# STUDY ON BED DEFORMATION IN LOWER MEKONG RIVER


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## ABSTRACT

This study presents field data for topography change, bed material, water surface elevation and hydrograph in Tan Chau reach in Vietnam to understand mechanism of the river change. These show that bank shifting tends to occur toward anti-clock wise and sand bars migrate downstream, resulting in a much larger bar, which is influenced by co-presence of non-cohesive and cohesive sediment and artificial works. In addition, bed material loads are originated by bank erosion. A 2-D numerical model is proposed to treat such river changes by introducing erosion rate formula for cohesive material and formula for estimating the thickness of sediment transport layer into a usual method. The new method is applied to the study reach which is 15km long and is supposed to be applicable for predicting bed deformation of natural river with fine sediment.


## 1. INTRODUCTION

The Mekong River is ranked twelfth in length and sixth in mean annual discharge, globally. It drains the area of 795,500km$^2$ from Himalayas, through Southwestern of China, Laos, Thailand, Cambodia and Vietnam. The Mekong delta which is located in Vietnam plays an important role in society and economic development, supporting 16 million inhabitants and contributing to over 27% of national GDP. Therefore, river change and associated bank erosion cause serious socio-economic problems.

Study reach is about 15km long, a part of Mekong River, which is located in Tan Chau near the national border with Cambodia, as shown in **Fig. 1**. Left bank of the reach in Thuong Phuoc has received strongest and fastest erosion which takes place frequently not only in flood season but also in dry season. Average erosion rate is estimated at about 30-50m/year. Such bank erosion causes damage of more than 100 houses. The bank erosion of Tan Chau side is estimated at about 6m per year, which is not so large comparing to other places. However, Tan Chau is populated densely and urbanized much more than others. Therefore, damages due to erosion are considered to be serious even if bank erosion takes place a little.

As above circumstances, Vietnam Government emphasizes that researches should be conducted for bank protections and preferable countermeasures. In 2001, Southern Institute of Water Resource Research - River Training Center conducted a research about erosion problems of several places [1]. But unfortunately, no reasonable methods have been proposed except a temporary bank protection.

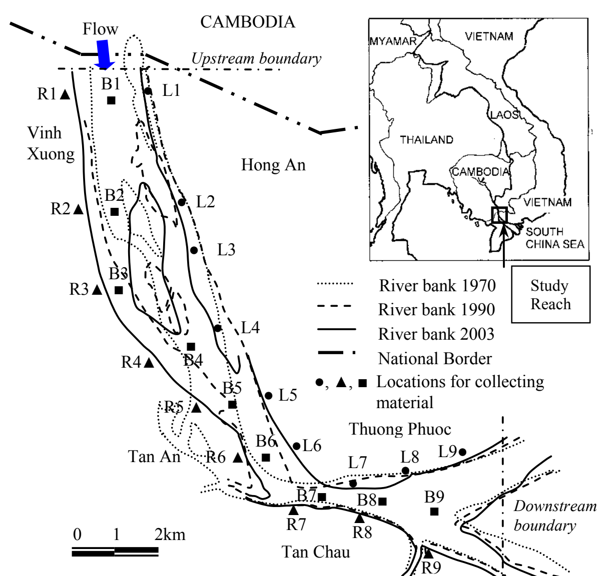


**Fig. 1** Comparison of shore lines at Tan Chau reach (120 km upstream from river mouth)

Present study describes circumstances of erosion and associated problems based on field data focusing on Tan Chau reach, 15km long, and propose a numerical method to treat such river changes. In the numerical method, new models treating with sediment exchange layer as well as with channel erosion for sediment composed of non-cohesive and cohesive material, are introduced into the 2-D methods which were proposed by Nagata et al [2] and Liu [3].

## 2. CHARACTERISTICS OF STUDY REACH

### (1) Hydrological characteristics

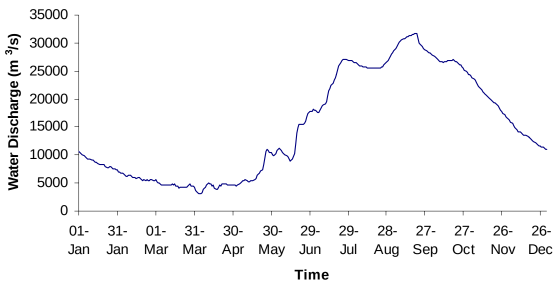


**Fig. 2** Hydrograph of Mekong River at Neak Luong gauss station in 2000 (Upstream of Tan Chau)

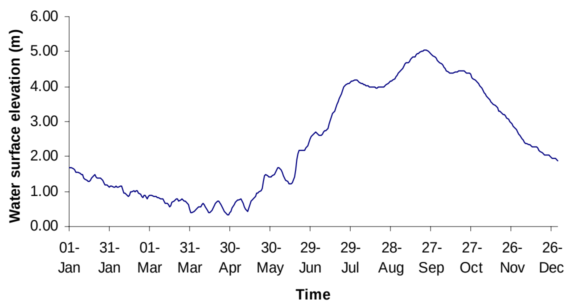


**Fig. 3** Water surface elevation at Tan Chau gauss station in 2000

Data for hydrograph and water surface elevation were provided by Mekong River Commission. **Figure 2** shows water discharge at Neak Luong gauss station in 2000, located at upstream of Tan Chau reach. The maximum discharge is 31,799$m^3$/s in September and minimum one is 3050$m^3$/s in April, respectively. Flood duration is about 7 months in which water level is rising during 3 to 4 months and lowering during 3 months. Its maximum difference can be 4.71m between dry and flood seasons, as shown in **Fig. 3**.

### (2) Material characteristics

Formation process of Mekong Delta may have been influenced for historically long time by seasonal, daily, tidal changes of hydrological quantities as well as by associated sediment transportation. In view of sediment phenomena, fine sediment transport such as suspended loads and wash loads may have dominated for long.

**Figures 4**, **5** and **6** show the size distribution curves for material collected at left bank, right bank and river bed in nine sections, respectively. The data were sampled in Feb., 2003, and their locations are denoted in **Fig. 1**. As shown in these figures, medium size of both banks is from 0.01mm to 0.08mm and composed of particles ranging from clay to find sand. Whereas, the medium size of bed ranges 0.15mm to 0.6mm, and no meaningful quantity of sediment finer than 0.1mm is included.

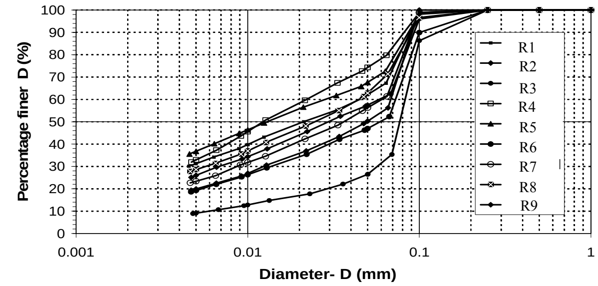


**Fig. 4** Material size at right bank

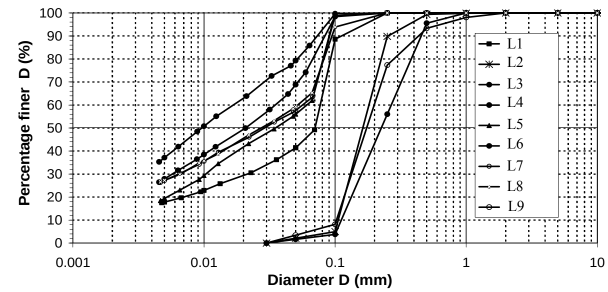


**Fig. 5** Material size at left bank

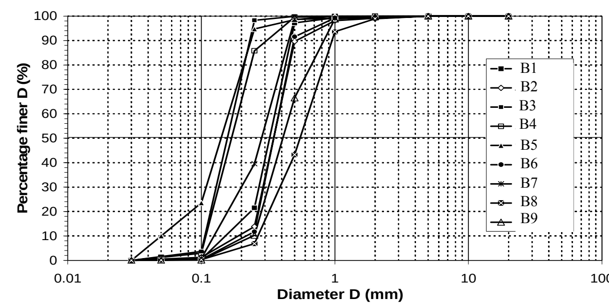


**Fig. 6** Bed material size

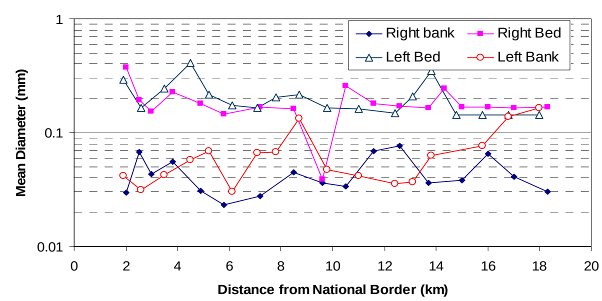


**Fig. 7** Mean diameter of material along Tan Chau reach

These differences can be seen clearly by distribution of mean diameter along study reach which are shown in **Fig. 7**. Such differences in sediment sizes between river banks and bed suggests that fine sediment, i.e. finer than 0.1mm in diameter, included in side banks is released once into flow, and thus transported far as wash loads and that sediment coarser than 0.1mm deposits onto bed and is transported as bed loads and suspended loads.

**(3) Topography change**

In **Fig. 1**, shore lines of study reach are shown including bank lines and islands. The lines denoted by 1970 and 1988 are obtained by map analysis provided by National Institute of Survey in Vietnam. The line of 2003 is determined by authors' direct measurement.

According to the results, two representative characteristics can be distinguished for channel shifting as follows. The bank lines in upstream reach where a large island (sand bar) is formed in 2003 have been shifting in accordance with movement of sand bars. In this circumstance, sand bars migrate and merge, resulting in a developed bar.

In comparison to such changes, the curved reach spreading upstream from Tan Chau and Thuong Phuoc shows a dramatic change that is caused possibly by curved flow, the presence like a stationary point, artificial bank protection works and several urbanizing performances. In fact, the both of left and right banks shifted over 1km at the upstream reach of Tan Chau between 1970 and 2003, although an area like a stationary point was formed between Tan Chau and Thuong Phuoc. In addition, river bed is expected to be scoured deeply along the right bank in Tan Chau because of curved flow as well as of narrow reach.

3. NUMERICAL CALCULATION

**(1) Governing Equations**

Depth integrated 2-D forms of mass and momentum conservation equations for flow are employed and described in the boundary fitted orthogonal curvilinear coordinate system, which is the same as the model proposed by Nagata et al.[2].

Referring to the results on bed and bank material shown in **Figs. 4**, **5, 6** and **7**, sediment transportation can take place in complex ways; bed loads and suspended loads including wash loads. In addition, cohesive sediment plays an important role on sediment transport and associated river change. In order to overcome such problems, several new relations are introduced into exchange layer model proposed by Hirano[4] and bed elevation equation. According to this method, bed surface can be distinguished clearly from bed load layer of which thickness is a function of bed shear stress.

This method is shown schematically in **Fig. 8**. If bed surface is covered thickly enough by bed material loads, the depth of bed load layer, $E_s$, will be evaluated as a function of bed shear stress and estimated by Egashira and Ashida's equation[5]. Whereas, if bed material is less than the saturated volume associated with bed shear stress, bed loads will take place in unsaturated condition and bed surface will be at the interface between unsaturated

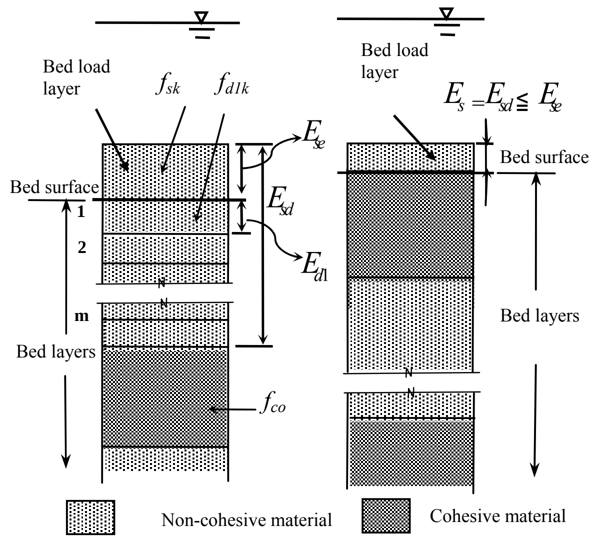


**Fig. 8** Schematic diagram describing multilayer model

bed load layer and cohesive sediment layer.

In this circumstance, continuum equation of each grain size for bed load layer is written as follows.

$$\overline{c_s}\frac{\partial}{\partial t}\left(\frac{f_{sk}E_s}{J}\right)+(1-\lambda)F_{sk}\frac{\partial}{\partial t}\left(\frac{z_b}{J}\right)+\left\{\frac{\partial}{\partial \xi}\left(\frac{q_{b\xi k}}{J}\right)+\frac{\partial}{\partial \eta}\left(\frac{q_{b\eta k}}{J}\right)+\frac{1}{J}w_k\left(c_{bek}-c_{bk}\right)\right\}=0 \qquad (1)$$

in which $F_{sk}=f_{d1k}$, $(\partial z_b/\partial t \le 0,\ E_{sd} \ge E_{se})$;

$F_{sk}=f_{co}$, $(\partial z_b/\partial t \le 0,\ E_{sd} \le E_{se})$;

$F_{sk}=f_{sk}$, $(\partial z_b/\partial t \ge 0)$

Continuum equation of each grain size for first layer is written as follows.

$$E_{d1}\frac{\partial}{\partial t}\left(\frac{f_{d1k}}{J}\right)+\left(f_{d1k}-F_{dk}\right)\frac{\partial}{\partial t}\left(\frac{E_{d1}}{J}\right)=0 \qquad (2)$$

in which $F_{dk}=f_{d1k}$, $(\partial z_b/\partial t \le 0)$;

$F_{dk}=f_{sk}$, $(\partial z_b/\partial t \ge 0)$

In these equations $J$ is the metric coefficient, $\lambda$ is the porosity, $q_{b\xi k}$ and $q_{b\eta k}$ are the sediment transport rate for size class-$k$ in $\xi$ and $\eta$ directions, respectively, $f_{sk}$ is the fraction of size class-$k$ in the bed load layer, $f_{co}$ is the sediment fraction of size class-$k$ in the cohesive sediment layer, $E_{dm}$ and $f_{dmk}$ are the thickness and fraction of size class-$k$ in the m-*th* bed layer composed of non-cohesive sediment, respectively (m=1,2..), $\overline{c_s}$ is the sediment concentration of bed load layer ($(1-\lambda)/2$[5] is used as

$\overline{c}_s$ for simplicity), $E_s$ is the bed load layer thickness, $E_{sd}$ is the thickness of non-cohesive sediment over cohesive sediment, $E_{se}$ is the thickness of equilibrium or saturated bed load layer estimated by the following equation[5].

$$\frac{E_{se}}{d_m} = \frac{1}{\overline{c}_s \cos\theta(\tan\phi - \tan\theta)} \tau_{*m} \tag{3}$$

in which $d_m$ is the mean sediment size of bed load layer, $\theta$ is the local bed slope, $\phi$ is the angle of repose and $\tau_{*m}$ is the non-dimensional bed shear stress specified by $d_m$. Relations among $E_s$, $E_{se}$ and $E_{sd}$ are as follows.

$$E_s = E_{se}\ , \ (E_{sd} \geq E_{se}); \quad E_s = E_{sd}\ , \ (E_{sd} \leq E_{se}) \tag{4}$$

Bed elevation is estimated by means of following formulas depending on the relation of $E_{sd}$ and $E_{se}$;

$$(1-\lambda)\frac{\partial}{\partial t}\left(\frac{z_b}{J}\right) + \overline{c}_s \frac{\partial}{\partial t}\left(\frac{E_s}{J}\right) + \sum_{k=1}^{n}\left[\frac{\partial}{\partial \xi}\left(\frac{q_{b\xi k}}{J}\right) + \frac{\partial}{\partial \eta}\left(\frac{q_{b\eta k}}{J}\right) + \frac{1}{J} w_k (c_{bek} - c_{bk})\right] = 0 \ , \ (E_{sd} \geq E_{se}) \tag{5}$$

$$\frac{\partial}{\partial t}\left(\frac{z_b}{J}\right) + \frac{V_e}{J} = 0\ , \ (E_{sd} \leq E_{se}) \tag{6}$$

in which $q_{b\xi k} = \xi_x q_{bxk} + \xi_y q_{byk}$ and

$$q_{b\eta k} = \eta_x q_{bxk} + \eta_y q_{byk}$$

Herein bed load rate $q_{bk}$ for size class-$k$ is defined as $q_{bk} = \sqrt{q_{bxk}^2 + q_{byk}^2}$ and is estimated by the following relation [3], [6].

$$q_{bk} = 17 \frac{\rho u_{*e}^3}{(\rho_s - \rho) g}\left(1 - \sqrt{K_c}\frac{u_{*ck}}{u_*}\right)\left(1 - K_c \frac{u_{*ck}^2}{u_*^2}\right) f_{sk} r_s \tag{7}$$

In Eq. (7), $\rho$ is the water density, $\rho_s$ is the sediment density, $u_{*e}$ is the effective shear velocity, $u_*$ *is* shear velocity, $u_{c*k}$ is critical shear velocity of size class-$k$, $K_c$ is the correction factor related to local bed inclination, which is determined after Parker's results[3],[6]. $r_s$ is introduced to describe the unsaturated bed load rate and is a function of relative depth $E_s/E_{se}$ as shown in **Fig. 9**.

Velocities near the bed are evaluated using curvature radius of streamlines:

$$u_b = 8.5 u_*,\ v_b = -N_*(h/r) u_b \tag{8}$$

in which $N_*$ is 7.0[7] and $r$ is the curvature radius of stream lines obtained by depth integrated velocity field.

Settling velocity of suspended sediment of size class-$k$, $w_k$, *is* estimated in terms of Rubey's formula[8] and quasi-equilibrium suspended concentration, $c_{bek}$, for size class-$k$ at reference level is evaluated as follows[9].

$$c_{bek} = 5.55 f_{sk}\left\{\frac{1}{2}\frac{u_*}{w_k}\exp\left[-\left(\frac{w_k}{u_*}\right)\right]\right\}^{1.61} r_s \tag{9}$$

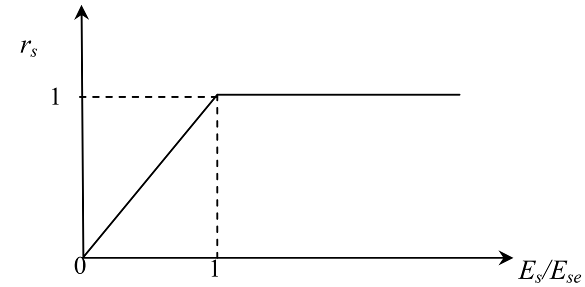


**Fig. 9** Relation between $r_s$ and $E_s/E_{se}$

in which $r_s$ is the same as the factor in equation (7). It is considered that equilibrium sediment concentration is formed at reference level when bed load layer is saturated, whereas it decreases with the decrease of relative thickness $r_s$, as shown in **Fig. 9**, because sediment can not be supplied fully through bed load layer for suspension. Therefore, the sediment concentration determined by equation (9) is called "quasi-equilibrium".

$c_{bk}$ is the suspended sediment concentration of size class-$k$ at reference level. When the vertical distribution of suspended sediment concentration is supposed to be the exponential distribution, the relationship between $c_{bk}$ and the depth-averaged value, $c_k$, is expressed as follows.

$$c_k = \frac{c_{bk}}{w_k h / D_h}\left(1 - e^{-w_k h / D_h}\right) \tag{10}$$

The erosion rate of cohesive sediment, $V_e$, is estimated in terms of Sekine et al.'s formula[10].

$$V_e = \alpha R_{wc}^{2.5} u_*^3 (1 - r_s) \tag{11}$$

in which $\alpha$ is the empirical coefficient and $R_{wc}$ is the water content ratio of cohesive sediment.

Suspended sediment transport is evaluated using the following continuum equation.

$$\frac{1}{J}\frac{\partial}{\partial t}(c_k h) + \frac{\partial}{\partial \xi}\left(\frac{c_k}{J} Q^{\xi}\right) + \frac{\partial}{\partial \eta}\left(\frac{c_k}{J} Q^{\eta}\right) = \frac{1}{J} w_k (c_{bek} - c_{bk}) + \frac{\partial}{\partial \xi} h\left(\frac{D_x \xi_x^2 + D_y \xi_y^2}{J}\frac{\partial c_k}{\partial \xi} + \frac{D_x \xi_x \eta_x + D_y \xi_y \eta_y}{J}\frac{\partial c_k}{\partial \eta}\right) + \frac{\partial}{\partial \eta} h\left(\frac{D_x \xi_x \eta_x + D_y \xi_y \eta_y}{J}\frac{\partial c_k}{\partial \xi} + \frac{D_x \eta_x^2 + D_y \eta_y^2}{J}\frac{\partial c_k}{\partial \eta}\right) \tag{12}$$

in which $h$ is water depth, $\xi_t$, $\eta_t$, $\xi_x$, $\eta_x$, $\xi_y$, $\eta_y$ are metrics, $D_x$ and $D_y$ are the dispersion coefficient in $x$ and $y$ directions, respectively ($D_x = D_y = D_h$ as a diffusion coefficient for simplicity).

Bank erosion with non-cohesive material is evaluated using the model of Nagase et al.[11]. This is based on the stability condition by angle of repose of material. In case of cohesive material, equation (6) is applied for this method.

**(2) Numerical Method and Computational Conditions**

TVD Mac-Cormack numerical scheme is used only for advection terms of momentum conservation equations and central difference method is employed for other terms. Definitions for locations of the hydraulic variables used in the method are shown in **Fig. 10**, where U, V and $Q^{\xi}$, $Q^{\eta}$ are ξ and $\eta$ components of velocity vectors and discharge fluxes, respectively. In the equations associated with sediment, the 1st order up-wind scheme (time and space) is employed for the terms of first-order spatial derivatives, and the central difference approximation is used for the terms of second-order spatial derivatives

Computational conditions adopted in this study are summarized as follows. Computation domain, which is shown in **Fig. 1**, is 15 km long. The initial topography of this reach is specified based on data obtained from field survey in 2003. However, some small reaches are ignored to simplify the computations. Flood plain is assumed to be expanded laterally about one kilometer from the both banks and its elevation is assumed to be equal to the bank elevation. The hydrograph which is shown in **Fig. 2** and water surface elevation which is shown in **Fig. 3** are used for upstream and downstream boundary condition, respectively. The value of $f_{sk}$ and $c_k$ at upstream boundary are estimated by use of collected bed material distribution and equilibrium hydraulic conditions. It is supposed that side bank region steeper than the angle of repose for non-cohesive sediment is composed of cohesive sediment and initial bed area is covered one meter deep by non-cohesive sediment.

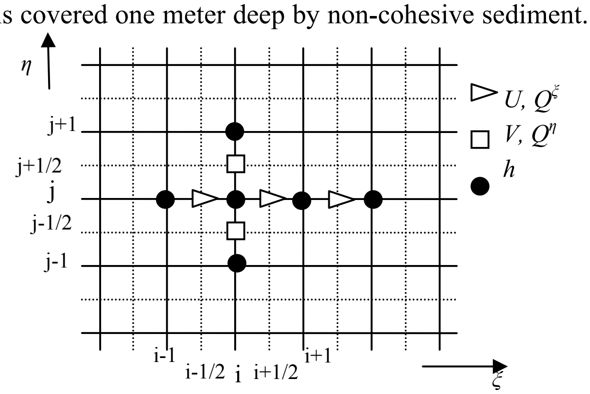


**Fig. 10** Defined locations of variables

4. RESULTS AND DISCUSSION

The computational domain and its grid system are shown in **Fig. 11**. **Figure 12** shows computed results on flow patterns of depth mean. **Figure 13** shows cross-sectional shapes and its sediment transport rate in ξ and η direction in dry season (June) and flood season (September), respectively. The results shown in **Fig. 12** suggest that the flow pattern is influenced very much as a whole by initial condition such as a presence of large sand bar and by the narrow channel shape at downstream of section 43. In addition, stream currents were strengthened along the right bank in the upstream from section 35. This was caused by moving to downstream of large bar which can be seen clearly the change of channel shape in section 10, 18 in **Fig. 13** and contour lines in **Fig. 14**. However, in downstream part of section 35, stream current were strengthened along left bank. Such change of flow pattern will cause a channel shift, and also will be affected by the caused channel change. In fact, as shown **Fig. 13**, the right bank was scoured deeply in section 35, while the left bank was scoured in section 43. The aggradations part of section 35 and section 43 can be understood as development of sand bars at left bank and right bank respectively. These developments may be same with the tendency which can be seen in **Fig. 1**.

As shown in the results of **Figs. 12, 13** and **14**, the computed channel changes correspond qualitatively with the tendency described in **Fig. 1**, so far as the channel shifting is concerned in the upstream of section 43. However, bed changes at some sections have not predicted so well. Therefore, grid step should be finer, and real conditions such as preferable initial channel shape, sediment characteristics associated with channel erosion, and artificial works should be introduced into computational conditions.

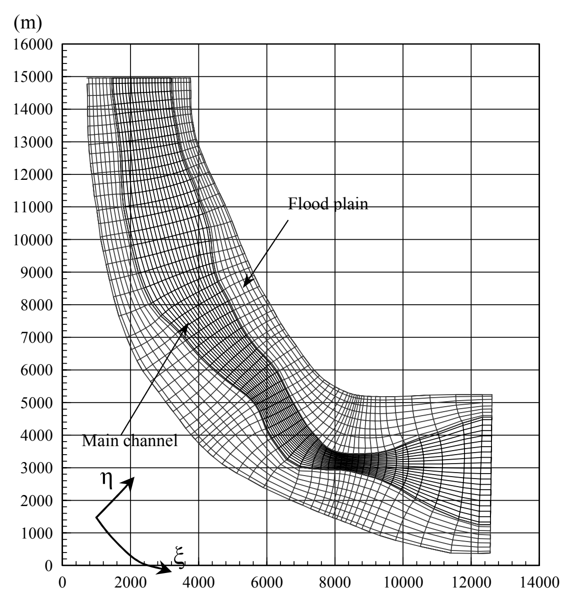


**Fig. 11** Computational domain and grid system

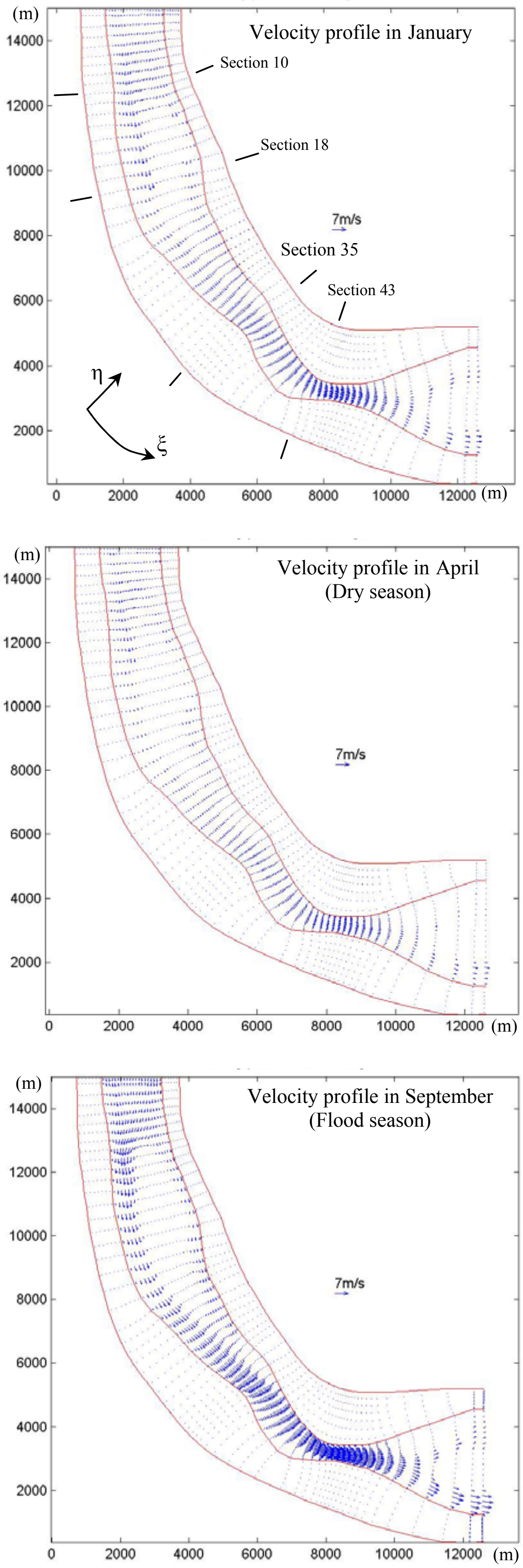


**Fig. 12** Computed velocity profiles in January, April and September

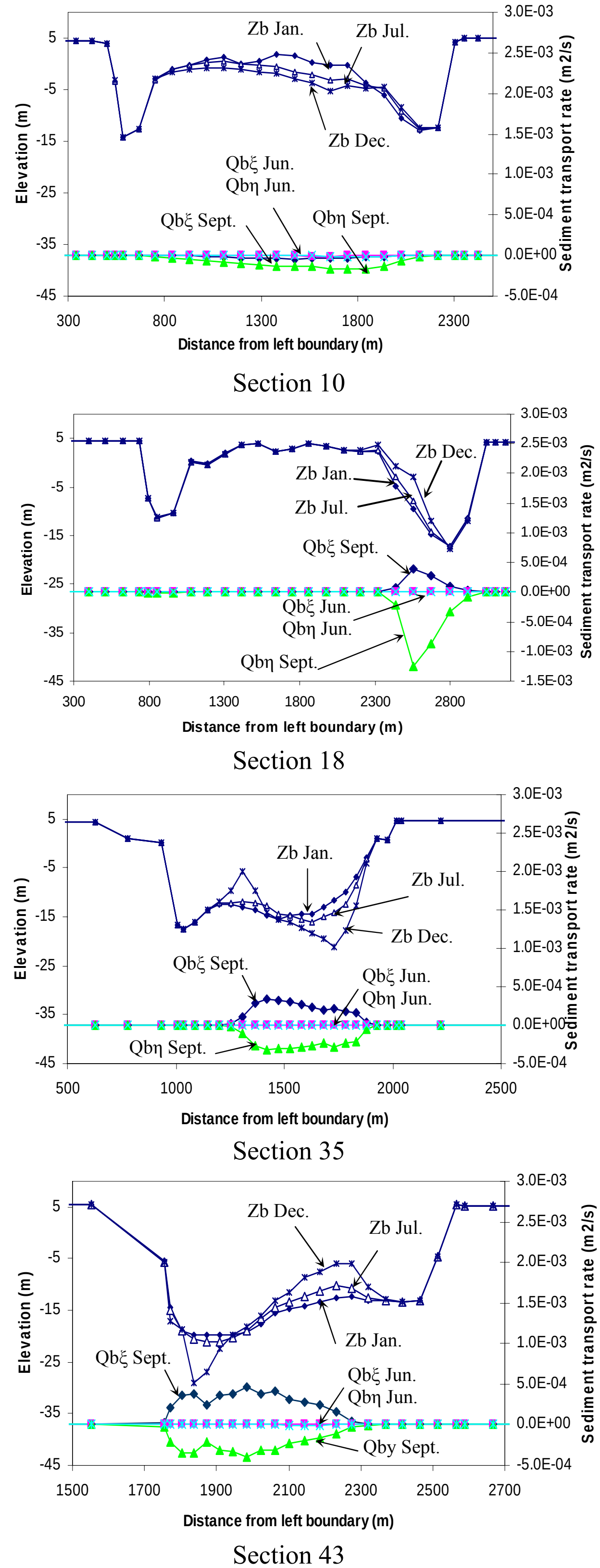


**Fig. 13** Channel deformation in section 10, 18, 35 and 43

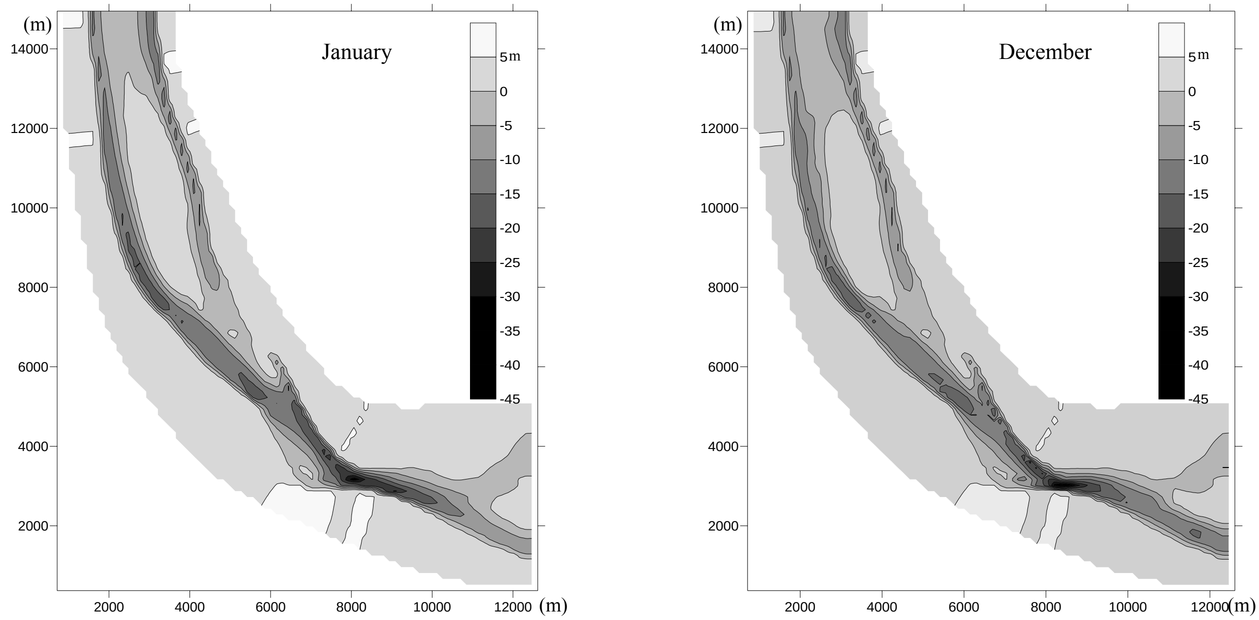


**Fig. 14** Contour lines of bed elevation in January and December

## 5. CONCLUSION

Channel change in part of Mekong River was investigated using field data and the numerical method to develop a tool treating channel change in which the presence of cohesive sediment plays important roles in sediment transport phenomena. Results and further problems are summarized as follows.

(1) Data of bed and bank material are provided to study the river change which is probably influenced by the co-presence of non- and cohesive sediments, and data analysis suggests that bed material can be produced due to bank erosions. Bank erosion and associated channel shifting have been controlled by a large bar, channel plane form and several artificial works in addition to the sediment characteristics and hydrological data variations.

(2) A 2-D numerical model describing bed deformation was proposed by introducing erosion rate formula for cohesive material and formula for estimating the thickness of bed load layer, and it was used to predict channel morphological process. The simulated results of flow pattern and bed deformation can explain a tendency of the channel shifting, migration to downstream of sand bars and emphasize that the presence of cohesive material influences the channel change.

(3) Further studies are desired for: study of historical formation process on Mekong Delta to evaluate present sediment phenomena, further refinement of numerical model. The comparison between simulation results and historical data of channel change will check the validity of numerical model. After that, the present model will be applied to predict the channel change in the future.

## REFERENCES

(1) Southern Institute of Water Resource Research - River Training Center, "Study on predictive shoreline erosion of Mekong River," (2001) (In Vietnamese).
(2) Nagata, N., Hosoda T. and Muramoto Y. "Numerical Analysis of River Channel Processes with Bank Erosion," Journal of Hydraulic Engineering, ASCE, Vol. 126, No. 4, 4, (2000), pp.243-252.
(3) B. Y. Liu "Study on Sediment Transport and Bed Evolution in Compound Channels," Thesis presented to Kyoto University, 1991.
(4) Hirano, M. "River-bed degradation with armoring," Proc. of JSCE, Vol. 195, (1971), pp.55-65. (In Japanese).
(5) Egashira, S. and Ashida, K. "Unified view of the mechanics of debris flow and bed-load, Advances in Micromechanics of Granular Materials," (Edited by H.H.Shen et al.) Elsevier, (1992), pp. 391-400.
(6) Kovacs, A. and Parker, G. "A new vectorial bed load formulation and its application to the time evolution of straight river channels," Journal of Fluid Mechanic, Vol. 267, (1994), pp.153-183.
(7) Engelund, F. "Flow and bed topography in channel bends," Journal of Hydraulic Division, ASCE, Vol. 100, No. HY11, (1974), pp.1631-1648.
(8) Rubey, W. W.: Settling velocities of gravel, sand and silt particles, American Journal of Science, Vol. 25, pp.325-338, 1933.
(9) Lane, E. W. and Kalinske, A. A. "Engineering calculation of suspended sediment," Transaction A.G.U., Vol. 22, (1941), pp.603-607.

(10) Sekine, M., Nishimori, K., Fujio, K. and Katagiri, Y. “On erosion process of cohesive sediment and erosion rate formula,” Annual Journal of Hydr. Eng. JSCE, Vol. 47, (2003), pp. 541-546 (In Japanese).
(11) Nagase, K. and Michiue, M. and Hinokidani O. “Simulation of bed elevation around contraction in mountainous river,” Annual Journal of Hydr. Eng. JSCE, Vol. 40, (1996), pp.887-892 (In Japanese).