"Drifting Cups on a Meandering Stream" in Korea

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The Posuk-Chung Pavilion is a defunct irregular stone water channel in Kyongju, Korea, once used for the 'meandering stream feast' by kings of Silla Dynasty during the first millennium. The poets were seated around this stone water channel who composed the Chinese poems, overlooking the streams. They had to take the punishment drinks unless they finished the poem before the drifting cup filled with the rice wine arrived at their seats on the meandering stream. In this paper, we have made computer simulation as well as model experiment on the ancient meandering stream of the Posuk-Chung Pavilion. The computational results are compared with the experiment and the channel flow characteristics are delineated here. It is discussed how the present Posuk-Chung channel is morphologically distinguished from the Chinese and Japanese meandering streams.

Key Words : Irregular Channel Flow, Meandering Stream Feast, Model Experiment, CFD Simulation, Morphological Transition.

1. The Origin of 'Drifting Cup on a Meandering Stream'

The 'meandering stream feast' was first initiated in the ancient China by a famous literary man and calligrapher named Wang Xhi Zhi in the early spring (the 3rd of March) of A. D. 353. He invited 41 distinguished poets to join him alongside a creek where the water was pulled to a meandering stream, with wine cups drifted on the water by which they composed the poems. Any poet who could not finish his poem before the cup arrived at his seat was punished by drinking three cups of rice wine. This archaic event was well documented by Wang Xhi Zhi himself in his famous book 'Narration of the Orchid Pavilion' and the term 'Drifting Cup on a Meandering Stream' was hence coined.

Since Wang Xhi Zhi, the culture of meandering stream feast has quickly spread in the Far East Asian countries : China, Korea, and Japan. The Posuk-Chung Pavilion had been used some time in the first millennium of the Silla Dynasty in Korea. There is a record in Nihon Shoki that similar events had been performed in Japan as early as sixth century. There are about a dozen such old historic remains in the Far East Asia. The Ran Ting in Shao Xing, China, is a meandering stream reconstructed in the twelfth century at the site where Wang Xhi Zhi was believed to have organised the feast. The Ya Shang Ting in the Forbidden City, Liu Bei Ting in the Tan Zhe Si in the suburbs of Beijing, Zuo Shi Yan Liu in the ruins of Yuan Ming Yuan Flower Garden in Beijing are the streams used by the Emperor Chien Long of Ching Dynasty in the eighteenth century. Japan also has a number of her own remains: Jyonangu, Gosho and Kamikamo-Jinsha in Kyoto, Mouetsuji in Hiraizumi, in the Imperial Palace of Nara, Gorakuen Garden in Okayama, Tazaifu-Tenmangu in Fukuoka, and Isoteien Garden in Kagoshima, Kyushu. In some of these temples and gardens, the old meandering stream feast is

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revived every year before a large gallery, either in the spring or in the fall.

It is not known exactly when the Posuk-Chung Pavilion shown in Fig. 1 was built but the history book Samkooksaki writes that the 49th King Hunkang of Silla Dynasty made an excursion with his subordinates to the Posuk-Chung in the year A. D. 879. Unfortunately, the wonderful culture of meandering stream feast has been eradicated from Korea because of a tragic incident that the 55th King Kyongae was slain in A. D. 927 at the ill-fated Posuk-Chung Pavilion by the invading army of a rival country named Hoobaikje. It is followed by the fall of one thousand year old Silla Dynasty in A. D. 935.

Posuk-Chung is a meandering open water channel made of 63 pieces of hammered granite side walls and flat bottom stones assembled in the sidel form of a rectangular cross-section shape. The main channel loop measures more than 10 meters in the long axis and 5 meters in the short axis. The loop is roughly of an oval shape but is modified by a couple of highly serpentine curves to break the monotony of the shape. The channel measures at a few typical points 30 cm wide and 22 cm deep. There is at present no pavilion left at the channel despite its name: no record shows when it was lost. Having been defunct such a long time, the channel has neither water supply nor drainage duct.

In the present paper, the meandering stream of the Posuk-Chung is reproduced by modern computational technique of solving Navier-Stokes equations. An experiment was also made by fabricating a 1/6.57 scale model of the channel using tin plate. In order to obtain accurate curves of the irregular channel shape, the author took an aerial photograph from the sky aboard a thermal air balloon. To remove branches of the nearby tree seriously hiding a few areas in the photographic image, the author took local pictures of the channel from the ground and made a photomontage using Adobe Photoshop.

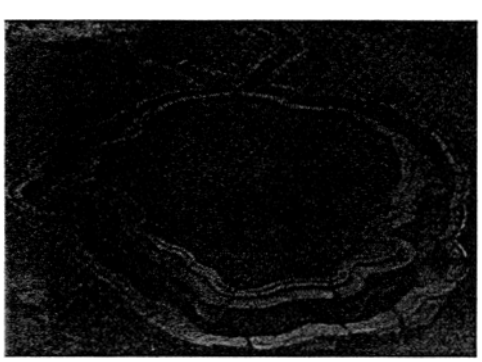

Fig. 1 Meandering stream of Posuk-Chung Pavilion

2. Computer Simulation and Model Experiment

The meandering stream obviously manifests elements of the river flow like meandering and braiding that exhibit three-dimensional characteristics. One thing particular is that the surface tension becomes increasingly important in the small-scale flows, especially in the model experiment. Flows separated from the main stream are stagnant, reversed and recirculating in the channel, which are time-dependent and three dimensional. These recirculating vortices can capture the wine cup drifted into the vortical region, if this region is not so small. Release of the wine cup from the vortex trap is also possible since the vortical flow is unsteady and fluctuates with time in its size and strength. An experimental study made earlier (Chang, 1990) revealed that the channel flow was, as a matter of fact, extremely complicated. Field measurement of flow velocity, pressure, turbulence, surface waves, surface tension and mapping of parameter-dependent passage of drifting wine cup are not only exhausting but also infeasible.

We consider the three-dimensional incompressible Navier-Stokes equations.

$$\rho\frac{\partial u}{\partial t}+\rho u\cdot\nabla u=-\nabla p+\rho g+\mu\nabla^2 u \qquad (1)$$

$$\nabla\cdot u=0 \qquad (2)$$

Considering complexity of the flow domain, the author used the FEM technique. An in-house code called DOLFINS (Drastically Operator-Lightened Finite-element Incompressible Navier-Stokes Solver) was used (Shim and Chang, 1994). To make the problem tractable, the author

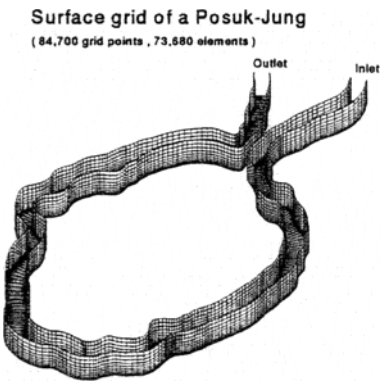

Fig. 2 Surface grid of the numerical model

assumed that there was no shear stress on the free surface and the channel flow is driven by the pressure gradient, not by gravitational force.

The scale model flow was visualized on the surface by the white medicine powder. Streaklines were photographed with various exposure. Mapping of the passage of drifting wine cup was not successful in the scale model experiment due to lack of dynamic similitude: depending on the material of the cup, the surface tension could become unreasonably large relative to other forces such as gravitational force, inertia force, shear force and unsteady acceleration force.

3. Flow in the Posuk-Chung Meandering Stream

Figure 2 represents the numerical model of the channel consisting of 10, 780 surface grid points, among the total 84, 780 points used in the entire domain (Chang and Shim, 1997). The flow enters the inlet plane with a predetermined uniform velocity and leaves the outlet of the channel without any flow gradient. The flow is assumed to have constant depth and smooth surface on the side wall and bottom plate. The Reynolds number in the prototype is believed to be of the order 10^5 while that of the experiment was in the range 500 to 5000. Computation was performed in the laminar flow regime, with the Reynolds number between 500 and 1000.

The velocity vectors on the free surface

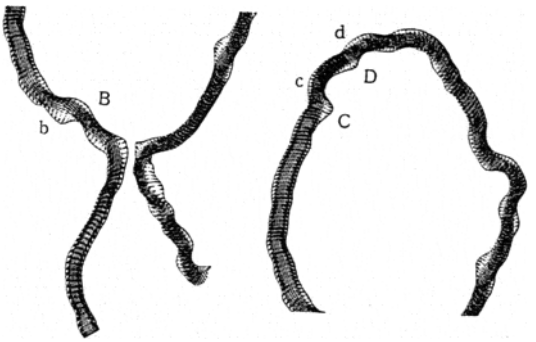

Fig. 3 Velocity vectors of the meandering stream

Fig. 4 Surface streakline in the model experiment

obtained by computation are plotted in Fig. 3. They show where the vortical flows are located in the channel and how strong they are. The three photographs of Fig. 4 show streaklines of the surface flow at the local sites labelled B-b, C-c and D-d. They are well compared with the numerical results.

To simulate the trajectory of a point mass drifting on the surface, which is an ultimate simplification of the 'drifting cup on a meandering stream', we use the Stokes number defined by

$$St=\frac{m_p}{C_D\cdot\frac{1}{2}\rho A\,|\,V_f-V_p\,|} \tag{3}$$

The motion of the particle relative to the fluid flow is then determined from

$$V_P=V_f+(V_{P0}-V_f)\exp\left(-\frac{\Delta t}{St}\right) \tag{4}$$

where V_{P0} is the initial velocity of the particle mass. The particle trajectory is highly dependent on such variables as initial conditions and particle properties. Figure 5 shows a particle trajectory calculated with Stokes number 0.3. We can sum-

marize that the particle mass will, in general, circulate near the outer bank of the channel due to the centrifugal force and could be trapped in a few recirculating vortex regions. It can also escape the vortex trap due to the changing size and strength of the fluctuating vortex.

4. Morphological Evolution of the Meandering Streams

The man-made meandering stream is ultimately a replica of the natural creek. The 'meandering stream' is brought into the garden of a palace partly for landscape and partly for enjoyment of the highly literate rulers of the palace. In the initial stage, the meandering stream feasts must have been conducted in a rather natural environment. Man-made meandering streams have been constructed afterwards in reduced size as a copy of the natural creek. The water was pulled from the neighbouring creek. The stream bed was laid with earth and pebbles and the channel was decorated at various places with rocks and flowers brought from the nature. The meandering stream of Ran Ting in Shao Xing, the streams in Isoteien Garden of Kagoshima, Jyonangu of Kyoto and Mouetsuji of Hiraizumi serve the examples.

To add controllability of the stream and durability as well, the stream was later constructed purely with stones, either assembled from hammered stone pieces or by chiselling a whole or a few pieces of big stone. The Posuk-Chung Pavilion belongs to the former and the Chinese meandering streams used by Chien Long Emperor belong to the latter. The Posuk-Chung Pavilion has a main channel of an oval shape with a couple of highly irregular serpentine curve forms. The shape looks roughly symmetric in overall appearance but remains asymmetric in the details. It is interesting to note that this slight deviation from the symmetry has been widely adopted in the western paintings and architecture for aesthetic achievement.

The shape of the meandering stream had been

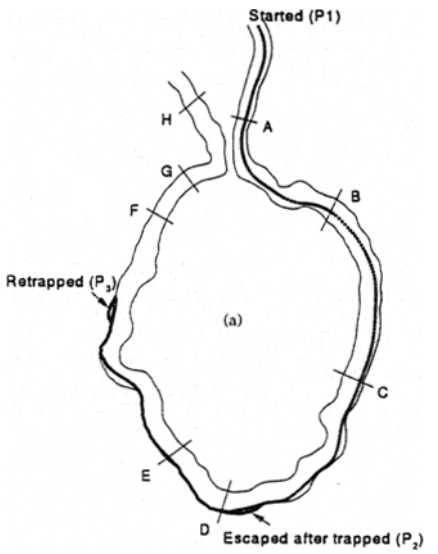

Fig. 5 Trajectory of the particle mass in the channel

Fig. 6 Meandering stream of Yuan Ming Yuan, China

also designed from the instrumental view-point. Since the channel is used to enjoy composing Chinese poems in a mood of contest among the participants (remember there is a punishment if the poem is not completed in a limited time), the drifting cup on a meandering stream definitely has the mechanical function of measuring time. The Chinese meandering streams of later period were dedicated to this function by carving out highly meandering, shallow and narrow grooves on the big flat marble stones: see Fig. 6. The channel shape is very winding and remains precisely symmetric. The narrow groove limits the lateral motion of the drifting cup so that the cup proceeds linearly along the channel to make

measurement of time precise. The meandering stream of this water clock function needs not to be that large and the channel can be made of valuable stones.

The ratio of the net projection area of the meandering stream to the total pavilion area is an important index indicating the functional purpose of a meandering stream. If this ratio is very low, then the meandering stream is spacious, its size is relatively large and the stream has landscape value in the design; if it is high, then the meandering stream is dense, its size is rather small and the clock function is emphasized. The former will be called here 'the rather natural' and the latter 'the significantly artificial'. In the latter design there is almost no room for the poets to sit inside the water channel. The meandering streams of Emperor Chien Long, namely, Ya Shang Ting in the forbidden city, Liu Bei Ting in the Tan Zhe Si and the Zuo Shi Yan Liu in the Yuan Ming Yuan are all good examples of this latter design.

The morphology of Posuk-Chung meandering stream stays in between the rather natural and the significantly artificial. It is artificial in the sense that it entirely consists of hammered stones, nearly symmetric in its shape, and no earth is left on the channel bed. It is not as large as the Ran Ting of China or the many Japanese meandering streams that are constructed to keep landscape value. It is not so small either as those Emperor Chien Long's water clocks in Beijing. There is enough room inside and around the channel so that, for example, more than ten persons can be seated. The drifting cup of Posuk-Chung is, in general, better controlled than in the rather natural stream due to the particular channel configuration: it well plays the function of a water clock except when the cup is unexpectedly captured by the vortex trap. It can be still considered somewhat natural since the pattern definitely simulates the sinuous natural creek and the channel of relatively large width allows the drifting cup to evade into its vortical shades occasionally. The ratio of the net projection area of the channel to the total pavilion area is low, suggesting that the channel is seriously designed to fit the garden landscape. Its shape shows, therefore, a definite transition of morphology among the many meandering streams in the Asian countries, from the rather natural to the significantly artificial.

5. Conclusion

The meandering stream feast has been a wonderful culture long common in the Far East Asian countries. It serves an excellent, isolated example that shows how a culture arisen in one country can be quickly spread to its neighbour countries and can be modified in the history. In this paper, the 'drifting cup on a meandering stream' of Posuk-Chung Pavilion is investigated numerically and experimentally. It visualizes the channel flow that had been lost with the fall of Silla Dynasty in the Korean history. A survey is also made on other existing meandering streams in China and Japan. It leads to finding that there was a morphological transformation of the meandering streams, from the rather natural to the significantly artificial. The former emphasizes the aesthetic value of the meandering streams and the latter does the time measuring function of a water clock in composing poems. It has been argued that the Posuk-Chung Pavilion curiously lays a bridge between the two drastically different design concepts of meandering stream.

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