Study on the Material Properties of Cement-sand-gravel

Xiuwen Li¹, Shunfu Zhang¹, Hao Wu¹, Dongcheng Tian¹,

¹China Institute of Water Resources and Hydropower Research, Beijing, 100038, China
²Research Center on Flood&Drought Disaster Reduction of the Ministry of Water Resources, Beijing, 100038, China
*Corresponding author: 553592704@qq.com

Abstract: Cement-sand-gravel dam is a new type of dam. The low-strength cement-sand-gravel material with low price is used for dam construction. This material is obtained by simply mixing water with a small amount of cement in the sand gravel of river bed or excavation waste slag and other materials easy to get near the dam site. In this paper, the effects of water binder ratio, fly ash, sand ratio, stone powder and other parameters in different mix ratio design on the properties of materials are studied. The results show that: (1) water to binder ratio has a great influence on the strength of cement-sand-gravel material; (2) fly ash can increase the later strength of cement-sand-gravel material; (3) when the sand ratio exceeds 25%, with the increase of sand ratio, the compressive strength of cement-sand-gravel material decreases sharply; (4) stone powder has a significant effect on the early strength.

1. Preface

The cement-sand-gravel material is a low-strength dam construction material [1,2], which is obtained by using the river bed sand gravel or excavation waste slag and other materials easy to obtain near the dam site, mixed with a small amount of cementing material and water. Cement-sand-gravel material is a special concrete with low strength, low bulk density, low glue, low temperature rise, small deformation and high permeability [3] Due to the use of cementing material, the sand gravel material is bonded as a consolidated body. Compared with the earth rock dam which also needs to be compacted, cement-sand-gravel material damming has higher strength. The characteristics of cement-sand-gravel material are mainly affected by unit water content, unit cementing material content and sand gravel material gradation [4].

Experts and scholars at home and abroad have studied the mechanical properties of cement-sand-gravel materials through uniaxial and triaxial tests. Through these tests and the actual project test results, some common features of cement-sand-gravel materials are obtained: The mechanical properties of cement-sand-gravel materials are between rockfill and concrete. When the amount of cement in the material is less, the behavior tends to rockfill, and when the amount of cement is more, the behavior tends to concrete. Although cement-sand-gravel material has lower compressive strength than that of concrete, its shear strength is significantly higher than that of rockfill. In the test, the water to binder ratio, the amount of cementing material, the sand ratio and the amount of fly ash, etc. have a significant effect on the compressive strength of cement-sand-gravel. There are peaks and softening segments in the stress-strain curve. Due to the lower requirements of the parent
material, the impermeability and corrosion resistance of the cement-sand-gravel material are worse than that of the concrete [4,5].

In recent years, in combination with Baisha, Hongkou, Jiemian in Fujian Province, Shoukoubao in Shanxi Province and other projects, China has carried out laboratory test and research on the relationship between compressive strength and sand rate, the relationship between compressive strength and amount of cementing material, the relationship between unit weight and sand rate, the relationship between VC value and water content, the relationship between the size of test piece and compressive strength, elastic modulus, tensile strength and shear strength, permeability, dry shrinkage, autogenous volume deformation and adiabatic temperature rise of cement-sand-gravel materials, and implemented construction in cofferdams of Jiemian, Hongkou and other projects and Shoukoubao permanent projects [4-7].

In this paper, several groups of cement-sand-gravel materials tests are designed to study the effects of water to binder ratio, fly ash, sand ratio and stone powder on the strength of the materials under different mix ratio conditions. The research results can provide reference for project application.

2. Test materials
The sand gravel used in the test is the excavated material of natural river bed. The gravel aggregate is not screened during sampling. Instead, it is directly loaded into the truck after being shoveled evenly.

Through sieving outside the laboratory according to the aggregate size of 80-150 mm, 40-80 mm, 20-40 mm and 5-20 mm, the natural sand rate of the excavated material is measured as 23% and the mud content is 2.3%. In aggregate material, the moisture content of sand is 0.8% and moisture content of stone is 0.8%.

The cement used in the test is PC32.5 composite Portland cement. According to GB175-2007 General Portland Cement Standard. The fly ash is taken from the fly ash produced by the thermal power plant.

Because the stone powder is added to the material, the test of stone powder content is designed to study the influence of stone powder on the mixing and strength of the material. The stone powder is made of limestone powder produced by the lime plant.

3. Mix ratio and test results

3.1. Influence of water to binder ratio on strength
As the water to binder ratio is the key factor to determine the strength of cement-sand-gravel, the data at home and abroad show that the strength of compacted roller concrete after hardening is closely related to the water to binder ratio, namely the "water cement ratio rule". During the test, the amount of fixed cementing material is 80kg/m³, the fixed sand rate is 25%, and the water to binder ratio is adjusted for the test to observe the influence of water to binder ratio on the strength change and workability of concrete.

![Figure 1 Variation curve of compressive strength with water to binder ratio](image-url)
It can be concluded from the figure that: ① The strength of cement-sand-gravel material increases gradually when the water to binder ratio is between 0.7 and 1.1; and the strength decreases when the ratio is between 1.1 and 1.5. ② When the water to binder ratio is greater than 1.1, with the increase of the water to binder ratio and the water content, the strength decreases obviously. The rule of 28d and 90d is the same.

When the water to binder ratio is less than 1.1, the water content is less, and the paste content of the cementing material is less, which results in dry and hard workability of the material and nearly granular. The friction between the particles is large, and these larger particles vibrate violently during the vibrating process. Under such circumstances, the vibrating process is not solid, and the voids in the test piece increase, which reduces the strength of the cement-sand-gravel. When the water to binder ratio is greater than or equal to 1.1, the test piece is prone to bleeding after vibration compaction, which makes the internal passage of the specimen generate, and the compressive strength will be greatly reduced. In general, the water to binder ratio is the key factor to determine the strength of cement-sand-gravel material when the workability of construction is satisfied. According to the law of strength change, considering the requirements of construction and workability, the water to binder ratio can meet the project design requirements within the range of 0.7 ~ 1.3.

3.2. Influence of fly ash on strength
Fly ash can not only reduce the cost of materials, but also contribute to the later strength growth of cement-sand-gravel materials. Therefore, fly ash content is also an important parameter in mix design. In the test, the fixed water to binder ratio is 1, the fixed sand ratio is 25%, and the amount of cement and fly ash varies in different test. The mix ratio design and test results of fly ash test materials are shown in Table 1.

| number | water consumption | fly ash (kg/m³) | cement (kg/m³) | Sand rate | stone powder | 28d (MPa) | 90d (MPa) |
|--------|-------------------|----------------|---------------|-----------|--------------|-----------|-----------|
| 1      | 100               | 30             | 50            | 25        | 20           | 5.1       | 8.2       |
| 2      | 100               | 40             | 40            | 25        | 20           | 5.4       | 7.4       |
| 3      | 100               | 50             | 30            | 25        | 20           | 3.1       | 5.2       |
| 4      | 100               | 70             | 30            | 25        | 0            | 3.6       | 7.9       |
| 5      | 100               | 60             | 40            | 25        | 0            | 3.1       | 6.7       |
| 6      | 90                | 60             | 30            | 25        | 0            | 2.8       | 6.6       |
| 7      | 90                | 50             | 40            | 25        | 0            | 2.9       | 6.1       |

It can be concluded from the table that: ① When the amount of cement is 30kg/m³, the amount of fly ash increases from 50kg/m³ to 70kg/m³, with little increase in 28d and obvious increase in 90d, which also shows that the fly ash is conducive to the later strength growth of cement-sand-gravel materials. ② When stone powder is mixed, the strength of 30kg/m³ fly ash in 90d is 60.8% higher than that in 28d, and the strength of 50kg/m³ fly ash in 90d is 67.7% higher than that in 28d. When stone powder isn’t mixed, the 90d strength of 30kg/m³ cement with 60kg/m³ fly ash is 135.7% higher than that of 28d, and the 90d strength of 70kg/m³ fly ash is 119.4% higher than that of 28d. The 90d strength of 40kg/m³ cement with 50kg/m³ fly ash is 116.1% higher than that of 28d. ③ When stone powder isn’t mixed, the water to binder ratio is the same. The greater the water cement ratio, the smaller the strength. When stone powder is mixed, with the same water to binder ratio, the greater the water cement ratio, the greater the strength. It can be seen that the water cement ratio is the key factor affecting the strength, and the stone powder can also affect the strength.
3.3. Influence of sand ratio on strength
The sand ratio has a direct impact on the construction performance of the mixture, the strength and durability of hardened concrete. As the largest proportion of cement-sand-gravel material is the sandstone originated from the project site, and the sand rate changes in a large range, it is necessary to find an "optimal sand rate" range through the sand rate test. In order to study the influence of sand ratio on the strength and workability of the material, 100kg/m³ cementing material was used, the best range of water to binder ratio was obtained by water to binder ratio test, and the sand ratio was adjusted.

![Figure 2 Variation curve of compressive strength with sand ratio](image)

Figure 2 Variation curve of compressive strength with sand ratio

It can be concluded from the chart that: ① When the sand ratio is in the range of 15% ~ 25%, the compressive strength increases gradually with the increase of sand ratio, and the strength increases about 45% in 28d and 65% in 90d. ② When the sand ratio is in the range of 25% ~ 40%, the compressive strength decreases gradually with the increase of sand ratio, and the compressive strength decreases obviously between 25% and 30%. ③ When the sand ratio is 25%, the strength of cement-sand-gravel material is the largest.

When the cementing material and the amount of water are fixed, with the increase of sand ratio, the ash margin will decrease, and the sand in the cement-sand-gravel that is not covered by the cementing material slurry will increase. As more and more unbonded sand leads to the increase of void ratio in the test piece, the large void ratio will make the compressive strength of the test piece drop sharply. Considering comprehensively, the sand ratio between 20% and 35% can meet the project design requirements.

In addition to measuring the compressive strength at different sand rates, the sand rate test also carried out uniaxial test to obtain the stress-strain curve of different sand rates, as shown in Figure 3.

![Figure 3 The stress-strain curve of different sand rates](image)

Figure 3 The stress-strain curve of different sand rates

It can be found that the stress-strain curve can be divided into three stages: elastic, plastic and softening. The elastic strength is reached between 0 ~ 0.5% of the strain, and the ultimate strength is
reached between 0.5 ~ 1% of the strain. Then the failure occurs, and the softening occurs after 1% of the strain, which is consistent with the single axial test law of Japan.

With the increase of sand ratio, the peak strength of cement-sand-gravel material decreases gradually. When the sand ratio is 20% and 40%, the stress-strain curve appears recycling in the softening stage. Considering the possible failure of cement-sand-gravel material, it can still bear certain strength, which is of great significance for the seismic of the dam. Of course, during the vibration process of the test piece, due to the too low or too high sand ratio, the test piece is not compacted, and the sandstone materials are less wrapped by the cementing material, which causes the existence of voids in the test piece and this situation. In addition, this situation may be related to the loading rate of the instrument.

According to the stress-strain curve, the corresponding elastic modulus of 20%, 25%, 35% and 40% cement-sand-gravel materials are 7.7GPa, 5.5GPa, 4.7GPa and 5GPa respectively.

3.4. Influence of stone powder on strength
Because the reaction between carbonate micro particles and aluminous minerals produces calcium aluminate, limestone powder can improve the compressive strength, reduce the amount of cement, and reduce the internal hydration and temperature rise of concrete. Limestone powder is rich in sources and low in price, about 1/10 ~ 1/100 of slag and silica fume, so stone powder instead of fly ash has been used in Longtan roller compacted concrete dam and other projects [8]. In order to study the influence of stone powder on the strength and workability of concrete, the amount of fixed cement and fly ash, the amount of stone powder (0 ~ 30kg/m$^3$), the fixed sand rate of 25% and the fixed water to binder ratio of 1 were used.

![Figure 4 Variation curve of compressive strength with stone powder content](image)

It can be concluded from the figure that: ① When the water to binder ratio is fixed and the amount of cementing material is constant, increasing the stone powder can effectively improve the strength of the cement-sand-gravel material. ② When the content of stone powder is 20kg/m$^3$, the strength of the material is greatly improved. Compared with 10kg/m$^3$ stone powder, the 28d compressive strength is increased by 24.4%, and the 90d compressive strength is increased by 7.7%. ③ Compared with the strength without adding stone powder, the effect of stone powder on the early strength is more obvious, and the influence on the later strength is less than that of fly ash.

4. Conclusion
Through the uniaxial test of cement-sand-gravel materials, the 28d and 90d strength of cement-sand-gravel materials with different water to binder ratio, fly ash content, sand rate and stone powder content are measured. Through the analysis of the test results, the following main conclusions can be drawn:

(1) The water to binder ratio has a great influence on the strength of cement-sand-gravel material, and the compressive strength of the material is the largest when the water to binder ratio is about 1.1.
Considering the construction and working requirements, the water to binder ratio can meet the project design requirements within the range of 0.7 ~ 1.3.

(2) Fly ash can increase the later strength of cement-sand-gravel materials. Without stone powder, the water to binder ratio is the same, the larger the water cement ratio is, the smaller the strength is; when stone powder is mixed in it, the water to binder ratio is the same, the larger the water cement ratio is, the greater the strength is.

(3) When the sand ratio is more than 25%, with the increase of sand ratio, the void ratio of cement-sand-gravel material will increase because of the increase of sand not covered by slurry, which eventually leads to the sharp decrease of compressive strength. Considering comprehensively, the sand ratio between 20% and 35% can meet the project design requirements.

(4) The effect of stone powder on the early strength is obvious, and the influence on the later strength is not as great as that of fly ash. When the content of stone powder is 20kg/m³, the strength of the material is greatly improved.

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