第 12 回国際岩の力学会議（北京）を参加して

-重要構造物の基礎岩盤の動的特性評価-

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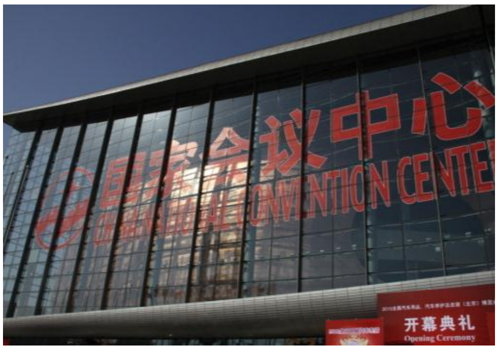
I took part in the 12th International Congress on Rock Mechanics (ISRM 2011) held in Beijing, P.R. China from 18th to 20th Oct. 2011, and made a post presentation titled as "Evaluation of dynamic behaviors of bedrock foundation based on FEM and DEM simulations". In this international congress, many famous professors and experts in the world, e.g. Profs. J.A. Hudson and T. Brown (the former presidents of ISRM), Prof. X. Feng (the selected-president of ISRM), Prof. N. Barton, et al, gave their lectures on the new development of rock mechanics and introduced their particular research fields. This congress provided a good opportunity to learn about the new research fields and methods in the aspect of rock mechanics, and more importantly, to exchange with other scholars on my research topic, from which I can acquire lots of good suggestions.

１．国際会議の概要

The 12th ISRM International Congress on Rock Mechanics with the topic of "Harmonizing Rock Mechanics and the Environment", organized by the International Society for Rock Mechanics (ISRM), was opened on October 18 at China National Convention Center, Beijing. More than one thousand of experts and scholars in rock mechanics field from about 50 countries and regions participated in this Congress. In the congress, 15 world-widely famous professors delivered keynote lectures, including the Rocha lecture and the Müller lecture. About 20 parallel sessions were held, e.g. Analysis and Design Methods, Dynamics and Blasting, Field Measurement and Site Investigation, and Laboratory Testing and Rock Properties, etc. These sessions demonstrated the latest achievements in international rock mechanics and engineering field in recent years, and provided a good opportunity for participants to have extensive discussions on the presentations with each other.



China National Convention Center

Communication with scholars

２．発表内容と成果

（日本語による概要）重要構造物（原子力発電所等）の基礎岩盤の選定において地震による断層を含めた基礎岩盤の強度、変形が岩盤構造物に与える影響を評価する必要がある。本研究では、一般的に動的解析に用いられる有限要素法(FEM)と不連続面のせん断・大変形

挙動を表現できる個別要素法(DEM)による動的数値シミュレーションを実施して、基礎岩盤の変形挙動を比較検討する。動的解析では、新潟県中越沖地震を対象地震とし、観測地点NIG019小千谷の地震動（水平加速度のEW成分）を選定した。地震動とは地震波が地下深部より伝達することにより生じるものだから、一次元応答解析(*k*-SHAKE)によって対象岩盤基盤面(深度200m)に入力する入力地震動を算出した。有限要素法と個別要素法の解析を比較するために、対象領域の条件をほぼ同等にして、ある実際の原子力発電所の基礎岩盤条件をもとに、基本モデルを作成する(Fig.1)。

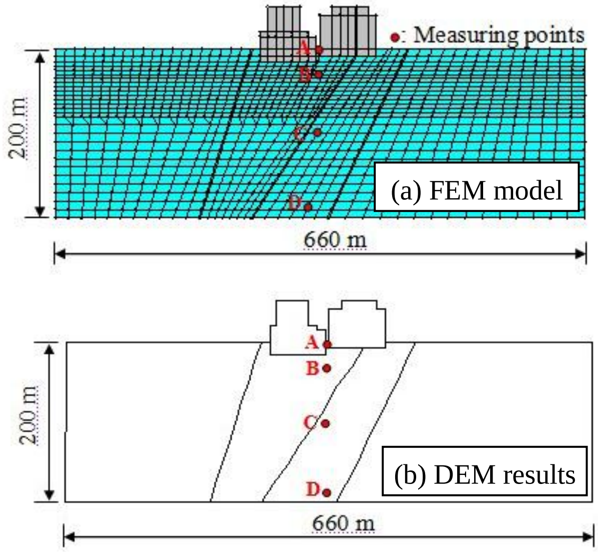


Fig. 1. FEM and DEM models

FEMとDEMの両解析結果においては、同等の地震動が起きているかを確かめるために基礎岩盤において任意の四点を選定し、その地点での波形の比較検討を行った。まずは、地震波が入力されている基盤面から近い地点である地下190mのFEM・DEM解析結果から分かるように、ほぼ同じ速度波形が得られており、両解析方法とも同じ地震動を再現できていることがわかる。次に、地表面・地下30mと地下100m地点のFEMとDEMの解析結果の比較を行う(Fig.2)。水平速度がほぼ一致しているが、その最大値について、FEMの方がDEMより大きくなっている。これは断層に対する影響の受け方が違うためと考えられる。

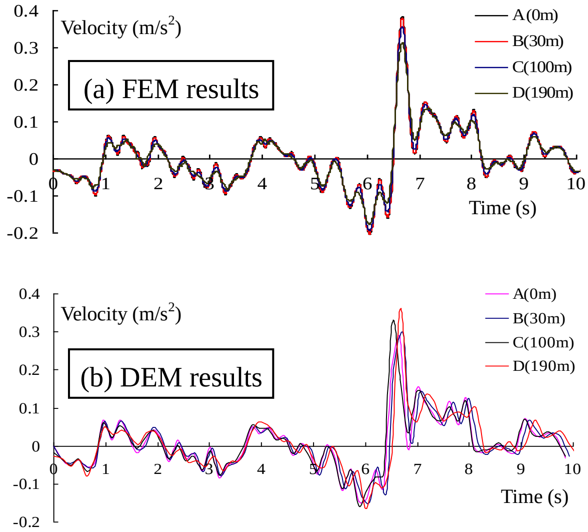


Fig. 2. FEM and DEM results

これらの任意の地点の速度波形の比較より、両手法による地震動はほぼ同じであるが、地震動の表現仕方の違いにより、水平速度の最大値において違いが生じた。特に、DEM 解析では、節理や断層を不連続体としてモデル化し、振動の減衰効果を働かせているため、FEM より実際に近い挙動を再現している。また、地震波入力基盤面から地表に行くにしたがってより顕著に断層に対する影響を受け、速度が減衰する地点もあることを判明した。この結果より、重要構造物の基礎岩盤の動的挙動を評価するために、岩盤内の既存節理や断層のせん断ずれ・開口を忠実に表現できる DEM 解析方法を用いるべきであり、それを用いた実現場の基礎岩盤の動的挙動の予測評価と考察を行った。

(English abstract) The seismic behaviors of the bedrock foundation concern the stability and safety of nuclear plants. In this study, both the FEM and the DEM were adopted to investigate the seismic response behaviors of the bedrock under a nuclear power plant located in Japan. The difference between those two methods in seismic simulations was investigated. The seismic wave

obtained from the Ojiya observation site during the Niigata earthquake was adopted in this study. The code of *k*-SHAKE was used to investigate the seismic wave at the deep rock formation with a depth of 200 m. The corresponding velocity and acceleration waves were input into the DEM and FEM models, respectively. The response waves at different locations from FEM simulations exhibit good consistency. With seismic waves propagating from the deep rock formation to the ground surface, the amplitudes at waves' peaks and troughs increase. However, according to the DEM simulations, the amplitudes of seismic waves decrease with the upward propagation of seismic waves. In addition, the DEM simulations show obvious divergences of waveforms. The comparison of response waves at the same locations indicates that the wave amplitudes obtained by the DEM simulations are smaller than those of the waves by the FEM simulations. Moreover, the difference in wave amplitudes becomes obvious with the decrease of depth of monitoring points. The differences between the FEM and DEM simulations were resulted from the treatment of discontinuities. The FEM can not present the large deformation behaviors of faults, underestimating the fault's weakening effect on the propagation of seismic waves. Relatively, the DEM with the capability of simulating the sliding and separation of faults can evaluate the effect of discontinuities well in seismic simulations. Therefore, the DEM can be regarded as a better method than FEM in seismic response evaluations of bedrock with discontinuities. The main results may provide suggestions to the numerical studies and safety evaluations of bedrock subjected to seismic loads.

３．今後の展望と感想

The seismic behavior of rock foundation remains as one of the most promising and fundamental problems in the academic and engineering aspects. However, it is still not well understood at present, due to the complexity of rock structure and the uncertainty of seismic waves. There are a mass of discontinuities existing in the rock mass, which principally governs the deformation and failure behavior of rock mass. Evaluating the effect of discontinuities properly is the key issue in the analyses of seismic responses of rock foundation. The geometric distribution of discontinuities in rock masses, such as the dip angle, the spacing and the density of discontinuities, influences the dynamic characteristics of rock foundation to a great extent. Therefore, more numerical simulations of DEM will be carried out in the future, to investigate the influences of geometric factors of discontinuities on the seismic behavior of rock foundation. Moreover, the mechanical properties of discontinuities like the normal and shear stiffness also have obvious effects on the scatting of seismic waves, which subsequently affects the reflection and transmission of seismic waves. In the future, DEM simulations will be performed on the effects of the mechanical properties of discontinuities.

Through taking apart in the 12th ISRM International Congress on Rock Mechanics, I learned much about the new research methods and theories for dynamic analyses of rock mass. Especially, I had a good opportunity to communicate with some scholar form other countries when I made my post presentation, and received good suggestions on the dynamic simulation, which would be very helpful for my future studies.