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A new measure for riverbank protection in braided channels with dramatic change of discharge

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ABSTRACT: After observation in series laboratory experiments, Porous Cylinders were tested for levee protection in the downstream Da-jia River at Kch-Juang reach, Taiwan. Morphological situation of the river is braided with steep slope and the bed material is mainly composed of cobble and gravel. In the middle of the main stream and with considerable distance away from the protected levee on river bank, four lines of porous cylinders were installed and arranged across a deep channel flowing towards the protected levee, which was reconstructed from a broken situation due to previous strong flow events. After the porous cylinders were initially installed in March of 2007, and before any major flood, the river-bed elevation around the installed porous cylinders was measured as a background reference. Since then, the East-Asian rainy season (plum rain) occurred in June, the Typhoon Sepat came in August, the Typhoon Wiptha came in September, and the Typhoon Krosa came in October, 2007. Elevation surveys between each strong-flow event indicate that the porous cylinders slowed down strong flow past them and caused deposition behind most cylinders which can reach 1.5 to 2.0m. Also, the deep channel with four lines of porous cylinders was divided into several paths, and detoured to downstream orientation from the original angle of attack and mainly detoured along the line-up direction of the porous cylinders. As a result, levee protection achieved due to this behind-cylinder deposition as well as detour of original deep channel which reduced the impact of momentum flux onto the levee.

Keywords: Porous cylinder, Levee protection, Bed scour/deposition, Angle of attack

1 INTRODUCTION

Currently, the existing measures employed in Taiwan for protecting levee include spur dike, groyne, riprap, anchoring the foundation of levee by piles, … etc.. These measures, although different in certain aspects, are all limited in their location, which must near the bank where the levee locates, and therefore, is passive to the attack of rapidly migrating flow. In this study, an active kind of measure is proposed, which can be installed in the deep channel of river far away from the bank, and deflects the flow before it approaches the protected bank.

Porous media with flexible material was employed in this study to reduce the risk of being destroyed by strong flow comes with cobbles and gravels. Local scouring is also considered. Heavy machine was utilized to install this measure deeply under the river bed.

In practice, to achieve the goal of levee protection, the channel with strong flow which destroyed the previous levee should be identified. A group of porous cylinders is needed instead of only single one. Firstly, porous cylinders were divided into several sub-groups. Depending on which direction we prefer to detour the main flow, porous cylinders in each sub-group then line up in a suitable direction which across the deep channel to form a suitable angle with the direction of potential strong flow. During high flow periods, around the flow-attacked faces of the porous cylinders, local scour occurs and also line up in the designate direction, while on the rear faces of the porous cylinders a zone of deposition occurs due to velocity decrease and increase resistance to the flow in the designate direction, and as a result, the original flow direction detoured towards the line-up direction of each sub-group of porous cylinders.

Installed in a distance from the protected bank, this measure can be a strong supplement to the existing levee-protection measures on the bank.

2 CHARACTERISTICS OF POROUS CYLINDERS

2.1 *Porous cylinders used in this study*

The idea on designing the porous cylinder is to make the mesh as large as possible to let the flow pass through, yet with a constraint that the outer shape can sustain under strong flow. The material used should be flexible and as economical as possible. The surface of the cylinder is simply a net with regular meshes. The interior of the cylinder is empty except the necessary structure to support the outer shape. Until now, two types are employed, one is vertical style and the other, horizontal style. The horizontal type can be put on the surface of river bed immediately downstream of a drop structure, with energy dissipation effect to prevent drop-flow erosion on the foundation of a dike. The vertical type can be used for bridge-scour prevention, river-flow re-orientation, or shore line protection. For large area protection, several rows of lined up vertical type are needed to accumulate collected effects. The cost is usually limited and its material is easily accessible (Huang, C.K., 2002; Huang, C.K., and Hsu, L.C., 2007).

2.2 *Flow around a porous cylinder*

Because the porous cylinder has an outer shape of a blunt body, similar flow characteristics do exist as the 3-D phenomena for flow past a bridge pier, which include horseshoe vortex on both sides of the pier, Karman vortex trail behind the pier, and vertical vortex near surface, etc. As sketched on Figure 1, part of the approaching flow, screened by the porous cylinder, becomes the center part of bleed flow (trans-passing flow) which passes through the porous media with reduced velocity, and other parts of approaching flow become two over-shooting flows with increased velocity. Existence of this bleed flow reduces the amount of velocity increase in the over-shooting flows and also restrains the occurrence of Karman vortex trail behind the cylinder, which also stabilize the flow field behind the cylinder. The zone of bleed flow is called the low velocity stable zone. The zone of over-shooting flow is called the high velocity unstable zone.

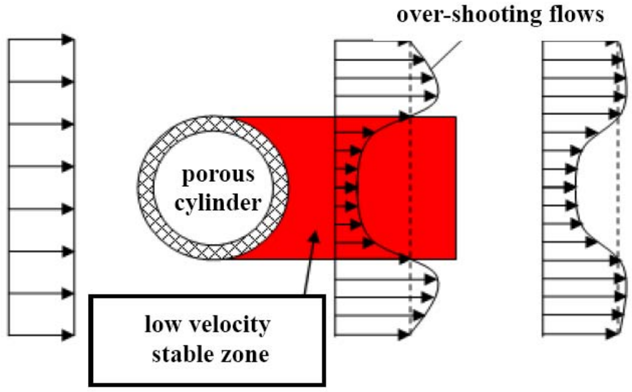

Figure 1 Top view of depth-averaged velocity profiles before and after a porous cylinder (Shi, W.R., 2007)

2.3 *Separation, vortex strength, and drag force*

It was found that, due to flow trans-passing through the cylinder, separation postponed to a higher flow condition, form drag reduced, and flow field stabilized (Fransson et. al, 2004, and Bhattacharyya et. al, 2006).The 3-D phenomena for flow past a cylinder is reduced by reducing the inertial force in the over-shooting zone. The pressure at the previous stagnation point is reduced due to trans-passing flow, and so the down flow on the front edge of the cylinder is reduced too, and so the horseshoe vortex becomes weaker. The trans-passing flow increase the inertia force in the longitudinal direction of low velocity stable zone and so reduce the Karman vortex shedding. Compared to a solid cylinder, the drag on a porous one by integration on the surface is reduced due to similar reasons.

3 FIELD EXPERIMENTS

3.1 *Nature of Da-jia river*

The watershed divides are higher than 3000 m., which makes this river a steep stream with series of hydro-power plants. The length of the main stream is about 124 km. The drainage area is 1,236 square km, with 90% are mountain and terrace. Upstream slope is 1/36, mid-stream is 1/43, downstream to the river mouth is 1/90. Averaged total volume of water per year is 2.5 billion cubic meter. Design flood for 100 year return period is 10,300cms (Water Resources Agency, 2002). The mean diameter of river-bed material, Dm, is, between 71.3 to 114.3 mm, categorized as Small Cobble.

3.2 *Levee-protection need in the study site*

The study site, shown on Fig. 2, locates at the downstream reach of Da-jia river and is not far from river mouth. In the aspect of fluvial morphology, this reach belongs to braided river with coarse material in plain area (relatively speaking) (Water Resources Planning Institute, 2001). Figure 2 shows that the study site, surrounded by a dotted square, is located downstream of the national high way 3 on the east side, and upstream of a coastal railway and provincial way 1 on the west side. In this reach, sediment transport only during high flow condition and mainly in the form of bed-load transport. Main channels, although not very deep, migrate slowly and will cause severe scour when they approach any bank. In Fig. 2, on the south (or left) bank of the study site, two main channels meet at the point B, where the levee on that bank was destroyed in a previous typhoon, and a new levee was just completed. Fig. 3 is a closer view of point B, the Kch-Juang levee, between levee section 1K+300 and 1K+500, two flows merge together and run through the left bank for more than 200 m. Fig. 3 was taken on June, 2006, during the plum rain season. On the site, we could see clearly that strong vortices were generated by the confluence of the two strong flows. Damage on the concrete surface can be seen from Figure 3. Protection on this reach of levee (and so the highway behind) from further damage is really necessary.

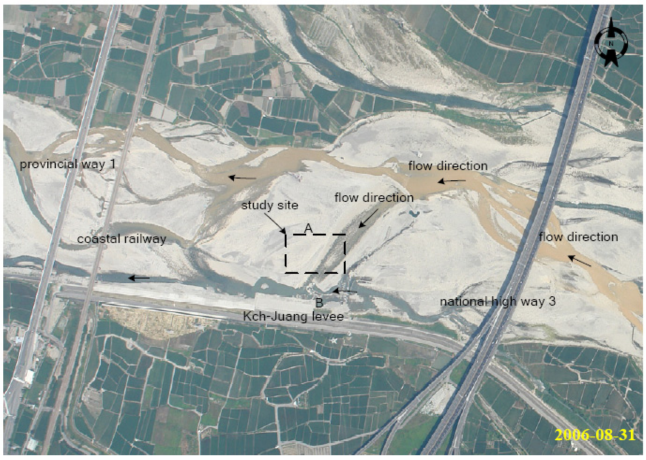

Figure 2 Aerial photo of the study site at Da-jia River

To fulfill this protection need, other than reinforcement on the levee, it is better that we can reduce the strength of the eddies around the bank or even move the strong flow away from the protected bank. To achieve the above goals, utilizing the porous cylinders were proposed by the authors and accepted by the Third River Management Office, WRA as a field test with very limited budge. The functions we anticipated are shown on Fig. 4, for each line-up of a sub-group of cylinders, the flow should create bed scour on the leading face of each cylinder and a belt of scour can be produced if the distance between the neighboring cylinders is near enough. On the other hand, on the rear side of the cylinders, deposition will occur due to velocity reduction which reduces flow capacity to move sediment. A zone of deposition will form. All together, combining these two effects, a detour of the channel flow could happen and so the strong flow may shift from here and change its direction away from the bank. Potential of destruction on the protected levee can then be released.

Figure 3 Two flows meet at the left bank levee-protection site

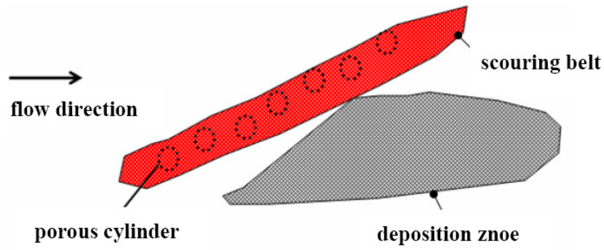

Figure 4 A belt of scour and zone of deposition within/behind a series of porous cylinders

After field investigation, we set up a strategy, according to the existing flow confluence, trying to move the meeting location of the two strong flows away from the protected levee. Four rows of porous cylinders were installed, as Fig. 5, across the main channel heading from north-east toward south bank. They were named as A, B, C, and D lines or series. On each row, 10 cylinders were installed, and named 1, 2, 3, …, until 10, from downstream to upstream (from west to east). For example, the B3 cylinder was the third cylinder countered from west toward east on the B line.

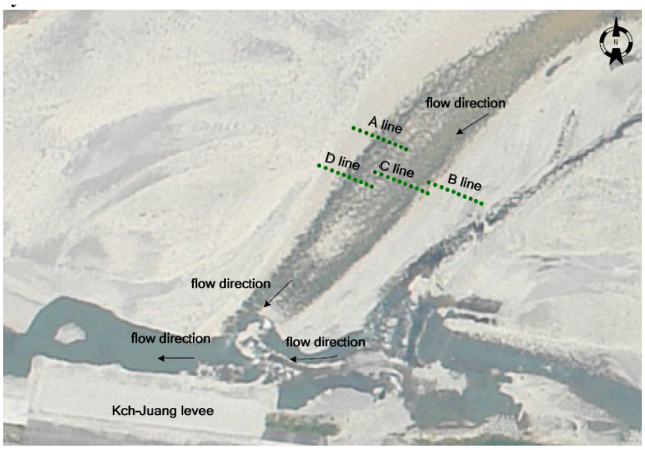

Figure 5 Relative location of field setup

3.3 *Installation and details of porous cylinder*

Market-available plastic material was chosen to assemble the porous cylinders for flexibility and economy. As shown in Fig. 6, three compound layers exist – outer, middle, and interior layers. Diameter of the cylinder is 1.24 m, and each segment is 1 m in height.

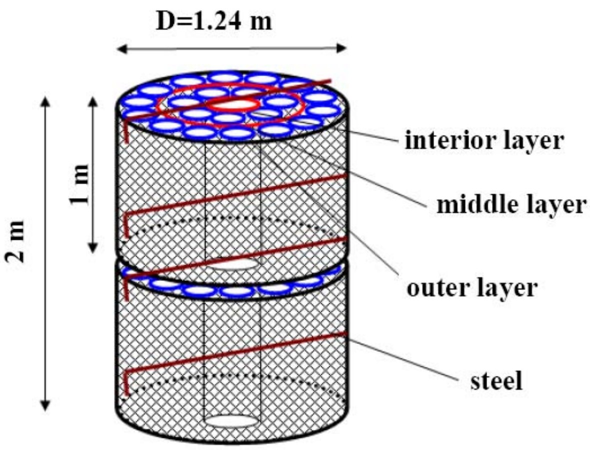

Figure 6 Design and details of a compound style of porous cylinder

Procedures of installation are shown in Figure 7. Firstly, the line of each sub-group was located, and then the position of each cylinder was determined (Figure 7a). Secondly, pile driving with a steel I-beam at each spot was done to an enough depth (Figure 7b). In this specific example, 4.8 m deep was designed for each pile, and 4 m distance between each neighboring pile. Totally, 40 piles were installed. To reinforce these 40 piles against strong flow during flooding time, another steel I-beam was installed at 2m downstream side between each two piles (Figure 8). The supporting pile was 5m deep and connected on bed surface with the existing piles by L-shape steel (Figure 7c). Two segments were finally put on each pile and finished the installation (Figure 7d, Figure 8). Site installation was carried by a contractor and finished on the end of March, 2007.

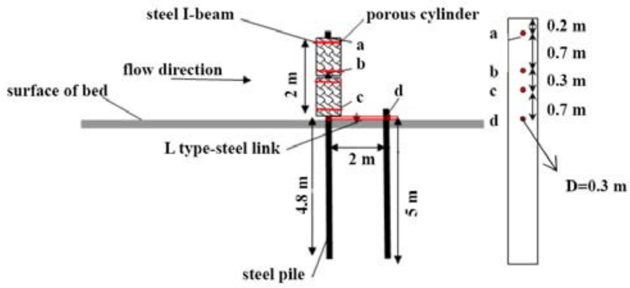

Figure 8 Dimension of all parts

3.4 *Discharge records during the site test*

Discharge records after site installation of the porous cylinder is very important to this study. For four reasons that we chose discharge records at a weir 15 km upstream from the site (Shin-Kang weir) as a reference to the site. Firstly, the records in the nearest gauge station were not available. Secondly, only significant discharges were needed since the bed material in the test site moves only during high flow situation. Thirdly, there is no large tributary between the test site and the chosen weir. Finally, Discharge measurement in this weir is relatively accurate due to water resources management purpose.

(a)Locate the site and orientation	(b) Pile driving	(c) I-beam and support	(d) Fixed the porous media

Figure 7. Procedures of site installation

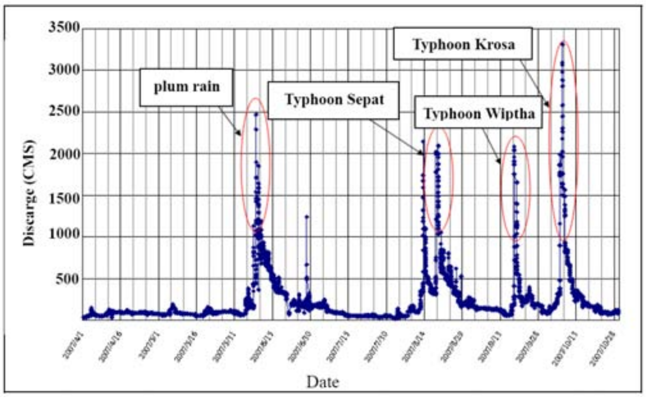

Fig 9. Discharge hydrograph at an upstream weir during the field test, 2007

Figure 9 is a 7-month discharge hydrograph between 1st April to 29th October of 2007. Four groups of significant discharge can be seen from Figure 9, which are the East-Asian rainy season (plum rain) occurred in June, the Typhoon Sepat came in 18th August, the Typhoon Wiptha came in 18th September, and the Typhoon Krosa came in 6th October, 2007.

Field observations were performed during the high flow periods with emphasis on the condition of protected levee and surrounding flow. Satellite images or aerial photos at important hours were purchased to see the migration of flow paths. After each significant flow and during flow-recession period, field surveys were performed to see the changes of bed elevation along each row of porous cylinder.

4 RESULT AND DISCUSSION

Field surveys were only performed on the back side of the porous cylinders due to limited budge. Four surveys were done following each significant discharge event, and are plotted on Figure 10(a), (b), and (c) for row D, C, and B, respectively. The date of each survey is noted in the indent.

Cylinders of row A were either destroyed or finally buried by sediment under the bed surface after the October typhoon, therefore, only rows B, C, and D were shown on Figure 10. Since the flow was complicated and many factors are involved in channel migration, the following discussion can only base on the limited data available, yet, the effects of the proposed measure can still be seen.

Row D was on the downstream of A, B, and C, as a result, based on Figure 10, deposition occurred at all cylinders of row D. Rows B and C were in front of D, with strong flow approaching, some had deposition and other had scour, but over all, deposition is the main feature.

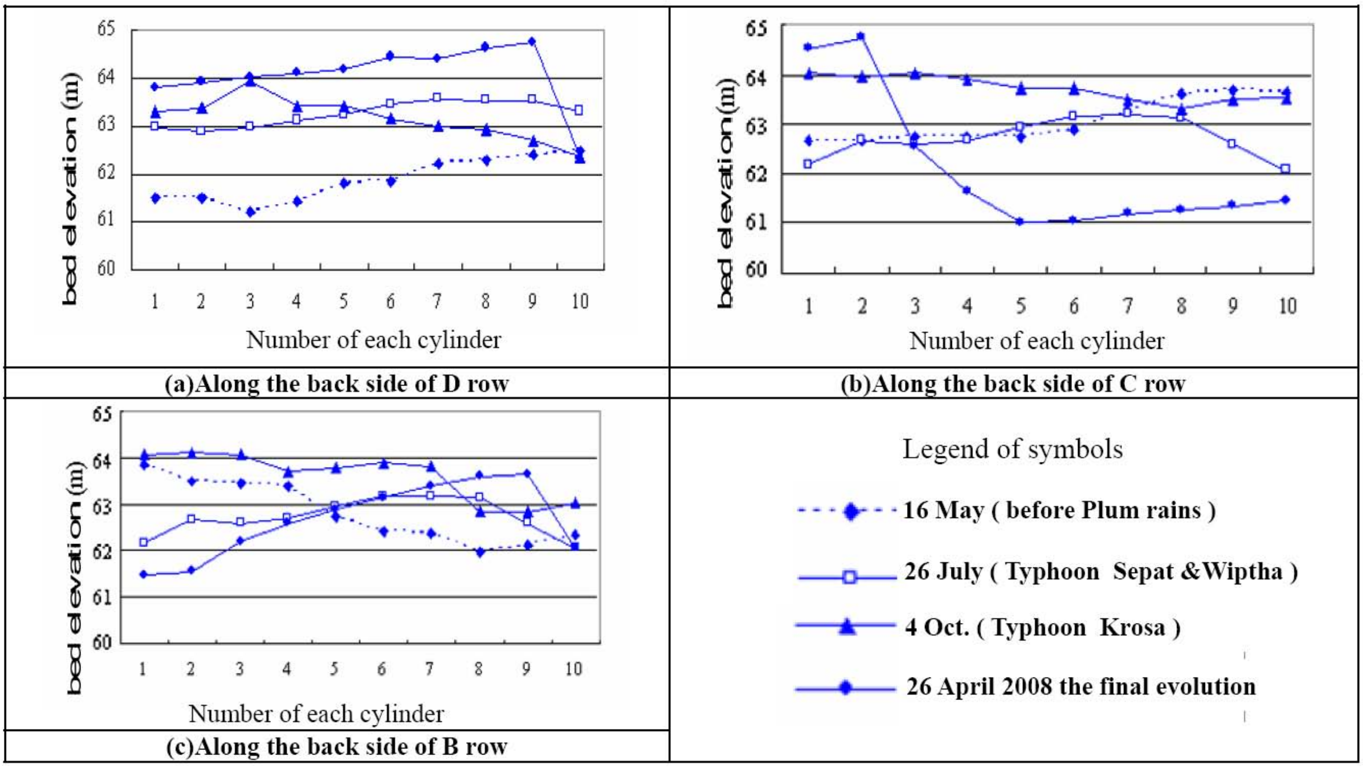

Fig 10. Evolution of bed elevation at each cylinder after each flood

4.1 *From newly installation to plum rain ended*

After newly installation on site, topography or elevation among all porous cylinders can be seen, based on survey on 16th of May in Figure 10 (a), (b), and (c). Row C located at a higher position. For row B, the elevation is higher in B1 and decrease to B10. Row D, compared with B and C, is obviously the lowest. The elevation difference between B1, the highest, and D3, the lowest, is 2.6m, with a distance 60m in between.

Figure 11 is a photo taken during a higher flow period and Figure 12, lower flow period immediately after plum rain (also refer to Fig. 9 for discharge information). In Figure 11, water depth is more than 2m, with velocity around 3 m/s. When flow passed through four rows of cylinders, a region of low-velocity zone behind the cylinders can be seen, and two flows formed surrounding those cylinders (Figure 11). One of the two flows, past row B, is the original path of deep channel. The other, made a detour, through the downstream side of row A and row D, and flowed towards the left bank with a smaller angle of attack. Between these two flows was the region of low-velocity zone.

In the low flow situation of Figure 12, obvious deposition was observed in the rear side of row D. Based on Figure 10(a), the deposition along row D is around 1.5m. Not much change in Row C (Figure11(b)). Based on Figure 10(c), the main channel shifted from cylinders B6~B10 to B1~B5, and resulted in 0.8~1.6m degradation along B1~B5 and 0.8~1m deposition along B6~B10. At this time point, the main flow was separated into two parts and the strike area by the flow enlarged, which reduced the erosion forces tremendously upon the foundation of levee.

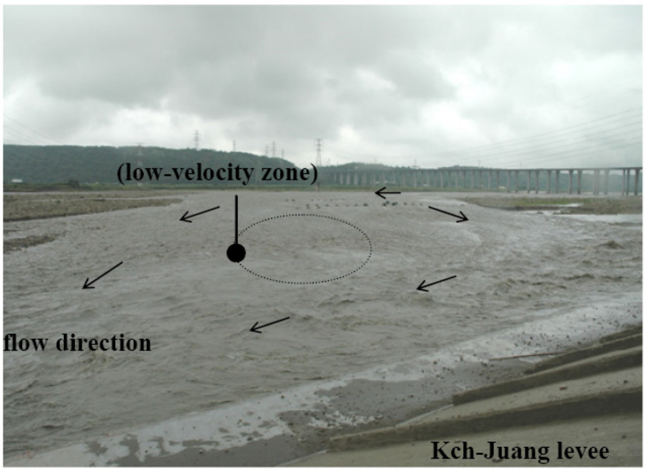

Figure 11 High flow during plum rain season on June 9th, 2007

Figure 12 Low flow after plum rain finished on June 15th, 2007

4.2 *After two major typhoons in August and September*

Based on Figure 10(a), the deposition during those two typhoons along D1 to D5 is around 0.5m and similar amount of degradation along D6 to D10, but all were still much higher than the original bed elevation. Deposition along C1 to C6 was about 0.7~1.5m (Figure 10(b)). Deposition along B1 to B7 was about 0.6~1.5m (Figure 10(c)). The original deep channel, past B1~B5 and C9~C10 before the two typhoons, was further shifted downstream, which meets the original goal of our plan.

At this time point, several cylinders were either destroyed by the previous flow with stone or were almost buried by gravels and cobbles. This reduced the following effect of the original design.

Figure 13 Satellite image (Formosa II) after Typhoon Sepat in August, Typhoon Wiptha in September, and before Typhoon Krosa in Oct., 2007

4.3 *After typhoon in October*

After the October typhoon, further deposition on row D up to 2~3m above the original bed (Figure 10(a)) and all cylinders were buried except D10. An emerged flood plain with about 2m deposition covered the row A and D area. Degradation occurred along C3~C10 (Figure 10(b)) and B1~B4 (Figure 10(c)), where a deep channel still passed. Some of the porous materials were removed by the flow and only the piles were left. Compared with Figure 13, satellite image on Figure14 shows that the two separated flows were further apart.

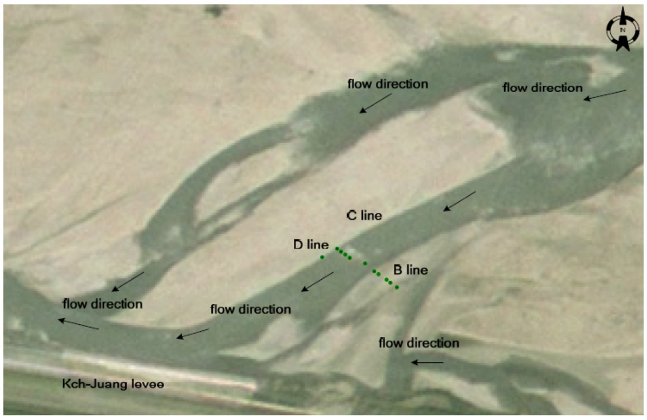

Figure 14 Satellite image (Formosa II) after Typhoon Krosa in Oct., 2007

5 CONCLUSION

1. Porous cylinders can screen out strong flow, reduce flow velocity, and so reduce the amount of sediment transport behind them. In a field test with steep slope and large moving cobbles, under a series of flooding flows, deposition occurred on the back side of the cylinders, and the targeted main flow was separated into less harmful flows.

2. Arrangement of porous cylinders into line by line is proved effective in this field test in terms of detouring main flow path and so reducing the angle of attack and eroding force at the protected spot.

3. Deposition in this field test is in the order as the height of the porous cylinder, which was 2 m above the river bed. Natural migration of deep channels contributed to part of degradation at the surveying spots.

4. Accumulation of serene-out effect was observed that a downstream row of cylinders had more deposition than its upstream ones.

5. Compared with the existing bank protection measures, which must be located around the bank, the porous cylinder can be installed far away from the protected spot. This give river engineers more degree of freedom and flexibility and so is more active.

6. This measure is suitable for mountain rivers with dramatic discharge change, such as rivers in Taiwan, Japan, or New Zealand, and can be combined with the existing measures

7. Porous cylinder is relatively inexpensive and easy for installation, so very worthwhile for future popularization.

8. Porous cylinder should be considered as wearable and need to be maintained after each flood, especially the most front row is the most vulnerable ones.

REFERENCE

Huang, C.K., 2002 : Redirection device for reduce flow erosion, R.O.C. patent No. 158884.

Huang, C.K., and Hsu, L.C., 2007 : New concept on bridge-pier protecting measure, Taiwan Highway Engineering, 33(5), pp.39-49. (in Chinese)

Shi, W.R., 2007 : Experiments on the flow past a porous cylinder, master thesis, dept. of hydraulic & ocean engineering, National Cheng Kung University. (in Chinese)

Water Resources Agency, 2002 : Information on the major rivers in Taiwan, MOEA. (in Chinese)

Water resources Planning Institute, 2001 : Investigation on the river morphology in Taiwan (1/2), Water Resources Agency, MOEA. (in Chinese)