Discussion on the Mechanism of the Differences of Sediment Transport Capability of the Different Alluvial Reaches in the Yellow River

Zheng Yanshuang a, Li Yong, Zhang Xiaohua, Shang Hongxia

Abstract

According to the principles of hydraulics, fluvial processes study and river sediment dynamics, the authors discuss the mechanism of different capabilities of sediment transport of different alluvial reaches in the Yellow River. The results are: the main reason of low sediment transport capability in Ningmeng Reach is weak hydrodynamic power, the narrow and deep cross-section profile determines the high sediment transport capability and the frequent hyper-concentrated floods during which the sediment settling velocity reduced by the increasing of hydro-viscosity and density resulting from high sediment concentration also improve the capability of sediment transport in the Lower Weihe, in the Lower Yellow River the strong hydrodynamic power is the most important factor conducing the high sediment transport capability, for the Xiaobeiganliu reach though the hydro-dynamic power is strong the big particle size of suspended sediments reduces the sediment transport capability.

Keywords: Yellow River, alluvial reaches, sediment transport capability; mechanism;

1. Introduction

Ningmeng Reach, Xiaobeiganliu reach, the Lower Yellow River and the Lower Weihe are typical alluvial reaches in the Yellow River. Because of the difference geographical location and water and sediment conditions, Sediment transport capacity has larger difference. Existing research results show that[1-3]: When the sediment coming coefficients of flood season is 0.01kg.s/m6 the Lower Yellow River and Xiaobeiganliu reaches reach relative equilibrium state. But the Ningmeng reach is only 0.0038kg.s/m6. It is only one-third of the lower Yellow River. Meanwhile, the Lower Weihe sediment coming coefficients of flood season is 0.1kg.s/m6 reaches relative equilibrium state. And the sediment coming coefficients is 0.07kg.s/m6 in the low sediment concentration state, High sediment concentration can reaches
In this paper discusses the main factors in mechanism of different capabilities of sediment transport.

2. The mechanism discussion of different capabilities of sediment transport of alluvial reaches

2.1 Incoming sediment comprehensive conditions and hydrodynamic power factors

The calculation of Sediment carrying capacity often used formula (1)[4], sediment transport capacity is equal to inflow sediment concentration under the equilibrium conditions between scour and siltation; Therefore, sediment coming coefficient can be expressed as equation (2), from equation (2) can be seen, sediment carrying capacity has related to two factors, one is inflow sediment concentration and the composition of sediment coming, another part is the integrated hydraulic, therefore, the paper directly analysis these two parts characteristics of the different reaches.

\[
S^* = K\left(\frac{\gamma_m}{\gamma_s - \gamma_m} \frac{V^3}{gH\omega_c}\right)^m = K\left(\frac{\gamma_m}{\gamma_s - \gamma_m} \frac{1}{g\omega_c} \frac{V^3}{H}\right)^m
\]

(1)

Sediment incoming coefficient can be expressed as:

\[
\frac{S^*}{Q} = \frac{K\left(\frac{\gamma_m}{\gamma_s - \gamma_m} \frac{1}{g\omega_c} \frac{V^3}{H}\right)^m}{Q} = K\left(\frac{\gamma_m}{\gamma_s - \gamma_m} \frac{1}{g\omega_c} \frac{V^3}{H}\right)^m \frac{V^3}{Q}
\]

(2)

\[
\gamma_m = \gamma + \frac{S}{\gamma_s}(1 - \frac{\gamma}{\gamma_s})
\]

(3)

\[
\omega_c = (1 - S_v)^{4.9} \omega_0
\]

(4)

\[
S_v = \frac{S}{\gamma_s}
\]

(5)

In formula, \( \gamma \): Average velocity (m / s); \( B \): Average river width (m); \( H \): The average water depth (m); \( n \): Manning roughness coefficient; \( \beta \): Longitudinal slope (°); \( S \): The average sediment concentration of the flood (kg/m^3); \( g \): Acceleration of gravity (kg/m^3); \( \omega_c \): Non-uniform sediment settling velocity of water (cm/s); \( \omega \): Settling velocity of muddy water (cm/s); \( Z \): Median particle diameter of suspended sediment (mm); \( J \): Average particle diameter of suspended sediment (mm); \( S \): Water density (kg/m^3); \( Z \): Muddy water density (kg/m^3); \( \gamma_s \): Sediment bulk density (kg/m^3); \( S \): Volume of sediment (sediment volume unit volume of muddy water) (%); \( k \), \( m \): Coefficient and index.
Table 1 Incoming sediment comprehensive factor and flow influence in different reach

<table>
<thead>
<tr>
<th>Factors</th>
<th>Project</th>
<th>Ningmen g Reach</th>
<th>Xiaobeigan liu reach</th>
<th>the Lower Yellow River</th>
<th>the Lower Weihe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive factors of hydrodynamic power</td>
<td>The average peak flow (m³/s)</td>
<td>1855</td>
<td>2102</td>
<td>2503</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>( \frac{H}{Q} )</td>
<td>0.0009</td>
<td>0.0019</td>
<td>0.0013</td>
<td>0.0015</td>
</tr>
<tr>
<td></td>
<td>The ratio of the Lower Yellow River</td>
<td>0.7</td>
<td>1.5</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Comprehensive conditions of sediment</td>
<td>The average sediment concentration</td>
<td>7.6</td>
<td>56</td>
<td>56</td>
<td>85.6</td>
</tr>
<tr>
<td></td>
<td>dcp</td>
<td>0.033</td>
<td>0.036</td>
<td>0.026</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
<td>d50</td>
<td>0.015</td>
<td>0.028</td>
<td>0.018</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>( \gamma_s - \gamma_m \ \frac{g \omega_c^2}{\gamma} )</td>
<td>14.1</td>
<td>14.7</td>
<td>18.7</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>The ratio of the Lower Yellow River</td>
<td>0.75</td>
<td>0.79</td>
<td>1.00</td>
<td>1.31</td>
</tr>
<tr>
<td>Two factors</td>
<td>Product value</td>
<td>0.0127</td>
<td>0.0280</td>
<td>0.0243</td>
<td>0.0368</td>
</tr>
<tr>
<td></td>
<td>The ratio of the Lower Yellow River</td>
<td>0.52</td>
<td>1.15</td>
<td>1.00</td>
<td>1.51</td>
</tr>
</tbody>
</table>

In the existing research results of the Yellow River sediment carrying capacity formula, the range of index m values is generally a value between 0.62 to 0.92 [5], this paper selects m = 0.75, K is a constant.

From Table 1 can be seen, compared to the lower Yellow River, Ningmeng reach has the most weakest hydrodynamic power conditions, which is only 0.7 times of the lower Yellow River, and has also exist big particle size of the sediments, so the general terms of sediment is only 0.75 times of the lower Yellow River, which reduces to the reach has weak sediment carrying capacity. For the Xiaobeiganliu reach relatively strong hydrodynamic conditions, but the particle size of suspended sediment particle size is fairly big, therefore, The product of two factors combined effects are 1.15 times of the lower Yellow River. In the Lower Yellow River has the stronger hydrodynamic power, the smaller of sediment particle size, settling velocity is small, combined effects of two factors are 1.51 times, therefore, which has large sediment transport capacity.

2.2. \( \sqrt{J/n} \) Values and cross-section profile

From the sediment of Comprehensive conditions view, that Can not fully explain the reasons for equilibrium conditions of the sediment between scour and situation which is relatively large difference, so
considering the proportion of sediment volume and sediment composition, and introduces water flow continuity equation and the equation of motion, further analysis of river bed resistance and cross-section profile factors on the impact of sediment transport capacity.

Flow continuity equation:

\[ Q = BHV \]  \hspace{1cm} (6)

Flow equations of motion:

\[ V = \frac{1}{n} H^{2/3} J^{1/2} \] \hspace{1cm} (7)

The incoming sediment coefficient formula can be expressed as:

\[ \frac{S^*}{Q} = \left( \gamma + \frac{(\gamma_S - \gamma)S}{\gamma_S} \right)^{0.75} \left( \frac{1}{g \omega_0} \right)^{0.75} \left( \frac{\sqrt{J}}{n} \right)^{1.25} \frac{1}{BH^{0.92}} \] \hspace{1cm} (8)

We can see that the value of \( \left( \frac{\sqrt{J}}{n} \right)^{1.25} \) is smaller in Ningmeng reach through the comprehensive analysis (Table 2), compared with the lower Yellow River, \( \left( \frac{\sqrt{J}}{n} \right)^{1.25} \) and are 0.36 times and 1.08 times respectively, at the same time it has cross-section profile of broad and shallow. The Lower Weihe \( \left( \frac{\sqrt{J}}{n} \right)^{1.25} \) value is only 0.39 times, however, the narrow and deep cross-section profile determines the high sediment transport capability in the lower Weihe, \( \frac{1}{BH^{0.92}} \) value is 2.36 times of the lower Yellow River.

2.3 Sediment concentration and sediment composition

In Table 2, \( \delta \), \( \lambda \), \( \Lambda \) represent the proportion, sediment volume, incoming sediment composition on the influence of sediment transport ability, compared with the lower Yellow River, the value of proportion difference is smaller in every reaches, the value of proportion of the Ningmeng Reach is 0.96 times to the lower Yellow River, the value of proportion of the lower Weihe is slightly larger when the sediment concentration is greater than 200kg/m3, That is 1.26 times for the lower Yellow River. Volume of sediment concentration on the correction term, the value of every reaches have large difference. Ningmeng Reach and the lower Weihe are 0.93 times and 1.04 times of the lower Yellow River respectively, it is 1.62 times when the sediment concentration is greater than 200kg/m3. From the point of view of sediment composition, sediment particles thickness has direct impact of sediment settling velocity, large settling velocity, sediment transport capacity is weak, on the contrary strong sediment transport capacity. Compared with the lower Yellow River, due to the Xiaobeiganliu and Ningmeng Reach have coarse particle size, so the value are 0.79 times and 0.84 times of the lower Yellow River, the
smaller size of the lower Weihe determines the value is the 1.23 times to the lower Yellow River. Therefore, from the comprehensive effects Factors of sediment point of view, the big particle size of suspended sediments and volume of sediment concentration have larger influence, in the Xiaobeiganliu Reach, the big particle size of suspended sediments is the main reason of sediment transport capacity, For the lower Weihe, volume of sediment concentration on the correction term, and small particle size of suspended sediments determine the strong sediment transport capability.

From the flow and sediment conditions can be seen, compared with the lower Yellow River, the comprehensive conditions of water and sediment is 0.29 times and 1.2 times in Ningmeng reach and the lower Weihe, but when the high sediment concentration occurs, it has strong transport capacity of the lower Weihe reach.

3. Understanding and recommendations

(1) In four alluvial reaches of the Yellow River, Ningmeng Reach has the minimum longitudinal slope, the lower velocity, the weak hydrodynamic power factors, with the bigger particle size, the larger settling velocity, these factors are the important reasons which leading to sediment transport capacity is less than the other reaches. for the Xiaobeiganliu reach though the hydro-dynamic power is strong the big particle size of suspended sediments reduces the sediment transport capability. In the Lower Yellow River has the broad and shallow cross-section profile, the smaller particle diameter, but the strong hydrodynamic power is the most important factor conducing the high sediment transport capability. The Smallest particle diameter of suspended sediments and sediment settling velocity, in particular the narrow and deep cross-section profile determines the high sediment transport capability in the lower Weihe.

(2) In addition, the sediment concentration of incoming flow has larger impact on the sediment transport capability, due to the sediment settling velocity reduced by the increasing of hydro-viscosity and density resulting from high sediment concentration also improve the capability of sediment transport. In flood seasons, the average sediment concentration is only 7.6 kg/m³ in the Ningmeng Reach, but in the Lower Yellow and the lower Weihe, the average sediment concentration are 56 kg/m³ and 85.6 kg/m³, which is 7.4 and 11.3 times of the Ningmeng Reach, and the frequent hyper-concentrated floods often occurred, this is the main reason which the lower Weihe has high sediment transport capability, but the Ningmeng reach sediment transport capability is weaker.

(3) The research results show that the difference of the natural attributes is the main reasons of both sediment transport capacity and sediment transport characteristics disparity of the Yellow River alluvial reaches, so in the development of Yellow River, We should consider the reach of the characteristics of science coordinate the development of river management and the task of sediment river erosion and deposition in the whole, for the characteristics of every reach, We should give full play to their strengths, to achieve maintain the health goals of the Yellow River

<table>
<thead>
<tr>
<th>Factors</th>
<th>Ningmeng Reach</th>
<th>Xiaobeiganliu reach</th>
<th>the Lower Yellow River</th>
<th>the Lower Weihe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>conditions of flow</td>
<td>The value</td>
<td>( \left( \frac{\sqrt{J}}{n} \right)^{1.25} )</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>The value</td>
<td>( \frac{1}{BH} )</td>
<td>0.0008</td>
<td>0.0014</td>
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<tr>
<td></td>
<td>The ratio of sediment</td>
<td>( \frac{1}{S} )</td>
<td>0.36</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Product value</td>
<td>1.08</td>
<td>1.86</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>The average sediment</td>
<td>0.39</td>
<td>1.43</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 2: Influence factor analysis of every parts
<table>
<thead>
<tr>
<th>sediment concentration (kg/m³)</th>
<th>0.69</th>
<th>0.72</th>
<th>0.72</th>
<th>0.73</th>
<th>0.71</th>
<th>0.90</th>
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<tbody>
<tr>
<td>( \frac{(\gamma_s - \gamma) S}{\gamma_s} )</td>
<td>1.01</td>
<td>1.08</td>
<td>1.08</td>
<td>1.13</td>
<td>1.05</td>
<td>1.75</td>
</tr>
<tr>
<td>( \frac{1}{(1 - S_s)^{0.75}} )</td>
<td>20.2</td>
<td>19.0</td>
<td>24.2</td>
<td>29.7</td>
<td>29.7</td>
<td>29.7</td>
</tr>
<tr>
<td>Two factors</td>
<td>0.29</td>
<td>1.13</td>
<td>1.00</td>
<td>1.20</td>
<td>1.17</td>
<td>2.32</td>
</tr>
</tbody>
</table>

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**References**


