DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

UDC 625.8

PROBLEMS OF IMPROVING DEFORMATIVE STABILITY OF VIETNAMESE ROAD NETWORKS ON RIVER SLOPES

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Statement of the problem. Due to the monsoon climate of Vietnam, the roads frequently face the deformation and fracturing of the roadfloodplain, particularly in floodplain areas which are always accompanied by cavitations erosion processes slopes and suffusion deformations. To increase the strength and stability of the structural elements of roads and structures they require structural measures to protect collapsearian slopes of ememembankmentmentments from them.

Results. In light of these requirements, it is important that we design a traverse device, justify and calculate their sizes, fulfill the conditions of flow of the Red River and provide measures to protect collapsearian slopes of ememembankmentmentments of roads.

Conclusion. The practice shows that under such situations where the choice of measures to protect collapsearian slopes of ememembankmentmentments and cavitation processes suffusion deformations requires the best option with the definition of the economic costs and sustainability. Choosing effective measures to protect collapsearian slopes of ememembankmentmentments is currently a complex and challenging task.

Keywords: roads, cavitation, soffits floodplain mounds traverse flood zone, subgrade, grass Vertiver, suffusion deformation, depth of erosion.

Introduction

Vietnam is a country with a complex river network. The urban settlements and agricultural districts are usually located in coastal areas and are thus prone to flooding. The road network all over Vietnam is a significant part of the country's road infrastructure.

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Failures of the subgrade and slopes of highways are common in river floodplains in monsoon season. Slides, torrents and craters invariably occur along the roads and might pose a significant threat to local communities and economy. Therefore one of the pressing issues in operation and maintenance of highways of Vietnam is developing preventive strategies for river floodplain slopes.

The highway Hanoi – Nam-Dinh runs mostly through the Red River floodplain (Fig. 1). Geologically dangerous in this area is flooding in monsoon season resulting in scour of the highway slopes.

In order to protect the highway subgrade from scour when there are flows in floodplains in road construction, it is recommended that the following regulation structures and measures are in place:

- dykes to impound water;
- straightening the riverfloodplain;
- anti-erosion equipment to protect the embankments;
- clearing the embankments and floodplains;
- straightening of the curves, etc.

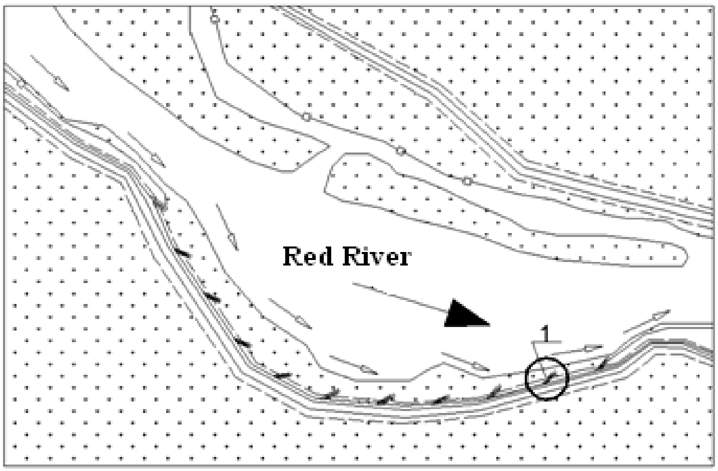

Fig. 1. Map of the highway Hanoi-Nam Dinh in the floodplain area of the Red River

However, the above engineering measures would often involve massive construction. Hence, in order to control the flow it is necessary to design control pressure hydrotechnical equipment, which is not at all cost-efficient. Our task is to design flood control equipment not only to meet the strength, reliability and durability requirements but also to be cost-efficient and easy to use. There are currently environmental pressures on hydrotechnical equipment, i.e. the overall effect on the environment should be made minimum.

Therefore, the engineering structures of river floodplains should deliver on that and be reliable, cost-efficient and environment-friendly.

1. A traverse for engineering protection

As a result of technical and environmental evaluation of existing control equipment for making deformations safe for the operation of transport structures, it is suggested that a traverse as engineering protection is analyzed, which is essentially a short cross dyke that serves to reduce the flow speed along the embankment and combat the effect on slopes (Fig. 2).

Fig. 2 indicates that the direction of the boundary stream of the transit flow depends on the adjacent angle of traverses. Using a traverse, the flow speed is reduced. A flow is originally a laminar one. This motion of water following its contact with a traverse slope assumes there is a turbulent or vortex water flow in the whirlpool and along the traverse. The resulting large whirlpool retains the energy of the original excitation. Through its short lifespan large whirlpools undergo considerable changes, i.e. they die out. It is due to their non-stability which causes them to split into smaller ones. It is studied in more detail for a simpler case when turbulence is isotropic, i.e. its characteristics are identical in identical axes. Large whirlpools get their energy immediately from the source of major motion and the smaller ones get theirs from the larger ones.

Vortex structures move more slowly than the environment. Therefore due to the movement of the vortex structure in relation to the liquid along the vortex contour, there are viscous tangent motions depending on the speed and radius of vortices. The larger it becomes, the smaller the radius of the vortices is. The lifespan of the smaller vortices is completely due to the viscosity forces affected by dissipation forces and their energy is converted into heat, i.e. a turbulent structure of the flow is the result of the generation of the vortices as well as of the dissipation of their thermal energy.

In considering the direction of the boundary stream of the transit flow along traverses, it is necessary to account for cavitation. All the water passing through the traverse profile accelerates and the local pressure decreases dramatically. If the pressure reduces to that of the saturated stream, cavitation occurs. The vapor bubbles occur in a liquid when the pressure is almost identical to that of the saturated vapor. When the pressure is restored due to the contraction, the vapor bubbles collapse and the environment becomes liquid again. Following the first collapse, there can be bubbles again.

A microstream of the liquid occurs when the restored pressure grabs a vapor bubble and then collapses it from inside. These microexplosions can cause local waves of higher pressure.

A combination of the pressure waves and microstream near the slope surface can considerably damage the traverse structure.

Cavitation also causes excessive noise and vibration levels. In addition, in our opinion, cavitation is the major cause of the destruction of traverses and highway embankments.

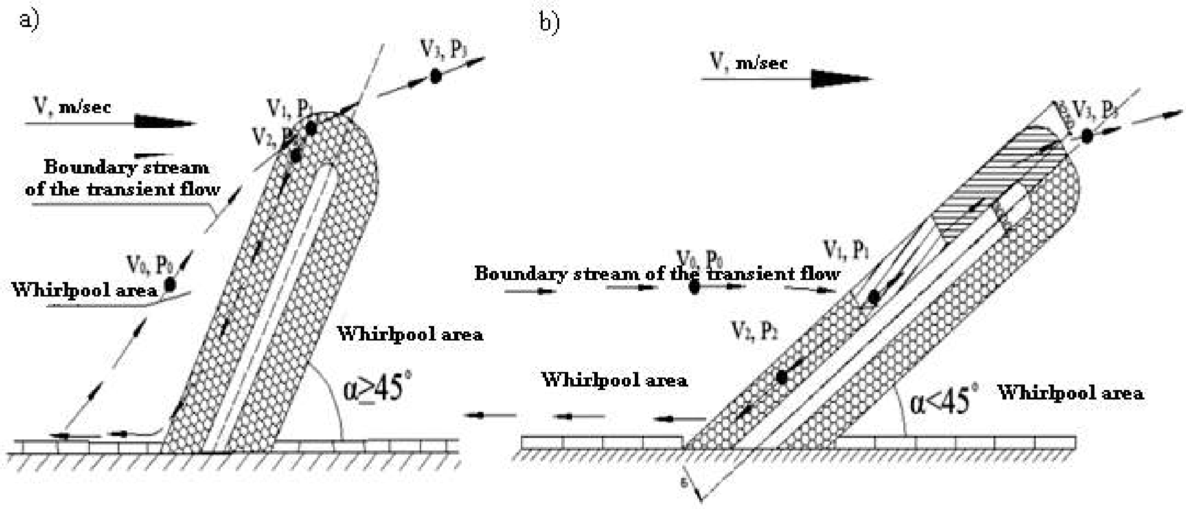

Fig. 2. Direction of the boundary stream of the transit flow for a traverse with:
a) the adjacent angle α ≥ 45°;
b) the adjacent angle α < 45°[3]

Fig. 3 indicates how a localized collapse of the bottom near the head of the traverse occurs. In order to prevent the holes of localized collapse from moving to the root of the traverse and embankment slope it is adjacent to, the minimum length of the traverse should be no less than four times as large as the water depth at its head. At the adjacent angle α ≥ 45° the holes of localized collapse occur not far away from the highway embankments and at α < 45 ° the hole of localized collapse is near the highway. This is really detrimental to the highway slopes.

The deepest holes of localized collapse *h* in cohesive and non-cohesive soils at the head of the traverse is given by the following formula [4]:

$$h = \left(2\frac{V_r}{V_0} K_l - K_\lambda \right) H_r K_m, \quad (1)$$

where V_r is the speed of the flow at the footing of the head of the traverse, m/sec; H_r is the depth of the vortex at the footing of the head of the traverse, m; V_0 is the eroding viscosity for washed out soils, m/sec; K_l is the coefficient describing an increase in the speed of the flow at the head of traverse for an insufficiently long structure; K_λ is the coefficient which is accepted to be 1.0 when the traverses are washed by the flow and 0.85 for poorly washedout structures; K_m is the coefficient depending on that of the traverse slope from the embankment.

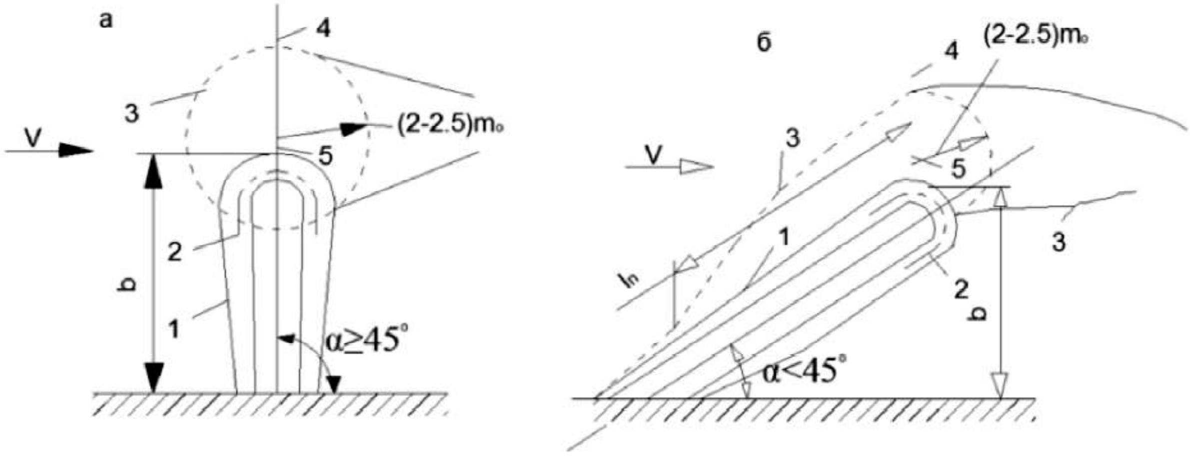

Fig. 3. Schematic of the traverses in the plan [3]:
a) at the adjacent angle α ≥ 45 °; b) the same at α < 45 °;
1 is the footing (prior to scour) of the traverse slope; 2 is the water edge;
3 is a schematic contour of the scour; 4 is a calculation section;
5 is a vertical with the deepest washingout

The scour speed V_0 for embankment soils depends on the type of the subgrade and is given by

$$V_0 = 1{,}15\sqrt{g}\left(Hd\right)^{1/4} K_i, \quad (2)$$

where g is the gravitational acceleration (g = 9.8 m/sec^2); H is the depth of the water flow; d is the average diameter of the soil particles; K_i = cosα is the coefficient considering the angle α formed by the traverse axis with highways.

The speed of the flow at the head of the traverse is given by

$$V_r = C_r\sqrt{H_r\delta}(ii_м)^{1/4}, \quad (3)$$

where δ is the coefficient of constriction of the flow in the river floodplain Q_n/Q; Q_n is water consumption for a household flooding in some of the i-th floodplain blocked by the embankment; i is the cross inclination angle of the free surface of a non-compressed flow into the flooding; i_m is the average inclination angle of the free surface over the embankment; C_r is the Chézy coefficient, m$^{0.5}$/sec is given by the roughness coefficient of the channel n_p at the depth of the flow H_r according to the formula

$$C_r = \frac{H_r^{1/6}}{n_p}. \quad (4)$$

Based on the above, cross dykes – traverses – are best for tackling the strength of slopes of Hanoi-Nam-Dinh in floodplain areas along the Red River in monsoon period (Fig. 4).

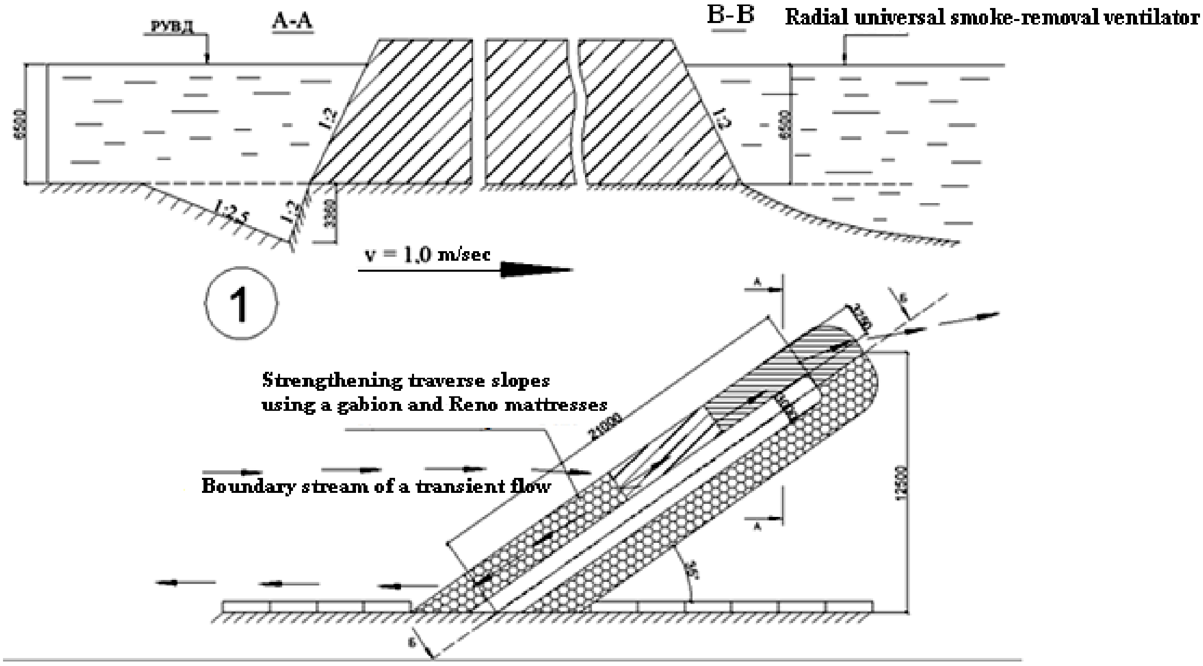

Fig. 4. Schematic of the traverse

2. Floodplain protection from suffosion deformations

However, having a traverse alone installed does not mitigate the risk of embankment scour. Following floodplain drainage, there is invariably water left inside the subgrade which will eventually start to drip off the embankment and bring subgrade particles with them – suffosion deformations (Fig. 5).

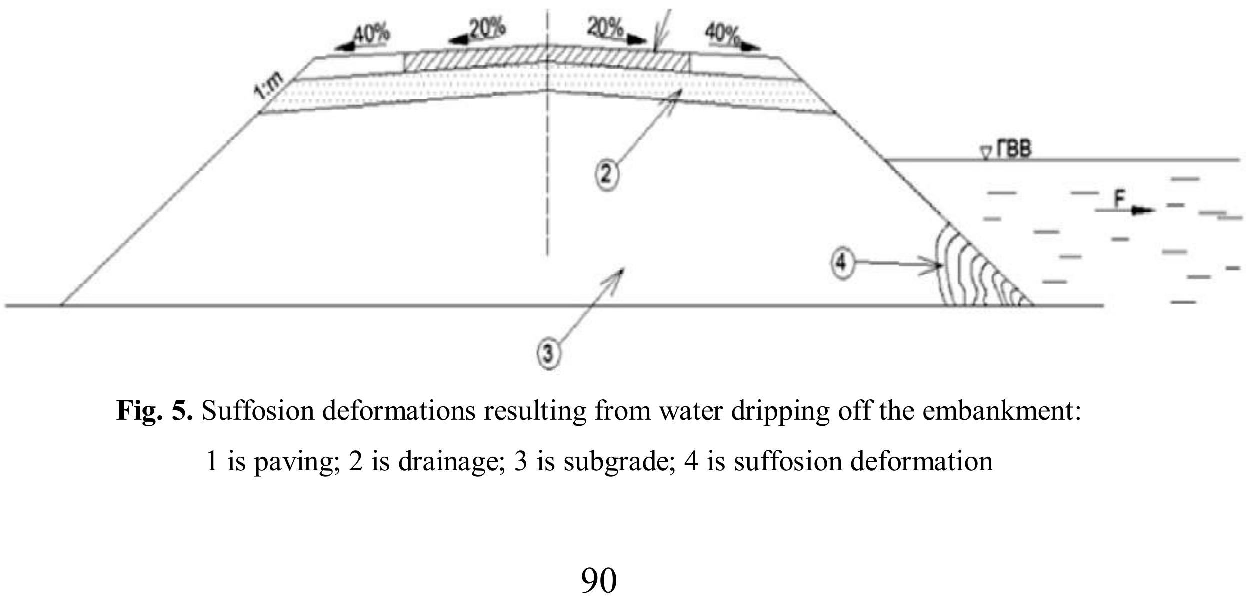

Fig. 5. Suffosion deformations resulting from water dripping off the embankment:
1 is paving; 2 is drainage; 3 is subgrade; 4 is suffosion deformation

The term “suffosion” (Latin “suffodio” — to dig) was first proposed in the late XIXth century by A.P. Pavlov which defined failure or dissolution of mineral particles by underground waters. Most specialists define it as a process of mechanical transfer of fine particles from a rockfill, filling of cracks or caves with a filtration flow of underground waters (Fig. 6).

As a result of suffosion, there can be not only holes on the earth’s surface but also voids inside a rockfill that are not visible. They come in different shapes: niches, elongated sinkholes and most commonly tubular channels of several meters in width and up to dozens of meters in length. The latter are frequently found in clay and loess rockfills. These voids make engineering and geological development of the area a lot more challenging and require a special study to be performed [1].

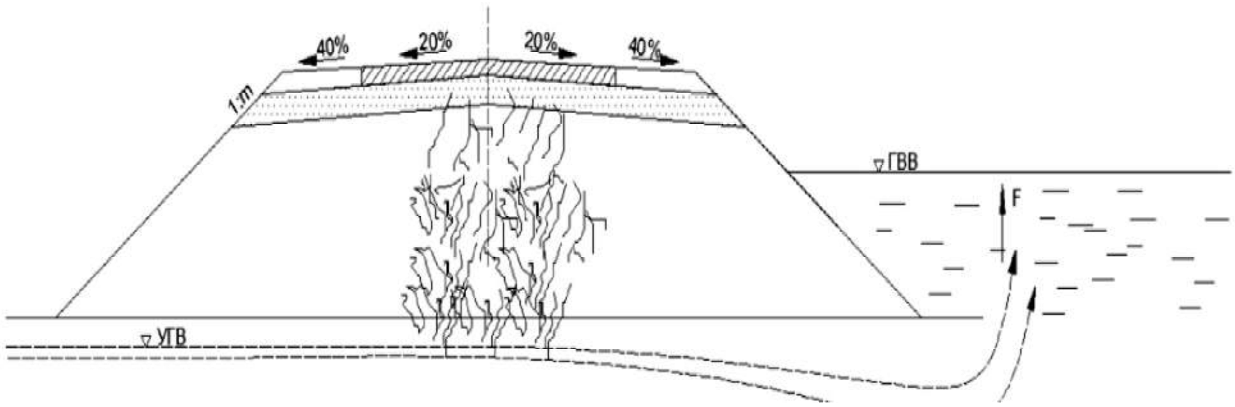

Fig. 6. Suffosion fall of floodplain embankment

In areas with a lot of storm precipitation traverses as well as slopes may fail due to suffosion fall progressing.

Therefore in order to protect floodplain embankments from scour and piping deformations, a combination of structures might be used [2]. In the lower part of a flooded slope, gabions and/or Reno mattresses are used and grass vegetation in the upper part (Fig. 7).

Volume gabions are steel woven wire mesh with hexagonal grids filled with rock, pebbles or crushed stone. Rocks can be crushed like crushed stone or rounded like rounded pebble. In order to facilitate transportation and assembly, wire mesh is delivered first and only after it was, are rocks filled, which is a big advantage it has compared to other traditional materials (Fig. 8).

Reno mattresses are industrial products which are volume structures of twisted wire mesh shaped like hexagonal grids. Due to their large size and relatively small height, they are called mattresses (Fig. 9, 10).

Fig. 7. A combination of strengthening structures

Fig. 8. Volume gabion

The following considerations should made in the chocie of these structures. They can be shaped in varied ways and heaving and pressure of the soil causes them to bend with no loss of their original properties. Resistant to deformation, structural composites can adapt to the environment. High-quality mesh materials and high-expertise installation make gabions last for over a hundred years. Assembly requires no large-scale preparation and blocks are easy and quick to install. Structures permit water very well, gabions make room for vegetation re-vitalizing it and making it an essential part of a landscape. Neither water nor vegetation roots affect the strength and integrity of the structure.

Fig. 9. Mesh of double twisting with hexagonal grids for Reno mattresses, Ltd. Timaks, Vladivostok

Fig. 10. Use of Reno mattresses for scour protection of embankments

In addition, heaving causes tiny particles of soil to wake up inside the structure and thus typical characteristics are on the rise with no change to the proportions and gabions become even stronger and more integrated into the landscape. This allows to reduce the extra drainage costs. The older a gabion is, the more advanced its properties are – natural-looking and mechanical strength. Gabions are essential to the preservation of ecological balance and protecting soils from negative environmental impacts (Fig. 11).

Fig. 11. Embankment slope protection

In order to protect the traverse from scour, it would be most ecologically reliable and sustainable to use turf vegetation on slopes. For a quick traverse of a stable grass turf vegetation on slopes to protect the soil from erosion, it is recommended that grain perennial grass is used. Following 2 or 3 years following the planting, they make up a thick turf layer of 5 – 12 cm in depth. A type of bushing or vegetation restoration of crops is crucial to good turf quality. Planting of perennial grass especially on slopes with scoured soils should be evaluated based on their soil protection (how they contributed to scour prevention) and soil-improving performance (accumulation of humus, nitrogen and other elements).

Planting with a fibrous root system becomes more aggregative and thus more erosion-resistant. Perennial grass is particularly good as it makes soils many times as erosion-resistant due to its root system: it connects individual soil particles and reduces the speed of flow at the soil surface. Besides, roots and plant residues enrich it with organic substances to promote its erosion resistance.

Aerial parts of plants are particularly efficient in soil protection. They dissipate kinetic energy of raindrops preventing the surface soil layer from failure and forming a weak water permeable coating. Projection vegetation layer defines how effectively soil is protected from raindrops. A 90% projective vegetation layer makes waste absorption 1.5 – 2.5 mm/min on calcareous and chestnut soils and 0.2 – 0.3 mm/min. In addition, while dissipating kinetic energy of raindrops, vegetation significantly reduces the transportation capacity of reservoir flows.

Thick and powerful vegetation absorbs about 60-90% of the emitted shortwave radiation of the sun and sky, 10—30 % is reflected and only 5—10 % penetrates the vegetation layer and absorbed by the soil. Besides, the vegetation layer absorbs a lot of carbon dioxide and releases oxygen into the atmosphere. The vegetation layer is also significant in water and heat mode of the underlying surface. Due to these, the vegetation layer is an active climate factor and influences physical processes in the atmosphere especially at its surface layer.

Perennial grass *Vetiver* fits the above requirements best. This grass has high germinative energy levels, standard growth rates, active turfing. They are resistant to pollution, easy to take care of. The grass trunk is vertical and from 0.5 to 1.5 m high. The grass grows in precipitation range of 200 to 6000 mm at the temperature of 9 to 45 $^{\circ}$C.

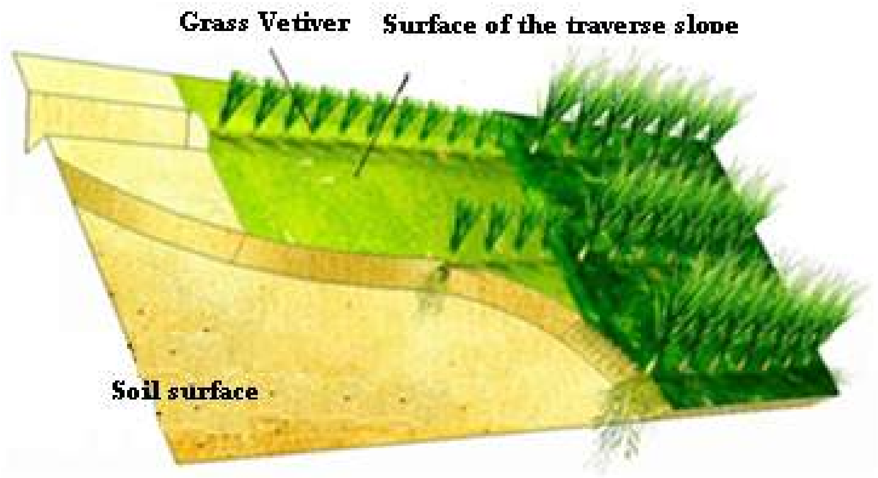

Fig. 12. Use of *Vetiver* grass for strengthening of the traverse in the embankments of the Red River

Conclusions

1. The major causes of the failure of traverse slopes and subgrade embankments in floodplains are cavitation and suffosion fall of the soil.

2. Based on the laboratory study of the properties of subgrades, it is necessary to identify scour of soils in designing traverses for the embankments of the Red River for improving the strength and stability of the floodplain embankments.

3. Practical operation of floodplains of road slope embankments and traverses indicates how necessary it is to develop preventive strategies to protect them from cavitation scour and suffosion deformation.

4. The most effective for strengthening traverses and slopes of floodplain embankments technically and economically are gabion and Reno mattresses as well as mixed vegetation.

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