You learned a lot about techniques, materials, calculation methods, etc. in engineering design.
What makes underground excavation design different to other fields of engineering design?
Examples:

- Reinforced concrete
- Steel constructions
- Wood constructions
- Compound materials
  (steel and concrete, or wood and steel, etc.)
Rock mechanics:
The material is not determined by the designer!
Differences to other fields of engineering?

The main difference to other engineering disciplines is that in rock mechanics the material is pre-determined, e.g.:

Steel, concrete, wood, compound material design.

The material is well determined.

It is possible to choose material with different characteristics.

Tests are easy to perform and to determine.
How to influence the rock mass?

There are chances to influence the rock mass behaviour around an underground opening:

**Shape, Orientation, Support Measurements**

To figure out the best shape and the best orientation is the most successful way to influence the rock mass behaviour around a tunnel.

So let us talk a little about the influence of the shape and the orientation of the building.
Figure 2.5: Orientation of the underground underground excavations in relation to the faults in the bedded sandstone surrounding the power cavern and transformer hall of the Mingtan Project. The red plane indicates the dip and strike of the faults.
Rockburst in an underground mine

(Photo: Hoek Rock Engineering, course notes)
Rockburst at Gothard base tunnel
Poor blasting

(Photo: Hoek Rock Engineering, course notes)
Good blasting

(Photo: Hoek Rock Engineering, course notes)
Achraintunnel road header
Achraintunnel road header
Figure 5.5: Ravelling of small wedges in a closely jointed rock mass. Shotcrete can provide effective support in such rock masses.

(Photo: Hoek Rock Engineering, course notes)
Example

A wedge failure in the roof of the top heading of the Rio Grande tailrace tunnel

(Photo: Hoek Rock Engineering, course notes)
Example

A 6m wide heading driven ahead of the tunnel to permit pre-reinforcement of potential unstable wedges in the roof

(Photo: Hoek Rock Engineering, course notes)
Example Ambergtunnel

Wedge failure in the roof of the top heading

Wedge forms the tunnel shape
Example Ambergtunnel

Wedge failure in the roof of the top heading
Example Ambergtunnel

Wedge failure in the roof of the top heading

Wedge forms the tunnel shape
Example

Figure 6.1: The 12 m span 8 m high top heading for the tailrace tunnel was constructed by full-face drill-and-blast and, because of the excellent quality of the massive gneiss, was largely unsupported.  

Foto: Hoek Rock Engineering, course notes
Example

A view of the 25 m span Rio Grande power cavern during excavation of the lower bench

(Photo: Hoek Rock Engineering, course notes)
Example

Partially completed 20 m span, 42.5 m height underground powerhouse cavern of the Nathpa Jhakri Hydroelectric Project in Himachel Pradesh, India. The cavern is approximately 300m below the surface.

(Photo: Hoek Rock Engineering, course notes)
Figure 11.23: Isometric view of the 3DEC$^4$ model of the underground powerhouse cavern and transformer gallery of the Nathpa Jhakri Hydroelectric Project, analysed by Dr. B. Dasgupta$^5$. 
Tunnel face instability Tunnel Steinhaus
Chienberg Tunnel Switzerland
Chienberg Tunnel Switzerland

Crater due to tunnel face instability
Figure 11.24: Large displacements in the top heading of the headrace tunnel of the Nathpa Jhakri Hydroelectric project. These displacements are the result of deteriorating rock mass quality when tunnelling through a fault zone.

(Photo: Hoek Rock Engineering, course notes)
Example

Figure 11.27: Side drift in the Athens Metro Olympion station excavation that was excavated by the method illustrated in Figure 11.25. The station has a cover depth of approximately 10 m over the crown.

(Photo: Hoek Rock Engineering, course notes)
Example

Installation of sliding joint top hat section steel sets immediately behind the face of a tunnel behind advanced through very poor quality rock.

(Photo: Hoek Rock Engineering, course notes)
Example: Spiling

Spiling in very poor quality clay-rich fault zone material.

(Photo: Hoek Rock Engineering, course notes)
Tauerntunnel loose gravel
Tauerntunnel loose gravel
Example Strenger Tunnel (high deformations)
Example Strenger Tunnel (high deformations)

Undeformed damping elements

Deformed damping elements
Example Strenger Tunnel (high deformations)

Deformed damping element
Cables and shotcrete were used to support the roof of the power cavern in the Mingtan Pumped Storage Project in Taiwan.

(Photo: Hoek Rock Engineering, course notes)
Example

Results achieved using well designed and carefully controlled blasting in a 19 foot diameter tunnel in gneiss in the Victoria hydroelectric project in Sri Lanka. Photograph reproduced with permission from the British Overseas Development Administration and from Balfour Beatty - Nuttall.
Example Cern

**Shafts**

PX16: Diameter 13 m

PX14: Diameter 18 m

**Chambers**

UX15: Span 35m, Height 42 m, Length 56 m

USA15: Span 22 m, Height 17 m, Length 63 m

LEP Beam tunnel

Ground Anchor galleries

UPX 16

ULX 16

UPS16

UJ 17

UJ 16

ULX 14

UPX 14

ULX 15

UPS 14

UJ 13

UJ 14

UJ 15

PM 15

PX 15

PX 16

PM 15
Example Cern different excavation stages
Example CERN displacements
Example Cern

Vertical displacement

Plastic zones
Figure 2.8: Displacement contours obtained from a two-dimensional finite element analysis of the seven excavation stages of the Mingtan power and transformer caverns. The layout of cables used to support the rock surrounding the caverns and the location and properties of the rock units are indicated in the figure. Shear failure of the rock mass is represented by the × symbols while tensile failure is shown by the o symbols. Note that almost all of the failures are within...