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基于混合边界条件的有限单元法GPR正演模拟

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Finite element method GPR forward simulation based on mixed boundary condition

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摘要 从Maxwell方程组出发,推导了探地雷达(GPR)有限元波动方程.阐述了透射边界条件和Sarma边界条件的原理,推导了这两种边界条件的理论公式;通过在衰减层内加入过渡带优化了Sarma边界条件的加载方法,压制了介质区和衰减层交界面处的人为反射.考虑到透射边界条件与Sarma边界条件不同的理论机制,提出了一种结合透射边界条件和Sarma边界条件的混合边界条件,它利用Sarma边界条件对到达边界区域的GPR波能量衰减功能和透射边界对GPR波能量的透射功能,使GPR波经过Sarma边界条件的衰减吸收后,再通过透射边界条件将剩余能量透射出去,集成了二者的优势.并以二维均匀模型中的中心脉冲激励源方式为例,通过Matlab程序实现,以GPR的全波场快照的直观方式,对比了有、无边界条件及不同边界条件对人工截断边界的处理效果,说明了该混合边界条件对到达截断边界处的GPR波的处理优于单一边界条件.最后,以基于混合边界条件的有限单元法对两个典型的GPR地电模型进行了正演模拟,指导了GPR数据处理与工程实践.

关键词 探地雷达, 有限单元法, 混合边界条件, Sarma边界条件, 正演模拟

Abstract: Based on Maxwell's equations, this paper deduces the finite element wave equation of Ground Penetrating Radar (GPR). It also describes the principle of the transmitting boundary condition and the Sarma boundary condition, deduces the theoretical formula of these two boundary conditions. By adding a transitional layer into the damping region, the adding method of the Sarma boundary condition is optimized, suppressing the artificial reflection at the interface between the medium zone and the damping region. Considering the different theoretical mechanisms of the transmitting boundary condition and the Sarma boundary condition, it proposes a mixed boundary condition combining the transmitting boundary condition and the Sarma boundary condition, which enables the remained energy of GPR wave to be transmitted through the transmitting boundary condition after it is attenuated and absorbed by Sarma boundary condition, integrating the advantages of the two conditions. In addition, it takes the center pulse excitation source in two-dimensional homogeneous model as an example, compares the processing effects based on the cases with or without boundary conditions, or with different boundary conditions, in a visualized way of snapshots for the full GPR wave field, through the realization of Matlab procedure. The result indicates that the effect of using the mixed boundary condition is superior than using a single boundary condition. In the end, a numerical simulation for two typical GPR earth-electricity models is carried out with the finite element method based on the mixed boundary condition, providing the guidance for GPR data processing and engineering practice.

Keywords Ground penetrating radar, Finite element method, Mixed boundary condition, Sarma boundary condition, Forward simulation

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