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FOW CHARACTERISTICS THROUGH INCLINED FINITE HUMP IN SLOPING OPEN CHANNELS

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خواص السريان خلال الانتقالات الرأسية المحددة الطول والمائلة من الأمام والخلف فى القنوات المفتوحة المائلة

يهتم هذا البحث بدراسة خصائص السريان خلال الانتقالات الرأسية المحددة الطول والمائلة بزوايا مختلفة من الأمام والخلف فى القنوات المفتوحة المائلة. ولهذا الغرض أجريت مجموعة من التجارب المعملية لدراسة التغير فى خصائص السريان مع التغير فى العوامل الأخرى المؤثرة على الجريان وتشمل هذه العوامل الميول الطولية للمجرى وأخذت صفر ، ٠,٠٠٥ ، ٠,٠١٠، ٠,٠١٥، ٠,٠٢٠، ٠,٠٢٥، وزوايا الانتقال من الأمام والخلف وأخذت ١٥° ، ٣٠° ، ٤٥، ٦٠، ٧٥، ٩٠° والارتفاع النسبي للانتقال وكانت ٠,١، ٠,٢ ، ٠,٣، ٠,٤، ٠,٥، ٠,٦، ورقم فرواد الابتدائي ونسبة العمق الابتدائى وقد اشتقت معادلات تربط المتغيرات المختلفة للسريان ولإيجاد الفقد النسبي فى الطاقة ورقم فراود الابتدائي. وقد تم إعداد مجموعة منحنيات تصميمية لا بعدية توضح طبيعة وشكل التغير بين خصائص السريان المختلفة. وبتحليل النتائج المعملية تبين أن نسبة الطاقة المبددة يزداد بزيادة الميل الطولى للقناة وزاوية ميل وارتفاع الانتقال ورقم فراود الابتدائى. وقد تبين أن معدل الفقد النسبى فى الطاقة يزداد بمعدل سريع وحتى زاوية ميل الانتقال عند ٣٠° فى الأمام والخلف وبعدها يقل معدل الزيادة إلى حد ما يكون ثابت تقريباً للزوايا الأكبر من ٣٠° فى الأمام والخلف للانتقال وكذلك تم دراسة تأثير جميع المتغيرات المؤثرة على خصائص السريان وتم تحليلها ومناقشتها بدقة.ـ

ABSTRACT

In this paper, an experimental study was carried out to investigate the characteristics of flow through inclined finite hump in a sloping rectangular open channel of constant width. Experiments were conducted with bed slopes of 0.00, 0.005, 0.010, 0.015, 0.020 and 0.025, and hump angles of 15°, 30°, 45°, 60°, 75° and 90°, and relative heights, of 0.1, 0.2, 0.30, 0.40, 0.05 and 0.60 to study the variation of the energy loss and relative water depth with the main parameters affecting the finite hump in sloping channel. These parameters include the channel bottom slope, the upstream Froude number, downstream Froude number, hump angle and relative height. Non-dimensional design curves are provided to relate the flow characteristics. The results show that, the rate of variation of the energy loss increases till a finite hump angle of about 30°. This rate of increase decreases behind this value of angle of finite hump. The energy loss increases with the increase of bed slope and relative height ratio. The energy loss is quite high at a relative height of 0.3. The effect of all parameters on the energy loss through the inclined finite hump analyzed and discussed.

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1. INTRODUCTION:

Open channel transitions have been extensively studied because of its applications in water engineering and their efficiency in reducing the energy loss in hydraulic structures. The design of most of the hydraulic structures necessitates a contracted stream to achieve the least cost structure if the location is technically feasible. The change in the cross section disturbes the flow within the contracted reach and near to it from both upstream and downstream. The change in the channel cross section, slope, and/or alignment over a specified reach is termed local transition. Such channel transitions are mainly used to avoid or minimize the excessive energy loss, to eliminate the cross waves, the resulting turbulence, and to ensure safety of both the structure and the downstream channel reach, see e.g. Hinds [1], ippen [2] and Engelund [3]. Also, local channel transition may change the flow regime in the channel at a particular location through or beyond the transition depending on incoming flow rate, contraction ratio and length of contraction. The flow through the transition may be subcritical, critical and/or supercritical. Each of these types of flow is preceded by subcritical flow upstream the transition and may or may not be followed by a supercritical flow.

Kindsvater, Carter and Lacy [4] and Kindsvater and Carter [5] carried out an experimental investigation to address the effects of different types of contractions on discharge characteristics. Formica [6] tested various design for channel transition (contraction and expansion) and the main results of his work are presented in Chow [7]. Vallentine [8] investigated the effect of thin plate contraction placed normal to channel axis. His observations covered data that include different regimes of flow. Laursen [9] studied the contraction coefficient at sudden expansion at bridge locations at the different types of flow. It was found that the contraction coefficient varies between 0.7 for about 30% contraction ratio and 1.0 for no contraction. Hager and Dupraz [11] derived a theoretical equation for obtaining the coefficient of contraction in terms of the contraction ratio, the inlet angle of the contraction, and the length ratio of the contracted reach. Alsamman [10] investigated the effects of the inlet angle of transition, contraction ratio and transition length ratio on the coefficient of contraction. Attia [12]investigated experimentally the effect of variable tail water conditions at the same discharge on the energy loss through sudden lateral transition.

In the present investigation, the effects of relative height, bottom slope, finite hump angle and Froude number on the energy loss through the inclined finite hump of the sloping channel are addressed based on experimental observations.

2. EXPERIMENTAL SET UP AND TEST PROCEDURE

The measurements were carried out in sloping rectangular open channel that is 9500mm long, 300mm width and 500mm height with glass wall 6mm thick and a steel plate bed. Fig. 1 depicts layout of the test facility. The water is supplied from a constant head overhead tank to the flume at a desired discharge that is continuously monitored with an on-line orifice meter. The flume side walls are made up of 6mm thick glass sheets. A tail vertical gate is provided at the downstream and of the flume to maintain a required water depth of channel flow. The water is finally collected in a sump placed in the basement from where it is pumped back to the overhead tank by a 16. HP pump. Depth measurements were taken using a needle point gauge with a reading accuracy of ± .1mm. Uniform flow conditions were reached using a carefully designed inlet tank. The slope was adjusted using a screw jack located at the upstream end of the flume while at the downstream end, the flume is allowed to rotate freely about a hinged pivot. The slope was directly determined using a slope indicator. A downstream adjustable gate was used to regulate the tail water surface elevation. The inclined finite hump with different angle of variations of 15°, 30°, 45°, 60°, 75° and 90° were fabricated from transparent perspex sheets.

3. THEORETICAL CONSIDERATIONS:

Figure 2, shows a definition sketch of flow through inclined finite hump in sloping rectangular channel. The variables affecting the flow through the inclined finite hump are shown in the figure and explained. The functional relationship of the energy loss through transition could be written as follows:

$$f_1\,(V_u , g , y_u , h , b , \Delta E , S_o) = o \qquad (1)$$

Using the dimensional analysis, the following dimensionless relationship is obtained:

$$\frac{\Delta E}{y_u} = f_2\left(F_u , \frac{h}{y_u} , \frac{b}{y_u} , S_o , \Theta \right) \qquad (2)$$

Keeping in mind the properties on the non-dimensional quantities in the following expression could be obtained from Eq. (2)

$$\frac{\Delta E}{y_u} = f_3\left(F_u , \frac{h}{b} , S_o , \Theta \right) \qquad (3)$$

It may appear better to analyze the energy loss through the transition as a ratio related to the upstream energy, E_u. Therefore, the E_u is used instead of y_u in the left hand side of equation (3) which becomes:

$$\frac{\Delta E}{E_u} = f_4\left(F_u , \frac{h}{b} , — , S_o , \Theta \right) \qquad (4)$$

The energy loss is computed using the following expression:

$$E_u = E_D + \Delta E \qquad (5)$$

Equation (5) may be rearranged to

$F_u^2 = 2 \,|(y_D/y_u - 1) + \Delta E/y_u| \,/\, |1 - 1/(b_D . y_D / b_u . y_u)^2|$ ....(6)

The above equation represents the relationship between F_u, y_D/y_u and $\Delta E/y_u$ as parameters

Again, equation (5) can be written as follows:

$\Delta E/E_u = y_u/E_u \,|(1+F_u^2/_2) - y_D/y_u + Fu^2/_2 (b_D/b_u)^2 (y_D/y_u)^2|$ ....(7)

Also, Eq. (7) represents the relationship between the efficiency (E_D/E_u = 1- $\Delta E/E_u$), $\Delta E/E_u$, F_u , and y_D/y_u as parameters.

From continuity equation

$F_u^2 = (b_D/b_u)^2 (y_D/y_u)^3 F_D^2$ ....(8)

The above equation represents the relationship between F_u, F_D and y_D/y_u as parameters.

in which

E_u and E_D = Specific energy upstream and downstream the hump respectively.

ΔE= Total energy loss between upstream and downstream sections.

y_u and y_D = Water depth upstream and downstream the hump respectively.

b_u and b_D = Bed width upstream and downstream the hump respectively.

V_u and V_D = Velocity upstream and downstream the hump respectively.

F_u and F_D = Froude number upstream and downstream the hump respectively.

h = Finite hump height .

S_o = Channel bed slope.

Θ = Transition angle.

By knowing either the value of velocity or depth upstream, downstream the hump, energy loss can be calculated by using equation (5) for the known values of different bed slopes, different hump angles and different contraction ratios.

4. RESULTS AND DISCUSSION

The variation of the relative energy loss $\Delta E/E_u$ with hump angle Θ for different relative heights h/b = 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 are presented in Fig 3 (a) , (b) and (c) for different tested bed slope So= 0.0, 0.015 and 0.025, respectively. From the figures, it can be observed that for a fixed So, the trend of variation between Θ and $\Delta E/E_u$ is increasing with a nonlinear trend. Also at a particular Θ, $\Delta E/E_u$ increases as the relative height h/b increases. The energy loss is the least value for h/b of 0.1 and a maximum value for h/b of 0.6. It is relatively small up to the relative height h/b of 0.3. The rate of increase in energy loss, Fig.3, is almost the same between the relative height 0.1 and 0.2, and 0.2 and 0.3, it has the 1.5 value between the relative height to 0.3 and 0.4. It increases to about 2 times between 0.4 and 0.5 and almost 3 times between 0.5 and 0.6 as compared to the increase in loss between the h/b of 0.1 and 0.2. The trend is almost the same for all other relative height.

As the angle of inclined hump Θ increases up to 35° the rate of increase in the $\Delta E/E_u$ is relatively high for all the h/b, being very high for the h/b of 0.6. Above Θ= 35° ,the increase in the energy loss is much slower.

Particularly for Θ greater than 45° at which the $\Delta E/E_u$ is almost constant for all practical purpose. This figure indicate that the slope has a remarkable effect on the energy loss. With increasing bed slope, the energy loss is increased.

Similarly, the variation of bed slope S_o with $\Delta E/E_u$ for different h/b is shown in Fig.4 (a) , (b) and (c) for Θ= 15°, 45°, and 90° respectively. From this figure, it can be observed that for a fixed Θ, the trend of variation between S_o and $\Delta E/E_u$ is increasing with nonlinear trend. Also, at a particular S_o , $\Delta E/E_u$ increases as h/b increases.

The variation of $\Delta E/E_u$ with F_u for different relative height h/b are presented in Fig.5 (a) , (b) and (c) for S_o= 0.0, 0.015 and 0.025 respectively at a fixed Θ= 30°. From this figure, it can be observed that for a fixed So, the trend of variation between F_u and $\Delta E/E_u$ is increasing with a nonlinear trend according to Eq. (7). Also, at a particular F_u, $\Delta E/E_u$ increases as the relative height h/b increases.

Figure 6 (a) , (b) and (c) presents the variation of $\Delta E/E_u$ with Θ for different h/b for S_o= 0.0, 0.015, and 0.025 respectively. From this figure, it can be observed that for a fixed S_o, the trend of variation between $\Delta E/E_u$ and Θ is a nonlinear trend. Also, at a particular Θ., $\Delta E/E_u$ decreases as h/b increases.

Also Figure 7 (a), (b) and (c) depicts the effect of the channel slope So on the E_D/E_u at different h/b for Θ= 15°, 45° and 90° respectively. From this figure, it can observed that for a fixed Θ, the trend of variation between S_o and E_D/E_u is a nonlinear trend. Also, at a particular S_o, E_D/E_u increases as h/b decreases.

Similarly, the variation of Fu with the efficiency E_D/E_u for different h/b is shown in Fig.8 (a) , (b) and (c) for S_o= 0.0, 0.015 and 0.025 respectively at a fixed Θ= 30°. From the figure the family of curves are similar hyperbolas of a higher order. Under the same value of Fu, the values of efficiency increase with the decreasing value of h/b. Also, with the same value of h/b, the value of h/b, the value of efficiency increases with the decreasing value of the F_u.

Fig.9 (a), (b) and (c) depicts a variation for F_u and F_D for different h/b for S_o= 0.0 , 0.015 and 0.025 at a fixed Θ= 30°. The relationship between Fu and F_D is a family of curves which are similar hyperbolas of a higher order according to Eq. (8). It can be shown from the figure that with the same value of h/b, the value of F_D increases with the increasing value of F_u. Also, with the same value of F_u, the value of F_D increases with the increasing value of h/b. From the figure, it is observed that an extension of the lower sides of the curves through the point (F_u=o , F_D=o) gives the hydrostatic case

Also, the variation of the submergence y_D/y_u with F_u for different h/b is shown in Fig. 10(a) , (b) and (c) for S_o= 0.0, 0.015 and 0.025 at a fixed Θ=30°. it is clear that, with the same value of h/b, the value of y_D/y_u

increases with the deceasing value of F_u. Also, with the same value of F_u, the value of y_D/y_u increases with the decreasing value of h/b . Fig. 10 demonstrates a family of curves, which are similar hyperbolas of a higher order By extending the lower sides of the curves through the point (F_u= o, y_D/y_u=1) the hydrostatic state prevails. On the other hand, an extension of the upper limbs of the earlier curves gives the critical condition at the downstream section.

5.CONCLUSIONS:

An experimental investigation is conducted on the flow characteristics through inclined finite hump in sloping rectangular open channels. It is concluded that, looking at the variation of the energy loss $\Delta E/E_u$ with range of hump angles, it appears that up to $\Theta=30^o$ and decreasing the angle of hump, the energy loss decreases, but above this hump angle $\Theta=30^o$ the effect of the boundary is insignificant. The energy loss is quite high if the relative height h/b ≥0.3. The energy loss increases rapidly up to $\Theta=30^o$ and trends to remain constant above $\Theta=45^o$.Thus, $\Theta=30^o$ appears to be critical defining a border value between the maximum energy loss and the value up to which energy loss increases rapidly as Θ increases from o^o to 30^o. The results indicate that, the most significant differences in energy loss occur with transition angle in the range less than 45^o. The total energy loss $\Delta E/E_u$ increases with increasing values of initial Froude number F_u, relative height h/b and channel slope S_o. Also, it is concluded that the relative water depth is a function of the initial Froude number and the bed slope. In all cases, the relative water depth increases nonlinearly with the increase of the initial Froude number and/or the increase of the bed slope. the initial Froude number, the hump angle and bed slope have major effect on the energy loss. Set of equations are presented in terms of the initial Froude number and relative water depth.

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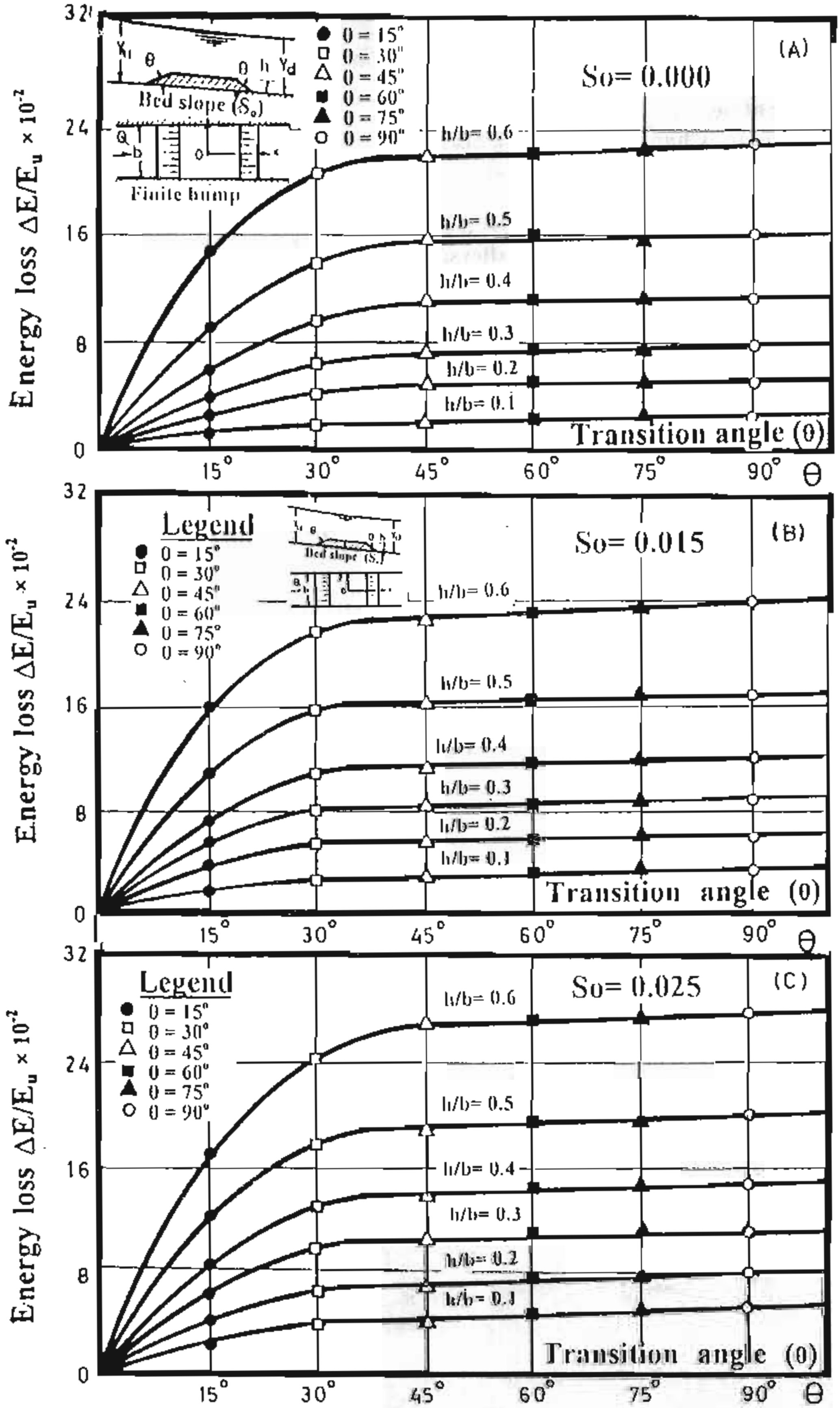

Fig. (3) Variation of relative energy loss $\Delta E/E_u$ with finite bump angle θ for different relative height h/b at different bed slope S_0.

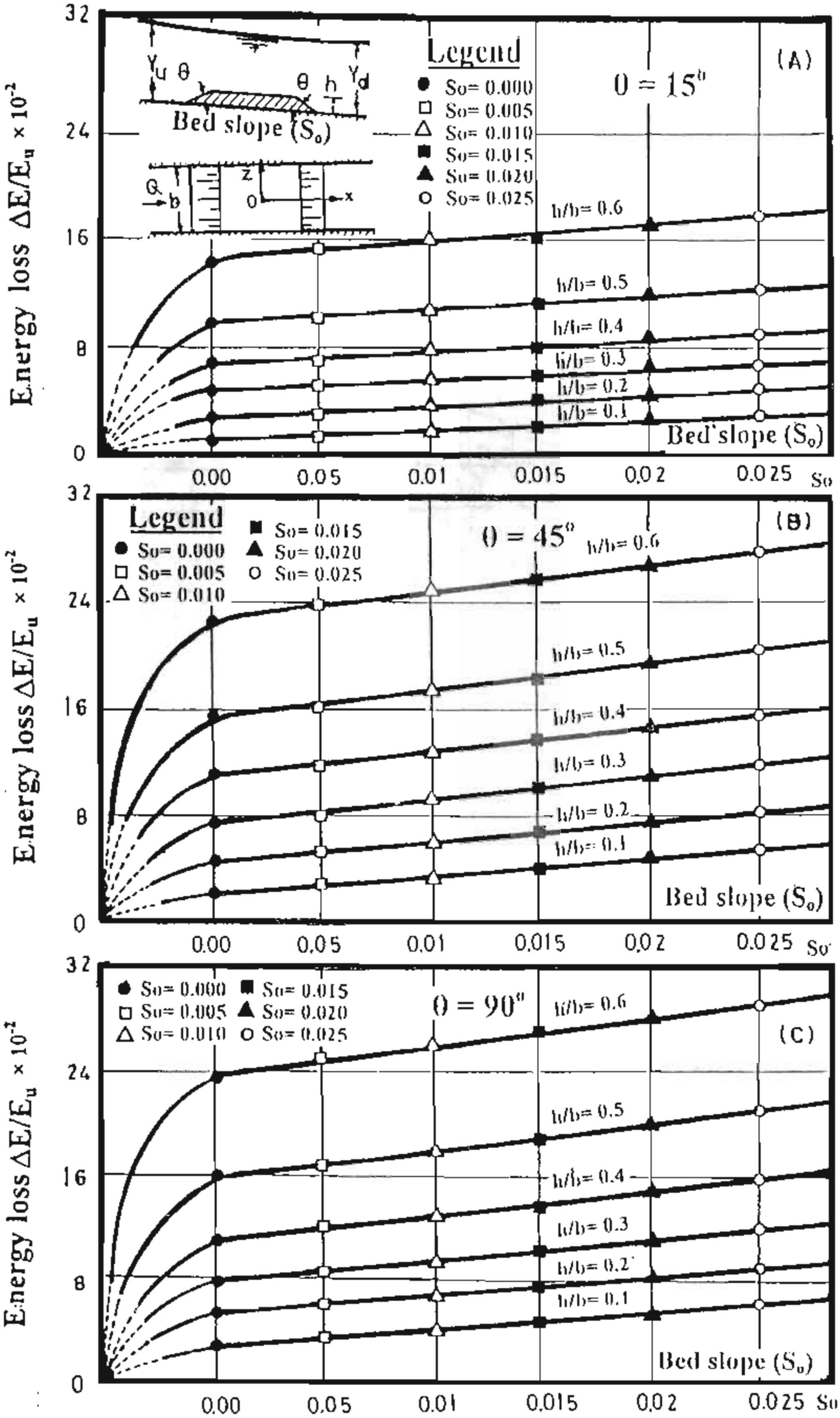

Fig. (4) Variation of relative energy loss $\Delta E/E_u$ with bed slope S_0 for different relative height h/b at different hump angle θ.

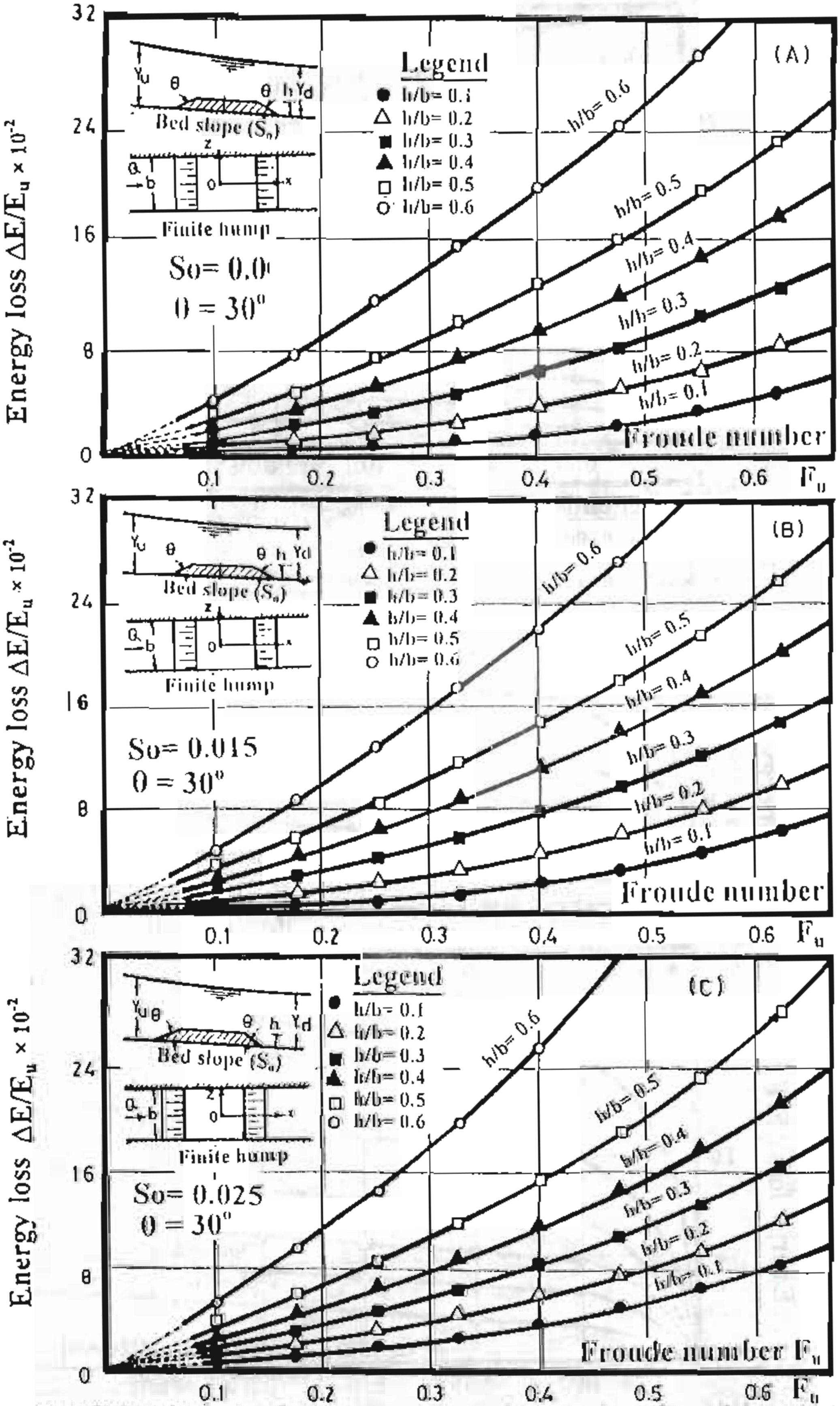

Fig. (5) Variation of upstream Froude number F_u with relative energy loss $\Delta E/E_u$ for different h/b at different S_0 for $\theta = 30°$.

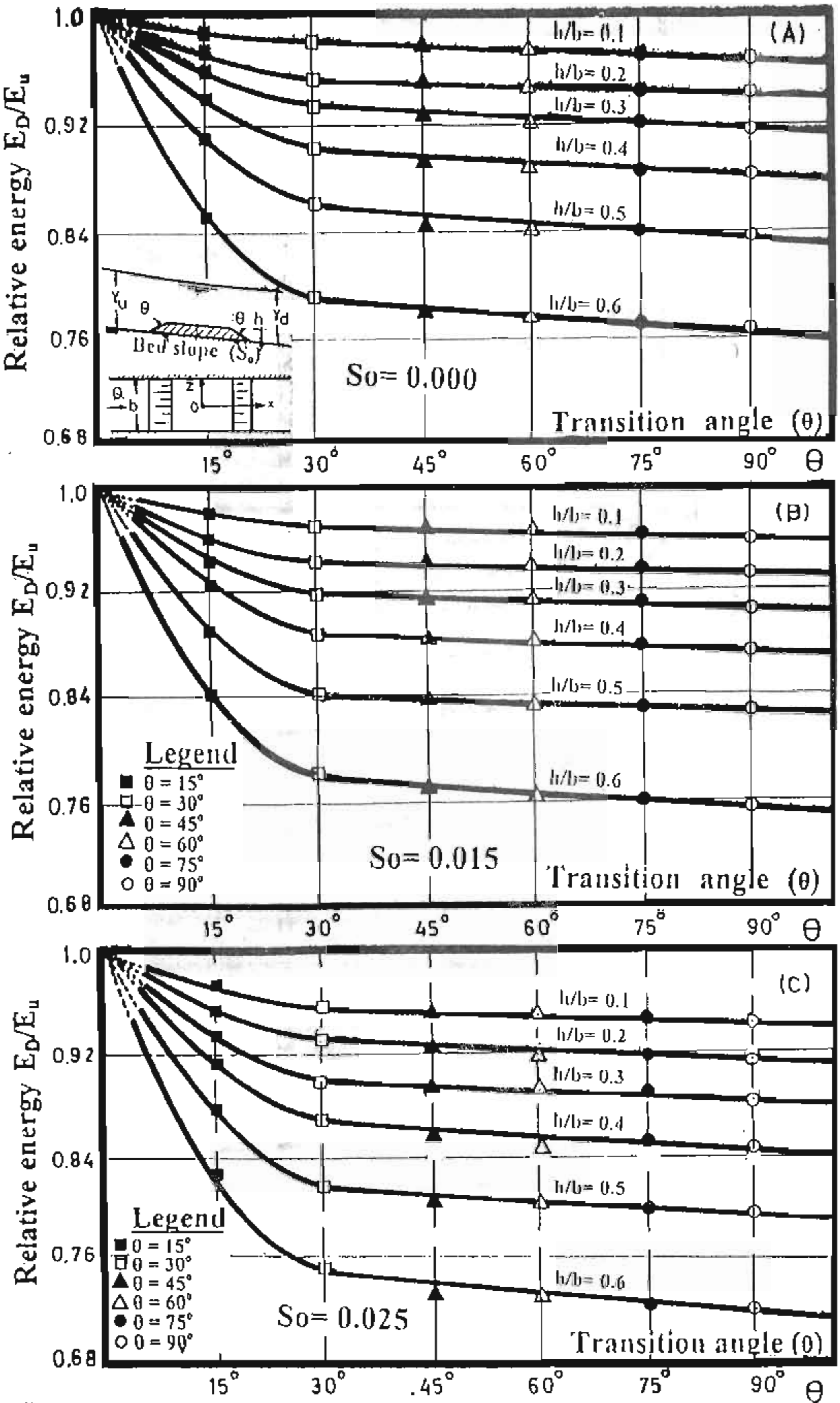

Fig. (6) Variation of relative energy E_D/E_u with finite hump angle θ for different relative height h/b at different S_0.

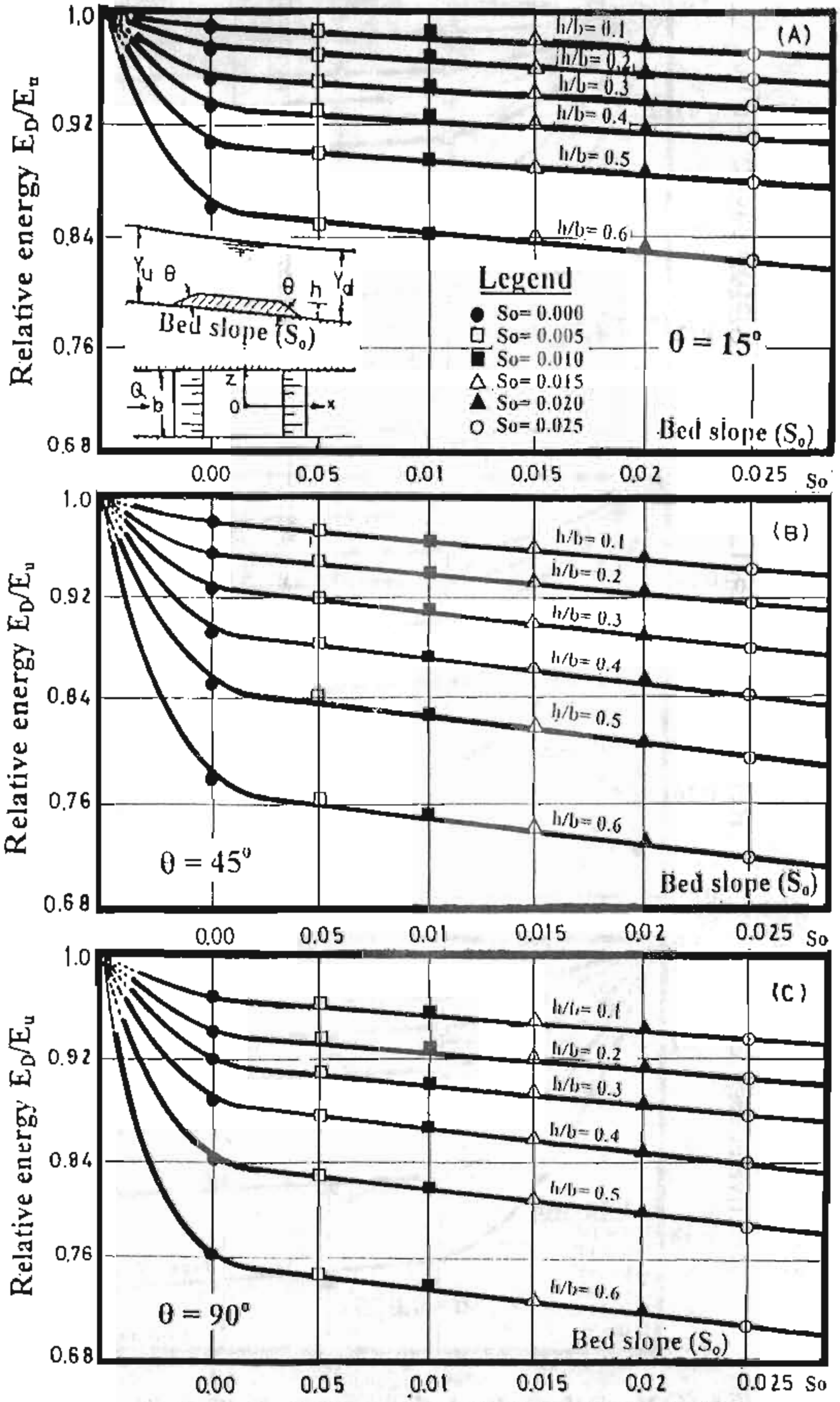

Fig. (7) Variation of relative energy E_D/E_u with bed slope S_0 for different relative height h/b at different hump angle θ.

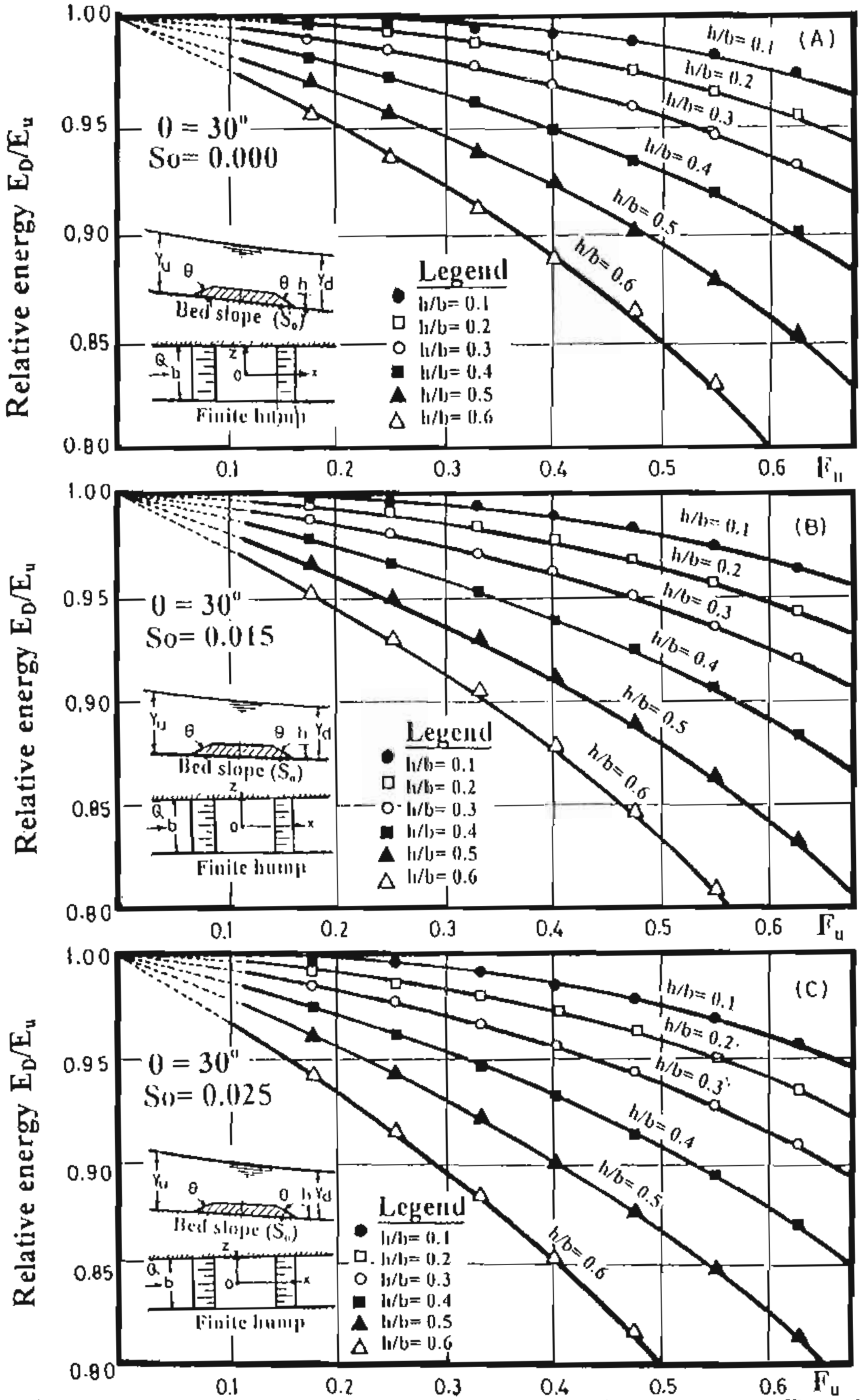

Fig. (8) Variation of relative energy E_D/E_u with upstream Froude number F_u for different h/b at different S_0 for $\theta = 30^0$.

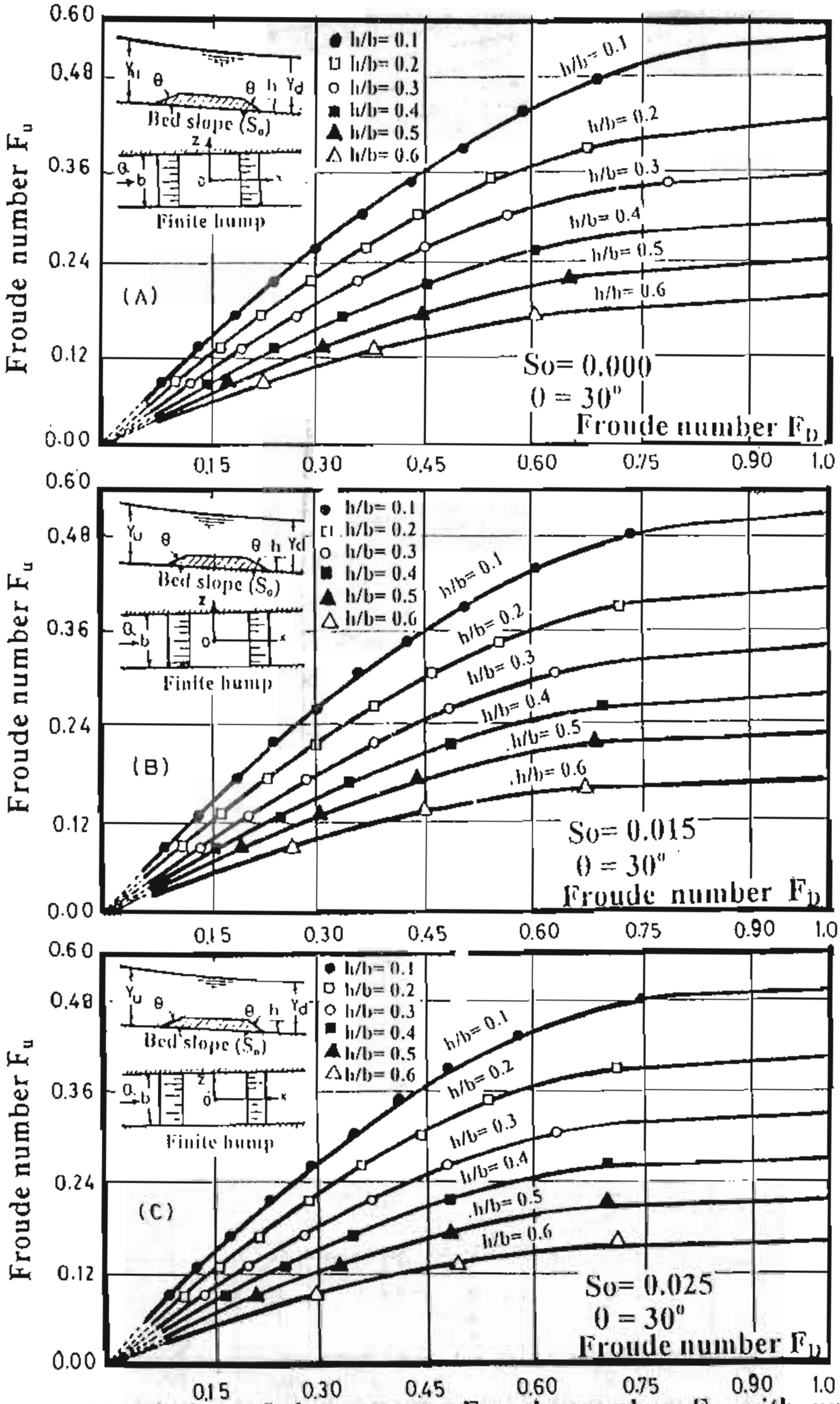

Fig.(9) Variation of downstream Froude number F_D with up stream Froude number F_u for different h/b at different S_0 for $\theta = 30^{\circ}$.

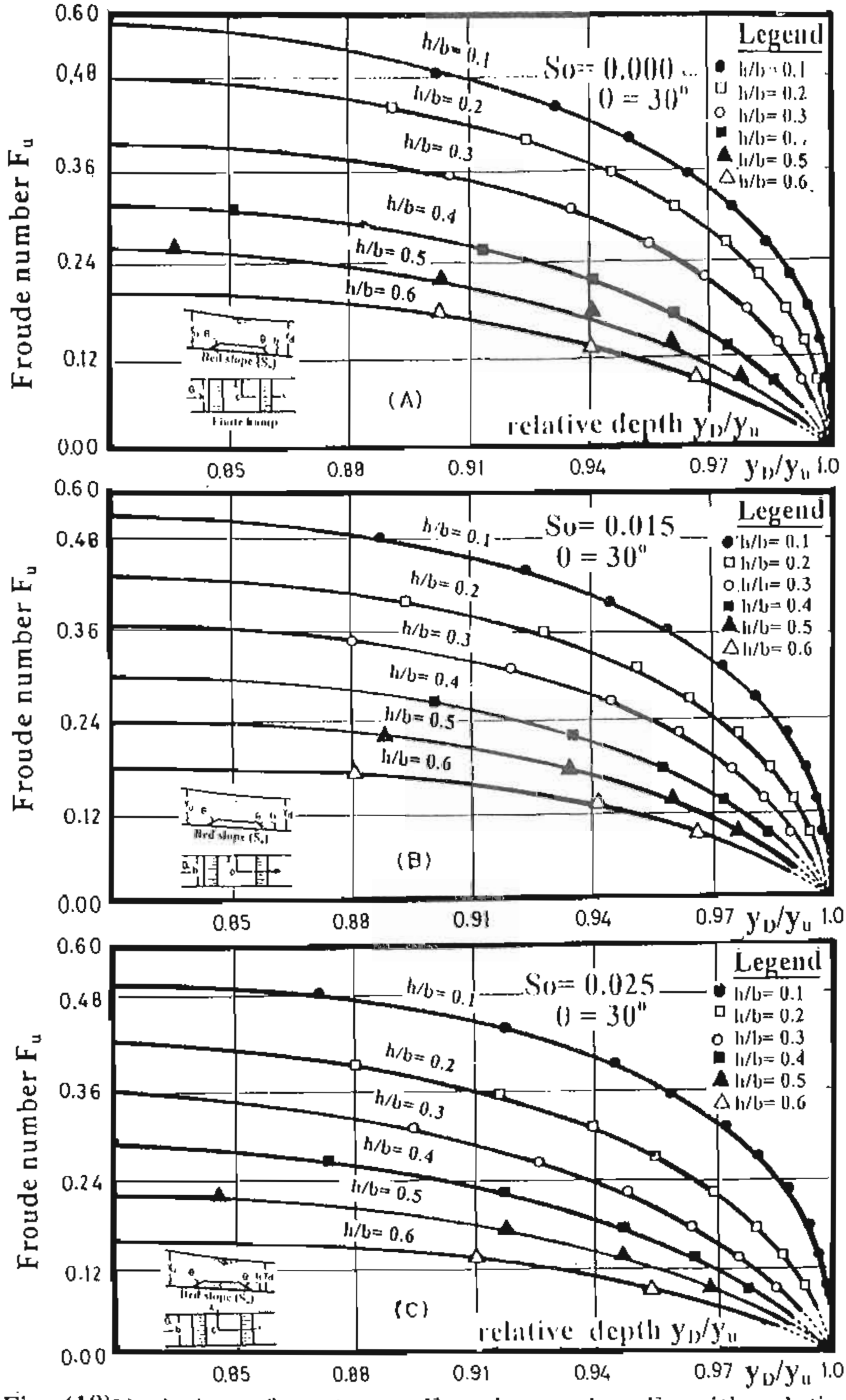

Fig. (10) Variation of upstream Froude number F_u with relative depth y_D/y_u for different h/b at different S_0 for $\theta = 30^0$