Fundamental Study on the Applicability of Seismic Surveys for Detecting Deep Cavities

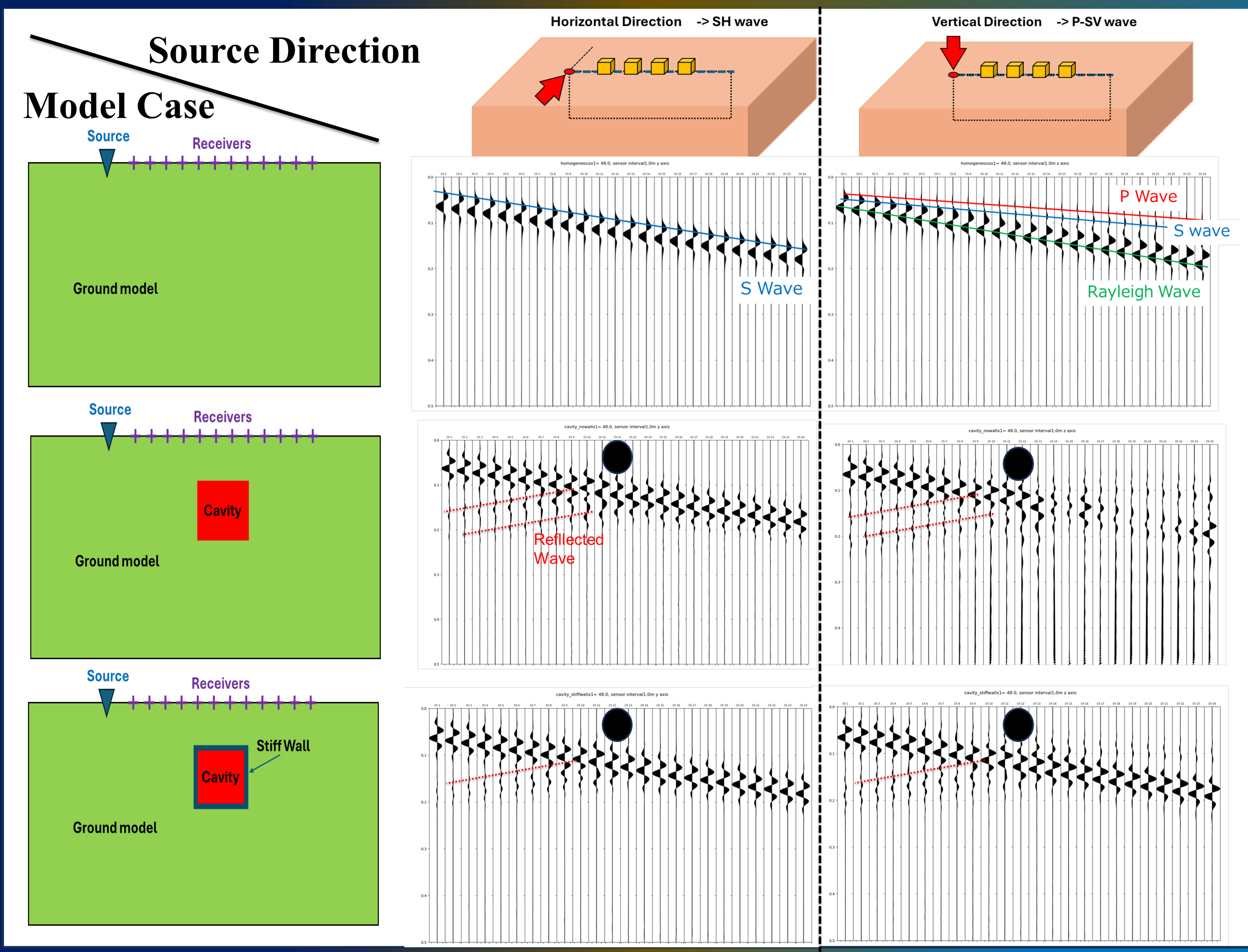
深部空洞検出のための地震探査の適用性に関する基礎的研究

Introduction

Nondestructive exploration technology in the ground is needed in many fields, such as infrastructure development, anti-disaster measures, archaeological investigations. However, high-resolution exploration deeper than 2m is difficult in a nondestructive exploration today. This study investigated the applicability of seismic surveys in the exploration of underground cavities by numerical model based on the finite difference method and field tests. The results indicated that detecting reflected waves from the cavity would be effective.

地盤内空洞の非破壊探査はインフラ整備や災害対策、考古学の調査など多くの分野で必要とされる。しかし、現在の非破壊探査では2m以深の高分解能探査は困難である。本研究では、有限差分法による数値モデルと実地試験により、地下空洞探査における弾性波探査の適用性を検討した。その結果、空洞からの反射波を検出することが有効であることが示された。

Numerical Simulation (FDM)



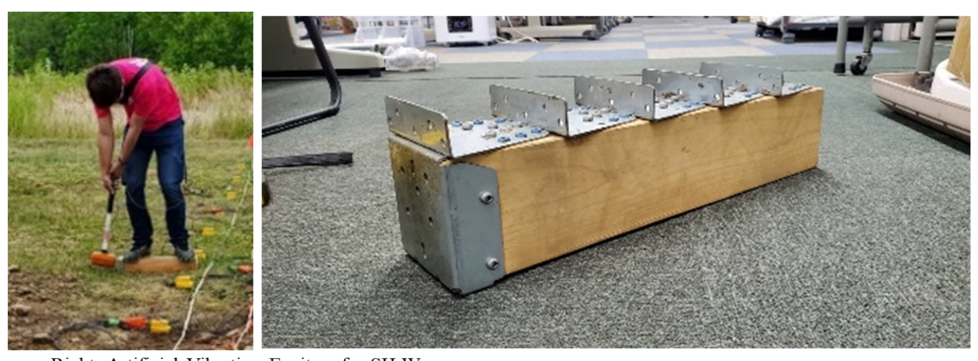
A subsurface survey generally inversely analyzes the distribution of geophysical quantities in the ground under investigation based on the results of wave propagation measurements. In seismic surveys, data is acquired by several receivers installed on the ground surface that receive wave propagation from a point source artificially generated on the ground surface. **The presence of regions such as cavities in the ground, where the geophysical quantities are significantly different** from those of the surrounding layers, modifies the propagation of elastic waves in the ground, which is reflected in the response at the ground surface.

In this study, **the ground is modeled as an elastic body by the finite difference method**, and elastic wave propagation at the ground surface is simulated in the presence of cavities in the ground. Here, from the viewpoint of stability of the analysis, **the cavities were assumed to be very low density, low wave velocity layers, and the shear stress was set to zero** in the cavities. In the homogeneous model propagation, only S waves were observed during horizontal excitation, while coupling of P and S waves and propagating surface waves were observed during vertical excitation.

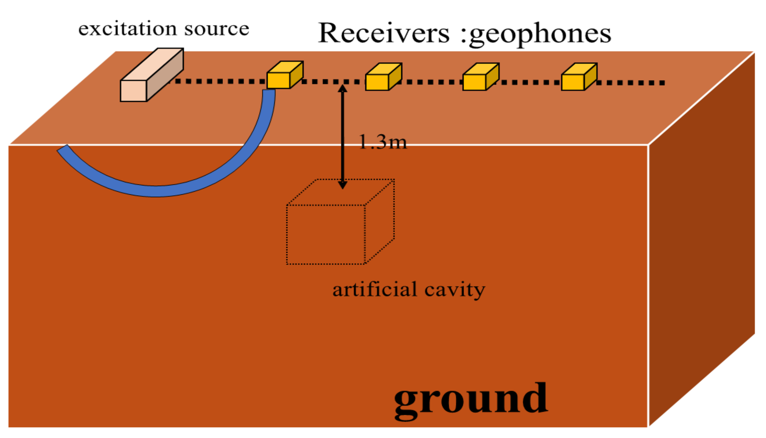
In the case of a cavity in the ground, the cavity surface was assumed to be a free surface. As a result, **reflected waves from the cavity were observed** in both the horizontal and vertical directions. On the other hand, in the case of vertical excitation, most of the surface waves were observed to decay just above the cavity. This was due to the fact that the cavity was regarded as an ultra-low velocity region, which confines part of the energy of the waves propagating in the cavity.

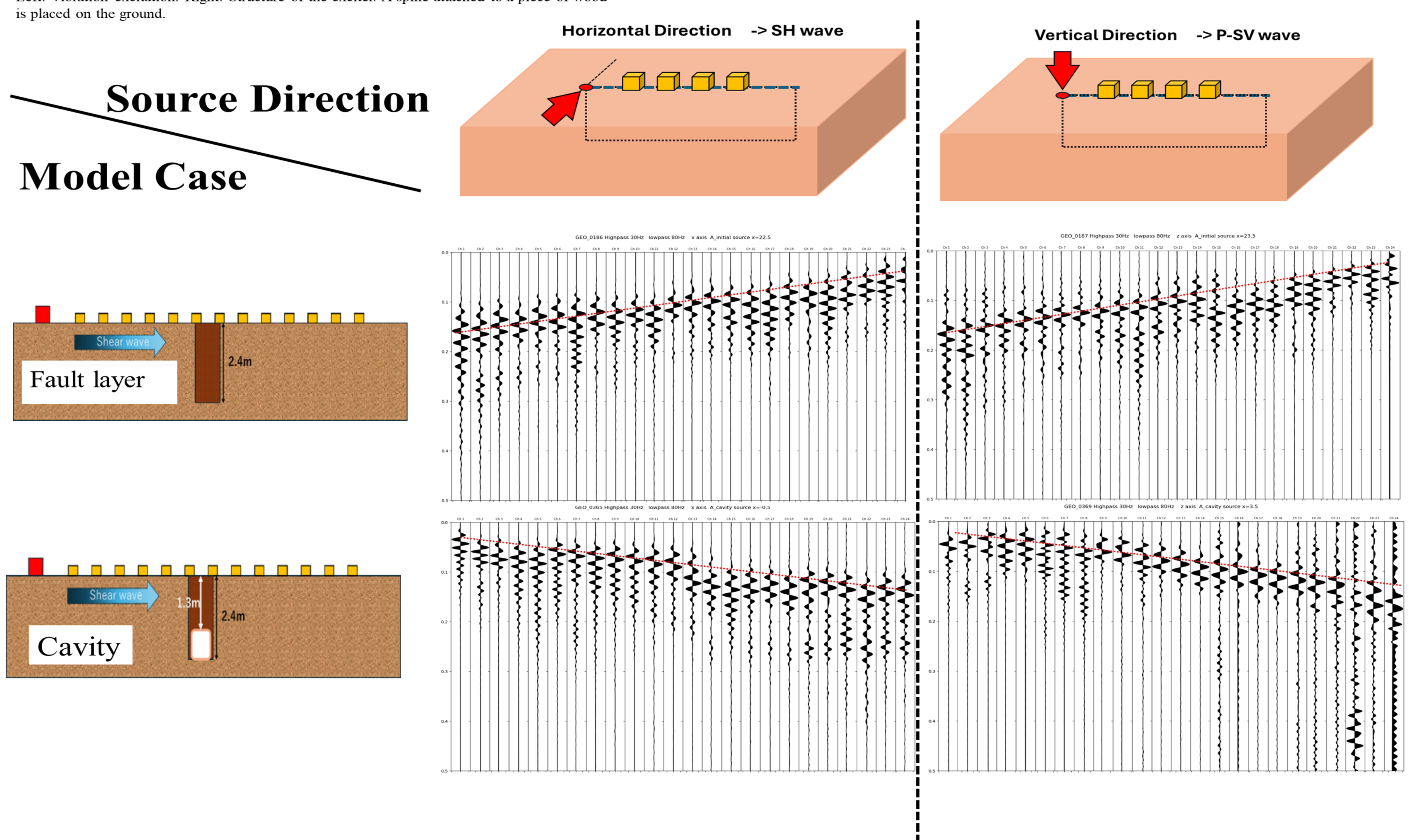
In the actual ground, wave attenuation due to dissipation was significant, as will be explained in the field test part. Waves that appeared to be P waves were also generated in the horizontal excitation model, whereas only s waves were generated in the elastic body model. This phenomenon indicates that the ground is microscopically granular and does not guarantee isotropic wave propagation, suggesting that the conventional elastic body model may not be sufficient. The author is currently interested in a propagation model that takes into account the dissipation inherent to granular ground.

Field Test



Right: Artificial Vibration Exciters for SH Waves
Left: Vibration excitation. Right: Structure of the exciter. A spike attached to a piece of wood is placed on the ground.





The detection of subsurface cavities using seismic wave propagation was investigated in field tests using a real ground surface in the Le Petau golf course in the town of Hokkaido, Japan. A horizontal excitation method was introduced along with a conventional vertical excitation method and its effectiveness in identifying wave reflections.

An artificial cavity was created to simulate subsurface anomalies. 24 geophones connected to an automatic data logger were used for the measurements, and the acquired data were subjected to extensive analysis, including bandpass filtering, amplitude normalization, and deconvolution, to elucidate the interaction between the elastic waves and the subsurface structure. Both vertical and horizontal excitation methods were employed to measure the reflection characteristics of artificially created cavities in a test field.

The results suggest that the cavities may be more clearly visible due to reflected waves when the excitation is done horizontally. Since the method of inversely analyzes seismic waves uses reflected and refracted waves from the cavity, it is important to compensate for distinct excitation and decaying waves.

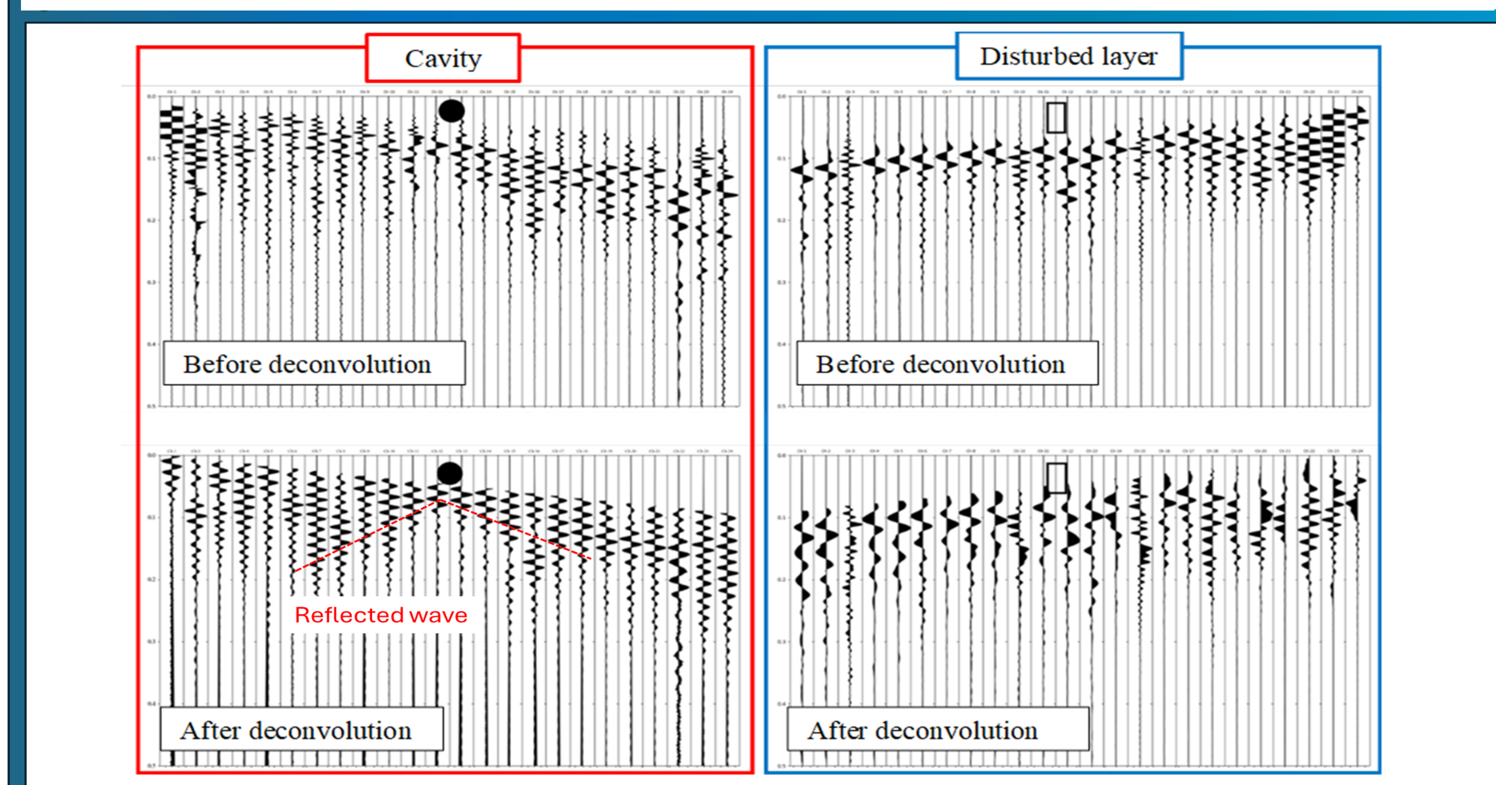


Figure. 8 Raw trace data from horizontal excitation and deconvolution processed data. The black circles in the left panel indicate the location of population cavities, and the rectangular area in the right panel indicates the location of the disturbed layer.

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