BEHAVIOR OF VARIABLE DENSITY MUNITIONS UNDER DAM BREAK FORCING

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INTRODUCTION

Munitions or Unexploded Ordnance (UXO) are ammunitions belonging to a larger family of explosives from past military activities. Sea disposal of munitions was a common practice from the late 1800s to 1970 when international conventions put an end to the practice. The exact quantity of munitions dumped into the Oceans globally is unknown due to sparse documentation but conservative estimates of known records stand at 1.6 million tons (Wilkinson, 2017).

After decades underwater, some munitions have resurfaced in the nearshore, presumably washed onshore or exhumed by high-energy wave action (Fig 1). Extreme events could be major causes of migration and exposure of UXO in the nearshore. A recent example is the appearance of two World War II naval munitions on the beaches of South Carolina, USA (Geib, 2018). The appearance of munitions in the nearshore, especially on the beach face causes public and environmental concerns. Attempts have been made to develop probabilistic models to help predict the behavior of munitions (migration, burial, and exhumation). However, the models are mostly limited to deeper underwater environments of the nearshore due to inadequate data for model validation (Rennie, 2017). The quantification of variable density munitions behavior in the swash zone remains poorly understood.

Figure 1 - Munitions on coastlines after decades underwater
Credit: Jonathan Pow (81mm on a UK beach)

Swash zone, the region extending from the beach face to the inner surf zone and characterized by the intermittent wetting and receding of waves is highly dynamic. The hydrodynamic processes in the swash-driving sediment transport can also impact the mobility and/or burial of objects such as munitions.

Biofouling, encrustation, and corrosion can alter the density of the underwater munitions, which consequently impacts the behavior of the munitions in the swash zone. Hence, this experimental study aimed to quantify the behavior of variable density munitions in the swash zone under dam-break scenarios. The findings of the study create more insights into the behavior of variable density munitions in the swash zone and can also serve as validation data for probabilistic models on munitions behavior in the swash zone under extreme events.

EXPERIMENTAL SETUP

A small-scale experiment was conducted in a double dam-break wave flume located at the Center for Applied Coastal Research, the University of Delaware between June 2021, and March 2022. Most prior dam break experimental set-ups are equipped with single-dam breaks where a gate is raised and the impounded water in the reservoir propagates onshore as a wave-bore. In this study, an additional gate and adjoining reservoir were incorporated to enable the generation of two incident wave bores on the swash with differential times (Fig 2).

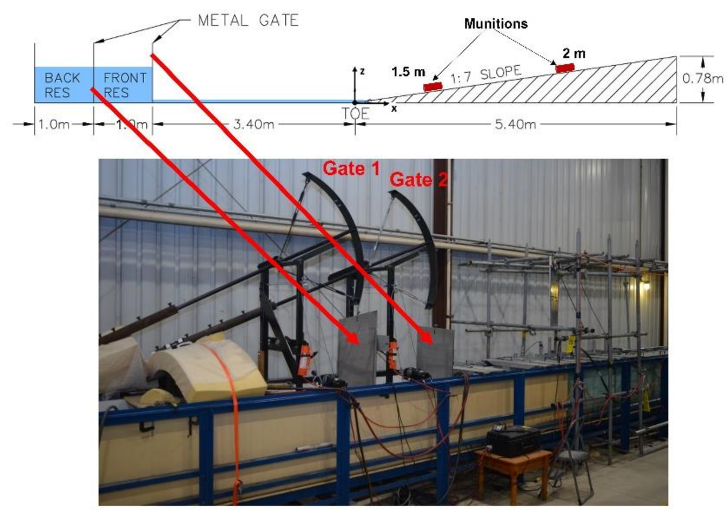

Figure 2 - Double dam-break experimental set-up a) Flume cross-section b) Gate area

Hydrodynamic trials with different gate-raising intervals were run to determine the combination that produces the biggest forcing condition. Case00, a case where the two gates are raised simultaneously produced the biggest forcing condition and this was subsequently used for the munitions experiment. The experimental flume section was 10.78 m long, 0.58 m wide, and 0.78 m deep (Fig 2). The double dam-break setup forcing, yields field-scale uprush velocities up to 2 m/s. The landward end of the flume contains a mobile sediment bed with a 1:7 slope and a median diameter (d_{50}) of 0.55 mm (Fig 2).

Five surrogate munitions cases with varying densities were tested: cross-sectional diameters 20 mm, 40 mm, 40 mm + R1, 40 mm + R2, and 40 mm + R3 (Fig 3). The R1, R2, and R3 indicate the ranks of Delrin coverings on the 40 mm munitions portraying the density changes due to biofouling, encrustation, and corrosion in natural environments. Each munition case was tested at two cross-shore locations - 1.5 m and 2.5 m - from the toe of the slope under five consecutive runs. Although both cross-shore locations are typical of swash zones, the 1.5 m location is farther offshore with the fluidization and bedform change likely to be the more dominant process influencing munitions burial and migration. Conversely, local scour is likely to be the more dominant process at the 2.5 m location. Five consecutive runs comprised a trial and after each trial, the bed was reset. Each munition case comprised three test trials, thereby implying 15 runs per munition case. A total of 150 munitions runs (30 trials) were conducted at initial proud and 50% burial depths while 35 hydrodynamic case runs (7 trials) were conducted. The hydrodynamics and munitions behaviors were quantified with current meters, water level sensors, pressure sensor arrays, and moisture sensors placed at different cross-shore positions in the flume.

Figure 3 - Variable density surrogate munitions

RESULTS

The averaged hydrodynamic runs observed at the toe of the slope (Station 7) show that the biggest wave bore velocities were >2 m/s (Fig 4). The velocities progressively decreased as the uprush traveled up the slope while the resulting backwash velocities were >1 m/s. The velocity time series produced a skewed-asymmetric shape (Fig 4) typical of inner surf zone velocities. The peak wave bore height at the toe of the slope exceeds 0.3 m (Fig 4) during propagation as afforded by the dam break mechanism rather than paddle-forced waves.

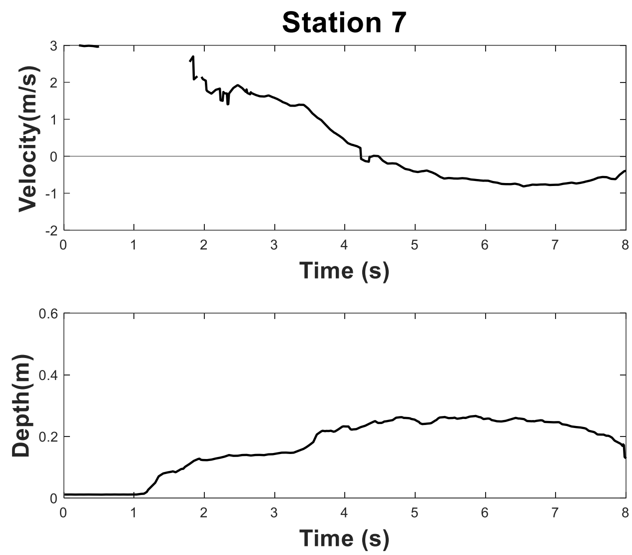

Figure 4 - Velocity and depth time series at the toe of the slope (Station 7)

The stochastic nature of munitions behavior makes it challenging to observe well-defined trends as a function of bulk density. Hence, the three trials comprising each munition case were averaged. Averaging the three trials for each munitions case better identifies the mean trend.

At 1.5 m to the toe, the smallest averaged migration (approx. 0.5 m) was observed in the 20 mm (biggest bulk density) and the biggest averaged migration (> 1.5 m) in the 40 mm + R2, - the munition type with the smallest bulk density at the 1.5 m location (Fig 5). Interestingly, the final mean positions after five runs of the 40 *mm* and 40 *mm* + R1 were essentially the same. The denser 40 *mm* with no covering recovered from the initial offshore movement to migrate onshore. Even the 40 *mm* + R2 experienced onshore migration for the 5th wave likely because it was at the inner surf/swash zone transition.

At 2.5 m to the toe, less averaged migrations (< 0.5 m) were observed in all cases (Fig 6). The smallest bulk density munition at the 2.5 m location (40 mm + R3) experienced the biggest average migration (Fig 6). At 2.5 *m* to the toe of the slope, hydrodynamic forces including backwash momentum were weaker leading to less migration with local scour processes being more important.

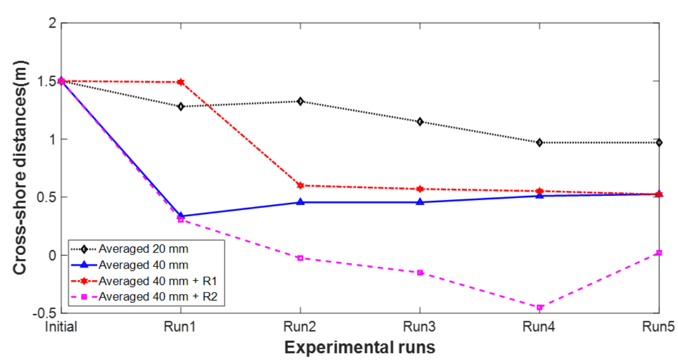

Figure 5 - Munitions trajectories at 1.5 m to the toe

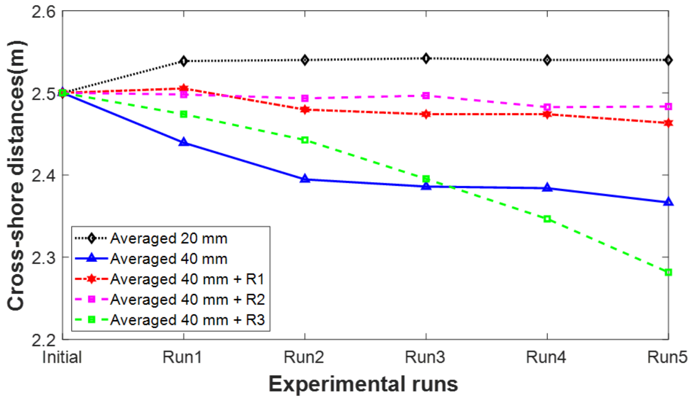

Figure 6 – Munitions trajectories at 2.5 m to the toe

The overall findings show that bulk density values impacted munitions migration regardless of initial burial status and cross-shore distance to the slope. Where net migration occurred, the 20 mm (biggest bulk density) migrated shorter distances than the 40 mm + R2: 0.1 m vs 0.8 m, respectively for proud cases at 2.5 m; 0.4 m vs 1 m for 50% burial cases at 1.5 m; and 0.7 m vs 1.4 m, for proud cases at 1.5 m. These observations will help to fill the parameter space related to bulk density for munitions behavior in the swash zone.

Finally, the observed general tendency of the munitions to move offshore despite the surge forcing conditions is presumably aided by gravity due to the steep slope of 1:7. Further research is needed to establish the role of gravity by observing the munitions under gentler slopes.

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