공간 지반 정보 시스템을 활용한 2차원 분지 모델링 기반의 홍성 지역 부지 효과 평가

Estimation of Site Effects at Hongsung Based on 2-Dimensional Basin Modeling within Spatial Geotechnical Information System

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요지

지하 토사 조건 및 지질 구조는 지진 시 지반 운동의 증폭에 관련된 부지 효과에 매우 큰 영향을 미친다. 본 연구에서는 국내 홍성 지역을 대상으로 시추 조사와 현장 탄성파 시험을 포함한 현장 조사 및 지표 부근 지질 정보를 획득하기 위한 부지 답사를 통해 부지 효과를 확인하였다. 홍성 지역은 1978년 계기 지진이 발생한 지역으로서 기반암 상부에 최대 약 50 m 두께의 풍화대 지층이 분포한다. 연구 대상 지역의 공간 지층 구조를 효율적으로 확인하기 위하여 지리정보시스템(GIS) 기법 기반의 지반 정보 시스템(GTIS)의 구축하였으며, 홍성 지역은 분지는 얕고 넓은 형상임을 확인하였다. 홍성 지역의 부지 지진 응답을 평가하기 위하여 대표 단면에 대한 2차원 유한 요소 해석을 수행하였다. 도출된 지진 응답으로부터 지반 운동이 기반암 상부 토사층을 통해 전단파가 전파되면서 증폭되고 분지 형상에 따른 전단파의 상호 작용으로 생성된 표면파로 인해 분지 경계 부근 진동 지속 시간이 증가됨을 확인하였다. 뿐만 아니라, 분지 내의 선정된 토사 부지들에 대해서 추가적인 1차원 유한 요소 지진 응답 해석을 수행하였으며, 본 연구 대상 분지가 매우 얕고 넓음에 따라 분지 경계 부근을 제외하고는 분지 내 대부분의 위치에서 2차원 지진 응답과 유사한 결과를 보였다.

주요어 : 부지 효과, 지진 응답, 분지 효과, 지리 정보 시스템, 지반 정보

1. Introduction

The stratification structure and physical properties of near-surface soils and geology, as well as the surface topography and basin geometry, affect the site effects relating to the amplification of ground motion during earthquake (Bakir et al., 2002). In order to estimate correctly the site effects and the corresponding ground motions from 2-dimensional (2D) wave propagation analyses, accurate modeling of the subsurface geological structure is preferentially required. Nevertheless, most of the pervious 2D analyses have been conducted based on simplified 2D basin models. These models have been developed empirically by the geological judgements without systematic investigation of spatial geologies based on intensive site investigation data (Marrara and Suhadolc, 2001). In this study, the geographic information system (GIS)-based spatial geotechnical information system (GTIS) is implemented for constructing a reliable model of the subsurface geological structure in the Hongsung area located on the Korean peninsula. On the basis of spatial geological information predicted across the study area within the 3-dimensional (3D) GTIS, a representative cross section is selected and the seismic response analyses using a finite element (FE) method are performed for more realistically evaluating the site effects. Moreover, 1-dimensional (1D) FE seismic response analyses were conducted, and by comparing their results with those of 2D analyses, the 2D basin effects are evaluated.

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2. Geotechnical Earthquake Engineering Characteristics of Hongsung Area within the GTIS

For the reliable prediction and application of spatial geotechnical information in the evaluation of earthquake ground motion with the subsurface geologic structure, in this study, a GTIS was developed based on GIS technology (Sun et al., 2007). A conceptual framework for this GTIS was designed to predict more reliably geotechnical information by incorporating a geostatistical kriging prediction method. In the field of geotechnical and earthquake engineering, a GIS is used either alone or in conjunction with specified model analysis techniques (Gangopadhyay et al., 1999). For the practical research described in this paper, the GTIS was developed based on GIS tools in combination with various specified expert techniques (Sun and Chung, 2007). The estimated geotechnical information could be utilized in 2D modeling for evaluating the site effects in the study area.

Hongsung has records of damage by an earthquake of magnitude 5.0 on October 7, 1978, as well as some historical earthquake events (Sun et al., 2005). Hongsung is a typical topography of old age with gentle relief. To determine the local geologic characteristics and estimate the corresponding site effects, various geotechnical investigations, which include boring investigations and seismic tests in field and resonant column tests in laboratory, were conducted at the Hongsung area (square area of 4 km by 4 km). Most areas in Hongsung are composed of 10 to 50 m thick weathered residual soils and weathered rocks beneath thin alluvial sands and silts. Furthermore, compiling synthetically overall in-situ seismic testing results, the shear wave velocity (V_S) was determined representatively to be 330 m/s for alluvial soil with fill, 450 m/s for weathered residual soil, 560 m/s for weathered rock, and 1,000 m/s for bedrock. These data were then utilized as the input properties for the seismic response analyses.

Figure 1, generated from the GTIS, shows the spatial variation of geotechnical layers at the Hongsung area and the locations of filed investigation sites. This GIS-based GTIS enables users to examine the geotechnical data referenced by spatial coordinates using the function of vertical and/or horizontal slice and cut of a 3D ground volume and to export this data in the form of ASCII or DXF, which can be easily imported in other numerical tools.

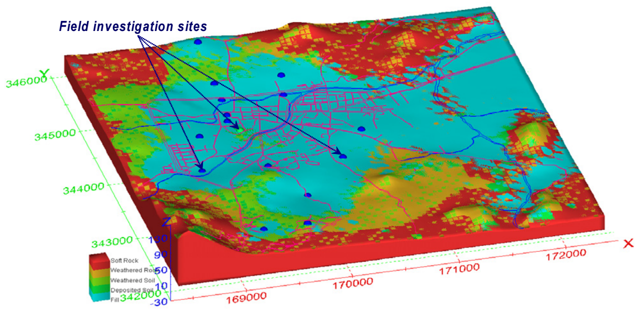


Figure 1. Spatial geotechnical layers and investigation sites of Hongsung (4 km by 4 km area).

3. 2D Seismic Response Analysis

For the evaluation of the site effects in the Hongsung which shows geologic basin shape especially in the direction of north to south (N-S), 2D seismic response analyses were performed using the general-purpose FE method program, ABAQUS (Hibbitt et al., 1998). A 2D section was chosen to investigate the 2D basin effects, as illustrated in Figure 2. In this study, the spatial coordinates of the interfaces between geotechnical layers predicted within the GTIS were imported to use for the generation of an accurate 2D model reflecting the actual basin geometry in Hongsung. The dimensions of the selected cross sections

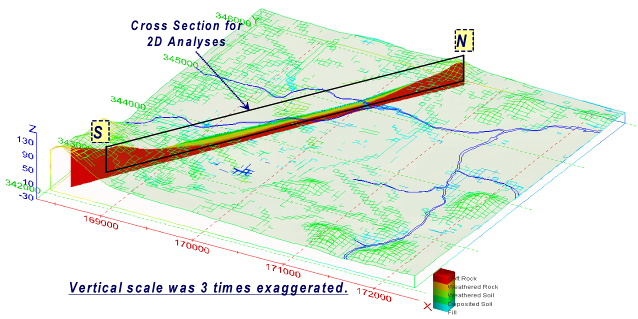
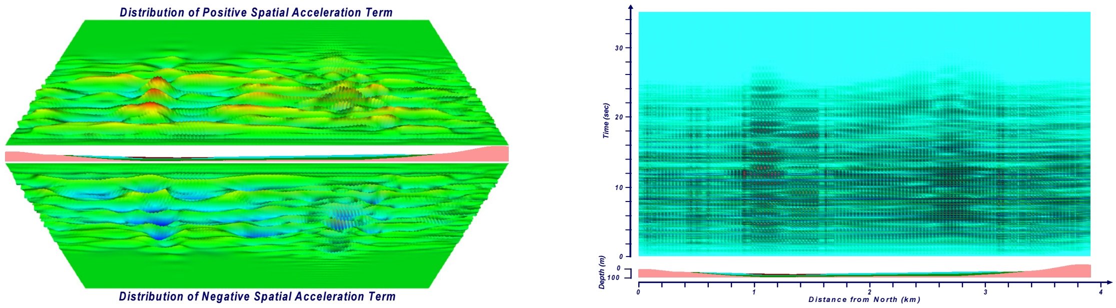


Figure 2. Cross section selected for 2D modeling.

for FE modelings consist of 3,900 m in length and 128 m in height (for N-S section). It is true that the subsurface soil structures show very shallow and wide (flat) shapes with about 3,620 m in width and 60 m in maximum depth. Two artificial input motions composed of a total duration time of 16 seconds (AS 16 motion) and 25 seconds (AS 25 motion) were synthesized with a peak acceleration of 0.10g in bedrock underlying soil layers for the seismic response analyses.

With regard to the time responses of the basin, the acceleration time-histories across basin were examined based on those on the output nodal points from the 2D analyses. Figure 3 shows the typical results of acceleration time responses. These results were built by interpolating the time-histories at surface output nodes. Figure 3(a) is the bird view illustrated with both positive and negative fluctuations in acceleration levels. Figure 3(b) is the plane view illustrated with shade in duration.



(a) Bird view for the AS 16 motion (b) Plane view for the AS 25 motion

Figure 3. Acceleration time-responses on basin surfaces from 2D analyses.

The duration of motions was considerably prolonged at the interior locations adjacent to the basin edges. This phenomenon is mainly interpreted as the trapping of shear waves and the generation of surface Rayleigh waves. Moreover, the complexity of seismic responses was clearly observed at the basin edges because the waves were reflected at the inclined bedrock. At the central part of the basins, the motion of low frequency was dominant because the incident waves were mainly propagated vertically without any wave reflection and the high frequency components of motions were filtered through soil layers like the typical 1D seismic response. Generally, the seismic responses were greatly influenced by the subsurface geotechnical structures modeled into alluvial soil, weathered residual soil and weathered rock overlying bedrock in this study.

4. Comparisons between 1D and 2D Seismic Responses

For the purpose of comparing with the 2D results and assessing the 2D site effects, additional 1D FE seismic response analyses were conducted at a total of 9 selected soil sites. From the results of the 1D and 2D seismic response analyses, the peak ground accelerations (PGAs) were first investigated as depicted in Figure 4, of which the additional locations (named as the distance) selected for the 1D analyses were also shown in the lower subset. Throughout the inside of basin, the trend of the quantitative differences in the accelerations between the 1D and 2D analyses was not observed with the exception of the basin edges. In general, the basins are divided into a shallow and wide basin and a deep and narrow basin, according to the value of 0.25 in the ratio of depth to width (Kramer, 1996). For the basin section chosen in Hongsung, the ratio was about 0.017, which indicates an extremely shallow and wide basin shape. The subsurface geometry in the basin edges showed a gently sloped bedrock shape.

Furthermore, in order to estimate 2D basin effects on the basis of the results from 1D and 2D seismic response analyses, the acceleration response spectra at the selected soil sites were also determined from both analysis techniques. The spectral ratio of 2D to 1D was additionally calculated and compared from the soil sites in the basins. From the comparisons at the sites at or near the basin edges, it was generally observed that the spectral accelerations from the 2D analyses were somewhat higher than those from the 1D analyses in a long-period range, despite those of the 1D being higher than those of the 2D, resulting in a short-period range in a few cases. This can be explained by the generation of surface waves. Nevertheless, the 2D effects that showed a large spectral acceleration in 2D analyses were not distinguished, because the basins at Hongsung showed the shallow and wide basin configuration.

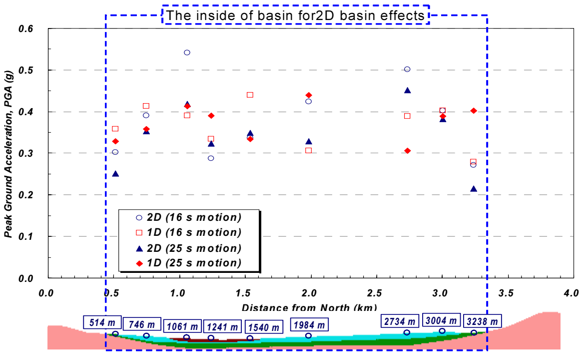


Figure 4. Comparisons of PGAs from the 1D and 2D analyses.

5. Conclusions

In order to sensibly estimate the site effects at Hongsung, a GIS-based GTIS for predicting reliably of spatial geotechnical information was built. 2D seismic response analyses for a cross section (N-S basin) were conducted by generating FE models based on the spatial coordinates of the geotechnical layers interpolated within the GTIS. Particularly, the subsurface soil structures at the 2D basin in Hongsung showed very shallow and wide shapes having the value of 0.017 for the ratio of depth to width. From the 2D analyses, it was observed that the durations at the interior parts near the basin edges were prolonged primarily because of the surface waves generated by the reflection of shear waves. On the other hand, the central parts of the basins exhibited low frequency motion. 1D FE seismic response analyses were additionally performed at the selected 9 soil sites. From the comparison results of the response spectra, the differences between the 2D and 1D analyses were scarcely observed at most plain sites in the interior of the basin.

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