AN EVALUATION OF SUSPENDED SEDIMENT CONCENTRATION MODELS UNDER BREAKING WAVES

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INTRODUCTION

Implementing the effects of turbulent kinetic energy (TKE) is essential in producing accurate suspended sediment concentration (SSC) models, especially under breaking wave conditions. SSC is commonly attributed to two different turbulent sources under breaking wave conditions: 1) bed-friction and 2) breaking-induced turbulent vortices. Numerous studies have endeavoured to quantify the effects of TKE and incorporate them into SSC models. To name a few: Mocke & Smith (1992, henceforth MS92), Shibayama & Rattanapitikon (1993, henceforth SR93), Jayaratne & Shibayama (2007, henceforth JS07), and Yoon et al. (2015, henceforth Y15). The present study evaluates these 4 existing SSC models and validates them against recently published datasets from the *'CROSSTEX'* (Yoon & Cox, 2010), *'SandT-Pro'* (Ribberink et al., 2014) and *'SINBAD'* (vdZ et al. 2015) projects. Following critical evaluation, suggestions are made to enhance existing SSC models, and these findings are then incorporated into producing two new SSC models that indicate improved accuracy.

EVALUATION OF EXISTING SSC MODELS

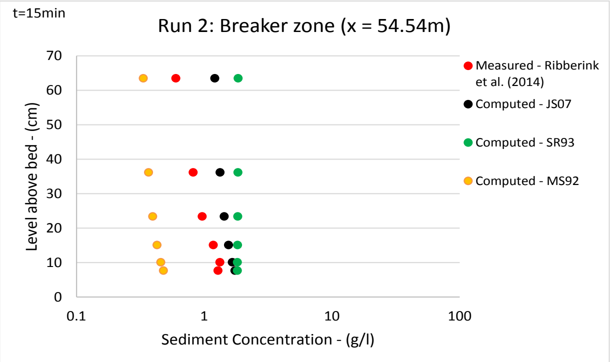

Figure 1 - SSC Computed (JS07, SR93 & MS92) vs. Measured (*'SandT-Pro'* - Ribberink et al., 2014) - just after wave breaking initiation (breaking initiated at *x* = 54m; where *x* = 0m is at the wave generator).

It was found that almost all the existing SSC models tested in this study predicted SSC to a relatively good level of accuracy before the plunging point, showing good agreement with data even after wave breaking had initiated (R^2 ranging between 0.783 - 0.955). Figure 1 indicates a quasi-linear concentration profile for all tested SSC models as well as the measured data. At this point, which is pre-plunging, internal TKE (bed-shear/bottom-friction) is solely responsible for the entrained sediment. In Fig. 1, MS92 is seen to under-predict SSC throughout the whole water column. The magnitude of the discrepancy between measured SSC and SSC computed using MS92 is seen to be even greater in Fig. 2. The reference concentration formula of MS92 consists of a turbulence dissipation term that was modelled after periodic bores. Beach and Sternberg (1996) found that the levels of SSC induced by plunging breakers were 4-6 times as much as those found under bores or unbroken waves. This may be one of the reasons MS92 is seen to under-predict in wave-breaking (especially plunging) conditions.

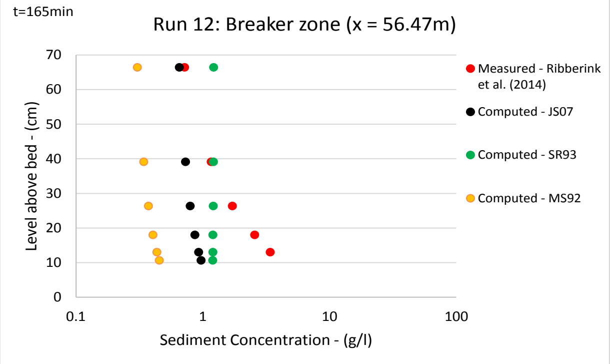

Figure 2 - SSC Computed (JS07, SR93 and MS92) vs. Measured (*'SandT-Pro'* - Ribberink et al., 2014) - at the plunging point (*x* = 56.47m).

Though to a lesser extent, a similar trend can be observed for SR93 and JS07 in both Figs. 1 and 2. Both models are seen to marginally over-predict SSC pre-plunging (i.e. before external TKE is injected) but under-predict considerably in the lower water column (z<30cm) post-plunging. After the initial breaking of the wave, the wave plunges and injects a large amount of aerated and pressurised water into the water column, generating highly turbulent vortices. These turbulent vortices penetrate the water column and travel obliquely downwards (Nadaoka et al., 1989) and shoreward in the direction of flow (Peregrine & Svendsen, 1978). As these vortices approach the bed, they induce dense clouds of sediment to suspend, causing the measured SSC levels to increase exponentially. This is clearly visible in Fig. 2 as the concentration profile of measured SSC is seen to increase considerably, becoming almost diagonal.

The large discrepancies found in Fig. 2 can also be accredited to the time at which the measurements were taken. Fig. 1 was taken at t=15mins, when the breaker bar was in the initial stages of its development. At t=165 (Fig. 2) however, the breaker bar was almost fully developed. This would have had a considerable impact on the height of the plunging waves, and therefore on the intensity of the resulting turbulent vortices - entraining more sediment. The relatively poor accuracy observed in the lower water column between measured and computed SSC suggests that the tested models do not adequately incorporate the high levels of external TKE found under strong plunging breakers, but also that they are affected by the presence of a breaker bar. These are both crucial points that need to be considered in order to improve the performance of SSC models under breaking wave conditions.

NEWLY PROPOSED SSC MODELS

It was speculated that one of the problems with MS92 was its turbulence dissipation term that was modelled after periodic bores. It was suggested that the model's performance could be enhanced by incorporating a different dissipation term that was better suited for breaking wave conditions. MS92 also consisted of numerous parameters that were highly dependent on the wave height (H) and water depth (d), making the resulting equations very sensitive to these parameters. This, in turn, led to very large discrepancies (up to two orders of magnitude) when tested against certain datasets (e.g. Sato et al., 1990). By changing the dissipation term and including a new tuning parameter *'B'*, which varied depending on relative wave height, a new model was derived. The new model, referred to as 'L18-1' has improved accuracy and is no longer sensitive to H and d - more stable.

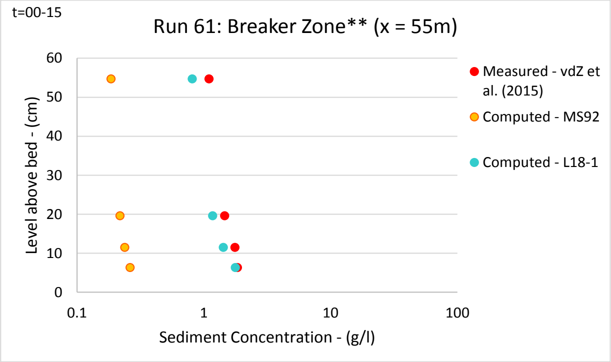

Figure 3 - SSC Computed (L18-1 and MS92) vs. Measured (*'SINBAD'* - vdZ et al., 2015) - after wave breaking initiation (breaking initiated at $x = 54$m)

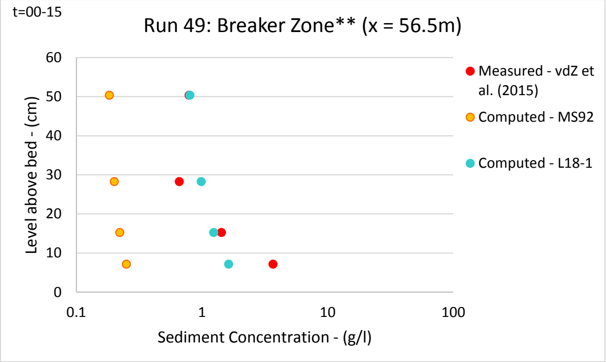

Figure 4 - SSC Computed (L18-1 and MS92) vs. Measured (*'SINBAD'* - vdZ et al., 2015) - soon after the plunging point ($x = 55.5$m).

Both Figs. 3 and 4 indicate significant improvement in accuracy from MS92 to L18-1. The new model shows very good agreement with measured data before plunging (in Fig. 3 $R^2 = 0.93$), suggesting that the new model is adept for predicting SSC under conditions with little/no external TKE, e.g. spilling breakers. There is still some discrepancy between measured and computed SSC in the lower water column post-plunging.

DISCUSSION & CONCLUSIONS

One of the greatest challenges found in accurately predicting SSC under plunging breaker conditions seems to lie in effectively incorporating the external TKE into the sediment transport formulation. This is no trivial task as the complex relationship between SSC and TKE is not fully understood. Yoon & Cox (2012) discovered through experimental analysis that though suspension and turbulence were found to be somewhat closely related, approximately 50% of measured suspension events were caused by mechanisms other than breaking-induced TKE. Often high levels of TKE were measured, but corresponding SSC levels were low and vice versa. A deeper understanding of the governing hydrodynamic forces in and around plunging-generated turbulent vortices is crucial in parameterising such forces and incorporating them into SSC formulations. There have been successful attempts (e.g. Y15 and L18-2; second of two newly proposed models) to incorporate measured cross-shore (u), alongshore (v) and vertical fluid (w) velocities to compute time-averaged TKE, but to make such models more robust and widely applicable, it is necessary to thoroughly understand the depth-varying TKE structure and how it dissipates throughout the water column. This issue could be aided by using simultaneous TKE and SSC measurements at numerous different elevations above the bed (z) and at different cross-shore locations (x). The conference presentation will address these problems in more depth and cover further analysis and discussion of all 6 models validated against the 4 different datasets (3 field-scale and 1 small-scale).

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