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Experimental and theoretical research of the interaction between high-strength supercavitation impactors and monolithic barriers in water

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Experimental and theoretical research of the interaction between high-strength supercavitation impactors and monolithic barriers in water

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Abstract. The article describes experimental and theoretical research of the interaction between supercavitating impactors and underwater aluminum alloy and steel barriers. Strong alloys are used for making impactors. An experimental research technique based on a high-velocity hydro-ballistic complex was developed. Mathematical simulation of the collision the impactor and barrier is based on the continuum mechanics inclusive of the deformation and destruction of interacting bodies. Calculated and experimental data on the ultimate penetration thickness of barriers made of aluminum alloy D16T and steel for the developed supercavitating impactor are obtained.

Overcoming of distance in water with high-velocity body penetration and efficient overcoming of underwater barriers at depth is a complex technical task. A solution of this tack requires from researchers to develop new approaches. The aim of this work is to develop an experimental and calculation methodology for predicting the results of the supercavitating impactors (SI) interaction with underwater barriers, in particular their ultimate penetration thickness.

Experiments on the investigation of SI interaction with underwater barriers were carried out on the hydro-ballistic complex [1]. Preliminary studies of SI motion in water at velocities of more than 1000 m/s have shown that steel SI do not withstand loads and are destroyed when moving in water [2,3]. To solve this problem, it is necessary to use more durable materials, for example tungsten alloys, capable of withstanding loads when moving in water in the velocity range 1000 ... 1500 m/s [4].

Figure 1 shows the appearance of the SI sample developed for this purpose from the alloy tungsten + nickel + ferrum (WNiFe).

Figure 1. Appearance of the SI from WNiFe

The plates made of aluminum alloy D16T and steel were used as underwater barriers.

Figures 2 and 3 show the results of SI interaction with the barrier made of aluminum alloy D16T 40 mm thick after passing in water 3.2 m at the water entry velocity V = 1098 m/s. The external state of the inlet and outlet barrier bores suggests that the SI interaction with the barrier occurred at a right angle, which characterizes the stable water motion regime. The velocity of SI collision with the barrier is V_0 = 1022 m/s. The residual SI velocity after penetration of the barrier is 913 m/s. The high magnitude of the after-barrier velocity indicates an even greater supply of the impactor kinetic energy.

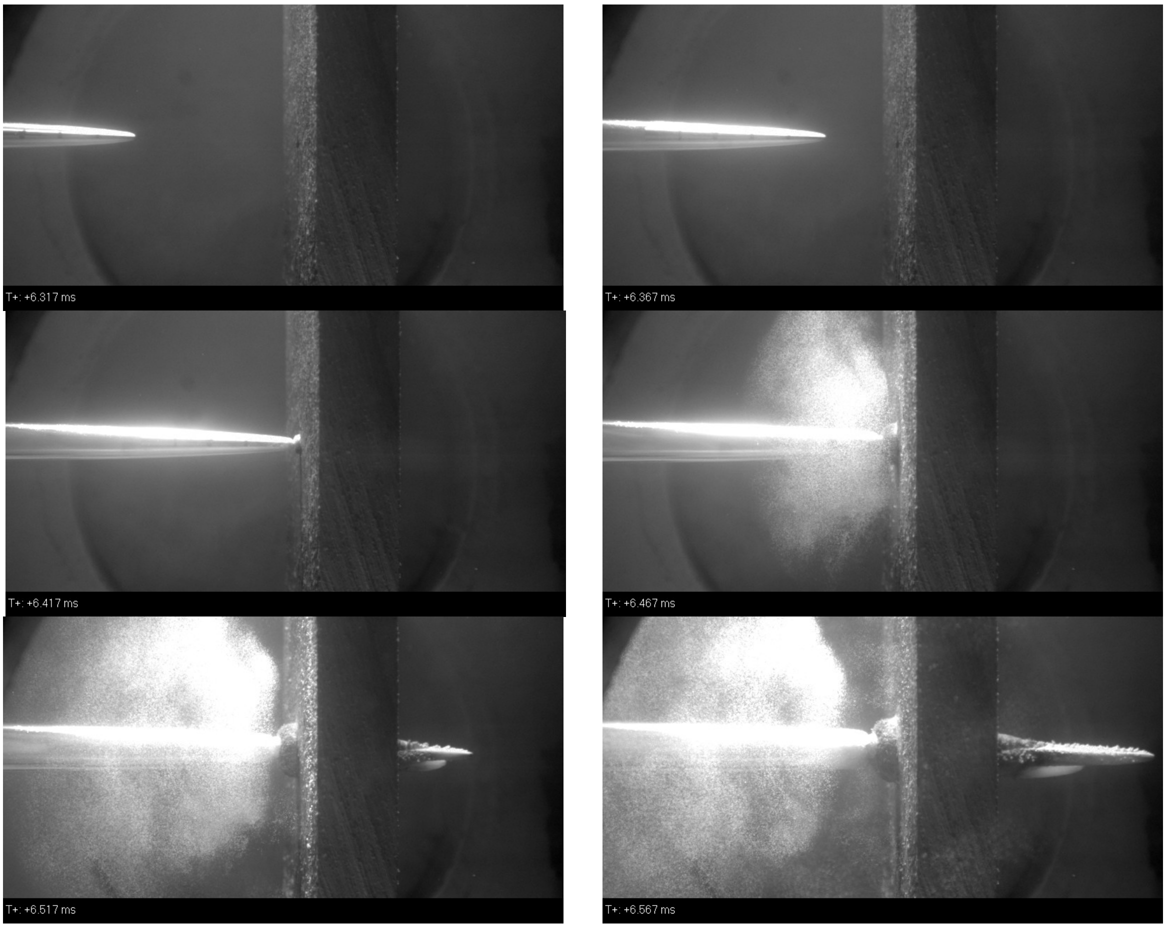
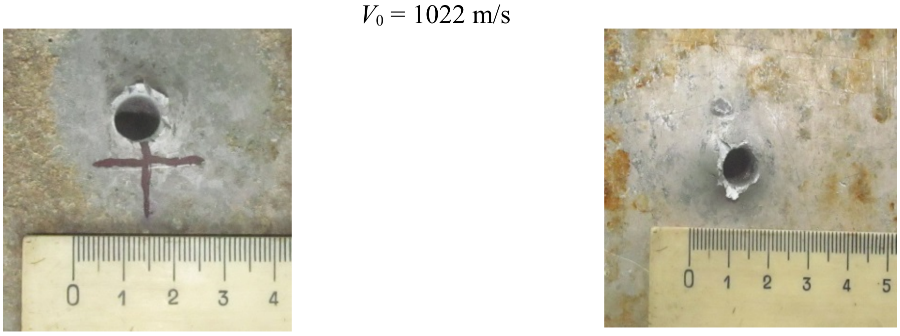


Figure 2. Photographic record of SI interaction with barrier made of alloy D16T thick 40 mm at V_0 = 1022 m/s



a *b*

Figure 3. Result of SI collision with barrier made of alloy D16T thick 40 mm at V_0 = 1022 m/s: *a* – inlet bores; *b* – outlet bores.

An analysis of the SI penetration interaction with the barrier is carried out using a mathematical model describing the collision process in the continuum mechanics framework [5] in an axisymmetric statement by the large particles numerical method [6] and a complete dimensioned formulation by a numerical finite element method [7, 8].

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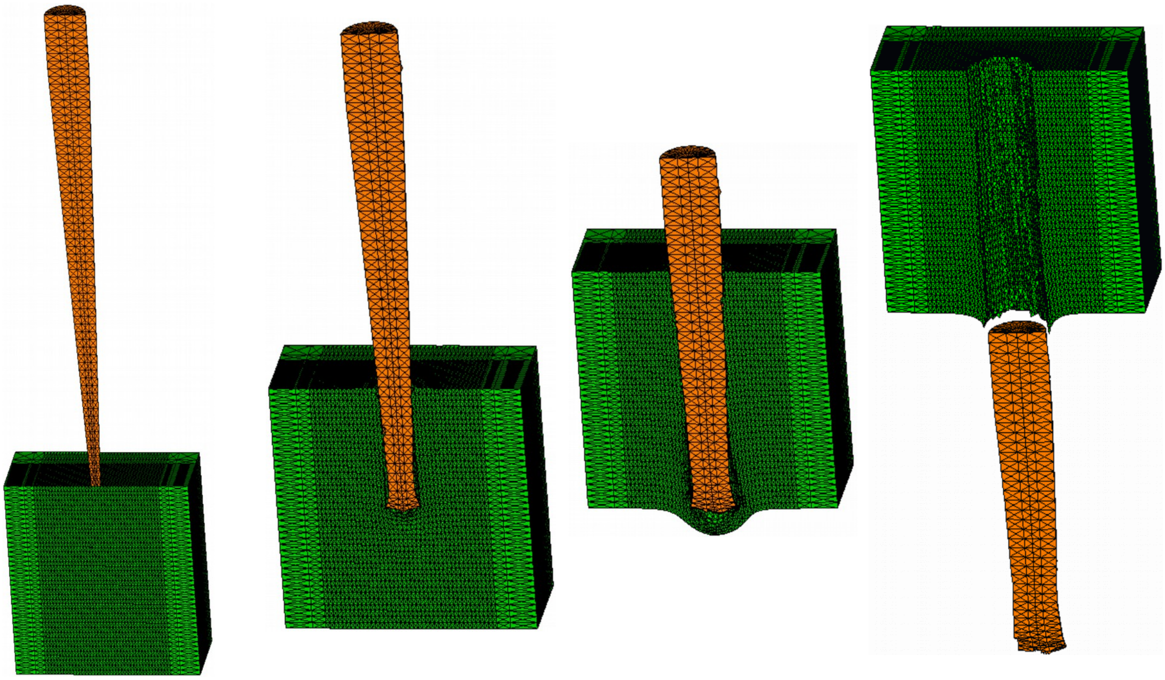
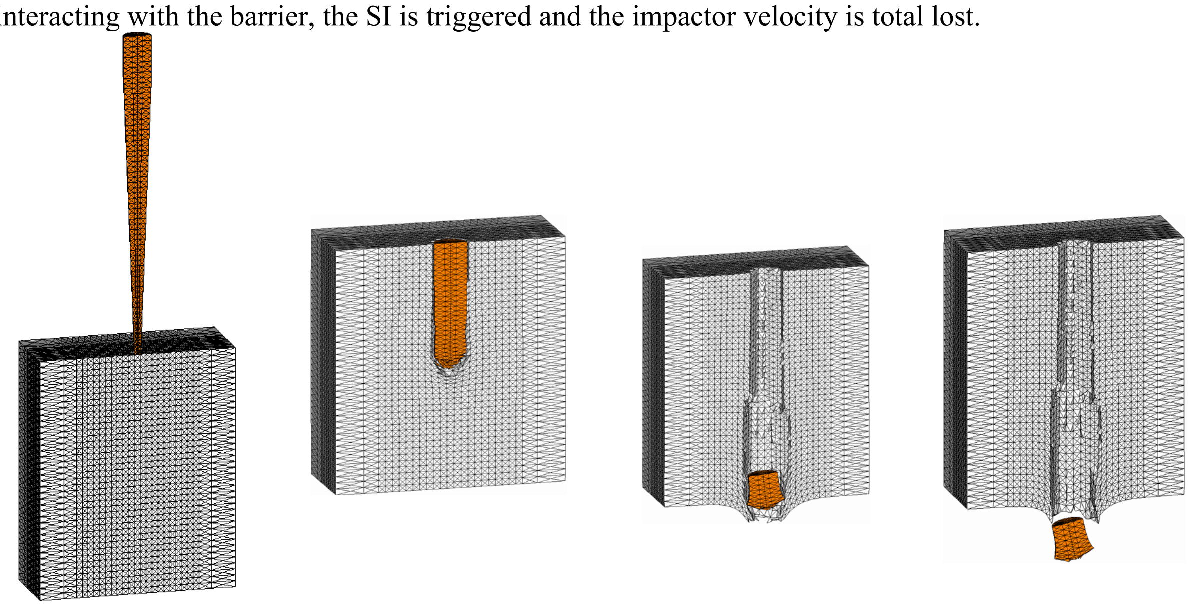
Figure 4 shows the results of mathematical modeling under conditions that repeat the experiment described above. The interaction process lasts about 150 microseconds. The impactor hole through the barrier. In this case, it deforms at the head, acquiring a shape close to cylindrical. In the penetration process it loses velocity to 858 m/s. The discrepancy of after-barrier velocity with the experiment was 6 %.



0 µs 40 µs 80 µs 150 µs

Figure 4. Chronogram of SI collision with barrier made of alloy D16T thick 40 mm at V_0 = 1022 m/s

By mathematical modeling the limiting penetration thickness of the barrier from the alloy D16T is determined. This thickness for the SI at the impact velocity V_0 = 1022 m/s is 83 mm (Figure 5). When interacting with the barrier, the SI is triggered and the impactor velocity is total lost.



0 µs 100 µs 200 µs 242 µs

Figure 5. Chronogram of SI collision with barrier made of alloy D16T thick 83 mm at V_0 = 1022 m/s

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Figures 6 and 7 show the experiment results where the water entry SI velocity is $V = 1131$ m/s and SI interaction with the compound barrier. The first barrier is a steel plate 45.4 mm thick; the second barrier is plate of D16T alloy 40 mm thick as "marker" at a distance of 195 mm from the first. After passing through the water at 3.2 m, the SI velocity when touching the barrier was $V_0 = 1054$ m/s. The SI breaks the first barrier through and leaves a small depression which is the "marker". The movement of the spall steel barrier fragment is also recorded.

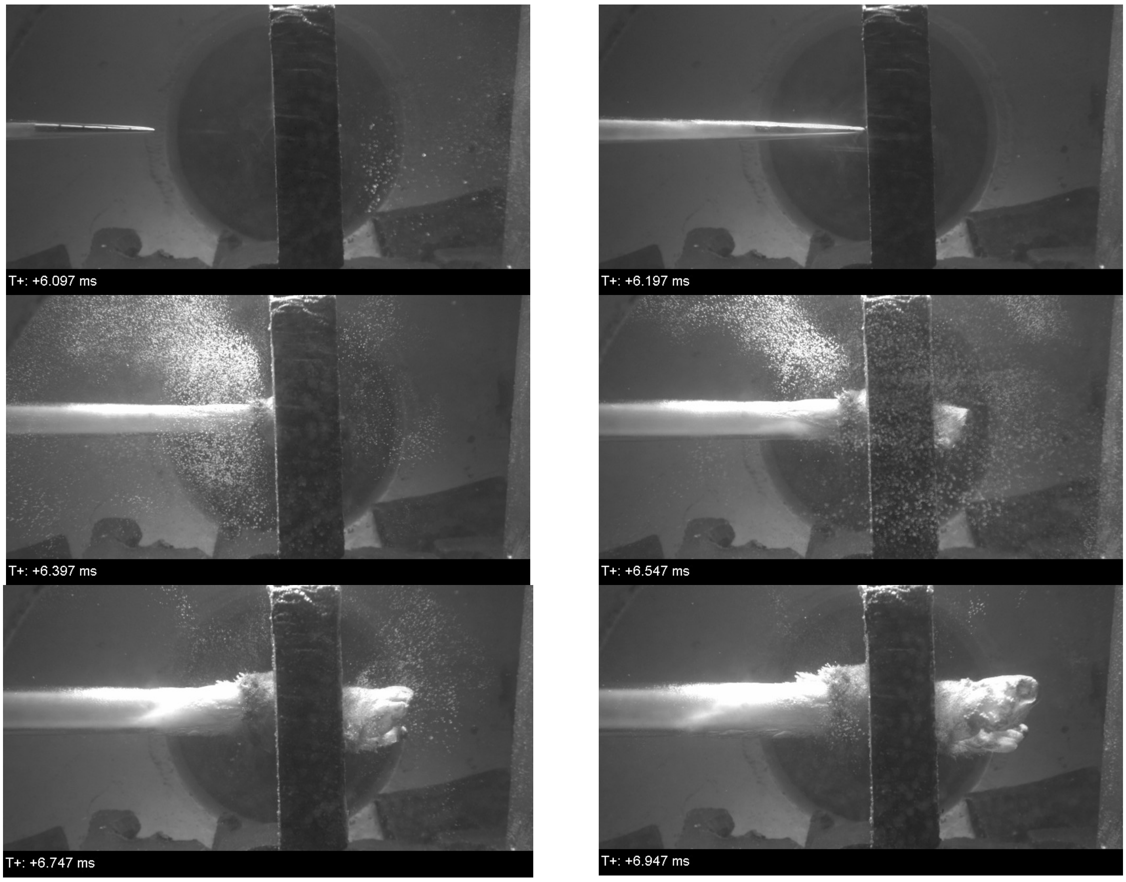

Figure 6. Photographic record of SI interaction with steel barrier 45 mm thick at $V_0 = 1054$ m/s

a *b* *c*

Figure 7. Result of SI collision with steel barrier 45 mm thick at $V_0 = 1054$ m/s: *a* – inlet bores; *b* – outlet bores, c – crater on the barrier «marker» face.

Figures 8 and 9 show the mathematical simulation results of the collision the SI and the compound barrier under repeating experiment conditions in the cylindrical coordinate system *z* (cm), *r* (cm) as the distribution of the mass velocity vector related to the mass center velocity of the projectile V_c (in the left half-plane), pressure distribution (GPa) (in the right half-plane) as a function of time *t*.

The steel barrier penetration process lasts about 200 microseconds. Firstly, the impactor pierces the barrier and further deforms at the head, acquiring a compact shape. When moving to the barrier rear side, impactor pushes ahead a steel barrier fragment as called - a "cork". A burn through was formed in the barrier. The impactor rest weighing 57 grams and the steel "cork" interact with the "marker" barrier at a speed of 201 m/s lasts about 150 µs until their full stop in the barrier at insignificant depth.

The analysis results show that the steel plate 45.4 mm thick is broke through by the SI almost at the limit of through penetration. It has been experimentally established that when the impact velocity of the SI is reduced to 894 m / s, penetration of the same barrier is not observed.

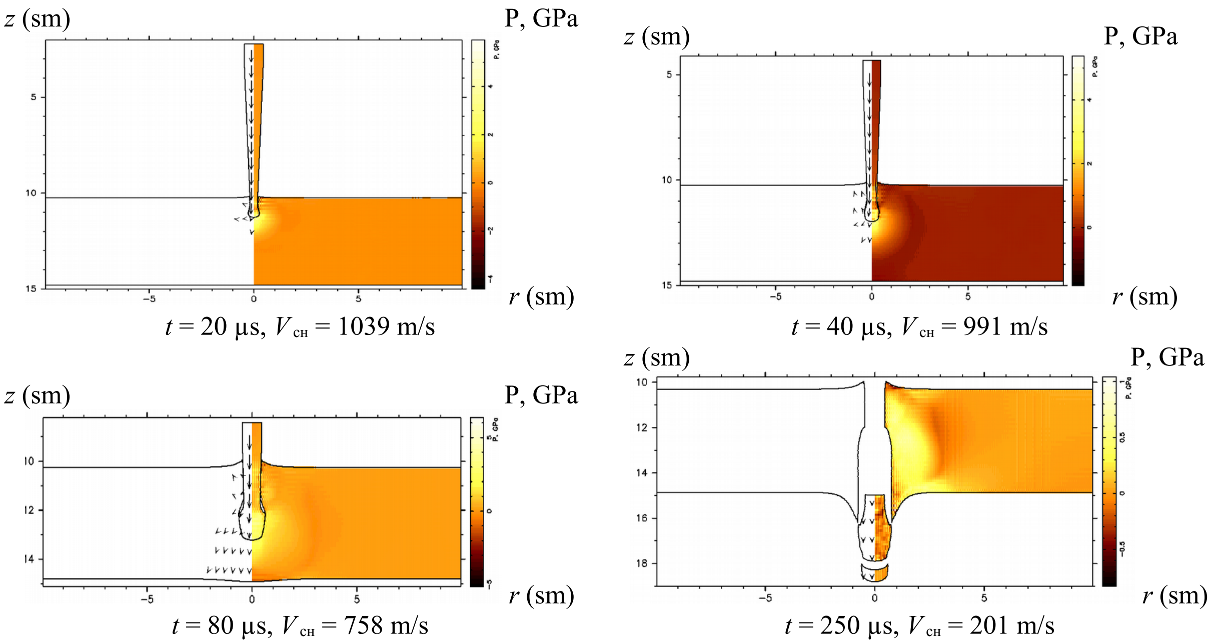

Figure 8. Chronogram of SI interaction with first steel barrier 45.4 mm thick at V_0 = 1054 m/s.

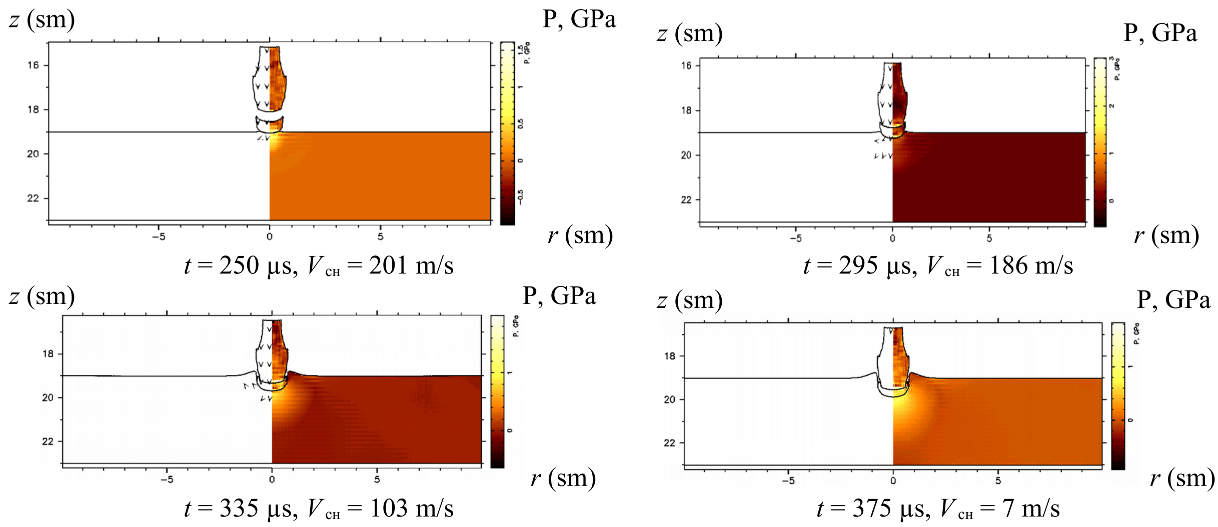

Figure 9. Chronogram of SI fragments interaction of SI and first barrier fragments with «marker» barrier at $V_{сн}$ = 201 m/s

Thus, the calculation and experimental technique for investigation of the interaction of the SI with underwater barriers was developed on the basis of the high-speed hydro-ballistic complex. For the numerical realization of predicting the interaction of the SI with underwater barriers, methods for dynamical interaction of impactors and barriers have been developed in the axisymmetric statement by the large particles numerical method and the complete dimensioned formulation by the numerical finite element method in the framework of continuum mechanics with allowance for the deformation and destruction of interacting various materials bodies.

The calculated and experimental data about the ultimate penetration thickness of barriers from aluminum alloy D16T 83 mm and steel 45 mm at the impact velocity of about 1000 m/s for the developed SI are obtained.

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