Effect of fine sand of Hong river on properties of fresh and hardened concrete

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Abstract. For many years, fine sands from deposits along several rivers in Vietnam were not effectively exploited for manufacturing of building materials, especially for concrete products. It is caused by limitation in standard specification and lack of strong technical support. This study aims to expand application of the river's fine sand in producing ready mix concrete. In this research, we investigate the effect of the Hong river's and the Lo river's sands with fineness modulus from 1.0 to 2.5. Experimental results show that when fineness modulus of sand decreases, both water demand and segregation of fresh concrete are increased. The increments can be cut down by increasing water-reducing admixture dosage and using an adequate compaction regime. Decreasing maximum coarse aggregate size from 40 mm to 10 mm also reduces segregation. Variation of mortar excessive coefficient from 1.25 to 1.76 has limited effect on compressive strength. Meanwhile, increasing the sand to aggregate ratio dramatically reduces slump of fresh concrete, especially when fine sands were used. Fitting equations between cement to water ratio and compressive strength were studied. The results show that the cement to water ratio of concrete using finer sand needs to be increased to maintain compressive strength.

1. Introduction
Coarse and fine aggregates, account for 60% to 80% of the concrete volume, have a significant effect on the structure, properties and techno-economic parameters of concrete. Therefore, using local aggregates is one of the priorities to improve the efficiency of concrete. Nowadays, fine aggregates for construction in Hanoi are mainly exploited from the Lo river and the Hong river. While the Hong river's sand is fine and dark colour, the Lo river’s sand is coarse and light colour. Depending on the season, the clay and silt content in the Hong river's sand may vary in a wide range. Therefore, the Hong river's sand is usually used for backfilling works and for producing mortar.

The survey in [1] shows that the fineness modulus of the Hong river's sand used in Hanoi construction sites has varied from 0.7 to 2.0. According to the fineness modulus, particles with less than 0.63mm in size are comprised of more than 90% of the Hong river’s sand. The specific gravity of the sand was stable at 2.66 g/cm³, the content of silt, dust and clay was 0.82% on average, with a maximum value of 1.4%. Clay content, organic impurities, chloride content meet the standard requirements. Thanks to the above characteristics, the Vietnam regulator has approved the use of the Hong river’s sand in producing concrete up to grade B25.

In Vietnam, primary researches on application of fine sand including the Hong river's sand in concrete published in the 1970s [2, 3] have pointed out the effect on the properties of fresh and hardened concrete. These studies have carried out classification and appropriate adjustment for effectively use of fine sand in concrete. Recent studies in laboratories [4, 5] show that with appropriate
technology, the Hong river’s sand can be used to produce concrete with a strength from 10 MPa to over 90 MPa. However, the on-site practical application is still very limited.

Fine sand is also used in manufacturing of a wide range concrete product all over the world. Fine sands from rivers and dunes are used in civil, industrial, transportation, irrigation and hydropower projects in various countries: Russia, China and Australia, just to name a few. The use of fine sand is supported by many researches, standard recommendations and guidelines.

In one hand, water demand in concrete using fine sand is higher than in concrete using coarse sand since the fine sand has more specific surface area than the coarse sand. In the other hand, to achieve the equivalent compressive strength, the amount of cement should be increased to maintain the cement to water ratio. Studies in [3,6,7] show that an optimum sand to aggregate ratio in concrete must be reduced when the fineness modulus of sand decreases. When the required workability is relatively low, gap-graded concrete causing by the absence of intermediate size fraction in aggregate has some advantages. However, when fine sand is used in high workability concrete mixtures, segregation may become a problem.

To promote a wider utilization of the Hong river’s sand in concrete, especially in high workability concrete, we conduct a research on water demand, segregation, compressive strength and other properties of the concrete.

Based on the test result, we propose to revise current standards and recommendation on production of concrete with fine sand.

2. Materials and methods
In this study, blended portland cements of Tam Diep and But Son Cement Plants named C1, C2 and C3 conforming the ASTM C1157-11 were used for concrete mixtures. Properties of cements were shown in Table 1.

| Properties                           | Cement |
|--------------------------------------|--------|
|                                      | C1     | C2     | C3     |
| Density, g/cm³                       | 3.05   | 3.10   | 3.11   |
| Specific surface, cm²/g              | 3.250  | 3.570  | 3.650  |
| Water for normal consistency, %      | 29.0   | 29.0   | 28.5   |
| Setting time, min                    |        |        |        |
| Initial                              | 115    | 105    | 115    |
| Final                                | 230    | 215    | 235    |
| Compressive strength, MPa            |        |        |        |
| at 3 days                            | 28.5   | 27.5   | 31.9   |
| at 28 days                           | 49.1   | 46.3   | 51.0   |

Three types of the Hong river’s sand named sH10, sH15, and sH20 with fineness modulus of 1.0, 1.5, and 2.0, respectively and the Lo river’s sand called sL15, sL25 with fineness modulus of 1.5 and 2.5 were used. Note that the sL15 sand was intentionally processed to have the same gradation as sH15 sand. Properties of the sands are shown in Table 2.

We used crushed limestone named S1, S2 and S3 with maximum size of 10 mm, 20 mm and 40 mm, respectively as coarse aggregates. High range water-reducing admixtures type G (HR1000 and SSA2000 of SilkRoad) were also used to produce high slump concrete mixtures with slump retention ability.
Table 2. Properties of the sands

| Properties            | Hong river sand | Lo river sand |
|-----------------------|-----------------|---------------|
|                       | sH10            | sH15          | sH20          | sL15 | sL25 |
| Density apparent, g/cm³ | 2.68            | 2.67          | 2.66          | 2.67 | 2.65 |
| Density SSD, g/cm³     | 2.65            | 2.64          | 2.64          | 2.66 | 2.64 |
| Density OD, g/cm³      | 2.63            | 2.63          | 2.62          | 2.65 | 2.63 |
| Water absorption, %    | 0.6             | 0.7           | 0.5           | 0.5  | 0.5  |
| Bulk density, kg/m³    | 1.310           | 1.340         | 1.390         | 1.330 | 1.440 |
| Fineness modulus       | 1.0             | 1.5           | 2.0           | 1.5  | 2.5  |
| Dust, silt and clay content, % | 1.1    | 0.7           | 0.7           | 0.9  | 0.5  |

Raw materials were mixed in a laboratorial portable concrete mixer. Actual concrete proportions were estimated by mean of the weight of materials for each batch and actual unit weight of concrete mixture. For each mixture, a group of 150x150x150 mm cube specimens were casted. The specimens were deformed after 24 hours and cured in standard conditions.

3. Properties of concrete mixtures

We used C1 cement and S2 coarse aggregate in samples to study the effect of sand on water demand. In this case, 400 kg/m³ cement content was selected. Figure 1 shows the test result and trend lines of slump against water content for mixture using different sand.

![Figure 1. Slump versus water content](image)

It is shown that, water demand of mixture increased when fineness modulus of sand decreased. Water demand of 40 mm to 120 mm slump mixtures made with sL25 sand was from about 185 kg/m³ to 200 kg/m³. Meanwhile for mixtures made with sH15 and sH10 sands, the water demand was from 190 kg/m³ to 210 kg/m³ and from 200 kg/m³ to 220 kg/m³ respectively. Bleeding in concrete mixture would take place if water content was above the maximum value of this range. Using finer sand can shift the limit of water content to a higher value. Therefore, the water-reducing admixture was essential for making high slump mixtures.
High range water-reducing admixture HR1000 from SilkRoad was used to improve the slump of concrete mixture with fixed water content. We used C1 cement and S4 coarse aggregate in this mixture and the test results are shown in Figure 2.

**Figure 2. Admixture dosage versus slump**

Figure 2 presents the difference in slump of the mixtures with the same admixture dosage. To achieve the same slump value, a higher admixture dosage was needed. Using sH10 sand instead of sH15 sand required extra 0.3% dosage of admixture to reach the equal slump without adding water. However, to avoid the negative effect of admixture on setting time, the maximum admixture dosage should be agreed with the manufacture's recommendation.

Application of fine sand yielding the gap-graded concrete can promote the segregation, especially in high slump mixtures. Bleeding and segregation of the concrete in the relation with several parameters were investigated. The series of concrete mixtures with C3 cement, with and without admixture HR1000 was prepared and tested.

According to standard method, the segregation was determined by mean of the percentage mortar volume difference between top and bottom halves of the concrete mixture in the mould after 25 sec. vibration. The segregation after 10 sec. vibration was also measured for comparison. The test results are presented in the Table 3.

As expected, the concrete mixtures with slump under 100 mm had a zero bleeding while the high slump mixtures had a bleeding value of 0.2% to 0.3% that within the allowable range. Bleeding in concrete mixture can be adjusted by mean of water content and admixture dosage selecting.

Test results of mixtures from P1 to P6 clearly showed the effect of the slump on the segregation. An increase in the water content from 181 kg/m³ in mixture P1 to 193 kg/m³ in mixture P2 improved the slump from 40 mm to 85 mm that caused the increasing bleeding from 1.3% to 2.1%. The direct relation between water content and segregation cannot be found. The slump can be improved by increasing water content or by using admixture (mixtures P4 in comparison with P2 and P5 with P1) without affecting the segregation.

In mixtures P3, P5 and P4, P6 the water content was reduced. The admixture dosages were increased to keep the same slump. In the results, the slump as well as the segregation were decreased due to changing in viscosity and thixotropy of the mixtures in the presence of admixture. Thus, the effective way to reduce the segregation was by using admixture to decrease the water content.

Test results in Table 3 also reveal the effect of the fineness modulus of sand on the segregation in concrete mixture. Attaining equal target slump of mixtures P3 and P7 with constant water content, the
admixture dosage had to increase. Decreasing fineness modulus of sand from 1.5 in P3 mixture to 1.0 in P7 mixture increased the segregation from 4.4% to 4.9%.

Table 3. Parameters of mixtures

| ID | Aggregate | Parameters | Slump, mm | Bleeding, % | Segregation, % after 25 sec 10 sec. |
|----|-----------|------------|-----------|-------------|-----------------------------------|
| P1 | sH15      | S4 181     | 0         | 2.10        | 40 0 1.3 -                        |
| P2 | sH15      | S4 193     | 0         | 2.10        | 85 0 2.1 -                        |
| P3 | sH15      | S4 190     | 0.25      | 2.09        | 160 0.2 4.4 2.1                  |
| P4 | sH15      | S4 194     | 0.5       | 2.10        | 200 0.3 6.6 3.2                  |
| P5 | sH15      | S4 181     | 0.5       | 2.10        | 165 0.3 4.1 1.9                  |
| P6 | sH15      | S4 176     | 1.5       | 2.08        | 200 0.2 5.1 2.3                  |
| P7 | sH10      | S4 191     | 0.5       | 2.10        | 175 0.3 4.9 2.6                  |
| P8 | sH20      | S4 178     | 0.5       | 2.28        | 170 0.1 3.8 1.7                  |
| P9 | sH15      | S1 193     | 0.5       | 2.11        | 180 0.2 3.1 1.5                  |
| P10| sH15      | S2 187     | 0.5       | 2.16        | 165 0.2 3.6 1.3                  |

It was also found that reducing maximum size of coarse aggregate can decrease the segregation in concrete mixture regardless changing in slump or water content. In case of 10 mm coarse aggregate (S1), adding 193 kg/m³ water can yield 180 mm slump concrete mixture with segregation of 3.1% (P9). Meanwhile, with 40 mm coarse aggregate (S4) the segregation was dramatically increased to more than 4% in P3 and P5 even these mixtures had lower slump (160 mm) or lower water content (190 kg/m³ and 181 kg/m³). For concrete with fine sand, the smaller coarse aggregate was preferable to avoid the segregation.

Note that changing vibration time from 25 sec. to 10 sec. reduced the segregation of all mixtures. In the result, segregation was less than 4% - required limit value for high slump mixture. Although the risk of segregation in fine sand concrete mixture was higher in comparison with coarse sand mixture, changing compaction regime by mean of shorten optimum vibration time was practical recommendation to reduce segregation.

4. Effect of the mortar excessive coefficient

Following the guideline on proportioning concrete mixtures in Vietnam, fine and coarse aggregate contents were determined considering the recommended optimal mortar excessive coefficient (Ke) [6]. Mortar excessive coefficient was calculated as ratio between the mortar volume and the void of coarse aggregate in cubic metre of concrete mixture. According to Bazhenov Iu.M. [7] for a given conditions, there are optimal mortar excessive coefficient corresponding the maximum workability as well as maximum compressive strength of concrete. However, consider the fact that the cost of fine aggregate, especially of fine Hong river's sand, is lower than of the coarse aggregate, increasing the mortar excessive coefficient will reduce the cost of concrete. So the optimal Ke value should be selected considering both technical and economical aspects. Study on mortar excessive coefficient were conducted with C2 cement and SSA2000 high range water reducing admixture from SilkRoad and presented in Table 4. Note that sL25, sL15, sH15 and sH10 sands were used in mixtures K1-K6, K7-K10, K11-K16 and K17-K20 respectively; D4 and D2 coarse aggregates were used in mixtures K1-K16 and K17-K20 respectively.
Table 4. Proportion and properties of mixtures

| ID | Materials, kg/m³ | Ke | Density, kg/m³ | Slump, mm | Compessive strength, MPa at 7 days | Compessive strength, MPa at 28 days |
|----|------------------|----|----------------|-----------|-----------------------------------|-----------------------------------|
|    | C    | W    | F.Ag  | C.Ag | SP |                               |                                   |
| K1 | 417  | 199  | 458   | 1.399 | 4.17 | 1.06 | 38.5 | 48.3 | 38.5 | 48.3 |
| K2 | 419  | 200  | 561   | 1.282 | 4.19 | 1.25 | 38.3 | 48.9 | 38.3 | 48.9 |
| K3 | 420  | 199  | 663   | 1.174 | 4.20 | 1.46 | 39.2 | 47.4 | 39.2 | 47.4 |
| K4 | 418  | 198  | 748   | 1.087 | 4.18 | 1.66 | 38.7 | 48.4 | 38.7 | 48.4 |
| K5 | 419  | 199  | 781   | 1.048 | 4.19 | 1.76 | 37.5 | 47.2 | 37.5 | 47.2 |
| K6 | 421  | 200  | 810   | 1.011 | 4.21 | 1.86 | 35.7 | 44.2 | 35.7 | 44.2 |
| K7 | 398  | 189  | 618   | 1.276 | 3.98 | 1.36 | 33.6 | 41.5 | 33.6 | 41.5 |
| K8 | 399  | 190  | 706   | 1.179 | 3.99 | 1.45 | 34.2 | 41.6 | 34.2 | 41.6 |
| K9 | 401  | 189  | 793   | 1.087 | 4.01 | 1.66 | 33.8 | 40.8 | 33.8 | 40.8 |
| K10| 396  | 190  | 831   | 1.048 | 3.96 | 1.76 | 33.5 | 39.7 | 33.5 | 39.7 |
| K11| 418  | 199  | 457   | 1.399 | 4.18 | 1.06 | 33.3 | 41.4 | 33.3 | 41.4 |
| K12| 418  | 199  | 570   | 1.276 | 4.18 | 1.26 | 33.9 | 42.3 | 33.9 | 42.3 |
| K13| 417  | 198  | 673   | 1.169 | 4.17 | 1.47 | 34.8 | 43.8 | 34.8 | 43.8 |
| K14| 418  | 199  | 746   | 1.087 | 4.18 | 1.66 | 35.1 | 43.1 | 35.1 | 43.1 |
| K15| 420  | 199  | 780   | 1.048 | 4.20 | 1.76 | 34.2 | 42.6 | 34.7 | 42.6 |
| K16| 419  | 200  | 812   | 1.011 | 4.19 | 1.86 | 33.7 | 39.6 | 33.7 | 39.6 |
| K17| 398  | 190  | 614   | 1.254 | 3.98 | 1.25 | 32.8 | 39.8 | 32.8 | 39.8 |
| K18| 400  | 189  | 711   | 1.153 | 4.00 | 1.45 | 33.5 | 40.3 | 33.5 | 40.3 |
| K19| 399  | 190  | 790   | 1.066 | 3.99 | 1.65 | 32.8 | 40.4 | 32.8 | 40.4 |
| K20| 397  | 191  | 829   | 1.024 | 3.97 | 1.76 | 32.2 | 37.3 | 32.2 | 37.3 |

Test results in Table 4 show that increasing mortar excessive coefficient reduced the workability of concrete mixture. At low level of Ke (from 1.06 to 1.25), concrete mixture was harsh and caused the collapsed slump cone. As the Ke increased, the sand to aggregate ratio is increased consequently increased the water demand and decreased the workability. The decreasing range of slump depended on the fineness modulus of sand. Using the Lo river's sand sL25, Ke increment from 1.06 to 1.86 caused reduction of slump from 200 mm to 110 mm. Meanwhile, for sL15 and sH15 the reduction was from 215 mm to 50 mm. For sH10 sand, Ke increment from 1.25 to 1.76 caused slump loss from 160 mm to 25 mm. To maintain the workability, we should increase the water reducing ability of admixture by changing admixture type or by increasing admixture's dosage.

Concerning compressive strength, mortar excessive coefficient had a limited effect on it. Increasing Ke of concrete mixture with sL25 sand from 1.06 to 1.86, compressive strength at 3, 7 and 28 days ages slightly decreased at high Ke value. But the absolute difference was less than approximately 5 MPa. At the Ke value from 1.25 to 1.76 (corresponding to sand to aggregate ratio from 0.30 to 0.43) the difference in compressive strength had no statistical significance. Despite of different origin, sL15 and sH15 sands had the same effect on both workability and strength of concrete. At 3 and 7 days, compressive strength was not sensitive to increasing of Ke. At 28 days, compressive strength slightly reduced no more than 5 MPa at the high level of Ke. The same picture was discovered with sH10 sand. The reduction in compressive strength at high level of Ke was less than 3 MPa.
This test results were agreed with preceding studies of Tin D.D. [2] on fine sand of the Da river and of Kiem N.M. [8] on coarse sand. Variation of Ke in range of ±0.25 from recommended tabulated value had no significant effect on strength. In the same time, increasing of Ke caused slump loss. Therefore, to lower the cost by increasing the sand content while maintaining the required properties of concrete, we had to increase the admixture dosage. At the same time, the smaller coarse aggregate and shorter vibration time were recommended.

5. Effect of the cement to water ratio
It was widely agreed that in the certain range the compressive strength of concrete can be estimated by using the equation (1). Depending on the raw materials, the parameters can vary. Based on the statistical analysis it is acceptable that b equals to 0.5, so the equation (1) can be transformed to the equation (2). Parameter A in (2) was regard to the quality of the raw materials.

\[
\frac{R_{con}}{R_{cem}} = a \times \frac{C}{W} + b \tag{1}
\]

\[
\frac{R_{con}}{R_{cem}} = A \left( \frac{C}{W} + 0.5 \right) \tag{2}
\]

Where:
- \( R_{con} \), \( R_{cem} \): compressive strength of concrete and of cement;
- C, W : cement and water contents;
- a, b, A : parameters of the equations.

To quantify the effect of fine sand on the compressive strength of concrete, series of concrete mixtures of C2 cement, S4 coarse aggregate and SSA2000 admixture were tested. The cement content of the mixtures was varied from 345 kg/m³ to 432 kg/m³. Test results were used to establish the regression between cement to water content and compressive strength (equation 1) by mean of the least square method. Parameter A of the equation 2 is the average value for each determination. The results are shown in Table 5.

| Fine aggregate | Age, days | Parameters of Eq.1 | Parameter of Eq.2 |
|----------------|-----------|--------------------|-------------------|
|                |           | \( a \) | \( b \) | \( A \) |
| sL25           | 3         | 0.933 | -0.893 | 0.651 |
|                | 7         | 0.809 | -0.649 | 0.647 |
|                | 28        | 0.833 | -0.695 | 0.649 |
|                | 3         | 0.744 | -0.605 | 0.592 |
| sL15           | 7         | 0.622 | -0.370 | 0.584 |
|                | 28        | 0.690 | -0.512 | 0.581 |
|                | 3         | 0.757 | -0.598 | 0.610 |
| sH15           | 7         | 0.742 | -0.582 | 0.600 |
|                | 28        | 0.722 | -0.550 | 0.595 |
|                | 3         | 0.623 | -0.440 | 0.537 |
| sH10           | 7         | 0.613 | -0.436 | 0.527 |
|                | 28        | 0.535 | -0.277 | 0.527 |
As shown in Table 5, using finer sand reduces the compressive strength of concrete. The parameter a of equation 1 defining the slope of the fitting straight line. It is showed that increment in fineness modulus will increase the difference in compressive strength corresponding to the similar increment of C/W. To maintain the compressive strength of concrete the C/W ratio of fine sand concrete should be increased.

Concerning equation 1, the parameters a and b were varied in the wide range (the slope a was varied from 0.54 to 0.93 and the intercept b from -0.89 to -0.28) depending on the fineness modulus of sand. Meanwhile the parameter of equation 2 was more stable and not depend on the origin of sand. We recommended that the value of parameter A should equal 0.65, 0.59 and 0.53 for concrete mixture using sand with fineness modulus 2.5, 1.5 and 1.0 respectively. This value can be used in selecting proportion of concrete.

6. Conclusions
The results presented in this paper show that the fine Hong river’s sand can be effectively used in producing ready mix concrete.

Experimental results show that when fineness modulus of sand decreases, both water demand and segregation of fresh concrete are increased. They can be cut down by increasing water-reducing admixture dosage and using an adequate compaction regime. Decrease maximum coarse aggregate size from 40 mm to 10 mm also reduces segregation. Variation of mortar excessive coefficient from 1.25 to 1.76 have limited effect on compressive strength. Meanwhile increase the sand to aggregate ratio dramatically reduces slump of fresh concrete, especially when fine sands are used.

Fitting equations between cement to water ratio and compressive strength are found. It shows that the cement to water ratio of concrete using finer sand needs to be increased to maintain compressive strength.

In the next stage, we will study the behavior of the reinforced fine sand concrete members in different loading conditions and their practical implementations.

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