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The Hierarchical System of River Bed Relief

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The interaction between the flow and movable bed in the self-organizing dynamic system 'stream flow - channel bed' leads to quasi-periodic flow structure formation and fluvial relief development. The hierarchical system of the macroturbulent structures in the river flow can have a wide range of size from depth order to meander length order. The river channel relief is also hierarchical system of dunelike features with the same range of size.

The quantitative basement for description of stream flow - channel bed interaction is the analysis of the initial instability of the wave-like structures of the flow and channel bottom relief. Stability analysis of 3-D equations of momentum and conservation in curvilinear coordinates leads to solutions that predict the continuos (both in longitudinal and lateral directions) spectrum of amplitude growth of unstable in time channel bed waves. The topography of this continuos spectrum is complex, five types of channel forms were defined: 1) 2- and 3-D ultramicroforms with the length of depth order, 2) 3-D isometric in plane microforms; 3) 3-D elongate mesoforms; 4) 3-D macroforms, 5) long (up to 100 channel width) and narrow megaforms.

These unstable waves have their analogy in the relief of the river channel. The hierarchy of the channel relief forms in the rivers and experimental flumes usually consists of six to eight levels. The experimental data on ripples and antidunes in flumes and megaripples in river channels satisfactorily fit the field of ultramicroforms in the theoretical spectrum. 2- and 3-D megaripples usually coexist in the channel and form wavy bands stretched across the channel. The length of 2-D megaripples increase with depth D_0 and Froude number $Fr = U\big/\sqrt{gD_0}$ (U is mean flow velocity) and can be calculated with use of the formula : $L_x = 5.4 D_0 Fr$. The length of 3-D megaripples is usually 1.2-2.0 times larger than those of 2-D ones

The dunes of the first and second orders correspond to the field of microforms. These bed forms are most common in large river channels with sandy alluvium. They form a well-defined maximum on the spectrum of natural channel bottom elevations.

The dunes of the third order and the bars of the second order, and (partly) of the order one, correspond to the field of mesoforms. The boundary between dunes (bed forms) and bars (which determine the channel morphology during the period of low flow) is rather indefinite in natural channels with changing discharge and depth. The boundary between microforms and mesoforms on the theoretical spectrum is also not clear. This raises some classification problems, because the length of small mesoforms and of microforms (which can be both dunes and bars) increases with the Froude number, and the length of large mesoforms (which can also be dunes and bars) decreases with Froude number. As the first approximation the boundary between microforms and mesoforms is situated at the field of wave-lengths $L_x = 8.2 D_0 \exp(2.0 Fr)$.

The field of macroforms corresponds to large bars, islands and channel meanders. The local maximum of the rate of amplitudes growth exists in the field of macroforms on the theoretical spectrum. The lengths of these forms increase with depth and as Froude number and bottom resistance λ decrease: $L_x = 6.28 D_0 \lambda^{-1} Fr^{-1}$ when $0.1 < Fr < 0.5$ and $L_x = 62.8 D_0 \lambda^{-1} \exp(-3.1 Fr)$ when $Fr > 0.5$.

Well-defined maxima on the spectrum of natural channel bottom elevations also corresponds to these forms, but it is usually shifted to a smaller wavelength. The main reason for this phenomenon is secondary effects (for example, helical flow), which become very important as the amplitude of the channel forms grows. When the width of the long unstable wave is less than two widths of the channel, the influence of this wave on the bank erosion is small. When the width of the long unstable wave (the initial bar) becomes more, than two widths of the channel, bank erosion takes place around this bar. The alluvial form often stops its movement down the channel, being stabilized by vegetation and thin floodplain alluvium, and therefore effects a general channel pattern, forming an island or a meander. As a result, two shallow riffles appear on each meander in the zones of channel curvature change, and these secondary waves of the bottom elevation have the same length, as the initial undulations that cause the meander formation. The most frequent value of length/width ratio for macroforms is about four , so the length of developed meanders L_m must be about eight widths of the channel W_0

There had been relatively little investigation of very long and narrow forms of channel relief (megaforms). Coupled lateral vortices with the horizontal axis along the channel were studied in flumes. In the natural river channels the braids, which are following parallel courses for a long distance, are known. Parallel braiding may be the natural analogue of the theoretical megaforms.