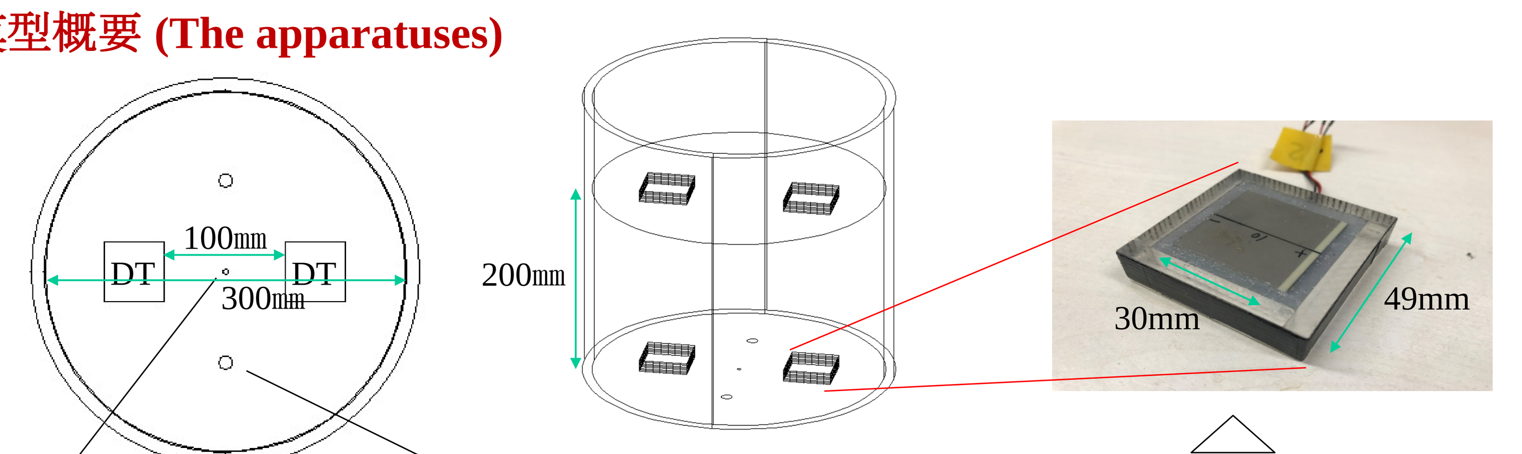
Dynamic wave propagation in soil around a cavity

地中空洞周りの波動伝播特性

Dynamic wave survey is usually conducted to investigate the structure of the ground. However it is not effective for detection of subsurface cavities. In this study, with the aim of improvement on cavity detection method, model tests were conducted to look into wave propagation through the model ground during the process of cavity formation. DEM (Discrete Element Model) simulations were also conducted with the presence of a subsurface cavity to compare it with the model test results. In the model tests, decrease in wave velocity and lowpass frequency ($f_{lowpass}$) was observed while in DEM simulations, only decrease in $f_{lowpass}$ was observed.

地盤中の地層構造を認識するために弾性波探査による方法が多く用いられているが、地中に空洞がある場合にその存在は一般に検知が困難である。本研究では、空洞検知手法の改善を目的として、地盤中に空洞が発生する過程の弾性波伝播特性の遷移を、模型試験および、個別要素法を用いて検討した。模型試験ではゆるみと回折による速度と$f_{lowpass}$の減少、DEMでは回折による$f_{lowpass}$の減少が確認された。

模型概要 (The apparatuses)

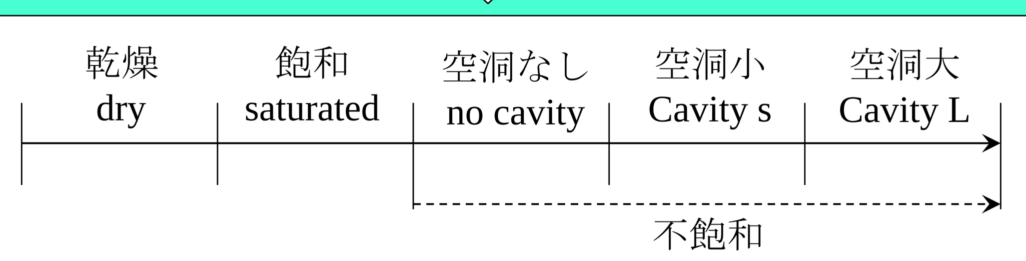


空洞生成時に開閉するスリット(直径5mm)
An opening through which soil and water can be drained and form a cavity
(5mm in diameter)

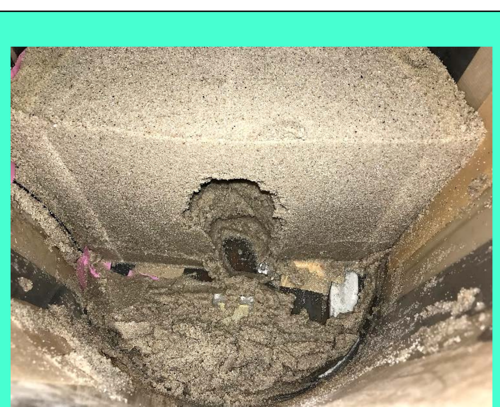
飽和状態調節用の給水・排水口(直径5mm)
An opening used to change saturation condition by supplying and draining water.
(5mm in diameter)

ディスクトランスデューサー：電圧と変位を変換する
Disk Transducer
: It converts voltage into displacement and vice versa.

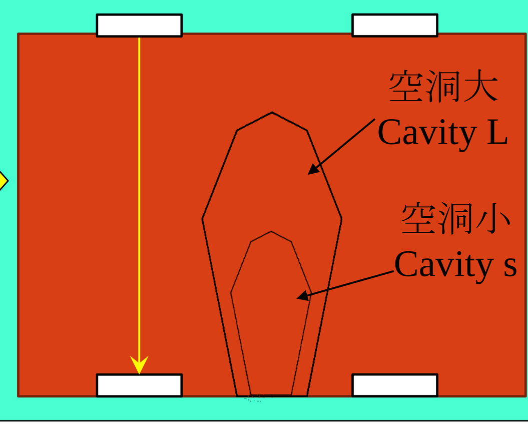
上部のDTから数nmの弾性波(2kHz-30kHz)を発生させ、下部のDTで受信する試験を以下の5通りの地盤状態で行う。
Elastic waves (2kHz-30kHz in frequency, a few nanometers in displacement) are transmitted from the upper DT and received by the lower DT. The ground conditions were as below.



実験条件 (Conditions)

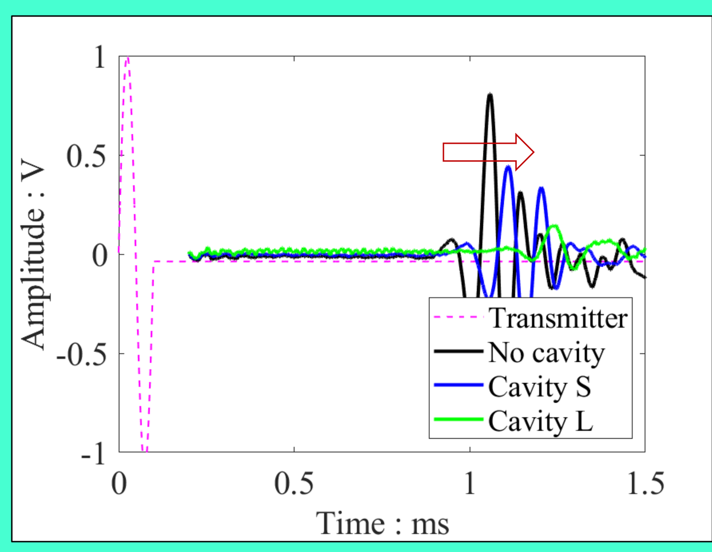


試験後の断面と推定される試験中の空洞断面
The cross section after the experiment and the assumed cross section during the expansion of the cavity.

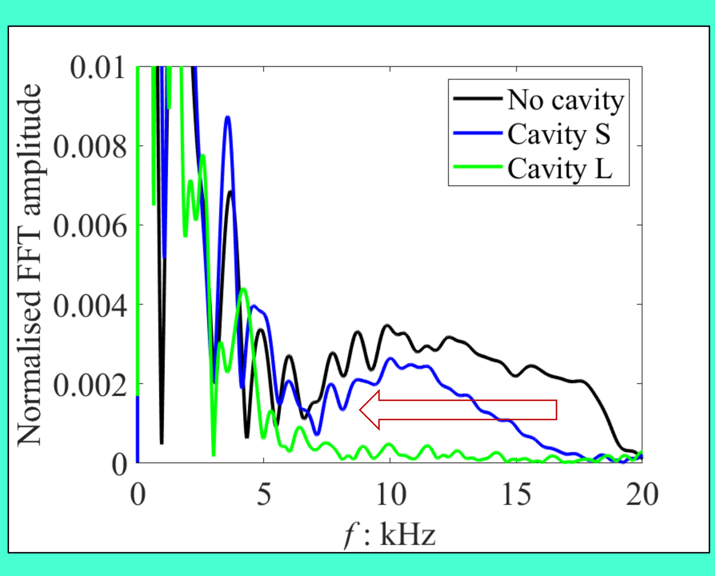


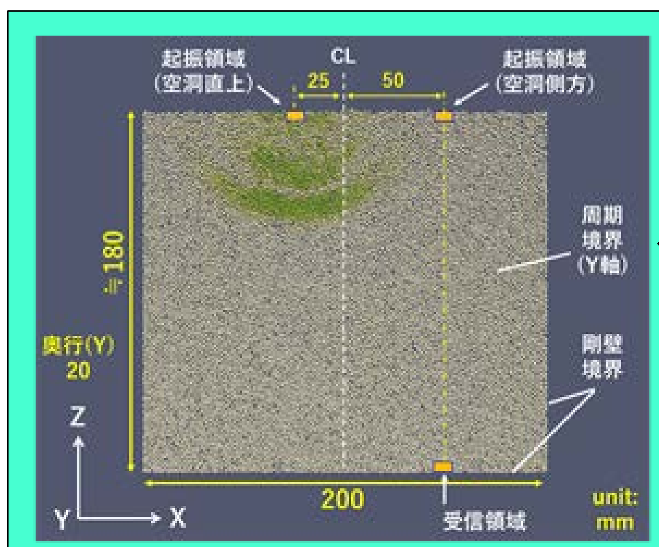
実験結果 (Results)

地盤状態ごとの弾性波伝播速度。空洞の拡大とともに伝播速度の減少が見られる。これは空洞とともに周りのゆるみが拡大したためと思われる。
Measured elastic wave velocity in the process of cavity formation. Decrease in velocity can be observed in accordance with cavity expansion. The cause is assumed to be the expansion of loosened area around the cavity that accompanied cavity expansion.



また受信波の周波数成分について比較した。ここで、地盤が伝播可能な最大周波数$f_{lowpass}$は地盤状態に応じて決定されることが分かっている。空洞の拡大に伴って$f_{lowpass}$の減少がみられた。
Comparison of frequency components of the received waves. $f_{lowpass}$ (the maximum frequency that can pass through the ground) is determined by the ground condition. $f_{lowpass}$ decreased in accordance with the expansion of the cavity.

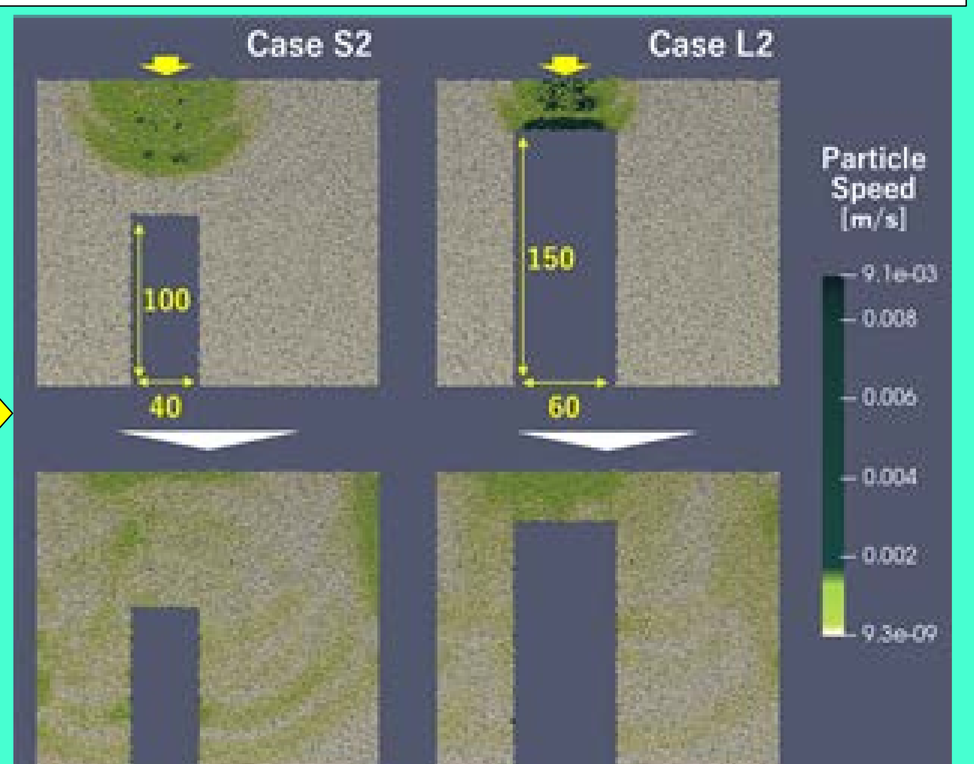




個別要素法で用いたモデル (DEM Model)

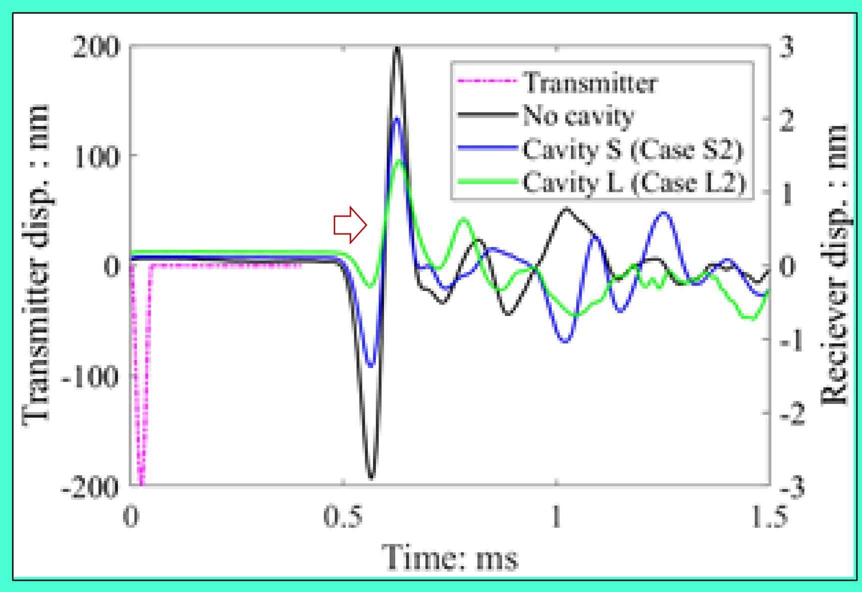
上部の2領域いずれかで発生させた弾性波を底面上の領域で受信する。以下では空洞直上の領域から発生させた弾性波について示す。
The model designed for DEM simulation. Elastic wave transmitted from either of two regions at the surface is received in a region at the bottom.

空洞は右のサイズで発生させた。空洞の安定のために粒子間に5kPaのサクションを考慮した。剛壁境界と同様、空洞境界でも波の反射を確認した。
Cavities were arranged as shown on the right. For the stability of cavities, suction of 5kPa was given. The reflection of elastic wave was observed both at the sample boundaries and the cavity boundaries.

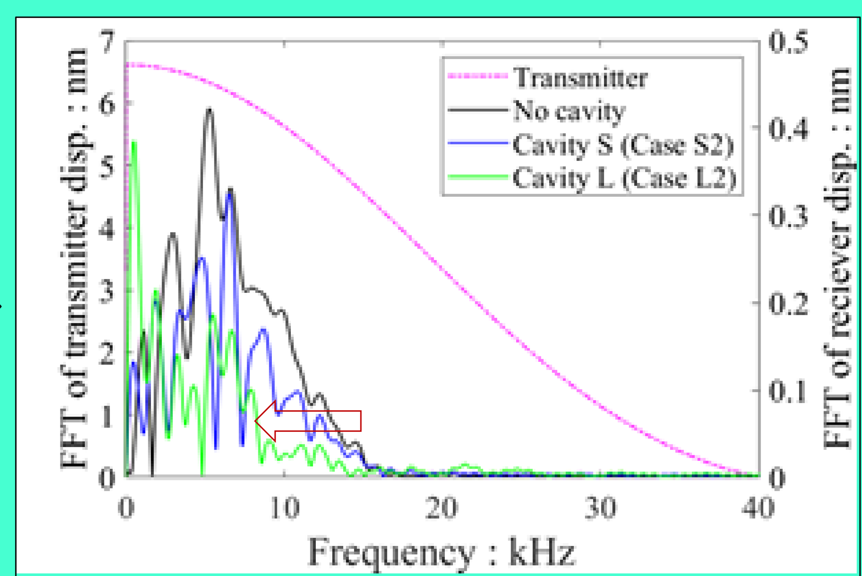


DEMの結果 (DEM results)

受振領域での時刻歴応答。空洞なしの場合に比べて空洞が大きいほど波の立ち上がりが若干遅いことが確認された。
The response at the receiver region. The dropping point was observed a little later when the size of the cavity was large.



受信領域での時刻歴応答の周波数スペクトル。模型試験と同様、空洞の拡大に伴って高周波数帯成分の減衰がみられた。
The frequency spectra of the received waves. Same as the model test, the higher frequency component dropped for the cases with a large cavity.



結果の比較 (Comparison of the results)

模型実験での結果の変化には空洞周りのゆるみの発生により、密度の低下と伝播経路の回折という二通りの影響があったと考えられる。一方でDEMではサクションを大きくした結果回折のみの影響を反映した結果になった。粒子の条件を考慮することで空洞周りのゆるみをDEMで再現しその影響を可視化する研究が必要である。
In the model test, the results were affected by ground loosening around the cavity in two ways: the decrease in density and the diffraction of the propagating path. On the other hand, in the DEM simulation, the results were affected only by the diffraction because suction had to be increased in order to sustain the structure. By considering the particle conditions, the loosening around the cavity has to be reproduced in DEM modeling to visualize its impact on the results.

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