RIVER BANK EROSION IN CENTRAL VIETNAM

TRAN TAN VAN
Vietnam Institute of Geosciences and Mineral Resources (VIGMR)

ABSTRACT: A few years ago (2000-2002) a research project entitled "Geohazards in coastal provinces of Central Vietnam (from Quang Binh to Phu Yen) - current status, causes, predictions and recommendation of mitigation measures" was conducted by Vietnam Institute of Geosciences and Mineral Resources (VIGMR). The problem of river bank erosion was surveyed and studied along 25 major rivers and their tributaries totaling more than 850km in length. In this paper, some special cases are highlighted, causes are presented and a method for determining river meanderness as an indicator of future bank erosion is proposed.

SOME SPECIAL CASES OF RIVER BANK EROSION

The problem of river bank erosion was assessed based on the classification suggested by Nguyen Thanh et al., (2001), Table 1 and represented on an 1/500,000 inventory map. Suffering this hazard most severely were Thach Han (Quang Tri province), Huong (Thua Thien-Hue province), Vu Gia-Thu Bon (Quang Nam province), Tra Khuc and Ve (Quang Ngai province) rivers. Some cases of special interest occurred along the Hieu (Quang Tri province) and Vu Gia-Thu Bon (Quang Nam province) rivers.

Table 1 River bank erosion severity classification (Nguyen Thanh et al., 2001).

No.	River bank erosion severity	Ke (%) coefficient	Erosion rate (m/year)
1	Severe	> 30	> 10
2	Moderate	10÷30	2÷10
3	Weak	< 10	< 2

Bank collapse, subsidence and erosion along the Hieu River

Bank collapse, subsidence and erosion occurred continuously along the Hieu River at Hau Vien village, Cam Lo district town since 1990s. By the time this survey took place, the number of sinkholes totaled 41 with diameter and depth ranging on the average 0.7-1.2m and 1-2m respectively. The phenomenon was studied by a number of institutions and was explained differently. For example, in 1993 the Provincial Department of Science, Technology and Environment in collaboration with the Institute of Geology (Vietnam Academy of Science and Technology) gave it an active faulting origin. The Faculty of Geology, Hue National University (2000) drilled 15 holes to survey the soil subsidence problem but didn't arrive at a clear and convincing reason.

Our survey in 2001 indicated that after the 1999 historic flood, the right bank of the river was eroded severely with a section 450m in length, 0.5-3.5m in width and 5-5.3m in depth washed away. In total, within a period of 10-15 year, the bank retreated at some places up to 30m. According to our survey, soil subsidence and river bank erosion are closely associated. Underlying the Quaternary sediments of alluvial, alluvial-marine origins, consisting of loose sand, clay, grit and pebble, totaling 4-10m in thickness, is the dark grey, fractured and bedded, clayey and dolomitized limestone of either Cu Bai (D_{1-2} *cb*) or Cam Lo (P_2 *cl*) Formation, which cropped out only recently when the overburden sediments were washed away.

Figure 1 Bank erosion along the Hieu river.

Distributed along the Hieu River fault, coupled with water table fluctuation, the limestone is subject to karstification, forming underground cavities and resulting in the wide spread, though small but annoying, ground collapse. This accelerates river bank erosion and vice versa as local people rightly note that river bank erosion takes place even during the dry season, when the river water level drops down sometime rapidly and suddenly. Based on the bank cross-section, the flow morphology and the current situation of erosion and subsidence, the problem was classified as moderate (Fig.1).

Bank erosion along the Vu Gia-Thu Bon river system

The Vu Gia-Thu Bon river system (Quang Nam province) is made up of several major tributaries e.g. Thu Bon river (Tinh Yen), Cai (Vu Gia) river, Bung, Giang, Kon and Khang rivers. The Thu Bon river itself flows mostly in the SW-NE direction and strongly braids at its downstream, numerously confluencing and dividing to result in a dense network which finally drains out mostly at Dai rivermouth.

Geologically the downstream part consists mostly of Late Pleistocene (Q_{III}) yellowish quartz sand of Da Nang Formation; marine white sand of Nam O Formation; Middle Holocene lagoonal cohesive silt and clay of Ky Lam Formation; and Middle-Late Holocene Aeolian-alluvial-marine clay and silt. At Dai Loc, the Vu Gia river dissects the Neogene conglomerate, sandstone and siltstone of Ai Nghia Formation which is more than 300m in thickness.

Being one of the largest river system in Central Vietnam with the hydrological regime strongly varying in one of the most geologically complicated areas, bank erosion and flow siltation take place severely and intensively, causing considerable socio-economic and environmental damages.

Figure 2 Bank erosion along Vu Gia river, at Dai Cuong Commune.

The problem of bank erosion along the Thu Bon river system was surveyed and studied at several sections, of which of special interest was the section from Tam Hoa commune on the Vu Gia river to Giao Thuy junction, where the Vu Gia confluences with the Thu Bon river (Fig.2). This has been in the recent years one of the most active sections in terms of bank erosion. The Vu Gia river after meandering at Tam Hoa changes its course perpendicularly from NE to SE, directly attacking the My Hiep 1 village, Dai Cuong commune. Its first attempt to straighten its course appeared in 1997 becoming more and more obvious in subsequent years. Meanwhile, a little bit downstream the local dyke department undertook rigorous protection along the Quang Hue river, which used to connect the two Vu Gia and Thu Bon rivers. Unfortunately, this protection also reduced the flow from Vu Gia to Thu Bon rivers during the flood season, forcing the first to find a new course i.e. to straighten. By July 2000, the Vu Gia river completed its straightening at My Hiep village (Dai Cuong Commune), forming a more than 1 km long new Quang Hue river, connecting with the old Quang Hue river at My Hiep 3 village, causing severe erosion along its two banks and discharged more than half of its volume onto the Thu Bon river. The disaster severely affected not only the local people who lost during 1997-2001 more than 300ha of arable land while more than 300 families themselves had to resettle. Moreover, Da Nang City therefore suffered from severe fresh water shortage and had to use blackish water, 7-11 times containing as high salt content as allowable. Inundation and erosion meanwhile accelerated downstream of the Thu Bon river from Giao Thuy junction to Dai rivermouth, severely threatening the Hoi An World Heritage.

During July-October 2001, the Ministry of Agriculture and Rural Development (MARD) and Quang Nam province authority constructed a spillway to close down the new Quang Hue river mentioned above and to rock rip-rap more than 3 km along the Vu Gia and the new Quang Hue rivers. The aim was to direct the Vu Gia river to Da Nang City during the dry season while allowing the flood water to escape into the Thu Bon river. The work cost tens of billion VND but still was regarded as a temporary measure. Other tens of billion VND were spent, again the bank and the bottom of the old Quang Hue river. The result was that water could no longer flow along it as its bottom was too high.

It was pity though that in July 2001 (i.e. immediately before that work started), the authors of this paper reported to both Quang Nam province and Da Nang City authorities about the problem and the low feasibility of that project, it anyway was carried out. And Nature responded immediately. In fact, just after a small rain during October 2001, a shoulder more than 100m in length upstream of the spillway was washed away. The Vu Gia river continued its straightening course at even higher discharge. The new Quang Hue river broadened by 100m, i.e. twice as wide as compared to itself before the flood, while both of its banks were severely eroded. In particular along the right bank, downstream of Dai Phuoc village, erosion encroached farmers' houses causing longitudinal cracks hundreds of m in length and 5-10cm in width. Numerous small sinkholes appeared 10-15m from the water edge. These were the clearest evidences of inevitable erosion. MARD, after careful survey, decided to pump in 12.257 billion VND for the bank protection and spillway repair.

On a river section 9km in length from Tam Hoa village to Giao Thuy junction, more than 5.2km was eroded (Ke = 57.7%), erosion rate reached 20÷30m/year, the situation was assessed as severe.

A few points worth considering with regards to MARD's decision could be made on the basis of field survey and air-photo analysis:

+ Hydraulic gradient between Vu Gia and Thu Bon rivers at this location was quite high, up to 2m upon a length of just 2km.

+ The cross-section of the Vu Gia river, a bit upstream (200m) of the new Quang Hue river, showed its bottom was dissymmetric, deeper on the right side (1.5-2.7m) and shallower on the left side (just 0.4m 50m to the bank), average flow velocity at depths 1.5m and 0.4m was 3.2m/s and 0.94m/s respectively. Obviously this was one of the reasons for the right bank to be eroded both vertically and laterally.

+ On the left eroded bank of the new Quang Hue river, which was 4.3m high and composed of alluvial fine sand and clay (aQ_{IV}^3), at depth of 3-3.3m within the black organic clay there was even a well-preserved wood tree trunk. This confirms an ancient river course at this location.

+ Quite a few ancient river courses were found in the vicinity, particularly at Dai Thang and Dai Cuong communes, on the right bank of the Vu Gia river, confirming its tendency to confluence with the Thu Bon river. This was nearly the straightening of a big meander, especially during the flood seasons. Thus, in case of big flood and rigorous bank protection, it would be likely that the Vu Gia river would abandon the current course to follow the new one to drain all of its water into the Thu Bon river. The protected bank and spillway would risk to appear on the left bank of the new Vu Gia river course and, similar to the old Quang Hue river, would be totally ineffective.

+ It was possible during our survey to identify the widespread exposure of the Neogene alluvial-lacustrine conglomerate, gritstone, sandstone and siltstone of the Ai Nghia Formation (N *an*) with remnants of ancient flow courses. Results of urban geological survey for Da Nang City (1994) mentioned of the existence of an active dome in the area. Thus, the Ai Nghia river has dissected, and is dissecting well-cemented Neogene sediments with limited lateral and vertical erodibility. Moreover, the Ai Nghia river is even bifurcated to the

NE of Ai Nghia Townlet also due to the presence of these Neogene sediments.

In brief, the possibility of sharing water with Da Nang City is very limited and the tendency of the Vu Gia river to displace its course toward the South and discharge to the Thu Bon river is very clear. The bank protection and spillway project undertaken by MARD, in its best case, would not be able to mitigate the accelerated flooding downstream of the Thu Bon river, which would revoke numerous unpredictable problems, in particular with regards to Hoi An Ancient Town - the World Cultural Heritage.

CAUSES OF RIVER BANK EROSION

River bank erosion types

River bank erosion can happen in one of, or combination of the following types:

- Continuous or seasonal gradual surface erosion.
- Gradual piece-by-piece erosion.
- Sudden, large-scale erosion (or collapse).

All these types of river bank erosion were observed in Central Vietnam but attention (or maybe budget limit) was usually paid on the third type, or combination of all types. Structural engineering measures (groins, rip-raps, river taming etc.) are and usually applied only at most critical sections.

River bank erosion can be classified according to its failure surface. Rotational failure causes more land loss than other types but fortunately is less popular. It takes place usually at high bank, with typical arc-shaped failure surface. Rotational failure was identified at quite a few locations, e.g. along the left bank of Tra Khuc river at Tinh Son commune (Son Tinh district, Quang Ngai province), left bank of Ve river at Hanh Thien commune (Nghia Hanh district, Quang Ngai province).

Plane failure takes place at lower bank following any possible critical plane, not necessarily dissecting the bank foot, with relatively flat, elongated failure surface along the bank. Plane failure usually takes place due to the undermining effect of the water course together with the appearance of vertical tensional cracks on the bank top. Plane failure was found in many places e.g. at Ha Nha (Dai Loc district, Quang Nam province) along the right bank of the Vu Gia river, at Tinh Son and Nghia Dung communes, along the Tra Khuc river (Son Tinh district, Quang Ngai province).

Bank slump can take place at the bank foot or other places with remarkable permeability difference due to the excessive pore water pressure that exceeds the bank soil shear strength, for which a typical example at the right bank of the Hieu river (Cam Lo district, Quang Tri province) can be cited.

Major processes and causes of river bank erosion

River bank erosion can take place due to one of, or the combination of such endogenous, exogenous and anthropogenic causes as:

- Surface erosion:
  + Erosion and wash away due to flow at the bank foot, water waves or gully due to surface run-off;
  + Due to the loose soil fabric, texture and composition (sand and silt).
- Underground processes:
  + Fluctuation of moisture or pore water pressure in different soil types, for example:
    i) Clayey soil can expand/shrink when wet/dry. Moreover, its strength also depends on pore water pressure and moisture content.
    ii) Sandy bank can be temporarily steeper than the soil angle of repose due to capillary strength or other temporary stabilizing factors. Erosion will take place when these factors are removed.
    iii) Loose sand interbeds can be subject to piping erosion either due to surface or underground flows, resulting in cavity along the water path.
    iv) Loose and fine sandy bank can be subject to liquefaction upon sudden increase in pore water pressure due to earthquakes or rapid drawdown.
    v) When the infield water level is higher than the riverside level (due to the higher up of underground water table, due to variation in the river water level, due to wind, wave or boat action, and especially when the flood water lowers down etc.), an underground flow can appear toward the river, resulting in hydraulic pressure to cause sliding.
    vi) The gravimetric flows of water within tension cracks or other types of discontinuities or boundary between two different soil types can lubricate and result in considerable hydraulic pressure, decrease in soil strength and eventually cause bank failure.
    vii) Underground karstification (e.g. along the Hieu river, Cam Lo district, Quang Tri province), combined with the above mentioned conditions to cause bank subsidence, erosion etc.
  + Exogenous factors e.g. plants, animals etc.
- Flow action:
  + Due to flow kinetics or water chemistry

+ Due to changes in flow morphology (formation of sand bar, course straightening etc.) resulting in re-distribution of flow kinetics.

− Active tectonics (displacement, uplift/subsidence or their combination).

− Systematic meandering of flows in alluvial plain.

− Gravitational landslide, especially at meanders of rivers in "through" valleys, with high banks in weak soils.

− Human activities e.g. deforestation, grazing of riverine vegetation for arable land or urbanization etc., resulting in accelerating floods both in terms of frequency and intensity, increasing sediment transport.

− River bank protection measures, especially local taming measures more than often result in increased erosion downstream. Flow straightening or bifurcation usually cause unpredictable consequences, including also erosion and development of new meanders. Examples are accelerated and intensified erosion along the right bank of Tra Khuc river at Nghia Dung commune due to construction of some improper groins just a few tens of m upstream; or erosion of the right bank of Ve river at Hanh Tin commune (Nghia Hanh district, Quang Ngai province), the right bank of Cai river at Xuan Son Nam commune (Dong Xuan district, Phu Yen province) due to construction of groins upstream etc.

− Uncontrolled sand/gravel extraction from the river.

− Construction of dam and reservoir upstream etc.

Erosion mechanism varies depending on the soil types e.g.:

− Clayey bank, having low permeability, slow drainage can become unstable leading to large scale failure due to rapid drawdown and undermined footing. Bank height is an important parameter for assessing clayey bank stability as it is less stable than sandy bank of similar height.

− Sandy bank can be eroded due to surface run-off causing gradual and small loss. The rate of surface erosion depends on such factors as:

+ Direction and velocity of the near-bank flow.

+ Variation of the flow turbulence.

+ Variation in the shear stress affecting the bank.

+ Piping and destructing strength of wave.

+ Fine, rounded sand drains water more slowly hence is more easily eroded than coarse, angular sand. Fine sand.

− Clay-sand interbedding bank is subject to more complicated erosion. Sand interbeds can cause cavity in-between clayey interbeds below and above. In that case the bank is more than often eroded due to piping or underground erosion.

In brief, river bank erosion depends simultaneously on flow hydraulic – dynamic – morphologic (destructing) processes and mechanical properties (resisting strength) of bank soil. In other words, it depends on the interaction between the hydraulic forces acting on the river bank and bottom and bank soil gravity, which is a very complicated relationship.

Timing of river bank erosion

There are opinions that river bank erosion in Central Vietnam differs from that in North or South Vietnam in that it takes place only during flood season. Other opinions are that erosion takes place during peak flood, overflowing the bank, when the flow hydraulic energy is at its peak. All these opinions are not fully justified.

Bank erosion in Central Vietnam rivers happens mostly during flood retreat, when the bank is in its saturated state. The rapid drawdown results in the loss of the confining pressure that supports the bank, while the field-side water also flows out toward the river, creating the so-called negative excessive pore pressure, hydraulic pressure difference, that both increases the shear stress and decreases the soil strength.

Nevertheless, this doesn't mean river bank erosion takes place only during flood season as many other factors can also cause the disaster. Bank erosion along the Hieu river in Cam Lo district, Quang Tri province (May-June 2001, during the low water season) or Tra Khuc river at Nghia Dung commune, Quang Ngai province (October 2001, not yet the flood season) are typical examples. Local people in Cam Lo were even totally right when they noted that the lower the water level in the Hieu river, the stronger the bank erosion.

PREDICTION OF RIVER BANK EROSION FOR COASTAL PROVINCES OF CENTRAL VIETNAM

Based on a number of factors that need evaluating when it comes to river bank erosion, the availability of data as well as their usability for small and medium scale prediction, the authors used the following factors:

− Mechanical properties of bank soil, shown on the engineering geological maps;

− Flow morphology, expressed in terms of local meanderness (or sinuosity); and

− Specific active tectonic conditions for each river of interest.

These factors were evaluated separately by comparing with the bank erosion inventory map. Other factors e.g. hydrology, human activities etc. were considered external. Thus summing up the above mentioned factors gave the so-called "intrinsic vulnerability" or "intrinsic susceptibility" to bank erosion, which was classified into:

- Highly vulnerable;
- Moderately vulnerable; and
- Stable.

Local flow sinuosity (meanderness) is determined as follows:

− It is applicable only for downstream, alluvial plain, where exist loose sediments that can be subject to erosion;

− The downstream river is then divided into major sections where the river valley abruptly changes its direction following fault systems;

− For each such section, determine the valley direction and further divide it into smaller sub-sections (how small it is depends on the length of the typical meander in such a section);

− The local flow sinuosity is the ratio between the length of the river course and the length of the corresponding river valley.

River valley direction is a stable parameter and each river section can change only within the frame of each valley section. Thus using this method, after some period of time the local flow sinuosity can be re-determined to know whether it is increasing or decreasing, i.e. the river is increasing its sinuosity or is straightening. Comparing the so determined sinuosity with the current status of river bank erosion allows finding some threshold and on that basis predicting erosion potential.

REFERENCES

Nguyen Van Hoang, Tran Trong Hue, Le Thi Minh Tam, (2001). Applying the erosion-siltation evaluation-prediction method for the Vu Gia-Thu Bon river system (Quang Nam province). *J. Earth Sciences*, No. 4/2001, Hanoi (In Vietnamese).

Nguyen Van Tuan, (2001). Summarizing reports on bank erosion of Central Vietnam rivers. University of Natural Science, VietNam National University, HaNoi.

Nguyen Vien Tho, Nguyen Thanh, (2001). Study, prediction and prevention of bank erosion for Central Vietnam rivers from Quang Tri to Quang Ngai provinces. Hue National University.

Tran Tan Van, Pham Kha Tuy, Nguyen Xuan Giap, Thai Duy Ke et al., (2002). Geohazards in coastal provinces of Central Vietnam (from Quang Binh to Phu Yen) - current status, causes, predictions and recommendation of mitigation measures. *Final project report*. Archived Vietnam Institute of Geosciences and Mineral Resources, Hanoi.

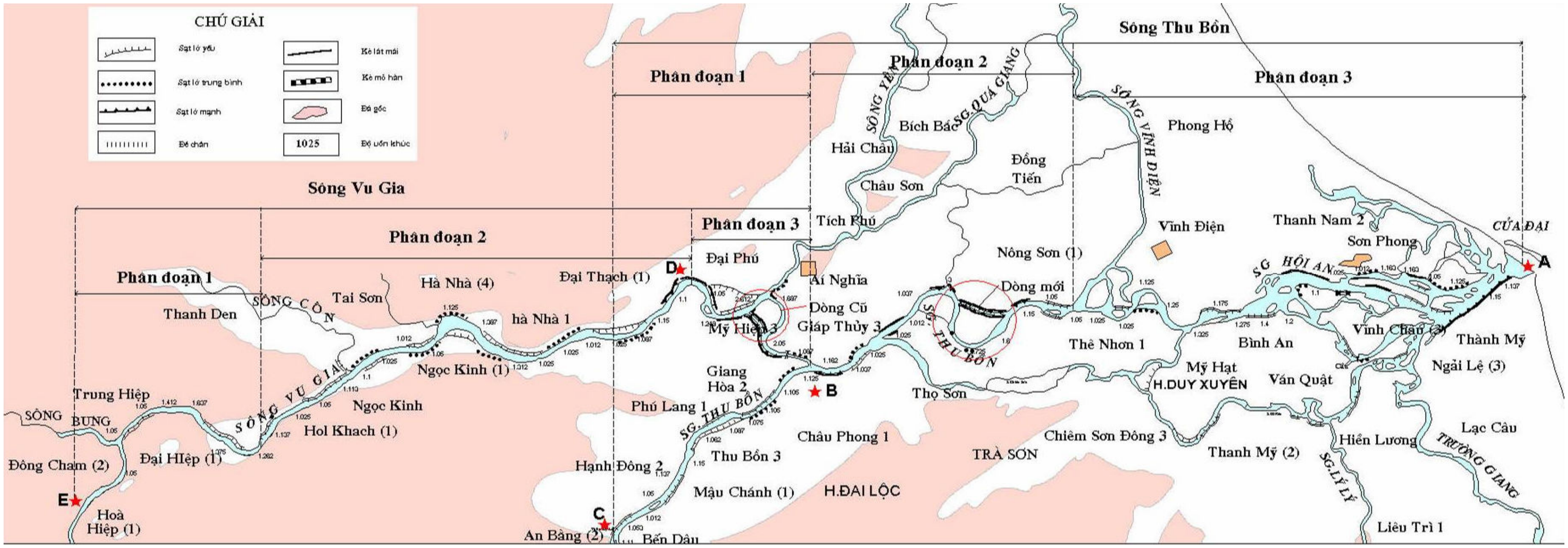

Figure 3 The erosion situation along VuGia and ThuBon rivers, QuangNam Provice

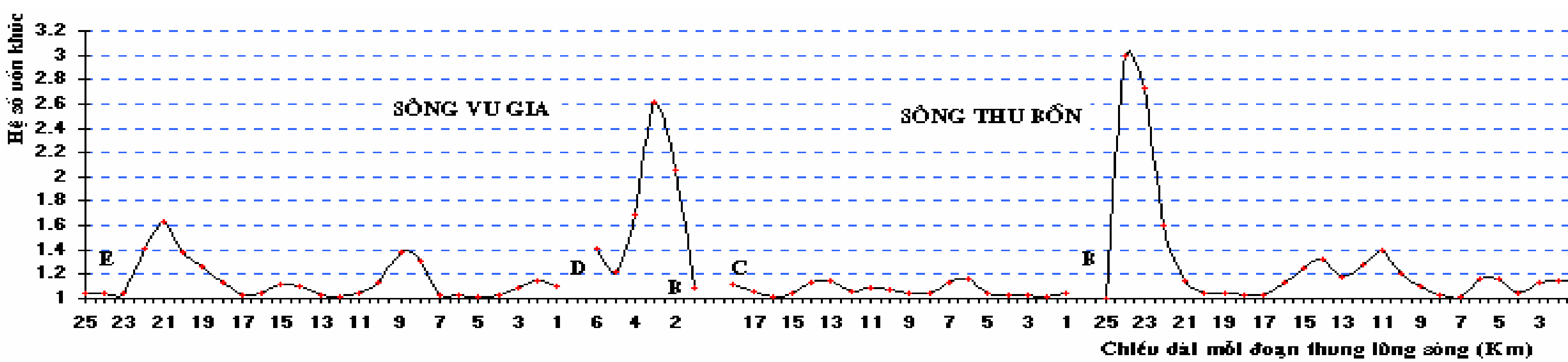

Figure 4 Diagram showing the Meandering Degree of VuGia and ThuBon rivers