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Role of Sediments on River Morphology and a Methodology to Study Biphasic Flows Systems Using Piv

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ABSTRACT: *Mexico has a great variety of rivers, with different fluvial environments and sediments types, which play an important role in its morphology. Knowledge lack about sediment dynamics in streams increases fluvial infrastructure vulnerability. In rivers, sediment transport in suspension is a water quality indicator while bed transport contributes with its morphology. Sediments also constitute an important element in the environment degradation. Minerals and plants remains are also part of solid materials that streams drag. In spite of these facts, most of fluvial hydraulics theories consider, in a simplistic way, that solid material composition transported by rivers is simple and thus be able to use simple formulas and models. In many cases, sediment transport is pulsating (like waves) and the real (measured) doesn't correspond to transport capacity. In a fluvial environment, sediment and water constitute a biphasic system that can be studied using the optical technique known as particle image velocimetry (PIV) in order to obtain information with a tangible physical meaning. This modern technique can be modified to investigate simultaneously solid and liquid phases dynamics and thus contribute to the knowledge of the complex fluid-sediment dynamics. In this paper morphological rivers context is analyzed, also sediments participation and a methodology to study two phases flows is proposed.*
KEYWORDS *-Particle image velocimetry, potamology, river morphology, sediments, two phase flows*

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I. INTRODUCTION

As stated by Dr. Jean Jacques Peters+ [1], Academician of Brussels University and Consultant of the National Water Commission (CONAGUA), every day, every year, more frequently, in the world and in Mexico, civil society pays a very high cost for not know/recognize the importance of sediment in water systems management, particularly rivers. This situation results in serious fluvial infrastructure damage and human lives irreparable loss. In this context, a potamological approach "Potamology" (from the Greek "potamos": river and "logy": science) is required to solve fluvial engineering problems, improve water resources integral management but in particular, understand sediment influence on rivers morphology.

Solid particles from rocks or soils are known as "sediments" and are transported by runoff and wind. Most of sediments come from rocks transformation and basin geology determines the type of mineral transported by rivers. Sediments can be produced by natural processes (land surface erosion, main channel erosion and its tributaries, ground natural movements) or artificial, generally due anthropogenic activity (vegetal cover destruction, engineering structures, mining and quarrying, urban and industrial waste). This solid material ends up depositing along riverbeds, lakes or lagoons, in the sea and in basins lower zones, particularly in flat areas, contributing with its morphology and/or altering the existing one. In fluvial hydraulics, sediments are, with water, part of a biphasic system, which plays an important role in channels morphological dynamic. There is a standard classification for particles size and usually sediments are measured with flow rate to obtain a "solid load". Cohesion intervenes under a certain size.

Erosion, transport and sedimentation of solid particles depend on several factors: size, density and shape. It can be affirmed that sediments have a physical impact on environment due the deterioration that they cause to hydraulic works, doing navigation more difficult and costly. Also have a chemical impact since they contribute with environment degradation, water turbidity increasing which avoids sunlight passage which is fundamental for fauna and flora life; in certain cases sediment data are used as a water quality indicator (mainly that which constitutes the "wash load"). Pollutants present in streams are not transported alone; they do so in combination with sediments, in particular with the fine fraction (silt and clays) and play a crucial role in water bodies hydrodynamics. Mineralogical composition is another important factor in solids behavior in contact with dissolved substances; e.g., flocculation phenomenon of finest (alumino-silicates and colloids). In addition to minerals, plant remains are part of solid particles transported by streams.

1.1 Rivers geomorphological context

It is interesting an analysis in the context of high (Zone 1), middle (Zone 2) and low (Zone 3) basin to understand sediments role in rivers morphology, see Figure 1.

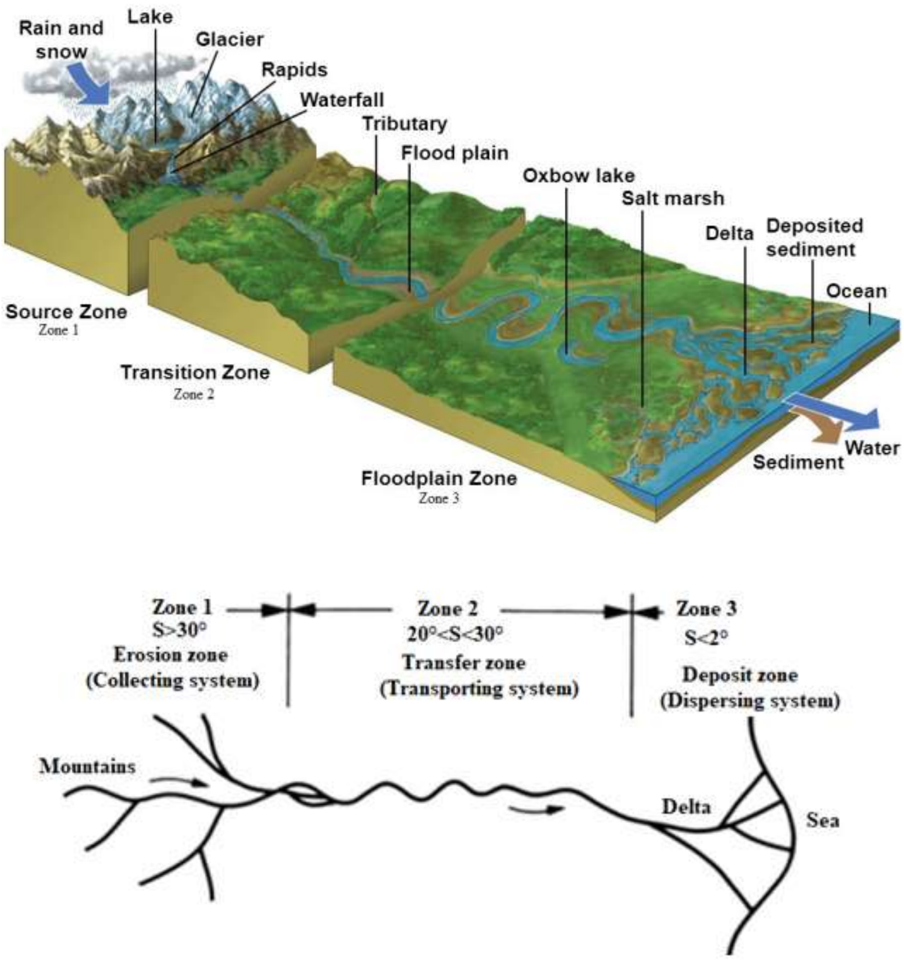

Fig. 1:Top image: Schema of a river corridor. Lower scheme: Three zones and their upstream and downstream relationships are shown [2].

Zone 1: Rivers are formed by rocks erosion. Channel is progressively encased. Products of soil erosion and scouring are transported to basin lower areas. Sediment production depends on rocks nature (geology and tectonics); landslides contribute appreciably. In the upper basins, geology and tectonics determine river beds shape, where river is encased in mountains (tectonic movements, faults and folds). Vegetation helps to control soil erosion; however, crops on slopes, erosion at slope foot, landslides and gullies, provide solid material to the river. Climate changes affect these processes.

Zone 2: There is a certain balance between flow transport capacity and sediment contributions. This area is a transfer zone and rivers transit through varied terrains, with presence of erodible materials but also sectors where resistant formations can control bed movement. In this area, not only geology determines the form, it also influences soil mechanics. Floodplains are common. When floods occur, rivers provide sediments to these areas, and when water level descends, it drags sediments into the riverbed, in a continuous mass and energy transfer process (see Figure 2).

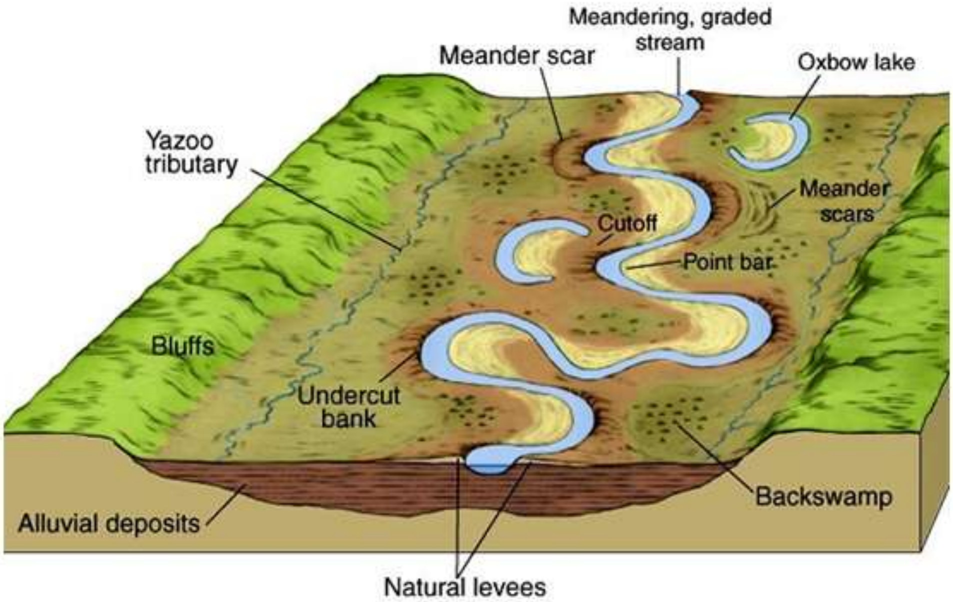

Fig. 2:Typical floodplain. Source: http://hrsbstaff.ednet.ns.ca/mcallip/Geog10/

Zone 3: River transport capacity lack causes that sediments deposited. In this zone, geomorphological context is diverse. When alluvial strip between mountain foot and sea -or a lake- is narrow, land crossed by the river has a very heterogeneous composition (case of Pacific Coast in Mexico). Material brought to sea can be quite thick (case of Balsas River, Mexico). River mouth type will depend on sea action intensity and river action. Rivers that transport large amounts of solid material into the sea coastline create a "delta". When sea has strong tides and/or waves, material is eroded and transported to one side of the coast, forming lagoons separated from sea by a bar. Rivers with weak solid contribution, in seas with strong tides, form "estuaries". When sediment load is low, estuaries remain unchanged. Figure 3 shows an example of the complex fluvial dynamics that can be understand by means Ebro river mouth evolution.

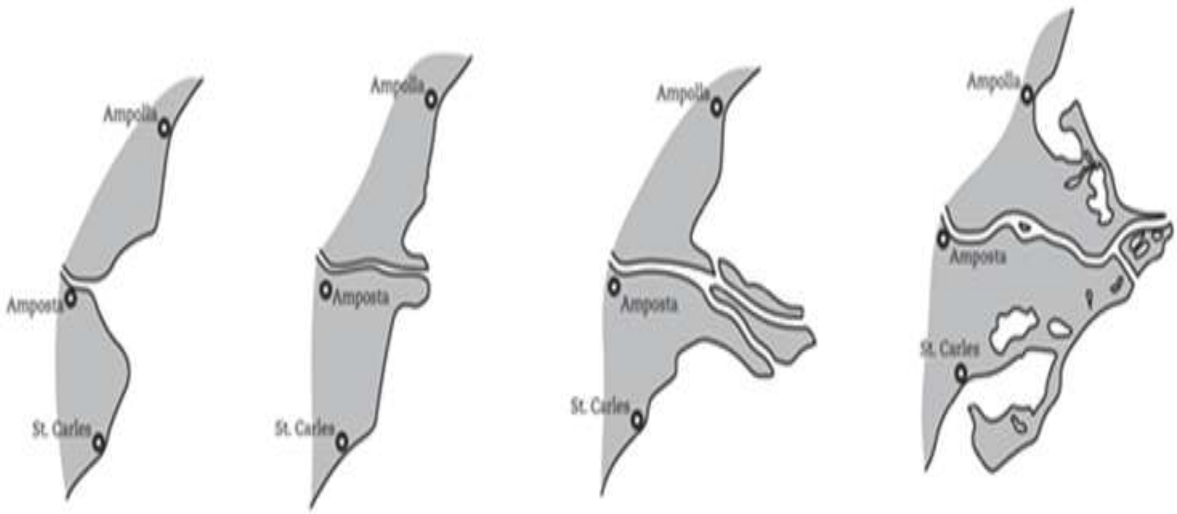

Fig. 3:Ebro River mouth evolution (Spain), from estuary to delta [1].

1.2 Rivers types according to sediment load

Based on parameters of flow and amount of sediment transported, many river patterns types are proposed [3]. Excess of transported solid material causes deposition, a deficiency causes erosion and between the two extremes is the stable channel. According to field observations and empirical relationships, it can be stated that rivers can change its morphology (river metamorphosis) over time as long as the flow and sediment transported change in a sufficient magnitude. Experience shows that variations in hydrological regime associated with changes in quantity and sediment load type, are manifested in many morphology adjustments (channel width, water level, sinuosity, meanders wave length). Figure 4 shows and example of river classification with high and low sediment load and sediment size [3].

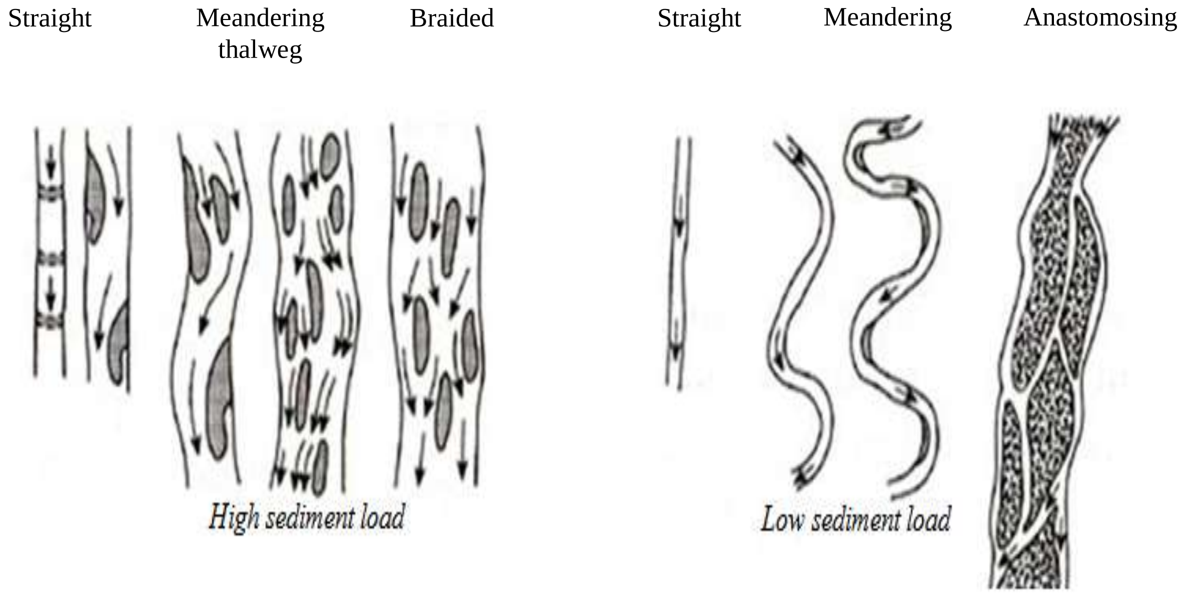

Fig. 4:*River types according to sediment load [3].*

When facing engineering problems due to sediment loading, it is possible to reduce them considering its origin: a. Sediments that originate in basin surface: are reduced by applying soil conservation techniques b. Sediments that come from banks and rivers bed: are reduced with large dams reservoirs, diversion dams and by building small dams in streams and canyons c. Sediments that come from industrial and urban waste: are reduced by applying sanitary techniques on solid waste management.

1.3 Fluvial forms and interactions

Those dedicated to fluvial hydraulics should recognize all processes responsible for morphological changes, not only the hydraulic ones but also those related to sediment transport. Morphology physical processes are: sediment transport, bed evolution and margins erosion. In relation to rivers classification, from a morphological point of view, it should be taken into account that their typology can be based on: a. Form of the plan view b. Existence and types of sandbars and islands. However, physical processes responsible for the development of one type or another are not yet fully understood. On what have been achieved consensuses is the fact that there is an interaction between transported sediment, channel bed morphology, flow dynamics and the dynamics in plant, in time and space, as shown in Figure 5.

Fig. 5:Scheme of rivers dynamics and role of sediments in fluvial morphology (own elaboration).

II. METHODOLOGY TO PERFORM TWO PHASE FLOWS RESEARCH

Rivers are a turbulent flow example, composed of two phases, one liquid (continuous phase) and another solid (dispersed phase). Research in this field is based on the necessity to know more about the interaction between turbulence and solid particles that are transported by a fluid, as occurs in natural streams, in particular the mechanisms that generate sediment transport.

In literature it's possible to find abundant researches which have contributed to the understanding of the interaction between fluid flow and solid particles in suspension through numerical and experimental techniques [4]. Despite the progress, it is necessary to carry out more studies, mainly experimental, in laboratory physical models, using new observation and/or measurement techniques, which could provide detailed information about this interaction.

1.4 Velocity measurement by means of particle image velocimetry technique (PIV)

Velocity measurement classical techniques in turbulent flows, such as hot wire anemometry and laser Doppler anemometry LDA, give an important spatial and temporal resolution, but have the disadvantage of measuring in only one point at a time [4]. An alternative is the particle image velocimetry technique - PIV, which has the advantage of measuring velocities in a plane and/or in a volume (at many points at a time) providing general information about the phenomenon and the possibility of selecting, about these results, a particular area or point to do measurements with other techniques. PIV is a non-intrusive optical measurement technique, by means of which an indirect measurement of fluid velocity is doing, based on the measurement of the velocity of tracer particles, which don't induce physical or chemical flow alterations. At present, temporal resolution of this equipment is still low [4]. In the current paper a methodology that allows velocities simultaneous measurement of liquid and solid phases in channels flow with suspension solid particles transport (two-phase flow) using PIV is presented. Methodology was tested in an open channel of small dimensions with successful results [5].

1.5 Experimental set up to study two phase flows in open channels

Standard PIV technique employs a single high-resolution camera for image acquisition. In this modified proposal, two cameras are adapted (see Figure 6). Analysis zone is illuminated by a pulsed laser, which is synchronized with images acquisition. An optical filter is installed in each camera; therefore only one phase could be visible for each of them.

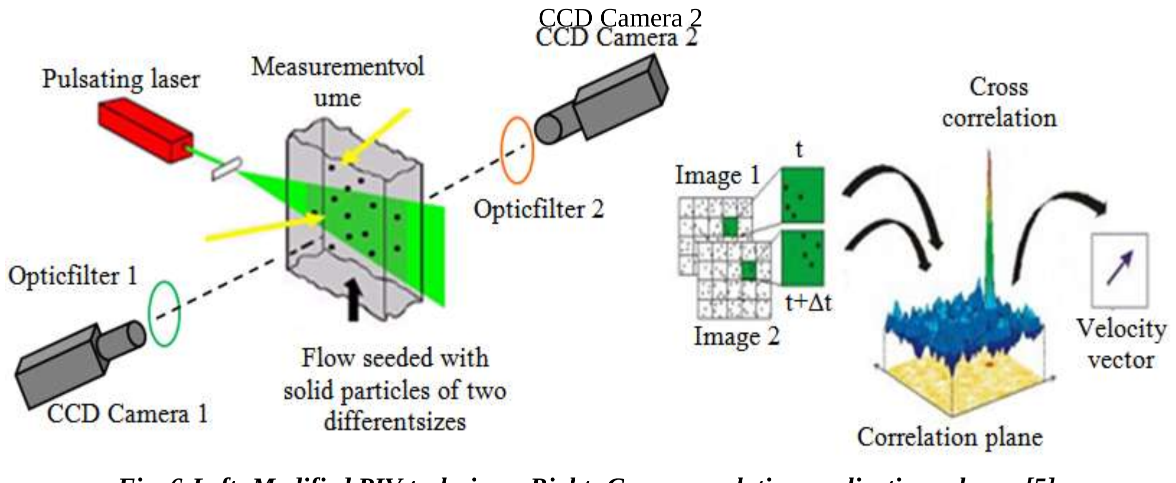

Fig. 6:Left: Modified PIV technique. Right: Cross-correlation application scheme [5].

Flow should be seeded with fluorescent particles of two different sizes (which scatter light with different wavelength) in order to distinguish and represent each phase (solid and liquid), see Figure 7. Particle size that represents solid phase should be at least ten times the size of those corresponding to the liquid phase, in order to distinguish them in the images ([5] used synthetic solid particles with size of ~100μm for solid phase and ~10μm to represent liquid phase). For two phases separation (solid and liquid) in case of not having fluorescent particles, it is possible to control images gray scale, in such a way that small particles are out of the visual field.

Laser pulses are synchronized with images/frames acquisition and time between each pulse is selected based on average flow velocity. With high-resolution CCD cameras (CCD: *charge-coupled device*) located in front of each other, at right angles to the illuminated plane, image pairs of tracers and solid particles are acquired, one image at a time t and the second at a time t+Δt.

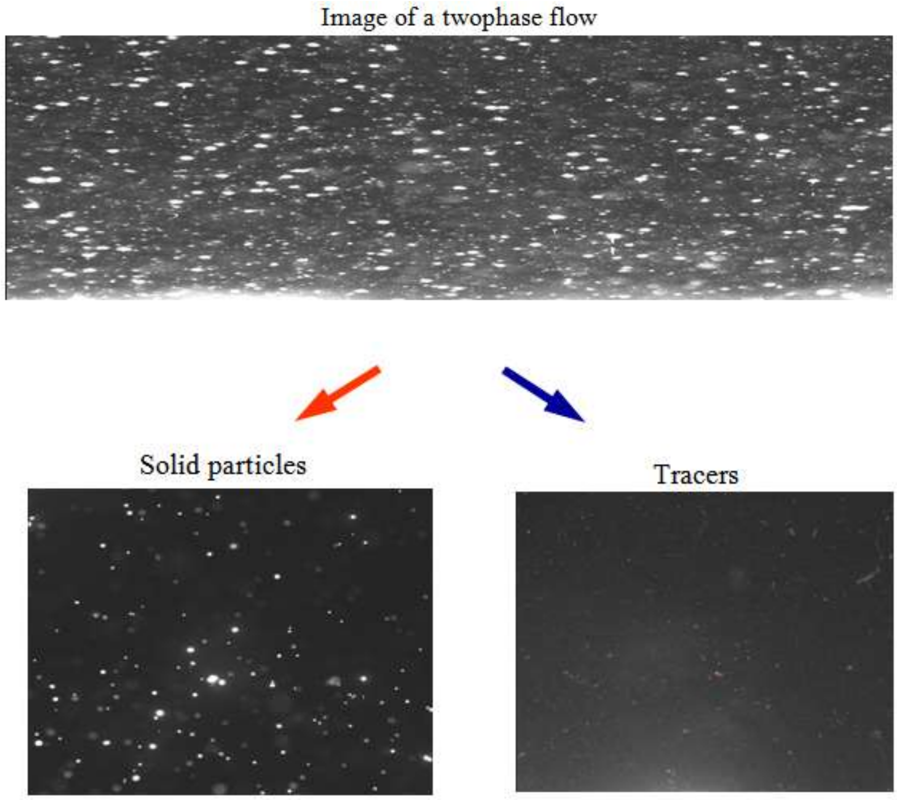

Fig. 7:Example of a biphasic flow and phase separation using optical filters [5].

Measurement area is divided into smaller called interrogation areas. In each pair of interrogation areas a standard cross-correlation is applied which results in an average displacement vector of the particles present [4]. Higher correlation is indicative of the most probable particles set displacement. Repeating this procedure for all interrogation areas pairs, a map of particles average displacement vectors is obtained. Dividing displacements by time between images and multiplying this result by a Scale factor (S) obtained by means of equipment calibration, these are converted into velocity data. Before implementing the technique, it is necessary to perform preliminary tests in order to verify optical filters operation and cameras alignment accurate.
Figure 8 shows superimposed velocity fields of solid phase (red vectors) and liquid phase (white vectors) and the tuning of the technique is checked: solid phase follows liquid phase and vectors tail coincide. Figure 9 shows velocity profiles at different distances from a bed form that seems a river dune, with height h, which was installed at the channel bed to perform other experiments. Velocity profiles verify again the tuning of the technique and the existence of a delay of solid phase (red line) with respect to liquid phase (blue line).

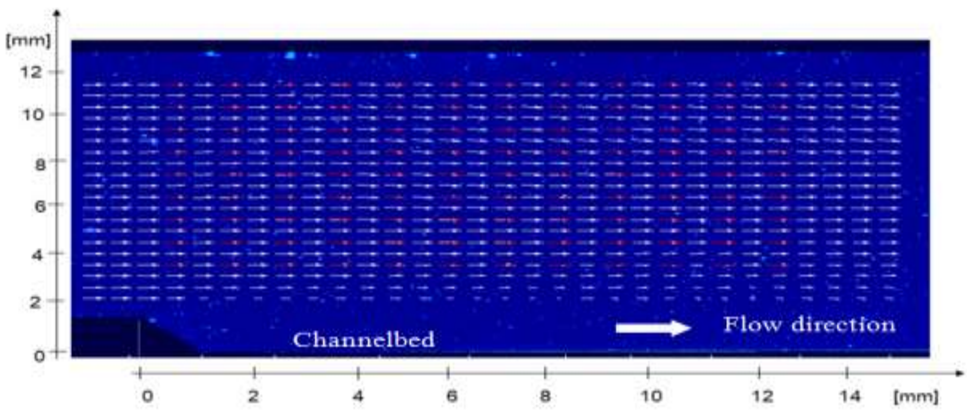

Fig. 8:Velocity fields superposition of solid (red vectors) and liquid (white vectors) phases [5].

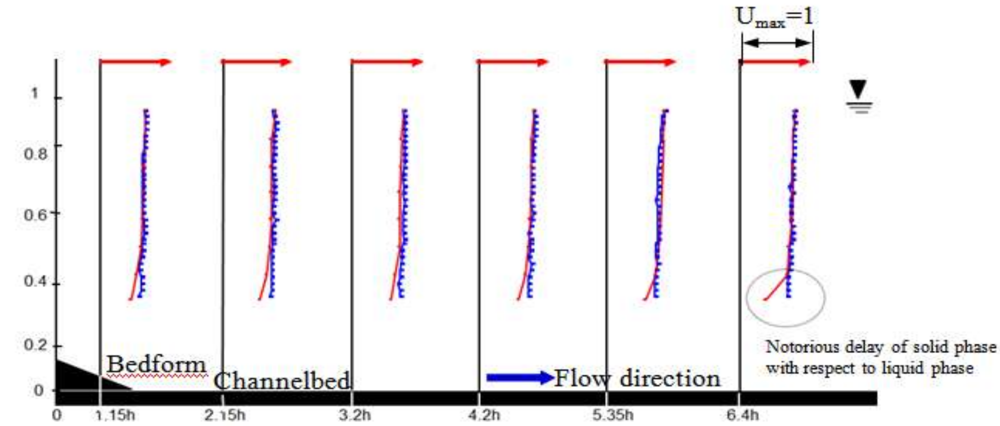

Fig. 9:Adimensionalized velocity profiles [5].

Solid phase images offer the possibility to do a study about solid particles concentration in the vertical. Figure 10 shows three results of a concentration study from an automated analysis of solid phase images [5]. Three zones were defined at different heights, in which an automated counting of visible particles was carried out. Knowing particles number, its volume and density, it is possible to calculate concentrations in mass on volume units, assuming that control volume thickness is the same of the laser light plane. Highest concentrations occur close to bed, while around free surface the lowest were obtained. This result is also consistent with what happens in natural currents, in which sediments tend to precipitate. Variation of solid particle concentrations over time (~20%) is associated with flow behavior. [5] comments that turbulent flow structures can move particles in an organized manner and produce fluctuations in concentrations even if particles are initially evenly distributed.

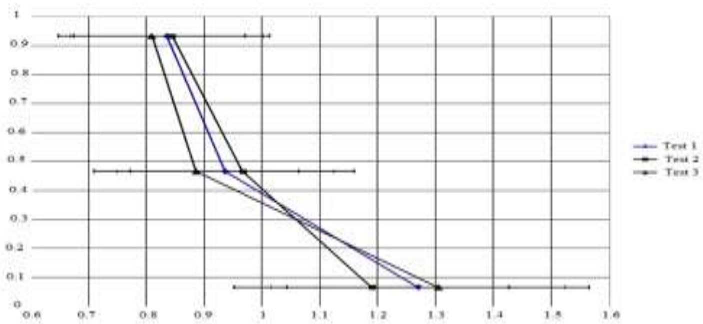

Fig. 10:Heights as a function of on-screen counting concentrations (adimensionalized).
Results of three experiments are shown [5].

III. CONCLUSIONS

- There is a long-term adaptation of river morphology to flow and sediment.
- River geometry adapts continuously to flow changes, with a certain delay, and also to changes in solid load.
- Ignore fluvial processes and the role played by sediments results in high costs for community, due damages produced to fluvial infrastructure.
- Channels geomorphology is result of many factors: hydraulic, sedimentological, geological, tectonic, bed resistance to erosion. The role of sediments is crucial in this topic.
- Changes in climate and hydro-meteorology affect soil erosion, hydraulic regime and river courses evolution.
- Modifying PIV standard technique by the use of fluorescent particles of different size and different wavelength of the scattered light in combination with the use of optical filters installed in each camera, it is possible to measure simultaneously liquid and solid phase velocities in a flow seeded with solid particles in suspension.
- In case of not having fluorescent particles to separate solid and liquid phases, it is possible to control the gray scales in images in such a way that smallest particles remain outside of visual field. This strategy is very useful particularly for the case of solid particles concentration studies.

- PIV has the advantage of being a non-intrusive technique that provides reliable velocity data.

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