Scientific Research and Essays Vol. 5(6), pp. 572-581, 18 March, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2010 Academic Journals

Full Length Research Paper

Calculation of the time-varying mean velocity by different methods and determination of the turbulence intensities

Gökçen Bombar[1]*, Mehmet Şükrü Güney[1], Gökmen Tayfur[2] and Şebnem Elçi[2]

[1]Civil Engineering Department, Dokuz Eylul University, Izmir 35160, Turkey.
[2]Civil Engineering Department, Izmir Institute of Technology, Izmir 35430, Turkey.

Accepted 17 February, 2010

The raw velocity data for both stream-wise and transversal directions in unsteady flows, which are formed by generating input hydrograph, are obtained by using a flow tracker. The same hydrograph is generated 15 times and the mean values are found by calculating the average of all hydrographs. The time varying mean is obtained by using FFT, moving average, wavelet and EMD methods. The best time varying mean is selected according to prescribed criteria. Then, the 15 time series are processed and the stream-wise and transversal turbulence intensities are obtained. The mean of the product of fluctuations is also determined.

Key words: Unsteady flow, instantaneous velocity measurement, flow tracker, data processing.

INTRODUCTION

The time varying velocity data obtained during experiments are analyzed by decomposing the instantaneous velocity values into time-varying mean value and a fluctuation. In the case of velocity measurements in steady flows, the time mean velocity, $\bar{u}$ can be obtained easily by taking the average of the instantaneous velocity, u. In such a stationary process, it can be said that, $\bar{u}$ is not a function of time. An accurate definition of both the temporal mean value and the fluctuating component of the signal of measured quantities is one of the most difficult aspects of unsteady flows (Bares et al., 2008). In this case, there are several methods to obtain the time-varying mean velocity from the velocity records, such as the ensemble average, Fast Fourier Transform (FFT), smoothing algorithm, wavelet and the empirical mode decomposition (EMD) methods (Lin, 2005). Each signal analysis technique has advantages as well as disadvantages. The method to be used in a particular application must be carefully selected by taking account the nature of signals being studied (Qu, 2002).

*Corresponding author. E-mail: gokcenbombar@gmail.com. Tel: +902324127057. Fax: +902324531192.

MATERIALS AND METHODS

Experimental set-up, instrumentation and procedure

Experimental studies are carried out on an experimental system involving a rectangular channel of 80 cm width and 18 m length, as shown in Figure 1. The transparent sides of the channel made from acrylic are 75 cm high. The slope of flume is 0.001. The water is circulated continuously. The volume of the water supply reservoir is 27 m^3. The steel channel's rigid bed consists of uniform coarse sand, with D_{50} = 5.4 mm. The discharge is below the threshold for bed particle motion.

The input triangular hydrograph is generated by means of a pump whose speeds are specified. This approach of hydrograph generation consists of the regulation of the pump rotational speed by means of a pump speed control unit. It is possible to increase and decrease the pump speed at desired time increments. The generated hydrograph has a rising limb duration, T_r = 52 sec and a falling limb duration, T_f = 137 sec (Figure 2). The base flow cross sectional average velocity and flow rate are 25.6 and 19.9 cm/sec, respectively. The corresponding water depth, h_{base} is 9.7 cm, and the peak water depth, h_{peak} during the hydrograph

Figure 1. General view of the experimental system.

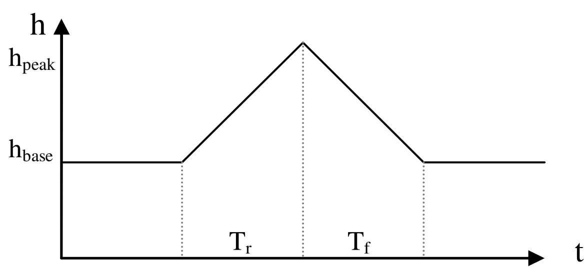


Figure 2. The generated triangular input hydrograph.

passage is 16.2 cm.

Flow tracker is used to measure instantaneous point velocities, u and v in stream-wise and transversal directions. The sampling frequency is 1 Hz. The flow tracker is installed at x = 11.0 m from the entrance of the flume and at a vertical distance z = 5.3 cm from the channel bottom.

Methods for calculation of time-varying mean velocity

The ensemble-averaged method is used to calculate the mean parameters for unsteady flows by repeating many experiments, tens to hundreds of times. Most applications are performed in oscillatory flows. Qu (2002) repeated one of the experiments 10 times in order to apply the ensemble-averaged method in the area of signal treatment.

Fast Fourier Transform consists of breaking up a signal into sine waves of various frequencies. But the Fourier analysis has a serious drawback, when transforming to the frequency domain, time information is lost. When looking at a Fourier transform of a signal, it is impossible to tell when a particular event took place (MATLAB, 2007a). Fast Fourier transform is used by Nezu et al. (1997) and Song and Graf (1996).

Smoothing algorithm takes the mean of the n previous data to obtain the value of n+1th value. This method was used by some re-searchers (Tu, 1991). In MATLAB, the command z = smooth (x, y, span, method) smoothes data y with specified method. The “rloess”, “rlowess” or “move” smoothing algorithms are used for the velocity data. “rlowess” is a robust version of local regression model that assigns lower weight to outliers in the regression using a 1st degree polynomial model (linear fit) while “rloess” is for quadratic fit. The method assigns zero weight to data outside six mean absolute deviations. z = smooth(x, y, 0.3,'rlowess') uses the robust lowess method where span is 30% of the data. The algorithm takes number of elements of x, multiplies it by 0.30 and rounds it to the nearest integer. The span depends on the type of the hydrograph. “move” smoothes data y using SPAN as the number of points to compute each element of z (MATLAB, 2007b).

A wavelet is a waveform of effectively limited duration that has an average value of zero. Similar to Fourier analysis, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet. Several families of wavelet are included in the MATLAB wavelet toolbox (MATLAB, 2007a). The “debauchies” wavelet number 1,2,3,4 and 5 are used in this study.

A new data processing method referred to as empirical mode decomposition (EMD) is recently developed to analyze the non-stationary time-series data (Huang and Shen, 2005; Lin, 2005). To accommodate the inherent non-linearity and non-stationary of many natural time series, EMD provides an adaptive and efficient method (Rao and Hsu, 2008).

In this study, the experimental raw data of stream-wise and transversal velocities are measured in a flume by the flow tracker manufactured by Sontek and they are processed to determine the time-varying mean by using all the methods aforementioned and the results are interpreted. The fluctuation components of the velocity data are then derived by the equations (1) and (2).

$$u = \bar{u} + u' \tag{1}$$

$$v = \bar{v} + v' \tag{2}$$

The turbulence intensities translated by RMS are calculated and the mean of the product of fluctuations $u'v'$ for steady state as well as in the rising and falling stages of the hydrograph.

RESULTS

Application of ensemble average data approach

The time variations of stream-wise and transversal velocity for all 15 hydrographs are given in Figures 3 and 4, respectively. The ensemble average of stream-wise velocity data is calculated by taking the average of all 15 times repeated data sets. The ensemble average contains scattering as illustrated in Figure 5.

Processing of ensemble average results with FFT, smoothing algorithm, wavelet and EMD approaches

In order to find the mean of time varying velocity by using the FFT, smoothing algorithm with “rloess”, “rlowess” and “moving average”, debauchies wavelet and empirical mode decomposition (EMD) methods, the results of ensemble average approach are used for sake of simplicity. These methods are used as described below. These conditions are among the parameters affecting the peak value of hydrograph.

1. The FFT with 1 - 40 harmonics.

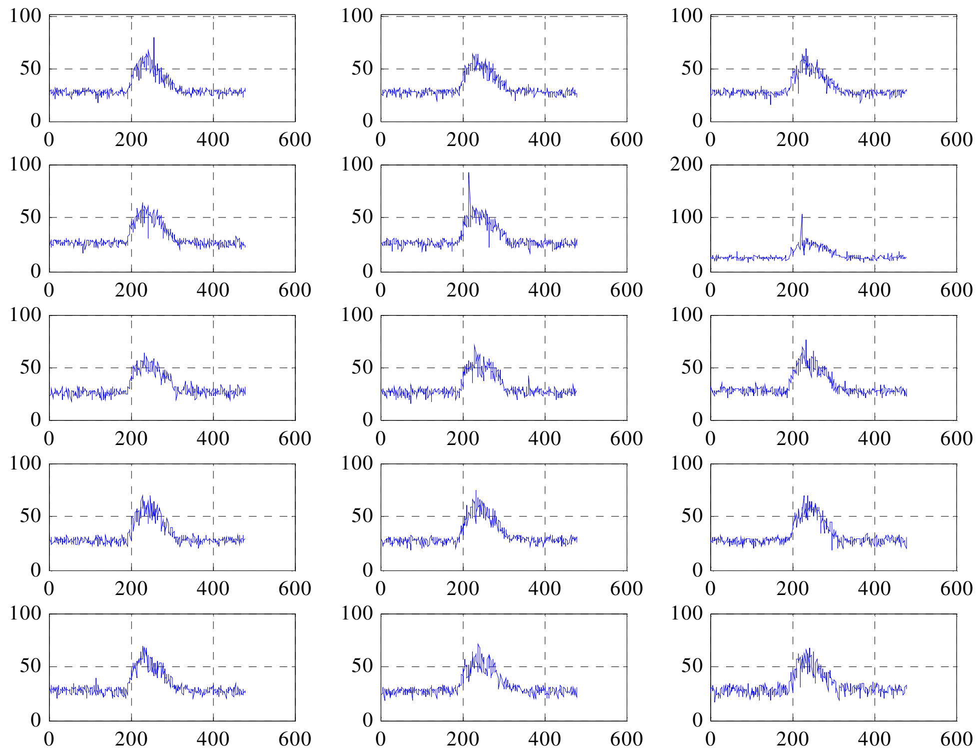


Figure 3. Time variations of stream-wise velocity for 15 repetitions, horizontal and vertical axis stands for time in sec and velocity in cm/sec, respectively.

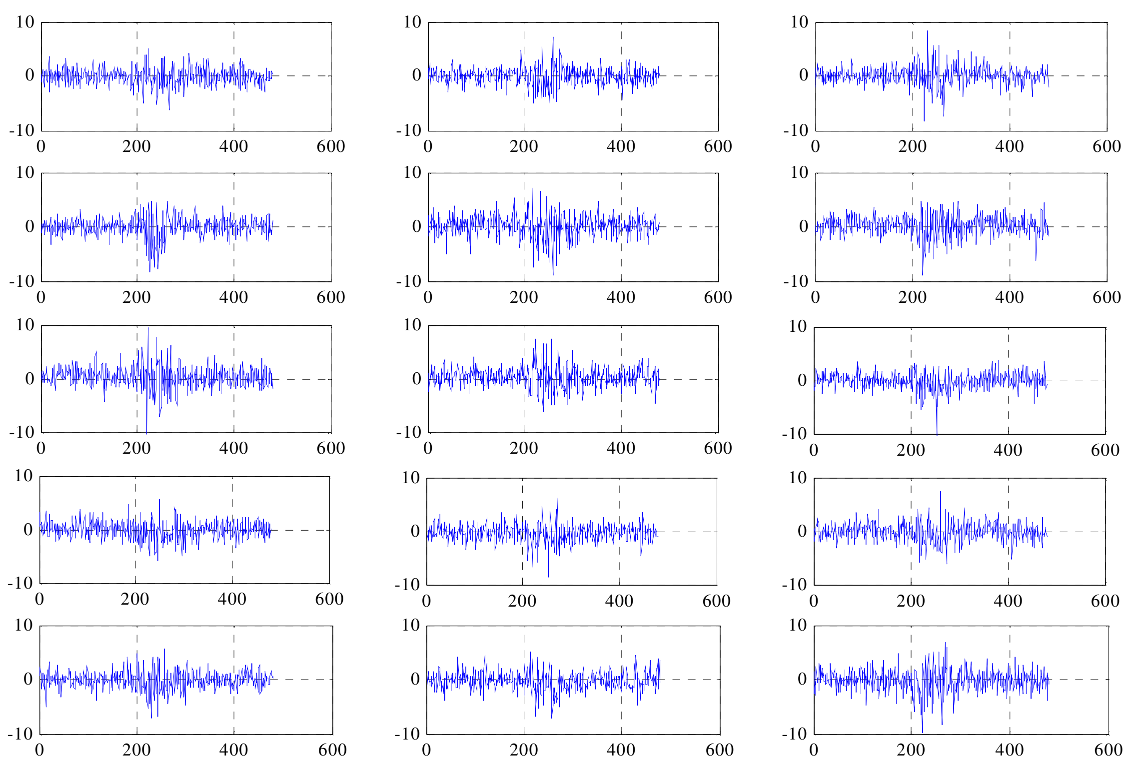
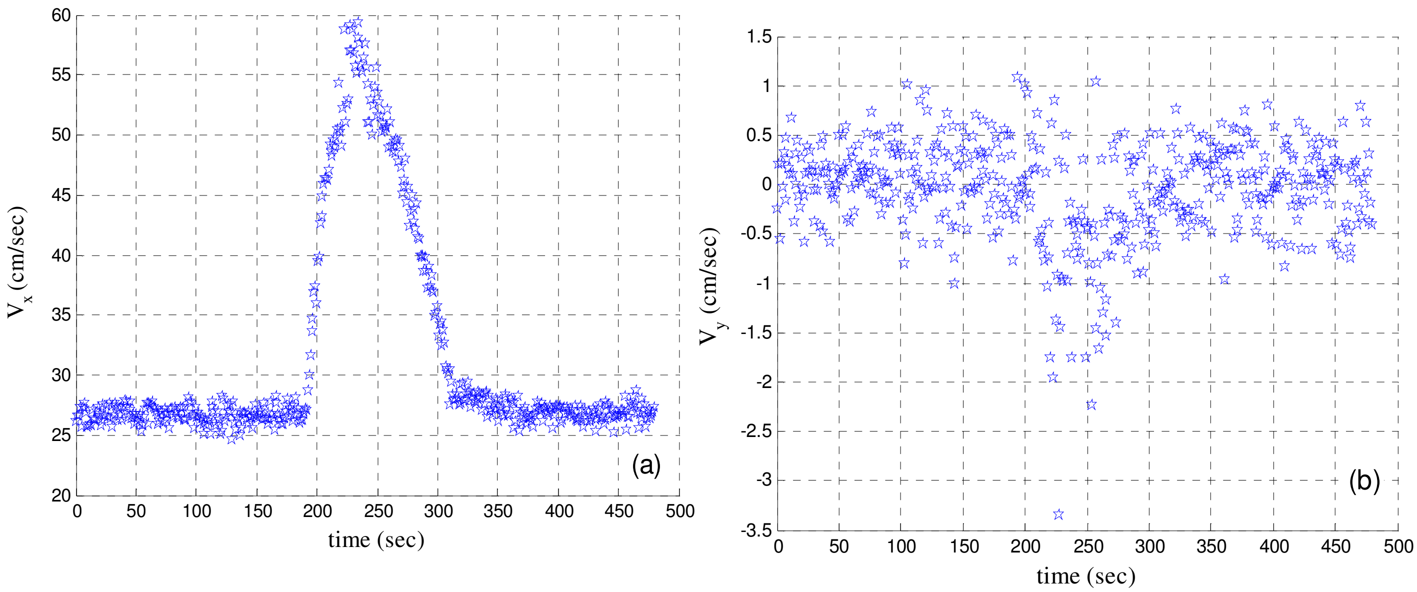


Figure 4. Time variations of transversal velocity for 15 repetitions, horizontal and vertical axis stands for time in sec and velocity in cm/sec, respectively.



(a) **(b)**

Figure 5. Ensemble average of (a) stream-wise (V_x) and (b) transversal (V_y) velocity.

2. The smoothing algorithm with robust lowess method with a span of 0.5% - 30%.
3. The smoothing algorithm with robust loess method with a span of 0.5% - 30%.
4. The smoothing algorithm with move method with a span of 1 - 20.
5. The debauchies type from 1 to 5 wavelet with level from 1 to 8.
6. The number of last imfs from 1 to 13 for EMD.

The results obtained with these values are depicted in Figure 6. These curves are obtained with the following percentage of importance selected in order to get the best mean curve.

1. The absolute differences between the raw data and mean curve should be minimum. Percentage of importance for this criterion is decided as 1%, since the minimization of this criterion is not the primary one.
2. The mean value of the steady phase which lasts 180 seconds is calculated by classical way. The mean curve should be as flat as possible, with minimum deviation from mean value. The percentage of importance is taken as 80%.
3. The parameter affecting the peak value must be selected so that the absolute value of their deviations must be minimized. The percentage of importance is selected as 9%.
4. The starting point of the calculated hydrograph must be compatible with that of the generated hydrograph. It is aimed to minimize the difference between starting times. The percentage of importance is chosen as 10%.

The mean of time varying stream-wise velocity obtained by using different approaches are illustrated in Figure 7. The steady state average value at measurement point is 26.67 cm/sec for all curves which are displaced for better observation. Although the debauchies wavelets give the minimum percentage, the values of rloess 10% curve having the least fluctuations is taken into consideration in the subsequent computations.

The mean of time varying transversal velocity obtained by using different approaches are illustrated in Figure 8. The steady state value fluctuates about zero but all curves are separated from each other, for better observation. The values of rlowess 15% curve having the least fluctuations are taken into consideration in the subsequent computations.

Determination of turbulence intensities

The results at measurement point, corresponding to the generated 15 hydrographs with rising and falling limbs durations 52 and 137 sec respectively, are cumulated in Table 1. The maximum, minimum and steady average values of velocity (cm/sec) are given in the first three lines. The values of the root mean square (*RMS*) parameter (cm/sec) which is a measure of the turbulence intensities are presented in the successive lines. This parameter is defined as follows:

$$RMS = \sqrt{\overline{(u')^2}} \tag{3}$$

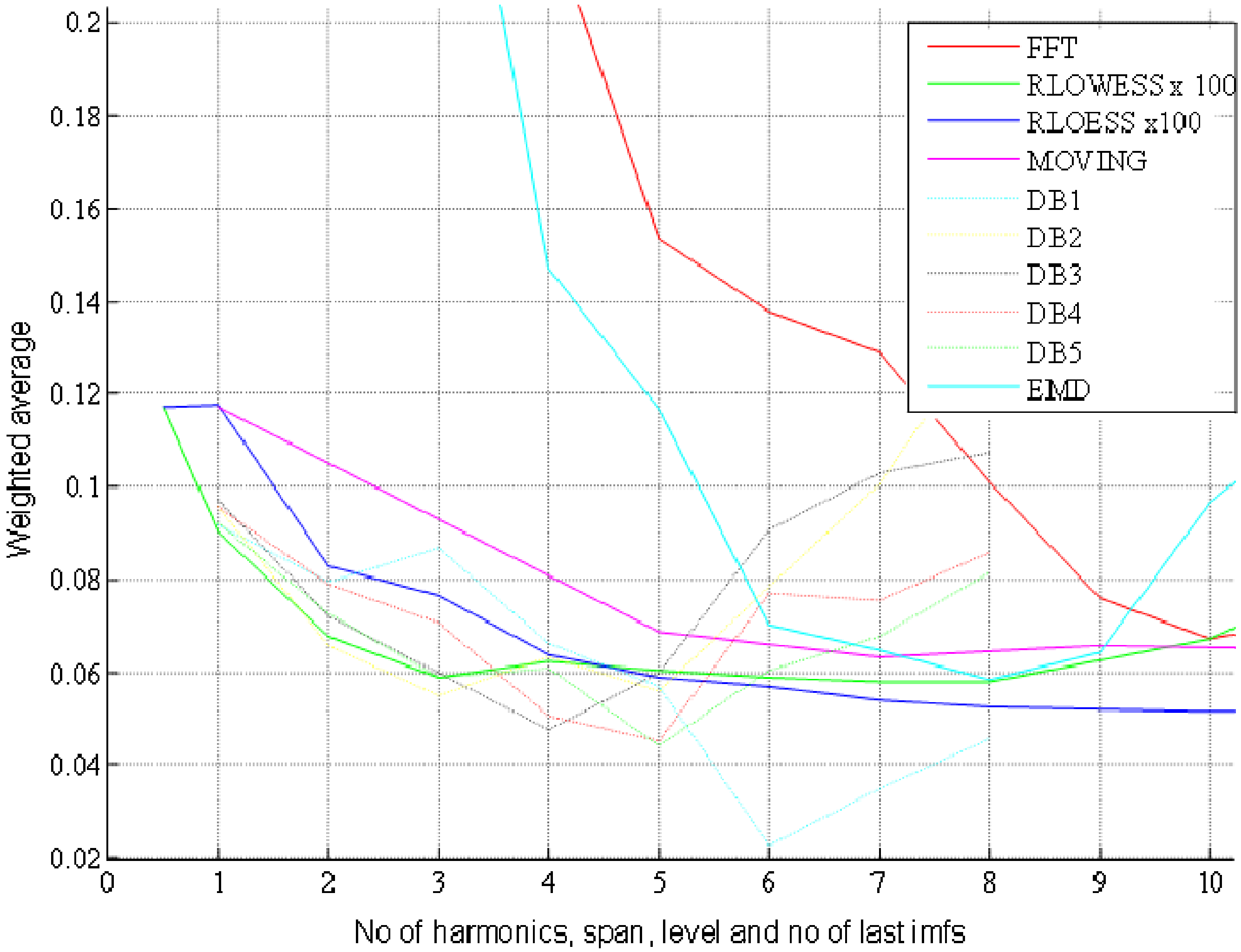


Figure 6. The percentage of importance related to mean stream-wise velocity curves.

Where u' denotes the fluctuation of the stream-wise velocity.

The subscripts of *RMS* in last four rows of Table 1 stands for the values belonging to total time series, steady, rising limb and falling limb parts of the time series, respectively. Figure 9 illustrates the turbulence intensity values for steady, rising and falling parts whose mean values are given in Table 2.

Similarly, the results obtained for the transversal velocity are given in Table 3. The RMS values in steady, rising and falling parts are illustrated in Figure 10, while their mean values are presented in Table 4. The mean values of the product $u'v'$ are also calculated, v' being the fluctuation component of the transversal velocity. The obtained values corresponding to steady, rising and falling parts are illustrated in Figure 11. The mean values of the product $u'v'$ are given in Table 5.

Conclusion

The experiments are carried out on an elaborate experimental system involving a rectangular channel of 80 cm width and 18 m length in Hydraulics Laboratory of Civil Engineering Department of Dokuz Eylül University. The input triangular hydrograph is generated by means of a pump whose speeds are specified. This approach of hydrograph generation consists of the regulation of the pump rotational speed by means of a pump speed control unit. The experiments are repeated 15 times. The point velocity is measured by using a flow tracker.

The ensemble averages of stream-wise and transversal velocities are obtained by calculating the average of all generated 15 hydrographs. These results which contain some fluctuations are refined by applying FFT, smoothing algorithm, wavelet and EMD approaches. The previously chosen four criteria are decided according to the rule of thumb. These criteria aim to get the best mean curve.

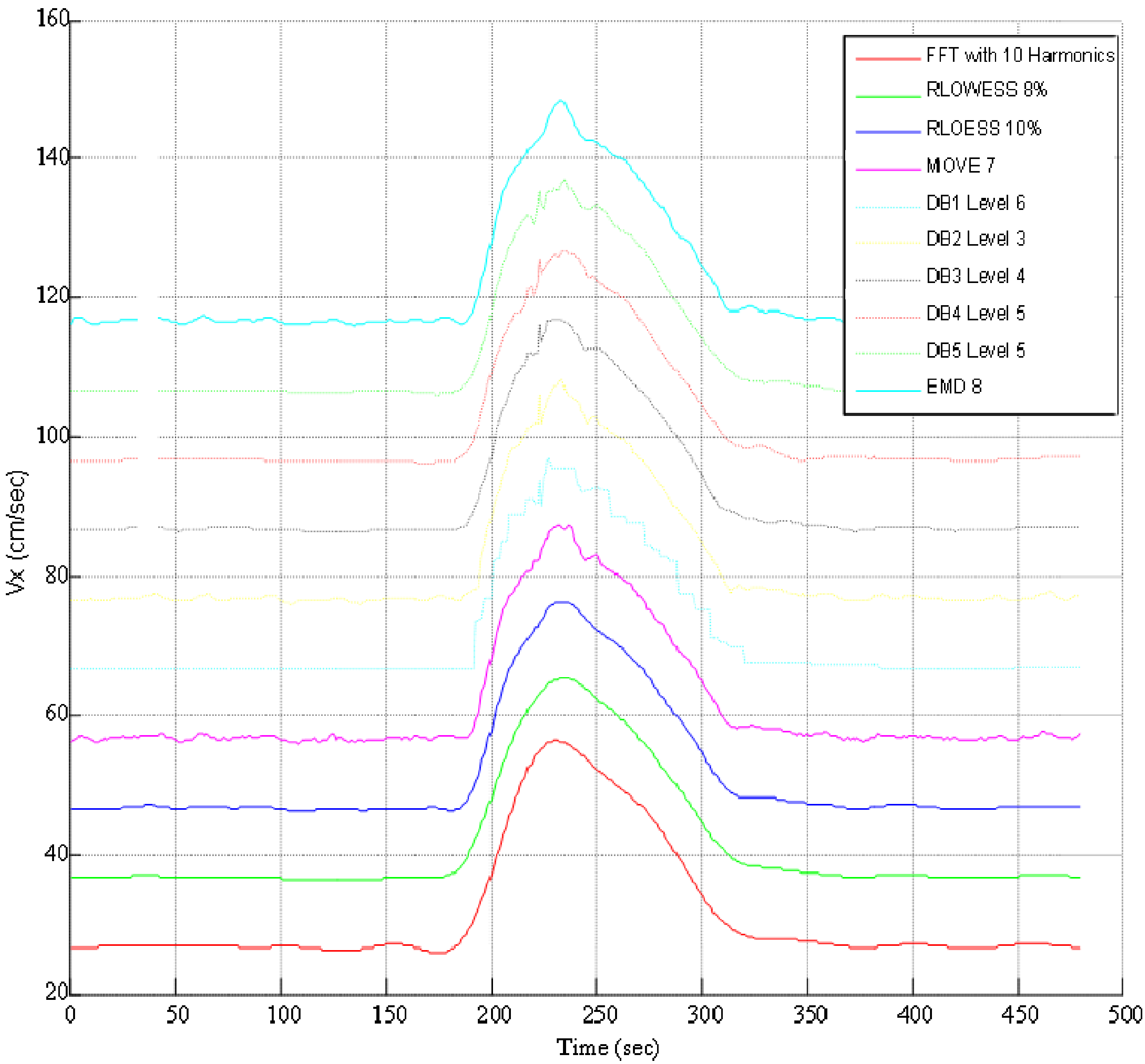


Figure 7. The mean of time varying stream-wise velocity obtained by using different approaches.

The rloess method with a span of 10% is chosen for the stream-wise velocity data, while the rlowess method with a span of 15% is selected for the transversal velocity data.

The stream-wise and transversal turbulence intensities are determined by means of the RMS parameter. It is revealed that for most of the hydrographs, the turbulence intensities are greater in rising stage compared to falling stage for both directions. These observations are in accordance with the experimental results carried out (Nezu et al., 1997).

The calculated mean values for the product $u'v'$ are negative as expected. The value corresponding to the rising part is found to be greater than that of falling part.

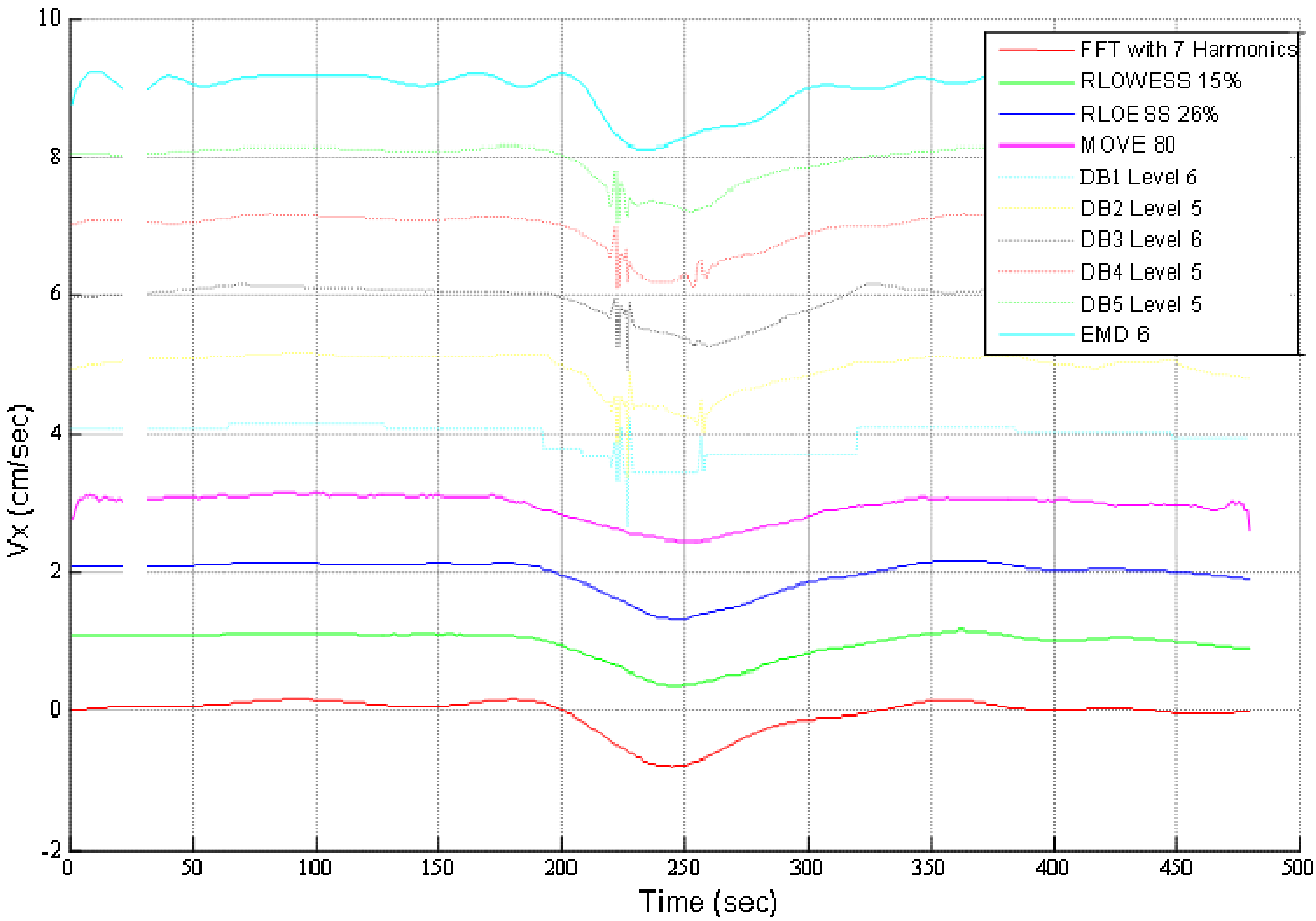


Figure 8. The mean of time varying transversal velocity obtained by using different approaches.

Table 1. Computed parameters for all stream wise velocity data.

	$\bar{u}$ **max**	$\bar{u}$ **min**	$\bar{u}$ **steady**	RMS **all data**	RMS **steady**	RMS **rising**	RMS **falling**
1	80.16	17.3	27.3	3.39	2.38	4.24	4.67
2	63.62	18.96	27.22	2.97	2.26	3.9	3.89
3	69.46	15.86	26.64	3.41	2.27	5.55	4.27
4	63.89	15.88	26.41	3.19	2.28	4.33	4.01
5	91.53	17.25	25.98	4.06	2.79	6.98	4.8
6	108.4	17.18	24.75	4.65	3.19	9.64	3.94
7	63.63	17.63	25.25	3.65	3.15	3.88	4.59
8	71.25	15.5	25.87	3.8	3.02	5.25	4.7
9	76.65	20.26	27.38	3.55	2.65	4.8	4.62
10	69.89	20.08	27.12	3.56	2.39	5.19	4.74
11	73.99	18.63	26.8	3.63	2.55	4.75	4.84
12	69.29	18.68	27.08	3.68	2.36	4.85	4.94
13	70.06	19.94	27.58	3.51	2.87	4.64	4.34
14	70.76	17.56	26.99	3.83	2.61	5.41	4.99
15	67.36	17.35	27.71	4.49	3.83	6.16	5.26

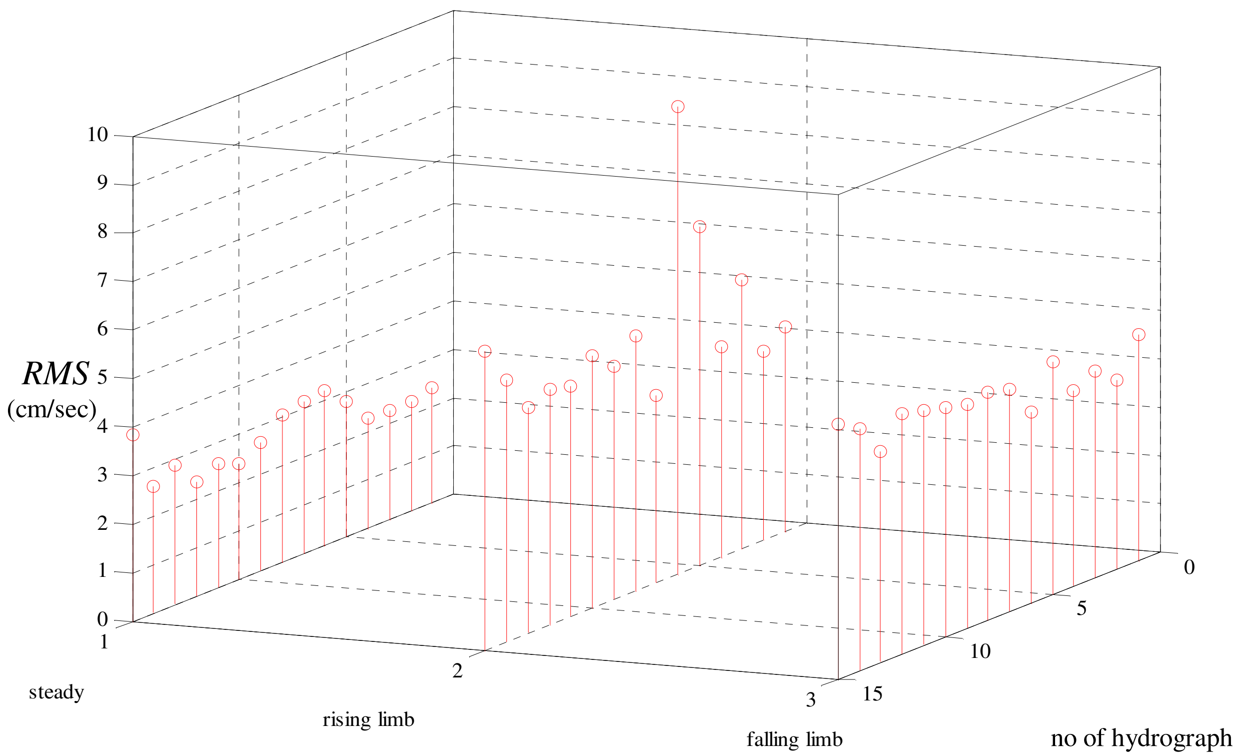


Figure 9. Turbulence intensities of stream-wise velocities for 15 hydrographs.

Table 2. The mean values of *RMS* for stream-wise velocity.

Part	Mean value of *RMS* (cm/sec)
steady state	2.71
rising limb	5.30
falling limb	4.57

Table 3. Computed parameters for all transversal velocity data.

	$\bar{v}$ max	$\bar{v}$ min	$\bar{v}$ steady	*RMS* all data	*RMS* steady	*RMS* rising	*RMS* falling
1	5.13	-6.31	0	1.47	1.15	1.9	1.79
2	7.15	-5.14	0.06	1.57	1.13	1.87	2.04
3	8.37	-8.49	0.02	1.66	1.08	2.45	2.14
4	4.92	-8.37	-0.04	1.68	1.12	2.71	2.02
5	7.07	-9	0.33	1.98	1.6	2.74	2.43
6	4.81	-8.98	0.32	1.8	1.26	2.46	2.2
7	9.67	-10.98	0.58	1.96	1.45	2.96	2.41
8	7.45	-6.35	0.35	1.84	1.33	2.37	2.39
9	3.91	-11.54	0.03	1.49	1.14	2.06	1.76
10	5.6	-5.84	0.1	1.56	1.31	1.93	1.85
11	6.07	-8.53	-0.16	1.59	1.31	2.01	1.95
12	7.49	-6.08	-0.06	1.62	1.27	2.08	1.94
13	5.57	-7.09	-0.07	1.56	1.21	2.33	1.85
14	5.09	-7.28	-0.08	1.61	1.38	2.05	1.72
15	6.86	-9.91	0	1.96	1.58	2.76	2.28

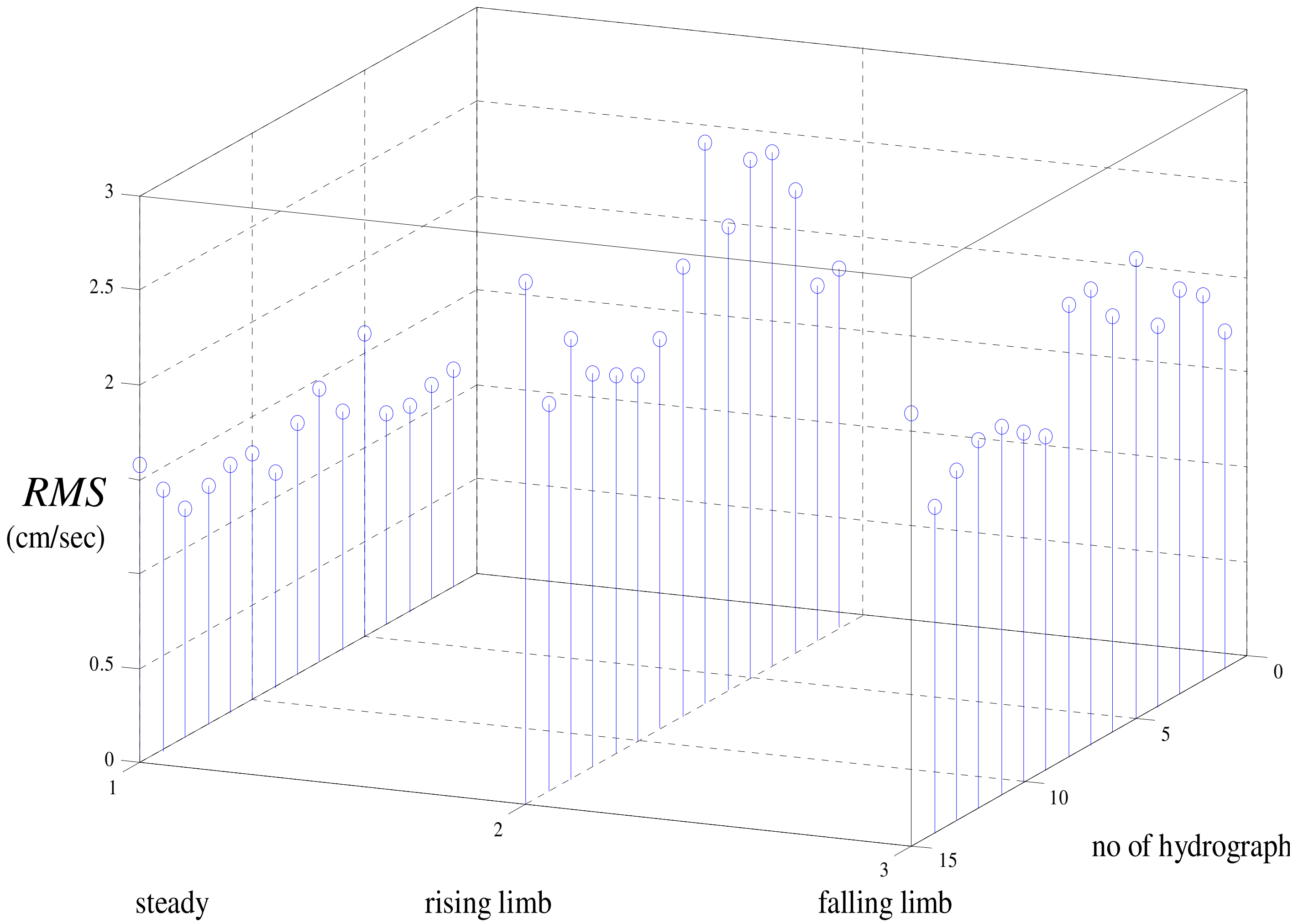


Figure 10. The mean values of *RMS* for transversal velocity.

Table 4. The mean of turbulence intensity of transversal data.

Part	Mean value of RMS (cm/sec)
steady state	1.29
rising limb	2.31
falling limb	2.05

ACKNOWLEDGMENT

The authors wish to express their special and sincere thanks to Prof. Dr. Turhan ACATAY who is the Founder Dean of our Faculty for his support and guidance during the construction of the elaborate experimental system and execution of the experiments. We also thank Prof. Dr. Mustafa ALTINAKAR for his valuable advice. The authors thank TÜBİTAK (project number 106M274) for the financial support.

SYMBOLS

$\bar{u}$, the time varying mean velocity in stream-wise direction; u, the instantaneous velocity in stream-wise direction; u', the fluctuation of the stream-wise velocity; $\bar{v}$, the time varying mean velocity in transversal direction; v, the instantaneous velocity in transversal direction; v', the fluctuation of the transversal velocity; T_r, the rising limb duration of the hydrograph; T_f, the falling limb duration of the hydrograph; h_{base}, the base flow depth of the hydrograph; h_{peak}, the peak flow depth of the hydrograph; *x*, the distance from the entrance of the flume; *z*, the vertical distance from the channel bottom; D_{50}, the median diameter of the sediments; RMS, the root mean square of velocity fluctuations; V_x, stream-wise

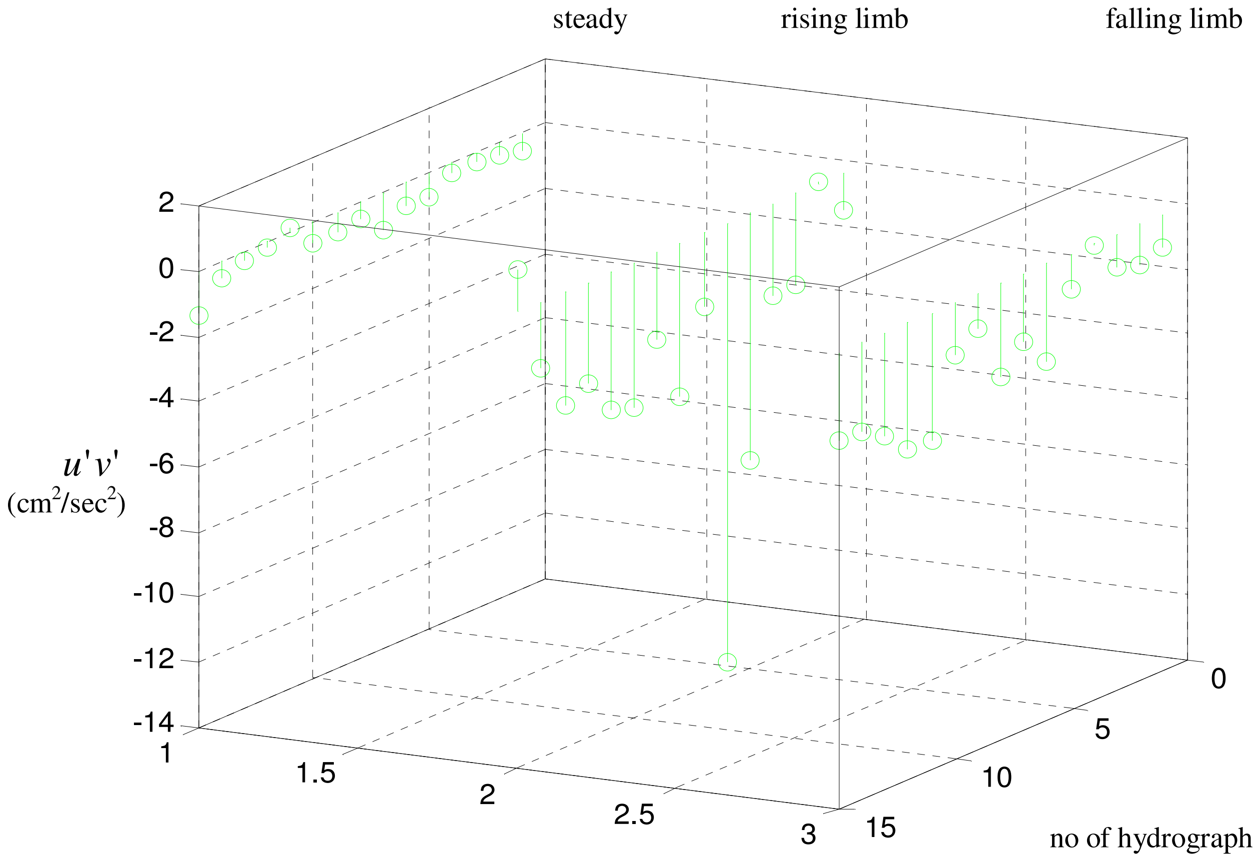


Figure 11. The mean values of *u'v'* for 15 hydrographs.

Table 5. The mean values of *u'v'*.

Part	Mean value of $u'v'$ (cm^2/sec^2)
steady state	-0.54
rising limb	-3.57
falling limb	-2.13

average velocity of 15 times repeated hydrographs; V_y, transversal average velocity of 15 times repeated hydrographs.

REFERENCES

Bares V, Jirak J, Pollert J (2008). Spatial and temporal variation of turbulence characteristics in combined sewer flow, Flow Measurement and instrumentation 19: 145-154.

Huang NE, Shen SSP (2005). Hilbert-Huang transform and Its applications, Interdisciplinary Mathematical Sciences.

Lin YT (2005). Decomposing non-stationary turbulent velocity in open channel flow, Final project.

MATLAB (2007a). Wavelet toolbox user's guide.

MATLAB (2007b). Curve fitting toolbox user's guide.

Nezu I, Kadota A, Nakagawa H (1997). Turbulent structure in unsteady depth-varying open-channel flows. J. Hydraulic Eng. 123 (9): 752-763.

Qu Z (2002). Unsteady open-channel flow over a mobile bed, École Polytechnique Fédérale de Lausanne, Thése no 2688.

Rao AR, Hsu EC (2008). Hilbert-Huang Transform Analysis of Hydrological and Environmental Time Series, Water Science and Technology Library.

Song T, Graf WH (1996). Velocity and turbulence distribution in unsteady open-channel flows, J. Hydraulic Eng. 122(3): 141-154.

Tu H (1991). Velocity distribution in unsteady flow over gravel beds, École Polytechnique Fédérale de Lausanne, Thése no 911.