Journal of Scientific & Industrial Research
Vol. 66, September 2007, pp.741-747

Performance characteristic of indigenously developed 24-bit seismic data recorder for earthquake seismology

Vishnu Kumar Pandey, Satish Kumar, B K Sharma* & M A Shamshi

Central Scientific Instruments organization (CSIO), Sector 30 C, Chandigarh 160 030

Received 19 June 2006; revised 10 April 2007; accepted 16 April 2007

This paper describes long term performance of CSIO developed seismic data acquisition tested on local, regional and distant earthquakes in comparison with imported data acquisition system. Waveform data is cross-correlated to test the similarity and validate the results. Two major earthquakes have been considered for cross-correlation procedure and the results have been analyzed and explained. CSIO developed 24-bit seismic data recorder has been explained.

Keywords: Earthquake, Seismic data recorder, Waveform data

IPC Code: G01V1/24

Introduction

A number of seismic data acquisition system (SDAS) to record earthquake data are available in international market[1]. CSIO, Chandigarh has developed various analog and digital data acquisition systems to fulfill a gap by developing indigenous technology. This paper describes the performance evaluation of CSIO developed 24 bit SDAS by comparing the recording of same events with similar 24 bit imported unit (REFTEK make) in term of first motion travel time, polarity and ground motion.

CSIO developed 24 Bit Seismic Data Recorder

A 24 bit SDAS (Fig. 1a) has been designed around PC-architecture concept for recording weak motion by incorporating 24 bit digitizer consisting of (Fig. 1b): i) Back plane card; ii) Processor module; iii) Disk-on-chip (DOC) module; iv) Pre amplifier and signal conditioning module; v) Analog-to-digital converter (ADC) modular card; vi) Sensor calibration card; and vii) Global positioning system (GPS) modular card with active antenna and large storage device (hard disk). CSIO design has 'Ethernet Interface' for transferring recorded data at very high speed. Inbuilt DOC contains embedded software to control system operation as per design. System is capable to function as a local node in any regional network. System software designed around VC++ as an inbuilt part of SDAS takes care of SDAS operations as per field parameters (pre event, post event, STA period, LTA period, trigger ratio, de-trigger ratio, sampling rate, minimum number of channel for trigger, filter in Hz etc.). Digital filtering is applied to incoming signals from seismic sensor and digitized values are stored at defined location in circular buffer. System software computes STA and LTA values to declare true seismic event, i.e. when STA/LTA is equal to or greater than trigger ratio, the instrument starts recording as per programmed parameters (CSIO, unpublished technical manual).

Results and Discussion

Comparison of Waveform and Travel Time of Recorded Earthquakes

CSIO developed 24-bit SDAS has been installed at IMD Seismological Observatory, New Delhi for long-term performance evaluation and the results were found comparable with the similar system installed at IMD, New Delhi. For further performance evaluation of CSIO developed instrument, it has been installed in CSIO seismological observatory, Chandigarh, along with similar imported seismic recorder of M/S Reftek. Reftek system was interfaced with three component short period L-4C-3D mark products make short period seismometer.

*Author for correspondence
Tel: 0172-2657266; Fax: 0172-2657267
E-mail: erbks@yahoo.com

The seismometer is a spring-mass sensor with electromagnetic transduction[2]. Its permanent magnet assembly is the seismic mass while the coil is attached to frame. As ground moves, the coil moves up and down in a magnetic field due to some external force. An induced EMF is generated, and this generates a voltage across the coil, which is proportional to velocity of the mass of seismometer. Output voltage of coil terminals gives measure of the ground motion (1). Calibration, repeatability and stability of transducer have been taken care during testing and data recording. However due to non-availability of an other three component seismometer at CSIO seismological observatory, a short period single component seismometer model S-13 (M/S Geotech make) has been interfaced with CSIO developed system.

Both the recorders have been kept in event trigger mode recording based on STA/LTA ratio. CSIO recorder recorded all the events, which have been recorded by Reftek instrument. Since CSIO recorder is connected with vertical component seismometer, therefore, data recorded by vertical component of Reftek recorder was compared. For the comparison of first arrival time and polarity of first motion, CSIO took local, regional and distance earthquakes (Table 1). To compare similarity of waveform of vertical component of these earthquakes, the waveform recorded by CSIO recorder has been merged with the waveform recorded by Reftek instrument (Fig. 2). Waveforms of earthquakes, which are recorded by CSIO instruments, are similar to that of recorded by Reftek instrument. Travel time of first P wave arrival of earthquakes recorded by CSIO recorder is comparable to that recorded by Reftek recorder (Table 1). Polarity of first ground motion recorded by both recorders is also same.

(a)

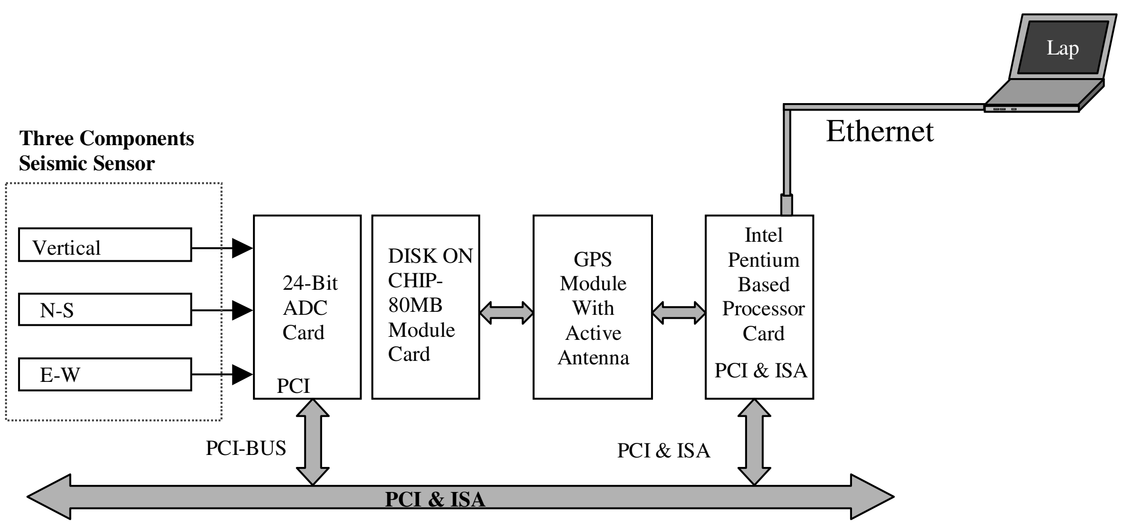
Comparison of Ground Motion using Cross-Correlation

In signal processing, cross-correlation (cc) function is the measure of degree of similarity between the two time series. If $x_1(t)$ and $x_2(t)$ is two time series, then cc function can be written as

$$r_{12}(\tau) = \int_{-\infty}^{\infty} x_1(t) x_2(t+\tau) dt \quad \text{... (1)}$$

Normalized cc function is written as

$$r_{12}(\tau) = \frac{1}{T} \int_{0}^{T} x_1(t) x_2(t+\tau) dt \quad \text{...(2)}$$



b)

Fig. 1—CSIO designed 24-bit seismic data acquisition system: a) Photograph; b) Block diagram

Table 1—Comparison of travel time and polarity for different type of earthquakes

Sl. No.	Date of events	EQ parameters[2] (Agency, USGS)	Reftek developed recorder data		CSIO developed recorder data		Nature
			P wave Arrival time UTC hh:mm:ss.mss	Polarity	P wave Arrival time UTC hh:mm:ss.mss	Polarity	
1	26/11/2004	Region, Haryana OT, 23:53:56 Lat, 30.68°N, Lon, 77.20°E D, 42 km, 3.7 M	23:53:59.247	D	23:53:59.248	D	Local
2	16/08/2005	Region, Uttranchal OT, 03:45:54 Lat, 30.92°N, Lon, 78.56°E D, 42 km, 4.4 M	03:46:19.450	C	03:46:19.452	C	Local
3	05/04/2004	Region, Hindukush OT, 21:24:04 Lat, 36.51°N, Lon, 71.03°E D, 187 km, 6.6 M	21:25:49.272	D	21:25:49.139	D	Regional
4	10/08/2004	Region, Hindukush OT, 01:47:32 Lat, 36.44°N, Lon, 70.80°E D, 207 km, 6.0 M	01:49:20.549	C	01:49:20.551	C	Regional
5	26/12/2004	Region, Indonesia OT, 00:58:53 Lat, 03.30°N, Lon, 95.98°E D, 30 km, 9.0 M	01:05:24.832	C	01:05:24.835	C	Distance
6	28/03/2005	Region, Indonesia OT, 16:09:36 Lat, 02.97°N, Lon, 97.11°E D, 30 km, 8.7 M	16:16:24.147	C	16:16:24.149	C	Distance

USGS: United State Geological Survey, USA; Lat: Latitude; Lon: Longitude; D: Depth; M: magnitude; hh: Hours; mm: Minutes; ss: Seconds; mss: Milliseconds

where N is number of samples in each time series. If the value of normalized cc function is +1 or near to this value then both time series are very similar to each other and if the value of cc function is -1 or near to it then both the time series are opposite to each other.

To perform cc operation, 1-second data was extracted from vertical component of waveform of similar earthquakes recorded by these two recorders. Likewise, 6 sets of 1-second data available related to 6 earthquakes were made for cc purpose. CSIO developed data acquisition system (DAS) recorded data at 60 samples per second rate while Reftek DAS recorded data at a rate of 100 samples per second. Therefore, to get the same sample rate, it is necessary to reduce the information in time series by resample technique of the data, which has more samples. Hence Reftek data was

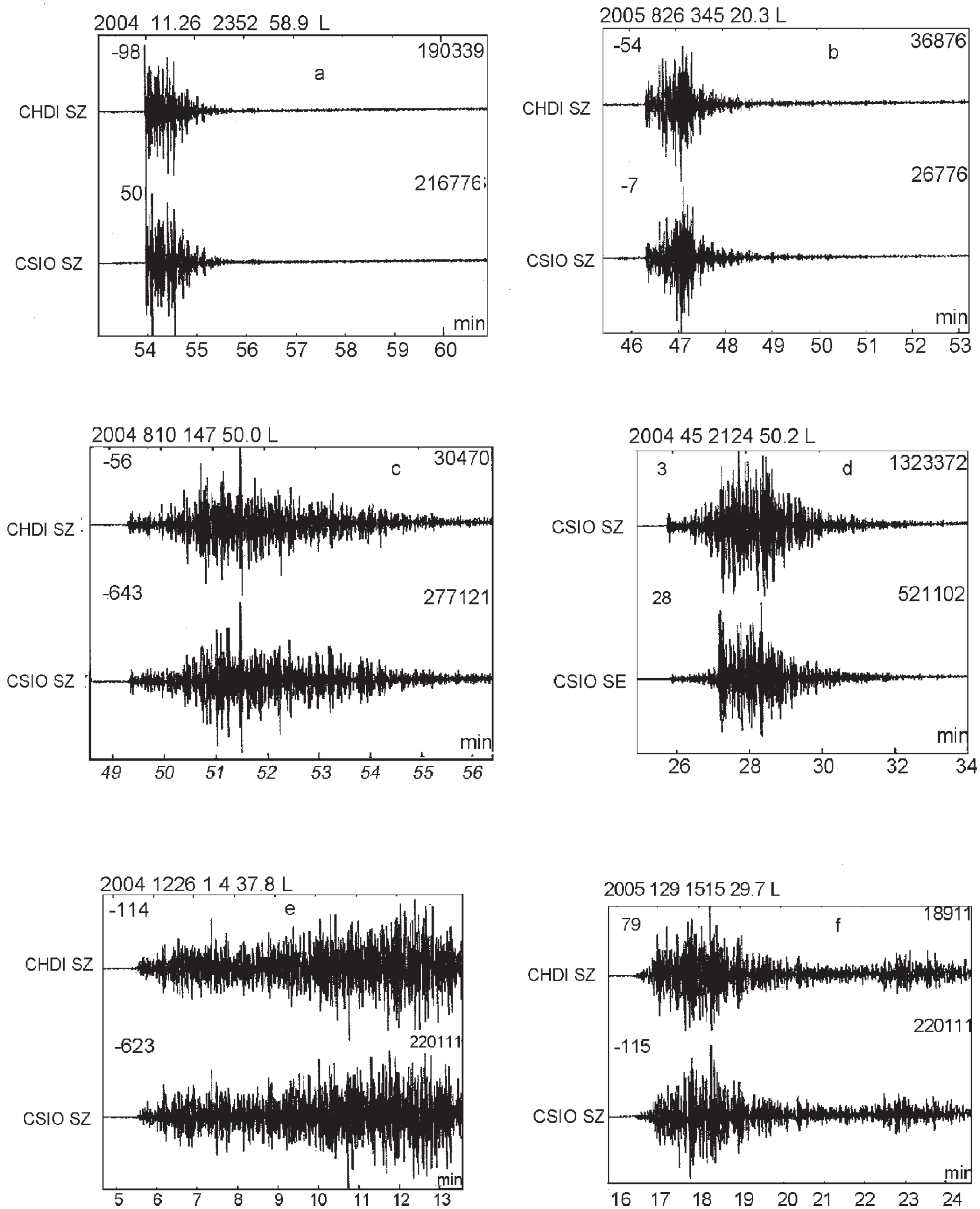


Fig. 2—Seismic data recorded by Reftek instrument (above) and data recorded by CSIO instrument (below) in all figures for earthquake: a) 26th November 2004 near Chandigarh; b) 16th August 2005 Uttarkashi; c) 10th August 2004 Hindukush; d) 5th April 2004 Hindukush; e) 26th December 2004 Indonesia; f) 28th March 2005 Indonesia

resampled from 100 samples per second to 60 samples per second. The resampling was done using polyphase filter implementation given in MATLAB signal processing tool box[3].

Since two different seismographs (24 bit resolution each), which have different sensors and different DAS, recorded two waveforms, therefore they would alter the recorded ground motion because of different instruments characteristics (generator constant, ADC bit resolution amplification etc). Therefore, instrument correction is required to apply to these 1-second waveforms in order to remove the effect of instrument on recorded ground motion. For applying instruments correction, it is considered that ground motion (velocity) due to an earthquake convolved with the impulse response of digital seismograph and thus gives output in term of counts or voltage. This can be written as

$$y(t) = x(t) * z(t) \quad \text{...(3)}$$

where *y(t)* is output of digital seismograph, *x(t)* is input ground motion and *z(t)* is impulse response of seismograph. Therefore, instrument corrected ground motion can be obtained by deconvolve the output time series to the impulse response of digital seismogram. This can be done by converting the output of seismograph i.e. digital seismogram into frequency domain and divide it by frequency response of instrument at each frequency step as given in Eq. (4) and Eq. (5) respectively.

$x_2(n)$

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{i\omega t}\,d\omega$$

$$Y(\omega) = \int_{-\infty}^{\infty} y(t)e^{-i\omega t}\,dt \quad \text{...(4)}$$

$$X(\omega) = \frac{Y(\omega)}{Z(\omega)} \quad \text{...(5)}$$

where *X (ω)* is corrected ground motion of the instrument in frequency domain, *Y (ω)* is recorded seismic signal in frequency domain and *Z (ω)* is frequency response of seismograph. Ground motion in time domain can be obtained by inverse Fourier transform of *X (ω)*

...(6)

The frequency response of seismograph can be calculated by combining frequency response of seismometer, filters and amplifiers used in digital seismograph and multiplying combined frequency response to total gain of seismograph at each frequency[4].

$$FR_{total} = FR_{seismometer} * FR_{filter} * FR_{amplifier} * FR_{ADC}$$
$$Gain_{total} = Gain_{seismometer} * Gain_{filter} * Gain_{amplifier} * Gain_{ADC}$$

Velocity frequency response of electromagnetic seismometer is given as[5]

$$T(\omega) = \frac{\omega^2}{\omega_0^2 - \omega^2 + i2\omega\omega_0 h} \quad \text{...(7)}$$

where ω_0 is angular natural frequency of seismometer, ω is angular frequency of input signal and *h* is damping factor. For estimating frequency response of Reftek system and CSIO system following parameters are required[6,7] respectively: natural frequency of seismometer, 1Hz, 1 Hz ;generator constant of seismometer, 276, 629 volts/m/sec[8]; damping factor of seismometer, 0.7, 0.7; and recording media gain, 1.907, 0.298 μvolts/count.

By re-sampling techniques, sample rate of Reftek recorded data has been reduced from 100 sps to 60 sps. Re-sampling reduces reference DAS recorded data 100 SPS to 60 SPS. Thus 60 samples in each time series were extracted from earthquake data. An 8-pole band pass butter-worth filter (1-5 Hz) has been applied to 1-second data and instrument correction has been applied. These 6 sets instruments corrected time series will be cross-correlated to test similarity between two waveforms recorded by CSIO DAS and reference system. For discrete data, Eq. (1) of cc can be written as

...(8)

where *j* represents amount of lag, which is number of sampling points by which has been shifted to the left. Since both data acquisition systems have been placed at same place, therefore whenever earthquakes

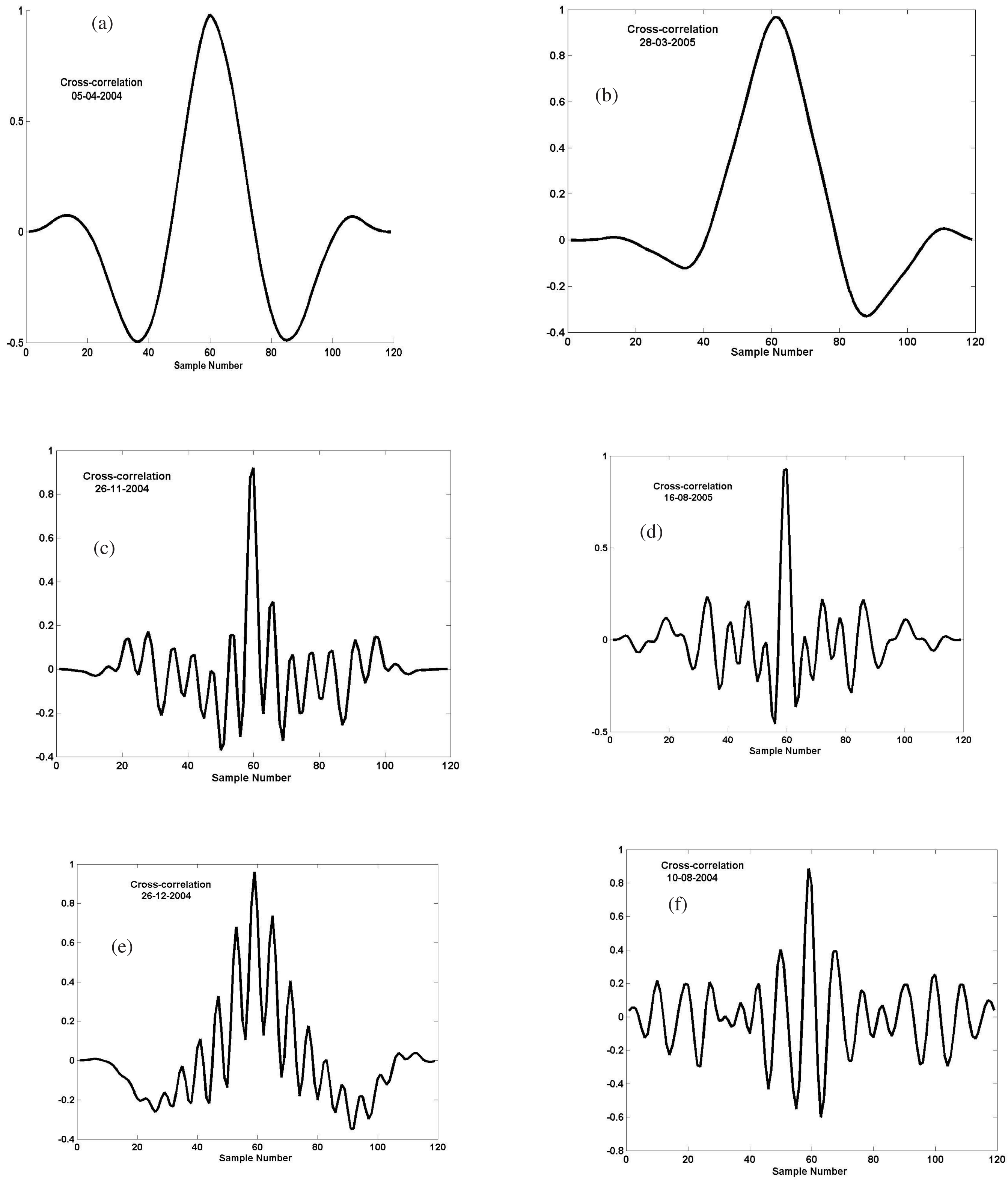


Fig. 3—Cross-correlation (cc) results of waveform data of following earthquakes (EQ): a) 5th April 2004; b) 28th March 2005; c) 26 November 2004; d) 16th August 2005; e) 26th December 2004; f) 10th August 2004

Table 2—Results of cross-correlation between CSIO developed and Reftek developed data acquisition systems

S No.	Date of earthquake occurrence	Cross-correlation coefficient at zero lag
1	26/11/04	0.92
2	16/08/05	0.93
3	05/04/04	0.98
4	10/08/04	0.90
5	26/12/04	0.96
6	28/03/05	0.96

occur, the input ground motion will be same. Therefore, data recorded by both systems after applying instrument correction should be same and hence cross-correlated should give values of normalized cross-correlation coefficient approximately near to one[9].

The results of cc of 1-second waveforms of six earthquakes were recorded by respective data acquisition systems (Table 2, Fig. 3). Normalized cc coefficients at zero lag are more then 0.9 in case of each earthquake. The cc coefficient (> 0.9) is good enough to indicate the good similarities between two waveforms under consideration. This is because when instrument corrections are applied, there is always some difference between theoretical approximation of system response curve based on mathematical formulation and in practical system response curve. Therefore results (Table 2) show that waveforms of local, regional and distance earthquakes recorded by CSIO recorder is very similar to waveforms recorded by reference unit.

Conclusions

CSIO developed 24-bit seismic data acquisition system recorded various local, regional and distance earthquakes since its installation at IMD Delhi observatory and CSIO observatory. Out of these earthquakes, six earthquakes were considered for comparison and performance evaluation of CSIO developed data acquisition system. M/S Reftek data acquisition system has been taken as a reference system for comparison. Two most important parameters (arrival time of seismic phase and polarity of all events) were fully comparable. Waveforms of all these earthquakes are comparable qualitatively. The results of cross-correlations are above 0.9 in all cases show and this great similarity of data recorded by CSIO developed system and reference system. Performance test proved that CSIO system is capable of recording any earthquake within instrument technical limitation and other seismic signal faithfully. All type of seismological analysis like hypocenter location, magnitude determination and spectral analysis can be carried out with time and waveform amplitude data recorded by CSIO system. The data recorded by CSIO 24-bit instrument is easily convertible into public domain analysis software like Seisan. CSIO is continuously engaged in further improving and developing new versions of seismic data acquisition system to meet the new technological challenges.

References

1 Bhattacharya S N & Dattatrayam R S, Recent advance in seismic instrumentation and data interpretation in India, *Curr Sci*, **79** (2000) 1347-1358.

2 USGS website: www.earthquake.usgs.gov/neic/epic/epic_rect.html

3 Stephen J C, *MATLAB Programming for Engineering* (Thomson Asia Pte Ltd., Singapore) 2002.

4 Havskov J & Gerardo A, *Instrumentation in Earthquake Seismology* (University of Bergen, Norway) 2001, 132-162.

5 Havskov J & Ottemoller L, *Seisan: Earthquake Analysis Software Manual* (University of Bergen, Norway) 2001, 220-227.

6 *Service Manual of Model L-4-3D: Low Frequency Geophone* (Sercel Incorporation, USA) 9-10.

7 *Technical Reference Documents for Reftek DAS 72A-07* (Refraction Technology Incorporation, USA) 1996, 86-89.

8 *Operation & Maintenance Manual: Portable Short Period Seismometer Model S-13* (Teledyne Geotech, USA) 1983, 1-5

9 Emmanuel C I & Barrie W Jervis, *Digital Signal Processing-A Practical Approach*, **2nd edn** (Pearson Education Ltd) 2002, 271-301