भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG, NEW DELHI 110002

व्यापक परिचालन मसौदा

हमारा संदर्भः सीईडी 48/टी-52 **04 फ़रवरी 2025**

तकनीकी समिति: रॉक मैकेनिक्स विषय समिति, सीईडी 48

प्राप्तकर्ता:

क) सिविल इंजीनियरी विभाग परिषद्, सीईडीसी के सभी सदस्य
ख) सीईडी 48 के सभी सदस्य
ग) रूचि रखने वाले अन्य निकाय

प्रिय महोदय/महोदया,

निम्नलिखित भारतीय मानक का मसौदा संलग्न है:

प्रलेख संख्या	**शीर्षक**
सीईडी 48 (26957)WC	**रॉक इंजीनियरिंग में संख्यात्मक मॉडलिंग – दिशानिर्देश का भारतीय मानक मसौदा** ICS 93.020

कृपया इस मानक के मसौदे का अवलोकन करें और अपनी सम्मतियाॅ यह बताते हुए भेजे कि यदि यह मानक के रूप में प्रकाशित हो तो इस पर अमल करने में आपके व्यवसाय अथवा कारोबार में क्या कठिनाइयाँ आ सकती हैं ।

सम्मतियाँ भेजने की अंतिम तिथि : **07 मार्च 2025**

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को उपरिलिखित पते पर संलग्न फोर्मेट में भेजें या manoj@bis.gov.in पर ईमेल कर दें ।

यदि कोई सम्मति प्राप्त नही होती है अथवा सम्मति में केवल भाषा सम्बन्धी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दिया जाएगा। यदि सम्मित तकनीकी प्रकृति की हुई विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेख को अंतिम रूप दे दिया जाएगा ।

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.in पर भी उपलब्ध हैं।

धन्यवाद ।

भवदीय,

(द्वैपायन भद्र)
प्रमुख (सिविल इंजीनियरी)

संलग्नक : उपरिलिखित

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG, NEW DELHI 110002

DRAFT IN WIDE CIRCULATION

Our Ref: CED 48/T-52 **04 February 2025**

TECHNICAL COMMITTEE: Rock Mechanics Sectional Committee, CED 48

ADDRESSED TO:

a) All Members of Civil Engineering Division Council, CEDC
b) All Members of CED 48
c) All others interests.

Dear Sir/Madam,

Please find enclosed the following document:

Doc No.	Title
CED 48 (26957)WC	**Draft Indian Standard** **Numerical Modelling in Rock Engineering — Guidelines** ICS 93.020

Kindly examine the draft standard and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments**: 07 March 2025**

Comments if any, may please be made in the attached format and mailed to the undersigned at the above address or preferably through e-mail to manoj@bis.gov.in.

In case no comments are received or comments received are of editorial nature, you may kindly permit us to presume your approval for the above document as finalized. However, in case of comments of technical in nature are received then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website www.bis.gov.in**.**

Thanking you,

Yours faithfully,

(**Dwaipayan Bhadra**)
Head (Civil Engineering)

Encl: As above

FORMAT FOR SENDING COMMENTS ON BIS DOCUMENTS

(Please use A-4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/table/fig etc. be started on a fresh box. Information in column 3 should include reasons for the comments and suggestions for modified working of the clauses when the existing text is found not acceptable. Adherence to this format facilitates Secretariat's work) (Please e-mail your comments to **manoj@bis.gov.in**).

Doc. No.: **CED 48 (26957) WC**

Title: **Draft Indian Standard Numerical Modelling in Rock Engineering — Guidelines**
ICS 93.020

LAST DATE OF COMENT: **07/03/2025**

NAME OF THE COMMENTATOR/ORGANIZATION: ________________________

Sl. No.	Clause/Para/Table/ Figure No. Commented	Comments/Modified Wordings	Justification of the Proposed Change

BUREAU OF INDIAN STANDARDS

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Draft Indian Standard

NUMERICAL MODELLING IN ROCK ENGINEERING — GUIDELINES

ICS 93.020

Rock Mechanics Sectional Committee, CED 48	Last date of comments: **07 March 2025**

FOREWORD

(*Formal clauses to be added later*)

Numerical modelling is the process of using mathematical equations and computer algorithms to simulate the physical phenomena of rock mechanics and rock engineering. It involves creating a numerical representation of the rock mass, applying boundary conditions and loading scenarios, and solving the equations to obtain the outputs of interest, such as stress, displacement, failure, or fluid flow. Numerical modelling can be done at different scales, from micro to macro, and with different levels of complexity, from linear to nonlinear.

Numerical modelling can provide invaluable insights into rock mechanics problems that are difficult to observe or measure directly. For instance, you can use it to evaluate the stability of underground openings, slopes, pillars, or stopes; assess the impact of mining-induced seismicity, blasting, or subsidence; optimize the layout, sequence of excavation, and timing of mining operations; improve the design and performance of rock support systems; investigate the interaction between rock and fluid such as groundwater or gas; and enhance the recovery and extraction of minerals or energy resources.

With the development of comprehensive tools for numerical modelling and analysis in rock mechanics and rock engineering, its uses are also becoming very popular. Almost all the project reports for the design of tunnels and other underground openings, slopes etc. are, now a days, use numerical analysis in some or the other ways. With time and development of more comprehensive numerical modelling tools and computation techniques, its uses are bound to increase.

Numerical modelling, therefore, is an important instrument in rock engineering, which assists in the design and prediction of failure in rock masses. Dependable results can be obtained from the models if the underlying assumptions, strengths, and weaknesses of the model are known.

This code covers the guidelines for the use of numerical analysis codes and highlight important points, which shall be taken care while performing the numerical modelling and shall be covered in the project reports having the numerical modelling and analysis.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Draft Indian Standard

NUMERICAL MODELLING IN ROCK ENGINEERING — GUIDELINES

1 SCOPE

Numerical modelling and analysis are being used for the designs in almost all the infrastructure projects in rock masses. Various tools/codes for the numerical analysis are available and are being used for the design purposes.

This code presents the guidelines for the use of numerical modelling & analysis in rock engineering and highlight important points, which shall be covered at every stage of numerical modelling and analysis.

It is also highlighted to give the justification at every stage/steps. Limitations of the numerical modelling shall also be clearly brought in the report. These guidelines also highlight the need of carrying out the numerical modelling and analysis during the construction stage of the project for the back-analysis.

2 VARIOUS STEPS/STAGES OF NUMERICAL MODELLING

Mainly following are various steps, which shall be covered during the numerical analysis and shall be discussed in the project design report.

a) Objective of the numerical modelling;
b) Rock mass and selection of numerical modelling approach;
c) Structure, sequence of excavation and supports;
d) Selection of failure criterion;
e) Input parameters;
f) Model preparation, mesh geometry and boundary conditions; and
g) Output and interpretation of results.

The assumptions and/or justification shall be highlighted in the report after every step/stage.

2.1 Objective(s) of the Numerical Modelling

The selection of modelling approach FEM (Finite Element Method), FDM (Finite Difference Method), BEM (Boundary Element Method), etc.) depends on the problem and the objectives. Therefore, the objectives of the study must be clearly known beforehand and shall be mentioned in the report.

Objectives shall also clearly define the special condition, such as, dynamic condition, additional groundwater surcharge, additional surface loading, different stages of excavation, etc. and the desired results.

2.2 The Rock Mass and Selection of Numerical Modelling Approach

Before starting the numerical modelling, one shall have basic understanding and the knowledge of the rock mass to be modelled. In addition, it is also equally important to have an idea of the behaviour of the rock mass with respect to the structure to be designed. There may be more than one rock mass class in the study area. All such rock classes shall be modelled using the representative input parameters. Expected problems during the excavation (for example, shear zones/weak zones, chimney, flowing ground, squeezing etc.) shall also be modelled separately. This shall be described in the report.

Proximity of tunnels or other engineering structure near to faults and shear zones and its expected effect on the stability of the structure in case of seismicity shall also be highlighted while discussing the geology.

Generally, designed life of the structure is considered as 100 years. In case of rock slopes, the freshly excavated rock mass seems to be stable but, after few years the rock mass starts failing depending upon the weathering conditions and weather ability of the rock mass. Similarly, in case of erodible joint filling the long-term support pressure is expected to be very high in water-charged rock masses. Therefore, it is important to understand the behaviour of the rock mass in long-term, which shall also be covered in the report.

There are three main types of numerical models/approaches: continuum models, discontinuum models, and hybrid models. Continuum models treat the rock mass as a continuous medium and are suitable for homogeneous and isotropic rock masses or large-scale problems. Discontinuum models explicitly model the geometry and properties of discontinuities, making them suitable for heterogeneous and anisotropic rock masses or small-scale problems. Hybrid models combine the features of continuum and discontinuum models, making them suitable for complex and realistic rock masses or multiscale problems. As mentioned, different numerical modelling approach is applicable in different rock mass conditions. Various numerical modelling approaches are listed in Table 1. When selecting a numerical model for rock mechanics analysis, it is important to consider several factors such as the objective of the analysis, available data and resources, accuracy and reliability needed, and assumptions and limitations.

It is important to give justification of selecting the particular approach over the other approach and how this is going to give better result to fulfil the objectives.

Table 1 Overview of Various Numerical Methods and their Applications

(*Clause* 2.2)

Sl No	Method	Application
(1)	(2)	(3)
i)	**Continuum Methods**	
	a) Finite difference method (FDM)	1) Divides the problem domain into a grid and approximates derivatives with differences. 2) Popular in applications like slope stability analysis and seismic wave propagation.
	b) Finite volume method (FVM)	1) The domain is divided into a grid of control volumes or cells, with each cell representing a small finite volume. 2) Used for solving the problems involving fluxes and conservation laws, for example, fluid dynamics, heat transfer, porous media flow.
	c) Finite element method (FEM)	1) Divides a complex geometry into smaller elements, making it possible to solve partial differential equations governing stress and deformation. 2) Used for simulating stress distribution, failure mechanisms, and plastic deformation in rock structures.
	d) Boundary element methods (BEM)	1) Solves boundary value problems by focusing only on the boundaries rather than the entire domain, reducing computational demands. 2) Useful for problems like underground excavations, where boundaries play a crucial role in stress redistribution.
	e) Meshless methods	1) Predefined mesh structure or grid is not required. 2) This is used in complex geometries, large deformations and moving boundary (higher flexibility in boundary condition) problems, for example, metal forming, soft body simulation, fracture mechanics, aerospace and automotive, biomedical engineering etc.
ii)	**Discontinuum Methods**	
	a) Discrete element method (DEM)	1) Models rock as an assembly of discrete particles or blocks that interacts at contacts. 2) Effective for simulating fragmentation, blocky rock masses, and dynamic loading.
	b) Discrete fracture network method (DFN)	1) DFN method is a specialized approach to simulate the behaviour of fractured rock masses. It focuses on explicitly modelling the geometry, distribution and connectivity of individual fractures in rock, rather than treating the rock mass as a continuous material. 2) These are often coupled with other modelling methods, like FEM and FDM.
iii)	**Hybrid Methods**	
	Discrete finite element method (DFEM)	Combination of FEM, DEM and this approach helps in more detailed modelling of discontinuous or fractured rock masses, which exhibit non-continuous behaviour.

As a guideline, Fig. 1 is given to highlight the applicability of different numerical modelling approach in different rock masses defined by Q-value (*refer* BIS Code for Q-system for the Q-value).

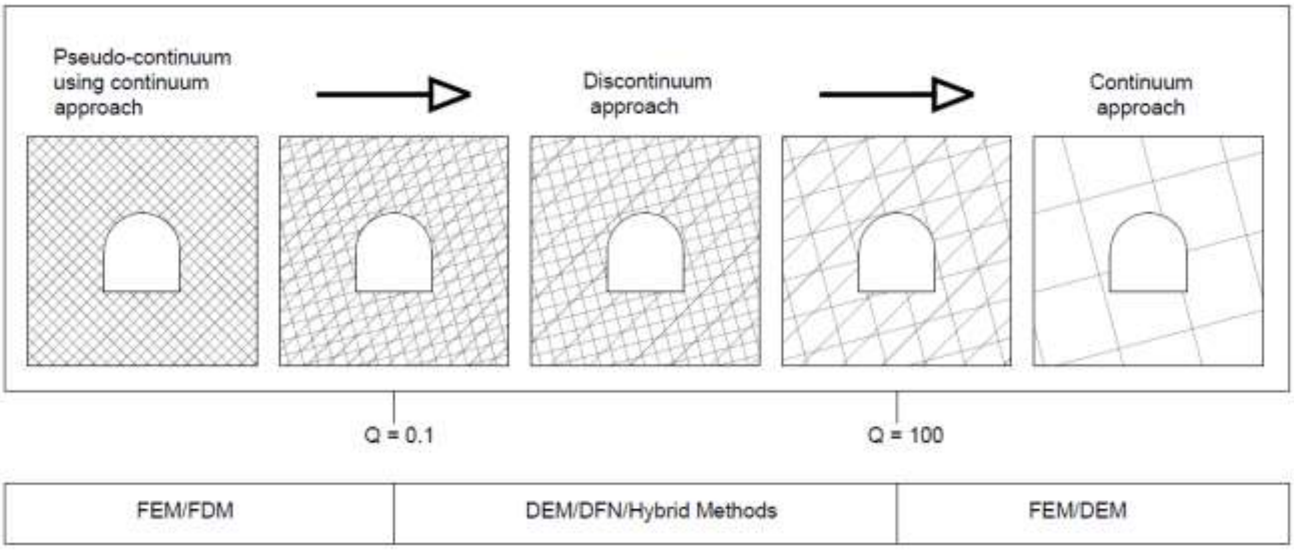

FIG. 1 APPLICATION OF CONTINUUM AND DISCONTIUUM APPROACH OF NUMERICAL ANALYSIS FOR DIFFERENT ROCK MASSES CORRELATED WITH Q-VALUE

2.3 Structure, Sequence of Excavation and Support Details

The modelling shall be carried out as per the geometry of the structure, sequence of excavation and supports. This includes:

a) The geometry of the rock slope (including the slope angle, slope height etc.) and planned stages and method of excavation. The supports at every stage of excavation;
b) Shape and size of underground opening. Any parallel tunnel nearby? Any cross-passage, if yes, at what angle? (In case of parallel tunnels, different models shall be prepared to study the safe distance between the two tunnels/tubes);
c) Sequence of excavation (full face, heading-benching, multiple face excavation etc.) and details of primary support at each stage of excavation of tunnel or underground opening; and
d) Various steps of construction and supporting shall also be mentioned.

Accordingly, the results of numerical analysis shall highlight the behaviour of the rock mass after each stage of excavation and supporting.

2.4 Selection of Failure Criterion

Rock failure criteria are used to predict how and when rocks will fail under external forces. In rock mechanics, these criteria are used to assess the stability and strength of rocks, and to design structures that can withstand deformation and failure. There are quite a few failure criteria. Out of which, two criteria are much popular in rock mechanics. These are the Mohr-Coulomb failure criterion and the Hoek-Brown failure criterion.

Each one of the two failure criteria have some limitations. Therefore, the designers shall clearly mention as to why they have preferred particular failure criterion over the other. Unavailability of input data for applying a particular criterion shall not be the sole reason.

2.5 Selection of Input Parameters

The results of the numerical modelling are very much influenced by the value of input parameters. Therefore, it is expected that due diligence has been adopted while selecting the input parameter values.

Laboratory tests on intact rock material shall be carried out as per various standards prescribed by standardization bodies, such as BIS/ISRM/ISO (Bureau of Indian Standards/International Society of Rock Mechanics/International Organization for Standardization) or any others agency. It must be ensured that the rock samples being tested truly represent the rock mass to be modelled. The rock sample shall be collected from the freshly excavated rock mass and not the rolling piece of rock mass or weathered piece.

In case of weak & soft rocks and easily erodible rock masses, the long-term behaviour of weathering shall be studied. Therefore, the input properties of such rocks shall be downgraded after some sort of studies for long-term behaviour study, for example, slake durability tests.

In case there is some effect of ground water is expected in the overall behaviour of the rock mass in the long-term (for example, weak and soft rock masses, erodible joint filling etc). this shall also be taken care of in the numerical modelling and analysis.

The *in-situ* stress values shall be determined in the field, if possible. The *in-situ* stress values are influenced by the presence of faults and shear zones and by the location of tunnel in hilly terrain (for example, a tunnel near to valley may have different *in-situ* stress compared to tunnel away from the valley). In case the *in-situ* stress values have been assumed, proper reasoning shall be given of selecting the particular values.

In case of dynamic analysis, the reason of selecting the input values require thorough reasoning and justification, which shall be highlighted in the report.

The input parameter values of all the parameters shall clearly be given in the report in a Tabular form for all the expected rock classes. In case the values of some input parameters have been assumed, give reasoning and justification of assuming the value.

2.6 Model Preparation, Mesh Geometry and Boundary Conditions

The process of preparing a numerical model is complex, requiring several steps such as defining the geometry and dimensions of the model domain, assigning material properties and constitutive laws, specifying boundary conditions and loading scenarios, selecting the numerical method and solver, and running the model. This process involves making simplifications and assumptions, dealing with uncertainties and variability, and validating the model with reality. Ultimately, it is essential to divide the model domain into elements or blocks, calibrate them with laboratory or field data, set parameters and criteria for convergence and stability, and check the results for errors or anomalies.

2.6.1 *Mesh Geometry Criteria*

A well-designed mesh is crucial for ensuring accuracy, stability, and computational efficiency in simulations. Mesh criteria depend on the specific numerical method (for example, Finite Element Method, Finite Volume Method) and the type of physical problem being solved (for example, fluid dynamics, structural mechanics).

Mesh criteria guide the process of discretization in numerical modelling, ensuring the mesh is sufficiently refined and shaped for the problem at hand while managing computational resources effectively.

2.6.1.1 *Element size and density*

Uniformity: Ideally, element sizes should be similar within regions with uniform material properties or behaviour.

Gradient-Based Refinement: In areas with high gradients (for example, stress, temperature, velocity), smaller elements are required to accurately capture changes.

Boundary Layer Meshes: For fluid flow problems, boundary layers (near walls or surfaces) often need fine meshes to capture shear forces and flow details accurately.

2.6.1.2 *Element shape and quality*

Aspect Ratio: Elements should ideally have a low aspect ratio (close to 1:1) for better numerical accuracy. Highly elongated elements can reduce accuracy and increase numerical errors.

Skewness: Elements should be as close to regular shapes (for example, equilateral triangles, squares) as possible. High skewness can lead to poor convergence and inaccurate results.

Warping: Elements should not be overly warped or distorted, particularly in 3D meshes. Distorted elements lead to inaccurate interpolations of field variables.

2.6.1.3 *Smooth transitions in element size*
To avoid sudden changes in mesh density, the transition between element sizes should be gradual. Large differences in neighbouring element sizes can cause inaccuracies and convergence issues in iterative solvers.

2.6.1.4 *Orthogonality*

In structured grids, maintaining orthogonality (90° angles between elements) is essential, especially in areas with significant gradients. Non-orthogonal elements can introduce errors in calculating fluxes and gradients.

In unstructured grids, orthogonality is less strict but should still be maximized where possible to improve accuracy.

2.6.1.5 *Mesh independence*

This criterion involves refining the mesh until further refinements have a minimal effect on the solution. This ensures that the solution does not depend on the mesh size or quality, and that results are converging to an accurate solution.

2.6.1.6 *Boundary condition representation*

The mesh should be fine enough to accurately represent complex boundaries and curves. Coarse meshes can lead to inaccurate boundary representation, particularly in complex geometries or when applying boundary conditions like loads, heat flux, or pressure.

2.6.1.7 *Aspect ratio and condition number*

A high aspect ratio or poor conditioning of elements can lead to inaccurate results and poor convergence of the numerical solution.

Condition numbers of element matrices (especially for finite element methods) should be minimized to ensure numerical stability.

2.6.2 *Boundary Conditions*

Boundary conditions define how the model interacts with its environment and can significantly affect the results of a simulation. Boundary conditions are essential to obtain realistic and reliable results in numerical modelling, as they ensure the model accurately represents the interaction between the system and its surroundings. Proper selection and implementation of boundary conditions are important to achieve stable, accurate, and meaningful solutions.

Applying boundary conditions on irregular or moving boundaries can be challenging and may require advanced techniques, like adaptive meshing or specialized boundary conditions.

Solutions can be highly sensitive to boundary conditions, especially in small or closed domains. Testing and validating different boundary setups may be necessary. In multi-physics or coupled problems (for example, fluid-structure interaction), ensuring accurate boundary conditions at the interfaces between different materials or physics is critical and challenging.

Boundary condition can be of any type, for example. displacement boundary condition, force boundary condition, inlet/outlet conditions, slip condition, no-slip condition, etc. Thus, the type of boundary condition depends upon the requirement of the numerical modelling and shall be selected accordingly. The report shall specify the reason of selecting the particular boundary condition and its benefit.

2.7 Output and Interpretation of Results

Interpreting a numerical model is an important step for analysing and evaluating its outputs. This process requires visualizing and plotting the outputs, such as stress, displacement, failure, or as per the requirements, and comparing them with the expected or observed behaviour.

Additionally, it is necessary to identify and quantify the critical regions or factors that affect the rock mechanics performance or response. It is also beneficial to conduct sensitivity and parametric analyses to assess the influence of different variables or scenarios on the outputs, as well as uncertainty and risk analyses to estimate the confidence and reliability of the outputs.

Interpreting a numerical model can be highly rewarding, as it can provide valuable information and insights to support decision-making and problem solving, as well as enhance knowledge and understanding. It is important to communicate and report the findings and recommendations of the model to the concerned authorities or decision-makers.

However, it is important to note that numerical modelling involves assumptions, uncertainties, and limitations, thus, it should always be used with caution and judgment in conjunction with other methods and sources of information in the supervision of an expert.

3 ASSUMPTIONS, JUSTIFIATION AND LIMITATIONS

The assumptions at every stage of the numerical modelling shall be clearly highlighted in the report. The assumptions must be backed by the justification with proper reason of the assumptions and selection of input values, model geometry etc.

At the end of the numerical analysis, the limitations of the study must also be highlighted with the precautions of using the results of the numerical modelling.

4 MODELLING DURING CONSTRUCTION STAGE AND FOR BACK -ANALYSIS

a) The results of numerical modelling carried out during the design stage shall be applied during the construction stage;
b) The designed stage numerical modelling results shall be compared with the monitoring results (such as deformation, pressure, etc.) during the construction. This will help in evaluating the numerical modelling results. The instrumentation program shall be carried out with full sincerity and the results shall never be overlooked and neglected;
c) In case there is any variations observed in the estimated deformation and or pressure values during the construction stage, the reason of this variation must be identified and accordingly the numerical modelling shall again be carried out;
d) The input parameters shall be evaluated and fresh set of input parameters may be used as per the actual rock mass condition. To avoid bias, the input parameter shall be collected by another team of experts (not the team who was associated during the design stage);
e) Actual support details shall be used in the modelling and back-analysis shall be performed; and
f) Keep in mind that these codes have the potential to allow much more realistic design, but they must not be used without careful calibration – prior to – during and – post completion of any modelling.