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SOME FLING RESULTS FOR KOECELI 1999

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Abstract

The translation invariant (un-decimated) discrete wavelet transform (uDWT) with de-noising is useful in recovering the low-frequency, acceleration fling-pulse and therefore the velocity fling-pulse and the displacement fling-step. The transform corrects the baseline error embedded in the acceleration and velocity fling-pulse, an error which normally makes double time integration virtually impossible without offsets in velocity and trends in displacements. Sophisticated methods exist, which enable recovery of the velocity and displacement, however the wavelet provides an automated method and recovers features embedded in the event time-history, such as acceleration transient errors, and the fling-pulses, which other methods can only infer.

The wavelet transform is a reasonable and effective alternative for correcting recorded data from strong motion instruments. The invariant transform works by stretching the DWT digital filter i.e. by pushing zeros between the filter coefficients in a dyadic manner. This method is referred to as *a' trous algorithm* i.e. with holes. Furthermore the data is also de-noised, rather than filtered, by applying a threshold, this is especially important at the low-frequency end of the recorded data. Filtering will remove the low-frequency noise and the low-frequency signal, an appropriate threshold on the other hand will remove the low-frequency noise outliers, but not the low-frequency fling signal data. This paper concentrates on the fling pulses obtained from the Kocaeli 1999 event.

Introduction

Baseline errors and their correction are part of the problem encountered in double-time integrating the acceleration time-history to velocity and displacements. The root of the problem lies in the limitations of the instrument itself. Any object subjected to wave-like motion such as a ship on the high seas, an aircraft flying in the atmosphere or a seismometer subject to ground motion, respond in 6 degrees of freedom, which includes pitch, roll and yaw. Most seismometers currently available are 3 degrees of freedom instruments and do not explicitly measure the accelerations due to pitch, roll and yaw. However, these accelerations are sensed by the 3dof accelerometers and therefore make an erroneous contribution to the acceleration time history and make the double-time integration almost impossible. Discussions of these errors with various solutions are found in, Trifunac et al., (1971,2001), Bogdanov and Graizer (1976), Grazier, (1979, 2005, 2006, 2007, 2010), Iwan et al, (1985), (1998), Chiu, (1997), Boore *et al* (2002), Wang, *et al* (2003), Boore, (2001), Boore, and Akkar (2009), Boore and Bommer, (2005), Baker JW (2007), Chen S.-M, and C-H Loh (2007), Wu & Wu (2007), Chanerley and Alexander (2010), Chanerley *et al* (2013). The recorded data on integration give dc shifts in velocity and linear or quadratic trends in displacement in the latter portion of the record, which is a consequence of variations in the baseline of the signal acceleration. These, as described, are brought about by instrument noise, tilts/ground rotations, cross-coupling, giving abrupt jumps in acceleration. The un-decimated wavelet transform provides a novel solution to this problem, is automated and

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which yields additional information, which can only be inferred when using other methods. This paper concentrates on obtaining fling-pulses from the Kocaeli event (1999), which represent the cumulative effect of almost all of the seismic radiation from a fault (Somerville *et al*, 1997).

Fling

The propagation of a rupture towards a site at a velocity that is almost as large as the shear wave velocity causes most of the seismic energy from the rupture to arrive as a single pulse at the beginning of the record (Somerville *et al*, 1997). These strong velocity pulses can cause considerable damage and are due to either directivity (two-sided velocity pulse) or tectonic deformation (one-sided velocity pulse), the latter known as ‘fling’ (Abrahamson, 2001). Both the Sakarya and Yarimca, Durukal (2002), are near fault and show directivity and fling effects with large one-sided velocity pulses in the horizontal components. These pulses then give rise to large dynamic and residual displacements. The objective here is to recover these fling pulses from the recorded time histories, of the Kocaeli 1999 event using the un-decimated wavelet transform.

Using the Un-decimated Discrete Wavelet Transform

The un-decimated discrete wavelet transform (uDWT), Coifman and Donoho, (1995), used by Chanerley et al, (2013) and Chanerley and Alexander, (2010), is a reasonable and effective alternative for correcting recorded data from strong motion instruments. The usual *modus operandi* of the wavelet transform, is digital filtering followed by decimation, this causes aliasing and shift variance, the decimated samples are left unprocessed and then during reconstruction the data are interpolated, overall therefore the DWT, Debauchies I., (1992), Donoho, D L (1995), will introduce some distortion. Therefore the way around this is not to decimate the data, but to keep the original data and data length by using the translation invariant wavelet transform, which operates without decimation and therefore retains the same length of data. The invariant transform works by stretching the filter i.e. pushing zeros between the filter coefficients in a dyadic manner. This method is referred to as the *a’ trous algorithm* (i.e. with holes). Furthermore the data is also de-noised by applying a threshold, rather than filtered, this is especially important in this application at the low-frequency end of the recorded data. Filtering will remove the low-frequency noise and the low-frequency signal, an appropriate threshold on the other hand will remove the low-frequency noise outliers, but not the required low-frequency signal data. De-noising is a non-linear method of removing unwanted signals, it’s advantageous because the spectra of signal and noise can overlap, whereas when filtering they should not, because filtering will remove noise as well as signals which should be retained. However the transform still reduces the bandwidth in octaves as the level increases as in decimation, except that data is not discarded as during a decimation process. Instead the *a ’trous algorithm*, by pushing zeros in between the filter coefficients in a dyadic manner, divides the frequency response in octaves. The frequency response for the Haar wavelet in Figure (1) shows how the frequency band is divided by two (50Hz, 25Hz, etc.) after each up-sampling by adding zeros in powers of two, between the filter coefficients In this particular case the low-pass filter coefficients are given by:

L1 = [0.7071 0.7071]; j=1 (Haar/dB1)
L2 = [0 0.7071 0 0.7071 0]; j=2
L3 = [0 0 0 0.7071 0 0 0 0.7071 0 0 0]; j=3
etc

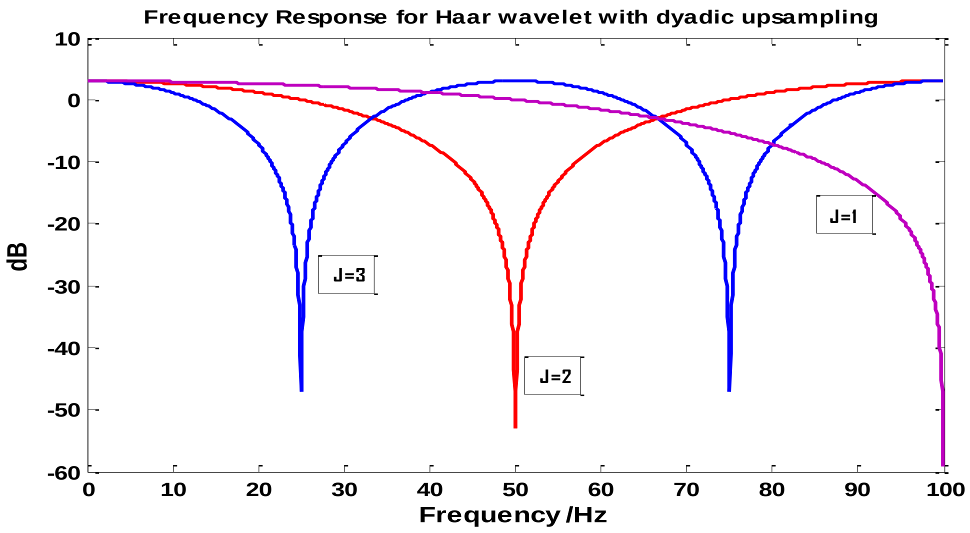

Figure 1

The original Haar coefficients are given in level 1 (L1) above, then the zeros are increased as $(2^{j-1}-1)$, where j is the next level of decomposition. The *á trous* algorithm imitates the sub-sampling (decimation) of the filtered signal as shown in Figure (2), by up-sampling the low-pass and high-pass filters. Their impulse responses (i.e. filter coefficients) are up-sampled versions of the filter coefficients from the previous level. Figure (2) shows the un-decimated case for both the analysis and synthesis filter banks, it should be noted that data remains at the same length, but the filters coefficients are dyadically interpolated. The *á trous* transform can be applied as a circular convolutions with multiplications by zero elements, being omitted.

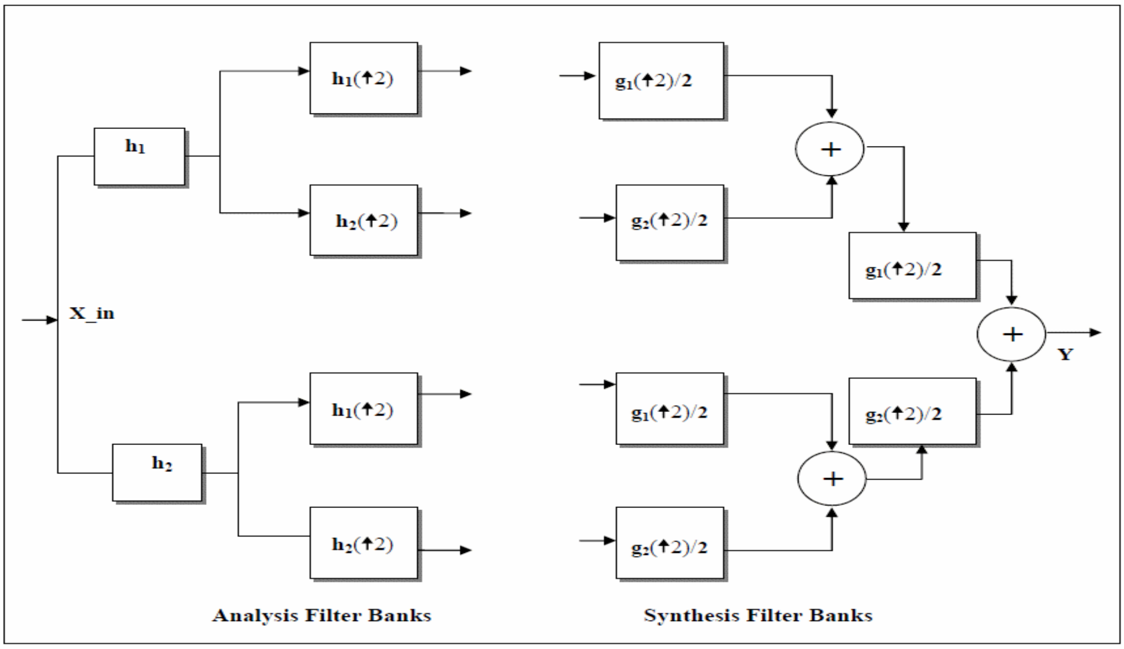

Figure 2. The un-decimated wavelet transform filter banks, showing the dyadic up-sampling of the filter coefficients, i.e. the pushing of zeros in between the coefficients

The Kocaeli Event 1999

On the 17th August 1999 (Mw 7.4), districts Kocaeli and Sakarya, and 12th November 1999 (Mw 7.2), district Duzce, earthquakes struck the industrial heartland of Turkey, severely affecting the districts of

Kocaeli, Sakarya, Bolu and Yalova. The earthquake arises as a result of the motion of the north Anatolian block of crust, compressed by the Arabian and Eurasian plates (Durukal, 2002]).The Kocaeli earthquake is associated with the North Anatolian fault, which has a length of 1500km and is one of the most active and largest strike-slip faults in the world. It can causes destructive earthquakes by slipping at an average rate of 20–25 mm/year. The earthquake which occurred in Kocaeli on August 17th, 1999, ruptured about 145km of the surface. The epicentre was at the eastern end of the Marmara Sea, in Golcuk, and the depth was about 10km. The Kocaeli earthquake took about 18,000 lives

The Kocaeli earthquake in particular recorded 6 strong ground motions within 20km of the fault, these are at stations in Sakarya, Yarimca, Izmit, Duzce, Arcelik, and Gebze. This paper presents long-period, fling results for some of the recorded strong motions of the aforementioned 6 stations, the data is obtained from the Turkish, National Strong-Motion Observation Network (TR-NSMN). The stations closest to the fault rupture are Yarimca and Sakarya, at 4.4km and 3.3km respectively, with PGA's of 0.3g and 0.4g respectively with Sakarya on stiff soil whilst Yarimca on soft soil. Both Sakarya and Yarimca were subject to forward directivity effects differences in soil types also influence the ground motion with Sakarya being on rocky sites and Yarimca on soft soil sites.

Sakarya E-W and Vertical Components (1708199900:01:39.07)

The wavelet transform is applied to the Sakarya EW and Vertical component recorded at a sampling rate of 100Hz with a total of 38881 points. The Fig 4 shows the resultant plot of both the low-frequency and higher frequency sub-band reconstructed. The level of decomposition for these results is at level 8, using the bi-orthogonal wavelet *bior2.2*, which has linear phase in both decomposition and reconstruction. The total time for this event is 388.81sec, but in this case the plots are zoomed for clarity of results around the peaks. The maximum displacement is 194.9cm, the residual displacement is 167.1cm and the peak velocity is 81.01cm/sec.

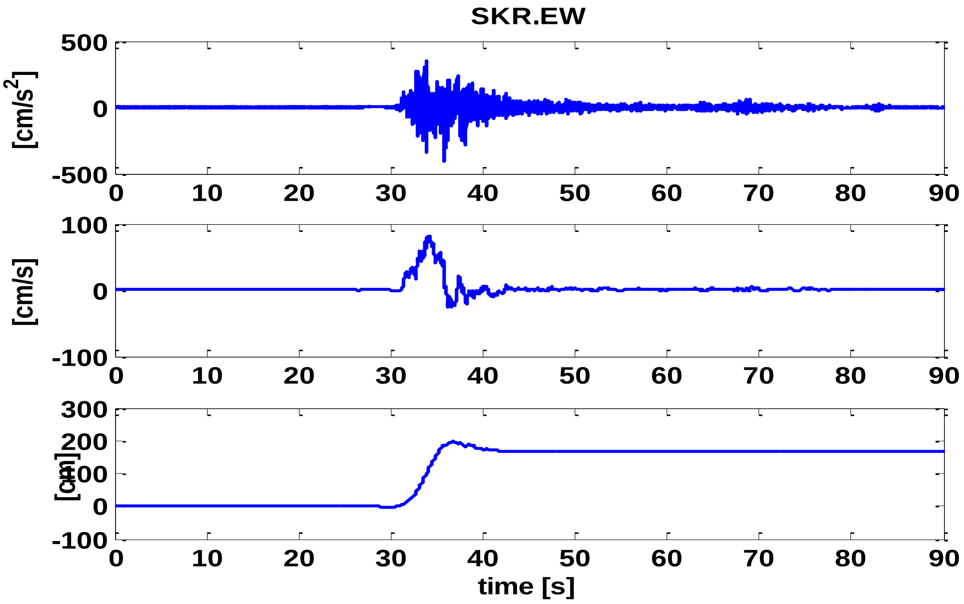

Figure 3. Resultant acceleration, velocity and displacement plots

If we now examine Fig 4, this shows the recovered low-frequency sub-band, fling-pulse, which has an acceleration pulse-period of 8.9sec, a maximum acceleration of -27.4cm/s^2 and a pk-pk magnitude of 48.7cm/sec^2. The velocity fling-pulse has a peak at 55.89cm/sec and a one-sided pulse-period of 6.95sec. The peak displacement is 194.2cm and the residual is 167.1cm.

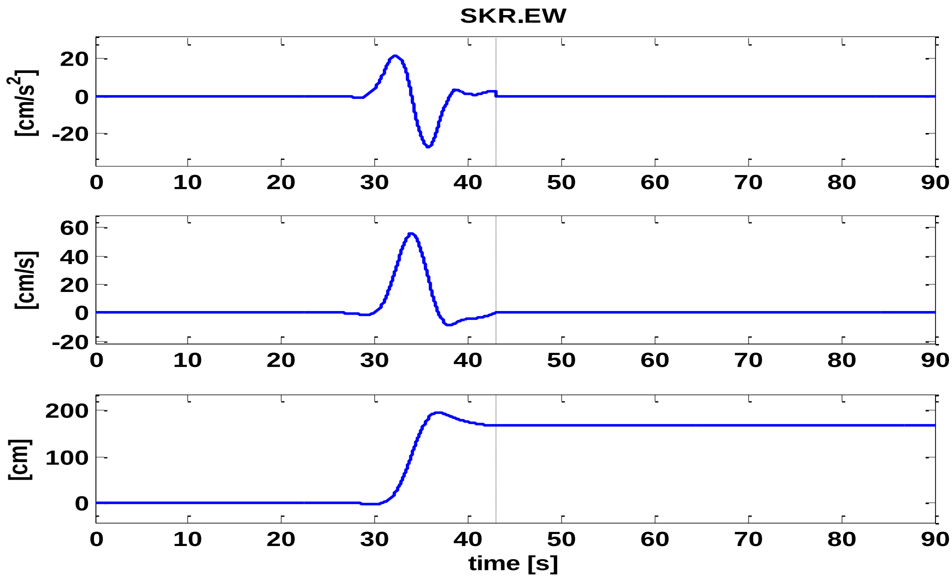

Figure 4. The acceleration and velocity fling-pulse, and the displacement fling-step.

The fling data for the vertical component was recovered using *bior2.2* as for the EW component, also at level 8 decomposition. The fling pulse is shown giving a two sided velocity pulse. Table 1 gives a summary of the fling data for the Sakarya station.

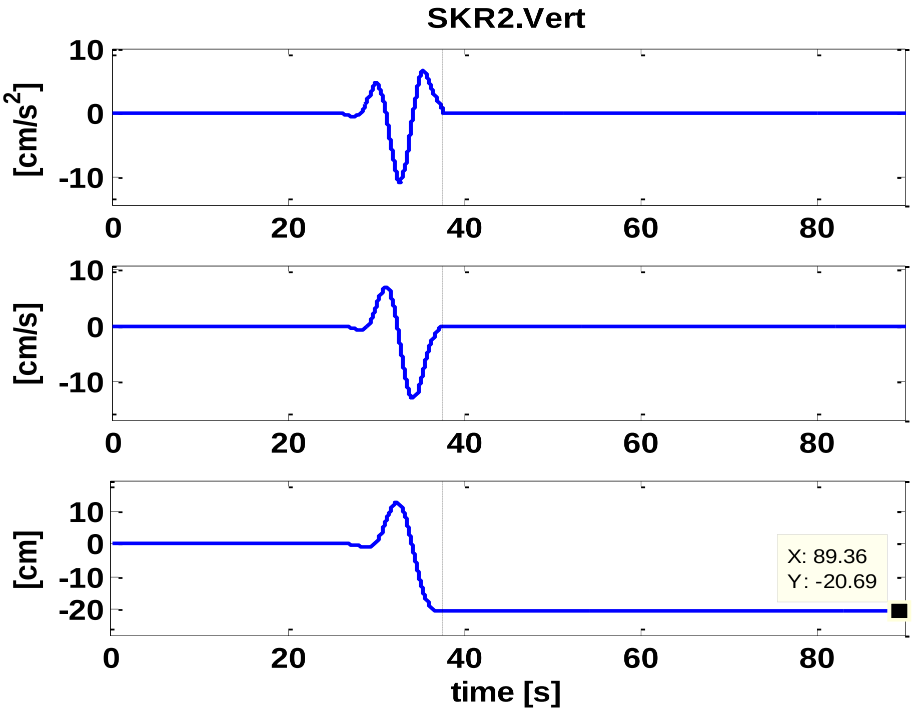

Figure 5. The acceleration and velocity fling-pulse, and the displacement fling-step.

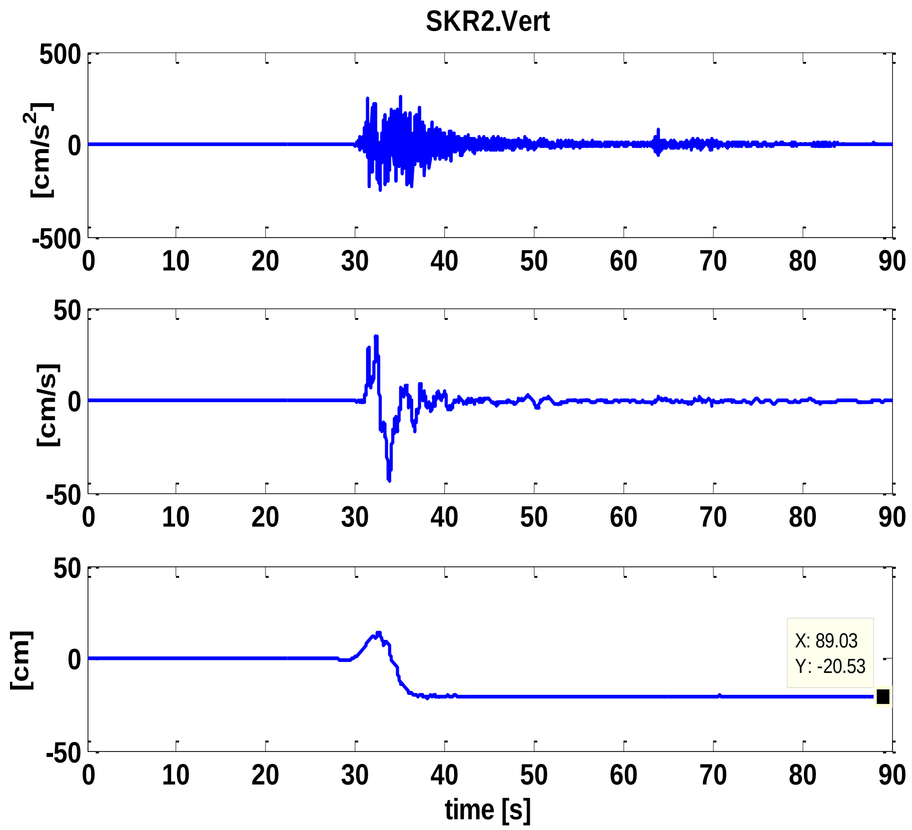

Figure 6. Resultant acceleration, velocity and displacement plots

Table 1 Sakarya low-frequency sub-band 'fling' summary

Summary for Sakarya (Kocaeli 1999) Fling Data from Figures 4 and 5						
East-West Comp	-27.4	55.89	194.2	8.9	6.95	167.1
Vertical Comp	-10.8	-12.77	-20.69	9.26	8.38	-20.69
	Peak Accel	Peak Vel	Peak Displ	Pulse Width (Accel)	Pulse Width (Vel)	Residual Disp
	cm/s/s	cm/s	cm	sec	sec	cm

The existence of a large, velocity fling-pulse in the E-W direction (fault parallel) suggests that it is due to a permanent tectonic deformation rather than due to directivity effects (Abrahamson 2001), (Somerville *et al*, 1997), (Durukal, 2002. The vertical direction showed a two-sided velocity pulse and a displacement of approximately 20 cm.

Yarimca Petkim Station (YPT) Components (0817199903:01:39)

The Yarimca Petkim station demonstrates similar strong motion characteristics to that of the Sakarya station, with strong pulses and substantial residual displacements. As for Sakarya, the station is within a 20km radius of the epicentre. One-sided pulses occur in both the fault normal and fault parallel directions suggesting tectonic deformation. According to Somerville *et al* (1997), the radiation pattern shows that it is usually expected that the fault normal one-sided pulse is significantly larger than the fault parallel pulse, here the reverse is true. The fault normal pulse, though large is smaller than the fault parallel pulse, moreover both have a similar profile and suggest therefore a tectonic effect rather than that due to directivity, or perhaps a combination of both. Figures 7, 8 and 9 show the fling-pulses and fling-steps for acceleration and velocity and displacement for the fault parallel (EW) component the decomposition was performed using *bior2.2,* at level 9 decomposition in all cases.

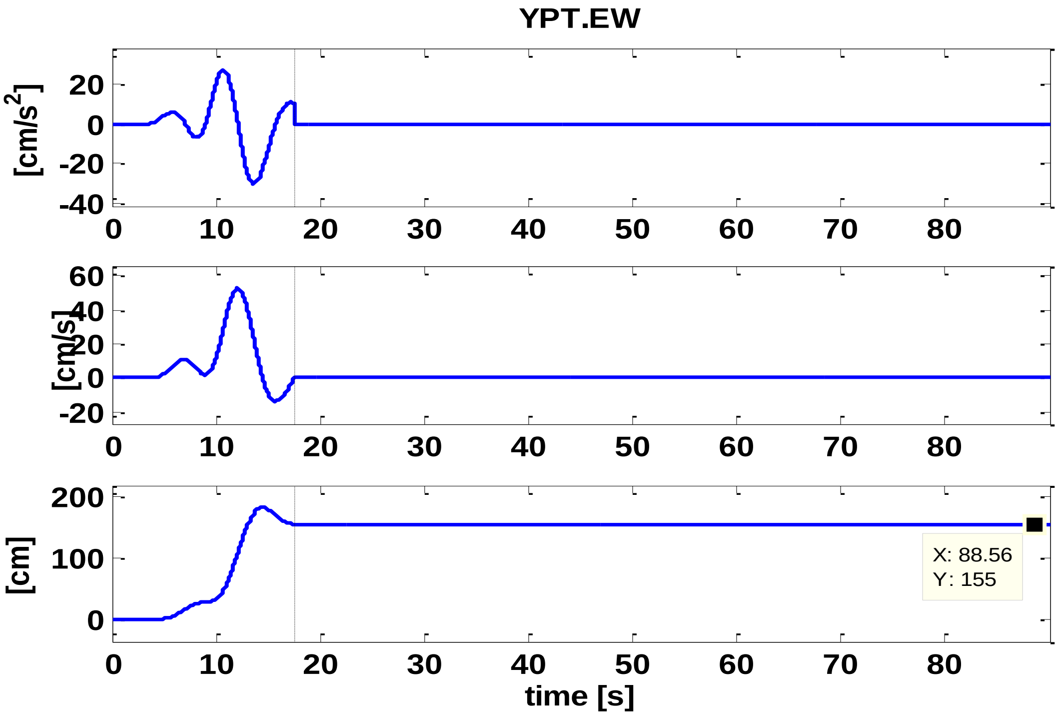

Figure 7. The YPT-EW acceleration and velocity fling-pulse, and the displacement fling-step

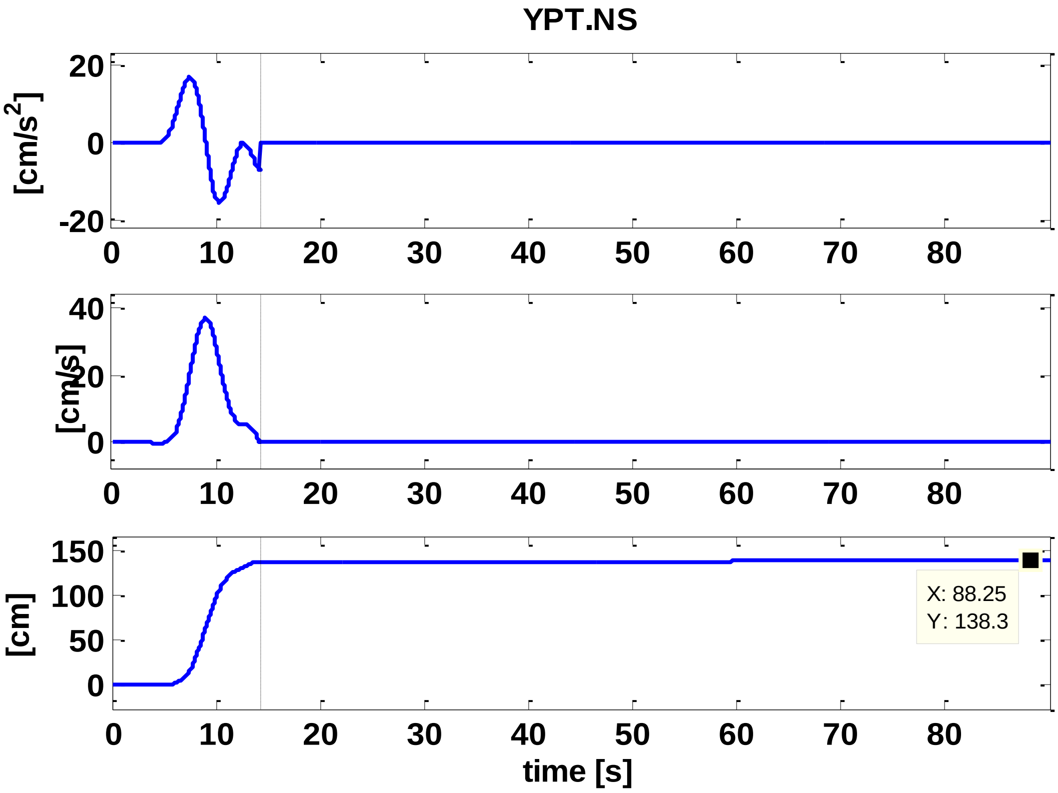

Figure 8. The YPT-NS acceleration and velocity fling-pulse, and the displacement fling-step

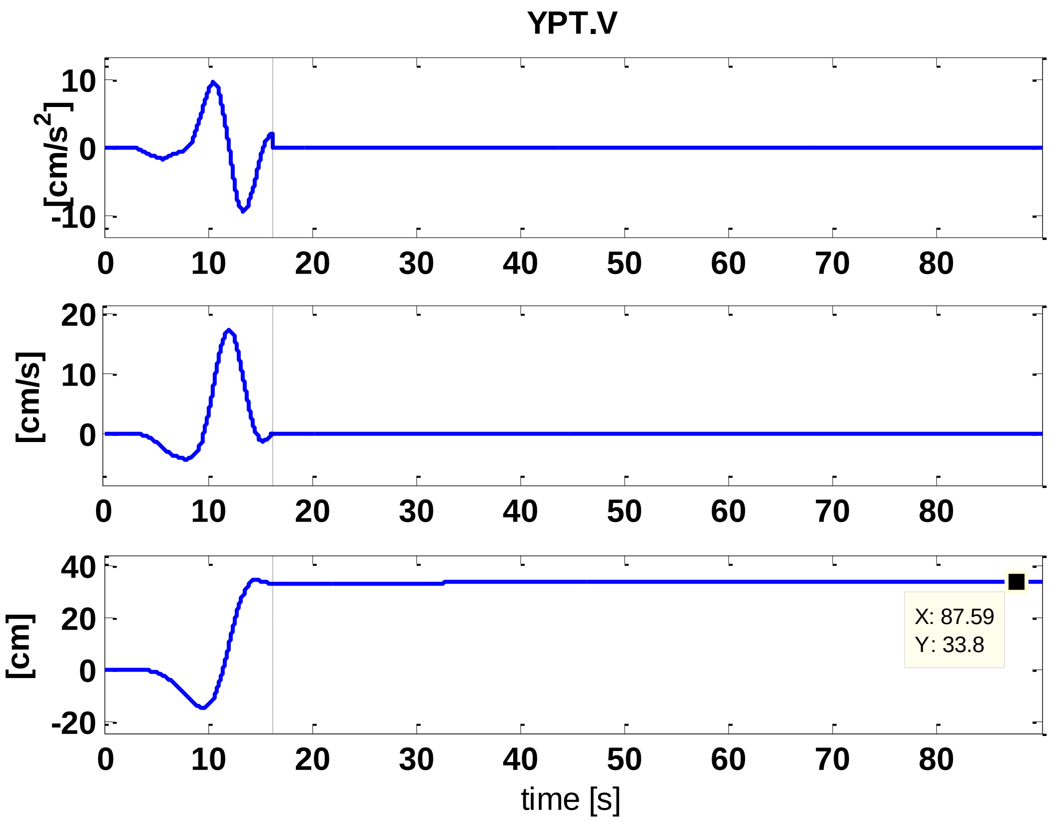

Figure 9. The YPT-Vertical acceleration and velocity fling-pulse, and the displacement fling-step

Table 2 gives a summary of the fling-data only for the Yarimca (YPT) station, the fling-pulse peak velocity (EW) is shown as 52.84cm/s/s, whereas the overall peak velocity is 86.23cm/s, the overall peak displacement is 184cm and the residual displacement is 155cm. Similarly for the (NS), the fling-pulse peak velocity is 36.95 cm/s, the overall peak velocity is 85.35 cm/s and the peak and residual displacement is 138.3 cm.

Table 2 Yarimca low-frequency sub-band 'fling' summary

Summary for Yarimca (YPT) (Kocaeli 1999) Fling Data from Figures 7 and 8						
East-West Comp	-29.83	52.84	182	6.71	8.97	155
North-South Comp	16.6	36.95	138.3	7.61	8.93	138.3
Vertical Comp	9.7	17.16	34.5	7.3	5.2	33.8
	Peak Accel	Peak Vel	Peak Displ	Pulse Width (Accel)	Pulse Width (Vel)	Residual Disp
	cm/s/s	cm/s	cm	sec	sec	cm

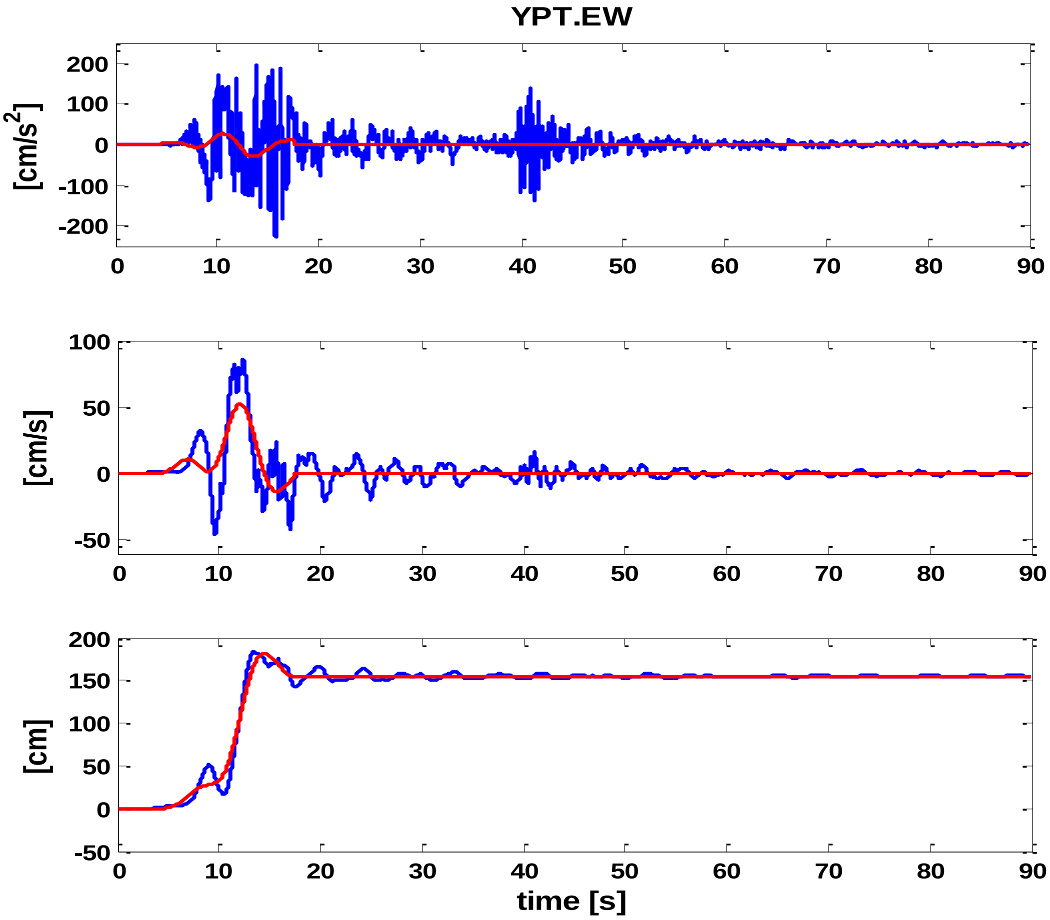

Figure 10. The YPT-EW acceleration and velocity fling-pulse, and the displacement fling-step, superimposed on the overall resultant time histories for the acceleration, velocity and displacement.

Finally, Figure 10 shows the fling-pulse for the acceleration and velocity and the fling-step for the displacement superimposed on the overall time-history profiles, after processing using the un-decimated wavelet transform and integrating the corrected time-history.

Summary

The un-decimated wavelet transform is a novel method for analysing seismic events from recorded time histories. The advantage of using the transform is that it produces additional information hitherto unobtainable. In particular and in the context of this paper, the transform is able to isolate and recover fling-pulses and fling-steps from the Kocaeli 1999 event and draw some conclusions with regard to directivity effects and or tectonic deformation. Furthermore, analysis of structures such as bridges, dams, tall buildings, often use time histories in conjunction with response spectra, which include rupture directivity effects, these sorts of structures are sensitive to long period ground motions.

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