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FRAZIL AND SKIM ICE INITIATION IN STREAM

RESULTS OF LABORATORY INVESTIGATION

Final Report

The research project is the continuation of earlier studies and it is based on the hypothesis that frazil is formed if

(1) the water temperature $t_v<0°C$,

(2) the temperature on the water surface $t_h<-0.15°C$,

and (3) the cross-sectional water velocity $v>0,067(MC)^{0.305}R^{0.5}$,

where C=Chezy coefficient, M=0.7C+6, R=hydraulic radius.

The object of the research project is to verify the mathematically formulated conditions and to establish a theory of frazil and skim ice formation.

The first condition is generally known and adequately verified.

The second condition has not been yet unequivocally formulated. The water surface temperature has a decisive influence on the formation of ice on the water surface and its development. At present we are not able to measure it precisely yet and we have to rely on its determination by a calculation.

For the calculation the following formula is recommended:

$$t_h - t_v = \frac{q_o (\sqrt{MC}\ R)^{0.61}}{12\ 436\ v} \qquad [°C] \qquad (1)$$

The general validity of this formula has not been proved yet; this holds true in particular for the dependence on the channel roughness.

One of the objects of the laboratory experiments was to verify the formula (1). The fundamental thermal balance equation is valid

$$q_o = \alpha(t_h - t_v) \qquad (2)$$

where q_o is the heat flux between water surface and atmosphere, α is coefficient of heat transfer between water and water surface.

From previous experiments the following relation has been derived

$$\alpha = B_k . v \qquad (3)$$

In the formula (1) B_k equals

$$B_k = \frac{12\ 436}{(\sqrt{MC}\ R)^{0.61}} \qquad (4)$$

The coefficient B_k is dependent on Chezy coefficient C

and hydraulic radius R. The laboratory experiments were focused to finding relation $B_k=fn(R)$ and $B_k=fn(C)$. The tests results for $B_k=fn(C)$ and R=const. are plotted on Fig.1. For hydraulic radius R=0.29 the relation (4) is described as

$$B_k = \frac{26\ 460}{(MC)^{0.305}} \qquad (5).$$

The plotted results show that relation (5) is not right but valid equation is

$$B_k = \frac{6\ 330}{C^{0.22}} \qquad (6).$$

The tests results for $B_k=fn(R)$ and C=const. are plotted on Fig.2. Chezy coefficient C=70 $m^{0.5}/s$. From the relation (4) we acquire

$$B_k = \frac{1\ 045}{R^{0.61}} \qquad (7).$$

From the tests new relation was derived

$$B_k = \frac{893}{R^{0.61}} \qquad (8).$$

The relations (6) and (8) allow a derivation of new formula for B_k

$$B_k = \frac{2\ 275}{C^{0.22}R^{0.61}} \qquad (9)$$

and coefficient α

$$\alpha = \frac{2\ 275\ v}{C^{0.22}R^{0.61}} \qquad (10)$$

and water surface temperature

$$t_h - t_v = \frac{q_o\ C^{0.22}\ R^{0.61}}{2\ 275\ v} \qquad [°C] \qquad (11)$$

The tests carried out at the Refrigerated Flume Laboratory at CREEL, Hanover, New Hampshire showed that frazil and skim ice can be formed simultaneously. From the tests results it is derived:

A) only frazil is formed in case

(1) $t_v < 0°C$ (12)

(2) $v >= 0.335C^{0.61}R^{0.5}$ [m/s] (13)

B) only skim ice is formed in case

(1) $t_h < 0°C$; (14)

t_h is calculated according to formula (11)

(2) $v <= 0.02C^{0.61}R^{0.5}$ [m/s] (15)

or in case

(1) $t_v > 0^oC$ (16)

(2) $t_h < 0^oC$ (17)

(3) $0.02C^{0.61}R^{0.5} < v < 0.335C^{0.61}R^{0.5}$ (18)

C) frazil and skim ice are formed simultaneously in case

(1) $t_v < 0°C$ (19)

(2) $0.02C^{0.61}R^{0.5} < v < 0.335C^{0.61}R^{0.5}$ (20)

Water velocity entraining 50% of the initial ice particles from the water surface into the depth of the flow is expressed by relation

$$v = 0.081C^{0.61}R^{0.5} \qquad (21).$$

Frazil and anchor ice can be formed exceptionally also when the water velocity $v<0.02C^{0.61}R^{0.5}$ viz. in the case when $tv<0^{0}C$ and skim ice is piled up. In such case frazil is not formed by the entraining of initial ice particles from the water surface but it is formed from ice particles given off during piling skim ice up. Piling skim ice up occurs first of all under the shore ice but also at collision of skim ice floes.

Freezing-up of the water surface can occur at the water velocities $v>0.02C^{0.61}R^{0.5}$. In this case supercooling of water and frazil formation has not to occur.

Prague, September 20, 1991

Dr. Václav Matoušek

Derivation of Bk=fn(C)

results of laboratory tests

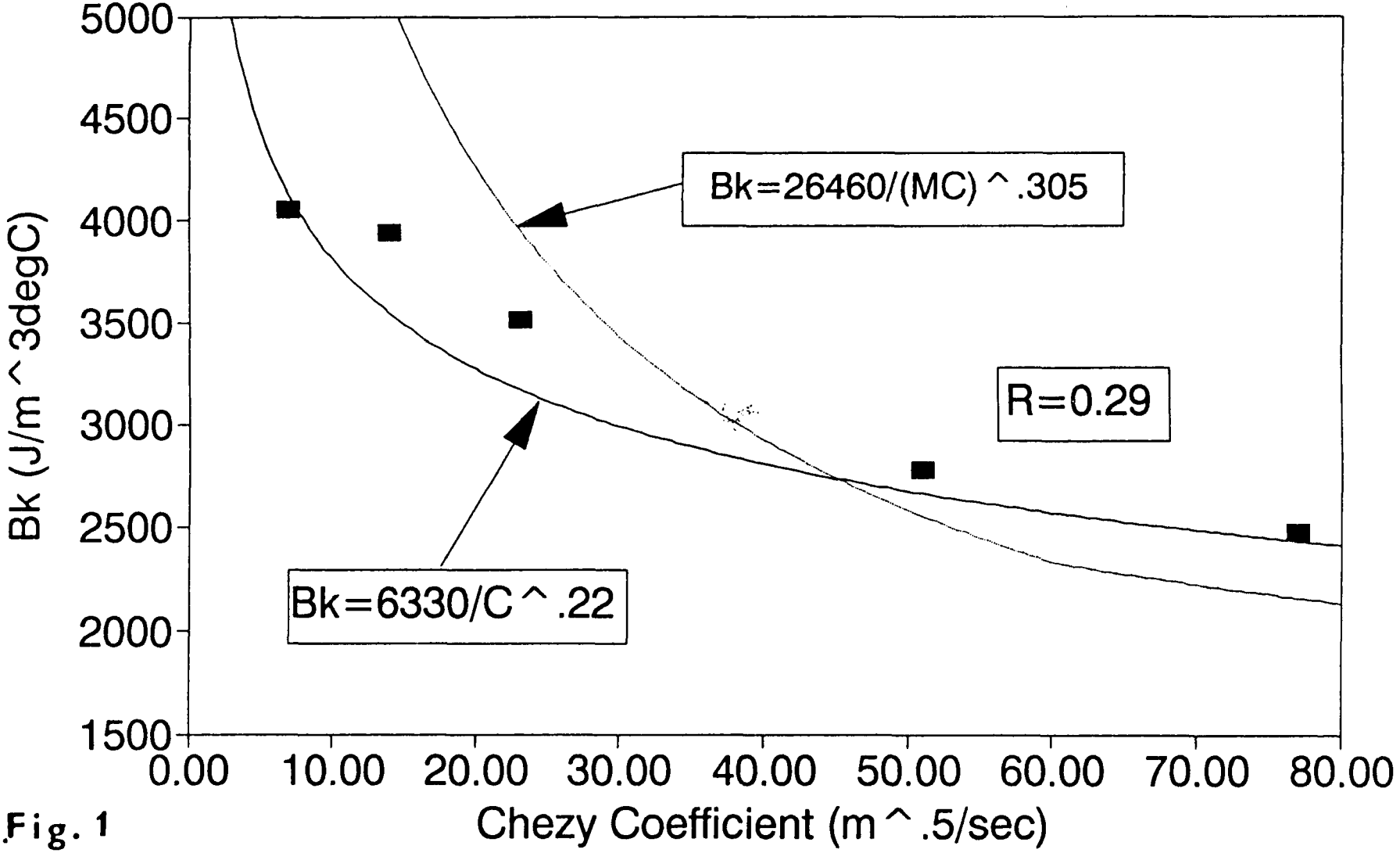

Fig. 1

Derivation of Bk=fn(R)

results of laboratory tests

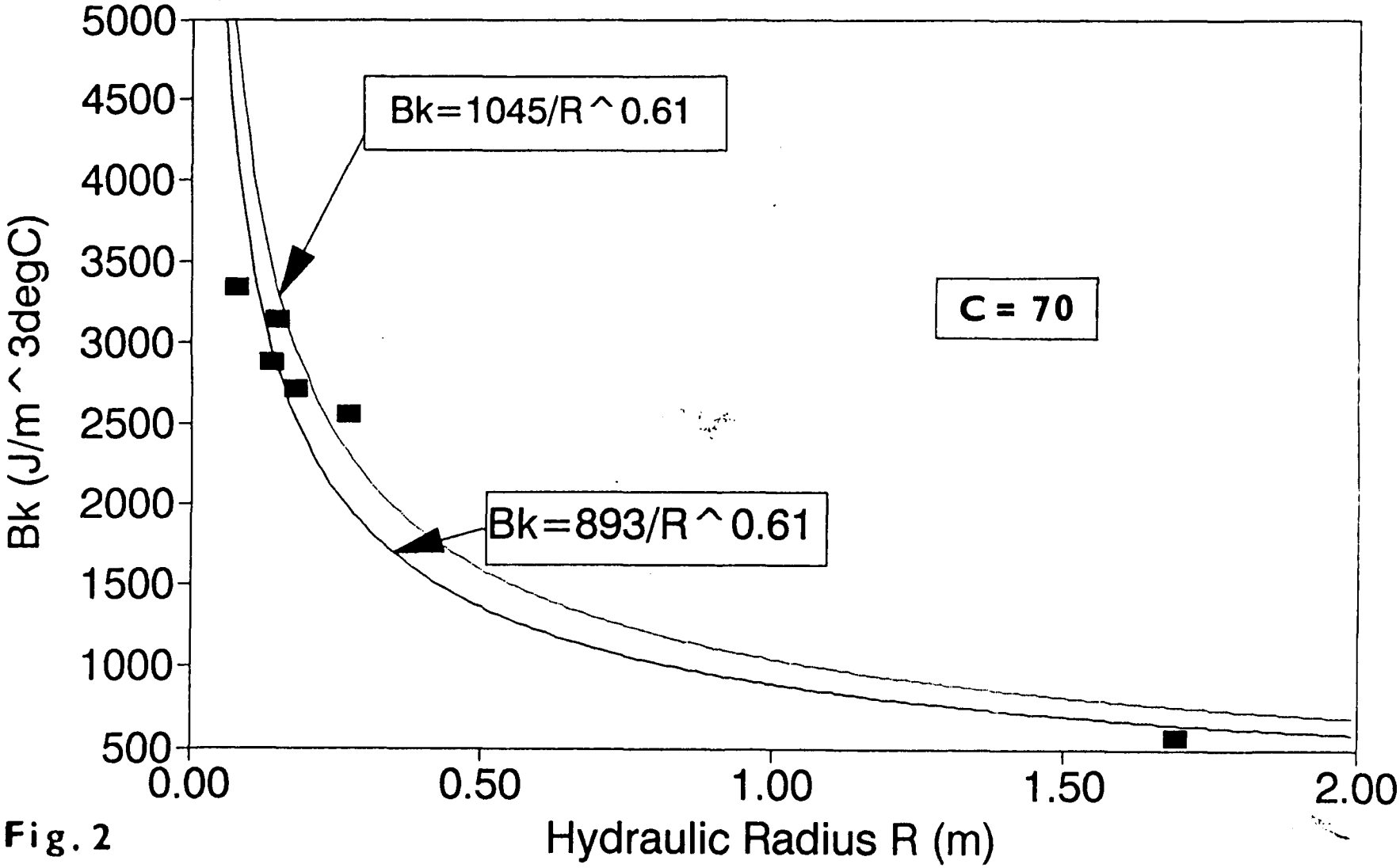

Fig. 2