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RADIAL BASIS FUNCTION NETWORK BASED DESIGN OF INCIPIENT MOTION CONDITION OF ALLUVIAL CHANNELS WITH SEEPAGE

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Incipient motion is the critical condition at which bed particles begin to move. Existing relationships for incipient motion prediction do not consider the effect of seepage. Incipient motion design of an alluvial channel affected from seepage requires the information about five basic parameters, i.e., particle size d, water depth y, energy slope S_f, seepage velocity v_s and average velocity u. As the process is extremely complex, getting deterministic or analytical form of process phenomena is too difficult. Data mining technique, which is particularly useful in modeling processes about which adequate knowledge of the physics is limited, is presented here as a tool complimentary to model the incipient motion condition of alluvial channel at seepage. This article describes the radial basis function (RBF) network to predict the seepage velocity v_s and average velocity u based on experimental data of incipient condition. The prediction capability of model has been found satisfactory and methodology to use the model is also presented. It has been found that model predicts the phenomena very well. With the help of the RBF network, design curves have been presented for designing the alluvial channel when it is affected by seepage.

KEY WORDS: Incipient Motion, Radial-Basis Function, Sediment Transport, Shields' Diagram.

Bimlesh Kumar, Gopu Sreenivasulu, Achanta Ramakrishna Rao: NÁVRH ALUVIÁLNEHO KANÁLA S POUŽITÍM SIETE „RADIAL BASIS FUNCTION NETWORK" (RBF) V PODMIENKACH POHYBU DNA KORYTA, OVPLYVNENÉHO PRIESAKOM Z KANÁLA. J. Hydrol. Hydromech., *58*, 2010, 2; 38 lit., 5 obr., 1 tab.

Návrh aluviálneho kanála s ohľadom na iniciáciu pohybu dna koryta, ovplyvneného priesakom vyžaduje informáciu o piatich základných parametroch: veľkosti častice d, hĺbke vody y, sklone čiary energie S_f, rýchlosti priesaku v_s a priemernej rýchlosti prúdenia u. Pretože proces je extrémne zložitý, získať deterministickú alebo analytickú formu riešenia je ťažké. Príspevok opisuje získavanie údajov (data mining technique), bežne používané pri modelovaní. Opisuje aj sieť tzv. „radial basis function (RBF)" na prognózu rýchlosti priesaku v_s a priemernej rýchlosti u; výpočet je založený na experimentálnych hodnotách v štádiu začínajúceho sa pohybu častíc v koryte. Bola konštatovaná dobrá schopnosť modelu prognózovať začínajúci pohyb; je uvedená tiež metodológia používania modelu. Bolo zistené, že model predpovedá uvedené javy veľmi dobre. Je tu opísaný návrh aluviálneho kanála ovplyvneného priesakom pomocou návrhových kriviek vytvorených pomocou siete RBF.

KĽÚČOVÉ SLOVÁ: začínajúci pohyb, RBF, transport sedimentov, Shieldsov diagram.

Introduction

Incipient motion of bed material in an alluvial channel due to flowing water refers to the beginning of movement of bed particles that previously were at rest. Incipient motion of sediment is a very important process because it represents the difference between bed stability and bed mobility. Incipient motion is a basis for the analysis and design of stable river beds. Determining the incipient motion of sediment and the bed load transport rate is very important to hydraulic engineering. The response of an alluvial bed to forcing by a fluid which flows through and over the bed has been the subject of continuous inquiry for over a century (*Shields*, 1936; *Mantz*, 1977; *Lavelle* and *Moffeld*, 1987; *Buffington* and *Montgomery*, 1997; *Rao* and *Sitaram*, 1999; *Pilloti*, 2001).

Channel seepage has been identified as a significant loss from the irrigation channels from both water quantity and environmental degradation perspectives. Seepage losses from alluvial channels have been estimated to range from 15 to 45% of total inflow (V*an der Leen* et al., 1990). Recently, Australian National Committee on Irrigation and Drainage (*ANCID*, 2006) has indicated that a significant amount of water (10 to 30 percent) is lost in the form of seepage from alluvial channel. Losses from on-farm channel systems to the ground water system have been variously estimated to contribute about 15–25 % of total ground water accessions (*Van der Lely*, 1995). Thus, it is important to study or analyze seepage phenomena undergoing in the alluvial channels (*Hotchkiss* et al., 2001). Generally two types of seepage flow can occur in the field, i.e. injection (upward seepage: ground water contribution to the channel) and suction (downward seepage: contribution of water from the channel to the ground water). There are many contradicting reports in the published literature about the hydrodynamic effects of seepage on hydraulic resistance, stability and sediment transport characteristics of the alluvial channels. *Watters* and *Rao* (1971), *Willetts* and *Drossos* (1975), *Maclean* (1991) and *Rao* and *Sitaram* (1999) reported that suction increases the bed material transport, where as *Harrison* (1968), *Burgi* and *Karaki* (1971), *Oldenziel* and *Brink* (1974), *Richardson* et al. (1985) and *Nakagawa* et al. (1988) reported that suction decreases the mobility of bed material transport as compared to no-seepage. Similarly *Burgi* and *Karaki* (1971), *Oldenziel* and *Brink* (1974), *Richardson* et al. (1985), *Nakagawa* et al. (1988), *Cheng* (1997) and *Cheng* and *Chiew* (1999) are reported that injection increases the transport rate or it is ineffective in promoting bed load transport (*Harrison*, 1968) when compared to no-seepage transport rate. But *Watters* and *Rao* (1971) and *Rao* and *Sitaram* (1999) reported that injection reduces the sediment transport rate and increases the stability of the particles or it does not aid initiating their movement. A complete discussion on this aspect can be found in *Lu* et al. (2008). However, it is very interesting to note that the design methods are not available to take care the seepage effects while designing the alluvial channels. Here, it may be worth to mention that Shields diagram does not include the effect the seepage on incipient motion.

In parallel with research into sediment transport has been the emergence of new modeling paradigms such as data mining (DM). This has opened up new opportunities for modeling processes about which the level of available knowledge is too limited to put the relevant information in a mathematical framework. DM is presently being utilized in almost all branches of science as an alternative and complementary to the more traditional physically-based modeling system. Many types of models have been proposed over the last twenty-five years including polynomial regression, neural networks, radial basis functions, and splines (*Blanning*, 1975). DM techniques have been used to study several hydrologic and hydraulic phenomena including water quality, stream flows, rainfall, runoff, sediment transport, and to infill missing data (*Tatang* et al., 1997; *Haas*, 1998; *Govindaraju*, 2000; *Kumar* and *Rao*, 2010). *Nagy* et. al. (2002) and *Cigizoglu* (2002) have also been successfully applied to the sediment discharge prediction. *Caamaño* et. al. (2006) has used DM technique to derive the bed load sediment transport formula. *Dogan* et. al. (2007) has applied model to predict total sediment load.

The objectives of this study are to develop a Radial basis function network model for simulating and predicting incipient motion of alluvial channel with seepage and to demonstrate the practical capability and usefulness of this technique.

Experimentation

The experiments were conducted in two types of laboratory flumes. Flume characteristics, seepage arrangement and procedure of experimentation have been discussed below:

Flume 1: This is a tilting type of flume (so that the bed slope can be changed either in positive or negative direction) of size 3.60 m in length, 0.1575 m in width and 0.20 m in depth. Sand bed thickness of 0.05 m was maintained in the flume. Sand bed is laid on a perforated sheet at an elevated level from the channel bottom covered with a fine wire mesh (to prevent the sand falling through) to facilitate the seepage flow through the sand bed. The space between the perforated sheet and the channel bottom acted as a pressure chamber to allow seepage flow through the sand bed either in a downward or an upward direction by creating a pressure difference lower or higher, respectively, than the channel flow. Thus, the sand bed was subjected to seepage over a length of L = 2.4 m from the downstream end of the flume and the remaining length of 1.2 m was used for the stabilization of the inlet flow. The seepage arrangement is shown in Fig. 1.

Flume 2: This flume has a 0.23 m thick sand bed in a straight, rectangular, smooth, rigid-walled flume

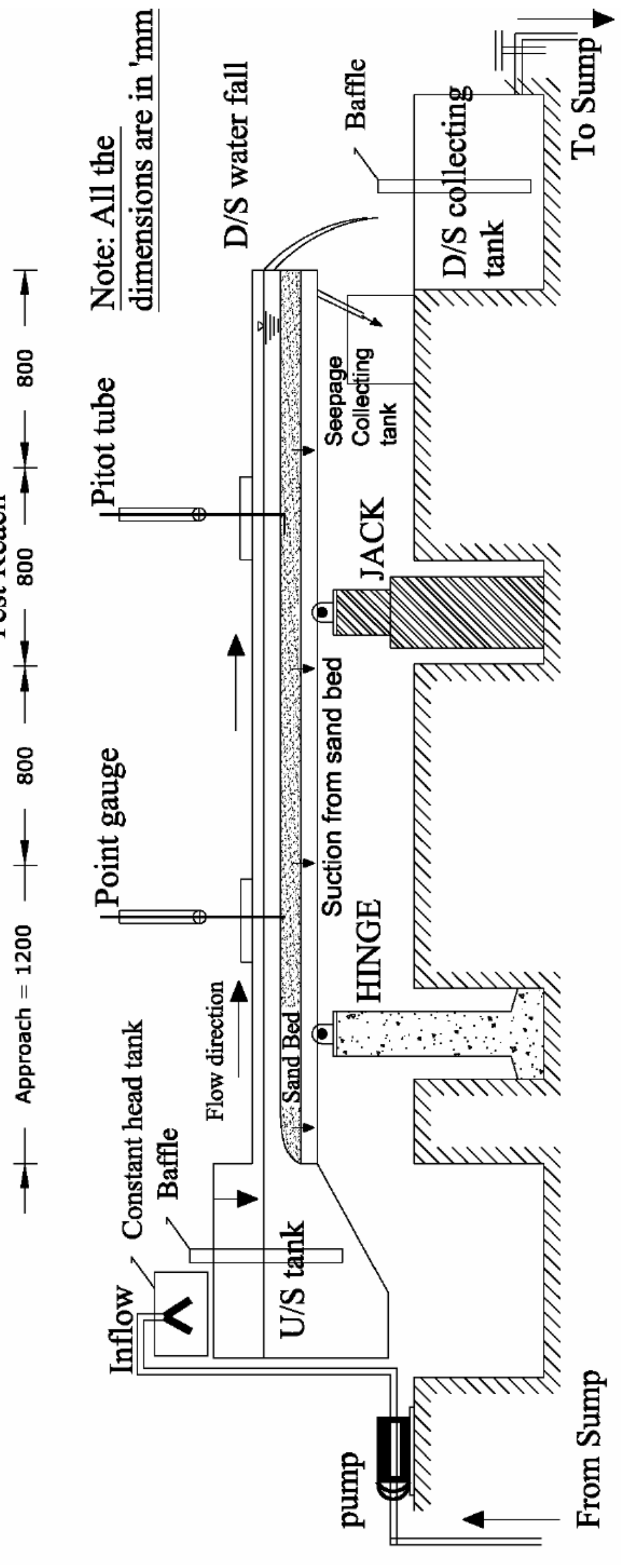

Fig. 1. Schematic diagram of flume 1.
Obr. 1. Schematický diagram koryta 1.

0.615 m wide and 1.416 m long, facilitating the application of uniform seepage in either direction perpendicular to the bed over a length of 1.275 m. Maintaining the water-surface elevation in the water jacket lower or higher than the water level in the main channel can control the rate of seepage flow in suction or injection. The only means of flow between the main channel and the water jacket surrounding it is due to seepage through the sand bed. The sand bed is supported on a perforated aluminum plate covered on its top with a fine wire mesh.

Sand sizes for experiments

Six different sizes i.e., d_{50} = 0.58, 0.65, 0.8, 1, 1.3 and 3 mm were used as bed material for seepage studies. All sizes have fairly uniform material with gradation coefficient $\sigma = 0.5(d_{84}/d_{50} + d_{50}/d_{16})$ is in the range of 1.08 to 1.3 (where d_{16}, d_{50} and d_{84} are the sizes pertaining to 16, 50 and 84 per cent finer respectively). In order to generalize the model and improve its predictability, experiments conducted by *Rao* and *Sitaram* (1999) has been also taken and analyzed during the modeling process.

Procedure and measurements

Initially, the sand bed was made plane for all the experiments with a required bed slope, S_0. Then inflow discharge, Q was allowed. After reaching stable conditions, slowly seepage flow, q_s (suction or injection) was allowed to set the condition to incipient motion. A tailgate at the downstream end of the channel was used to adjust the flow depth. Pressure tapings were provided at some sections inside the sand bed to measure the seepage gradients to verify the uniformity of seepage flow. The criterion for incipient motion developed by *Yalin* (1976) has been used in the present case also, which is incipient motion with seepage. Before and after the application of seepage, the water surface elevations were measured with an accuracy of ± 0.015 mm of water head at regular intervals along the channel by using a digital micro manometer in order to determine the water surface slope, S_w. Flow depths, y, along the central line of the channel were measured at regular intervals using a point gauge. The amount of Q and q_s were measured either volumetrically or with calibrated orifice meters. The values of S_f has been calculated based on the values of S_0 and S_w. In the modeling, u (average velocity) has been used instead of Q and v_s (seepage velocity) is used for seepage term in the modeling process. The value of 'u' has been calculated by dividing Q with area and same way value of v_s has been calculated. Thus, the basic variables S_f, u, v_s, and y for each particle size (d) were obtained in every experimental run and presented in the form of Tab. 1.

According to *Rao* and *Sitaram* (1999) the incipient motion observations with seepage follows the following equation:

$$\ln(\tau_{bo}/\tau_{co}) = -0.2525(\tau_{cs}/\tau_{co})^{-2.917} \text{ for } \tau_{bo}/\tau_{co} \langle\ 1, \qquad (1)$$

where τ_{bo} is bed shear stress, τ_{co} – the Shield's critical shear stress, τ_{cs} – the critical shear stress after application of seepage. Present experimental observations have been also processed through the Eq. (1) and plotted in the Fig. 2. As shown in the Fig. 2, all the data points taken in the present experiments fall on the curve proposed by *Rao* and *Sitaram* (1999), indicating the validity of the present observations.

Radial basis function network modeling

The Radial Basis Function (RBF) network model can be viewed as a realization of a sequence of two mappings. The first is a nonlinear mapping of the input data via the basis functions and the second is a linear mapping of the basis function outputs via the weights to generate the model output. This feature of having both nonlinearity and linearity in the model, which can be treated separately, makes this a very versatile modeling technique (*Haykin,* 1994). The RBF network has a feed forward structure consisting of a single hidden layer of J locally tuned units, which are fully interconnected to an output layer of L linear units. All hidden units simultaneously receive the n-dimensional real valued input vector X (Fig. 3).

The main difference from that of multilayer perceptron networks is the absence of hidden-layer weights. The hidden-unit outputs are not calculated using the weighted-sum mechanism; rather each hidden-unit output Z_j is obtained by closeness of the input X to an n-dimensional parameter vector μj associated with the jth hidden unit (*Haykins,* 1994). The response characteristics of the jth hidden unit (j = 1, 2, 3… J) is assumed as:

T a b l e 1 Experimental data.
T a b u ľ k a 1. Hodnoty z experimentu.

No of runs	d_{50} [mm]	u [m s^{-1}]		y [m]		v_s [m s^{-1}]		S_f	
		Min^m	Max^m	Min^m	Max^m	Min^m	Max^m	Min^m	Max^m
3	0.58	0.199	0.23	0.0131	0.0334	0.00033	0.00053	0.00133	0.00194
32	0.65	0.167	0.28	0.0304	0.0911	0.00003	0.00093	0.00045	0.00196
3	0.8	0.24	0.265	0.0139	0.0185	0.0004	0.00061	0.002	0.0034
9	1	0.18	0.32	0.0122	0.0514	0.00037	0.0017	0.00093	0.0059
3	1.3	0.23	0.30	0.0204	0.0221	0.0005	0.00096	0.0024	0.0041
1	3	0.47		0.028		0.0012		0.0082	

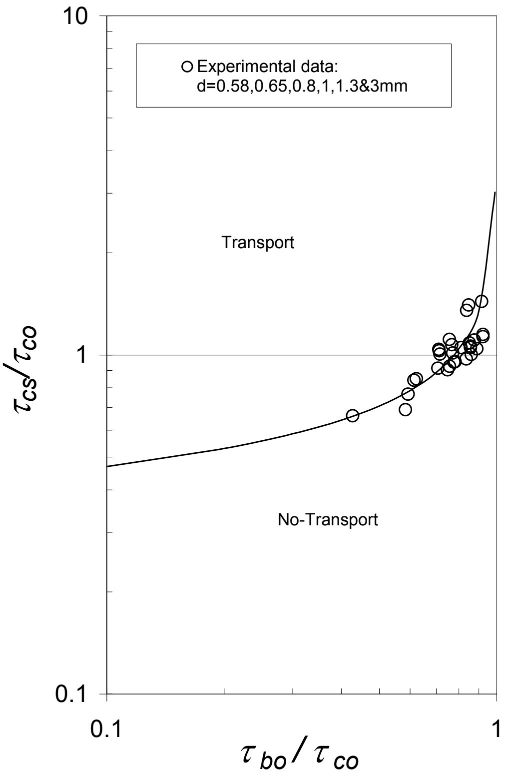

Fig. 2. Validations of the present observations.
Obr. 2. Verifikácia pozorovaní.

$$Z_j = K\left(\frac{\left\|X-\mu_j\right\|}{\sigma_j^2}\right), \tag{2}$$

where K is a strictly positive radially symmetric function (kernel) with a unique maximum at its centre μ_j and which drops off rapidly to zero away from the centre. The parameter σ_j is the width of the receptive field in the input space from unit j. This implies that Z_j has an appreciable value only when the distance $\|X-\mu_j\|$ is smaller than the width σ_j. Given an input vector X, the output of the RBF network is the L-dimensional activity vector Y, whose lth components (l = 1, 2, 3…..L) is given by:

$$Y_i(X) = \sum_{j=1}^{J} w_{lj} Z_j(X). \tag{3}$$

For l = 1, mapping of Eq. (2) is similar to a polynomial threshold gate. However, in the RBF network, a choice is made to use radially symmetric kernels as 'hidden units'. From Eqs. (2) and (3), the RBF network can be viewed as approximating a desired function f (X) by superposition of non-orthogonal, bell-shaped basis functions. The degree of accuracy of these RBF networks can be controlled by three parameters: the number of basis functions used, their location and their width (*Poggio* and *Girosi*, 1990). There are several common types of functions used, for example, the Gaussian, $\phi(z) = e^{-z}$, the multiquadric, $\phi(z) = (1+z)^{1/2}$, the inverse multiquadric, $\phi(z) = (1+z)^{-1/2}$ and the Cauchy $\phi(z) = (1+z)^{-1}$. In the present work, multiquadric function has been adopted because of its following qualities (*Allison*, 1993) :

- *smooth* (following statistically significant variations where necessary in a non-abrupt way, continuous to all orders, and behaving close-to-linearly elsewhere).
- *no-nonsense* (no uncontrolled, unnecessary or erratic departures from the data).
- *unbiased* (following statistically significant variations faithfully but ignoring insignificant ones).
- *economical* (the number of basis functions determined primarily by the statistical significance of the data and not by the number of dimensions).

A training set is an m labeled pair $\{X_i, d_i\}$ that represents associations of a given mapping or samples of a continuous multivariate function. The sum of squared error criterion function can be considered as an error function E to be minimized over the given training set. That is, to develop a training method that minimizes E by adaptively updating the free parameters of the RBF network. These parameters are the receptive field centers μ_j of the hidden layer units, the receptive field widths σ_j and the output layer weights (w_{ij}). The training of the RBF network is radically different from the classical training of standard feed forward neural networks. In this case, there is no changing of weights with the use of the gradient method aimed at function minimization. In RBF networks with the chosen type of radial basis function, training resolves itself into selecting the centers and dimensions of the functions and calculating the weights of the output neuron. The centre, distance scale and precise shape of the radial function are parameters of the model, all fixed if it is linear. Selection of the centers can be understood as defining the optimal number of basis functions and choosing the elements of the training set used in the solution (*Yuhong* and *Wenxin*, 2009). It was done according to the method of forward selection or reduced error algorithm. Heuristic operation on a given defined training set starts from an empty subset of the basis functions. Then the empty subset is filled with succeeding basis functions with their centers marked by the location of elements of the training set; which generally decreases the sum-squared error or the cost function. In this way, a model of the network constructed each time is being completed by the best element. Construction of the network is continued till the criterion demonstrating the quality of the model is fulfilled. The most commonly used method for estimating generalization error is the cross-validation error. Entire modeling has been done in the Matlab®. To get a better fit different combination of centers, RBF functions and regularisation parameter have been tried. The total numbers of data points at inicpient condition are 51. It contains the present experimental data. The basic parameters which define the incipient condition are u, d, y, v_s and S_f. Input patterns are d, y and S_f and the output parameters of the model are v_s and u. The main parameter in order to get a good fit with an RBF is the maximum number of centers. To get a better fit different combination of centers, RBF functions and regularisation parameter have been tried. The best fit model is a radial basis function network using a multiquadric kernel with 21 centers and a global width of 0.0831. The model ouput and experimental point have been plotted in Fig. 4a) and 4b). The value of R^2 approaches to 1. R^2 can also be interpreted as the proportionate reduction in error in estimating the dependent when knowing the independents. This shows that the predictability of the present model is good.

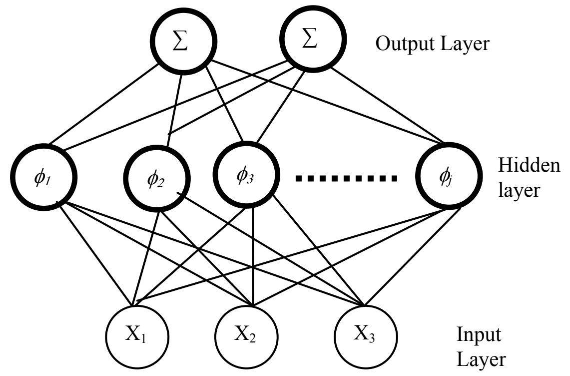

Fig. 3. Structure of a RBF network.
Obr. 3. Štruktúra siete RBF.

Design curves

Basic design variables to design the channel at incipient motion are particle size d, flow depth y, flow velocity u, seepage velocity v_s and friction/energy slope S_f. Out of these five variables at least two of them are to be known to solve the remaining three variables. Based on the RBF model design curves have been generated in order to predict the other unknown parameters. As discussed, the seepage affects the bed shear and hence the conventional Shields curve cannot be used to predict such incipient motion conditions affected with seepage. Because at test reach the flow rate is varying due to seepage and due to seepage the flow depth will be decreased and hence the energy slope will not be constant. The main important observation here is due to the seepage the depth of flow is decreased in the main channel and hence the main flow velocity also be affected. A stable relationship between sediment transport and flow can at best only be expected in a situation where the mechanisms controlling sediment transport are dependent only on the rate of flow of water in the channel and seepage occurring through the channel. Thus, it is felt that the 'stream power concept' is more appropriate for describing seepage induced incipient motion in alluvial channel. Stream power concept for sediment transport has been introduced by *Velikanov* (1954) and developed by *Bagnold* (1966) and *Bull* (1979). Stream power is the time rate of potential energy expenditure per unit boundary area

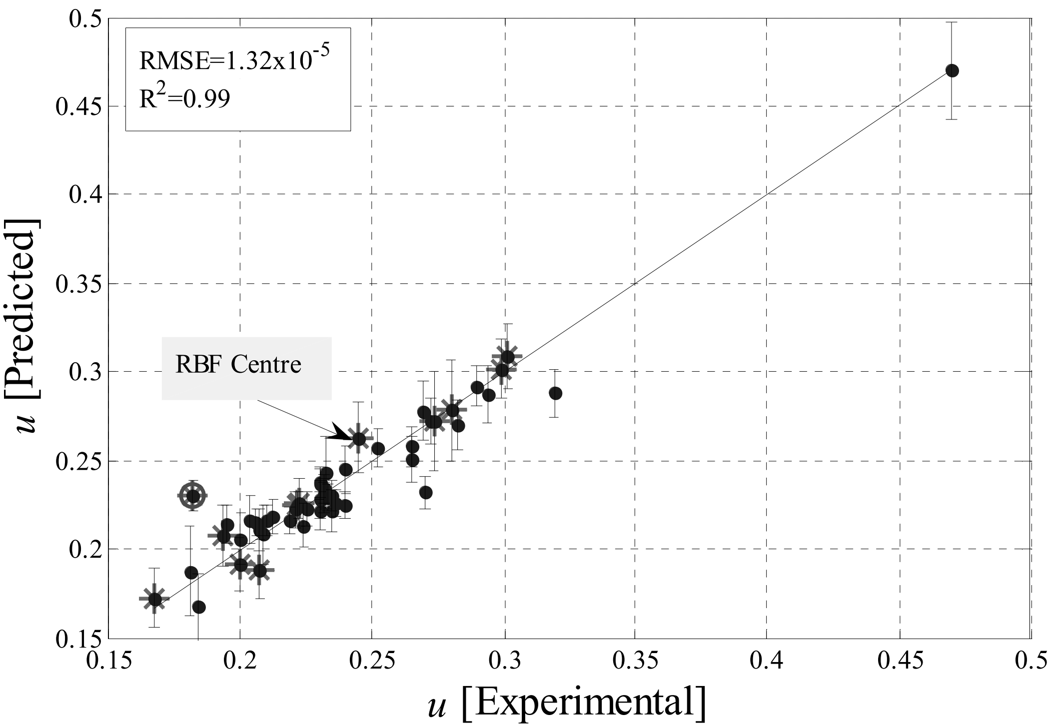

Fig. 4a) Modelling result for *u*.
Obr. 4a) Výsledky modelovania *u*.

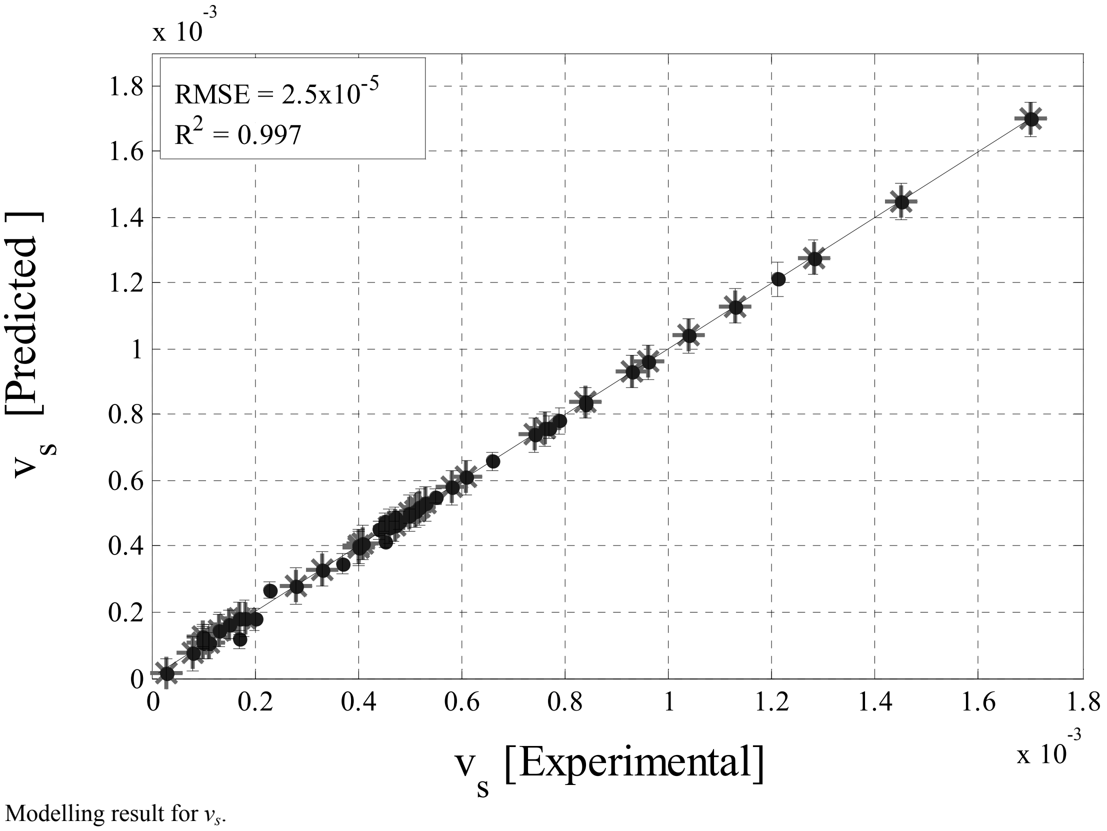

Fig. 4b) Modelling result for v_s.
Obr. 4b) Výsledky modelovania v_s.

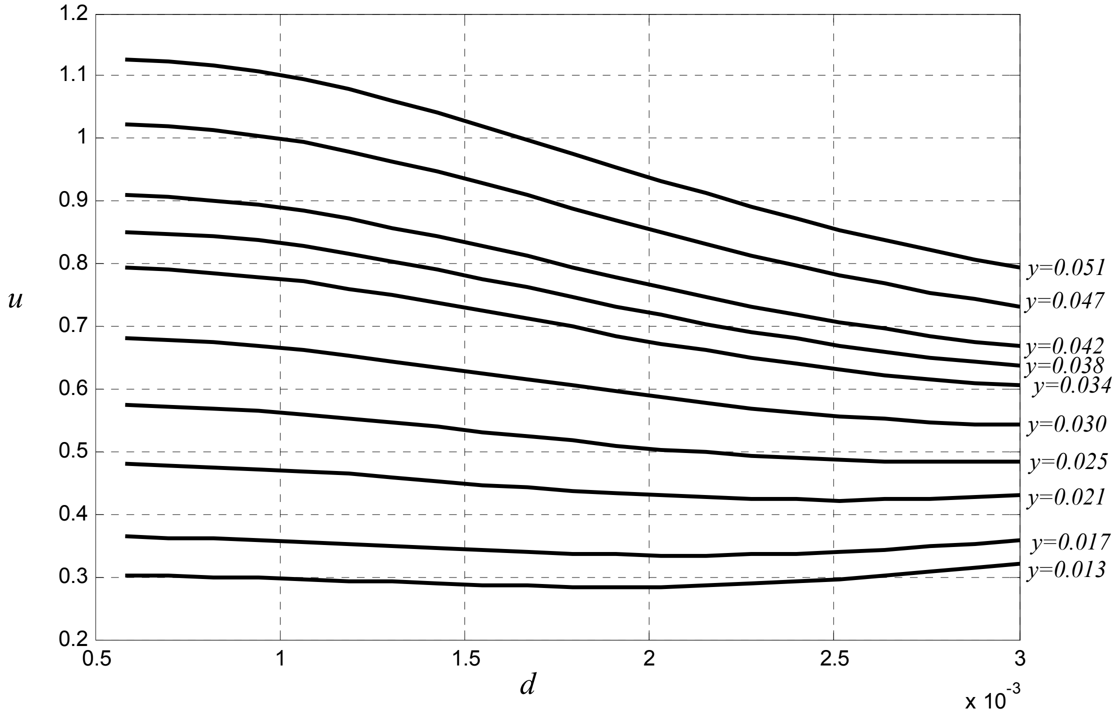

Fig. 5a) Design curve (when *d* and *y* are known, the value of *u* can be predicted).
Obr. 5a) Návrhové krivky (ak *d* a *y* sú známe, *u* môže byť vypočítané).

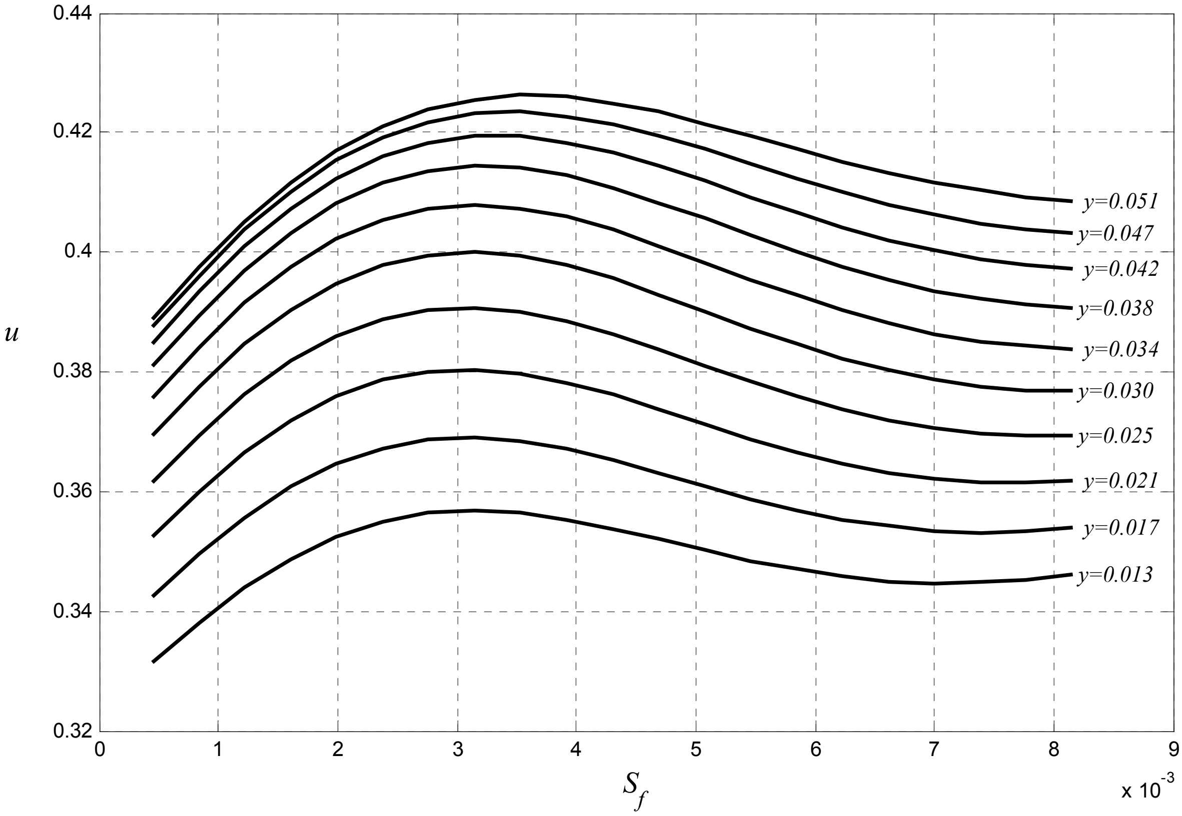

Fig. 5b) Design curve (when *y* and S_f are known, the value of *u* can be predicted).
Obr. 5b) Návrhové krivky (ak *y* a S_f sú známe, *u* môže byť vypočítané).

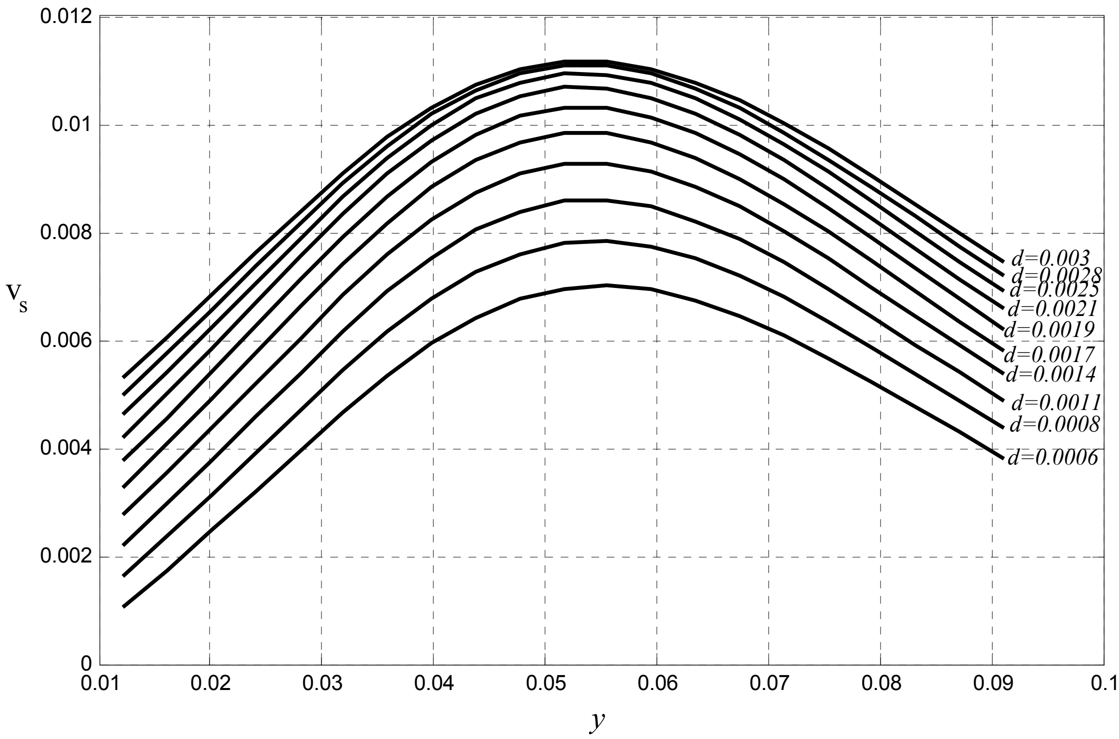

Fig. 5c) Design curve (when y and d are known, the value of v_s can be predicted).
Obr. 5c) Návrhové krivky (ak y a d sú známe, v_s môže byť vypočítané).

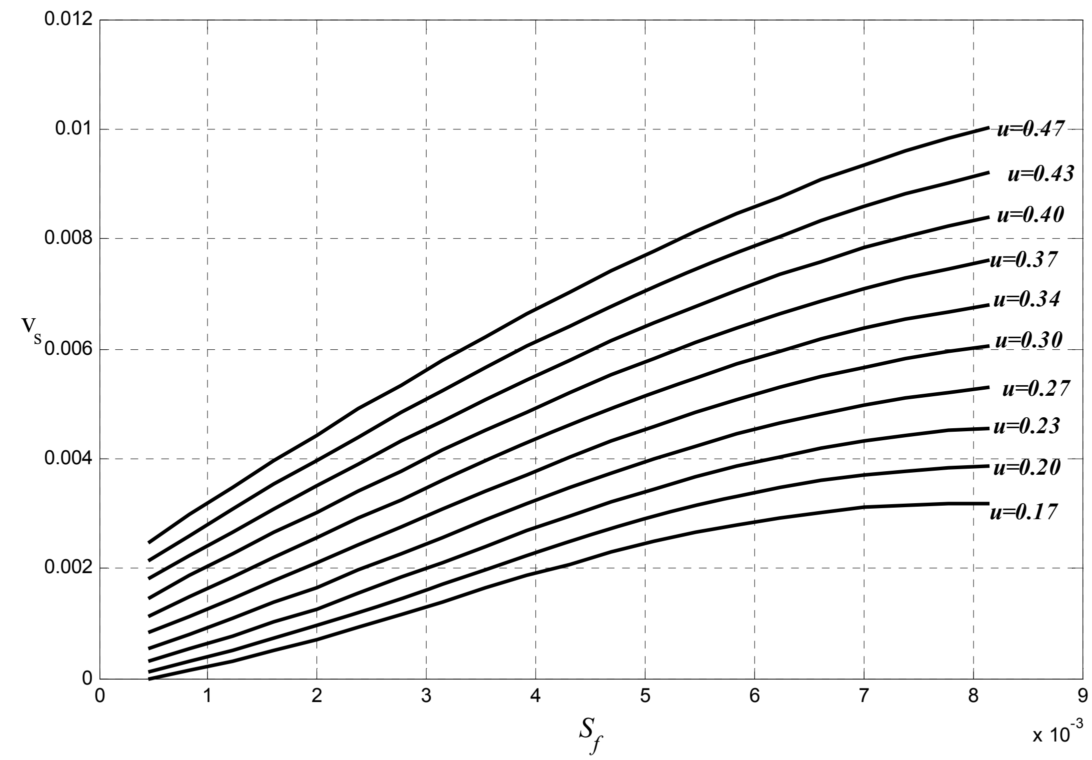

Fig. 5d) Validation curve. (With the help of validation curve, the value of v_s (or S_f and u) can be rechecked with the known values of other two parameters.)
Obr. 5d) Validačné krivky. (Pomocou validačných kriviek môžu byť znova vypočítané hodnoty v_s (alebo S_f a u), ak poznáme iné dva parametre.)

(*Bagnold*, 1966) given by bed shear stress multiplied by average velocity of flow. Given basic knowledge of a stream cross section (depth of flow, average velocity and average bed slope) it is possible to compute the stream power per unit boundary area for a range of flows. In functional form, stream power can be expressed as follows:

$$\text{Stream power} = f\left(Q, S_f\right) \propto f\left(y, u, S_f\right). \qquad (4)$$

Hence, if discharge per unit width is considered, stream power is combination of depth of flow, y, slope of the channel, S_f and average velocity, u in the channel. Since the main aim of the present work is to design the channel at threshold condition, stream power is the controlling parameter for initiation of the sediment particles. So the model to be represented the combination of the y, S_f and u. As shown in the Fig. 5a), at particular constant particle size, u will increase with increasing y. This is due to increasing y will increase the flow velocity assuming that the energy slope and seepage velocity is constant. Fig. 5b) shows the overall characteristics of the stream power. As y increases, u will increase and with constant y, rising S_f means more stream power. The fourth parameter seepage velocity v_s is having influences on the other three parameters at incipient motion. The influence of v_s at incipient motion can be seen from the Fig. 5c). With constant d, v_s first increases and then decreases with increasing flow depth. Design of alluvial channel can be performed on the basis of charts given in the Figs 5a) to 5c). Use of these design charts requires knowledge about at least two parameters. Suppose that particle size and flow velocity or water depth are known, S_f can be estimated from the Fig. 5a). Based on the values of S_f and y, u can be estimated from the Fig. 5b) and the values of seepage velocity v_s from the Fig. 5c). Fig. 5d) has been provided to cross check the measurements made through Figs 5a) to 5c). Here, it is worth to mention that the subjectivity of these design curves (Figs. 5) lie in the experimental range covered in the present paper.

Conclusion

Seepage flow from channel boundaries alters the bed hydrodynamics. This has also an affect on incipient motion prediction. Inclusion of seepage as parameter for incipient motion prediction is not available in the literature. Data modeling technique is frequently utilized to construct the physical model of such cases which is having very complex phenomena. In the present work, RBF approach is considered for designing the incipient motion with seepage phenomena. The model fits the phenomena very well. Thus, this approach gives an approximation route of designing the system. Design charts have been developed for designing the alluvial channel affected with seepage.

List of symbols

Used for incipient motion

d	– particle diameter [m],
d^*	– dimensionless particle diameter,
d_{16}, d_{50}, d_{84}	– diameters of particles at 16%, 50% and 84% finer by weight [m],
B	– width of the channel [m],
Q	– discharge in the channel [$m^3\ s^{-1}$],
q_s	– seepage discharge [$m^3\ s^{-1}$],
S_f	– energy slope,
S_o	– bed slope,
S_w	– water surface slope,
u	– average velocity [$m\ s^{-1}$],
y	– flow depth [m],
v_s	– seepage velocity [$m\ s^{-1}$],
τ	– shear stress [$N\ m^{-2}$],
γ_s	– sediment particle specific weight [$N\ m^{-3}$],
γ	– specific weight of fluid [$N\ m^{-3}$],
ν	– kinematics viscosity of the fluid [$m^2\ s^{-1}$],
τ_{bo}	– bed shear stress without seepage [$N\ m^{-2}$],
τ_{bs}	– bed shear stress with seepage [$N\ m^{-2}$],
τ_{co}	– critical shear stress without seepage [$N\ m^{-2}$],
τ_{cs}	– critical shear stress with seepage [$N\ m^{-2}$],

Used for metamodel

j	– the number of neurons (and centers) in the hidden layer,
R^2	– correlation coefficient,
x	– input vectors,
w_{1j}	– the weights in the output layer,
μ	– centers,
η	– model output,
σ	– width,
ϕ	– RBF functions type,
$\lVert . \rVert$	– the Euclidean norm.

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NÁVRH ALUVIÁLNEHO KANÁLA S POUŽITÍM SIETE “RADIAL BASIS FUNCTION NETWORK” (RBF) V PODMIENKACH POHYBU DNA KORYTA, OVPLYVNENÉHO PRIESAKOM Z KANÁLA

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Hydrodynamické vlastnosti kanála sú výrazne ovplyvňované priesakom z neho. Tento jav zároveň ovplyvňuje prognózu iniciácie pohybu častíc dna kanála. V literatúre nie je známe riešenie, ktoré zahrňuje priesak z kanálov ako parameter pre výpočet iniciácie pohybu častíc kanála. Modelovanie údajov je častá metóda používaná pri konštrukcii fyzikálnych modelov takých javov, ktoré sú veľmi zložité. V tejto práci je použitý prístup s využitím “radial basis function (RBF)” na výpočet začínajúceho pohybu dna s priesakom z kanála. Model charakterizuje tento jav veľmi dobre a dáva možnosť navrhnúť tento systém s uvážením priesaku. Boli vypočí-

tané návrhové krivky, umožňujúce návrh aluviálnych kanálov s uvážením priesaku.

Zoznam symbolov

d – priemer častice [m],
d^* – bezrozmerný priemer častice,
d_{16}, d_{50}, d_{84} – priemery častíc zodpovedajúcich 16 %, 50 % a 84 % ich celkovej hmotnosti (začínajúc od jemnejších) [m],
B – šírka kanála [m],
Q – prietok kanálom [$m^3 s^{-1}$],
q_s – priesak [$m^3 s^{-1}$],
S_f – sklon čiary energie,
S_0 – sklon dna kanála,
S_w – sklon hladiny,
u – priemerná rýchlosť [$m s^{-1}$],
y – hĺbka vody v kanáli [m],
v_s – rýchlosť priesaku [$m s^{-1}$],
τ – tangenciálne napätie [$N m^{-2}$],
γ_s – merná hmotnosť sedimentovaných častíc [$N m^{-3}$],
γ – merná hmotnosť kvapaliny [$N m^{-3}$],
ν – kinematická viskozita kvapaliny [$m^2 s^{-1}$],
τ_{bo} – tangenciálne napätie na dne kanála bez priesaku [$N m^{-2}$],
τ_{bs} – tangenciálne napätie na dne kanála s priesakom [$N m^{-2}$],
τ_{co} – kritické tangenciálne napätie na dne kanála bez priesaku [$N m^{-2}$],
τ_{cs} – kritické tangenciálne napätie na dne kanála s priesakom [$N m^{-2}$],

Symboly metamodelu

j – počet neurónov v skrytej vrstve,
R^2 – korelačný koeficient,
x – vstupný vektor,
w_{1j} – hmotnosti výstupnej vrstvy,
μ – centrá,
η – výstup z modelu,
σ – šírka,
ϕ – typ RBF funkcie,
$||.||$ – Euklidovská norma.