Educational Course Curriculum

Mechanized Underground Construction Technologies and Equipment Design

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By Vasily Anishchenko,

Information about the Author:

PHD in Engineering,

Department of Mining Machinery,

Topic of Doctoral Thesis: “RATIONALE FOR THE CHOICE OF PARAMETERS OF RACK-AND-PINION DRILLING RIGS FOR SLANT DIRECTIONAL AND HORIZONTAL WELLS OF LARGE DIAMETER WITH VARIABLE PROFILE”

Background Projects:

- Multiple microtunneling jobs across Europe, 2006-2023
- Turkmenistan-China Gas Pipeline HDD crossing. 56 inches, 1.3 miles, 2009
- Metro construction, Minsk, Segmental lining, OD of the tunnel 20 ft, 3x1.5 miles, 2014-2016
- Microtunneling crossing for the Transcaspian Gas pipeline, ID of the tunnel 1800 mm, unconsolidated gravel under a riverbed, 0.6 and 0.8 miles. 2014-2017
- Slant Directional drilling projects for heavy oil in Tatarstan handed over the technology and supervised 20 holes 0.6-1.2 miles long. Holder of the patent for ADI 360 rack and pinion drilling machine which performed the job at the oil field, 2015-2017
- Microtunnels in permafrost in Siberia, Krasnoyarsk Region, 2016,
- Titanium mining projects using rack and pinion drilling machinery in the republic of Komi 2016-2018,
- Multiple HDD crossings in North Dakota, Illinois and Canada, 2016-2023,
- Drilling 250 horizontal holes under concrete foundation to lift the dam of a hydro power plant, hole diameter – 8 inches, length of the drill holes - 600 ft, developed mathematics for the gyro-based steering system created for the project 2018-2021,
- Author of several patents for drilling machinery produced in the US and pending.

At present: Chief Engineer at Robins HDD, IL, USA

Major objectives of the course:

- Introduce modern underground construction technologies in various geological conditions to future civil engineers,
- Educate students in the safety of underground utility installations, disclose the possible risks and ways to manage them,
- Develop the students’ ability to design drilling, tunneling, and mining machinery,
- Enhance the student’s engineering skills pertaining to basic project management,
- Boost the students’ confidence in taking decisions pertaining to the correct choice of applicable technologies for drilling, tunneling, excavation of shafts and underground galleries,

- Educate civil engineers with equal efficiency in all existing trench and trenchless utility construction technologies, which would entice technological choices based on objective approach to the project data,
- Acquaint students with mathematical approach to data analysis in underground construction processes and equipment design,
- Solve the problem with educated specialists in the trenchless construction industry.

Module I

Underground Construction Technologies

1. Introduction to mechanized tunneling technologies and machinery.			
Lecture 1	2 Academic hours	History of tunneling. General safety principles	• Ancient tunnels (Egypt, Persia, Rome, China), • Coal mine galleries in England in the 18th century, • London tunnels, • Gun powder blast tunnels through rock, • New York tunnels with compressed air, • Modern tunneling technologies.
Lecture 2	4 academic hours (2 parts)	Available tunneling technologies	• Open face. Compressed air. Construction of mining galleries, • Sink Tunnels, • Drill and blast, • NATM, • Mechanized tunneling techniques. General Idea. Preliminary calculations.
Lecture 3	2 academic hours	Comparison and limitations for each of the available tunneling technologies.	• High water pressure (basic calculation principles), • Strong and abrasive rock (idea about Scheft Index and UCS), • Geometrical properties of the tunnel (minimum bending radii, diameter, inclination). Basic principles of calculating trajectory, • Logistical limitations, • Possible ways to expand the limits (examples of using IJS for pipe jacking, conveyor for the whole length of the tunnel, California switches, slurry pipelines).
Lecture 4	2 parts 4 academic hours	Navigational systems for tunneling	• Types of navigational systems, • Lazer-target based navigational systems, • Total stations for control, • Optical navigational systems for auger drilling and microtunneling, • Gyroscope based systems, • Basics for calculating tunneling trajectory.

Project 1	*2 parts 4 academic hours*	*Comparison between tunneling methods. Galleries and transport tunnels. Based on real project assignments.*
Project 2	*2 parts 4 academic hours*	*Comparison between tunneling methods. Microtunnels. Segmental lining and pipe jacking. Based on real project assignments.*

2. Introduction into drilling technologies and drilling machinery for mining			
Lecture 1	2 academic hours	History of drilling techniques. World drilling records	• Antient Chinese and Roman drilling rigs, • Drilling for oil at the beginning of the 20th century, • Introduction of top drive into drilling in the 1940s, • Horizontal directional drilling, 1970s, • Introduction of mud motors and RSS, • Evolution of navigational systems for drilling.
Lecture 2	4 academic hours (2 parts)	Basic drilling technologies	• Drilling rigs, • Pumps used for drilling, • Mud motors. Basics for pressure-flow diagrams, • Rotary steering systems, • Drilling fluids. Basics.
Lecture 3	2 academic hours	Types of drilling rigs	• Vertical drilling rigs for oil and gas drilling as well as geothermal drilling operations, • SDD rigs, • Horizontal directional drilling rigs and tolling, • Water mining rigs, • Drilling rigs for mining, • Rigs and tolling for geological survey operations.
Lecture 4	2 academic hours	Navigational systems for drilling	• History of navigation, • Hazards of drilling with limited navigational options, • Inclinometers, • Walk-over systems for horizontal drilling, • Gyro-based navigational systems, • LWD and MWD systems.
Project 1	*2 parts 4 academic hours*	*Choice of the correct type of drilling rig. Basic principle of compiling specifications for a drilling rig. First part for vertical drilling, second part for horizontal drilling*	

Project 2	*2 parts 4 academic hours*	*Choice of the correct type of additional equipment for a rig. First part for vertical drilling, second part for horizontal drilling*

3. Introduction into the most important geological parameters for drilling and tunneling. Geomechanics			
Lecture 1	2 academic hours	Drilling in rocky ground	• Types of major minerals, • Unconfined Compressive Strength, • Abrasive properties, • Weathering description, content of residual soil, • Granular structure and texture, • Specific gravity, • Permeability, • Size of cavities in formation, • Formation gas pressure, • Lab measuring tools and methods, • Effect of each of the properties on drilling effectiveness, hole stability and penetration rate. Choice of correct tooling.
Lecture 2	2 academic hours	Drilling in alluvial soil	• Specific Gravity, • Granular Structure, • Angle of internal Friction, • Water content, • Plasticity, • Water permeability, • Expansion factor, • Thickness of the layer, • Cohesion, • Lab measuring tools and methods, • Effect of each of the properties on drilling effectiveness, hole stability and penetration rate. Choice of correct tooling.
Lecture 3	2 academic hours	TBM Cutting head for various geological conditions	• General principles of designing a cutting head for a TBM of large and small diameters, • Cutting discs. Types of cutting discs. Existing types of bearings and shaft seals for cutting discs, • Active seals for cutting discs, • Knives and cutters, • Positioning of tools on the surface of the cutting wheel,

			• Cutting wheel openings.
Lecture 4	2 academic hours	Drill bits and tooling for drilling	• Types of drill bits for various geological conditions, • PDC bits. Engineering, types, overcut and engineering principles, • Tricone drilling bits. Seals and bearings. Tolerances, TCI inserts, • Types of bent subs.
Project 1	*2 academic hours*	*Choice of tunneling cutting tools based on geological parameters*	
Project 2	*2 academic hours*	*Choice of drill bits and drilling technology based on certain geological conditions*	

4. Open face tunneling			
Lecture 1	2 academic hours	Drill and blast method	• Safety and regulations, • Face drilling and face charges, • Lining. Anchors, spray concrete, steel reinforcement, • Logistics in the tunnels and galleries at the construction state.
Lecture 2	2 academic hours	New Austrian Method	• History of the method, • Stability of the face, • Equipment for the technology, • Basic calculation for stabilizing the face, • Economic viability of the method, • Risk management.
Lecture 3	2 academic hours	Compressed air partial face excavation	• History of the technology, • Modern TBMs with compressed air, • Hyperbaric works. Risks, redundancy, and safety requirements, • Equipment and cutting tools, • Personnel access to the face under compressed air, • Ways to achieve face stability in alluvial soil before going hyperbaric.
Lecture 4	2 academic hours	Dealing with emergency situations at the job site	• Examples of emergency situations with open face tunneling machines, • Loss of stability at the face, • Water pockets and high ground water level, • Loss of stability of the tunnel lining, • Surface settlement and sink holes, Gauss equation for calculating surface settlement to be used when preparing for the project, • Loss of shaft wall stability, • Actions to prevent and actions to react.

Project 1	*2 academic hours*	*Parameters for the choice of the open face technology. Comparison*
Project 2	*4 academic hours*	*Hyperbaric safety requirements. Analysis of a micro tunneling project where cutter had to changed at 3 bar pressure in silt under a river bed*

5. Earth Pressure Balance tunneling technology.			
Lecture 1	2 academic hours	Earth pressure balance in the excavation chamber	• Concept of earth pressure balance. Earth pressure balance diagrams in projects, • Ways to plan necessary earth pressure balance. Applicable laws of soil mechanics, basic calculations, • Ways to measure earth pressure balance. Physical principles of the pressure sensors, • Ways to keep the pressure balance, • Soil conditioning ways, • Foam and foam generators. Calculation principles behind foam injection process and equipment, • Polymers for soil conditioning. Organic chemistry principles behind long molecule conditioning additives.
Lecture 2	2 academic hours	EPB machinery for Pipe jacking	• Concept of pipe jacking, • Determining tunnel trajectory, • Design of pipes, • Logistics in the tunnel, • Logistics on the surface, • Equipment for pipe jacking, • Basic calculation of jacking forces, • Ways to reduce jacking force in pipe jacking, • Rectangular and non-circular tunnels, • Risk mitigation.
Lecture 3	2 academic hours	EPB machinery for segmental lining	• Concept of segmental lining, • High precision concrete segments, • Plastic coated segments, • Principles of segment design, • Types of segments, • Logistics in the tunnel, • Logistics on the surface, • Additional equipment for segmental lining. Basic principles for compiling specifications, • EPB machinery, • Risk mitigation.
Lecture 4	2 academic hours	Dealing with emergency	• Examples of emergency situations with earth pressure balance machines,

		situations at the job site with EPB technology	• Loss of stability at the face, • Water pockets and high ground water level, • Loss of stability of the tunnel, • Surface settlement and sink holes, Gauss equation for calculating surface settlement to be used when preparing for the project, • Loss of shaft wall stability, • Hyperbaric accidents, • Prevention is better than cure, actions to prevent and actions to react to emergencies.
Project 1	*2 academic hours*	*Project preparation and implementation for pipe jacking EPB machinery.*	
Project 2	*4 academic hours*	*Segmental lining project preparation and implementation using EPB technology.*	

6. Slurry tunneling technology			
Lecture 1	2 academic hours	Slurry logistics in mining and tunneling	• History of Slurry pipeline logistics in mining and tunneling, • Major functioning principles of Slurry circuit in tunnel boring machines, • Slurry equipment, • Excavation, • Stone crushing and formation of slurry, • Drilling fluids for slurry TBM tunneling. • Pumps and major principles of hydraulic calculation of pressure losses, • Penetration rate calculation, • Separation plants • Determining the parameters and number of pumps in the slurry circuit.
Lecture 2	2 academic hours	Slurry machinery for Pipe jacking	• Logistics in the tunnel, • Logistics on the surface, • Equipment for pipe jacking with slurry TBMs, • Ways to control the face pressure, • Controlling jacking forces along the pipeline, • Introduction into IJS, calculating and IJS positioning principles, • Navigational systems for pipe jacking, • Risk mitigation.
Lecture 3	2 academic hours	Slurry and mixed type machinery for segmental lining	• Geological conditions to use slurry in segmental lining,

			• Mixed mode segmental lining TBMs, examples of projects (TBM-Slurry, Slurry box + EBP), • Logistics in the tunnel, • Logistics on the surface, • Basic principles for compiling specifications, • Risk mitigation.
Lecture 4	4 academic hours	Slurry handling, separation plants	• Basics of fluid control for slurry tunneling, • Basics for controlling loss of pressure in the slurry line based on slurry parameters and project information, • Separation plants for various geological conditions • Granular structure of slurry cuttings, • Pumps, types, rates, pumping head, service, and pump diagram understanding, pump control equipment. Basics of electrics for pumps. • Shakers: sizing, adjusting to geological conditions, • Desanders and desilters: types, sizing, pressure control, • Centrifuge and flocculation for file particle control.
Lecture 5	2 academic hours	Dealing with emergency situations at the job site with slurry tunneling technology	• Examples of emergency situations with slurry machinery, • Loss of stability at the face, blocked cutting wheel, • High water pressure, • Bucking of a tunnel, loss of stability, • Surface settlement prevention, • Loss of shaft wall stability, • Hyperbaric accidents, • Pump failures, • Prevention is better than cure, actions to prevent and actions to react to emergencies.
Project 1	*2 academic hours*	*Project preparation and implementation for pipe jacking slurry machinery.*	
Project 2	*4 academic hours*	*Segmental lining project preparation and implementation using slurry technology.*	

7. Auger boring. Applicable conditions and limits of technology			
Lecture 1	2 academic hours	Auger boring technology	• History of auger boring, • Existing auger boring technologies and type of machinery,

			• Geological data for auger boring. Limiting conditions, • Shafts for auger boring operations, • High precision auger boring operations, • Length limiting factors for auger boring, • Calculating penetration rate and the working parameters for auger boring machinery (torque, jacking force, RPM) • Risk analysis.
Lecture 2	2 academic hours	Guided auger boring technology vs auger boring without guidance	• Pilot drilling, • Navigation, available navigation equipment, • Casing installation, • Compressed air for steering a horizontal auger boring machine, • Job site logistics, • Soil conditioning, • Emergency soil stabilization, • Auger boring in complicated geological conditions.
Lecture 3	2 academic hours	Navigational systems for auger boring, project planning	• LED target and visual channel, • Potential of using gyro and TUnIS systems for long distance auger boring, • Filter plate, selecting LED distance, checking the LED target positioning, • Walk over systems used for auger boring, • Job site layout, necessary equipment, • Assessing the condition of the shaft and proper machine positioning, • Logistics at the job site, project planning.
Project 1	*2 academic hours*	*Choice of auger boring machinery against certain geological conditions.*	
Project 2	*4 academic hours*	*Auger boring project analysis.*	

8. Horizontal directional drilling technology			
Lecture 1	4 academic hours	Introduction to the technology	• History of horizontal directional drilling, • Introduction to the HDD technology, • Choice of equipment based on the geological conditions, • Down hole assembly • Drilling rigs, sizes, producers, types, design, major components and functions, operational safety, • Mud pumps, pressure-flow diagrams, • Drill rods, major parameters, • Drill tools,

			• Mud motors: choosing the right mud motor + tooling + pump + fluid filters, • Drill bits. Parameters of drill bit choice, face load calculation. Types of drill bits (PDC and Tricone for large-size holes and soft ground, drill bits for small size holes in unconsolidated formation). • Mud cleaning units • Air hammers and hydraulic hammers for pilot drilling in rock, • Equipment for air hammering in rock, choice of compressor and down hole assembly. • Preparation of the job site, • Safety of operations.
Lecture 2	4 academic hours (2 parts)	Pilot drilling	• Considerations for the choice of the drilling trajectory, • Geometrical and technological basics of meeting in the middle, • Geometrical calculations to plan a drilling line, • Mathematical basis for calculating the optimal drilling trajectory correction, introduction into damping functions and fixed radii based bit path calculations, • Drilling fluid break outs and measures to prevent them. Mathematics behind calculating fracking pressure for formation. • Mathematical theories behind calculating the penetration rate. Various approaches and experimental data. • Down hole assembly for pilot drilling (bits, centralizers, calibrators, bent subs, weeper subs)
Lecture 3	2 academic hours	Navigation systems	• The concept of LWD and MWD • Navigational equipment for directional drilling: walk over systems, inductive magnetic systems, beacons, gyro systems for horizontal drilling, • Types of gyroscopes and scientific principles of their functioning. Mechanical gyroscopes, • Lazer-optical gyroscopes, physics behind the design, wave propagation through optical lines and wave phase shift, mathematical principles for calculating geometrical deviations,

			• Resonators. Sagnac effect, interferometers, history of the discovery, mathematics behind interferometry, • Comparison between existing navigational methods, navigation choice chart.
Lecture 4	4 academic hours	Reaming and hole cleaning	• Stability of the horizontal drill hole, • Ways to deal with filtration and permeability of the formation, • Drill rod buckling, mathematical ways to describe buckling, • Calculating pressure and flow rates of drilling fluid, nozzle choice for the flow rate, laminar and turbulent flow in the hole, • Pressure losses in the hole, • Necessary rheological properties of drilling fluid for reaming in various geological conditions, • Drill rig modes for reaming, working with two rigs, • Push-reaming and pull-reaming, • Types of reamers: fly cutters, various types of barrel reamers, hard rock reamer, soft rock reamers,
Lecture 5	2 academic hours	Emergency situations while drilling	• Problems with drilling fluid return, • Loss of hole stability, • Lost drill string, fishing operations, types of fishing tools for horizontal holes, • Breach of hole trajectory: “dog leg” after pilot drill and after reaming, deviations in plane and profile), • Packers for cementing the hole, • Plug cementing (Well or zone abandonment, isolation of zones and drill hole stability: isolating one pressure zone from another, drilling through fractured rock or weak formations with constant fluid loss.
Project 1	*2 academic hours*	*Dimensioning proper drilling rig for the job. Pilot drilling. Specification of down hole assembly and trajectory calculation. Choice of navigational system.*	
Project 2	*4 academic hours*	*Specification of equipment. Dimensioning mud pump and mud motor. Choice of reamers. Calculating the production rate and proper specification of mud separation equipment.*	
Project 3	*2 academic hours*	*Dealing with emergency situations.*	

9. Shaft construction.

Lecture 1	2 academic hours	Shaft construction principles	• General theory of shallow shaft construction, load distribution on the walls, general description of available technologies, • Shafts for pipe jacking. Dimensioning, • Shafts for segmental lining tunnels, • Drain shafts for draining ground water, • Shafts for foundations and underground structures like underground parking
Lecture 2	2 academic hours	Drilled shafts and bored-secant piles	• Preferred geological conditions for the method, • Design of the shaft, • Dealing with silty ground and high water pressure at the bottom of the shaft, • Available types of reinforcement, • Limits of the technology,
Lecture 3	2 academic hours	Sheet piles, soldier piles and steel sheets, trench boxes and speed slide rails	• Types of sheet pipes, • Calculations to determine the necessary type of the sheet pipe, • Arrangement of the shaft bottom, • Safety of working at heights.
Lecture 4	2 academic hours	Pre-cast segments, mechanized shaft sinking machines for various ground conditions	• Precast segments, • Shaft sinking process, • Shaft sinking machines for unconsolidated ground, • Shaft sinking machines for rocky ground, • Shaft sinking machines for mining, • Limitations for the technology.
Lecture 5	2 academic hours	Preventing emergency situations and stabilization of the formation	• Ground freezing, • Cementing for dry unconsolidated formation, • Chemical ground consolidation, • Preventing flooding, silt and quicksand flowing into the shaft, • Preventing the shaft floating.
Project 1	*2 academic hours*	*Calculating the load distribution on the shaft.*	
Project 2	*4 academic hours*	*Choice of the most viable shaft construction technology based on various project conditions. Analysis of previously constructed projects.*	

10. Drilling technologies to support underground construction and tunneling			
Lecture 1	2 academic hours	Technology and machinery for jet grouting	• Insights into the jet grouting technology, • Practical aspects of jet grouting and range of applications, • Pumps and jets, choice of correct pumping mode to keep the appropriate diameter of the ground pipe,

Lecture 2	2 academic hours	Multiple purpose drilling machinery and technologies	• Vibro-lance gravel compacting rigs, • Excavator mounted drill rigs, • Water well drilling equipment and technologies, • Geological survey rigs and core extraction technology, • Geothermal drilling technologies, • Drilling machinery and technology to stabilize the formation for tunneling.
Project 1	*2 academic hours*	*Reinforcing foundations, construction of underground parking stations.*	

Module II

Underground Construction Machinery

1. Design of major components of a tunnel boring machine.			
Lecture 1	2 academic hours	General concept of TBM design	• General description of the functions in the tunnel boring machine, • General description of the functional components and parts of the tunneling equipment, • General description of major mechanical components of the tunnel boring machine: cutting head, main bearing, gears, drives, seals of various types, jacks, steering cylinders, • Electronic steering functions. Analogue and digital systems. Available PLC systems, • Major hydraulic systems, • Electric power systems. Low, middle, and high voltage systems.
Lecture 2	2 academic hours	Major mechanical parts of a TBM part 1	• Types of cutting heads. Ways to determine the type of the cutting head, overcut, • Cutting tools. Cutters and buckets. Type of steel, types of hard allow and hard facing, production technology, necessary parameters for various types of geological conditions, quality control, service, and ways to restore. • Cutting discs. Cutting edge. Materials and angles for various rock properties. Geotechnical information to determine the loads and distance between the cutting discs. Bearings for various types of loads. Tolerance and loads. • Stone crusher types of various TBMs. Materials used to build a stone crusher,

			hard facing, ways to determine the necessary torque and rpm, crushers for large diameter TBMs, • Pressure wall.
Lecture 3	2 academic hours	Major mechanical parts of a TBM part 2	• Central drive parts, • Central shaft and seal packs. Tolerances, materials, types of seal packs, greasing and cooling the seals, spline. Basic strength calculations for shaft loads, • Gear boxes. Basic theory of a planetary gear box. Geometry, tolerances, and basics of strength calculations for gear boxes, • Drives. Calculation of the torque and rpm of the central drive. Calculation of the consumed power of hydraulic drive.
Lecture 4	4 academic hours (2 parts)	Hydraulic systems of a pipe jacking tunnel boring machine	• Hydraulic systems of a tunnel boring machine, • Cylinders and hydraulic motors, • Positional hydraulic valves, • Pressure regulators, • Types of hydraulic pumps hydraulic pump (pressure compensating, load sense pumps) • Filters, check valves, shuttles vales and other parts of a hydraulic system, • Hydraulic oil cooling and filtering systems in a tunnel boring machine, • Water cooled systems, • Basic hydraulic calculations.
Lecture 5	4 academic hours	Electric and electronic systems of a Tunnel boring machine	• Basics of electric systems. Circuits and switches, • Sensors, signals, industrial processors, and PLC systems, • Basics of electronics: voltage dividers and resistors, capacitors, amplifiers and transistors, • Communication systems and protocols, • Electric motors. Synchronous and asynchronous electric motors, • Power stations and generator sets, • Basic electric calculations.
Lecture 6	4 academic hours (two parts)	Material logistics systems in tunnel boring machines	• Slurry machines. Circuit control systems. Valves. Flow meters. Basic calculations for designing slurry circuits based on project parameters. • Centrifugal pumps. Types of the pumps and the most well-known producers of pumps, pumping head, flow speed and pressure. Calculating pressure losses,

			• Belt conveyors. Types of conveyors, rollers, tensioners, cconveyor drives. • Auger conveyors, basic calculations, systems of soil conditioning, types of drives, power packs and gates. • Locomotive logistics, tunnel trains. Basic logistics calculations, mathematical modelling of tunnel logistics. Calculations for the choice of locomotives, composition, and design of trains, • Modelling the rails and sleepers in various types of tunnels, • Material logistics components of the surface infrastructure: designing separation systems and material loading systems.
Lecture 7	2 academic hours	Combining mechanical, electronic and hydraulic components	• Basic design of a hydraulic power pack and its control unit, • Steering and control system of a TBM, ways to design a control interface, • Safety rules and international safety standards for control systems.
Lecture 8	4 academic hours	Designing navigational systems for TBMs	• Laser and laser target, basic math behind angular spreading of a laser beam, • Water level design. Materials and types sensors, • Mechanical gyroscope, mathematical theory behind the gyroscope design, • Physics behind laser optical gyro systems, • Interferometers and resonators. • Mathematics behind the Sagnac effect. Major producers of gyro steering systems, • Optical steering systems.
Project 1	*2 academic hours*	*Central drive design*	
Project 2	*4 academic hours*	*Design of logistical systems for a tunnel boring machine*	

2. Design of pipe jacking TBMs			
Lecture 1	2 academic hours	Jacking systems for pipe jacking	• Choice of the necessary jacking force, • Loads and strength of steel structures of the jacking frame, • Hydraulic systems (speed of the cylinder extension, open loop hydraulic system for jacking frame),

			• Control and measuring system, pumps, pressure transducers, heat exchanges, rated power of a jacking system.
Lecture 2	2 academic hours	Pipe jacking machine	• Choice of geometrical parameters of the machine can, • Steering link and types of seals. Design of a steering seal, • Design of the tail skin of the tunnel boring machine, • Greasing system of a pipe jacking TBM, • Sensors of pipe jacking TBM, • Telescopic station.
Lecture 3	4 academic hours	Support systems for Pipe Jacking	• Bentonite grease circuit for pipes, proper positioning of grease nozzles in the pipes, bentonite valve stations, • Systems for delivering high viscosity suspension to the face a tunnel boring machine, • Design of various types of jacking pipes, • Interjack stations and systems for installing the IJS and disassembling it. Force distribution along the tunnel. Placement of IJS along the tunnel in various, • Force distribution and jacking force control systems for long distance pipe jacking. Major physical principles behind the jacking force measurement.
Lecture 4	2 academic hours	Logics of controls of a pipe jacking TBM	• Functions of the TBM and parts of the machines performing the functions, • Safety blocking of functions, • Standards for safety, • Sensors of the TBMs and operator's reactions to the readings.
Project 1	*6 academic hours*	*Tunnelling systems for short and long-distance pipe jacking. Aspects of piloting a pipe jacking TBM. Visiting actual pipe jacking job site.*	
Project 2	*2 academic hours*	*Pipe jacking TBM design based on project analysis*	

3. Design of segmental lining TBMs			
Lecture 1	4 academic hours	Segmental lining machine. General concept	• Major systems of the TBM, • Excavation chamber arrangement for various types of TBMs, • Soil conditioning equipment, • Ground pressure control systems of a TBM, • Material handling systems of a TBM, • Tail skin seals and greasing system,

			• Grouting system of a TBM, calculating the pumping rate and balancing the pressure of the high pressure grouting pumps, • Design of logistics systems, • Design and composition of gantries.
Lecture 2	2 academic hours	Major components of a segmental lining machines	• Segment erector. Design. Loads, choice of bearings and variants for drives, tolerances and precision of positioning, • Systems for injecting soil conditioning chemicals to the face of the TBM, foam generators. Ways to calculate the balance of water and tenside, • Auger conveyor. Major functional parts: drive, seals, auger, hard facing, material conditioning systems, pressure control, adjustment systems and electronic control of the functions, • Segment logistics systems inside the gantries, cantry crane. Basics for structural strength analysis, • Ventilation in the tunnel and in the tunnel boring machine, • Support systems for a segmental lining machine.
Lecture 3	2 academic hours	Design of the equipment for producing segments	• Design of segments of a segmental lining machine: various types of segments, • Segment molding forms for traditional segments, • Special forms for segmental lining.
Lecture 4	2 academic hours	Logics of controls of a segmental lining TBM	• Functions of the TBM and parts of the machines performing the functions, • Safety blocking of functions, • Standards for safety, • Sensors of the TBMs, possible reactions and operator's reactions to the readings, • Trouble shooting a TBM.
Project 1	*2 academic hours*	*Segmental lining TBM design. Visiting a job site with a segmental lining TBM.*	
Project 2	*4 academic hours*	*Segmental lining project analysis*	

4. Design of horizontal directional drilling rigs			
Lecture 1	2 academic hours	General concept of a horizontal directional drilling rig	• History of horizontal directional rig design, • Types of HDD rigs, • Major components of an HDD rig,

	2 academic hours	Rack and pinion rig design	• Geometry of a rack and pinion pair, • Design and strength calculations for a rig rack (mast), • Designing an anchoring system for a rack and pinion mast, • Undercarriage of a rack and pinion rig. Placement of components. Rigs with a power pack on board and stand-alone power packs, • HDD rig carriage, • Rod loading systems of HDD rigs, • Tracks, • High pressure pump, choosing the right size, • Break out unit of a horizontal directional drilling rig.
	4 academic hours	Rotary and travel drives	• Rotary drive. Defining the ration of RPM and torque, • Defining the type of drive. Electric or hydraulic, • Electric drives, • Direct hydraulic drives vs hydraulic motors with gear boxes, • Bearing housing. Achievable tolerances, basic strength calculation, • Defining the radial load on the central bearing of a horizontal directional drilling rig, • Choice of the thrust bearing, shaft and rod deflection, calculation of deflection due to rod buckling, • Travel drives, direct hydraulic travel drives, • Direct hydraulic drives vs hydraulic motors with gear boxes, • Defining the torque of the thrust drive, shaft choice.
	2 academic hours	High pressure pumps	• General design information, • Crank case and crank shaft design, • Valves. Design, tolerances, • Piston pumps vs plunger pumps. Examples of designs from various pump producers, • Pump pressure and rate. Design of a pump with definite parameters.
	2 academic hours	Hydraulic systems of an HDD rig	• Closed loop pumps, • Open loop pumps, • Choice of valves for different functions for various types of HDD rigs,

			• Cooling circuit. Calculations for heat exchanges, • Filtering systems, • Trouble shooting a hydraulic system of an HDD rig
	2 academic hours	Electronic systems of an HDD rig	• PLC systems based on Siemens products, • PLC systems based on Parker controller and software, • CAN BUS protocols, connection between controllers and functional parts of an HDD rig, • Solenoids, • Proportional pressure control, • Proportional follow control, • Trouble shooting of an HDD rig
Project 1	*2 academic hours*	*HDD rig design. Applicable calculation methods.*	
Project 2	*6 academic hours*	*Visiting and analyzing an HDD job site.*	
Project 3	*6 academic hours*	*Visiting an HDD rig pro duction facility.*	

5. Innovative drilling and tunneling machine design			
Lecture 1	2 academic hours	Combining different underground construction methods	• Designing machinery for continuous pipeline installation • CPI of TSG, • Direct Pipe of Herrenknecht, • Direct Line of MTS) • E-Pipe of Herrenknehct, • Existing patents for various trenchless pipeline installation methods.
Lecture 2	2 academic hours	Geological survey and geothermal drilling rigs	• General design of drilling rigs of various types. Classifications of drilling rigs, • Rigs with a winch driven top drive, • Rigs with a cylinder driven top drives, • Rack and pinion rigs, • Top drive of a drilling rig. Design based on the geotechnical conditions, • BOP units, • Separation plants, • Pumps, • Connection between the drill hole design, geological conditions, and the design of a drilling rig.
Lecture 3	2 academic hours	Slant directional drilling rigs	• Slant directional drilling technology and major aspects of machine design, • Mast position adjustment, • Systems to work with blow out preventors in inclined position,

			• Pipe feeding systems for SDD rigs, • Special hydraulic and electronic solutions for drilling equipment working with adjustable angle.
Project 1	*2 academic hours*	*Design of the main drive of a drilling machine*	
Project 2	*4 academic hours*	*Choice of the drilling rig parameters proceeding from the project information*	

6. Shaft sinking machinery and machinery for metro stations construction			
Lecture 1	2 academic hours	Design of a shaft sinking machine	• Major parts of the shaft sinking machine, • Selective and full-face cutting heads, • Shaft lining, • Working under ground water, • Consolidating the ground, • Systems for transporting materials to the surface mud skips and winches, slurry pumps, vacuum extraction systems, • Shaft sinking navigation systems.
Lecture 2	2 academic hours	Cutters for shaft sinkers	• Selective cutters for alluvial soil and soft rock conditions, • Cutting wheel for hard rock shaft sinking machinery, • Loads on the cutters. Bearing housing and cutting tools.
Lecture 3	4 academic hours	Excavation of material	• Calculating penetration rate. Comparing mechanized shaft sinking penetration rate with mechanized and drill-and-blast methods, • Balance between the winch power, speed, lifting capacity and the volume of a mud skip related to penetration rate of a mechanized shaft sinking machine, • Vacuum aerodynamics. Design of vacuum extraction systems, • Vertical slurry systems, adjusting the pumps, calculating power consumption, limit of pumping head, reading pump diagrams, • Mechanical shaft wall lining. • Examples of shaft sinking machines and projects.
Lecture 4	2 academic hours	Machinery for the construction of metro stations	• Machinery for open face excavation, • Design of inclined tunnel boring machines, • Drilling machines for shallow metro stations.

Project 1	*2 academic hours*	*Types of shaft-sinking machines, shaft sinking machine design.*
Project 2	*4 academic hours*	*Shaft sinker project analysis.*

7. Underground construction project management			
Lecture 1	2 academic hours	Managing pipe jacking projects	• Connection between technology and machinery, • Analyzing project data, reading and optimization geological profile, • Choice of a tunnel boring machine, • Production of pipes, requirements to the pipe quality, pipe seals and ground water pressure, connection between the pipes and TBM, • Compiling specifications for tools and equipment, • Planning manpower, • Time management, • Planning ground operations and logistics, • Planning materials to be used at the job site, • System or reporting, data analysis, • Trouble shooting, preventive maintenance.
Lecture 2	2 academic hours	Managing segmental lining projects	• Connection between technology and machinery, • Analyzing project data, reading and optimization geological profile, • Choice of a tunnel boring machine, • Production of segments, production of plastic-coated segments, • Compiling specifications for tools and equipment, • Planning manpower, • Time management, • Planning ground operations and logistics, • Planning materials to be used at the job site, • System of reporting, data analysis, • Trouble shooting, preventive maintenance.
Lecture 3	2 academic hours	Managing drilling projects	• Connection tween technology and machinery, • Project analysis, analysis, and optimization of geological profiles, • Planning manpower, • Specification of drilling and auxiliary equipment,

			• Planning logistics, loading, unloading procedures, • Planning rig anchoring, • Time management, • Data analysis. Reading and understanding information from the sensors of the machinery, • Planning pipe pull in operation. Preparation for emergencies.
Project 1	*4 academic hours*	*Tunneling project planning based on certain project conditions.*	
Project 2	*4 academic hours*	*Drilling project planning based on certain project conditions.*	

The course takes 2 years, and it is based on previously received skills in general engineering disciplines like strength of materials, CAD design and theoretical mechanics. Every lecture is followed by a workshop to develop practical skills and ability to take engineering decisions referring to the topic. After several related topics have been covered by lectures and workshops students accomplish projects and tests.

Module 1. Underground Construction Technologies

92 lecturing hours,

92 workshop hours,

58 Project consulting hours,

Module 2. Underground Construction Machinery

80 lecturing hours,

80 workshop hours,

40 Project consulting hours.