

BHA FAQs

Question: Is there any benchmark case to validate the accuracy of the Wavenology BHA solver ?

- **Answer:** In the demo package (2019-04), following cases include the analytical solutions:
open_hole ---- the reference data is in the sub-folder "reference"
steel_pipe ---- the reference data is in the sub-folder "reference"
benchmark_ring_monopole --- the reference data is in the sub-folder "Compare"
benchmark_ring_dipole --- the reference data is in the sub-folder "Compare"

Question: Does the Wavenology BHA solver support anisotropic and poroelastic materials ?

- **Answer:** No. In the current version, Wavenology BHA does not support anisotropic and poroelastic materials; they are supported in Wavenology EL in the Cartesian coordinates only.

Question: What is the distribution of a ring source? How to define a ring monopole, dipole & quadrupole source ?

- **Answer:** If we define the order of a ring source as n , the ring source will have a magnitude distribution in a circle as: $\cos(n \cdot \phi + \phi_0)$, ϕ_0 is the initial angle, default as 0. So,
 - a. $n=0$: the magnitude distribution will be a constant in the circle, this is a ring monopole source. In this case, ϕ_0 will be ignored;
 - b. $n=1$: the magnitude distribution will be $\cos(\phi + \phi_0)$ in the circle, this is a ring dipole source.
 - c. $n=2$: the magnitude distribution will be $\cos(2\phi + \phi_0)$ in the circle, this is a ring quadrupole source.

Question: How to define the boundary conditions in Phi ?

- **Answer:** if the project's phi range covers the 360° circle, the boundary conditions in Phi should be Periodic. However, if the project has the same structure in every 90° and the source is a ring dipole source, following boundary conditions can be used in Phi
 - a. $\phi_{\min}=0$ with symmetry B.C., $\phi_{\max}=90^\circ$ with anti-symmetry B.C : this is due to the ring dipole has a distribution as $\cos(\phi)$, which is symmetry at 0, anti-symmetry at 90°
 - b. $\phi_{\min}=0$ with symmetry B.C., $\phi_{\max}=180^\circ$ with symmetry B.C : this is due to the ring dipole has a distribution as $\cos(\phi)$, which is symmetry both at 0 and 180°
- For the ring monopole & quadrupole source, similar settings can be used also. More detail can be referred to the "Sources & Excitation" section of the manual.

Question: How to define the boundary conditions at Rmin ?

- **Answer:** if Rmin=0, the boundary condition should be OPEN, which means the system is continuous at Rmin, it is the general physics in the real world. However, the diagonal of cell at Rmin is smallest. Due to the nature of the WCT BHA solver - FDTD, the simulation Δt is determined by the shortest diagonal of all cells. In order to save the simulation time, a larger Δt is desired, which can be obtained by increasing the diagonal of the cell at Rmin. One method is making the Rmin>0 with a small value, for example, Rmin= ΔR , and setting the boundary condition at Rmin as Hard. According to our experience, for a uniform R grid setup, if we set the Rmin= ΔR with Hard boundary at Rmin, the Δt will be 1.5 times bigger than Rmin=0 setup. And the simulation result has about 1.5% difference only. But due to Δt increases with 1.5 times, for a fixed time window, the total simulation time will be 67% of that in Rmin=0 setup.

Question: How to obtain pressure data at the receivers?

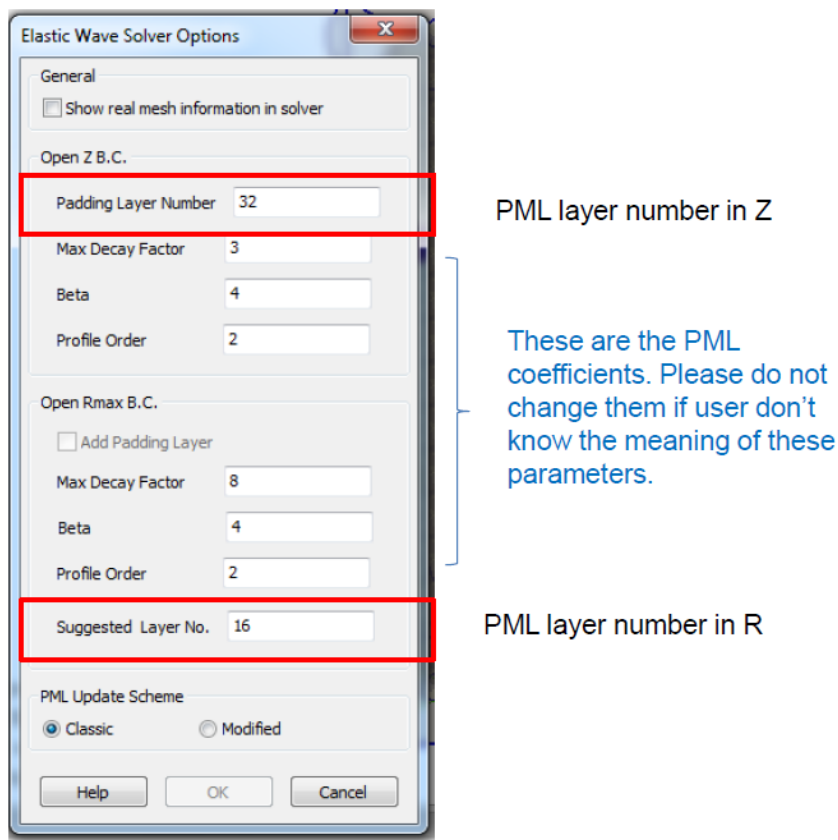
- **Answer:** In a fluid, the pressure p is equal to the negative normal stress components τ_{rr} , $\tau_{\theta\theta}$ and τ_{zz} . So one can just use any of these three components, for example, $p=-\tau_{rr}$.

Question : How to specify the mesh? On what basis the number of cells in each direction must be chosen?

- **Answer:** Starting from Wavenology v2.0.8 (April, 2019), the BHA solver supports the non-uniform mesh and can be automatic, so it is recommended to use this automatic mesh. Most demo cases in this new version use non-uniform meshes already in the new demo package (2019-04). Based on our tests, we suggest the user to use non-uniform mesh setting, at least, non-uniform mesh in R & Z, and uniform mesh in Phi, to obtain the best balance between simulation accuracy and the simulation time (Advanced mesh section of the manual). For a mesh, including the uniform mesh and the non-uniform mesh, in general, the sampling density should be in the range of 10-20 cells (points) per wavelength (PPW) at the highest frequency f_{max} of interest. This is a general sampling density required for the 2nd order FDTD method (more specifically for the BHA applications, in order to reduce the dispersion error caused by the long length in Z, we prefer PPW-R=10-16; PPW-Z=20). When using a uniform mesh (manual option), Wavenology GUI also shows the corresponding PPW for this uniform mesh, and the shown PPW should satisfy the above requirements. However, a very special consideration is the Phi direction: (1) If a centered ring or point monopole source is used and the formation is axis symmetric, N_{ϕ} can be chosen as 1 to save the CPU time. (2) As the cylindrical mesh becomes coarser as the radius increases, the sampling density in Phi should be sufficient (>10 PPW) at the radius of the outermost discontinuity (usually the radius of the borehole). So the PPW in the Phi direction should be referred to the radius of the outermost discontinuity; thus the default reference value for R is the borehole radius (10 cm usually). (3) The user can consider the symmetry property of the ring source and the structure of solid in the Phi direction to save time. For example, if the formation is axis symmetric and the center ring source is a dipole, one can just model a quarter of the problem in the Phi direction by using the "Symmetry Boundary Condition" at Phi=0 and "Anti-Symmetry

Boundary Condition" at $\Phi=90$ degrees to reduce the CPU time to 1/4. More details can be referred to the "Sources & Excitation" section of the manual.

Question : PML documentation & setting. Could you provide me a documentation about the PML that explains the following parameters shown in following [Error! Reference source not found.](#) , so that I can know how to change them based on the mesh used in each simulation to obtain better results.



Answer: For the PML, we use the technology similar to the paper "Unsplit complex frequency-shifted PML implementation using auxiliary differential equations for seismic wave modeling", Wei & Yang, GEOPHYSICS, 2010, vol. 75. However, we find this kind of PML has some limitations and can't work very well in some situations. Through our tests, the default parameters can fit most cases already. Therefore, except for the cell number in the PML, we don't encourage the user to modify other PML parameters.

The physical length of PML is about 1 wavelength. Therefore, if the user wants to change the PML thickness, it is better to check PPW of mesh firstly, then change the cell number for PML to make it at least more than 1 wavelength. The default PML cell number is based on the property of the BHA applications: strong guided mode along Z (use a 2λ PML thickness), weak R-radiation outside the borehole boundary (use 1λ PML thickness).

Questions: I have my analytical solution for a BHA case, why my result is different from the results in the Wavenology BHA solver ?

Answer: (1) Maybe the source is different. For example, in WCT BHA, the ring monopole uses the "volume source density of stress rate (Pa/s)" as the excitation, it is different from a pure **pressure** source.

(2) Maybe the excitation pulse is different, even in both two methods, they all use the Ricker wave. Due to the detail implementation of the Ricker wave might be different, even they looks very similar, the wave form have difference. So, the results comes from two method are different.