procedures for performance-Based design. PEER report 2001/09.
Theodulidis, N., Kalogeras, I., Papazachos, C., Karastathis, V., Margaris, V., Papaioannou, Ch. and Skarlatoudis, A. (2004) HEAD v1.0: A unified Hellenic Accelerogram Database. *Seismological Research Letters* **75:1**, 36-45.
Trifunac, M.D. and Brady, A.G. (1975). A study on the duration of strong earthquake ground motion. *Bulletin of the Seismological Society of America* **65**, 581-626.