A Technical Solution to Improve the Existing River Dikes for both Flood Prevention and Transportation Purposes

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Abstract. In the demand for socio-economic development, today, many river dikes in Vietnam are planned to be used as roads, and this is an indispensable trend. However, these river dikes have general characteristics of being filled with various types of soil which are heterogeneous, and not being compacted following the criteria before filling, so they need to be reinforced for both ensure the flood prevention safety and meet the technical requirements of traffic roads. In Vietnam and in the world, there are no specific studies on the re-use of the existing weak soil of embankments with adhesives, namely fly-ash and cement for treatment of foundation that meet the technical requirements of the upper base layer when transportation is involved. In this study, the authors focus on the solution of using the existing weak soil of embankments with fly-ash and cement to strengthen the stability of the river embankment served as the upper base layer in the traffic load affected zone, and the river embankment sub-structure combined with transportation purpose. By using methods of laboratory experiment, the authors propose the appropriate river embankment sub-structure to guarantee flood prevention and transportation combination.

1. Introduction

The Vietnam river dike system has been through a long history of formation and development. Currently, the total length of the river dike system in the Red River Delta is about 3,000 km, including 2,417 km length of dike in Northern Delta, and 420 km length of dike in the Thanh - Nghe area. The Red River system has 1,667 km of dikes and 750 km of dikes are in the Thai Binh river system. These river dikes were formed through different periods, the fill soil layers were heterogeneous and were filled in many stages with flood prevention requirements. Therefore, when there are traffic vehicles on the dike surface, it is hardened resulting in cracking and settlement. Dike-road combination is an indispensable demand in the current stage in order to create a completed connection to the transport network and promote the socio-economic development and serve people. Several river dikes in Vietnam have been planned (partly or entirely) as roads and severed transportation for many years such as Huu Duong river dike, left embankment of Duong river dike, Thai Binh river dike, right embankment of Cau river dike, etc. Specifically, the inter-provincial routes such as ĐT276; ĐT283; ĐT291; ĐT280 of left and right bank of Duong river dike have been planned for traffic road corresponding to class IV road. In the process of improving these river dikes for both flood prevention and transportation purposes, they were mainly implemented according to experiences or on the basis of current standards and regulations on traffic road without a specific study. Many questions are raised around the issue of dike-transportation combination as what will affect the stability of dikes when transportation is involved; are there horizontal cracking, vertical cracking, sliding? There have been a number of studies on technical solutions to enhance the strength and stability of river dikes, but
research on the re-use of the existing weak soil of embankment with adhesives, namely fly-ash and cement have not yet been mentioned and have no specific study. Besides, fly ash is a waste from the electrical industry but it can be used in many material production industries.

In this paper, the authors focus on the study of solutions to strengthen the stability of the river embankment served as the upper base layer in the traffic load affected zone, and the study of foundation treatment solution in the river embankment sub-structure combined with transportation purpose. From which, proposing the appropriate river embankment sub-structure to guarantee flood prevention and transportation combination.

2. Materials and methods

2.1. Particle size distribution curve theory

Some basic theories about soil texture are mentioned such as Fuller Thomson Theory, Caquot and Faury, Papovic-Anderson, B.B. Okhotina and N.N. Ivanov, Talbot, Weymouth for discrete granular aggregate mixtures. Fuller’s curve provides the optimum density due to the wide range of particle sizes but often leads to difficulty in compacting the mixture [6]. However, due to the “rolling” effect of fly ash, the friction between the particles will be reduced. Fuller’s curve is a parabola or part of a parabola at its natural rate. Therefore, this study will use Fuller’s curve to study and construct an appropriate gradation aggregate with size of small particles are from 1 μm to 12,500 μm being suitable for the current status of river dikes.

2.2. Materials and composition of reinforced river embankment layer

The soil samples used for experiments in the laboratory were taken from the existing river embankment of Huu Duong dike (DHD), Bac Ninh Province. The parameters of DHD soil sample are shown in table 1.

| Sieve size (mm) | Mass retained (g) | Percent retained (%) | Cumulative retained (%) | Percent passing (%) |
|----------------|-------------------|----------------------|-------------------------|---------------------|
| 10             | 504.45            | 19.432               | 19.432                  | 80.568              |
| 5              | 406.88            | 15.673               | 35.105                  | 64.895              |
| 2              | 450.63            | 17.359               | 52.464                  | 47.536              |
| 1              | 448.12            | 17.262               | 69.726                  | 30.274              |
| 0.5            | 300.04            | 11.558               | 81.284                  | 18.716              |
| 0.25           | 165.74            | 6.384                | 87.668                  | 12.332              |
| 0.1            | 217.23            | 8.368                | 96.036                  | 3.964               |
| < 0.1          | 102.91            | 3.964                | 100                     | 0                   |

Fly ashes used in combination with cement to reinforce the embankment soil are Dong Trieu fly ash (TBĐT) which is taken from Dong Trieu thermal power plant, and Cam Pha fly ash (TBCP) which is taken from Cam Pha thermal power plant. These two types of fly ashes have a total content of three major oxides (SiO₂ + Al₂O₃ + Fe₂O₃) greater than 70%, thus they are classified as Class F according to American Standard C618 [1]. The contents of SO₃ and Cl⁻ are small, therefore these fly ashes are suitable for ground reinforcement. The specification of Dong Trieu fly ash (TBĐT) and Cam Pha fly ash (TBCP) fly ash are shown in table 2.
Table 2. Specification of Dong Trieu and Cam Pha fly ash samples.

| Parameters          | Unit | Dong Trieu fly ash (TBDT) | Cam Pha fly ash (TBCP) |
|---------------------|------|---------------------------|------------------------|
| SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ | %    | 85.34                     | 84.5                   |
| SO$_3$              | %    | 1.52                      | 0.59                   |
| Loss on Ignition    | %    | 6.66                      | 10.09                  |
| CaO                 | %    | 3.67                      | 0                      |
| ion clo (Cl$^-$)    | %    | 0.01                      | 0.02                   |
| (Na$_2$O)           | %    | 0.35                      | 0.24                   |

In this study the Nghi Son PCB40 cement is used. The chemical and mineral components of Nghi Son PCB40 cement are shown in table 3.

Table 3. The chemical and mineral components of Nghi Son PCB40 cement.

| Chemical components (%) | Mineral components (%) |
|-------------------------|------------------------|
| SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SO$_3$ | Na$_2$O | K$_2$O | CaO | C$_3$S | C$_2$S | C$_3$A | C$_4$AF |
| 20.32  | 4.98       | 3.24       | 62.2 | 0.10 | 1.12   | 0.25    | 0.72   | 0.150 | 51 | 25 | 8.16 | 10 |

After selecting the optimal relative values, the optimal designed Dong Trieu fly ash-soil ratio for Huu Duong dike is 15%, the same ratio is obtained for Cam Pha fly ash.

Figure 1. Particle size distribution of DHD soil and 15% fly ash mixture.

A total of 72 reinforced soil samples (the mixture of soil, cement and fly ash) were built, maintained and tested in a standardized laboratory to determine the sample properties at 14 days of age.
Table 4. Number of reinforced soil samples to be taken for each soil component.

| Type of test          | Soil condition | 10% cement + 90% DHD | (15% TBCP + 85% DHD) + 10% cement | (15% TBĐT + 85% DHD) + 10% cement | Total of samples |
|----------------------|----------------|----------------------|-----------------------------------|-----------------------------------|-----------------|
| Compressive strength| Saturated      | 6                    | 6                                 | 6                                 | 18              |
| Compressive strength| Watering       | 6                    | 6                                 | 6                                 | 18              |
| Elastic modulus      | Saturated      | 6                    | 6                                 | 6                                 | 18              |

2.3. Materials and composition of reinforced crushed aggregate base course

Particle size distribution of crushed aggregate base course is shown in figure 2.

![Particle size distribution curve of crushed aggregate base course.](image)

Gradation aggregates are reinforced with cement and fly ash (TB), in which the ratio of replacing TB to cement referred as adhesives (CKD) are 0%, 10%, 20% and 30% respectively. The two types of TB used in the study were from Dong Trieu and Cam Pha thermal power plants.

3. Results and discussion

3.1. Laboratory test result and reinforced river embankment analysis

The following table shows the above experimental results:
Table 5. Experimental results of reinforced soil samples at 14 days of age.

| Type of test                        | Unit   | 10% cement + 90% DHD | (15% TBCP + 85% DHD) + 10% cement | (15% TBDT + 85% DHD) + 10% cement |
|------------------------------------|--------|-----------------------|-----------------------------------|-----------------------------------|
| Compressive strength (Saturated)   | (MPa)  | 2.10                  | 2.11                              | 2.27                              |
| Compressive strength (Watering)    | (MPa)  | 2.45                  | 2.52                              | 2.67                              |
| Split compressive strength (Saturated) | (MPa)  | 0.29                  | 0.27                              | 0.31                              |
| Elastic modulus (Saturated)        | (MPa)  | 962                   | 970                               | 1048                              |

Figure 3. Comparison between saturated compressive strength and non-saturated after 14 days.

Figure 4. Comparison between split compressive strength of reinforced soil mixtures after 14 days.

Figure 5. Comparison of elastic modulus among reinforced soil mixtures after 14 days.

The test results show that:
- The saturated compressive strength is varied between 83.0÷85.6% of unsaturated compressive strength. The saturated compressive strength of the reinforced mixture is higher than that of TCVN 8858:2011 [2] (Rn ≥ 1.5MPa);
- Split compressive strength of the reinforced soil mixture varies from 0.27÷0.31MPa at age of 14 days, the ratio between the compressive strength and the split compressive strength of a saturated soil sample varies from 7.24 to 7.81 times;
- The elastic modulus of the reinforced soil layer with selected optimum ratios is varied from 962MPa to 1048MPa, the elastic modulus of this soil layer is quite high, which is a good basis for the material used in the road pavement.
- The proportion of 90% of reinforced soil (85% soil + 15% fly ash) + 10% of cement brought the highest values of Compressive strength, Split compressive strength and Elastic modulus. Hence, this proportion is the optimal ratio to reinforce the base of the dike to achieve the required combination of transportation.

3.2. Laboratory test result and reinforced crushed aggregate base course analysis

The test results show that:
- Reinforcement using fly ash to replace part of cement in the adhesives results in significantly increasing in the compressive strength ($R_n$), split compressive strength ($R_{kc}$) and elastic modulus ($E_{dh}$);
- Compressive strength, split compressive strength, elastic modulus of gradation aggregate (CPDD) used adhesives fly ash of Dong Trieu thermal power plant is higher than that of Cam Pha thermal power plant;
- The values of compressive strength, split compressive strength, elastic modulus increase when the volume of fly ash increases from 0%, 10%, 20% of CKD and decrease when the approach to 30%, thus using fly ash at the ratio of 20% obtains the best effect for the study.

3.3. The proposed river embankment sub-structure of the dike after studying

Through the experiments in the laboratory, the authors have determined the optimal proportion of gradation aggregate for reinforcement and the technical parameters achieved as follows:
- Determine the proportion of 90% of the reinforced soil (85% soil + 15% fly ash) + 10% of cement is the optimal ratio to reinforce the base of the dike to achieve the required combination of transportation.
- Determine the proportion of 96% of the crushed aggregate base course, reinforced by 4% adhesives (80% cement + 20% fly ash) is the optimal ratio to reinforce the surface of the dike.
- Gradation aggregate reinforced by adhesives (CKD) can be easily compacted, reducing the number of the compaction of aggregate.

From experimental results on the basis of technical specifications, the authors propose new river embankment sub-structure to ensure flood control and transportation combination including layers: concrete surface M300; crushed aggregate base course reinforced by 4% of adhesives (CKD); layer (soil + fly ash) + cement.

![Figure 6. The proposed river embankment sub-structure of the dike after studying.](image)

4. Conclusion

In this study, the authors propose a technical solution of using existing soil, fly ash and cement to reinforce the existing river embankment which meets the flood protection and transportation combination requirements. The optimal proportion of appropriate component is a mixture with 15% of fly ash, 85% of dry soil and 10% of concrete. Moreover, the authors also propose the crushed aggregate base course reinforced by fly ash and cement, in which the appropriate proportion, including 96% of crushed aggregate base course and 4% adhesives (80% cement and 20% fly ash).
References

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