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Vira Smirnova
Poltava University of Economics and Trade, Ukraine, e-mail: Vira_Smirnova@mail.ru

Conditions and mechanism of skewed meanders formation

Abstract: This article is an attempt to define the conditions and mechanism of meanders formation based on the analysis of multi-temporal maps and satellite images. It is noted that the formation of such meanders is due to the characteristics of the circulation of the river flow on a steep (90°) bend of the river with one relatively stable wing – a straight channel insert and an actively deformable other wing. This insert can be formed close to the native bank of a river or after cut-off channel. To describe skewed meanders it is proposed to use the parameter α * – the angle of the skew.

Keywords: river bends, skewed meanders, channel cut-off, straight channel section, corner of the skew

1. Introduction

In connection with the growing demands in fresh water and the land near rivers, a great importance is the ability to predict long-term changes in the morphology of river meanders and landscapes in general. A great part of research in this area is focused on the theoretical study of the meandering beds, modeling of meandering processes and on laboratory experiments (Blanckaert, 2011; Güneralp, Marston, 2012). However, the working out of the theoretical model, complete describing the process of emergence and development of meanders, proved to be extremely difficult. Therefore, it is important to carry out practical, field investigations of channel meanders to bring together as much as possible the theoretical ideas about the motion of an idealized river flow with the practice of formation and development of specific meanders.

The object of the present research was one of the varieties of river meanders – skewed meanders. The interest to such bends is called out by their unconventional development and difficulty of channel rearrangement predicting. Skewed meanders are hypertrophied form of a channel, the formation of which is connected with additional, including external factors. The large complexity of a meander channel is reflected in upstream or downstream skewness (Parker, Johanneson, 1989; Güneralp, Marston, 2012). They are often forced, as they are formed under the influence of a native bank (Chalov, 2011). E. Kondratev *et al.* (1982) considered such asymmetry a necessary condition of a loop meander. The theoretical basis of the given research of morphology and dynamics of meandering beds served the works by Chalov *et al.* (2004), Zavadsky *et al.* (2001), Kondratiev *et al.* (1982), and others. The practical results were obtained due to the analysis of multi-temporal topographic maps of the territory of the Poltava and the Chernihiv regions in Ukraine (for the period from 1848 to 1982), satellite images (2014-2016), as well as the results of visual observations for the period of 2013-2014. Sediment transport, level regime and water costs were not taken into consideration.

2. Main results

Most of the rivers on the researching are meandering and characterized by a wide variety of types, shapes and sizes of meanders. Mostly these are free bends formed in valleys with wide

floodplain, where the indigenous banks do not limit the displacement of the bed. However, in some areas (at the approach to the native banks and the transition of the channel from one side of the valley to the other one) and in special periods (under natural or artificial riverbed rectification) bends begin to behave unusually. In particular, they begin to skew up or downstream relatively to their axis of symmetry. It turned out that the number of skewed meanders was almost 5% on the rivers Desna, Psel and about 3% on the rivers Vorskla, Seim, Sula relatively to their total number. Such meanders were met singly, in pairs or in groups of 4-6 meanders on a short part of the river. Skewness effect was observed for free (looping, segment), forced, adapted, and even inscribed meanders. 55 skewed meanders were investigated in the time section and it made possible to identify the new laws of their development.

Skewed meanders can be placed on different parts of the river, but more often they are observed near the indigenous, or high inundated banks as well as in the central part of the bed, when it moves from one side of the valley to the other. Geometry axis of the majority of skewed meanders is oriented nearly parallel to the axis of the river valleys and peaks of meanders are faced down or toward the general slope of the valley bottom (Fig.1 a). Probably, this situation has a certain influence on the distribution of the flow of the jets at the bends of the river, and it may help the strengthening skewness effect. According to R.S. Chalov (2011), a meander location at the edge of a high flood contributes to the creation of conditions for the concentrated water discharge from the flooded plains and deepening process of alluvial channels, and it also contributes to the process of skewed meanders.

Figure 1. Example of the location of skewed meanders (A, B) on river Psel (a); morphological parameters of bed with skewed meanders (b): 1- floodplain; 2-axis valley; 3-bed center line; 4 straight insert

It was found that while considering process of skewing it is necessary to consider the part of the river, including two adjacent meanders and a straight insert of a bed (Fig. 1b). It is noted that the presence of a rectilinear insert is an obligatory condition of a skewed meanders formation. According to N.I. Makkaveev (1955), the formation of small stable straight sections between the curves of the opposite sign of the curvature (which is quite often observed in the case of natural bends) is due to the influence of the residual circulation, which prevents the development of a new bend just below the existing one. This may be a section of the river, located along the native bank, channel cut-off or a segment of the natural or artificial straight riverbed.

Each bight consists of upper and lower wings. The total length of two wings is the length of the bend (l). The boundary of the interface of two adjacent bends is the inflection point of the axial line of the channel. A step of the meander (L) is the distance between the inflection points or between the inflection point and the beginning of a segment of a rectilinear insert. The perpendicular from the middle of the segment, which is a step of a meander, characterizes the deflection (h_m) .For the characteristics of skewed meanders such parameters have been used: h^* – a „skewed boom „, the ratio of h_m/h^*, proposed by A.V. Zavadsky *et al.* (2001), and also α^* – the angle of skewness, the angle between the lines h_m and h^*. The essence of the parameter is to determine the degrees of displacement of skewed meander's tops with respect to its standard sinusoidal shape (Fig. 1b).

The measurements revealed that the absolute size (length and step) of skewed meanders is less than the average size of conventional meanders on the site. The ratio l/L, which characterizes the degree of development of these meanders varied from 1, 2 to 4. The values of the parameter h_m/h *, for the considered meanders, varied from 1.25 to 2.0. The obstruction angle α * varied from 20° to 40°. But sometimes in its development the peak of i skewed meander can describe a semicircle, and the value of α * can reach 120°. Most (68%) considered meanders had the removal of tops against the flow direction relatively to the axis of symmetry (upstream). The rest – were offset downstream. Similar results were obtained by foreign authors for American rivers [9]. There were also mixed bends pairs of adjacent bends with multidirectional offset. In three cases, there was a phenomenon when two adjacent bends skewed in one direction. These rectilinear insertions were observed above and below meanders.

The formation, development and straightening of skewed meanders

The formation of different kinds of meanders depends on the hydraulic, geometry and sedimentary conditions created at the site. Skewed meanders are a form of transformation of the meanders having a vertex displacement with respect to its geometrical axis. Therefore the moment of a meander top's offset and the emergence of skewness angle should be considered to be the beginning of the skewed meander formation. Let's consider stage by stage the process of a skewed meander formation caused by the changes of geometric and hydraulic conditions.

The first stage involves creating of geometric condition for skewness. The research has shown that the formation of such meanders is due to the occurrence of a steep (with an approach of angle of about 90 degrees) curve of bed with one deformable and one relatively stable wing. These conditions are created:

- when the channel approaches a native bank or a high floodplain bank;
- when one or some meanders are straightened;
- when the bed approaches to artificially strengthened banks.

Due to the formation of a sharp ┌ -shaped or ┐ – shaped bend and thanks to the relative stability of the straightforward insert, creating one of the wings of the meander, the conditions for skewed meanders appear (Fig. 2).

The second stage corresponds to the creation of specific hydraulic conditions and the transformation of a steep bend into a steep meander. At the convex bank of a bend there is a flow separation and the formation of the eddy zone below the separation place. In the apex of the bend an eddy „dead zone" is formed which prevents a forward movement of water. It is known that the flow of the river in the areas of a sharp bend at a right angle is due to the necessity to overcome a large hydraulic resistance.

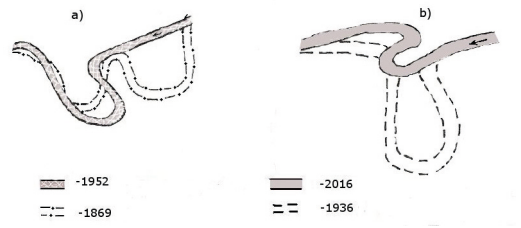


Figure 2. Formation of ┐ - shaped (a), and ┌ – shaped (b) bend of the river, and the lowering of the adjacent bend after channel cut-off on the river Vorskla

Local resistance within the knee at the angle of 90 ° can be up to 10 of input velocity heads (Mingaleeva, 2002). Therefore, the flow of the river, having the possibility of self-organization, seeks and finds the ways of the least resistance. In accordance with the known laws of mechanics, it is a smooth movement of a flow along a spiral. Thanks to such movement there is smoothing, „rounding" of the bend and the displacement of its top and the formation of a new meander. Initially, it is a small sloping segmental meander (l/L = 1,3-1,5), which rapidly develops and in a few years it becomes steep. The direction of the geometrical axis and development of the meander will depend on a bending wing which is more resistant to erosion (Fig. 3).

If the upper wing is stable, the top of the newly-formed meander is shifted downstream from the angle of the rotation, and if the low wing is stable, it is shifted upstream. The geometrical axis of a new meander is parallel to the straight-line insertion (channel cut-off, indigenous bank). An active development of this meander involves in the process the upper wing

of the existing adjacent meander. The uneven erosion of banks within the wings of this meander contributes to its skewness (Fig. 3). The level of development (l/L) of the adjacent meander at the beginning of skewness may change from 1.6 to 3.0.

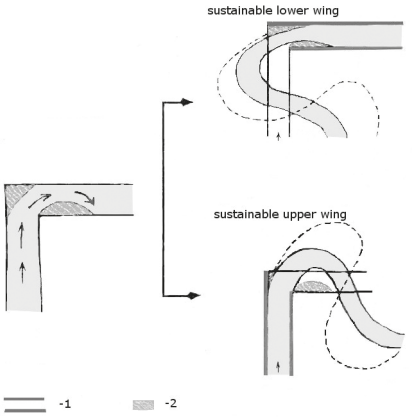
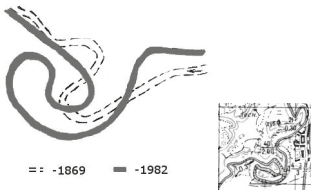


Figure 3. The formation and development of a new skewed meander at the site of a steep bend of the river with a stable lower and upper wings: 1-a relatively stable straight-line insertion; 2- an eddy zone

The third stage is connected with the lowering counter-bends and the formation of a pair of skewed meanders (Fig. 4a). Sometimes the second and the third stages occur almost simultaneously. The development of such meanders can last long enough, more than 150 years. Long-term preservation of skewness effect of meanders is facilitated by orientation of their geometric axis along the axis of the river valley. It looks like meander's „trying" to take the usual, normal to the axis of the valley, position. At the same time morphological characteristics of some meanders can reach maximum values: $h_m/h^* = 2{,}0$; $a^* = 120^0$.



a) b)

Figure 4. The development (a) and straightening (b) skewed meanders of the river Psel near the v. of Nizhna Manuylivka

It is noted that the formation and long existence of skewed meanders are more often observed on the basis of sharp bends with a relatively straight upper wing. For these meanders extreme meanings of the parameters h_m/h^* and a^* were registered. There are also skewed meanders with a straight lower wing. However, their development is not so vividly expressed. It was also noted that the long-term preservation of skewed meanders is facilitated by the presence of straight inserts.

The natural development of the majority of skewed meanders is usually completed by their cut-off. In several cases, the process of skewed meanders formation stopped due to changes in the conditions of a flow approach, caused by the deformation of a straight insert. This applies mainly to the inserts – «cut-off», which eventually lose their straightforwardness and begin to meander. Rectification of skewed meanders occurs through the formation of channel cut-off, either as a result of counter-erosion of banks on the wings or even on the top of the meander (Fig. 4b). At the same time, the ratio h_m/h^* is 1.25-1.4, sometimes reaching a maximum – 2.0. Mostly one from the pair of skewed meanders is rectified and it changes the conditions for the existence of another meander.

3. Conclusions

The research of the river meanders of the left bank of the Dnieper's tributaries showed the presence of up to 5% of the meanders with the effect of skewness The forecast of the formation and the development of such meanders is very difficult.

Skewed meanders are formed on the rivers with a meandering bed in the conditions of a sharp change of a smooth bed into a steep bed (at an angle of 90°). Such conditions are created when a bed approaches the indigenous or unwashed part of the bank, as well as in the process of formation of natural or artificial channel cut-off. A river flow, overcoming tremendous local resistance on a steep bend, seeks and finds the path of the least resistance, creating a new small meander. An important condition for this is the existence of a relatively stable straight-line channel insertion, which creates one wing of

the sharp bend, and also actively deformable channel within the other wing.

The longer straightness of the channel is preserved, the greater level of skewness the adjacent meanders receive. Therefore, the greatest angle of skewness has the meanders located near the indigenous banks. Geometry axis of the majority of skewed meanders is oriented nearly parallel to the axis of the river valley and the peaks of meanders are directed down or toward its overall slope.

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