Course Type	Course Code	Name of the Course	L	T	P	Credits
DE	NMND505	Design of Supports for Underground Excavations	3	0	0	3

Course Objective

To understand the mechanical behaviour of the rock mass surrounding the underground excavations and perform the geotechnical design of the support system to achieve a stable, safe and sustainable operation below ground.

Learning Outcomes

Upon successful completion of this course, the students will be able to:

- Understand the mechanical behaviour of the host media around the underground structure.
- Know different types of supports and related applications
- Design support system for different underground structures

Units	Course Content	Lecture Hours	Learning Outcomes
1.	**Introduction:** Underground excavation in rocks, types of underground excavations, excavation methods, rock supporting methods, geomechanics considerations	03	Overview of the underground excavations including the types, mode of excavation, importance and application of various support elements and geomechanics requirement in the design of underground excavations and supports.
2.	**Rock mass Classifications:** Introduction, Engineering rock mass classifications: Terzaghi's classification, Stand-up time concept, Rock Quality Designation (RQD), Rock Structure Rating (RSR), Geomechanics Classification (RMR), Modification to RMR, Rock Tunnelling Quality Index (Q-System), Geological Strength Index (GSI) and applications, estimation of rock mass deformation modulus	05	Understand the application of various rock mass classification schemes and integration of the concept in designing underground excavations.
3.	**Stresses around Underground Excavations:** Introduction, in-situ state of stress, two-dimensional state of stress, stress distribution around openings, stresses around multiple excavations, three-dimensional state of stresses and analysis	05	Providing exposure to the existing and induced stress fields surrounding the underground structures and defining the various forms of stress-induced damage and damage influence region surrounding the excavations.
4.	**Underground Excavation Failure Mechanism:** Introduction, structurally controlled instability, stress control instability, influence of excavation size on instability, influence of in-situ stresses on instability, fracture propagation mechanism and modes of failure of underground excavations, optimization of shape of structures to improve stability	06	Students will learn about various failure modes, times of such failure, causes of failure and controlling the failures through excavation optimizations.
5.	**Underground Excavation Support**	07	Learn about the basic mechanism of

	Design: Rock support and reinforcement, rock-support interaction analysis, ground response curve, support response curve, convergence confinement method and application, use of rock mass classification for support estimation, support system for difficult ground conditions		rock support used in underground excavations, including critical rock support and reinforcement principles and their utility in support design.
6.	**Analysis and Design of Different Types of Supports** **Rock Bolts and Wire Mesh:** Mechanical behaviour of the rock bolts, bonding annulus, load and deformation characteristics, axial and shear reinforcement effect on continuum and dis-continuum media, estimation of yield strength, pull-out test and application, cable bolt applications, wire mesh applications **Steel Supports:** Lining types, cast iron-steel linings, RSJ supports, rigid and yielding arches, design and selection of arches, lattice girders, forepoling, load and deformation characteristics with steel support applications **Concrete lining and Shotcreting:** Engineering properties of concrete, concrete segmental supports, cast in-situ or monolithic concrete lining, waterproofing of concrete lining;grouting, introduction to shotcreting, dry mix shotcrete, wet mix shotcrete, steel fibre reinforced micro silica shotcrete, mesh reinforced shotcrete, design of shotcrete support, application of various types of shotcreting, load and deformation characteristics with shotcrete applications	12	Student will learn about the practical aspects of rock reinforcement and support applied in underground excavations, covering rock bolts and wire mesh, steel support, concrete and shotcrete lining.
7.	**Support Design Exercises:** Case studies covering tunnel and cavern applications, support optimization and economic evaluation.	04	Provide basic exposure to the students on the techno-economic design of support systems for the underground excavation through case studies
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Textbooks:

1) Whittaker, B. N., Frith, R. C. (1990). Tunnelling: Design, Stability and Construction. Netherlands: Institution of Mining and Metallurgy.
2) Hoek, E., Kaiser, P.K., Bawden W.F. (2006). Support of Underground Excavation in Hard Rock. CRC Press, Taylor & Francis.

Reference Books:

1) Wang, S., Hagan, P.C., Cao, C. (2016). Advances in Rock-Support and Geotechnical Engineering. Netherlands: Elsevier Science.
2) Hoek, E., Brown, E.T. (2017). Underground Supports in Rock Excavations. CRC Press, Taylor & Francis.
3) Brox, D. (2017). Practical Guide to Rock Tunnelling. CRC Press, Taylor & Francis.
4) Aydan, O. (2018). Rock Reinforcement and Rock Support. CRC Press, Taylor & Francis.