Investigation for Required Number of Patches for Numerical Modelling in an Open Channel with Checker-Board Type Bed Formation

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Abstract: This paper presents numerical modeling of an open channel with heterogeneous bed strips. The bed formation comprises of checker-board like configuration. At any location along the channel, one half of the bed width was rough and rest half was smooth. The rough side was comprised of gravels. An attempt has been made to investigate how many patches of bed configuration will be required so that flow investigation can be made under periodic boundary condition. Simulation over a length of four patches with periodic boundary condition at inlet/outlet was performed for this purpose. A three dimensional Computational Fluid Dynamics (CFD) numerical model FLUENT was used in this work. The results have been presented in the form of primary velocity contours overlaid by the secondary velocity vectors. These results were calculated at different critical locations along the patches to investigate the flow development. It was observed that the flow patterns in the third and fourth patches are of the same style as that observed in the initial two patches i.e. the developing velocity contours and secondary velocity vectors happened twice in four patches. It can therefore be concluded that two patches are sufficient for any kind of numerical study in these types of bed formations under periodic boundary condition.

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1. Introduction

Water flowing in open channels, rivers, natural streams etc. are subjected to a number of conditions. These include roughness variation, existence of vegetation on the bed and floodplain, presence of sediments and boulders on the bed, mobile/immobile bed materials etc. Different planform types (meandering/straight), changing bed slopes, geometric sections and discharge situations also prevail in natural open channels. All this makes the flow in rivers a complex phenomenon. The river flow results in flooding due to overtopping of water on floodplains in rainy season which causes heavy losses to human life and property.

One of the situations which rivers can also encounter along their path of flow is the presence of a heterogeneous bed in longitudinal and lateral directions. This situation might result due to the presence of vegetation patches, boulders/sediments regions on the bed of the channel alongside the smooth surfaces. A combination of vegetation alone comprising of different densities, submergence level and flexibility in different zones of the channel bed can also result in heterogeneous bed roughness. In such cases the bed of the river will be comprised of smooth regions and rough regions in different zones of the bed.

A lot of research has been done on heterogeneous bed roughness in the past. Among the various researchers included are; Vermass et al. (2011) who performed experiments in a heterogeneous bed in Delft Technical University while Jesson, (2012, 2013) performed laboratory work at University of Birmingham, UK. Wang et. al (2006) performed experiments on longitudinally alternate smooth-rough bed strips. Mclean (1981) investigated the development of sand ribbons due to non-uniform bed roughness whereas Maclelland et. al. (2000) explored different turbulence characteristics over sediment strips. All these researchers examined the effect of heterogeneous bed on various flow parameters such as primary and secondary velocity fields, turbulent characteristics etc. Although numerical investigation has also been done in these types of problems but it is not too much. In the recent past numerical techniques have been used by Vermass et. al, (2007) and Choi et. al, (2007). Vermass used large eddy simulation to explore different flow aspects under heterogeneous bed conditions.

In this research work, an attempt has been made to investigate how many patches of the channel bed are to be used to achieve a fully developed flow region (in the sense of primary and secondary velocities) for a checker-board formation if periodic boundary condition is to be used. Flow development is an important parameter as all types of research work is to be conducted in the region of flow where it has been fully developed with out any change down stream the channel. This is valid both for experimental and numerical work. A three dimensional CFD code has been used for this purpose. The Reynolds stress model has been used in the present work. The boundary conditions used were periodic boundary conditions. The results were presented in the shape of primary and secondary velocities to investigate the flow development.

2. Experimental Set-up

The experimental data of Michael Jasson (2012) has been used in this simulation work. Jasson performed his work in the School of Civil Engineering, University of Birmingham, UK. He used acoustic doppler velocimeter (ADV) to gather the data. Figure 1 (a-b) represents his experimental set-up. Two channel beds were developed by him for experimentation, however only checker-board bed channel have been used in the present work. The channel used for experimentation was 22 m long. The plan view of channel bed has been shown in Figure 1 (a). The cross-section of the channel at any location was half rough and half smooth. The smooth side was developed by two smooth plastic sheets having a total thickness of 20 mm whereas rough portion consisted of two layers each 10 mm thick. The bottom one was smooth plastic sheet and upper layer was comprised of gravels having a thickness of 10 mm. Thus the total thickness of rough side was also 20 mm.

Different critical sections have been marked as CS1 to CS5 as shown in Figure 1 (b). The channel had a rectangular section with a width of 0.614 m. Each patch of the bed has a length of 1.825 m. After this length there is switch of roughness, that is smooth side turns to rough and rough to smooth, thus resulting in a checker-board like configuration. The discharge used during experimentation was 36.9 litre/sec. The flow depth was 122.1 mm.

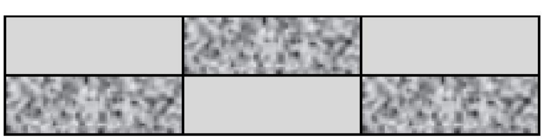

Figure 1 (a) Plan view of checker-board bed configurations

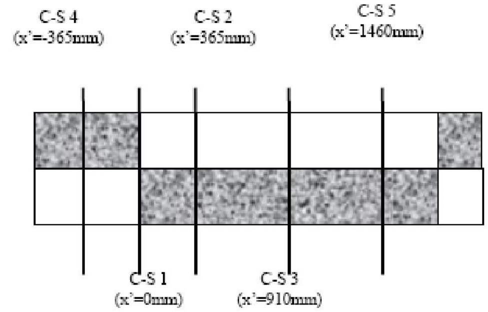

Figure 1 (b) Various sections along the patch

3. Numerical Parameters Used in Modelling

The numerical parameters used in this work included SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm for pressure velocity coupling. Reynolds stress model was employed for turbulence closure of the simulation work whereas standard wall function was used for near wall treatment. The boundary conditions were periodic boundary conditions at inlet/outlet, ‘‘symmetry’’ at the free surface and ‘‘wall’’ at bed and sides of the channel. Different roughness values were used for two patches of the channel section. The geometry was developed through the mesh generator ‘‘GAMBIT’’. A structured mesh has been used in the modeling. Mesh independence was achieved before performing the simulation work.

4. Results and Discussion

As is clear from the Figure 1(b), the distances of the critical sections for the first patch (measured from the inlet) as considered in this simulation work are 0.365m, 0.9125m, 1.460m and 1.825m. For second patch, these sections have distances of 2.19m, 2.7375m, 3.285m, 3.65m from inlet. For third patch, the distances are 4.015m, 4.5625m, 5.11m and 5.475m. For the last patch, these distances are 5.84m, 6.3875m, 6.935m and 7.3 m respectively. The results of simulated primary and secondary velocities over transverse sections taken at these locations have been presented in Figures 2-5.

An examination of Figure 2 (a-d) shows that in the beginning (Figure 2a) the water is moving from rough to smooth side. Towards the sides of the channel, the water is directed downward whereas it is directed upward from rough to smooth region in the central portion of the cross-section. As we move ahead (Figure 2b), two major circulations are developed. One over the upper part of rough side and other on the bottom region of the smooth side. Overall the flow direction remains from rough to smooth side. In the next section which is located at a distance of 1.465 m from inlet, the near bed movement is from smooth to rough side and strong secondary cells were developed on both rough and smooth regions. There were circulations close to vertical walls throughout the water depth on both edges of the channel section. For the location at a distance of 1.825 m (the position where switch over happens) the water movement was observed from smooth to rough side (Figure 2d). Some secondary cells were also observed over the section at this location. The primary velocity distribution has also been shown in these diagrams in the shape of contours. These contours show that primary velocity patterns remain unchanged along the span and there are strong velocities on smooth patches as compared to rough patches.

The results for the second patch have been shown in Figure 3 (a-d). These diagrams indicate that similar pattern of primary and secondary flow distributions has been observed as those in the first patch except that now the secondary flow direction is in the opposite sense to that of the first patch. This is because now the smooth part of the section is on the left side of the patch. Now if we consider two more patches from a distance of 3.65 m to 7.3 m downstream the inlet then it is very clear from Figures 4 (a-d) and 5(a-d) that the same pattern of primary and secondary velocities distribution is repeated as that in the first two patches.

As far as the primary velocity distributions are concerned, these are distributed over these sections in such a way that on the rough side their intensities are less as compared to the smooth side of the section. This has been observed in all the four patches. The repetition of the primary velocity distributions has been observed in third and four patches just like secondary velocities.

This means that for checker-board bed configurations to perform any type of numerical modeling with periodic boundary condition only two patches are sufficient. With two patches the primary velocity contours show that they remain unchanged along the span and secondary flow indicate that they are repeated after each two patches.

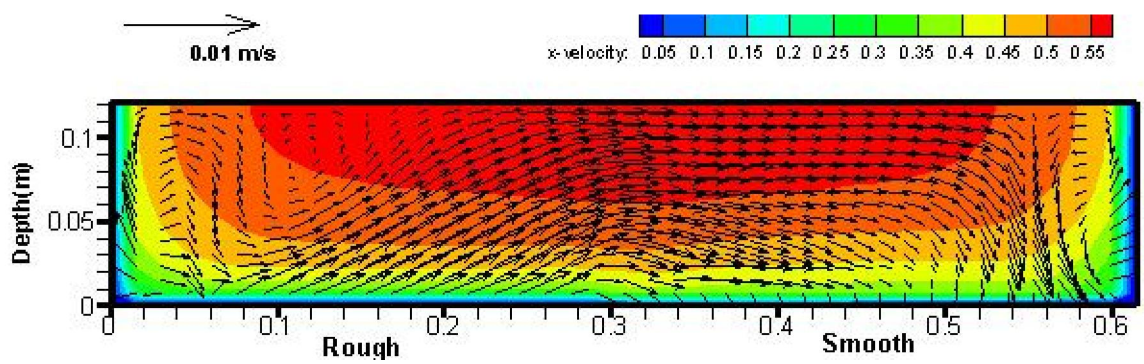

Figure 2 (a): Primary velocity contours and secondary velocity vectors at x=0.365 m

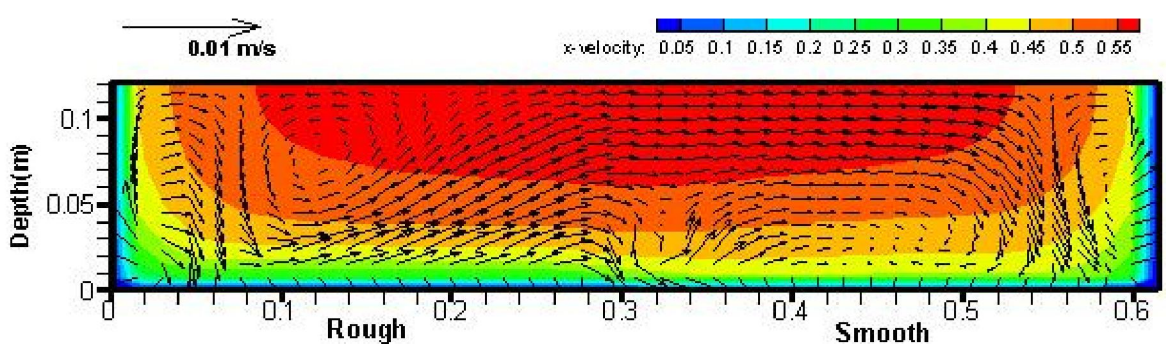

Figure 2 (b): Primary velocity contours and secondary velocity vectors at x=0.9125 m

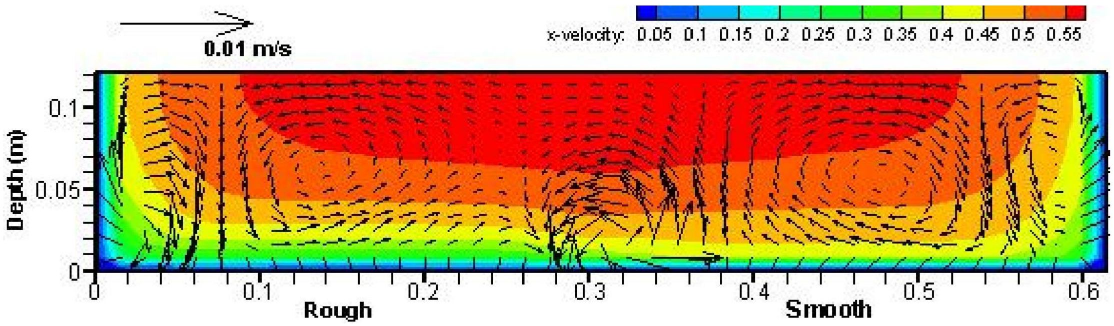

Figure 2 (c): Primary velocity contours and secondary velocity vectors at x=1.460 m

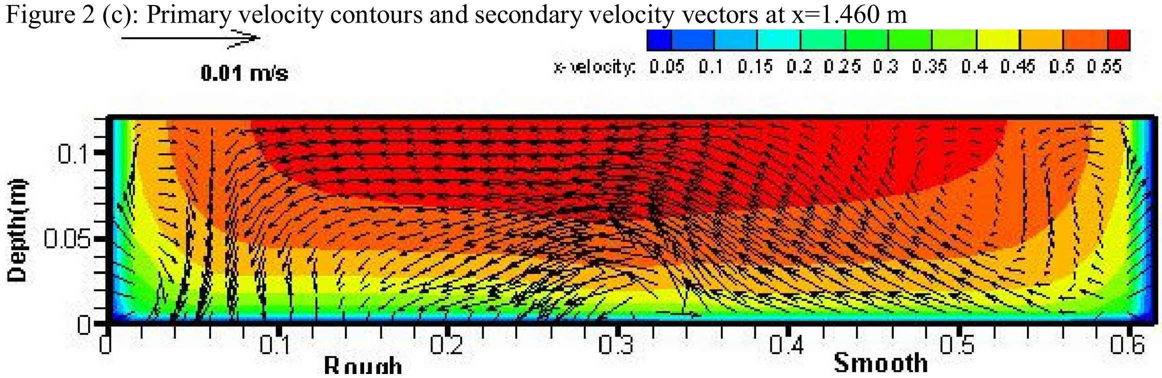

Figure 2 (d): Primary velocity contours and secondary velocity vectors at x=1.825 m

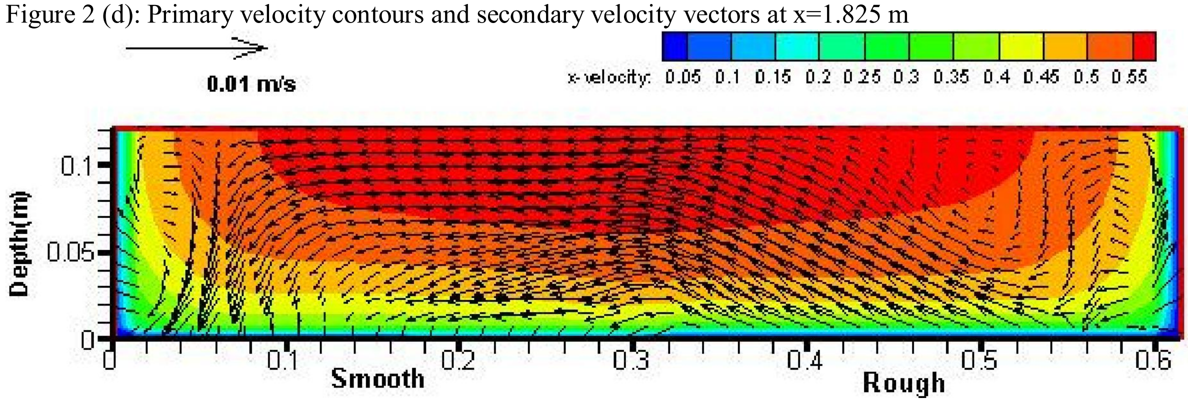

Figure 3 (a): Primary velocity contours and secondary velocity vectors at x=2.19 m

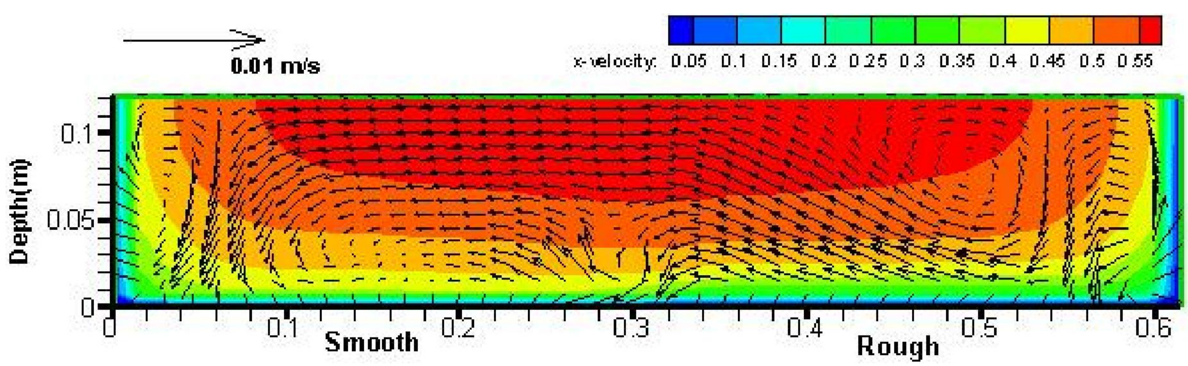

Figure 3 (b): Primary velocity contours and secondary velocity vectors at x=2.7375 m

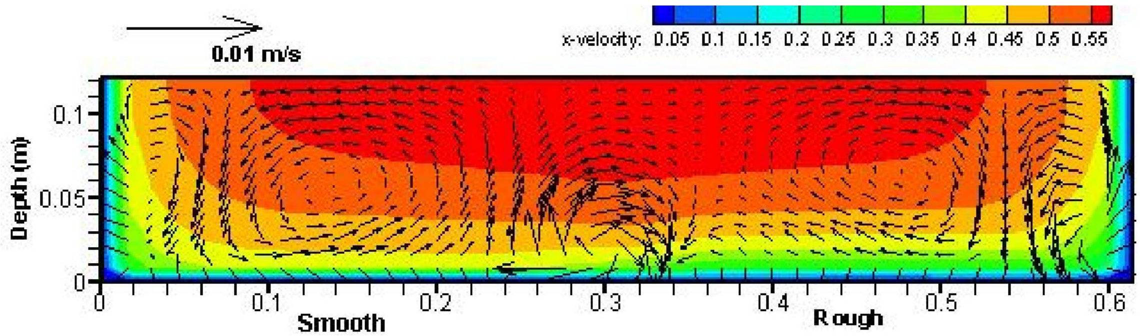

Figure 3 (c): Primary velocity contours and secondary velocity vectors at x=3.285 m

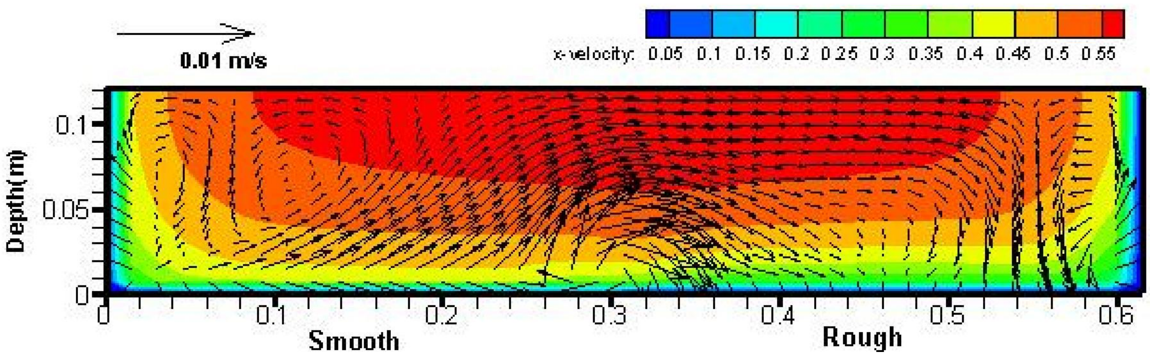

Figure 3 (d): Primary velocity contours and secondary velocity vectors at x=3.65 m

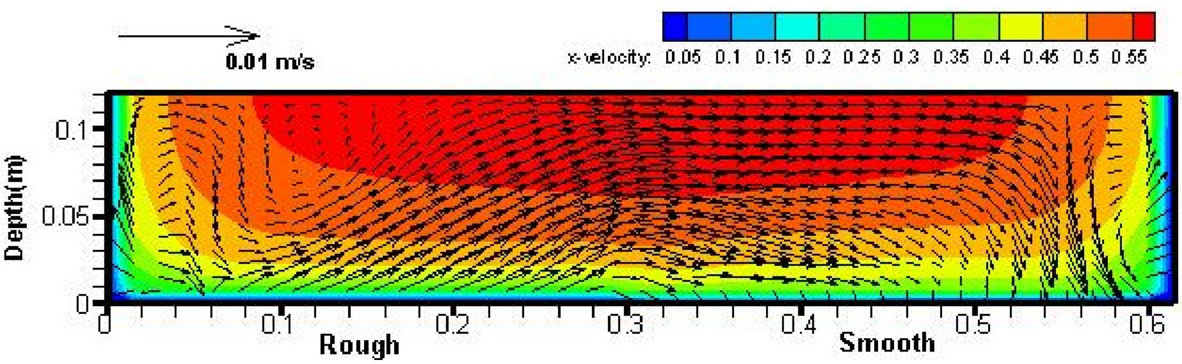

Figure 4 (a): Primary velocity contours and secondary velocity vectors at x=4.015 m

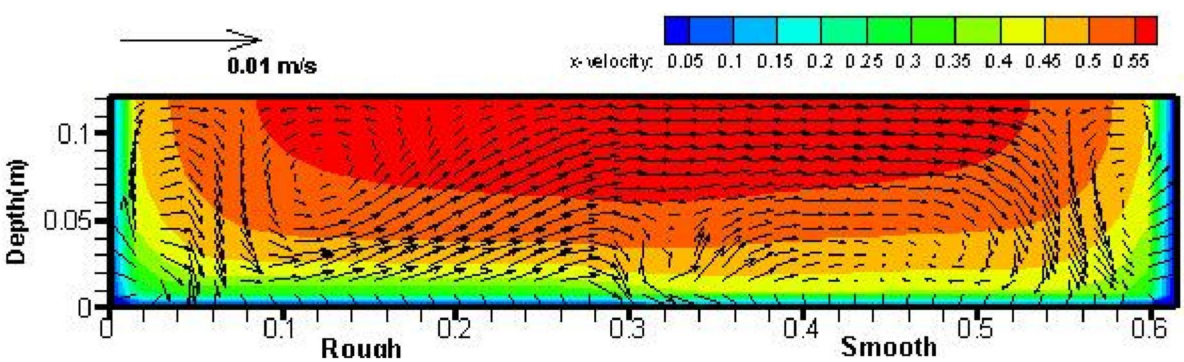

Figure 4 (b): Primary velocity contours and secondary velocity vectors at x=4.5625 m

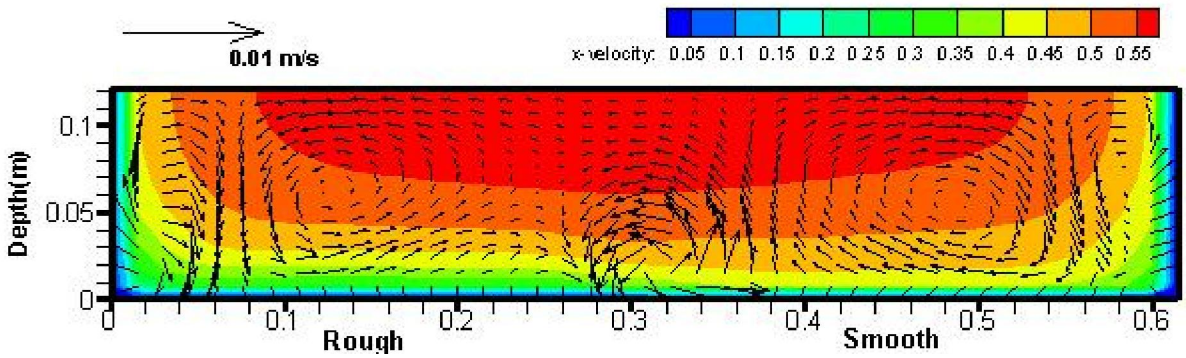

Figure 4 (c): Primary velocity contours and secondary velocity vectors at x=5.11 m

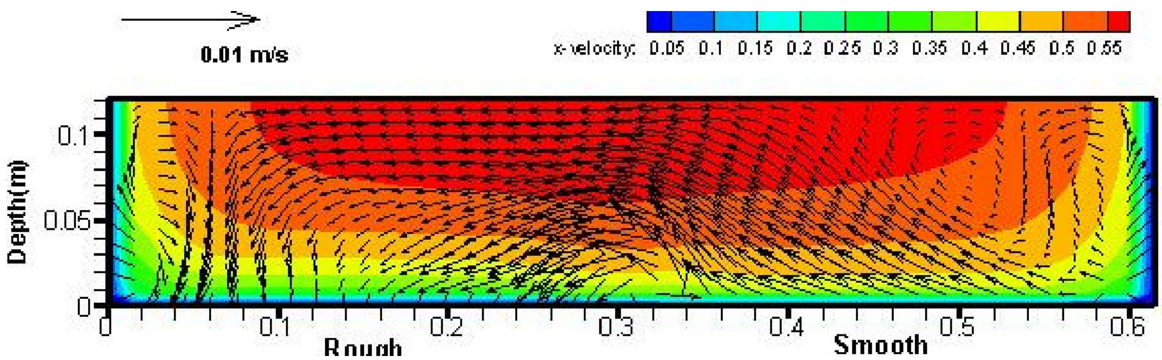

Figure 4 (d): Primary velocity contours and secondary velocity vectors at x=5.475 m

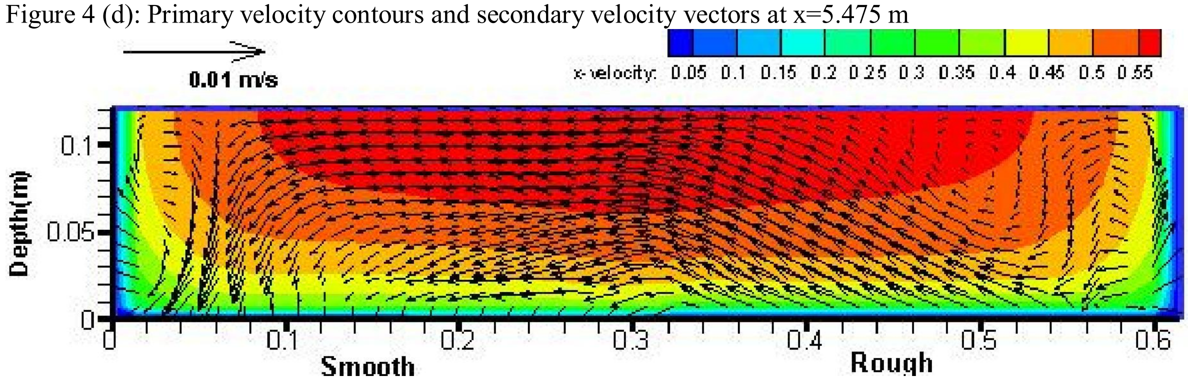

Figure 5 (a): Primary velocity contours and secondary velocity vectors at x=5.84 m

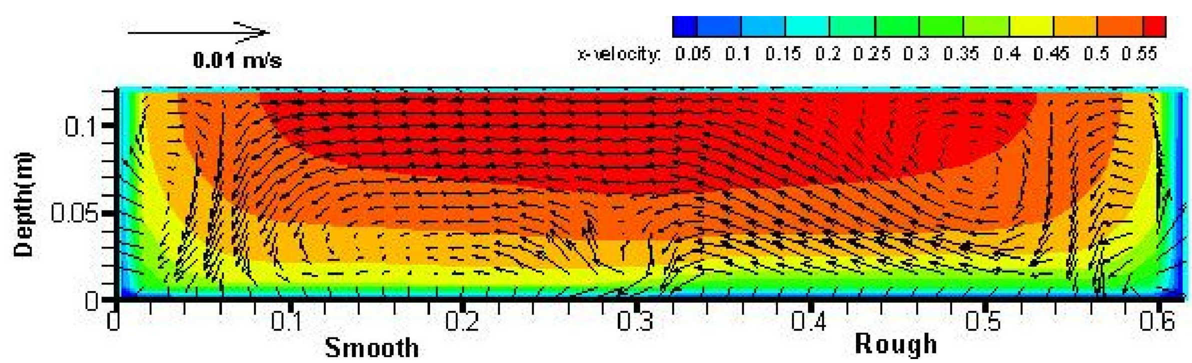

Figure 5 (b): Primary velocity contours and secondary velocity vectors at x=6.3875 m

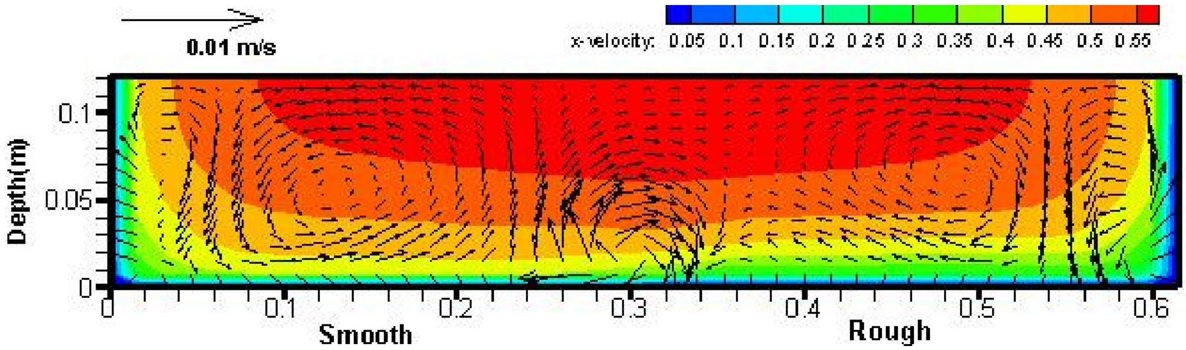

Figure 5 (c): Primary velocity contours and secondary velocity vectors at x=6.935 m

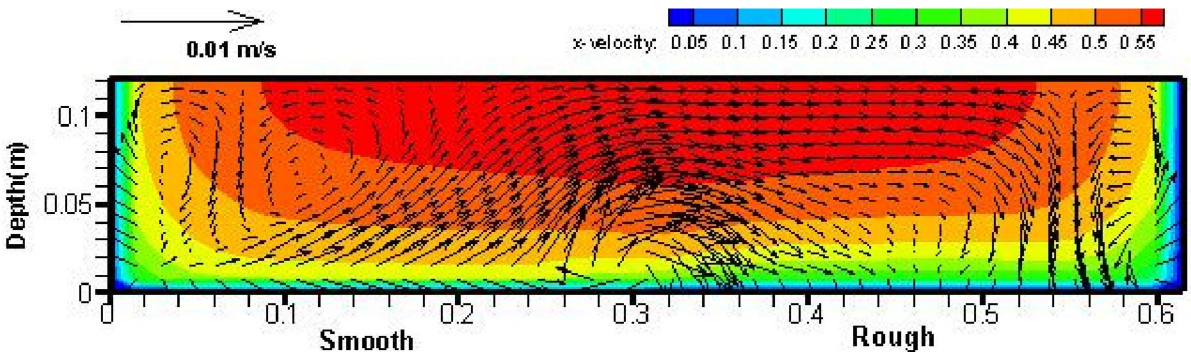

Figure 5 (d): Primary velocity contours and secondary velocity vectors at x=7.3 m

5. Conclusions

A numerical simulation has been conducted over a straight channel with checker-board like bed configuration. The objective was to investigate how many patches of such a bed should be considered so that a fully developed flow region can be obtained under the periodic boundary conditions. It was observed that the flow distributions patterns are repeated after each two patches. From this it can be concluded that if numerical modelling is to be performed for such a bed formation using periodic boundary condition then there will be no need of four patches, only two patches will be sufficient for exploring different aspects of the flow behaviour.

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