IMPORTANCE OF GEOTECHNICAL PARAMETERS IN DESIGN OF NUCLEAR STRUCTURES

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ABSTRACT

Authors have experienced that in most of the projects, Structural Designers struggle to obtain the realistic geotechnical parameters in spite of conducting detailed geotechnical investigations at the proposed site due to various reasons outlined in this paper. Discovery of any error in the adopted geotechnical parameters would have direct implication on the structural design, construction period and cost of the project, which sometimes lead to serious contractual problems. This paper highlights the importance of geotechnical parameters to be adopted in the design of nuclear safety related structures. It also discusses the methods of obtaining realistic geotechnical parameters at the investigation stage, and suggests guidelines for improving the quality of Geotechnical Investigation Report, which would help in making correct interpretation of the investigation results, and for obtaining realistic geotechnical parameters for the design of structures. Among all geotechnical parameters, parameters obtained from cross-hole tests results (especially shear wave velocity values) are considered critical and directly affect the dynamic characteristics of the structure. The detailed methods of obtaining reliable parameters from cross-hole test are also discussed in the paper.

INTRODUCTION

Information of subsurface conditions at a nuclear power plant site is vital at all stages of the site evaluation process. It provides the basic data for decisions on the nature and suitability of the sub-surface materials. The information on sub-surface materials is obtained through rigorous geotechnical investigations. Geotechnical investigations have to be efficiently planned so that they address need of each stage of the site evaluation, as the specific requirements of site evaluation will vary from stage to stage.

NECESSITY OF GEOTECHNICAL PARAMTERS

The most important consideration for any nuclear structure is to serve the desired purpose without any radioactive hazard to the plant personnel, public and environment under various normal and abnormal conditions. Thus the design of nuclear structures housing radioactive materials is based on the defense-in-depth philosophy by providing multiple barriers for the containment of radioactivity and detailed analyses of structures. Initial calculations for the thickness of such structures are based on the shielding considerations, and then design of these structures is also governed by various postulated loading conditions [1 – 2].

Occurrence of natural hazard, such as, earthquake may change existing ground conditions thereby affecting the structures located in the vicinity of its occurrence. It is a well established fact that the seismic behaviour of any structure is different for different sites. Seismic response of the structure basically depends on the local conditions like seismic history, geological features, soil properties of the site, etc. [3 – 5].

Considering all these, special attention is given in the selection of site for locating the nuclear structures [6 – 8]. Utmost care is taken in identifying and evaluating the appropriate founding strata that should be capable of transferring superstructure loads safely to the ground under various postulated loading conditions. Therefore, various site data such as sub-surface profile, ground water table, safe bearing capacity, modulus of subgrade reaction, coefficient of friction, mass density, Poisson's ratio, compression wave velocity, shear wave velocity, etc. must be available before going in for the analyses and design of structures.

CHALLENGES IN OBTAINING REALISTIC PARAMTERS

The study of engineering properties of substrata or sub-surface profile is very essential for understanding the load distribution mechanism of the superstructure through it, and its behaviour during the occurrence of natural hazard, such as, earthquake, flood, etc. The variation in formation of substrata imposes challenges in developing a correct understanding about its engineering properties during initial stage of the project planning. Sometimes even after conducting detailed geotechnical investigations, one is not able to mitigate certain degree of uncertainties about the substrata. The factors that induce degree of uncertainties are as follows:

(a) Variation in the formation of substrata and limited knowledge about its behaviour.
(b) Limitation of awareness of planning geotechnical investigations.
(c) Limitation of investigation equipment.
(d) Human ignorance during the investigation stages.

Traditional geotechnical engineering practice typically utilizes a wide variety of empirical correlations which contain varying degrees of epistemic and aleatory uncertainty. In addition to this, uncertainty induced due to the poorly controlled field test methods and due to disturbance in sampling is well known, and has been reasonably accepted up to certain extent. Sometimes human ignorance in mishandling the transportation of field samples to laboratory can also affect the geotechnical investigation results. To account for these uncertainties, the Geotechnical Engineer may be tempted to provide overly conservative values for the purpose of structural designs. However, for the performance based design of structures, the need of the hour is to arrive at best estimate values for the geotechnical parameters instead of adopting overly conservative values obtained by applying high factors of safety on the test results to account for the uncertainties. It may be noted that overly conservative foundation stiffness and/or safe bearing capacity values may lead to the incorrectly predicted failure mechanism of the foundations and/or structures, while reasonably accurate estimates of geotechnical parameters and reduced uncertainties in them can help in achieving the desired safety and economy of structures.

ENHANCING THE RELAIABILITY OF GEOTECHNICAL PARAMETERS

It has been experienced that sometimes Structural Designer finds it difficult to arrive at realistic geotechnical parameters for analyses and design of structures from the Geotechnical Report which may be attributed to the following reasons:

a) Poor planning of geotechnical investigations basically due to poor understanding of the project requirements pertaining to maximum expected loads and depth of foundation, etc.
b) Poor workmanship, improper calibration of equipment and human error may result in unrealistic values of geotechnical parameters.
c) Improper labeling of samples before transporting to laboratory for testing may also result in unreliable values of geotechnical parameters.
d) Ongoing revisions in codal provisions may sometimes result in conflict of interpretation of data at later stages.

It is believed that by adopting more realistic geotechnical parameters, the structures can be modeled more accurately and their performance can be studied in a more realistic manner. Minimizing the uncertainties in geotechnical parameters will increase the confidence level and at the same time will reduce the application of arbitrary safety factors.

GEOTECHNICAL DATA AND ITS IMPORTANCE TO THE NUCLEAR PROJECTS

Authors are of the opinion that by creating awareness about the effects of variation in geotechnical parameters on the structural performance and on the overall project may make project team more vigilant during geotechnical investigations. This will also help in the proper review of the Geotechnical Report. For the design of nuclear structures, following geotechnical parameters are of prime importance:

1. **Test Locations**:

Test locations have to be transferred on field with reference to Benchmark (BM) /Universal Transverse Mercator (UTM) coordinates by conducting initial surveying. The field test results need to be with respect to actual co-ordinates and reduced levels, as later on, this information is required by Construction Engineer to identify the test locations or to correlate it with other drawings. Information is also required by Structural Designer to correlate the geotechnical data with respect to proposed structural locations for using them in the design of various structures.

It becomes crucial to the project with increase in gap of time between geotechnical investigation work and commencement of the project work, as sometime topography of the project area (ground levels) may change, thereby creating difficult situations in adopting the foundation recommendations made by the Geotechnical Investigation Agency.

2. Sub-Surface Profile:

2.1. Various methods of obtaining information about sub-surface profile are discussed below with its significance to the project:

2.1.1. Geophysical Survey By Seismic Refraction Technique (SRT)

It provides preliminary information on sub-surface stratification (soil/rock) in vertical and lateral directions by using compression wave velocity (V_p) of various sub-surface strata. The results help in mapping subsurface profile by indicating:

(a) The thickness of substrata.
(b) Continuity of strata in both vertical and lateral direction.
(c) Discontinuities (factures /faults) in rock mass.

The subsurface mapping is one of the key factors for deciding suitability of site for nuclear power plant. In the area having high subsoil variation, it can be useful for conceptual planning as it can help in economizing the project layout based on its foundation requirements by correlating it with the available substrata. Use of substrata mapping can minimize the number of bore holes.

2.1.2. Geophysical Survey By Electrical Resistivity Test (ERT)

It also provides preliminary information on sub-surface stratification (soil/rock) in vertical and lateral directions with Schlumberger's method by using electrical resistivity of various sub-surface strata. It is more popular for identification of ground water aquifer. It is cheaper and a better choice than SRT for determining changes in sediment types and detecting boundaries.

2.1.3. Bore Logs

It is one of the most important data. It provides information about substrata which is based on visual observations of samples and field tests like standard penetration test (SPT), permeability test etc. Samples collected are tested in the laboratory to obtain various properties of substrata. Bore log is a key source of obtaining most of the geotechnical parameters for project and help in interpreting the choice of foundations/founding level, making recommendations/design for ground improvement, for preparation of tender documents etc.

2.1.4. Trial Pits

It is used for physical inspection of sub-strata and collection of samples (soil/rock) from shallow depth (up to 3m) above water table. It is also a source for conducting field tests like plate load test and California Bearing Ratio (CBR) test.

2.2. Importance To The Project:

Information about fault influences the selection of site. Foundation levels, choice of foundations and recommendations/design for ground improvement work are based on sub-surface profile. Variation in sub-surface profile considered at design stage and that actually encountered would have impact on the project through following:

(a) Under and/or over estimation of tender quantities in terms of excavation in soil/rock, concrete etc.
(b) Changes in choice of foundations.
(c) Changes in ground improvement recommendations.
(d) Substantial revision in the founding level may require reanalysis of structural designs.
(e) Revision in completion schedule of the project.
(f) Changes in the scheme of rainwater harvesting.
(g) Sometime it can also lead to serious contractual problems.

3. Ground Water Table (GWT)

3.1. Methods of obtaining information about groundwater table are discussed as below along with its usefulness to the project:

3.1.1. Electrical Resistivity Test (ERT)

As discussed above in 2.1.2, ERT is used to predict the depth of ground water table and can be used to provide continuous mapping of water table in the investigation area. It is difficult to know the seasonal variation effects as ERT results become unreliable in rainy season with saturation of the strata. The information is useful for locating deep aquifer's and is required for design of landfill/rainwater harvesting/identifying bore well locations.

3.1.2. Bore Logs/ Trial Pits/ Open Wells

These can be used to obtain ground water level and collecting samples from specific location. They can be used in monitoring ground water fluctuations by installation of Piezometer. Piezometer records can be helpful in analyzing the settlement in the nearby structures due to fluctuations in ground water table. Information is useful for planning excavation and ground improvement activities.

3.2. Importance To The Project

Ground water table has major effect on the Safe Bearing Capacity (SBC) of the founding strata. SBC of fully submerged soil is half of SBC of soil without water table. In addition to this, it is used in determination of the uplift pressure acting at the base of the foundation, and for estimating dewatering quantities for the preparation of tender. Its chemical composition can affect the durability of concrete in underground constructions.

Chemical analysis results of underground water will affect the overall cost of the project as they dictate the use of type of cement, anticorrosive treatment to reinforcement, cover to reinforcement, etc. Revision in information could lead to contractual problems.

4. Undisturbed Samples (UDS)

4.1. UDS is collected from bore holes and/or trial pits. It is useful in creating field conditions in laboratory for the soil/rock samples and minimizes uncertainty. Structural design in soil heavily depends on the laboratory test results on UDS.

4.2. Importance To The Project

Error in values can lead unrealistic assessment of substrata, resulting in under design or overdesign (depending on type of error) of the structures. Hence any major overlook in value can be a threat to safe performance of structures.

5. Field Tests

Important field tests are discussed as below:

5.1. Standard Penetration Test (SPT)

5.1.1. It is a field test for obtaining information about shear strength parameters of substrata. It is conducted in bore holes. At present, it is one of the important parameter as it can be empirically correlated to the shear strength parameters of substrata. In cohesion less soil it is used for deciding the safe bearing capacity and foundation level.

5.1.2. Importance To The Project

It is among important design parameters and any error in values can lead to unrealistic assessment of substrata, resulting in under design or overdesign (depending on type of error) of the structures. Choice of foundation heavy depends on it. Hence any major overlook in the values can have serious affect on the performance of structures.

5.2. Modulus Of Sub-Grade Reaction (K)

5.2.1. It is obtained through field tests or by using empirical correlations. It is mainly required in the evaluation of spring constants for static and thermal analyses by using commercial software.

5.2.2. Importance To The Project

Reliability of modeling the substrata in the analysis is based on the values of 'K'. Unrealistic 'K' values will generate erroneous outputs further resulting in under design or overdesign (depending on type of error) of the structures.

5.3. In-Situ Deformation Modulus (E) / Shear Modulus(G) And Safe Bearing Capacity (SBC) By Pressuremeter Test

5.3.1. It is one of the popular field tests for obtaining in-situ parameters of deeply seated strata. It is very helpful in soft rocks /highly weathered /highly fractured rocks where collection of sample in in-situ state may be difficult.

5.3.2. Importance To The Project

Test results provide in-situ values of 'E' and 'SBC'. The in-situ parameters are very useful in arriving at realistic values in weak strata and further providing a basis for recommending economical foundation system.

5.4. Coefficient Of Friction

5.4.1. This is generally taken from standard literature by using value of angle of internal friction. It is used for carrying out stability analysis (safety against sliding).

5.4.2. Importance To The Project

For structure unsafe against sliding, one has to adopt following measures:

a) The dead weight of the structures has to be increased either by increasing foundation thickness or lowering the depth of foundation to have more dead load of backfill earth over projected portions of foundations.
b) The depth of foundation has to be increased to provide confinement from sides.
c) Use of Rock anchors.

5.5. Poisson's Ratio (N), Compression Wave Velocity (V_p), Shear Wave Velocity (V_s), Low Strain Deformation Modulus (E) And Low Strain Shear Modulus (G)

5.5.1. These parameters are obtained from cross hole test in which the values of V_p and V_s are recorded during the testing. Values of ν, E and G are derived using empirical correlation between V_p and V_s.

5.5.2. Importance To The Project

The V_s value is essential for carrying out the soil structure interaction analysis for safety related structures. It is also used in analyzing liquefaction potential of strata. Value of low strain shear modulus (G) is used for the evaluation of impedance function based soil springs. All these parameters are used in dynamic analysis of the safety related structures. The design based on the unrealistic parameters can affect the performance of structures under seismic condition.

ACTIONS WHICH CAN IMPROVE RELIABILITY OF GEOTECHNICAL PARAMETERS

Authors are of the opinion that reliability of geotechnical parameters, and in turn, the quality of Geotechnical Report can be improved in the following ways:

1. Test Locations

Authors suggest that test locations could be decided by using hand-held Geo-Physical Survey (GPS) for obtaining co-ordinates in UTM and levels with respect to nearest permanent structure at the site. The accuracy level of GPS is up to 3 m for co-ordinates and up to 5 m for levels. The Geotechnical Investigation Agency must consider this as vital information and should incorporate the same in the Geotechnical Report with relevant details.

2. Sub-Surface Profile:

Authors suggest following for various methods of obtaining sub-surface profile:

2.1 Geophysical Survey By Seismic Refraction Technique (SRT)

It may be noted that the results are reliable for fairly uniform ground and for the area not having any the weaker strata overlaying the stronger strata. Seismic refraction results have to be interpreted by Geotechnical Engineer having experience in similar type of work. Reliability of results increases by correlating geophysical results with bore logs. This test does not provide information about the groundwater table.

2.2 Geophysical Survey By Electrical Resistivity Test (ERT)

ERT should be avoided in saturated soils. It is difficult to define soil-rock mixtures resting on bedrock. Soil overburden having higher resistivity than the underlying rock also produces poor test results. It is suggested to limit the use of resistivity test to an expansion of subsurface data obtained by borings.

2.3 Bore Logs

In heterogeneous strata, substrata information obtained could vary due to small exploration diameter. Further, revised layout may change the location of bore holes with respect to structures. Hence, wherever possible, use the information obtained from seismic refraction survey for identifying the bore holes locations with respect to project layout. In case project layout has not been finalized, then bore holes can be located in a grid pattern at about 50 m intervals in combination with the SRT results. Bore logs should be prepared as per Bureau of Indian Standards (BIS) guidelines [9]. In order to know the substrata profile and to obtain geotechnical parameters from the pressure bulb area, bore holes should be drilled at least up to a depth 1.5 times the width of foundations below the founding level [10].

2.4 Trial Pits

Generally trial pits are useful for identifying borrow pit, examining the utility of soil for laying foundations, reconfirming the recommendations made by Geotechnical Investigation Agency up to a shallow depth of about 3 m. It is suggested that Trial Pits should be excavated in the presence of Geotechnical Engineer for making his own observations. Trial pits information can be useful if the physical observations during their excavation are recorded in respect of following: (i) efforts required during excavation by mechanical excavator, (ii) logging of trial pits by visual inspection of sub-soil, (iii) estimation of SBC by using pocket penetrometer in cohesive soil, and (iv) location of ground water table.

3. Ground Water Table

3.1 Electrical Resistivity Test (ERT)

Sample of water cannot be obtained in ERT test and results may not be reliable in saturated soils. It is suggested that by correlating the ERT results with bore holes/open wells in the vicinity may help in reconfirming the ERT findings.

3.2 Bore Logs/Trial Pits/Open Wells

In bore holes, most of the time water used for drilling is mistakenly considered as ground water table. It is suggested to measure ground water table either after 48 hours of drilling or from its recharge water level after pumping out bore-hole water upto a depth of 5 m below its level. Samples for chemical analysis should be collected from the recharged water in a sterilized bottle.

4. Undisturbed Samples (UDS)

UDS is supposed to be with minimum disturbance as it is not possible to recover samples with zero disturbances. Hence utmost care has to be taken to minimize the disturbance during collection of the samples. In normal conditions UDS collection in cohesion less soils is not possible. It is necessary to seal both the ends of the UDS tube immediately with wax to avoid the loss of moisture content. It is advisable not to delay the testing of samples beyond fortnight.

5. Field Tests

5.1 Standard Penetration Test (SPT)

It is un-reliable for bouldery terrain and generally not recommended for cohesive soils. The values could be influenced by human error and method of execution. Tests to be precisely conducted as per the BIS guidelines [11]. It is also suggested to record number of blows against four consecutive penetrations of 150 mm instead of three suggested by BIS guidelines [11] .This will help in better interpreting the consistency in the substrata. Sudden variation if observed need to be substantiated (in bore log) with observations made during investigation. In clayey soils the moisture content of the sample should be immediately preserved applying wax coating for lab testing as it can be useful in consolidation settlement calculations.

5.2 Modulus Of Sub-Grade Reaction (K)

To avoid the size effect, field values should be considered only if the actual foundation size is less than or equal to 6 times the plate size otherwise values should be evaluated by using empirical relations.

5.3 In-Situ Deformation Modulus (E), Shear Modulus (G) And Safe Bearing Capacity (Sbc) By Pressuremeter Test

The pressuremeter test provides lateral values which are different from vertical values except for isotropic soils. Limitation of instrument capacity may restrict its use to the hard clay/soft rocks/highly weathered/highly fractured rock. It is suggested to decide the number of tests based on the size of foundation and the variation in the strata encountered. For large size foundations, such as, raft preferably three tests should be conducted in the zone of hard clay/soft rocks /highly weathered/highly fractured rock, and especially where collection of samples for laboratory testing is difficult.

5.4 Poisson's Ratio (N), Compression Wave Velocity (V_p), Shear Wave Velocity (V_s), Low Strain Deformation Modulus (E) And Low Strain Shear Modulus (G)

These parameters are obtained from the cross-hole test as per the guidelines indicated in [12]. The V_s and V_P values are recorded only at specific intervals and assumed to be constant in between those intervals. It is suggested that the test intervals should be decided after detailed study of the sub-soil profiles of source and receiver bore holes. It is also suggested to record the minimum three readings at the location of change of substrata as observed in any of the bore holes – one at the depth of change of substrata and one each at 250 mm above and below the location of change of substrata as shown in Fig. 1.

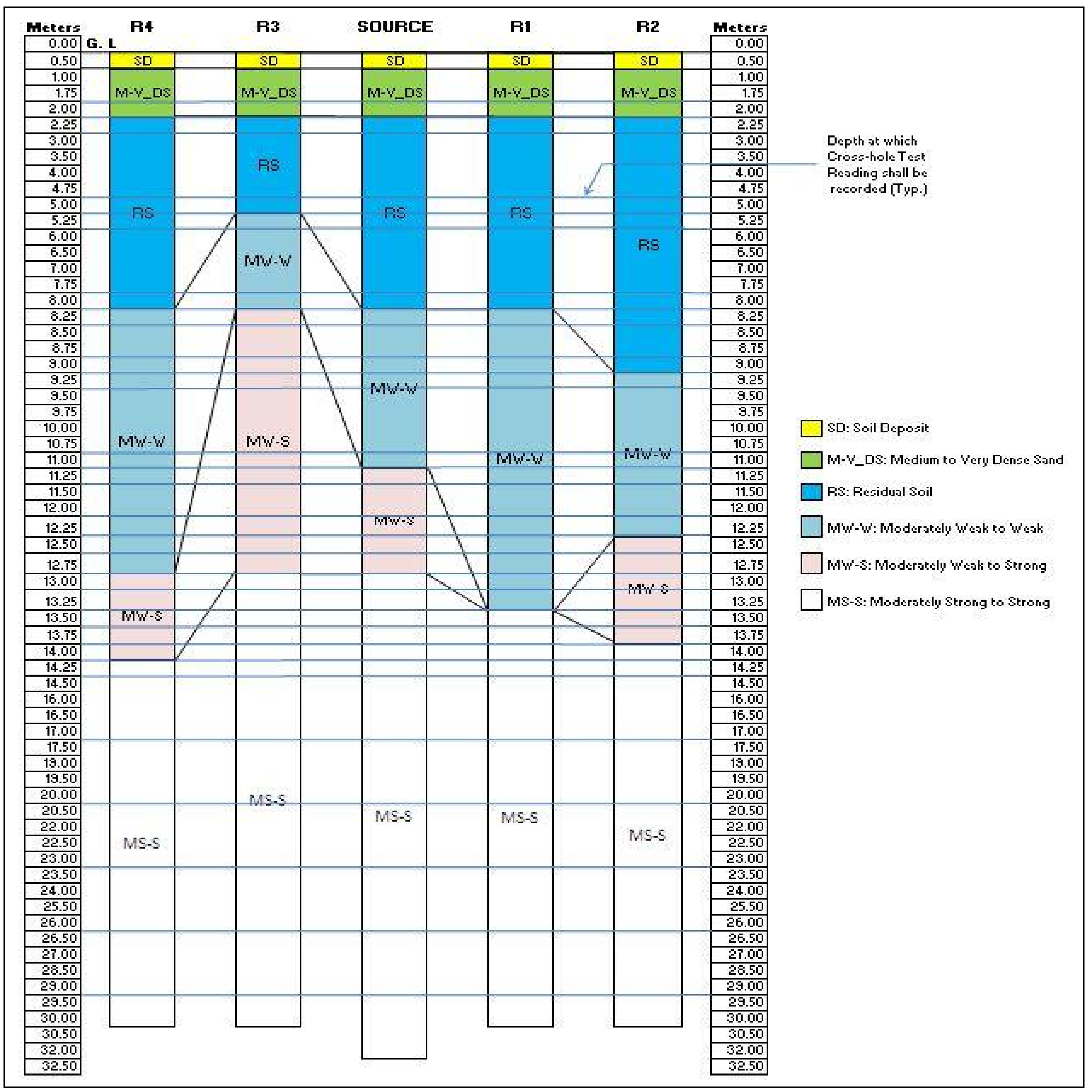

Fig.1: Typical Sub-soil Profile of Cross-hole Test

If substantial variation occurs in the change of substrata in the source and the receiver bore holes, then the depth of recordings should be decided based on the location of stratum transition in each bore hole by recording one at the depth of change of substrata and the others at 250 mm above and below it. Test results in rock should include detailed description of the substrata pertaining to fractures and fill materials within a 300 mm length, i.e., 150 mm above and below the specified test levels (see Fig. 2).

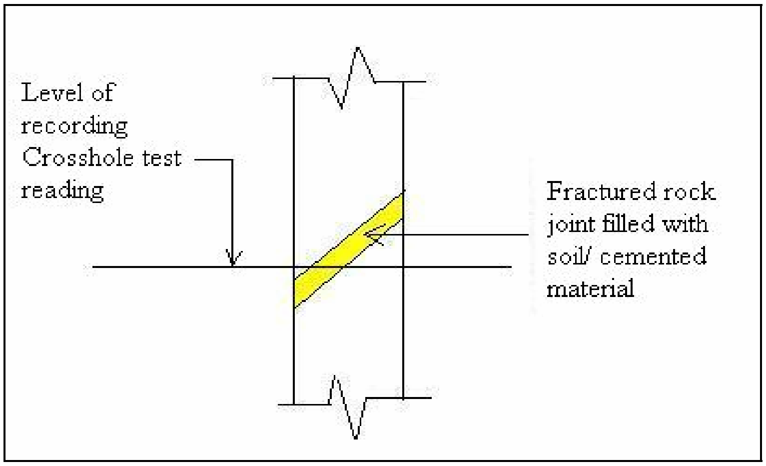

Fig.2: Effect of Fill Material in Jointed Rock on Crosshole Test Results

CONCLUSIONS

Geotechnical parameters including their determination and interpretation play an important role in the design, overall cost and construction scheduling of nuclear facilities. The various geotechnical parameters along with their importance have been identified, and the measures that could improve their reliability have been suggested.

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