EXPERIMENTAL STUDY OF MICROPLASTIC PARTICLE TRANSPORT AROUND SEA GRAVEL IN WAVES PLUS CURRENT CONDITIONS

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INTRODUCTION

Microplastics (MPs) are considered to be potentially the most harmful plastic fraction in the ocean (Law and Thompson, 2014). Guler et al. (2022) examined the transport of non-buoyant MP particles beneath irregular breaking waves over a live sediment bed in extended test durations. They identified that accumulation hotspots were largely governed by the particle Dean number

$$\Omega_p = H_0/(T_p w_{sp}) \quad (1)$$

where H_0 is deep water wave height, T_p is peak wave period and w_{sp} is the MP particle settling velocity. Larsen et al. (2023) developed an approach based on wave-induced transport velocity to predict the onshore transport of buoyant MP particles across a coastal profile. In the present study, we further this research to experimentally investigate the potential retention of MPs under the effects of combined (non-breaking) irregular waves and current in coastal waters by gravel patches having various coverage density.

MATERIALS AND METHODS

The experiments are conducted in a wave-current flume within the Hydraulics Laboratory at the Technical University of Denmark. Experiments were carried out on a sediment bed with median grain diameter 0.18 mm. A wave-absorbing porous slope of 1:5 was installed at the end of the flume to minimize wave reflection. The water surface elevation in the experiments was measured with five wave gauges. The water depth is 0.45 m in front of the wave maker and 0.30 cm on the sediment bed. The motion of the MPs having different shapes, dimensions and densities are investigated in the flume. Seven different non-buoyant MP groups having relative density in the range 1.062 - 1.358 are used, similar to Goral et al. (2023) (Table 1).

Table 1- Description of particle characteristics of MPs

ID	shape	density [g/cm^3]	dimensions [mm]	Ω_p
MP1	sphere	1.352	3.0	0.17
MP2	sphere	1.062	3.1	0.48
MP3	sphere	1.358	3.0	0.13
MP4	cylinder	1.195	5 x 4 x 4	0.23
MP5	plate	1.206	5 x 5 x 0.5	0.68
MP6	plate	1.197	5 x 5 x 1	0.49
MP7	cube	1.192	4.0	0.27

The aim of the present study is to investigate the retention of MP by various gravel configurations under combined irregular wave and current conditions. Generated irregular waves are based on a JONSWAP spectrum having a spectral significant wave height H_{m0} = 0.053 m and peak period T_p = 2 s at the paddle depth h=0.45 m. Waves alone, and in combination with following and opposing currents, were investigated. The mean (cross-sectionally averaged) current flow velocity in the flume (on the sediment bed) was also determined as 0.1 m/s, which corresponds to low tidal currents, see e.g. Ruiz-Montoya and Lowe (2014).

The gravel patches considered have lengths ranging from 60 cm to 240 cm, always spanning the 60 cm width of the flume (Figure 1). In Figure 1(a) circles represent individual gravel particles (having median size d=20.8 mm and S is the distance between neighboring gravels. In this study, S=6 cm and 4 cm have been considered, representing low and high density gravel patches, respectively. High and low density gravel patches cover approximately 65% and 35% of the sediment bed, respectively.

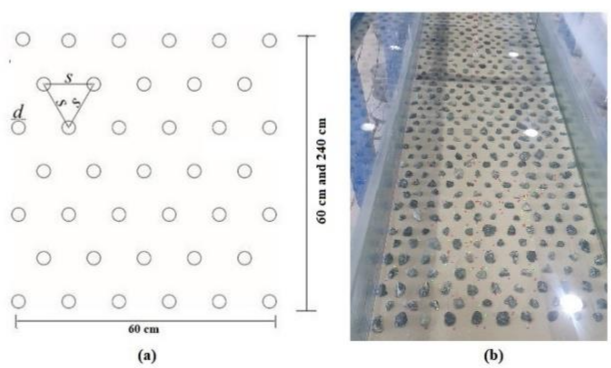

Figure 1 - (a) Configuration of gravel obstacle (not in scale-I), (b) A view of 60cm x 60cm obstacle patch with low density in the flume

All experimental cases were investigated with seven MP groups. At the beginning of the experiments 50 particles of each group were initially released (at x ≈ -17.5 cm, where x=0 defines the beginning of the gravel obstacle and the x axis points in the wave propagation direction), resulting in a total of 350 particles for waves only and waves with following current. Then, the particle distribution (and hence retention by the gravel patches) were determined by manually counting the particles lying within 5 cm bins designated along the flume.

RESULTS

The MP transport has been investigated on a pure sediment bed (no gravel, as control), under wave only conditions, as

well as on gravel covered beds involving both waves alone and in combination with following and opposing currents. Example results involving both high and low gravel density configurations are shown, for waves-plus-following current conditions (Figure 2, after 10 min of testing with MP3, see Table 1). Test results show that the gravel coverage ratios are effective in retaining MPs. For example, Figure 2 shows that MPs accumulated at the beginning of the high density gravel patch (Figure 2b), but were less easily retained if the gravel density was reduced (Figure 2a) under same wave and current conditions.
Figure 3 shows, MP distribution for same gravel obstacle (length and coverage ratio) under wave with following current conditions and wave-only conditions for MP1.

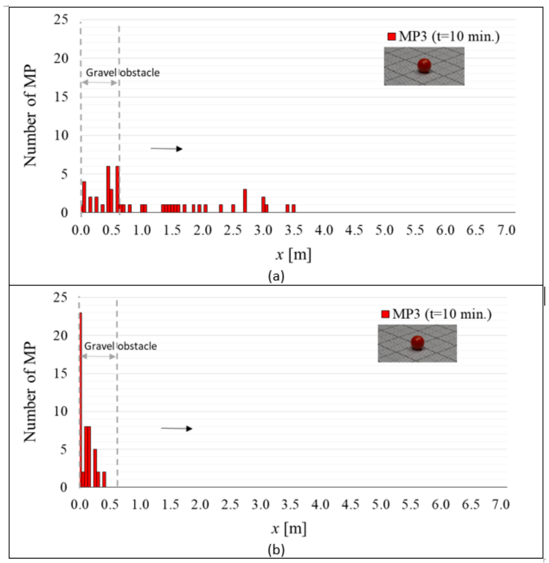

Figure 2 - Particle distribution along the wave channel for MP3 after 10 min test duration for waves-plus-following current conditions with a) 35% and b) 65% coverage ratio of gravel obstacle

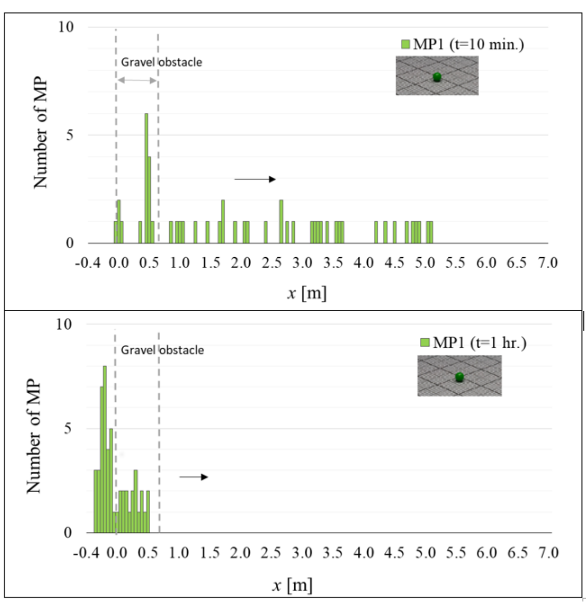

Figure 3 - Particle distribution along the wave channel for MP1 for the same gravel obstacle coverage with 65% under a) wave plus same direction current condition after 10 min. b) wave action after 1 hour

Observations also show that the MPs are much more mobile under combined wave and current conditions, relative to wave-only conditions. As an example it can be seen from Figure 3 that the MP1 particles (see Table 1) are distributed over a much larger area after only 10 min of combined wave and following currents, relative to wave-only conditions spanning durations as long as 1 hr.

CONCLUSIONS

The experimental results show that gravel patches are potentially effective in retaining MP pollutants. Hence, gravel patches (whether naturally occurring or man made) may be serve as potential sinks of MP pollutants in coastal environments. Retention effectiveness depends on both the climate (e.g. waves alone versus combined waves and currents) in addition to particle characteristics (e.g. their Dean number). In general, retention has been found to be less effective for particles having higher Dean number (i.e. more mobile particles with lower settling velocity) than for lower Dean number. In some cases, particles with highest Dean number were not retained, instead passing over the gravel patch to the end of the flume. Results will be analyzed quantitatively to investigate this dependence.

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