Study on Flow Structure and Local Losses of Gradual Transition within a Lotus-shape Open Channel

Xu-Feng YAN, Prof. Onyx Wing-Hong WAI
Department of Civil and Structure Engineering, the Hong Kong Polytechnic University, HKSAR, China

Abstract: Gradual channel transition is widely used in open channel designs. In this study, this type of channel transition was investigated by using physical modeling tests and simple 2-D numerical simulations. In the physical experiments, flow structures such as secondary currents with irregular anti-clockwise and clockwise circulations have been observed in both contraction and expansion regions. This flow structure is of particular significance because it may have essential impact on transport of matters such as sediments, contaminants and so forth. A commercial numerical model was employed to simulate the 2-dimensional flow structure in the gradual channel transition. The computed results of the longitudinal mean flow velocity and flow depth have a good agreement with the experimental results. This suggests that the 2-D commercial model is able to describe the flow structure appropriately in the gradual channel transition region. Moreover, numerical simulated results were utilized to calculate the local loss induced by different channel widths. Dramatic jumps would result at the position downstream close to the narrowest cross section. The jump phenomenon may be caused by the separation of the water surface. This finding may be useful in refining the frictional term in 2-D flow models such as shallow water models and Boussinesq models when hydraulics of open channel transition is being studied.

Keywords: *gradual channel transition, secondary currents, 2D numerical simulation, the local loss*

Study on Flow Structure and Local Losses of Gradual Transition within a Lotus-shape Open Channel

X. F. Yan Prof. Onyx Wai

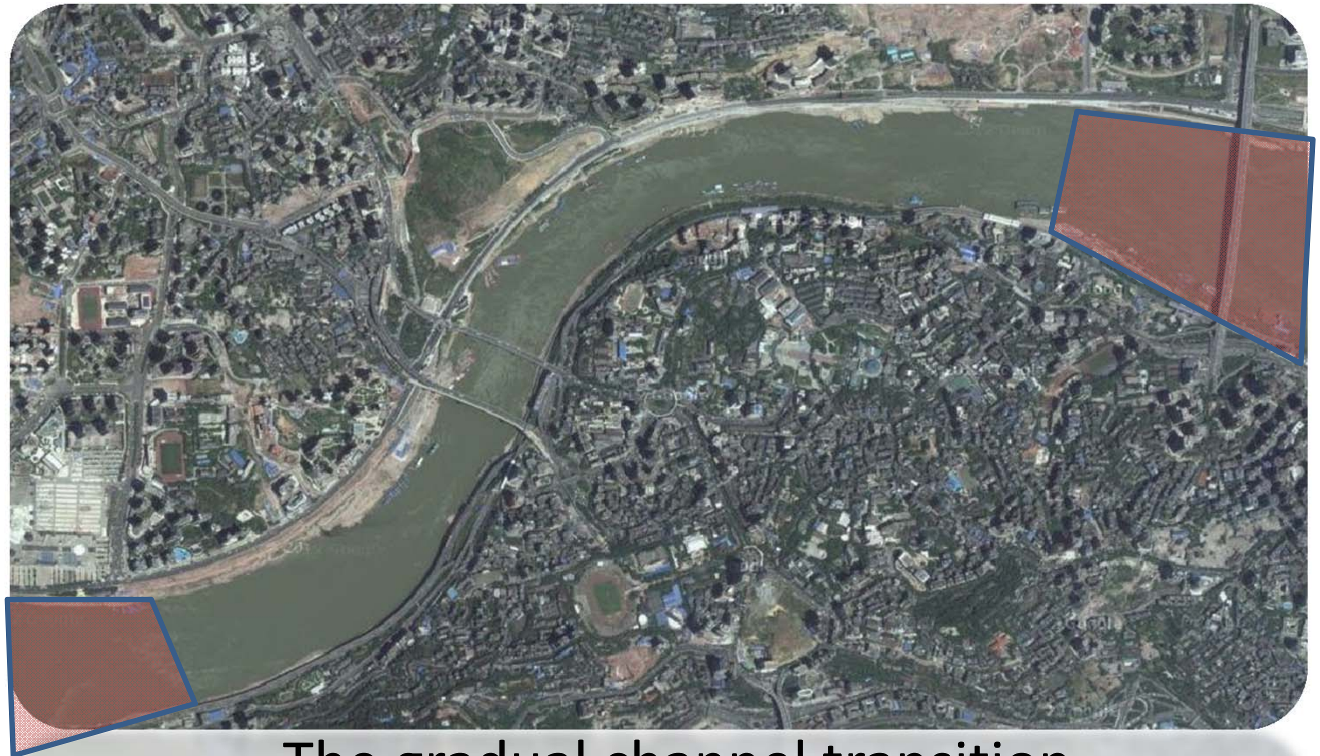
The Hong Kong Polytechnic University

17th November 2012

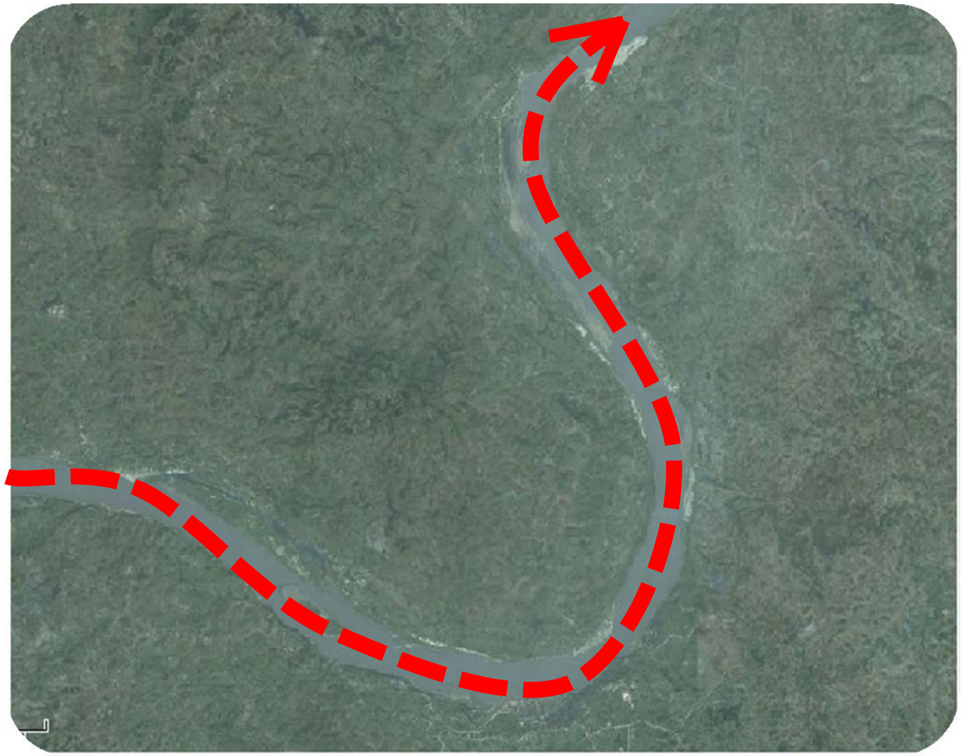
Content

Introduction and Significance

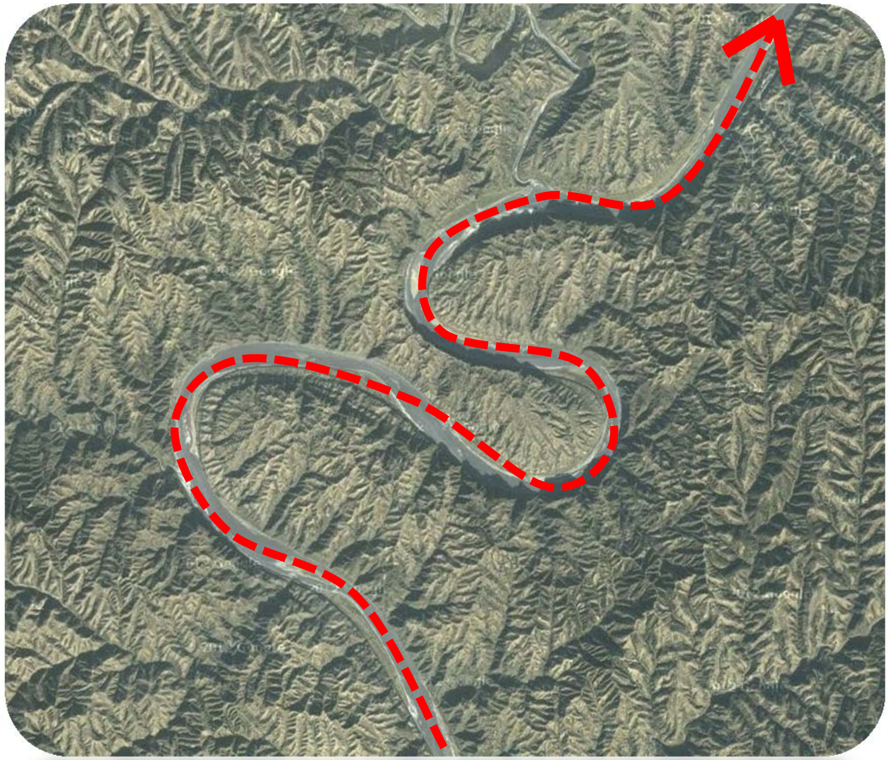
Numerous open channels exist in the nature, which are divided into a few types including the **straight, curved, confluent, gradually transitional** and so on. In Terms of gradual channel transition, the streamline **converging under contraction and diverging under expansion** will result in relatively **non-uniform flows.**



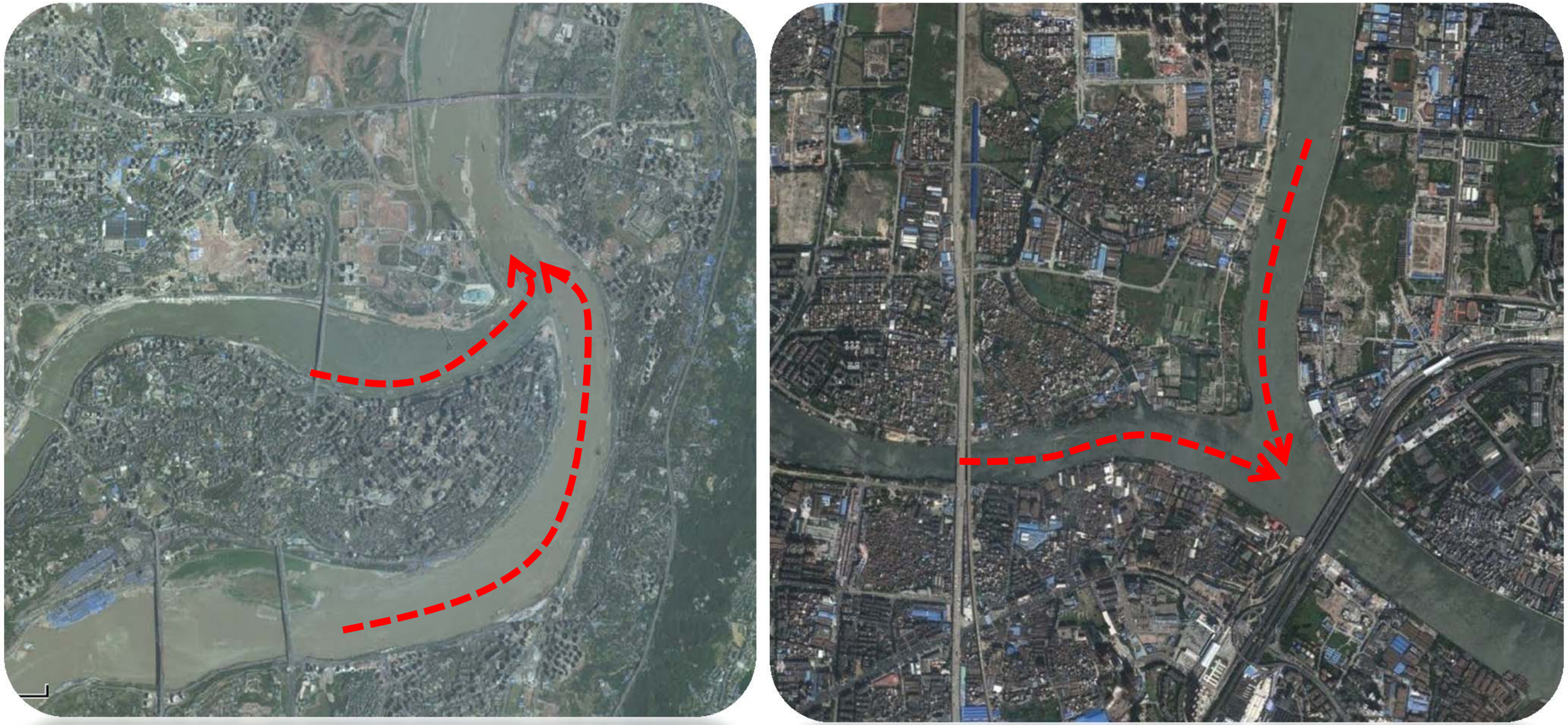
The gradual channel transition



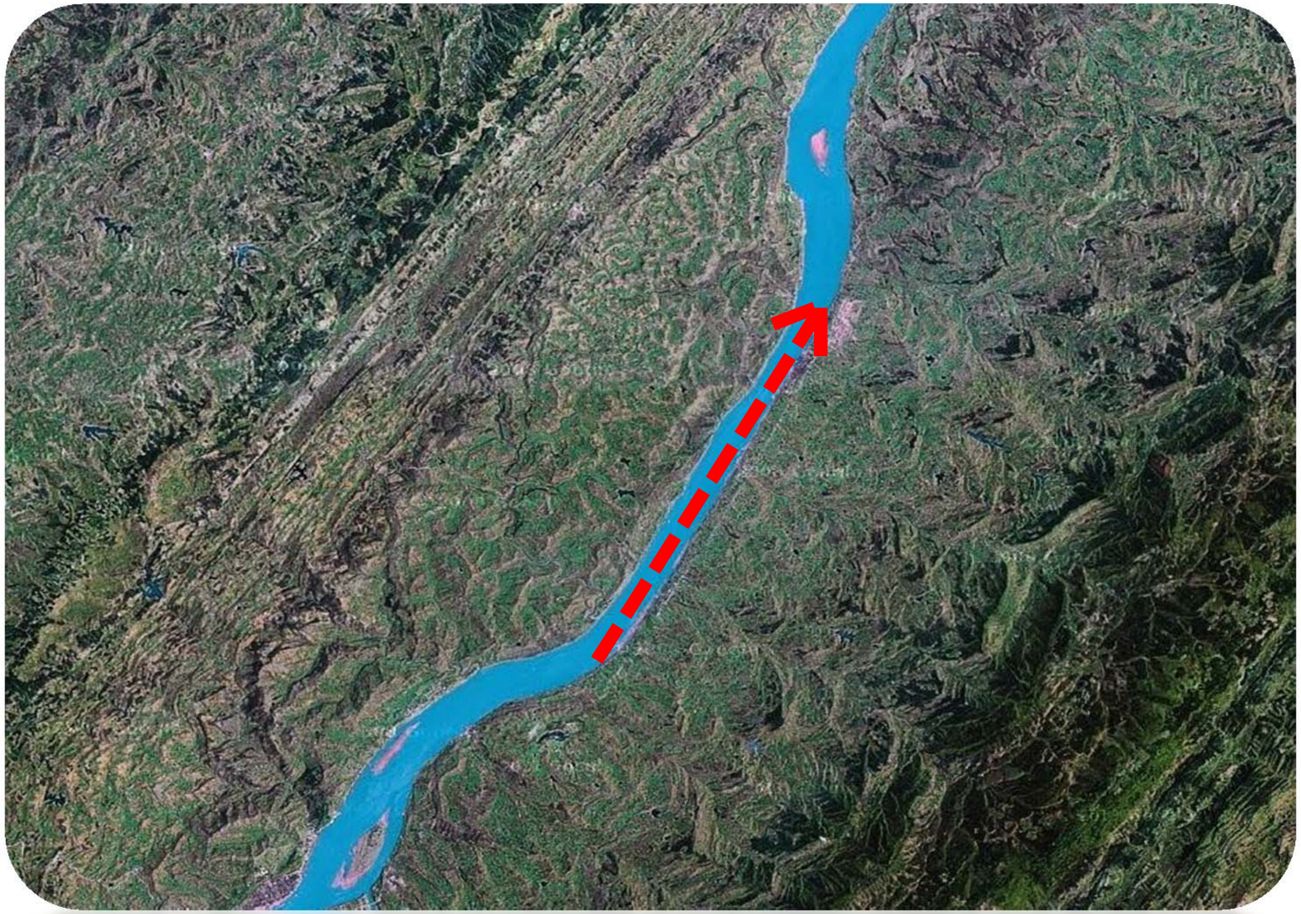
The single channel bend



The constant channel bend



The confluence



The straight open channel

➢Massive hydraulic knowledge including vertical profile, turbulent kinetic intensities and turbulent kinetic energy in **straight open channels, channel bends and confluences** have been presented in many research studies.

➢However, flows within the **gradual channel transition** are rarely observed.

Methodology

Including physical test, simple numerical modeling and calculation of the local loss

Physical test: Basic Configuration

- The experiment were conducted in a man-made flume located at the State Key Laboratory of Hydraulics and Mountain River in Sichuan University, China
- **28m** in length and **0.5m** in height
- **Plastered with cement** on the inner surface
- **Manning roughness** coefficient is roughly **0.012**
- **Bed slope is 0.2%.**
- The water flow is supplied by a **circulation system**
- In order to decelerate and accelerate the flow, each sidewall is horizontally moulded in the shape of "**Lotus**" expressed by **sinusoidal** curve (right side),

$$y = 0.2\sin\left(\frac{\pi}{3}x\right) \pm 0.5$$

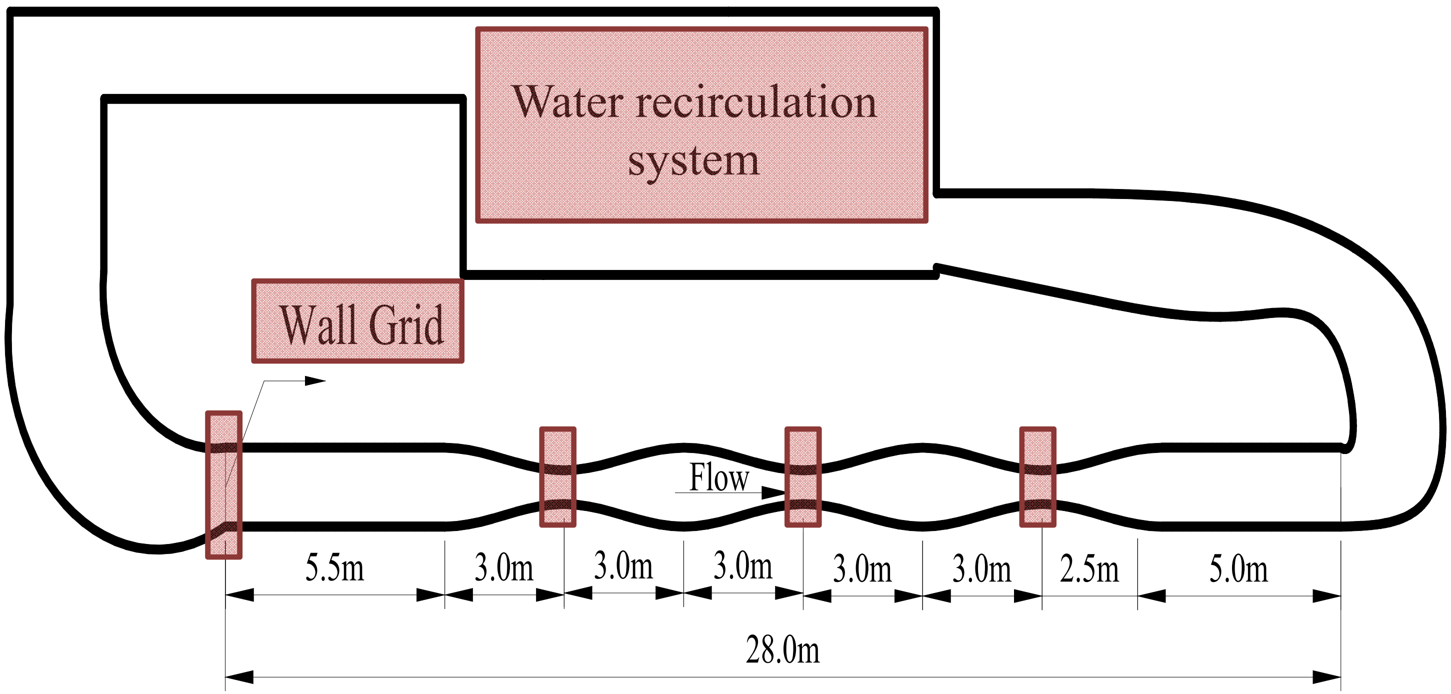
● Inflow condition: Flowrate of **100L/s** supplied by two pumps.

● A **grid wall** was installed to **create uniform flow** after the sharp bend.

● A straight upstream reach **with 5.5m in length** for further development of a uniform flow before the experiment reach.

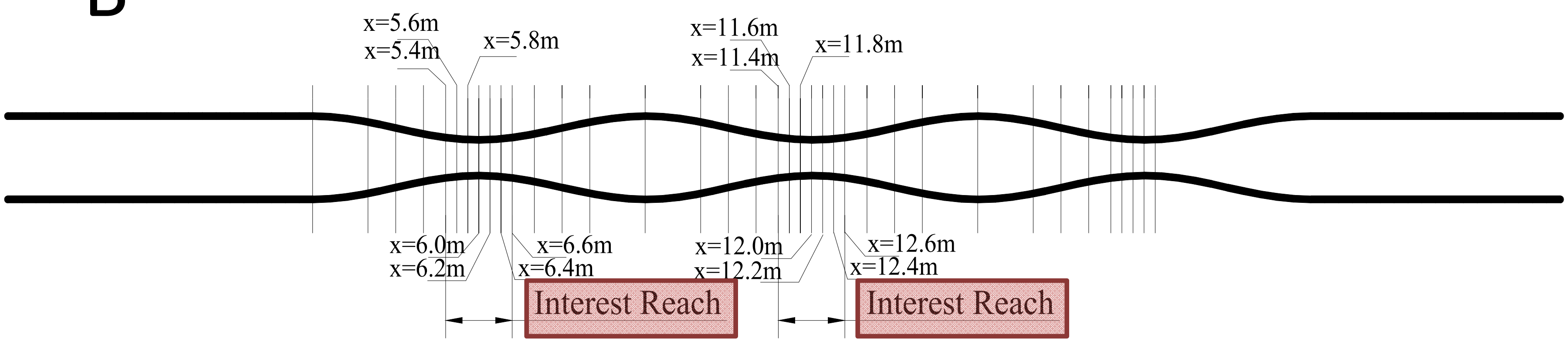
● The **narrow section** near the "Lotus Shape" is used to evaluate **the local loss of the channel transition** (see the following illustration.)

A



Sketch of the gradual channel transition

B



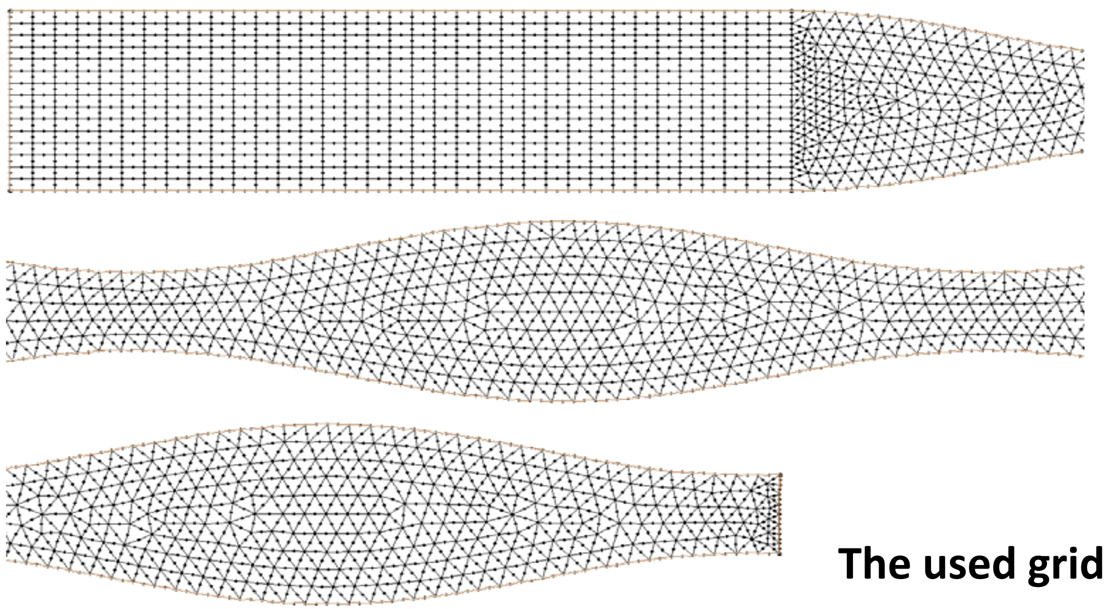
Sketch of the gradual channel transition

- Hydraulic parameters including **instantaneous flow velocities** in three dimensions as well as **flow depths** were measured.
- The former were measured by **Acoustic Doppler Velocimeter (ADV)** and the later were directly read from a **flow depth gauge** with the accuracy of 1mm.

Physical model of gradual channel transition

Numerical modeling: Employment of SMS

- **SMS, a commercial 2-D numerical model** was employed to simulate the flow within the gradual channel transition
- This model is based on the **depth-averaged shallow water equations**
- The equations are discretized using **Finite Volume Method (FVM)**
- **Triangular unstructured grids** are generated to fit the shape of the channel with gradually-varying width



The used grid

- The resolution of the model adequately presents the hydraulic information such as **flow depth** and **horizontal mean 2-D velocity** field

- The computed flow depths along the centre line were **validated against the experimental data**

- Once the commercial model SMS is validated for flows in gradual channel transition, the mean **longitudinal velocity will be used for the calculation of local losses** for particular flow conditions.

Calculation of the local loss

<u>Flow resistance is expressed as a frictional term</u> in the depth-averaged model in the shallow water equations, Boussinesq equations and so the forth. It is important to have the information of the local loss within the gradual channel transition

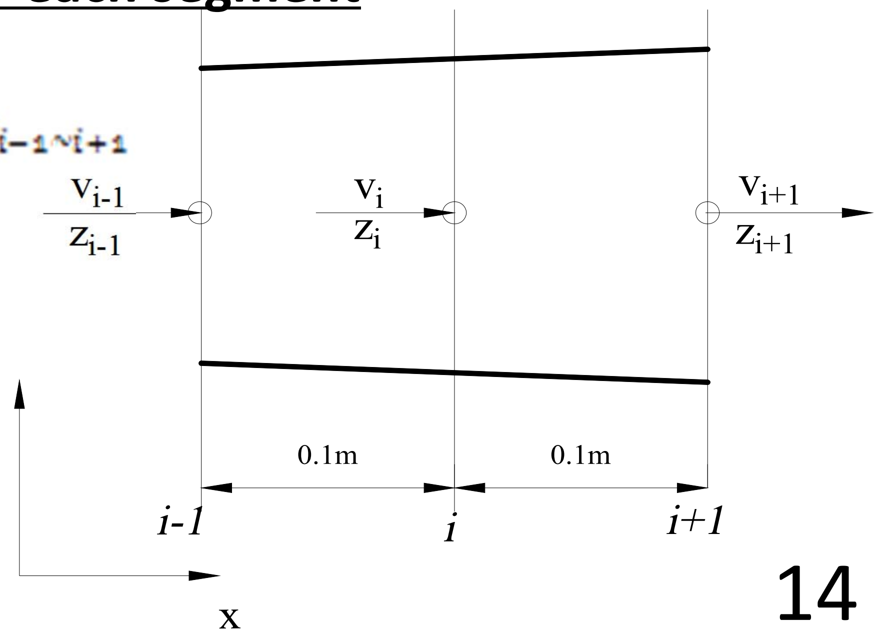
The calculation is illustrated as follow,

- we **<u>divided the control reach</u>** (1.2m in length of the two gradual channel transitions) around the narrowest cross section into many small segments **<u>with 0.1m in length for each segment</u>**

$$\begin{cases} z_{i-1} + \dfrac{\alpha_{i-1} v_{i-1}^2}{2g} = z_{i+1} + \dfrac{\alpha_{i+1} v_{i+1}^2}{2g} + h_{j_{i-1\sim i+1}} \\ h_{j_i} = \xi \dfrac{v_i^2}{2g} \quad , \quad h_{j_{i-1\sim i+1}} \approx h_{j_i} \end{cases}$$

From the above equations, we derive the expression of the local loss coefficient ξ as,

$$\xi = \left[(z_{i+1} - z_{i-1}) + \frac{\alpha_{i+1} v_{i+1}^2 - \alpha_{i-1} v_{i-1}^2}{2g} \right] / \left(\frac{v^2}{2g} \right)$$

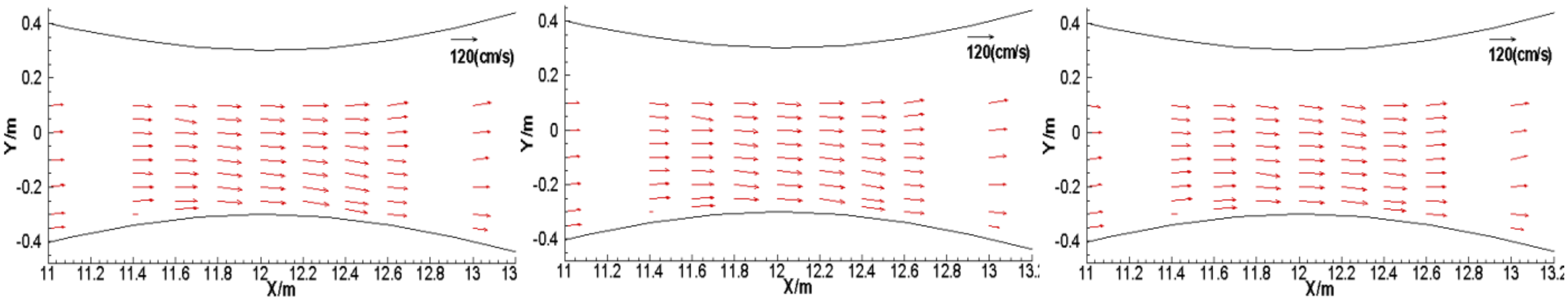


Result and Discussion

The velocity components U and V

The U-V velocity components are fairly simple:

- The streamline is **<u>more similar to the shape of the side wall</u>** when approaching the boundary



（a） z=0.105m （b） z=0.075m （c） z=0.035m

U – V velocity components field of the second particular gradual channel transitions

Result and Discussion

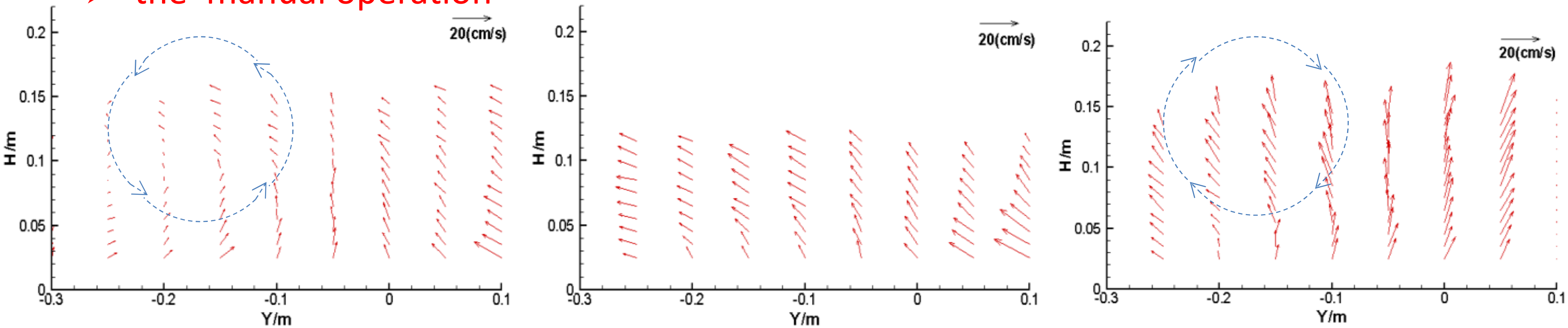
The velocity components V andW

In the comparison of the horizontal velocities, the transverse one seems to be **<u>more complicated</u>** :

- **<u>Secondary currents</u>** occur in both the contraction and expansion, and may **<u>circulate either anti-clockwisely (a) or clockwisely (c)</u>**
- The flow in the narrowest cross section is normal with **<u>no circulations</u>**

Possible errors in this physical test:

- the shortcoming of the design of the physical model
- the manual operation

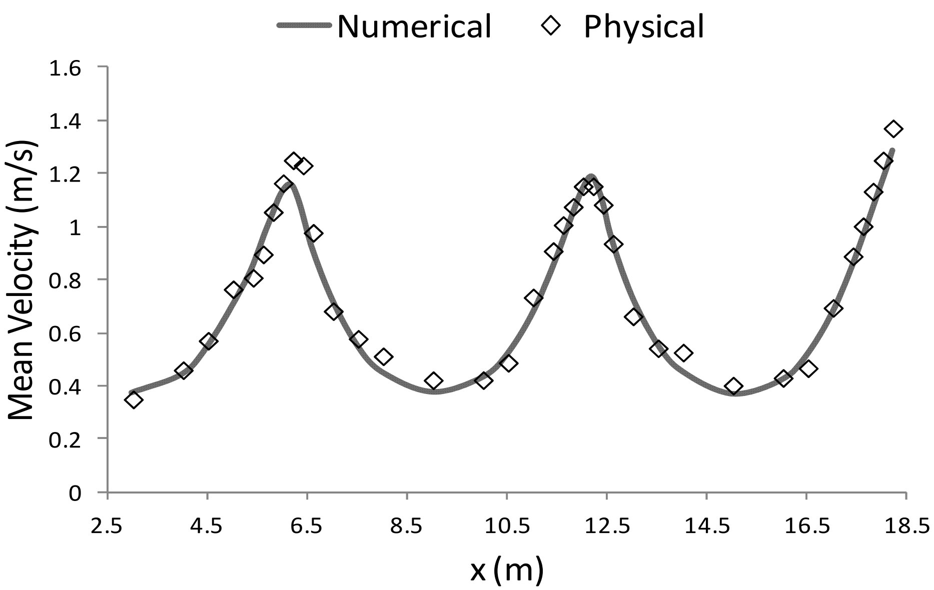


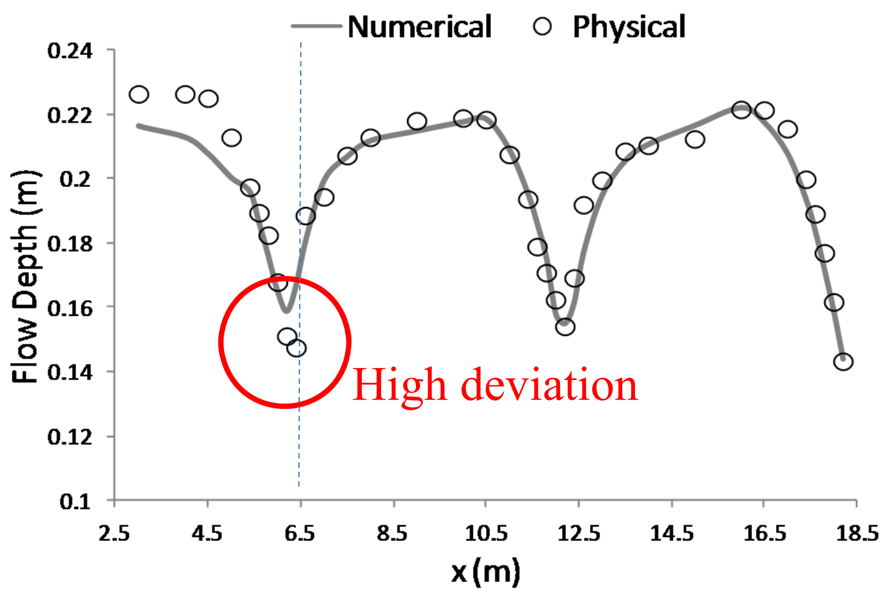
（a） x=11.4m （b） x=12.0m （c） x=12.6m

U - V velocity field of particular gradual channel transitions

The Hong Kong Polytechnic University
香港理工大學

Comparison between numerical result and experimental data

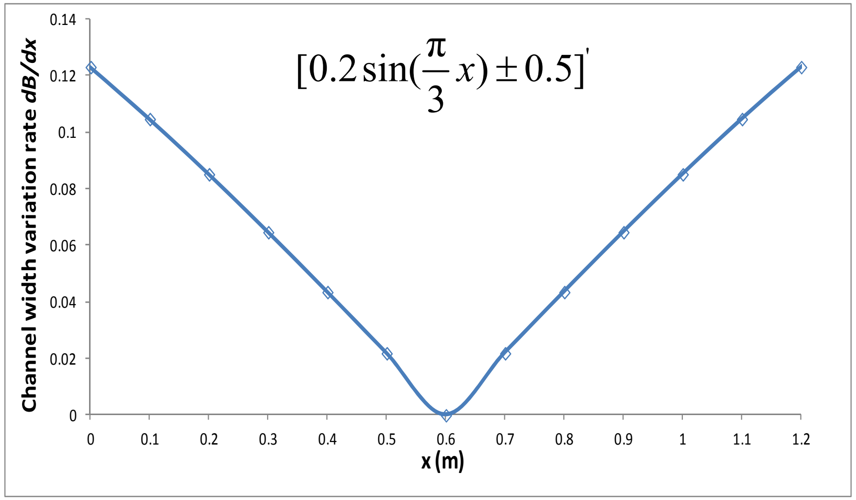




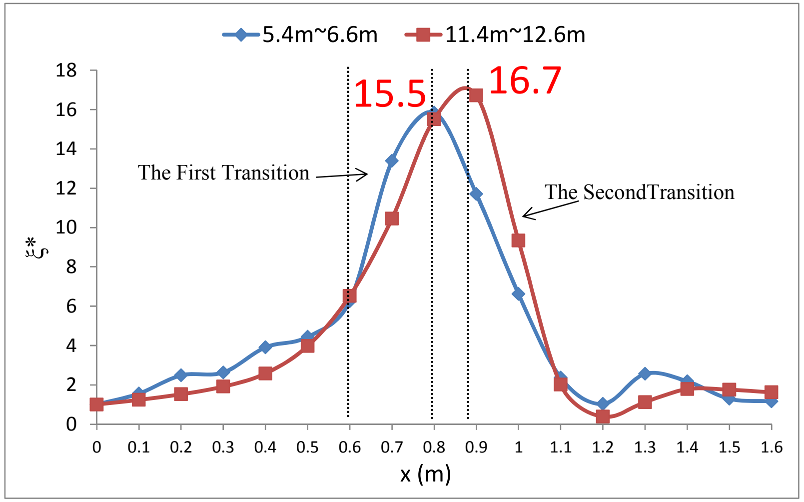
- The results show **good agreement between numerical simulations and the experimental data**, in particular ,the mean flow velocity.
- Only the **flow depth at x=6.4m shows a relatively high deviation of 10%** between the two approaches.
- The above demonstrations evidently show that **SMS is good for** simulating gradual channel transition flows.

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

Result in calculation of local loss

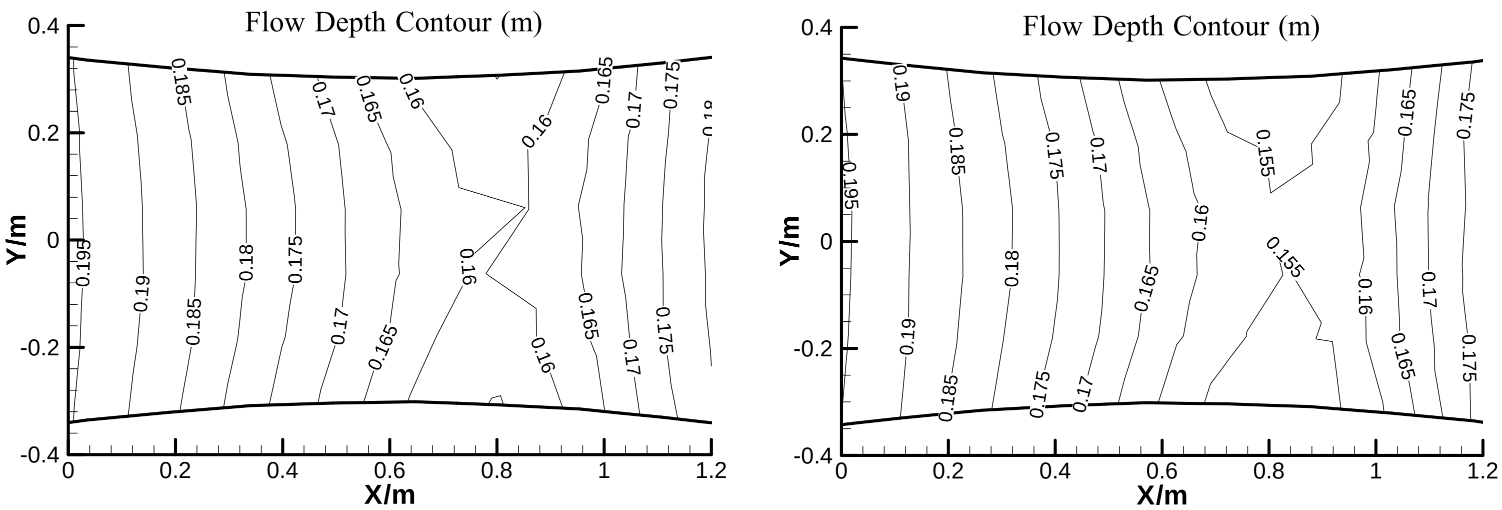


The channel width variation rate along the particular gradual channel transition



The variation of normalized local loss coefficient under the particular gradual channel transition

➢ The local loss slightly rises along the region of 0~0.6m, and subsequently **jumps** to maxima of 15.5 and 16.7, respectively, of **the first channel transition at x=0.8 and the second one at x=0.9.** After this jump, the local loss coefficient drops sharply.



Flow depth contour under the particular gradual channel transition

- The **<u>shallowest flow depths occur downstream of the narrowest cross section</u>** around x=0.8 ~ 0.9m. This implies that there are **<u>flow contraction and separation</u>** on the flow surface.

- This may **<u>cause of sharp jump in the local loss coefficient</u>**.

- Further research of the cause is necessary.

Conclusion

Some hydraulic characteristics of an open channel with the **combination of contraction and expansion** (referred herein as a **gradual channel transition)** have been investigated. The investigation is by means of laboratory experiments and numerical simulations by a simple 2-D commercial model. The findings are summarized below:

- **Secondary currents were observed** within particular gradual channel transition.

- A commercial **2-D hydraulic model**, namely SMS, was employed to simulate flows within the gradual channel transition. **Good agreement between experimental data and numerical results has been observed.**

- One important purpose in this research is to **identify the distribution of local loss** within the gradual channel transition. It is found that the local loss basically **levels off or at most very slowly increases in the contraction region**, but reveals a **dramatic jump to its maximum at the location near the beginning of the expansion region**. Subsequently the loss **drops sharply** to the normal value like the **contraction region**.

- Moreover, based on the flow depth contour information, the dramatic jump may be induced by the **contraction and separation** of flow around the inflow boundary of the expansion in the channel transition.

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Thank you