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Numerical modeling of underwater explosion by 1-Dimensional ANSYS-AUTODYN

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My research experiences

- Master Degree
- 2004-2008; China Ordnance Industry Booster Explosive Testing Center, North University of China; Supervisor, Prof. Wang Jingyu and Prof. Zhang Jinlin
- Nano crystalline HNS by Prefilming twin fluid nozzle precipitation using in EFI, Papers published in PEP, Journal of Hazardous Mat & ICT conferences.
- PHD
- 2008 to now, State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology; Supervisor, Prof. Jiao Qingjie
- ***Underwater explosion*** (former); Thermal decomposition dynamics and mechanism of nano-metallized explosive & propellants

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Outline

- **Background and objectives**
- **Typical problem-6.831g TNT under 100m**
- Mesh and boundary condition
- Peak pressure and time constant
- The impulse and energy flux density
- The first bubble maximum radius and period
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- Mesh size and cases
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- The impulse and energy flux density
- The bubble pulse properties
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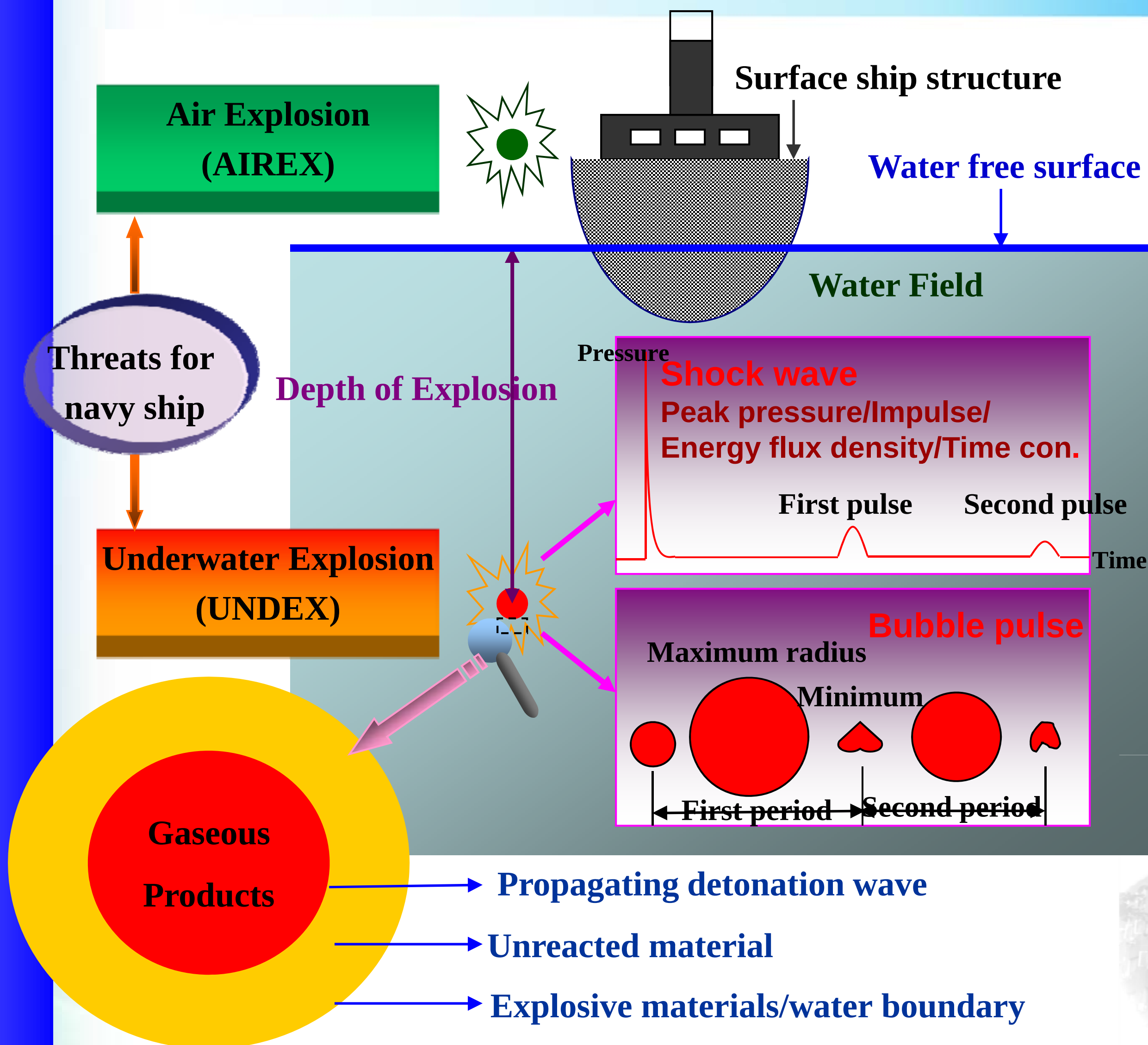
Background and Objectives



Key attributes: Ship's Anti blast Design & Analysis; Obtainable & Observable.
UNDEX Experiment: Expensive , Dangerous.
Analytical solutions: limit to very simple case.
Numerical simulation: time & cost saving.
Code: ALE3D; ABAQUS; LS-DYNA;MSC/DYTRAN ; DYSMAS; AUTODYN.
Problems: Unmatchable.
AUTODYN: 1D "wedge";

Validate the feasibility & accuracy of AUTODYN for UNDEX modeling

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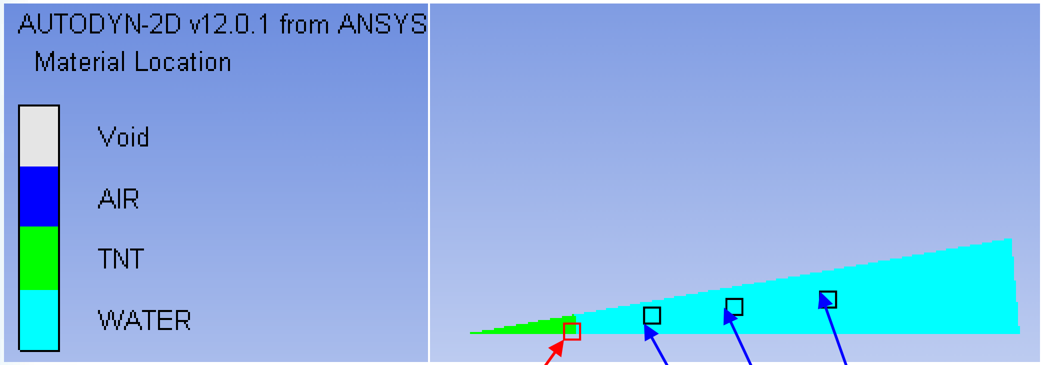
Typical problem-6.831g TNT under 100m

- 1-Dimensional wedge model—A simple model



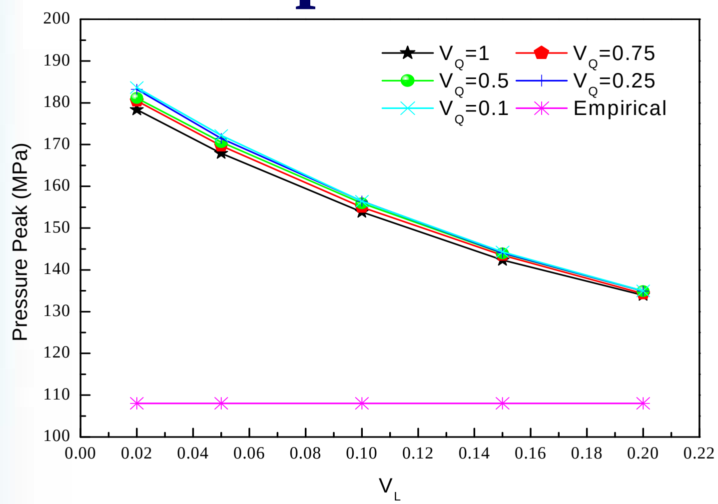
TNT was simplified to a spherical charge in the model. The shock wave reflection of free water surface was neglected.

- Mesh and boundary condition

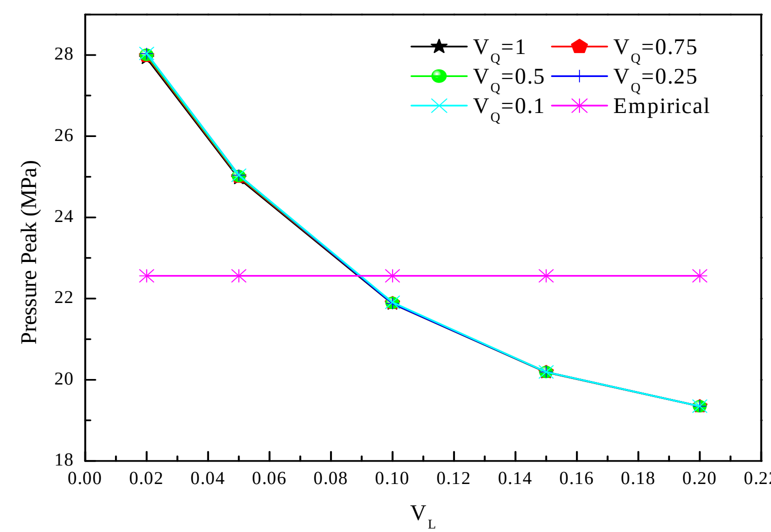
- Maximum radius of models were 20m with the “flow-out” boundary condition and the total mesh number was 18,000.
- Mesh size from center of TNT charge to 1m was 0.2mm.
- Mesh size was graded outward gradually for the remnant fluid domain.
- A gauge was located at the gas/water interface to capture the bubble period and radius (moved). The other gauges were fixed in the water domain range from 100mm to 2000mm to record the pressure time history (unmoved).

• Effects of quadratic and linear viscosity

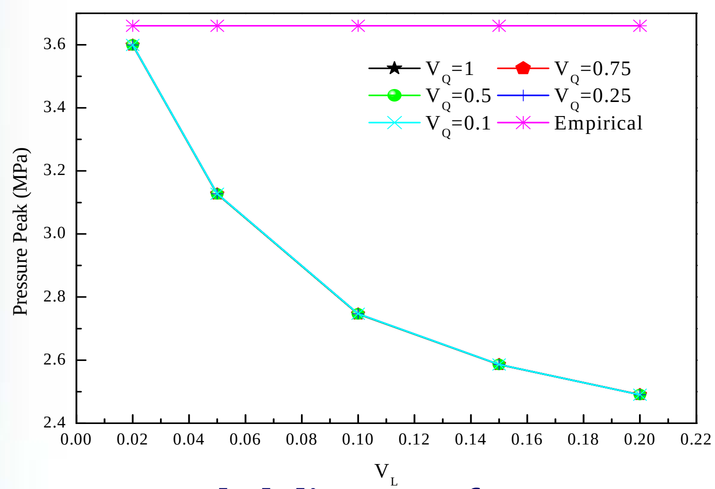
• Peak pressure



Scaled distance of 0.527



Scaled distance of 2.108



Scaled distance of 10.54

- V_Q: 1, 0.75, 0.5, 0.25 , 0.1 ;V_L: 0.2, 0.15, 0.1, 0.05 and 0.02
- Quadratic viscosity almost has no influence on the peak pressure
- The peak pressure increases rapidly with the decreasing of value for all scaled distances.

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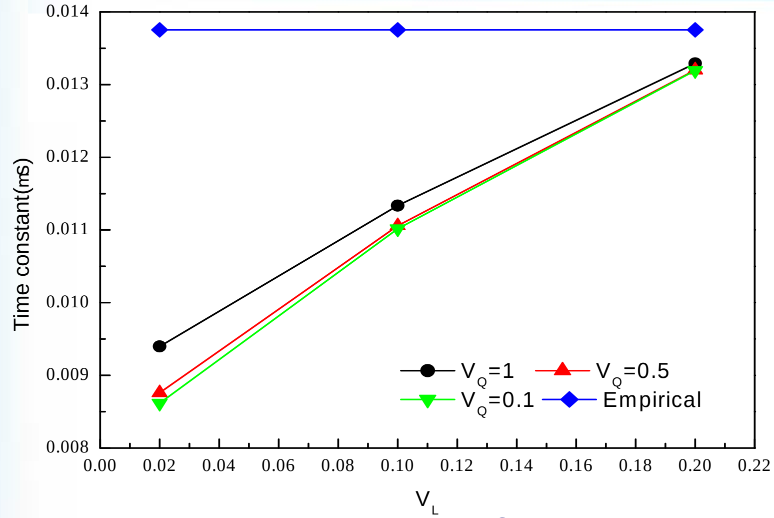
• Peak pressure

- Exists a value different from each scaled distance, with which the peak pressure equal or near to the empirical value.

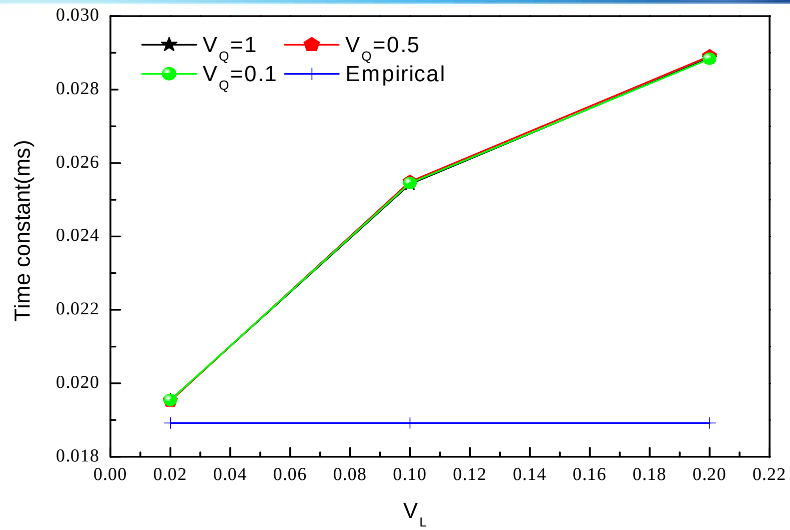
SD(m/kg$^{1/3}$)	0.527	1.054	1.581	2.108	3.689	5.27	10.54
V_L	0.2	0.2	0.12	0.08	0.05	0.04	0.02
V_Q	1	1	1	1	1	1	1

- May be a fixed value for given spans of scaled distance where the predicted peak pressure can agree with the empirical value in the acceptable extent.

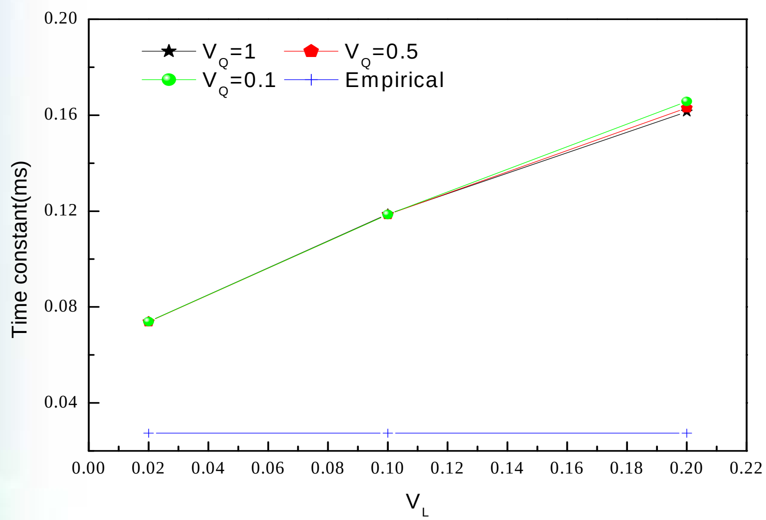
• Time constants (TC)



Scaled distance of 0.527



Scaled distance of 2.108

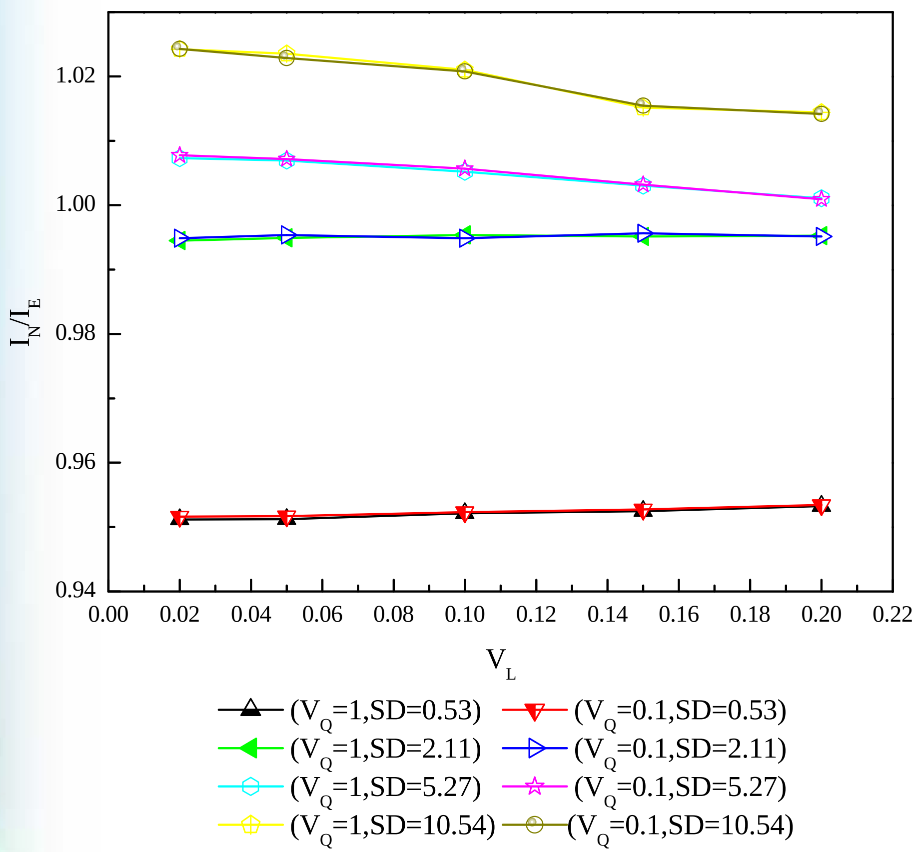


Scaled distance of 5.27

- Effects of V_Q and V_L on time constants are similar to the tendency of peak pressure.
- Simulation results of time constant can no be used in the calculation of Impulse…..

• Impulse of shock wave

- Poor modeling accuracy of the TC, empirical value of TC was used in the calculation of impulse and energy flux density.



- The V_Q and V_L have slight influences on the values of impulse in different scaled distance.
- The predicted values are near to the empirical values within 2%.

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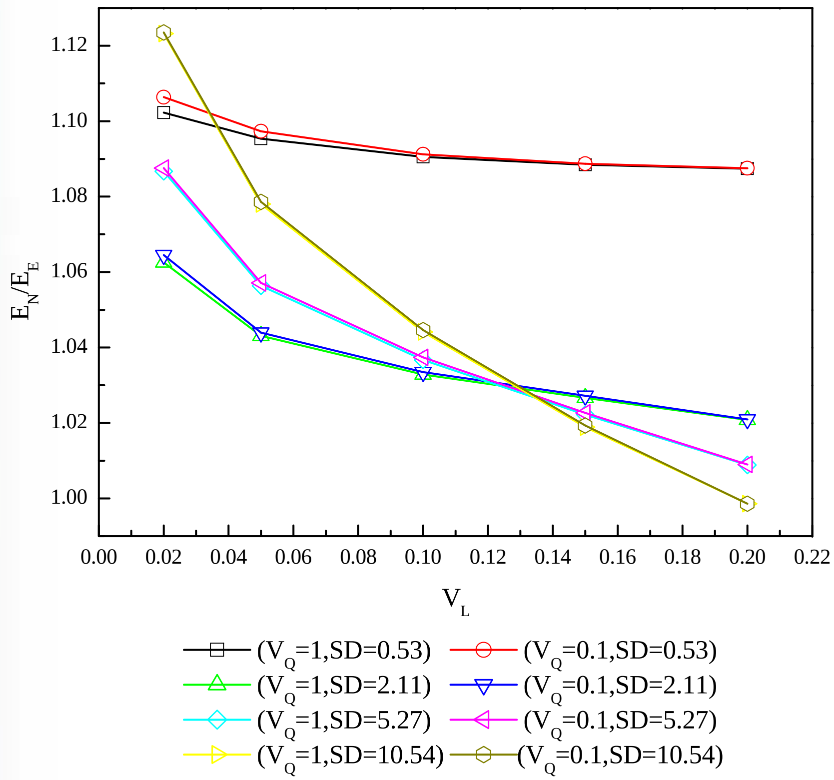
Energy flux density (EFD) of shock wave

- Climb for shock wave pressure history, use $P=0.1P_m$ as the start point of integration for impulse and energy flux density.



- V_Q also almost no effect on EFD
- V_L influences significantly on the EFD, especially for the larger scaled distances.
- The simulated values of EFD are also in acceptable agreement differing by less than 12%.

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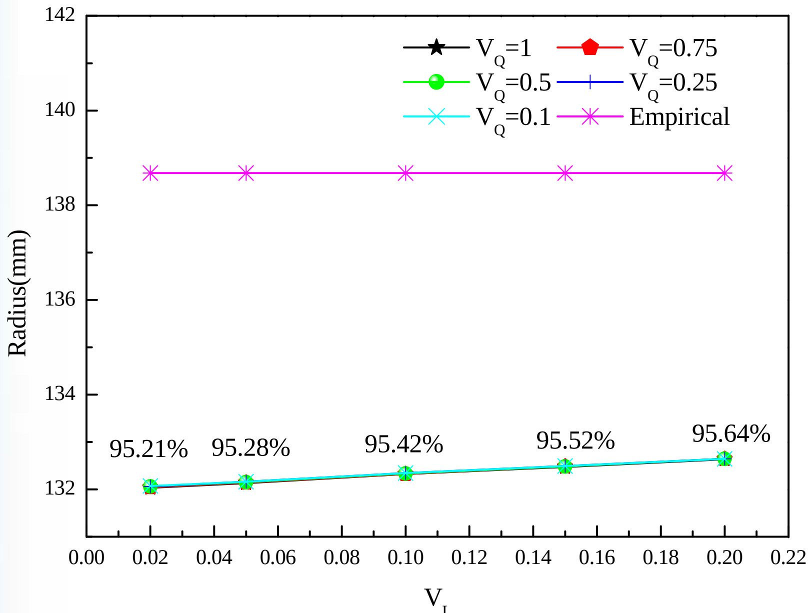
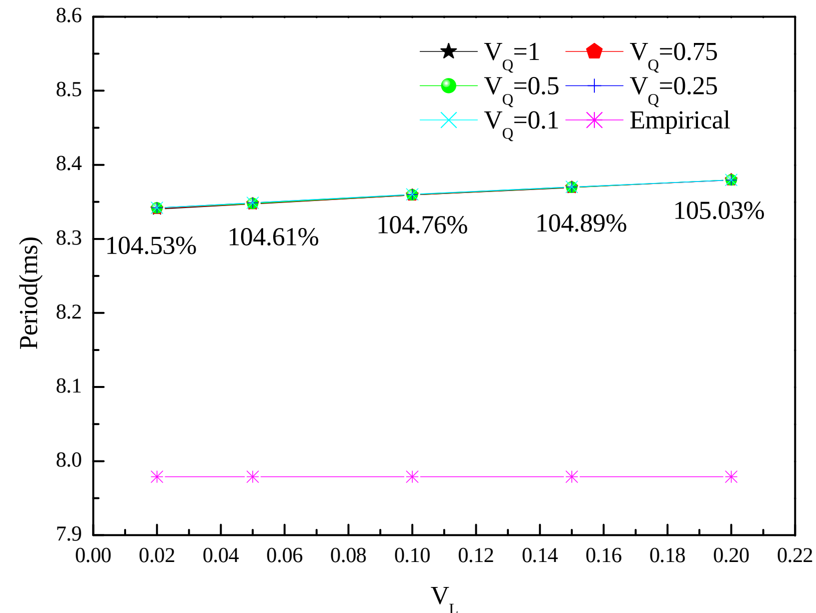
• The first bubble maximum radius &period





- Agree well with the empirical values by less than 5%
- Radius & period grow slightly with the increasing of V_L
- Comparable to the results of 2D axisymmetric AUTODYN Euler model considering pressure gradient and gravitational acceleration in the water field[1].

1. Abe A. and Katayama M.. 2007, Numerical simulation on underwater explosions and following bubble pulses. Symposium on Shock Waves (In Japanese). pp.319-322

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Effects study for underwater explosion

- **Introduction**
- V_L has vital effect on peak pressure modeling of TNT UNDEX. V_Q has almost no influence.
- Existing appropriate V_L (0.02 to 0.2) for some ranges of scaled distances in given grid sizes that key attributes are in acceptable agreements.
- Find this appropriate value using in UNDEX numerical simulation.
- Even though obtaining the value for typical problem, it is also doubtable that this value is applicable and feasible for different charge weights, charge depths and different explosives.
- Confirmation of the validity of the selected V_L for TNT, H-6, Pentolite and PETN with variable charge weight detonated in different water depth (with the empirical values).

Mesh size and cases

- 1D "wedge" model and flow-out boundary condition
- Combination of computation time and comparable of results, different reasonable mesh sizes were used for various ranges of charge weights.

Numerical mesh size for different charge weights

Charge weight (kg)			Mesh size for charge & water domains (mm)
0.001	0.01	0.05	0.5 (300m depth)
0.05	0.5	2.5	1.5 (300m depth)
2.5	25	125	4.5 (300m depth)
125	1250	5000	14.5 (300m depth)

Cases for effect of charge weight and depth on bubble pulse

Weight (kg)				Depth (m)			
0.01	0.5	25	1250	100	200	500	1000

- Refinement: V_L for SD from 3 to 10 was 0.34, from 1.5 to 3 was 0.68, for SD smaller than 1.5, take the default value. V_Q take the default value.

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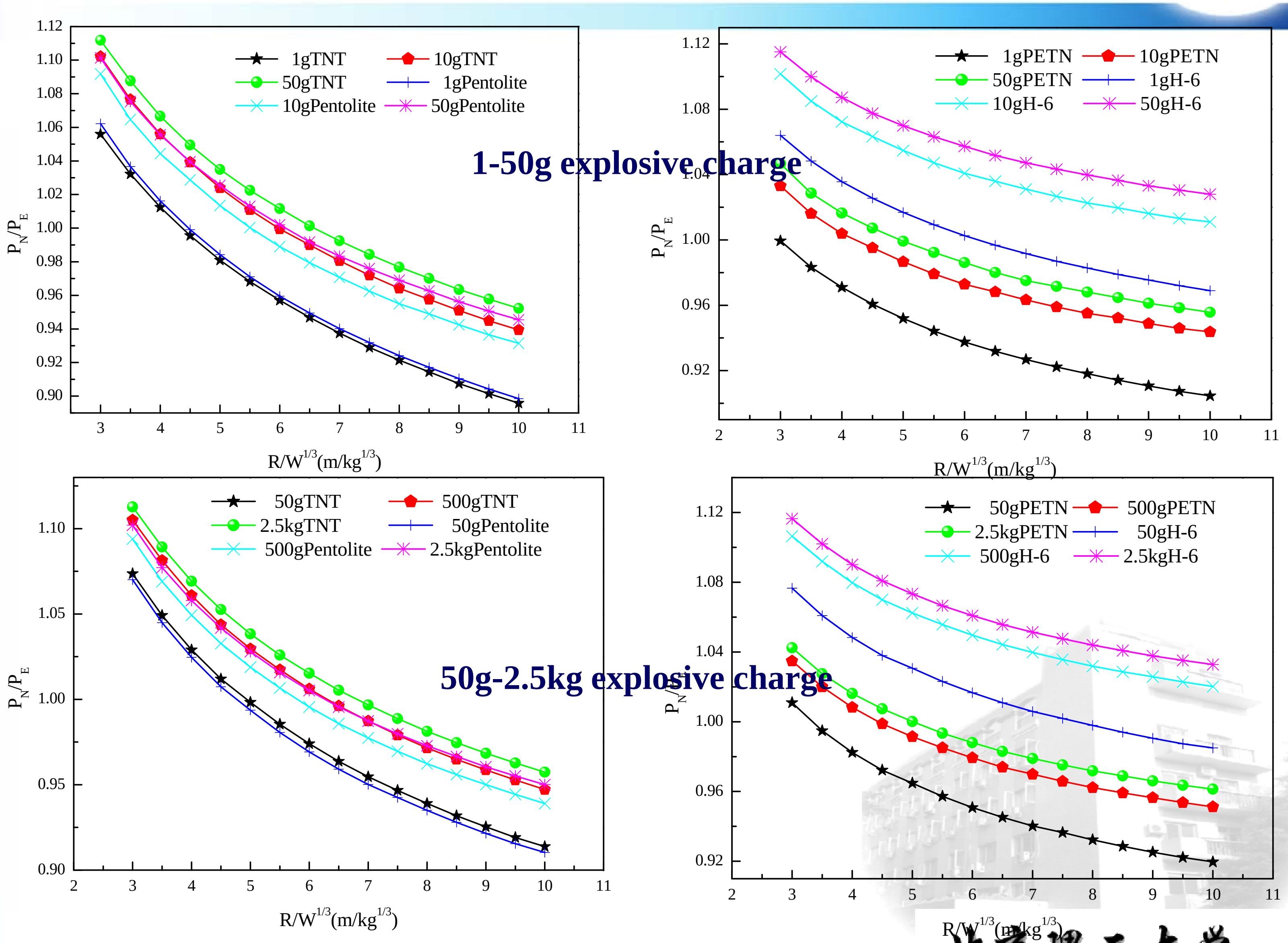
• Variations of peak pressure (SD 3-10)

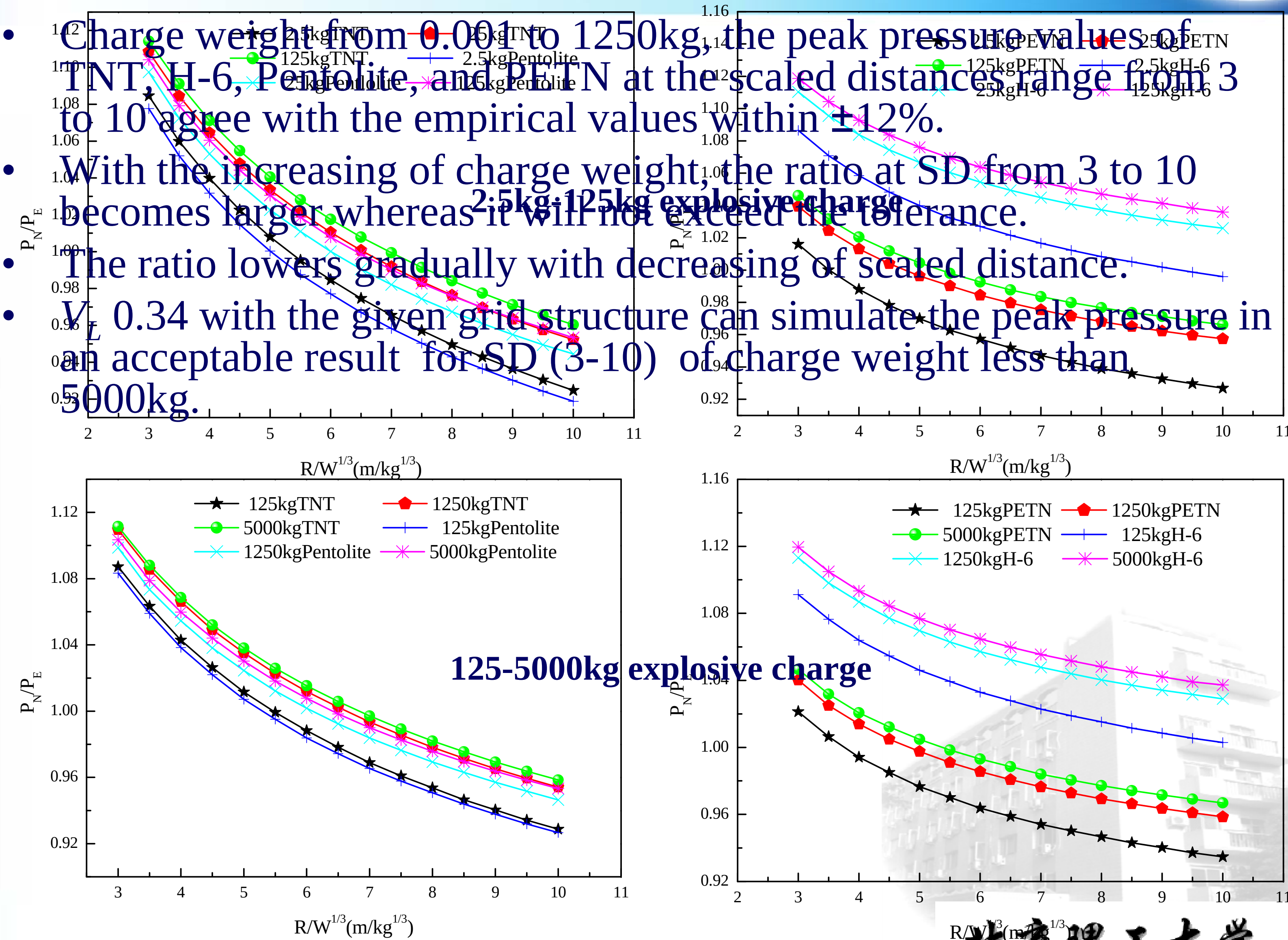


1-50g explosive charge

50g-2.5kg explosive charge

• Variations of peak pressure (SD 3-10)

- Charge weight from 0.001 to 1250kg, the peak pressure values of TNT, H-6, Pentolite, and PETN at the scaled distances range from 3 to 10 agree with the empirical values within ±12%.
- With the increasing of charge weight, the ratio at SD from 3 to 10 becomes larger whereas it will not exceed the tolerance.
- The ratio lowers gradually with decreasing of scaled distance.
- V_L 0.34 with the given grid structure can simulate the peak pressure in an acceptable result for SD (3-10) of charge weight less than 5000kg.



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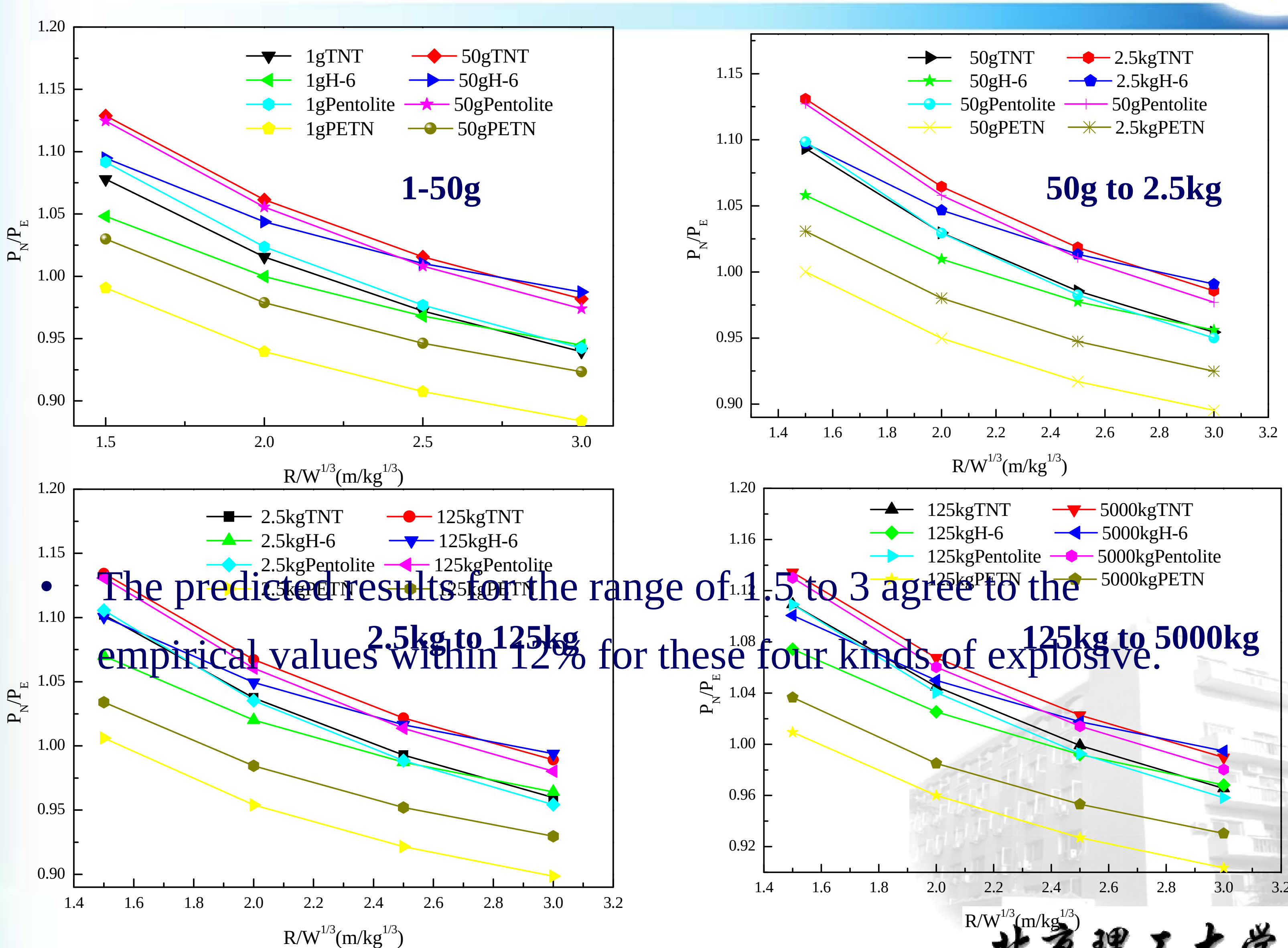
• Variations of peak pressure (SD 1.5-3)



• The predicted results for the range of 1.5 to 3 agree to the empirical values within 12% for these four kinds of explosive.

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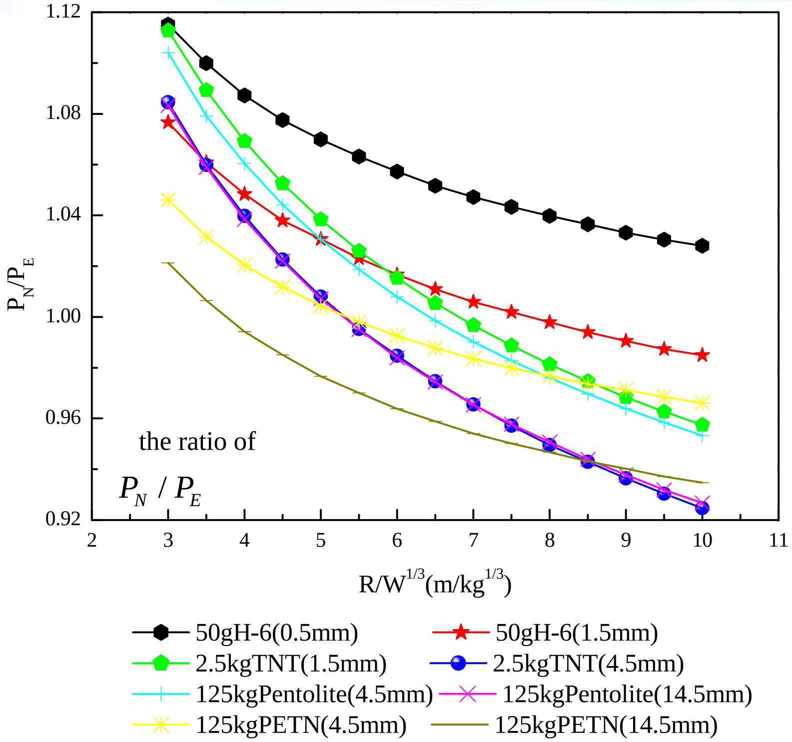
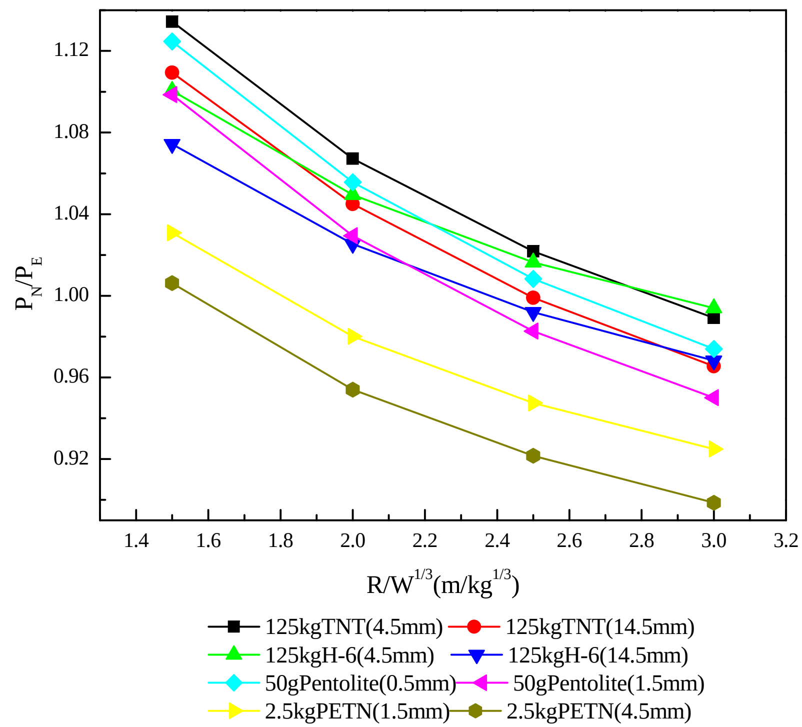
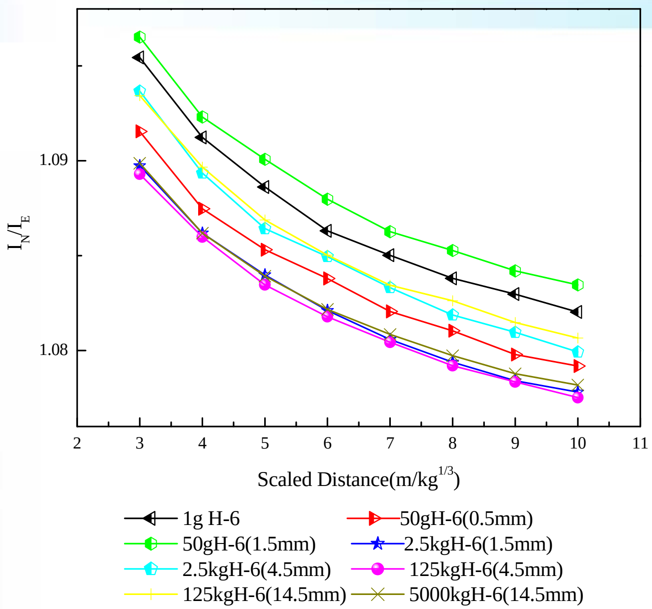
• Variations of peak pressure

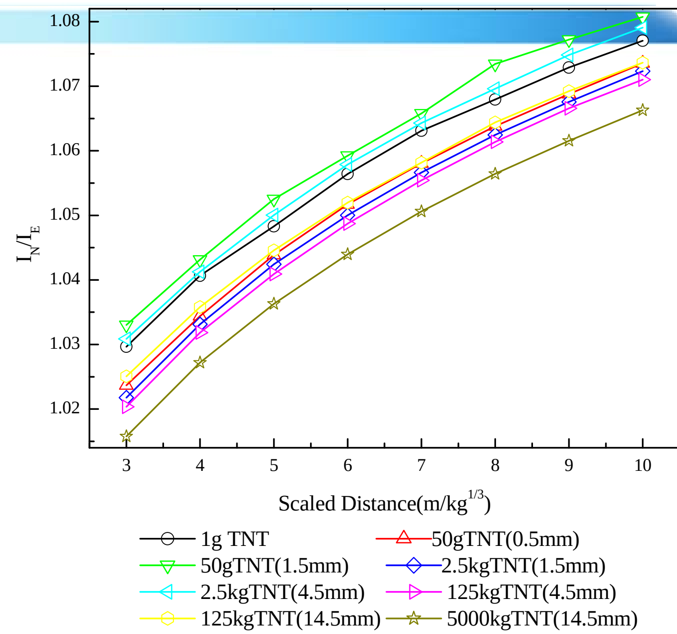


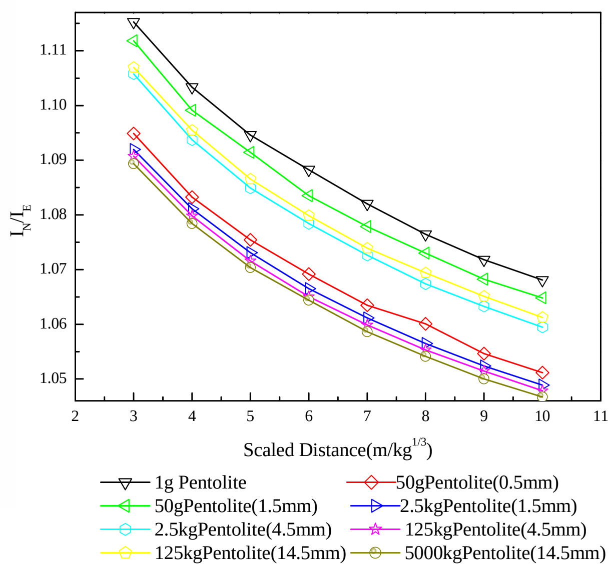


- The P_N/P_E decreases with the increase of the mesh size at the scaled distance 1.5 to 10 for TNT, H-6, Pentolite and PETN, whilst it is still in an acceptable range .

• Impulse







- The I_N/I_E increase with the enlarging of the charge weight in the same grid size
- For a fixed charge weight, I_N/I_E for TNT increase gradually with the increase of scaled distance, for H-6 and Pentolite, the ratio decreases .

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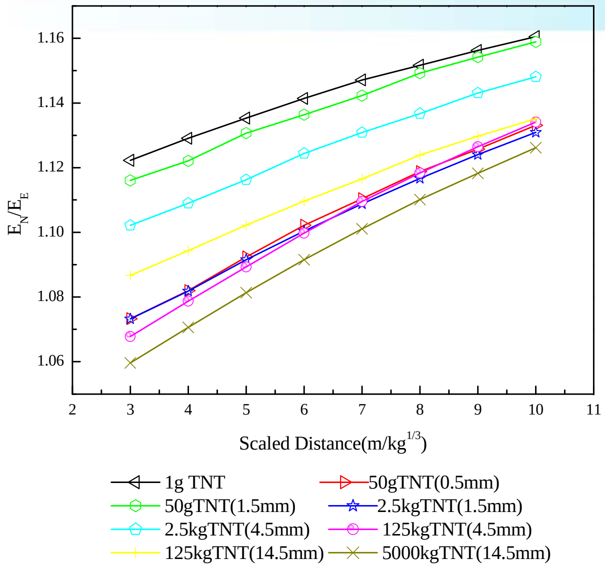
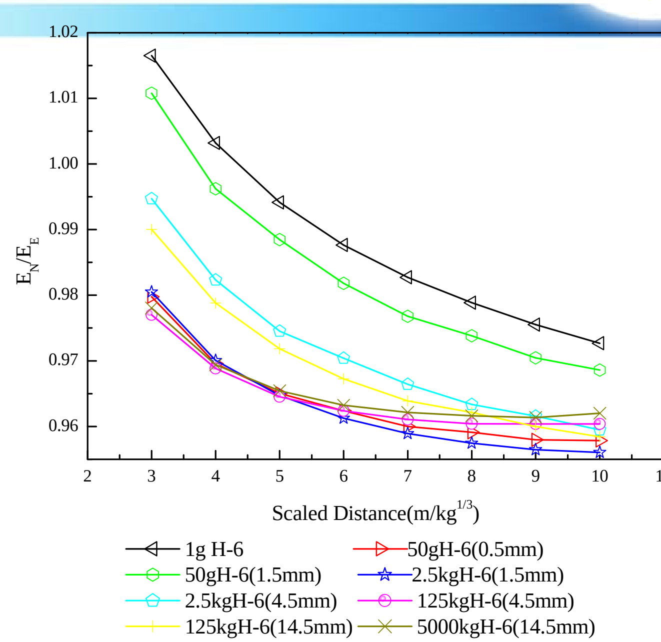
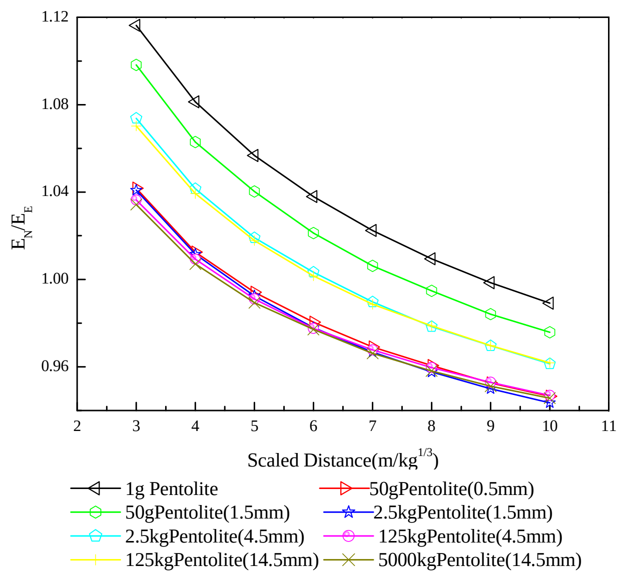
• Energy flux density







- The E_N/E_E have similar tendency with the I_N/I_E.
- The impulse agrees with the empirical values with in 12%
- The energy flux density agrees slightly poor than the impulse within 14%, especially for H-6 and Pentolite.

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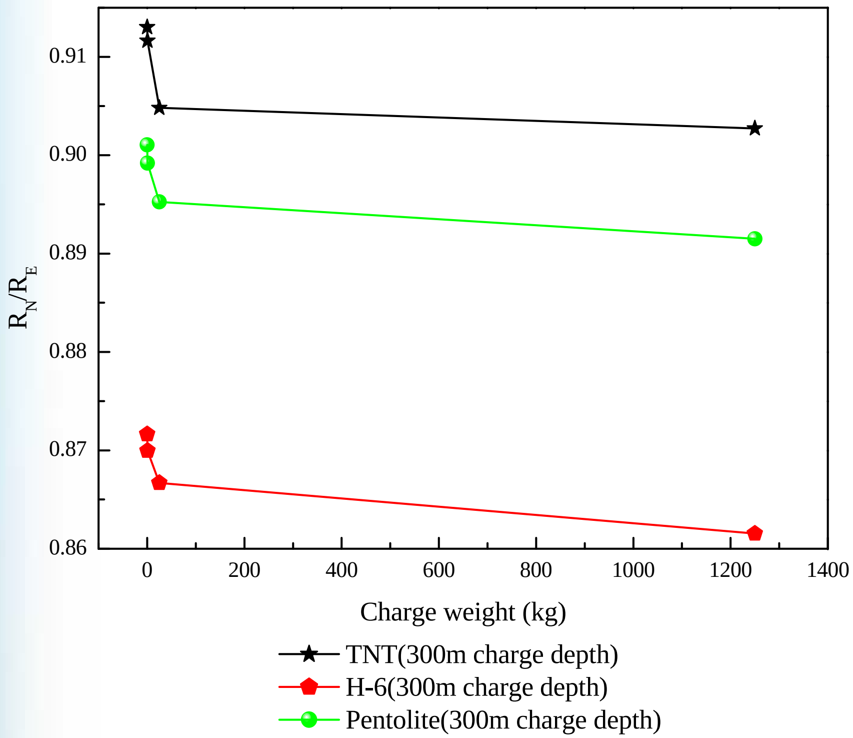
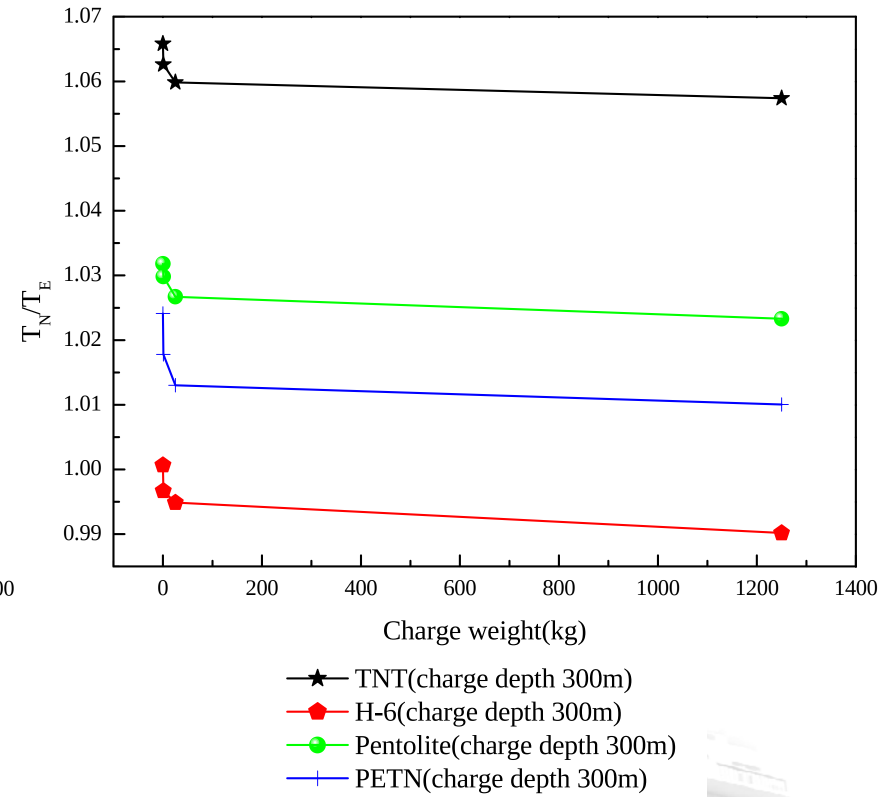
• Bubble pulse properties vs. charge weight





- The radius and period decrease with the increase of the charge weight, but the increasing extent is very slowly within 1%.

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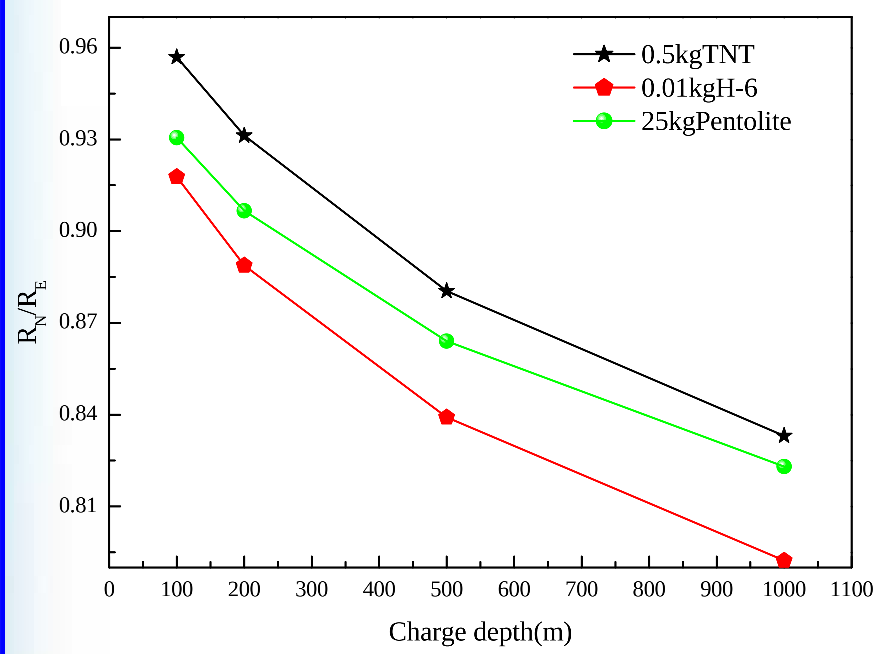
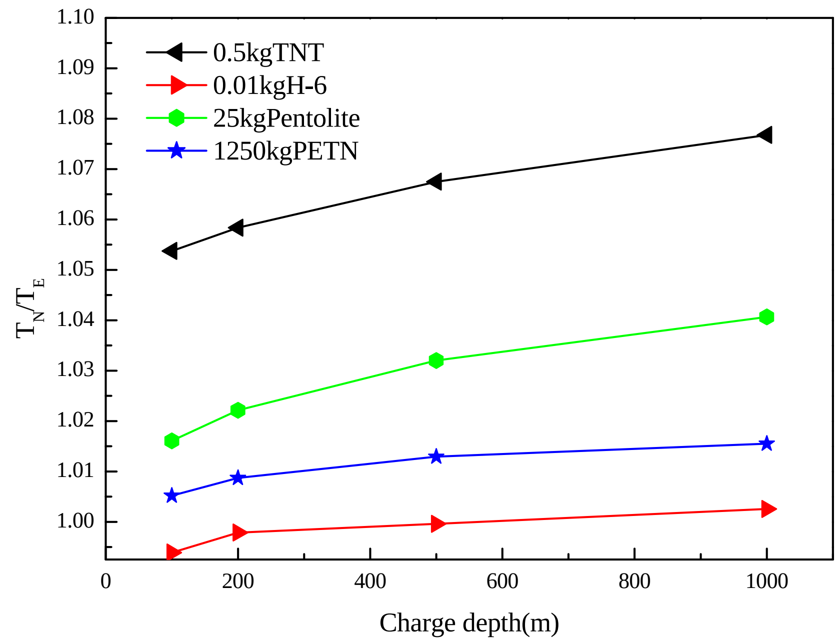
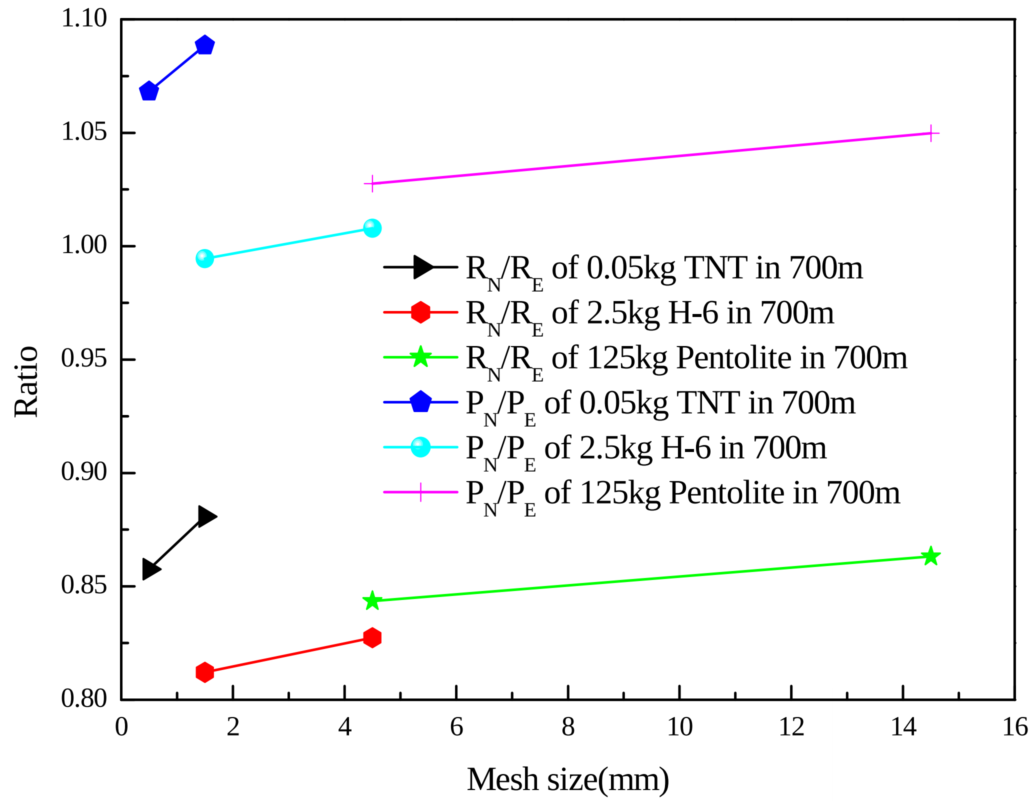
• Bubble pulse properties vs. charge depth





- The increase of the charge depth reduces the accuracy of the radius significantly, about 12%.
- For period, it also decreases with the increase of the charge depth and is moderately within 2%.
- The prediction of the period is more accurate and steady than the radius for all charge depths.

• Bubble pulse properties vs. mesh size



- The ratios increase with the increase of mesh size.
- Tthe first bubble maximum radius and period of TNT explosive are more sensitive to the mesh size than other explosives.

Conclusions and Future Endeavors

- Fixed values of quadratic and linear viscosity exist for the UNDEX model with a settled mesh structure in ANSYS-AUTODYN simulation process.
- V_Q and V_L, 1 and 0.034, 1 and 0.068 were applicable for the scaled distances range from 3 to 10 and 1.5 to 3, respectively.
- System based on given mesh size and viscosities was constructed for AUTODYN simulation of UNDEX key attributes for various kinds of explosives, wide range of scaled distances, charge depths and charge weights.
- Provide fundamental method for modeling of underwater explosion by simple 1-D AUTODYN.
- The modeling results of key attributes by AUTODYN were in acceptable agreement.
- Future work: Determination of EOS for aluminized explosive formulation
- Future work: Evaluation underwater explosion performance of formulations.

Acknowledgements

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Thanks a lot.