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Category

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The behavior of micro explosive charge underwater explosion near a rigid wall

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Abstract

The interactions between an underwater explosion and underwater structures is a research topic related to understanding strong impulsive forces for disaster preparation and prevention. This study is a part of series studying the behavior of underwater explosion bubbles near different boundaries and structures because understanding the boundary phases and the pulsation of bubbles could be a useful predictive tool. Micro explosive underwater explosions were conducted by detonating a very small amount of silver azide; the time evolution and attenuation of effects from the explosion were studied. Both numerical and experimental data were acquired and compared for underwater shock waves, gas bubbles and overpressures caused by the micro explosions.

Keywords: Underwater explosion; Shock wave; Bubble; Safety

Introduction

The bubble dynamics of underwater explosions has long been an important research field due to the need for mitigation and disaster prevention caused by industrial accidents associated with gas bubbles and liquid jet flows [1, 2]. Recent research has focused on the effect of impulsive forces due to liquid jets which have been observed to penetrate collapsing gas bubbles. The liquid and bubble interactions caused by underwater explosions with structures or objects nearby have not thoroughly examined the dynamic behavior of bubble pulsations, bubble motions and explosion cavities in fluid and bubble jet flows; structures or objects like oil platforms, offshore platforms, ships and submarines can be severely impacted by such interactions [3, 4, 5].

Liquid jets are extremely efficient in producing damage. Micro explosions behave similarly on a macroscopic level, but some important differences exist, most of which are from the nature of an explosion bubble [6]. If an explosion occurred close to a rigid boundary caused by a structure, a high velocity liquid jet is produced that penetrates the gas bubble of the explosion. To study these phenomena, small and scaled explosions were studied to obtain normalized parameters for converting to and predicting results for large-scale explosions.

The present study is part of a series of research initiatives on shock attenuation and hazard mitigation in complex media. This report presents an investigation on the propagation and mitigation of underwater explosion corresponding to gas bubble motions, incident shock pressures, bubble pulses and bubble jet flows using experimental and numerical methods.

Methods of underwater explosion experiments and visualizations

Fig. 1 shows the experimental setup of the underwater explosion equipment [7]. Explosions were generated by detonating silver azide (AgN_3) in small pellet form. These pellets were delivered as cylindrical charges each with a total mass of approximately 10 mg, and included a 1.5 mm diameter cylinder with an aspect ratio (length/diameter) of unity in which the AgN_3 was contained. Onto the charge was glued a 1.47 mm core diameter optical fiber (Mitsubishi Rayon Eska CK-60); illumination from a pulsed Nd:YAG laser (532 nm, 5 ns pulse duration, 85 mJ/pulse) was transmitted through the fiber and onto the pellet for initiating the explosions.

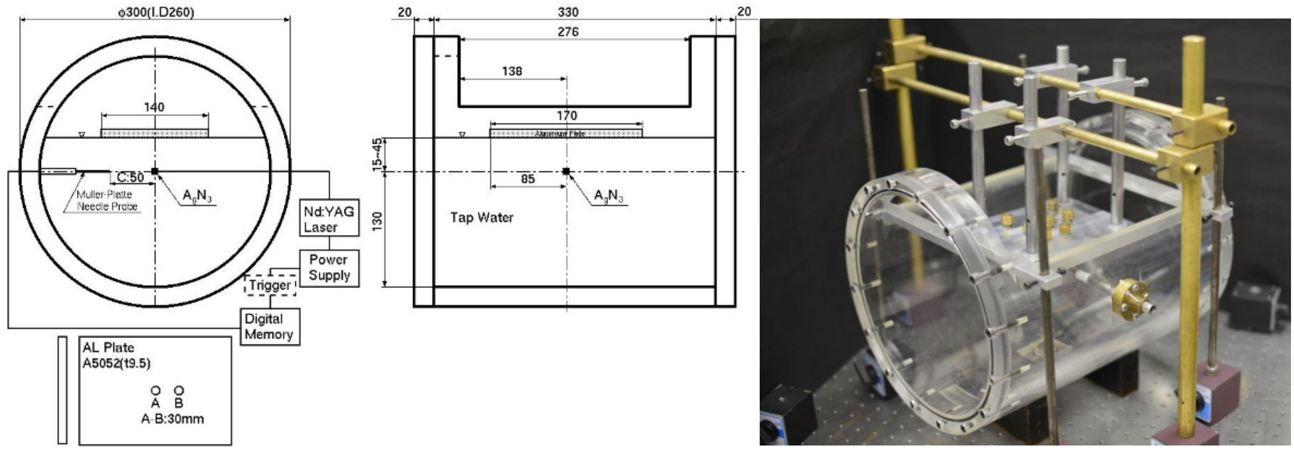

Fig. 1. Experimental setup for underwater micro-explosion experiments.

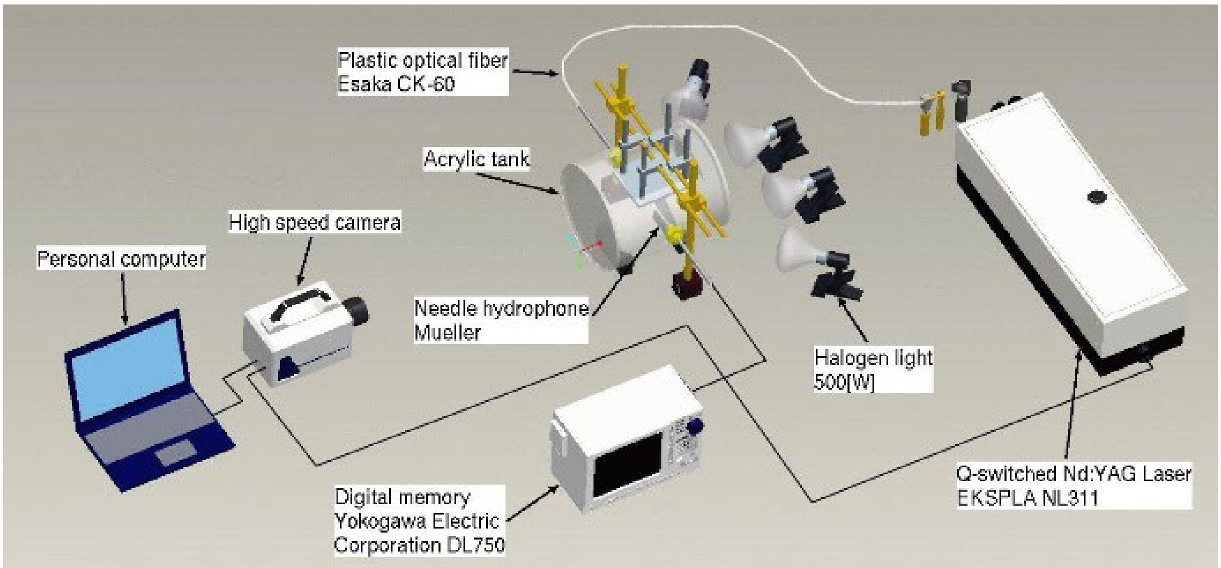

Fig. 2. Visualization of gas bubble motion by the back light or Schlieren method.

The silver azide pellets were placed horizontally at 15 to 45 mm from the free surface (charge depth) of the water. At the free surface was secured an aluminum plate having dimensions of 140 mm in length, 170 mm in width and 9.5 mm thickness. The hydraulic shock pressure caused by a micro explosion was measured using a piezoelectric polyvinylidenfluorid (PVDF) needle hydrophone (Müller-Platte-Gauge) that was placed 50 mm from center of the pellet, and dynamic pressures on the material surface were measured using a piezo-electric pressure transducer (PCB HM113A) at positions A and B in Fig. 1.

The micro-explosions formed bubbles and shock waves that were visualized by Schlieren imaging using a digital high-speed camera, as shown in Figs. 2 and 3. The high-speed camera was a Photoron Fastcam SA-1.1 with Shimazu HPV-2 used at frame rates between 30,000-to-1,000,000 frames per second (fps).

Numerical Simulation

Detonations and bubble behaviors interacting with a rigid boundary were numerically investigated using a multiple solver type hydrocode ANSYS® AUTODYN® [8]. An Eulerian solver was used and contained multiple components, including water, air, a solid surface and the gaseous phase of the silver azide explosion. The numerical region simulated was identical to the interior of the experimental cylindrical acrylic tank with an 80 mm inner radius; a 2D asymmetric numerical model was applied with the acrylic tank walls and the plate near the water surface, both of which were assumed to be rigid boundaries. The depth of the water, the AgN_3 charge weight and its position, and the pressure gauges were numerically set to be identical to the experimental conditions. The air region was 40 mm from the water surface and a flow-out

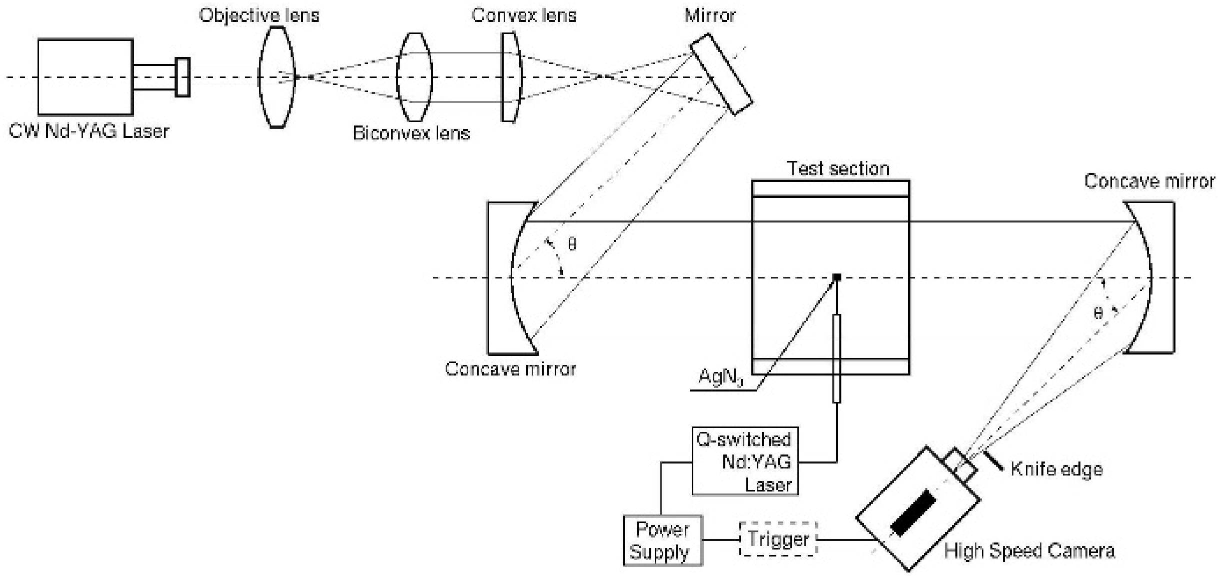

Fig. 3. Optical setup of the Schlieren imaging.

boundary condition was placed on the upper side of the air region. The numerical mesh size was uniformly 0.5 mm in the whole numerical model. Hydrostatic pressure gradients that depended on the water depth and gravitational acceleration were included in the simulations.

Before performing the simulations, the detonation phenomena of the silver azide pellets were numerically estimated by using a model only in the vicinity of the explosion with a mesh size of 0.02 mm. These numerical results were then transferred to the more expanded region encompassing the acrylic container with a coarser mesh size by using a "remapping" technique in AUTODYN. Hence, simulations used a sequential sequence from the explosions of the silver azide to the entire bubble behaviors within the container caused by the underwater explosive events.

A Mie-Grüneisen type, linear shock Hugoniot equation of state (EOS) and spall strength of −3 MPa were applied throughout the study. The water density at its surface was 10^3 kg/m^3. An ideal Gas EOS was applied to the standard state in air. For silver azide detonation, a JWL EOS was applied in addition to a constant 'on-time burning' model. Properties of the silver azide explosive were calculated by using KHT2009.

Results and discussion

Micro-explosions were used to demonstrate explosive shock loading expected for full-scale explosions. Experimental conditions of the underwater explosions were between 0.72 to 3 m/kg$^{1/3}$ and assumed to be from intermediate depths between 0.40 < Z < 5.55. Gravity effects were determined by the ratio of the period of the oscillation cycle of the bubbles to the square root of the ratio of charge depth and

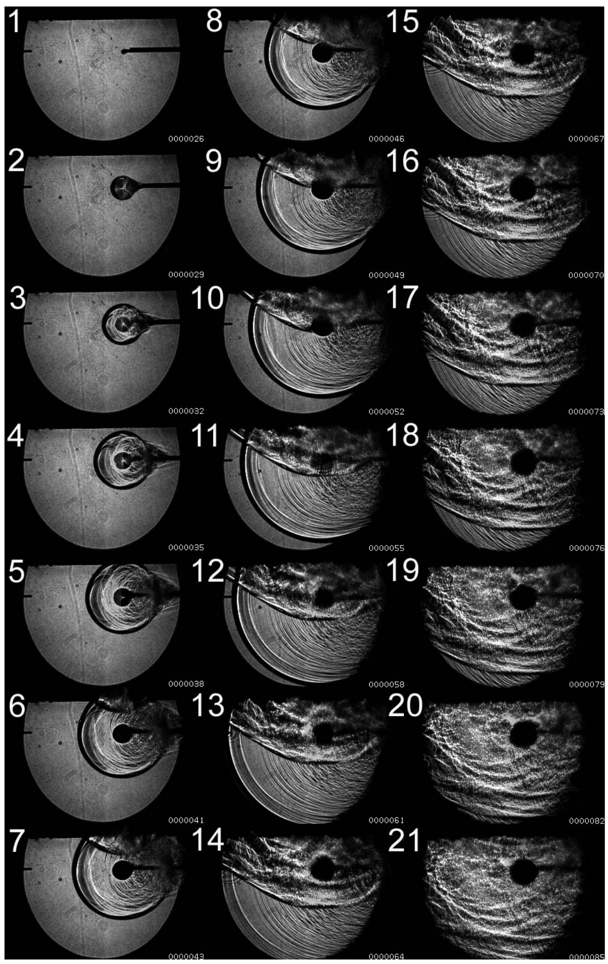

Fig. 4. Sequential Schlieren images near the rigid Al plate (Δt = 3 μsec).

gravitational acceleration, such that the Froude (Fr) number was smaller than 1 and typically between 0.06

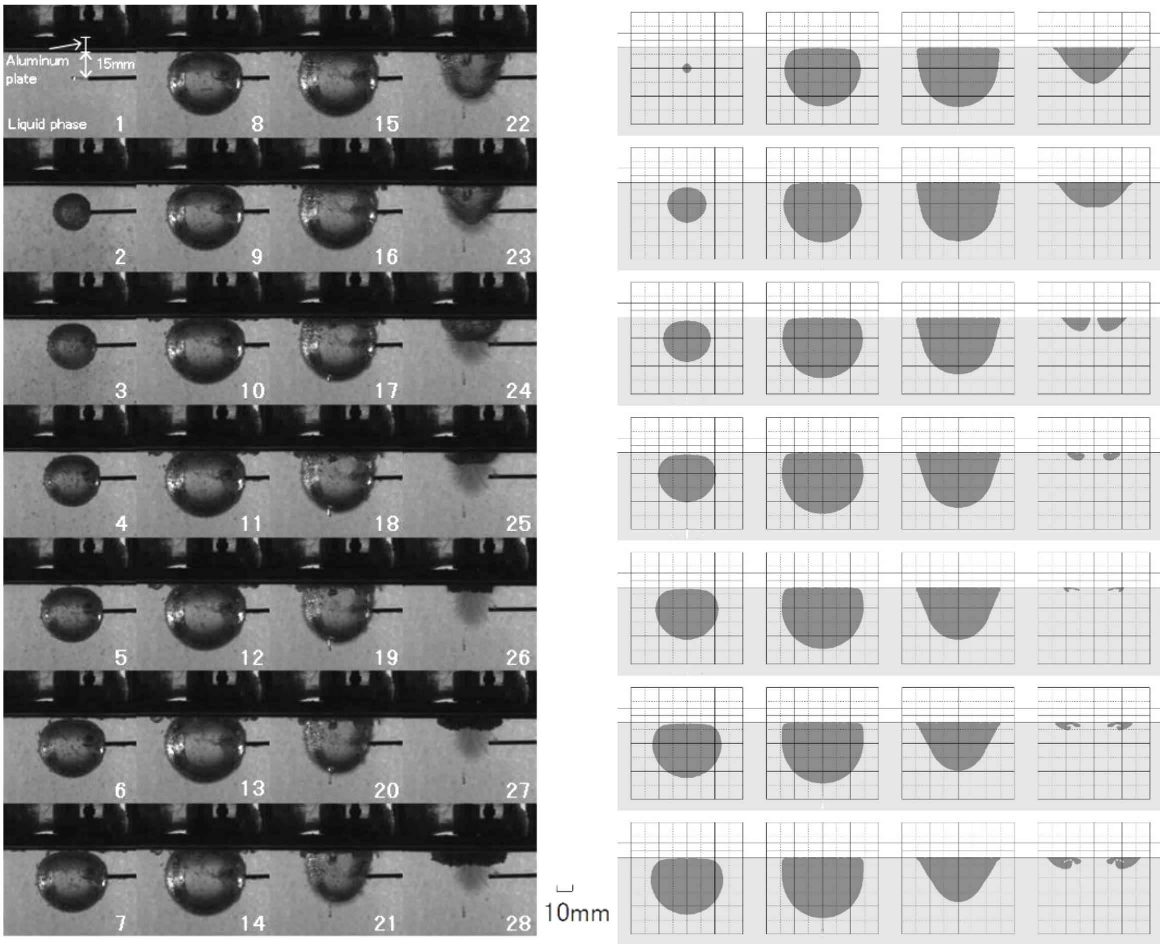

Fig. 5. Sequential photographs of the bubble motion near the rigid wall: (a) experiments, and (b) AUTODYN simulations, Δt = 0.2 μsec.

and 0.12; for these explosion conditions, gravitational effects are approximately negligible.

Fig. 4 shows sequential Schlieren images near the rigid Al plate. When the explosive was detonated, the shock wave traveled outwardly and its wave was reflected from the rigid Al surface. Measured incident shock speeds were 1436 m/sec. Reflected waves took over the underwater shock wave at rigid wall image frame 8, and after frame 10 fringes were observed which corresponded to refraction from the reflected waves and the cavitation clouds.

Figs. 5a and 5b show the sequential time transformations of a gas bubble near the rigid Al wall boundary for both experimental (Fig. 5a) and numerical (Fig. 5b) results. The gas bubble grew in size during images 1–12 and then the inside pressure began to drop which caused outward flow to stop when the boundary of the bubble began to contract, i.e. after image 12. The upper side of gas bubble was attached the Al surface and the bubble shape became an ellipsoid by the effect of interacting with the rigid boundary. After the maximum diameter of gas bubble, the pressure inside the gas bubble decreased, and a gas bubble began to contract. The gas bubble continued to move toward the Al rigid surface and collided with it in a strong upward flow. With impact, the bubble surface close to the Al was compressed and it was re-shaped into a different ellipsoid shape. As seen in Fig. 5a and 5b, as a whole, the computational results reflected very well the experimental results. However, a time difference did exist between the measured and the computed results.

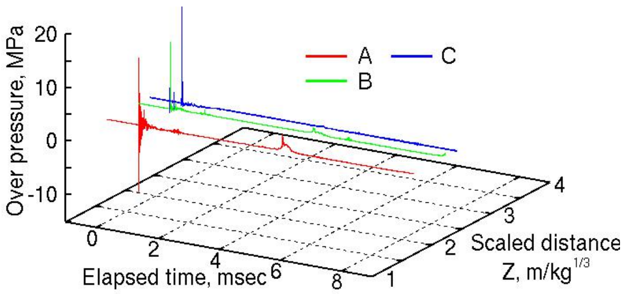

Fig. 6. Time and space variation of the over pressure near the rigid wall: A and B are over pressure at the Al surface and C is the hydraulic shock pressure.

Fig. 6 shows the time evolution of the experimentally-measured over pressure on the rigid wall at (A, B) and hydraulic shock pressure at (C). The pressure variation in C showed a first peak caused by impingement of the underwater shock wave, and then the pressure decreased quasi-exponentially until it attained a static value. At t = 4.8 msec, the bubble pulsations arose from a much slower effect than shock wave propagation. Fig. 7 shows an expansion of the time axis for positions A, B and C between 4 to 6 msec. The duration of the over pressure variations associated with bubble pulsation were very long when compared with the hydraulic pressure at C. The bubble pulsation pressures on the rigid wall at A were about 13 times greater than those at C.

Fig. 8 shows a comparison of the experimental and computed over pressure values at R = 50 mm. Differences exist that were related to peak shock pressures of the incident wave and reflected waves. Peak values of incident wave over-pressure and the reflected wave over-pressure had differences between 28% to 50%. One of the reasons for these differences could be related to a need to adjust the detonation properties of the silver azide explosive; the time variation of the pressure indicated a diffusive pressure profile.

Fig. 9 shows the time evolution of gas bubble diameters in which the experimental results were measured using the high-speed imaging camera whereas the numerical simulation results represent an averaged diameter from the volume of the gas bubbles. With the Al surface, the bubbles attained a maximum size at 2.4 msec and were both ellipsoid and spherical in shape. After the bubble's maximum size, they collapsed and rebounded by compression from the high pressure air region. The computational results contained time differences of between 1.2 to 1.9 msec versus the experimental results; this difference is expected to be a result of overestimating the micro-explosive properties in the numerical simulations.

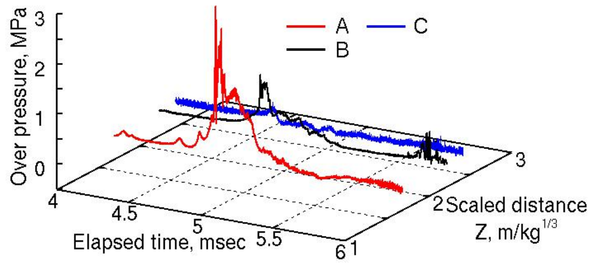

Fig. 7. Expansion of the time scale of bubble pulsation near the rigid wall: A and B are over pressure at the Al surface and C is the hydraulic shock pressure.

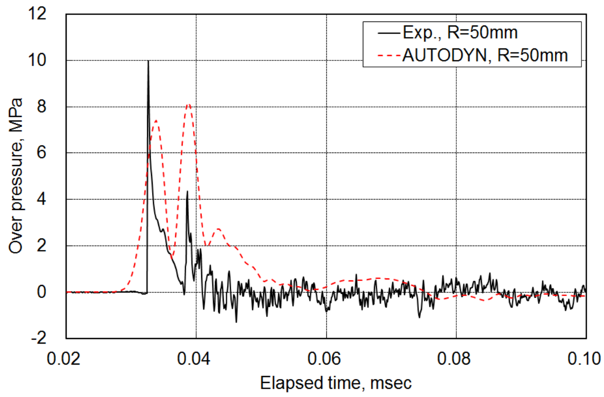

Fig. 8. Over pressure comparison at R = 50 mm from experimental and numerical results.

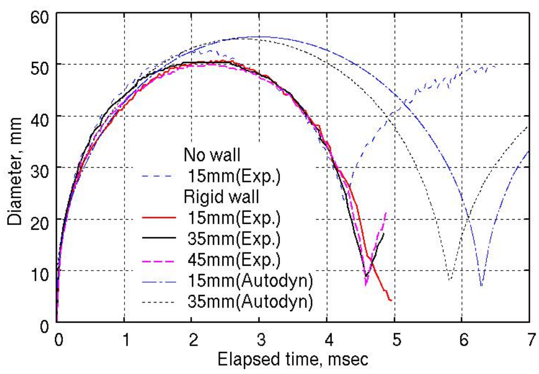

Fig. 9. Time variations of gas bubble diameter.

Conclusions

Underwater explosion experiments and simulations were performed using micro-explosions from silver azide pellets. The results point to strong shock waves, bubble jet and bubble pulse loads on a rigid Al plate within the water that, in full-scale explosion phenomena, could cause considerable destruction of structures within water.

During the micro-explosive testing from both experimental and simulation data showed the explosion caused gas in bubbles rapidly traveled toward an Al plate and then collided with it. The overpressure, i.e. ΔP_{max}, in bubble pulsations on the rigid Al wall was about 13 times greater than the hydraulic bubble pulse pressure; this difference represents a large influence that could cause destructive forces of structures in or under water. The experimental and simulation results mostly replicated each other, although some differences pointed to a potential need to reassess detonation properties of the silver azide for the numerical simulations.

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