Seoul National University

457.562 Special Issue on River Mechanics (Sediment Transport) .11 Bed forms



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1. Progression of bed forms

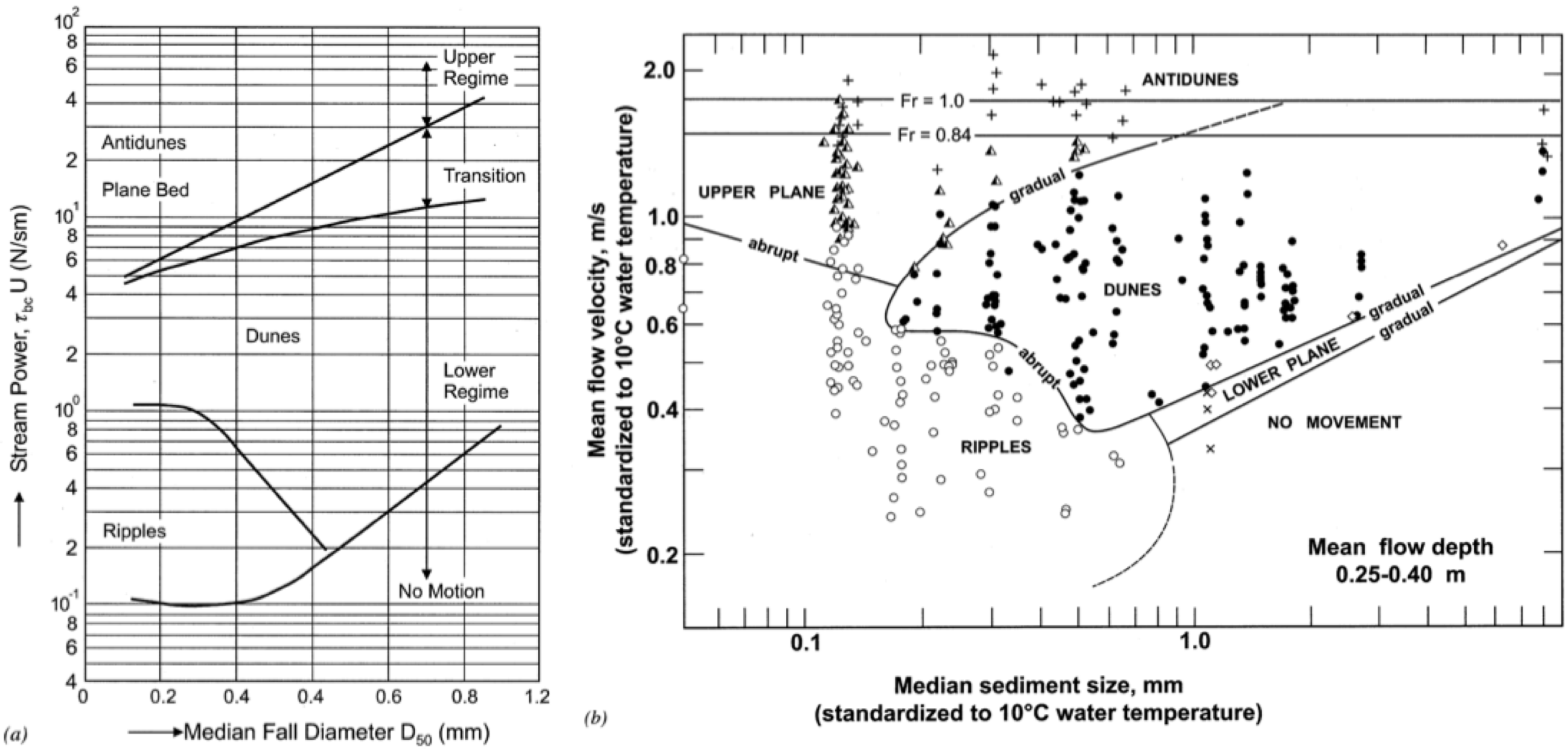
- Various bedforms are associated with various flow regim es. In the case of a sand-bed stream with a characteristi c size less than about 0.5mm a clear progression is evid ent as flow velocity increases.
- The bed is assumed to be initially flat. At very low impos ed velocity U, the bed remains flat because no sediment is moved.
  - As the velocity exceeds the critical value, ripples are first f ormed.
  - At higher values, dunes form and coexist with ripples.
  - For even higher velocities, well-developed dunes form in th e absence of ripples.

1. Progression of bed forms

- At some point, the velocity reaches a value near the criti cal value in the Froude sense.
- Near this point, the dunes are often suddenly and dramat ically washed out.
- This results in a flat bed known as an "***upper regime"*** (s upercritical) flat bed.
- Further increases in velocity lead to the formation of anti dunes and finally to the chute and pool pattern. The last of these is characterized by a series of hydraulic jumps.
- In the case of a bed coarser than 0.5mm, the ripple regi me is replaced by a zone characterized by a "***lower-regi me***" (subcritical) flat bed.

1. Regimes

(a) Simons and Richardson (1966) (b) Boguchwal and Soutard (1990)



1. Progression of bed forms

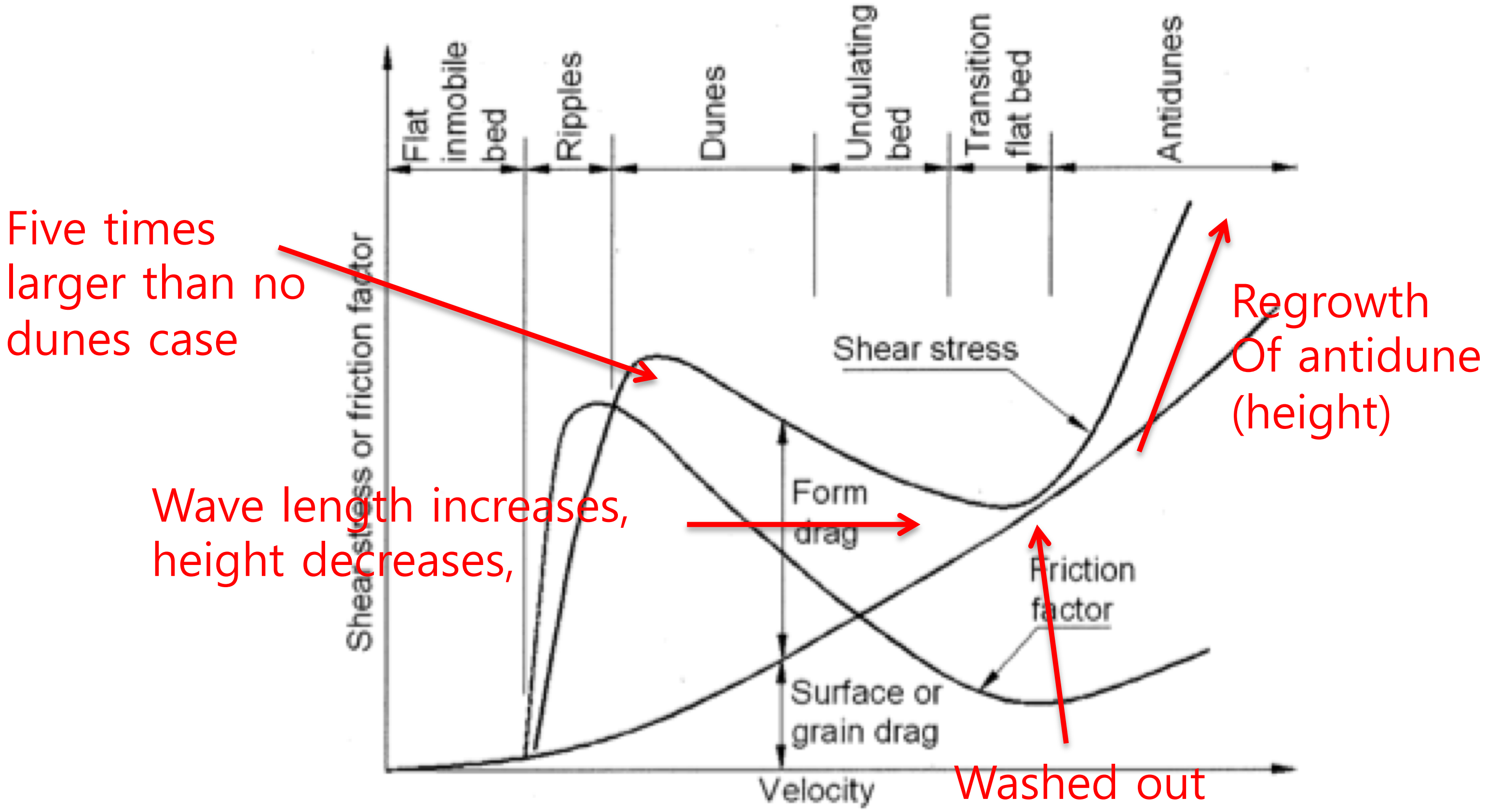
- The effect of bedforms on flow resistance can be explained as follows. As noted earlier for equilibrium flows in wide straight channels, the relation for bed resistance can be expressed in the form

$$\tau_b = \rho C_f U^2$$

- The effect of bedforms is to increase the bed shear stress to values often well above that associated with the skin friction of a rough bed alone.
- At very low values of U, the parabolic law is followed.
- As ripples and then dunes are formed, the bed shear stress rises to a maximum value.

2. Variations of bed shear to mean velocity

- Over the given erodible bed (Raudkivi, 1990)



3. Dimensionless characterization of bedform regime

- Discussion so far, we can conclude that the there are three important parameters describing bed forms

  Shields stress : τ^*

  Shear Reynolds number : $R_p = \dfrac{u_* D}{\nu}$

  Froude number : $F = \dfrac{U}{\sqrt{gH}}$

- Parker and Anderson have shown that equilibrium relations of sediment transport for uniform material in a straight channel can be expressed in terms of just two dimensionless hydraulic parameters. (R and R_{ep})

3. Dimensionless characterization of bedform regime

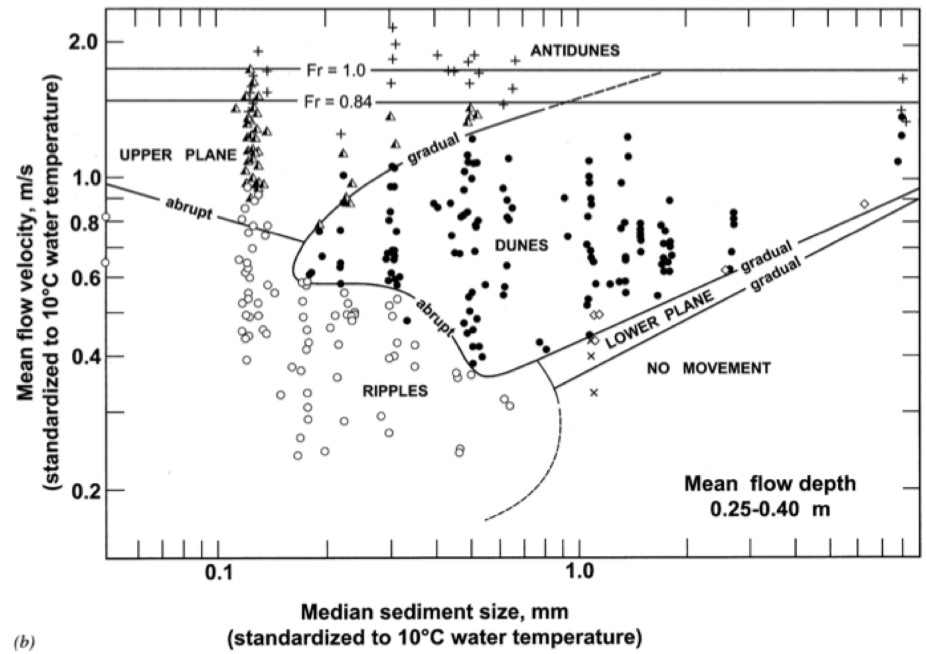
- Density difference and a particle Reynolds number

$$R_{ep} = \frac{\sqrt{gRD}D}{\nu} \quad R = \frac{\rho_s - \rho}{\rho}$$

Bedform type $= f\left(\pi_1, \pi_2; \mathrm{R}_{ep}, R\right)$

π_1 and π_2 can be replaced τ^* and F with S, and H / D

3. Dimensionless characterization of bedform regime



- Finer particles can be washed out when velocity high and change abruptly to upper regime from ripples
  - It means that finer particles cannot have dune regime.

- When F < 1, regime shift depends on the sediment size pretty much.

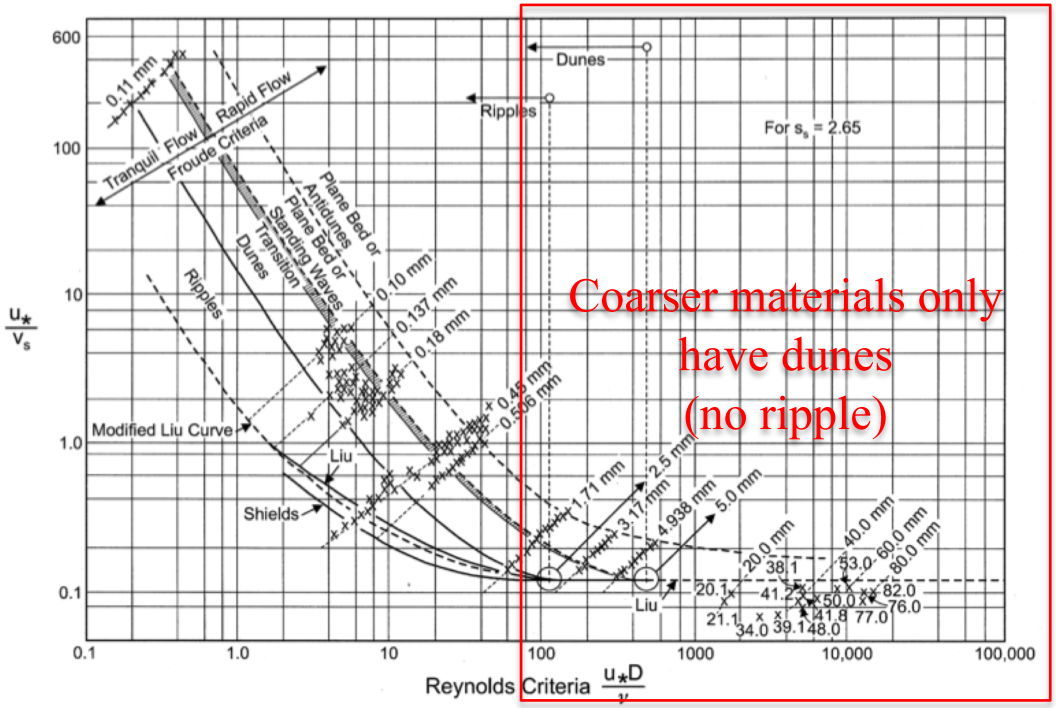
3. Dimensionless characterization of bedform regime

- The discriminator due to Liu (1957) (check the figure in th e next slide) uses one dimensionless hydraulic parameter

$$\frac{u_*}{v_s} \ (a\ surrogate\ of\ \tau^*)\ vs.\ R_{ep}$$

- The diagram is of interest in that it covers sizes much coa rser.
  - The various regimes become compressed as grain size incr eases
  - For the case of very coarse material, the flow must be supe rcritical for any motion to occur. As a result, neither ripples or dunes are to be expected.

3. Dimensionless characterization of bedform regime



- In fact, dunes can occur over a limited in the case of coarse material.
- For coarser grain sizes, the dune regime is preceded by a fairly wide range consisting of lower-regime flat bed.
- Many gravel-bed rivers never leave this lower-regime flat bed region, even at bankfull flow.

4. Effects of bed forms on river stage

- The presence of absence of bed forms on the bed od a ri ver can lead to curious effects on river stage.
- According to the standard Manning-type relation for a non erodible bed, the following should hold

$$U = \frac{1}{n} H^{2/3} S^{1/2}$$

- Channel is wide enough to allow the hydraulic radius to b e replaced with the depth H.
- Depth increases with increasing velocity (but only in rigid bottom).

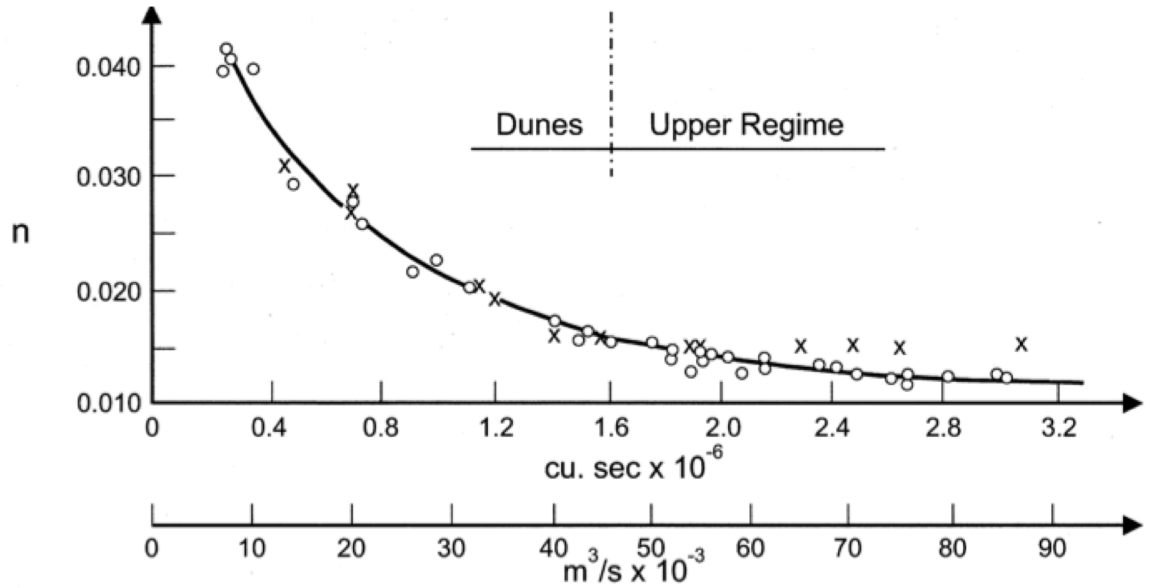
4. Effects of bed forms on river stage

- In a sand-bed stream, resistance decreases as U increas es over a wide range of conditions (wiping out ripple etc).
- At equilibrium,

$$\tau_b = \rho C_f U^2 = \rho g H S$$

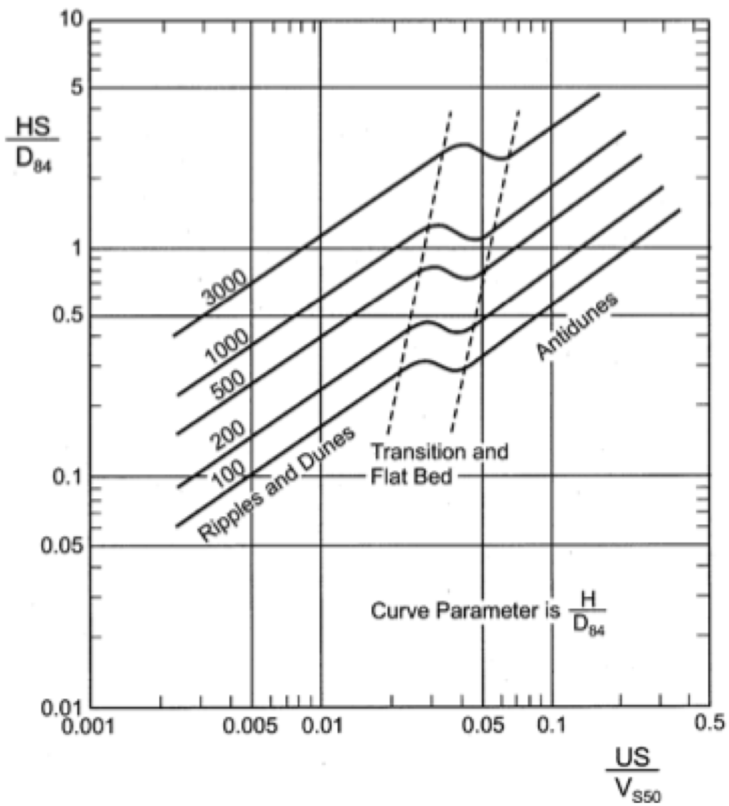
- This decrease in resistance implies that depth does not in crease as rapidly in U in a movable-bed stream.
- In fact, as the transition to upper regime quite suddenly, r esulting in a dramatic decrease in resistance.
- The actual result can be an actual decrease in depth as v elocity increases.

4. Effects of bed forms on river stage



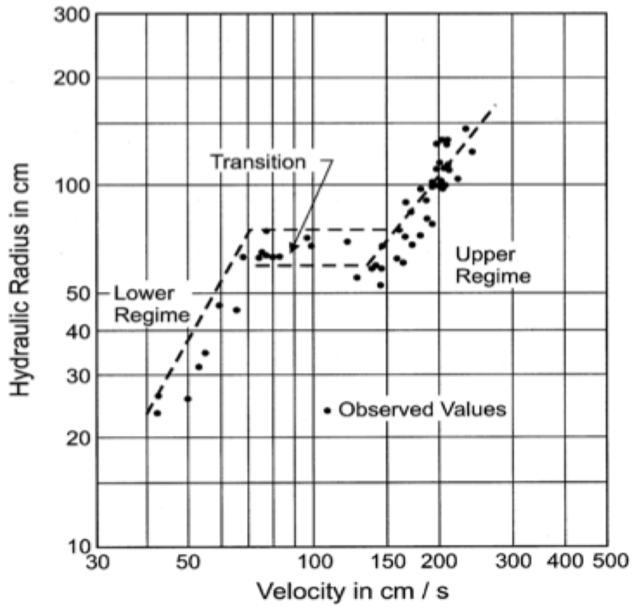
- The above plot shows how Mannng's n decreases as the flow dischar ge increases and the dunes are first elongated and finally washed out
- O : observations (Stevens and Simmons), x :computations. (Chollet a nd Cunge, 1980)
- Numerical model overestimate in the upper regime where most of the flow resistance should be mainly due to grain friction.

4. Effects of bed forms on river stage



- The effect of the transition phenome non on flow-stage discharge
  - Illustrated with a flow resistance diag ram (Cruickshank and Maza, 1973)
  - Flume and river data were used to de velop this dimensionless diagram sh owing the transition from the lower re gime to the upper regime.
  - In the transition region the flow depth is seen to decreases as the flow velo city increases.

4. Effects of bed forms on river stage



- State – discharge relationship
  - Rio Grande, New Mexico
  - Cruichshank-Maza relations capture the behavi or of the hydraulic radius,
  - which increase with flow velocity along the lowe r regime (ripples and dunes), remains almost c onstant for a wide range of flow velocities durin g the transition
  - and continues to increase again in the upper re gime due to the development of antidunes.
- Double values state-discharge
  - The discharge at which the dunes are obliterated is a little below bank-full in sand-bed streams with medium to high bed slopes.
  - As a result, flooding is not as severe as it would be otherwise.
  - The precise point of transition is generally different depending on whether th e discharge is increasing or decreasing.
- Temperature also control the transition to dunes or vice versa.