

行政院國家科學委員會專題研究計畫 成果報告

非均勻砂礫之分區可動性與啟動機率試驗研究

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非均勻砂礫之分區可動性與啟動機率試驗研究

Experimental studies on fractional mobility and entrainment probability of nonuniform sand/gravel sediment

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中文摘要

本研究探討非均勻砂礫之分區可動性與啟動機率。研究結果顯示分區可動性與無因次有效剪應力之關係可以累積對數常態分布表示，其均值與標準偏差在含砂量 < 0.34 時均隨含砂量線性遞減。研究結果亦顯示在無因次剪應力 < 0.25 時，啟動機率隨亂流強度而遞增；然而在無因次剪應力 > 0.25 時，啟動機率則隨亂流強度增大而遞減；無因次剪應力 $= 0.25$ 時，不同亂流強度所對應之啟動機率一致均為 0.3。

關鍵詞：非均勻砂礫，分區可動性，啟動機率，含砂量，亂流強度

Abstract

We investigate the fractional mobility and entrainment probability of nonuniform sand/gravel sediment. The results reveal that the relation between fractional mobility and dimensionless effective shear stress is well approximated by the cumulative lognormal distribution, with its mean and standard deviation linearly decreasing with sand content for the range < 0.34 . The results also reveal that for smaller values of dimensionless shear stress (< 0.25), the entrainment probability increases with the turbulence intensity, whereas for larger values of dimensionless shear stress (> 0.25), the entrainment probability decreases with the increase of turbulence intensity. For dimensionless shear stress $= 0.25$, the entrainment probabilities corresponding to different turbulence intensities consistently remain at 0.3.

Keywords: Nonuniform sand/gravel sediment, fractional mobility, entrainment probability, sand content, turbulence intensity.

1. Introduction

The condition of partial transport is important for modeling the process involving grain sorting or size-selective transport, such as bed armoring, selective deposition, and flushing of fine sediment from gravel riverbeds (Wu, 2000; Wu and Chou, 2003b). A stochastic partial transport model has been developed (Wu and Yang, 2004). The fractional mobility and entrainment probability are two important parameters of the model. In this study we investigate the effect of sand content on fractional mobility. The effect of turbulence intensity on entrainment probability is also investigated.

2. Experimental Study

The experimental study was conducted in a 40 cm by 12 m tilting flume located at Hydrotech Research Institute, National Taiwan University. A Hitachi KP-F100C 10-bit digital CCD camera was used to record the entrainment and transport of surface particles. Details of the experiments can be found in Wu and Yang (2004).

3. Results and Discussion

3.1 Effect of Sand Content on Fractional Mobility

The proposed stochastic partial transport model was used to evaluate the fractional mobility of sediment mixtures containing

various proportions of sand. A total of 8 data sets were analyzed, including our data with $f_s = 0.3$, BOMC data with $f_s = 0.06 \sim 0.34$, field data from East Fork River with $f_s = 0.59$ and Goodwin Creek with $f_s = 0.34$ (see Table 1).

Table 1. Mean, standard deviation, and R^2 values of best-fit lognormal distributions

| Data | Sand Content, f_s | Mean, μ_{LN} | Std. Dev., σ_{LN} | R^2 |
|-----------------|---------------------|------------------|--------------------------|-------|
| J06 | 0.06 | 0.0429 | 0.0152 | 0.91 |
| J14 | 0.15 | 0.0376 | 0.0130 | 0.91 |
| J21 | 0.21 | 0.0330 | 0.0112 | 0.84 |
| J27 | 0.27 | 0.0300 | 0.0095 | 0.88 |
| BOMC | 0.34 | 0.0255 | 0.0072 | 0.87 |
| C-1~C-7 | 0.30 | 0.0287 | 0.0082 | 0.89 |
| Goodwin Creek | 0.34 | 0.0269 | 0.0089 | 0.99 |
| East Fork River | 0.59 | 0.0263 | 0.0076 | 0.89 |

The calculated Y_i values for each data set along with their best-fit lognormal curve are demonstrated in Fig. 1, with the mean μ_{LN} , standard deviation σ_{LN} , and R^2 values of the cumulative lognormal distributions of all analyzed data sets listed in Table 1. Variations of μ_{LN} and σ_{LN} with f_s are shown in Fig. 2, where the decreasing trends of μ_{LN} and σ_{LN} are apparent for the range $0.06 \leq f_s \leq 0.34$. Two implications are acquired from such results. First, the reduction of μ_{LN} with f_s indicates that the value of θ'_i corresponding to the same level of Y_i is smaller for the higher f_s value, indicating that sands act to serve as a lubricant in the sediment mixture. The existence of fine-grained sand in the gravel/sand mixture is favorable to the mobilization of sediment grains. Second, the

decrease of σ_{LN} with f_s implies that the range of θ'_i corresponding to partial mobility is narrower for the greater f_s . In other words, for the lower sand content, the condition of partial transport exists over a wider range of flows. In summary, in the presence of more sand grains, the smaller value of μ_{LN} and the narrower band of θ'_i for partial mobility make the condition of full transport easier to achieve, which coincides with the observations that full transport is dominant in most sand-bed rivers. The results also indicate that sand content has a direct influence on grain mobility within a narrow range of f_s .

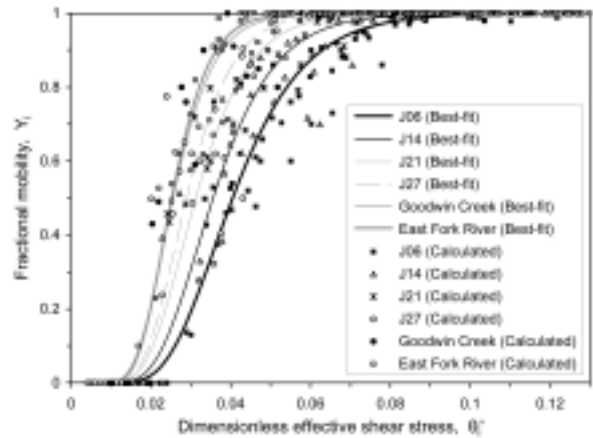


Fig. 1. Relation between fractional mobility and dimensionless effective shear stress

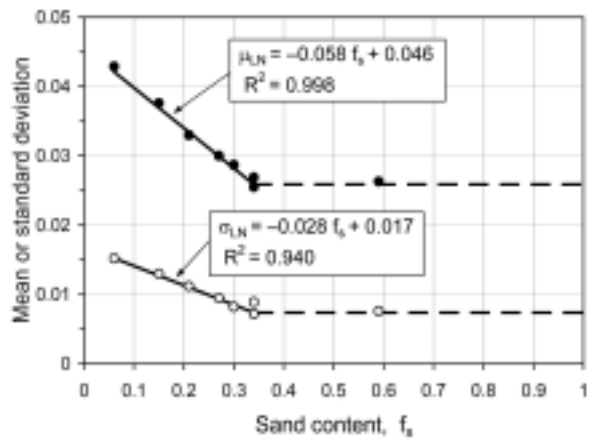


Fig. 2. Variations of μ_{LN} and σ_{LN} with sand content f_s

3.2 Effect of Turbulent Intensity on Entrainment Probability

The effect of turbulence intensity on entrainment probability is shown in Fig. 3, where opposite trends of variation for the smaller and larger values of θ are demonstrated. For the smaller dimensionless shear stresses ($\theta < \sim 0.25$), the entrainment probability increases with the turbulence intensity I_u ; however, for larger values of θ ($\theta > \sim 0.25$), the entrainment probability decreases with the increase of I_u . For smaller values of θ , the corresponding mean approaching velocities are lower, the greater turbulence intensity (i.e., the greater deviation from the mean approaching velocity) indicates that a larger proportion of fluctuating velocities will exceed the lifting threshold. Thus, the entrainment probability increases with the turbulence intensity. However, for larger values of θ , the corresponding mean approaching velocities are higher, the greater intensity of turbulence means that a larger proportion of fluctuating velocities will be lower than the lifting threshold. As such, the entrainment probability decreases with the increase of

turbulence intensity. The results also indicate that at $\theta \approx 0.25$, the entrainment probabilities are consistently ~ 0.3 irrespective of the turbulence intensity. In summary, for smaller values of θ , the greater turbulence intensity is favorable for the lifting of sediment particles, whereas for larger values of θ , the greater turbulence intensity results in the lower probability of entrainment.

4. 計畫成果自評

本研究內容與原計畫內容完全相符，預期目標亦全部達成。本研究首度將分區可動性觀念納入序率模式架構中，預測非均勻砂礫之部分運移現象。本模式採用最新之泥砂顆粒啟動機率研究成果，考量泥砂顆粒滾動與躍移之不同啟動機制，並結合實驗測得之滾動與躍移速度推估顆粒平均移動速度，本研究並以水槽實驗量測泥砂顆粒運動之序率特性，在國際頂尖學術期刊 WRR 上首度提出顆粒運動之動靜時間比研究成果，大幅增進序率模式之預測精確度。本研究並應用此模式推估非均勻砂礫之分區可動性，發現分區可動性在河床含砂量低於 0.34 時呈線性遞減，此為一

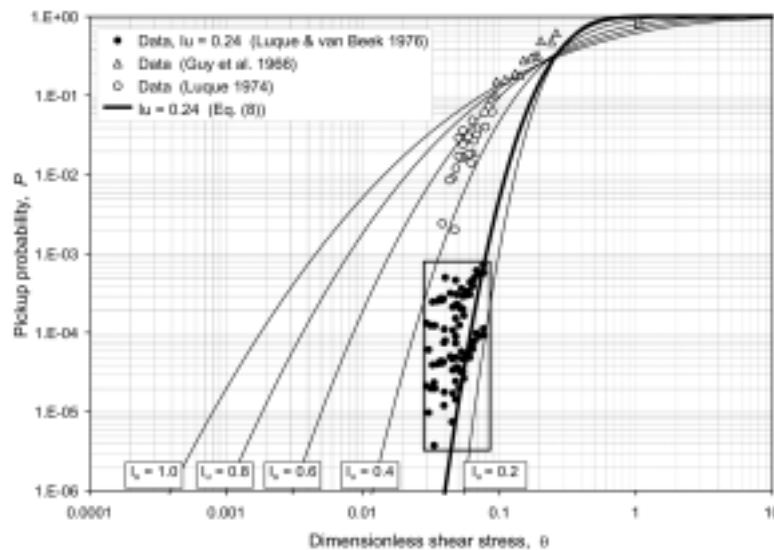


Fig. 3. Variations of entrainment probability with dimensionless shear stress for different values of turbulence intensity

具有突破性之新發現，有助於更深入瞭解部分運移機制及模式之後續應用。本研究並將亂流強度納入啟動機率預測模式中，探討亂流強度對泥砂顆粒啟動機率之影響，以改進傳統模式中亂流強度固定不變之缺點，並發現無因次剪應力在 > 0.25 與 < 0.25 時，亂流強度對啟動機率之影響趨勢恰好相反，此亦為一項重要之新發現。本研究之主要貢獻在於結合最新之泥砂顆粒啟動機率研究成果及非均勻砂礫分區可動性觀念於序率模式架構中，探討目前國際間十分關切之研究議題—非均勻砂礫之部分運移。由於礫石河川大部份時間都處於部分運移狀態，而部分運移機制與傳統砂質河床全運移機制有明顯之差異，因此目前國內外學術界均積極投入此項研究。本研究提出新穎之序率模式架構，並進行礫砂河床部分運移水槽實驗，將模式中複雜之參數一一釐清與量化，本研究涵蓋理論推導與實驗量測，匯集申請人近年之相關研究成果，內容十分豐富，而模式應用於分區可動性之評估亦有重大突破與發現，實為追求卓越學術研究之典範。

5. References

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