[11] 지하공간 3D GIS

3D GIS

- 3D GIS로의 발전

❖ 지도제작의 목적
❖ 소프트웨어의 한계
→ 평면데이터를 많이 사용함

➡ ❖ 소프트웨어에서 제공되는 기능이 늘어남
❖ 3차원 데이터를 다루는 분야가 많아짐

➡ 3차원 GIS의 기능, 함수에 대한 연구

- 3D GIS의 특징

❖ 3차원 좌표 이용
❖ 3차원 공간 분석함수
❖ 3차원 시각화

⇨ 2차원, 2.5차원 GIS가 3차원 공간에 존재하는 데이터를 고려할 때 가지는 단점들을 보완

3D GIS vs. 2D, 2.5D GIS

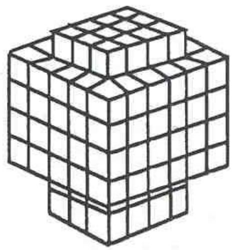
- 2D GIS
  - Z값이 속성으로서 저장됨-색, 등고선 등으로 표시
  - 한 쌍의 X, Y에 대해 복수의 Z값 불가능

- 2.5D GIS
  - x, y 평면상에서 z 방향으로 높이값 만큼 돌출 (extrude)
  - 3차원 visualization
  - 한 쌍의 X, Y에 대해 복수의 Z값 불가능-> plane, interface
  - 3차원 공간분석 함수 기능 없음

- 3D GIS
  - x, y, z 좌표로써 3차원 객체 저장
  - 3차원 visualization
  - 한 쌍의 X, Y에 대해 복수의 Z값 가능
  - 3차원 공간분석 함수

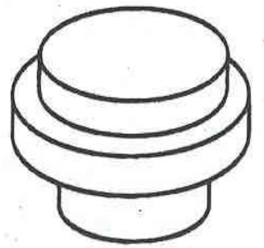
3D GIS의 대표적 모델

Volumetric Model



- 3차원 object의 내부 속성을 각 voxel마다 나타냄
- 연속적인 데이터
- 2D GIS의 Raster모델과 유사
- 광체의 품위, 오염물의 확산 등

Geometric Model



- 3차원 object의 surface를 수학적으로 정의하고 나타냄
- 불연속적인 데이터
- 2D GIS의 Vector모델과 유사
- 지층 구조, 지하수위 등

3D GIS의 대표적 모델 (비교)

• Comparison between geometric model and volumetric model (based on previous works by Kavouras (1992), Marschallinger (1996) and Raper (2000))

Characteristics	Volumetric model	Geometric Model
Emphasis	Defining and representing variations in internal properties of objects	Defining and representing the bounding surfaces of 3D objects
Variables	Continuous variables	Discrete variables
Comparison to 2D GIS	Analogous to raster-based representations in 2D GIS	Analogous to vector-based representation in 2D GIS
Advantage	Easy and efficient to perform Boolean operations and volume computations Easy to store and visualize the results of 3D spatial interpolation techniques	Easy to visualize objects by various degrees of surface smoothness More attractive for visual perception
Disadvantage	Large storage requirement for high resolution model Not attractive for visual perception due to “jaggy” approximations	Difficult to represent fragmented objects and variations in internal properties Difficult to perform Boolean operation between two objects

지하공간 3D GIS

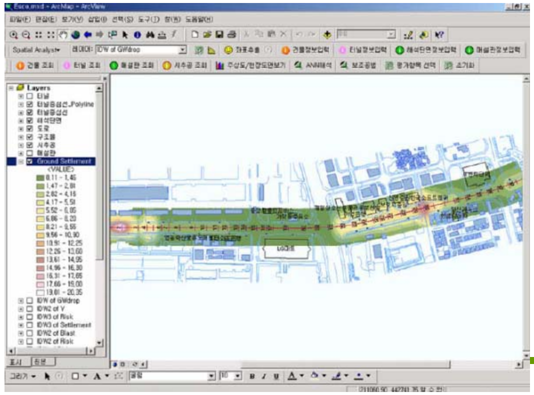
터널설계 지원 적용사례

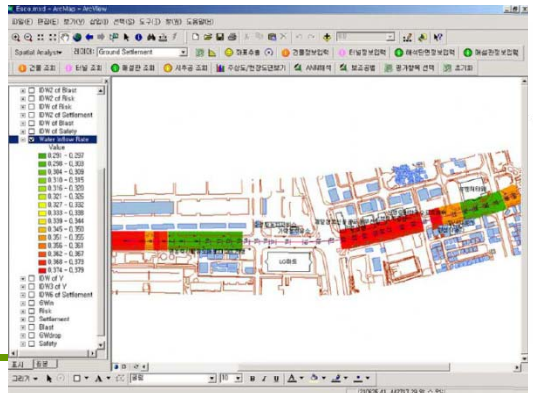
Research Background

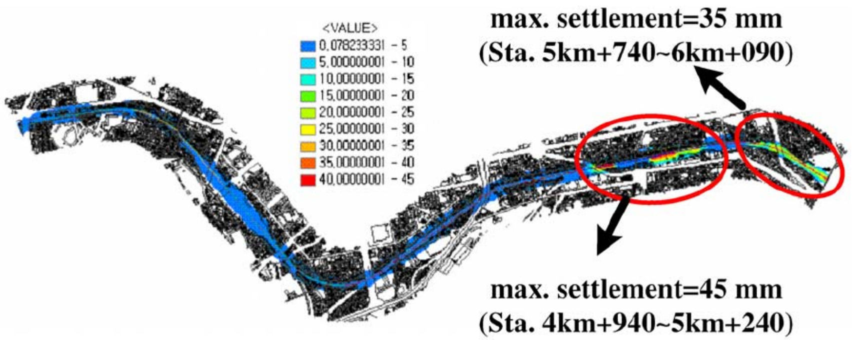
- Traditionally, the subsurface characterization was conducted **manually by geologists** and required **much time and effort**. However, nowadays, Geographic Information Systems (GIS) and Computer Aided Design (CAD) systems are widely used in the tunneling industry and play **important roles in the process of subsurface characterization**.
- **New trend**: geologists can **search** and **download** the **digital-ready data** including **boreholes, cross sections, remote sensing images, geological maps, topographical maps, hydro geological maps, structural geology maps** as well as **contours of the water table** that are required for subsurface characterization.

Research Background

- **Recent applications of GIS for tunneling projects**
  - **Kimmance et al. (1999) tried to use GIS as a geotechnical database system on airport line Metro Rail Transit (MRT) construction and discussed the design and architecture of database systems for a tunneling project. However, the functionality of the system was limited to query records stored in relational database tables.**
  - **Yoo et al. (2006) developed a GIS-based risk assessment system for tunneling as an extension of ESRI's ArcGIS. The program provided advanced functionalities for analyzing ground movement, utility damage and groundwater drawdown that can occur during tunnel construction. However, it could only manipulate and analyze two-dimensional (2D) data.**
  - **Yoo and Kim (2007) also used GIS for predicting tunneling performance in a high-speed railway tunnel; however, the aim of GIS utilization was limited to visualizing the performance prediction maps in 2D.**







Research Background

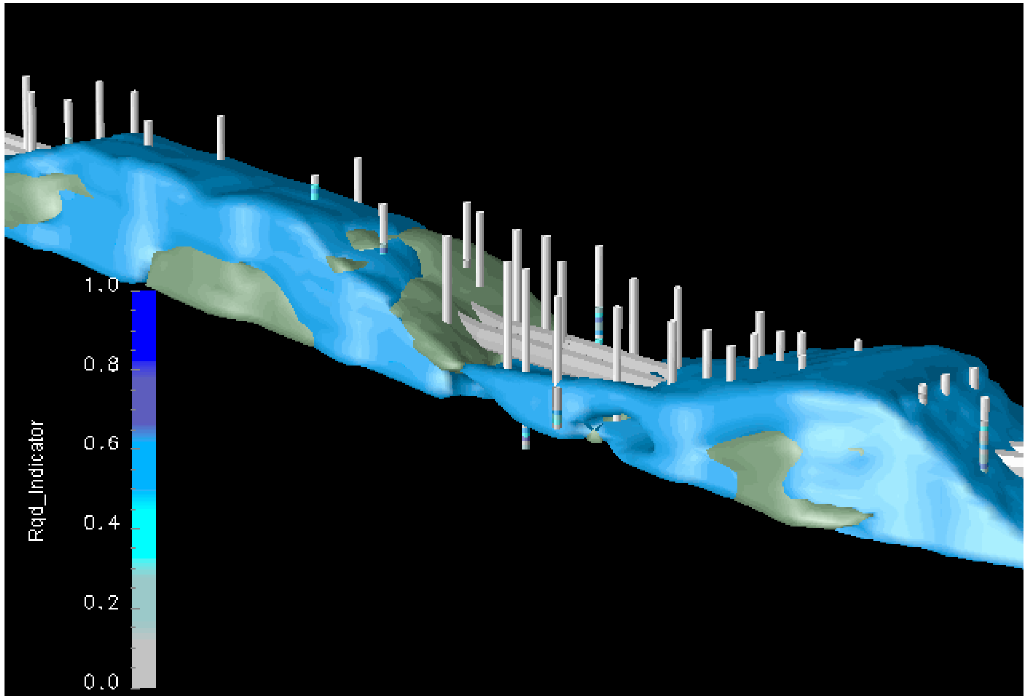
- **3D GIS for tunneling projects**
  - **Although a few attempts have been made to use 3D GIS for tunneling projects (Elkadi and Huisman, 2002; Kaalberg et al., 2003; Ozmutlu and Hack, 2003), these mainly focused on 3D geological modeling with extensive use of external software such as Lynx-GMS (Houlding, 1994), and they used GIS for 3D visualization of block models representing soil or rock types in the subsurface.**
- **Problems due to their excessive dependence on external software**
  - **Much data conversion among the various software and that is often time consu ming and tedious, especially for a large study area**
  - **Difficult to consider the quality control and quality assurance when converting data**
- **General 3D visualization tool**
  - **More specific functionalities such as rock mass classification, fault zone analysis , etc., are not available to support tunnel design work**

Purpose of Research

- This study presents a new extension, Tunneling Analyst (TA), that has been developed in ArcScene 3D GIS software, part of the ArcGIS software package, to improve 3D GIS functionality for the tunneling industry.
- The multiple indicator kriging method is used for estimating a 3D distribution of RMR values of the tunneling site from borehole and geophysical exploration data (volumetric approach).
- Modeling a 3D discontinuity plane is performed to generate a fault plane in GIS (geometric approach), and 3D spatial queries are carried out to identify tunnel sections with difficult tunneling conditions due to the fault.
- This presentation describes the concept and details of the TA development and its application to the Daecheong tunneling project in Korea, supporting the tunnel design work.

Volumetric Modeling Approach

- **To consider the rock properties in the subsurface, the volumetric modeling approach should be used with appropriate 3D geostatistical estimation techniques.**

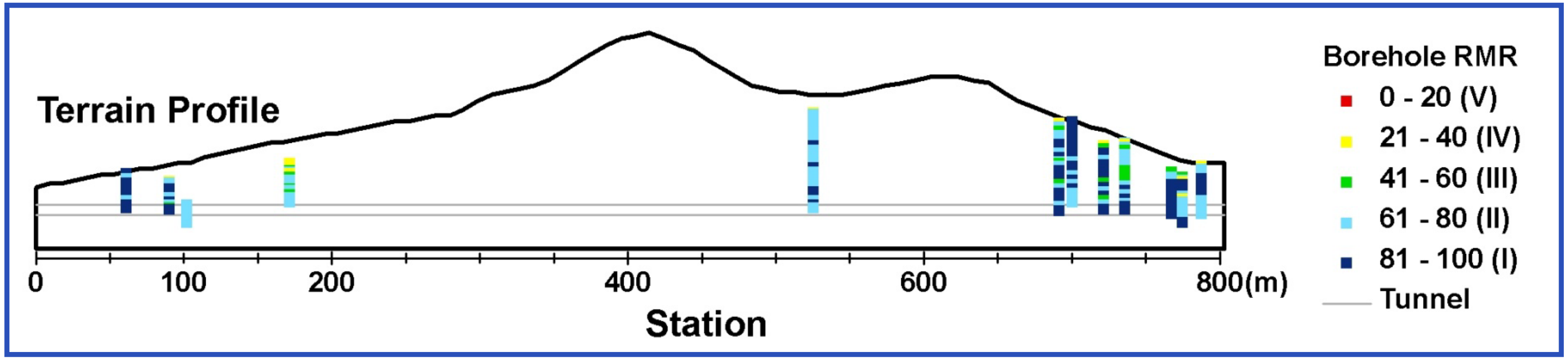


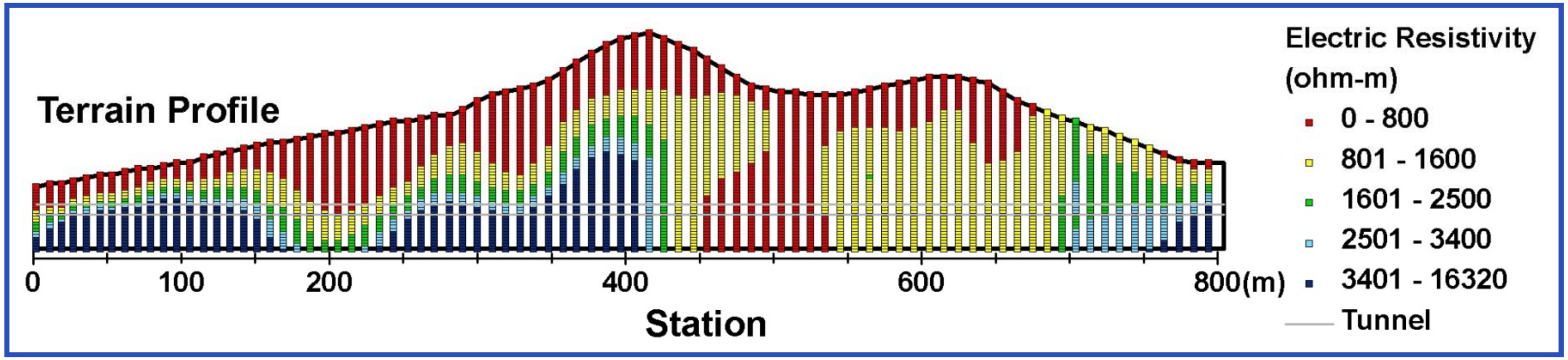
Houlding (2000)

- **The number of boreholes available in a tunneling site is usually limited due to the investigation cost.**

Volumetric Modeling Approach

- **In site investigation for tunnel design, nowadays, geophysical exploration as well as drilling logging is generally carried out to evaluate rock mass classes along the proposed tunnel alignment.**





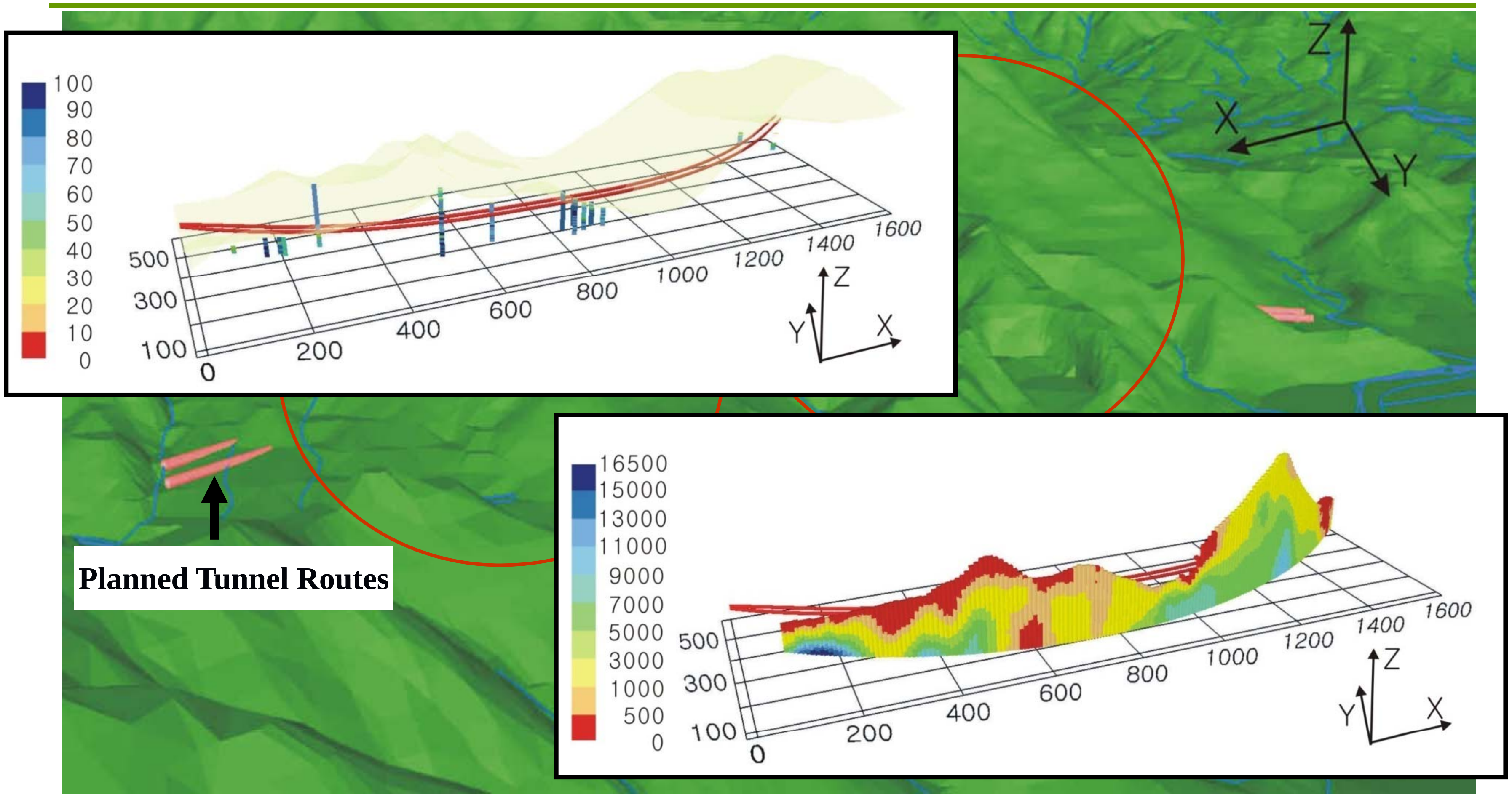
Volumetric Modeling Approach

- **Although they have same purpose in a tunneling project (i.e. site characterization), each data has both pros and cons**
  - **Borehole data**
    - **Pros: quantitative information for evaluating rock mass classes (e.g. RMR system)**
    - **Cons: limited number of data due to the investigation cost**

      →there can be many un-drilled sections along the tunnel route where no drilling logging exists
  - **Geophysical exploration data (e.g., electric resistivity, seismic velocity)**
    - **Pros: information that can cover the entire tunnel route including both drilled and un-drilled sections**
    - **Cons: information is not quantitative but qualitative**

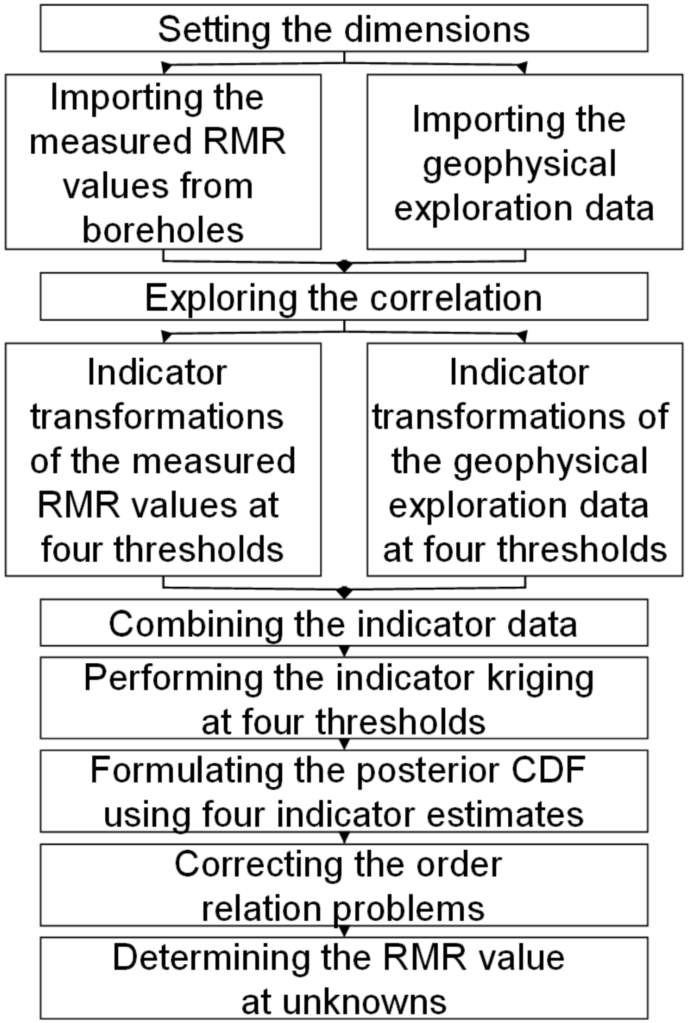
      →the uncertainty is generally much higher than that derived from borehole data

Volumetric Modeling Approach



By using the multiple indicator kriging method, boreholes and geophysical exploration data can make up for their weak points

Volumetric Modeling Approach

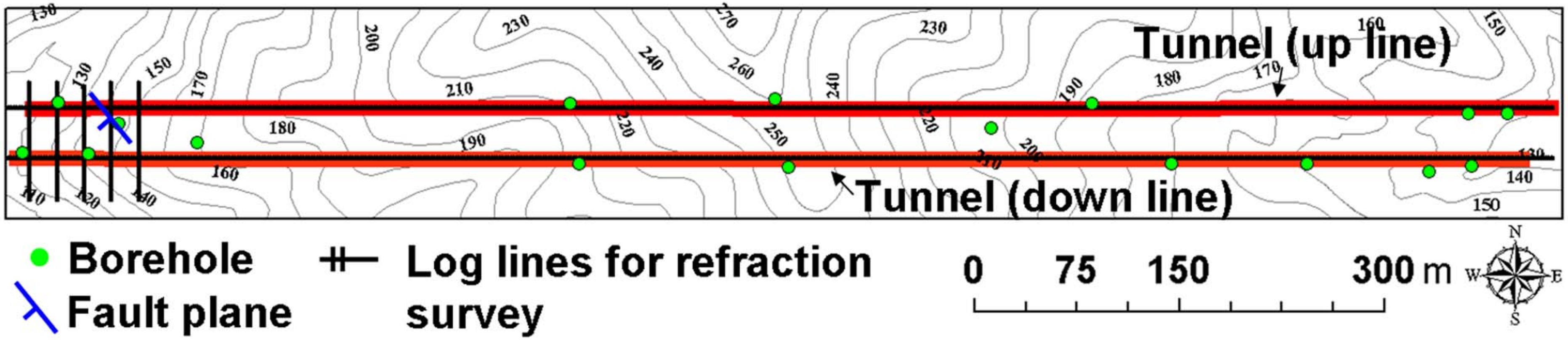


Procedures of multiple indicator kriging for estimating 3D distribution of RMR values

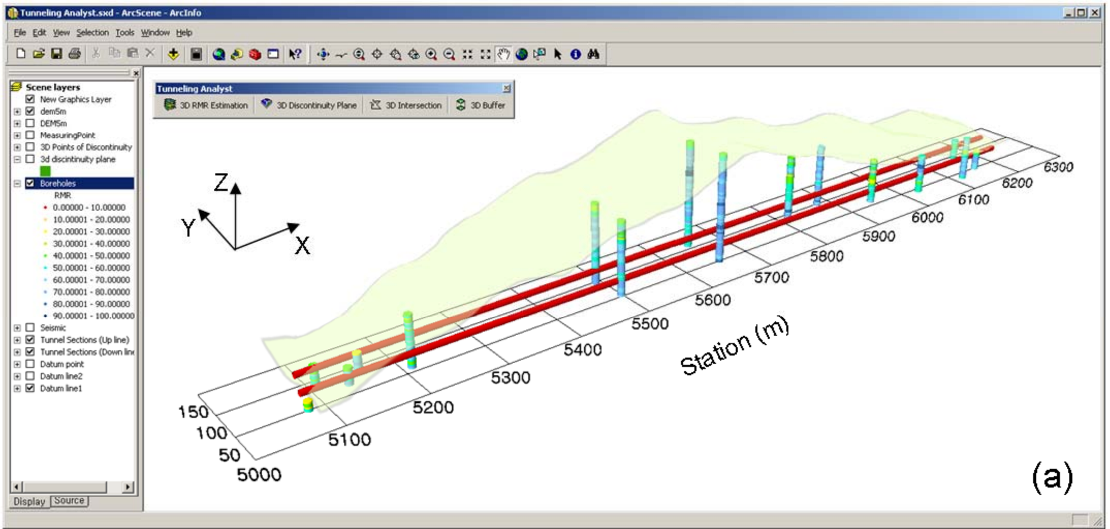
Application

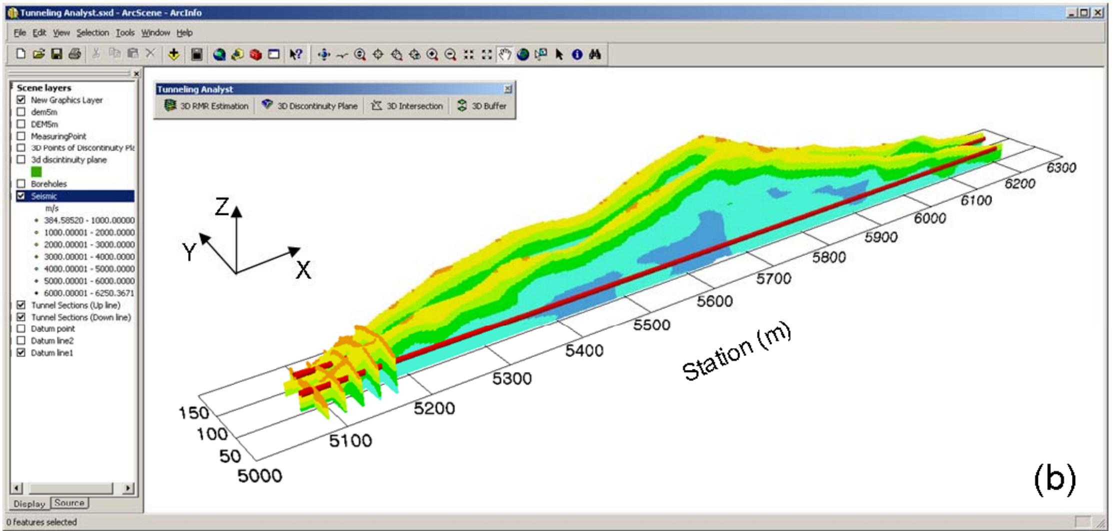
The Daecheong tunnel design project

- The Daecheong tunneling site in Korea (1135m × 150m)
- Twin tunnels with diameters of 13.4m and a length of 1.1 km under a mountainous environment
- The geology in the study area consists of 0–4m thick layers of colluvium followed by a 1–12m granitic residual soil layer. Underlying the soil layer is a 1–12m completely weathered granite layer followed by moderately to slightly weathered granite layer



Application

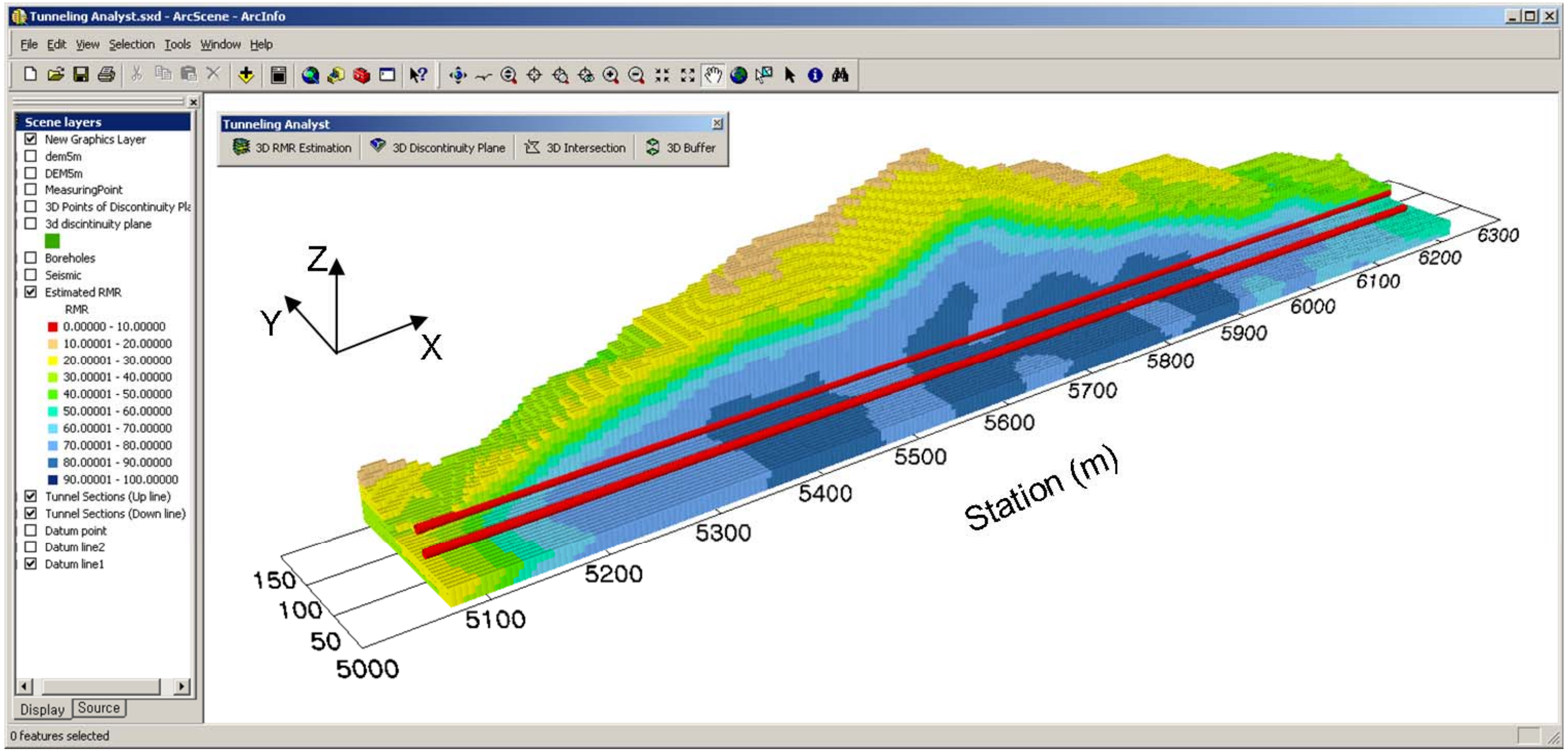




3D distributions of site investigation data. (a) Measured RMR values from boreholes. (b) Seismic velocity (m/s) from seismic refraction survey.

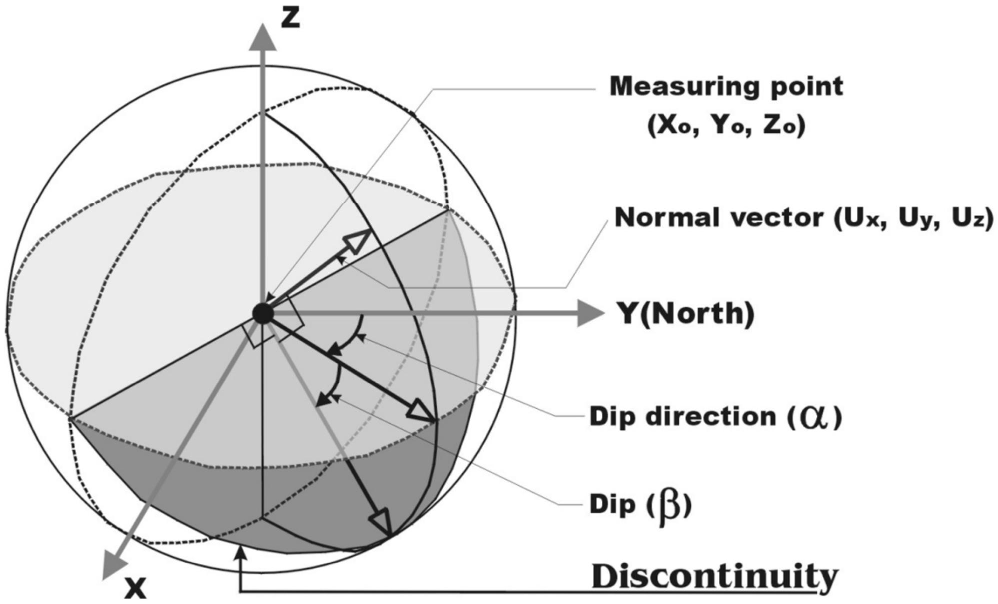
Application

- **3D distribution of estimated RMR values in study area**
  - **Project dimensions: 5070-6205m with 5m spacing in an X-direction**
  - **0-150m with 5m spacing in an Y-direction**
  - **100-280m with 5m spacing in an Z-direction**



Geometric Modeling Approach

- Modeling a 3D discontinuity plane using simplest fitting function



Orientation of a discontinuity: spatial relationship between measured values and the normal vector in XYZ space

Measuring point (X_0, Y_0, Z_0)

Dip/Dip direction (α, β)

↓

Normal vector

$U_x = \sin(\beta)\sin(\alpha)$

$U_y = \sin(\beta)\cos(\alpha)$

$U_z = \cos(\beta)$

↓

Plane equation

$Ux(X-X_0)+Uy(Y-Y_0)+Uz(Z-Z_0)=0$

↓

Points on the plane

↓

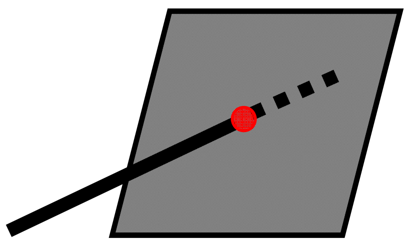
TIN surface representing the discontinuity

Procedures for generating a 3D discontinuity plane from a structural measurement

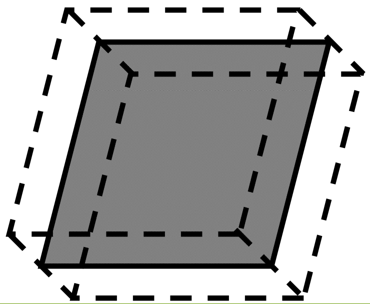
3D Spatial Query Functions

- **Possible queries in GIS to support tunnel design work**
  - **"Select all faults and joints that are pierced by a proposed tunnel alignment." This query may be used to search for discontinuities that need consideration of the angle between a proposed tunneling direction and their dip direction. It can also indicate where the fault will appear on the tunnel alignment during excavation**
  - **"Select the set of tunnel stations within 20 m of the intersection between a proposed tunnel alignment and a fault plane." This type of query can be used for identifying tunnel sections with unstable ground conditions such as a fracture zone that needs strong supporting systems**

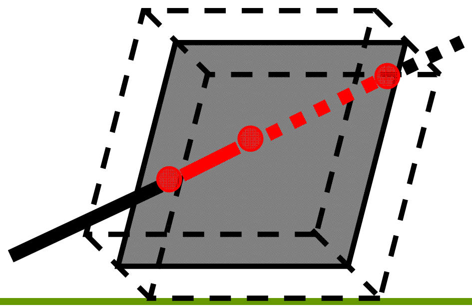
3D Intersection



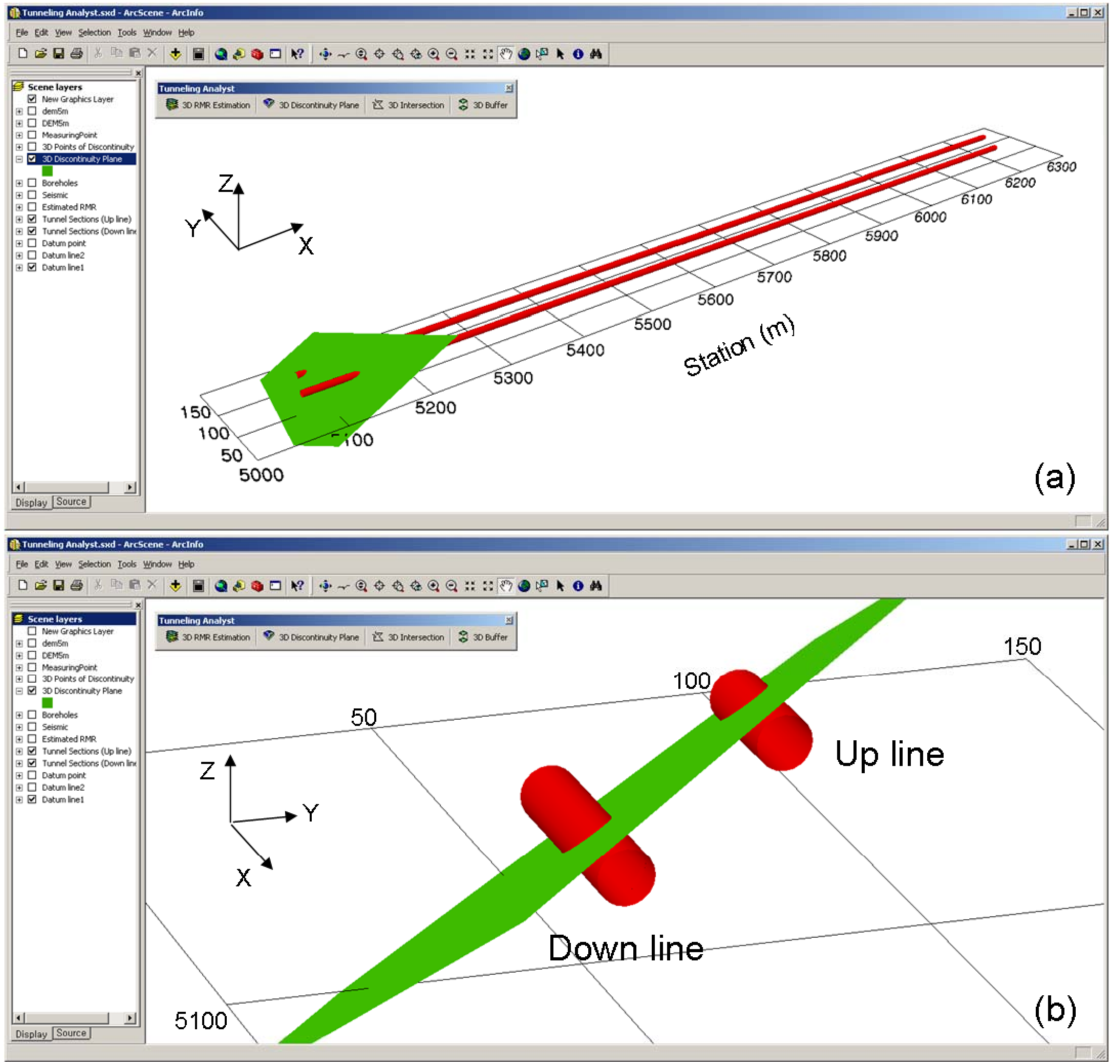
3D Buffer

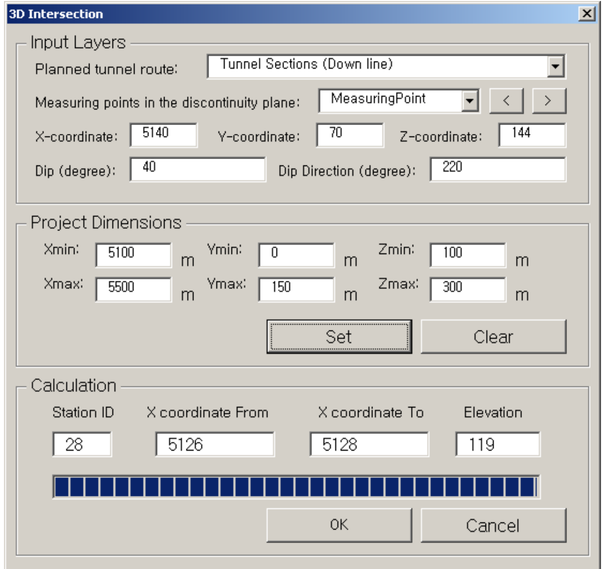


3D Intersection & Buffer



Application





(a) 3D view of generated fault plane and (b) tunnel sections within a 10m buffer zone of fault plane.