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Assessment the Accurate Response of Embedded Pile in Layered Earth with Different Methods of Analysis

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Abstract – *Accurate assessment of lateral capacity of pile foundation is a compound problem incorporating soil-structure interaction. In the present study, two different methods have been suggested to calculate the lateral load carrying capacity and lateral displacement of a single pile embedded in layered soil strata. Generally, piles are used to transmit the load from superstructure to deeper soil. In case of both on-shore and off-shore structure pile can be subjected to lateral load due to wind, seismic, wave thrust or any other accidental load. This research is being proceeded for more accurate estimation on lateral load carrying capacity, deflection shape of non-pours material based linear elastic single embedded pile using theoretical concept-IS Code Methodology and finite element concept-PLAXIS 3D FOUNDATION. The applicability of this manner is deemed to be bounteous help at least for practical purpose.*

Key Words: **Embedded pile, Layered soil, Lateral capacity, Depth of fixity, Soil-Structure interaction, Finite element.**

1. INTRODUCTION

With the development of economy, building volume and height are increasing, and the forms of foundation are quietly undergoing changes. The proportion of shallow foundation is decreasing but the proportion of deep foundation is increasing gradually with embedded pile concepts, where piles are discretized by means of volume elements and the pile-soil interaction is modelled with interface elements as widely used standard finite element approach. Pile foundation has many advantages such as high load bearing capacity, small uneven settlement, strong ability of anti-liquefaction.

Pile can be subjected to lateral forces due to earthquake, wind, wave thrust etc. Hence, a proper understanding of response of pile under lateral loading has a great importance and complex problem as the mechanism of transfer of lateral loads to the subsurface strata that is dependent on the characteristics of sub-soil and pile itself, known as soil structural interaction problem. A proper concept of load transfer mechanism of pile to soil is required for analysis and design. An axially loaded pile transfers vertical loads to the soil using frictional concepts between pile and surrounded soil and bearing capacity of soil at base level of pile. At the time of application of load pile settles and to oppose this movement of pile, soil offers a frictional resistance through the perimeter of pile which is called friction resistance and if the major part of the super imposed load transfer through friction then that pile is called friction pile, if the load transfers to the soil at the base of pile then the pile is called end bearing pile. In case of laterally loaded pile, pile behaves as a transversely loaded beam. Pile transfers lateral load to the soil and get restricted by lateral capacity of surrounded soil. The total soil resistance act on pile shaft balances the external horizontal load or moment of pile show in Fig-1. This is the basic mechanism of lateral load distribution of pile to the surrounded soil.

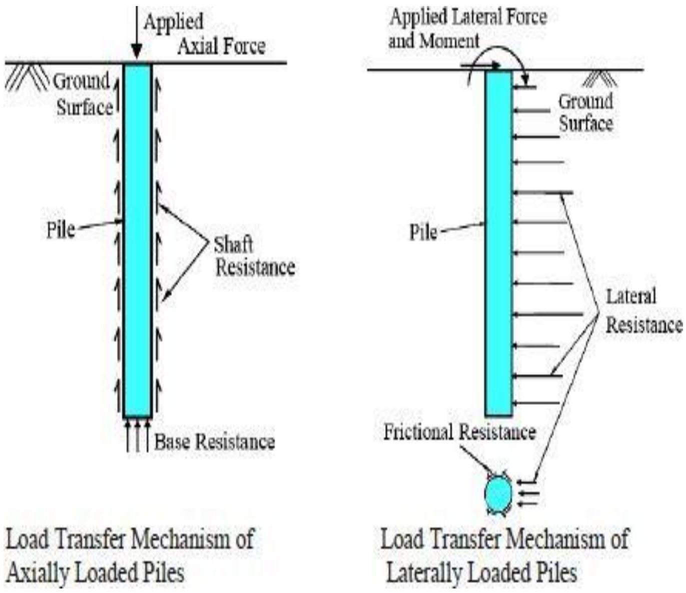

Fig-1: Load transfer mechanism of pile.

The appraisal of lateral capacity of short pile embedded in a bi-layer cohesive soil deposit is already developed which estimate the allowable lateral capacity of the pile is readout by the lateral displacement within the pile soil interaction in an elastic behavior (e.g. [1]). The single pile behavior in an elasto- plastic soil cluster is obtained which estimates the response of p-y curves in sand-clay deposit in multilayering effect (e.g. [2]). Some researchers developed the lateral and vertical loads by using p-y curves in a cohesive and cohesionless soils with different soil parameters is evaluated the response of pile foundation in different layered soil by using FEM approach (e.g. [3]). The response of pile structure in a numerical approach due to lateral load by using 3D FEM analysis which estimated the maximum displacement of structure (e.g. [4]). Performance of model for pile groups, validated results for single pile in compressive, tension and effectiveness of model for bored pile verified by developing analytical software (e.g. [5]). The response behavior of group pile embedded idolized reinforcement slope in soil medium is elastrated by forming 3D finite element mesh (e.g. [6]) already estimated. Researcher verification by designing of an efficient tools 2D, 3D for showing an overall basic concept of a complex deep foundation problem (e.g. [7]). Comparison of the behavior of monopile by using several FEM software under lateral cyclic load (e.g. [8]). An analytical simulation has been used to assess the behavior of single passive piles with horizontal earth movements (e.g. [9]).

Very recent approach is esteemed the different force performance on a pile acting like a lateral load in a bridge pier which develop the overall response incorporating soil structure interaction (e.g. [10]). Lateral deflection of pile in a multi-layer soil medium due to the high magnitude of ground motion is estimated (e.g. [11]). Lateral load distribution of a single pile in a pile group using PLAXIS 3D that conclude the lateral load is being subjected to a pile group will not be distributed to same proportion to all piles (e.g. [12]). The interaction between pile and soil of passive pile group subjected to soil movement was analyzed by ANSYS software considering three-dimensional FEM model estimate the normal pile soil contact stress and average lateral pressure along the pile and the separation between pile and soil was modeled, the lateral pressure acting on pile was properly calculated (e.g. [13]). The response of piles under lateral load due to sloping ground for a long flexible pile had been taken were represented by an equivalent plate element subjected to plane strain analysis and the soil strata was represented by 15 nodal triangular element of elasto-plastic Mohr-Coulomb model, estimate the lateral resistance of a long flexible pile decreases with the increase of slope of ground level. The increase in the embedment length increases lateral resistance of pile. The lateral resistance of pile group can also be increased by increasing relative density of sand (e.g. [14]). Some investigation developed the displacement of pile group is less than the lateral deflection obtained from single pile. For pile spacing less than 6D, result in a large lateral deflection of pile group under lateral load. The resistance of lateral movement of all single piles of same pile group will not be same. The resistance of piles of trailing row is more than of leading row. The pile within leading row has significant closed values with that obtained from single isolated pile. Signification high different on the p-y curve of closed pile group (i.e. s=2D) (e.g. [15]).

The significant amount of work has been done by estimation of response for embedded pile in layered soil. But still it is unknown that the accurate response by two different methods have been suggested to calculate the lateral load carrying capacity and lateral displacement of a single pile embedded in layered soil strata that may be very much useful for practical purpose.

2. METHODOLOGY

Comparison the accuracy by evaluating the allowable load bearing capacity and the behaviour of embedded pile with different diameters using IS code methodology and finite element approach in layered soil with distinct parameters.

2.1 Theoretical Investigation Using IS:2911-2010

For the theoretical investigation purpose considerable soil profile shown in Fig-2.

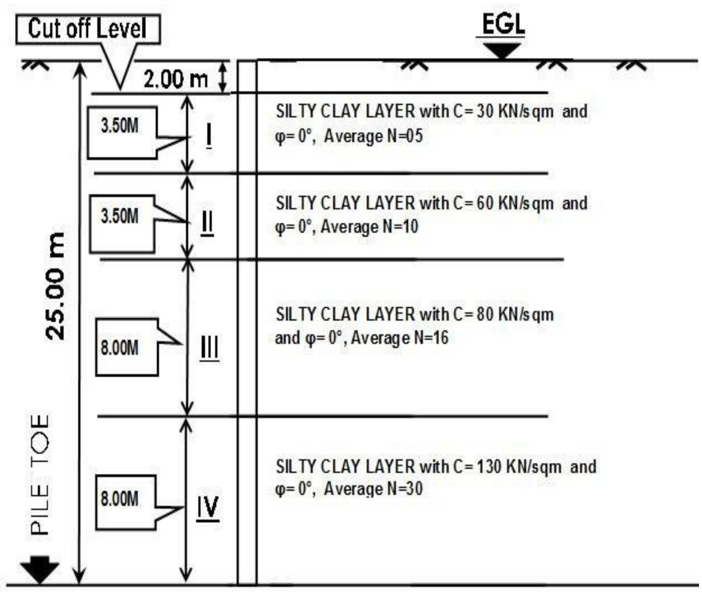

Fig-2: Soil profile.

2.1.1 Problem Statement

The problem described herein is supported with the following information:

- Pile diameter = 500 mm
- Cut-off = 2 m from existing ground level
- Pile head is fixed.
- Concrete grade = M25

- Maximum permissible deformation criteria = 1% of the pile diameter at cut-off level

2.1.2 IS Code Methodology

The depth of fixity of piles have been calculated as per Amendment No. 3 to IS:2911-2010 (Part I/Sec 2). Refer Appendix -C.
Grade of concrete of piles = M25
Diameter of pile (B)= 500 mm
Young's modulus of pile material (E) = $5000\sqrt{f_{ck}}$ = 25000 N/mm^2 = 250000 kg/cm^2
Moment of inertia of pile (I) = 306796.16 cm^4
KB = 21.60 kg/cm^2 (From C-2.3.2)
Stiffness factor (R) = $(EI/KB)^{1/4}$ = 244.11 cm
$L_1 = 0$
$L_1/R = 0$
$L_f/R = 2.17$
Depth of fixity (L_f) = 5.25 m
Under lateral load considering the allowable horizontal displacement of pile at GL = 1% pile diameter, so the displacement of the 500 mm diameter pile = 5 mm
Lateral load for fixed head (Q) = $12EI_y/(L_1+L_f)^3$ = 3.20 t = 32 kN

Considered another three different diameter of pile 600 mm, 700 mm and 800 mm. Calculation will be same as above as per the consideration of IS:2911-2010. The results will be shown in result analysis part (Table -1,2) in this paper.

2.2 Numerical Study Using Finite Element Software

Numerical analysis is the study of algorithms that use numerical approximation for the problems of mathematical analysis. The overall goal of numerical analysis is the design and analytical technics to give approximate but accurate solutions to toughest problems. Usual methods of this study used in the analysis of pile is the finite element.

A continuum is splitted into a number of (volume) elements in the finite element method. Each element consists of a number of nodes. Each node has a number of degrees of freedom that equate to distinct values of the unknowns in the boundary value problem to be solved. Analysis were accomplished with several trail meshes with progressing mesh depuration until the displacement changes very minimal with more depuration.

In recent past, standard finite element-based software are accessible like FLAC 3D, PLAXIS 2D, PLAXIS 3D etc. which can be used for modelling and exploring problems regarding foundation engineering. Herein finite element analysis has been done using PLAXIS 3D FOUNDATION software.

2.2.1 Modelling in PLAXIS

Finite element approaches can be used for detecting the behavioral response of pile in soil. PLAXIS 3D has been used as a three-dimensional program to model pile, soil and soil pile interaction using the notion of plain strain condition with the factors under consideration are the modulus of elasticity and poison's ratio of soil and pile material, cohesion, angle of internal friction and unit weight of soil etc. Many other factors like the depth of fixities of pile, movement of soil around the pile, history of previous loading, vertical loads coming on piles, slenderness ratio of piles etc.; should be made subjected for the lateral load study of piles. The four basic components namely input, calculation, output and curves are comprised in PLAXIS 3D foundation program.

Unit of length, force parameter has been chosen m and kN. Wide range of soil geometry i.e. length = 50 m and depth = 40 m have been adopted to gate more appropriate result.

2.2.2 Modelling of Geometry

In the input program the boundary conditions, problem geometry with appropriate material properties are defined. The problem geometry is the representation of a real three-dimensional problem. The model includes an idealized soil profile, structural objects, construction stages and loading.

Minimum dimension of drawn has been taken x = 40 and y = 50 to fit the soil model property.

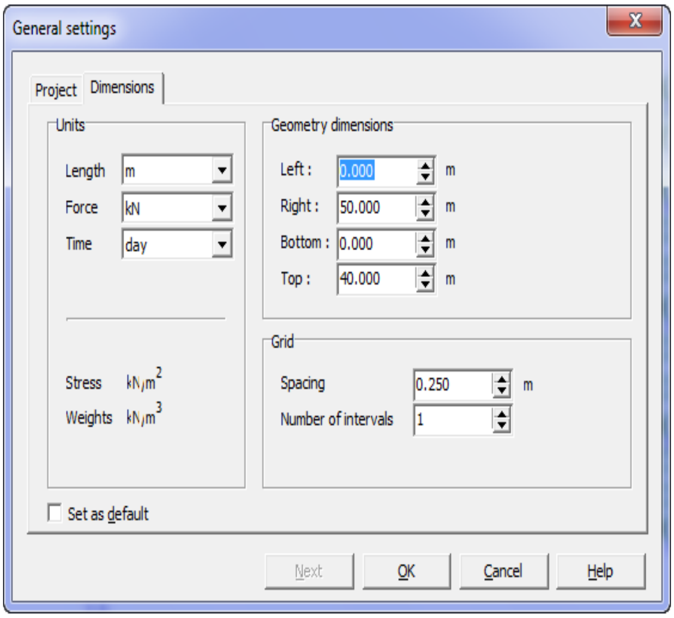

Fig-3: Setting area of modelling.

Four earth layers have been taken shown in below:
LAYER 1:
Material model : Mohr-Coulomb, Material type : Drained, γ_{unsat}, γ_{sat} = 18 kN/m^3, E_s = 15000k kN/m^2, m = 0.35, c = 30 kN/m^2, Ø = 0°, R_{inter} = 0.95

LAYER 2:
Material model : Mohr-Coulomb, Material type : Drained, γ_{unsat}, γ_{sat} = 18 kN/m^3, E_s = 15000k kN/m^2, m = 0.35, c = 60 kN/m^2, Ø = 0°, R_{inter} = 0.95

LAYER 3:
Material model : Mohr-Coulomb, Material type : Drained, γ_{unsat}, γ_{sat} = 18 kN/m^3, E_s = 15000k kN/m^2, m = 0.35, c = 80 kN/m^2, Ø = 0°, R_{inter} = 0.95

LAYER 4:
Material model : Mohr-Coulomb, Material type : Drained, γ_{unsat}, γ_{sat} = 18 kN/m^3, E_s = 15000k kN/m^2, m = 0.35, c = 130 kN/m^2, Ø = 0°, R_{inter} = 0.95

The soil material model should be selected as "MOHR COLUMB MODEL". The Mohr-Columb model requires total of five parameters-poison's ratio, dilatancy angle, friction angle, modulus of elasticity, cohesion.

PILE:
Material model : Linear elastic, Material type : Non-porous, Unit weight, γ = 25 kN/m^3, Grade of concrete = M25, E = 25*10^6 kN/m^2, Poison's Ratio (m) = 0.15
INTERFACE:
Interface has been assigned to interpret an imaginary dimension used to define thickness of interface. If the virtual thickness is higher, the elastic deformation will be more. Conversely if the virtual thickness is two smalls numerically, ill condition may transpire. Virtual thickness has been considered as 0.1 factor.

MESHING:
After generation of soil cluster, material, load and fixities full geometry has to be splitted in number of small elements, called meshing. The mesh element size can be adjusted by using a general mesh size varying from very coarse to very fine and also by using line, cluster and point refinements. In this case study, meshing has been done applying medium coarseness and 15 nodal triangular elements type have been embraced that will impart more accurate results.
After assigning the model geometry and 3D mesh generation, initial stresses are applied.
The calculation procedure can be performed automatically or manually.

CALCULATION PHASE:
The most important calculation type in PLAXIS 3D Foundation is the staged construction. In every calculation step, the material properties, geometry of the model, loading condition and the ground water level can be redefined. During the calculations, a multiplayer that controls the staged construction process (ΣMSTAGE) is incremented from zero to the ultimate level that is generally 1.0.
Phase 1
Pile casting.

1. Calculation type: Plastic.
2. Control parameters = >
3. Additional steps = 250
4. On "reset displacement to zero" so that displacement after the stage of initial stage would be zero.
5. On delete intermediate stapes.
6. Select staged construction then define and assign pile cluster.

Phase 2
Loading.
Lateral load is applied on the top of pile.

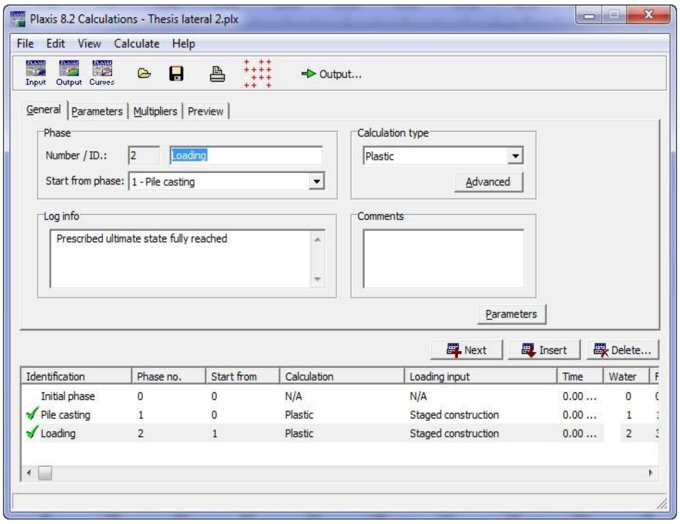

Fig-4: Phases of calculation.

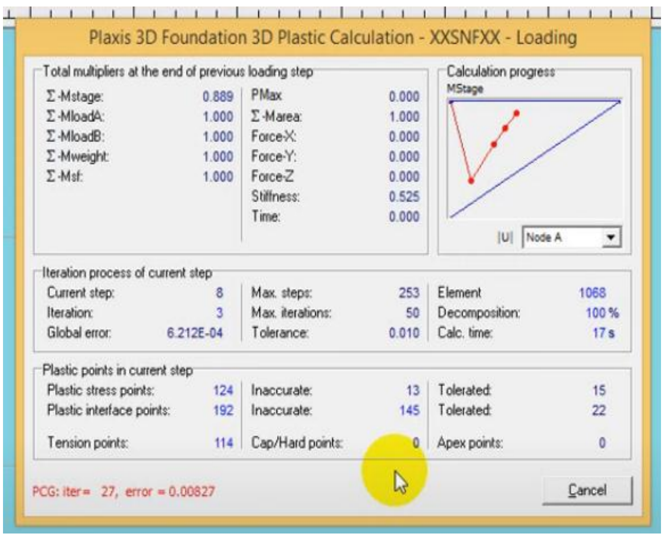

Fig-5: Phases of calculation in detail.

3. RESULT ANALYSIS

Theoritical calculation is already exhibited in methodology part. From experimental assessment, obtaining the displacement response of embadded pile in layered soil with respect to the variation of load and depth below cutoff level is schematized in Fig- 6.

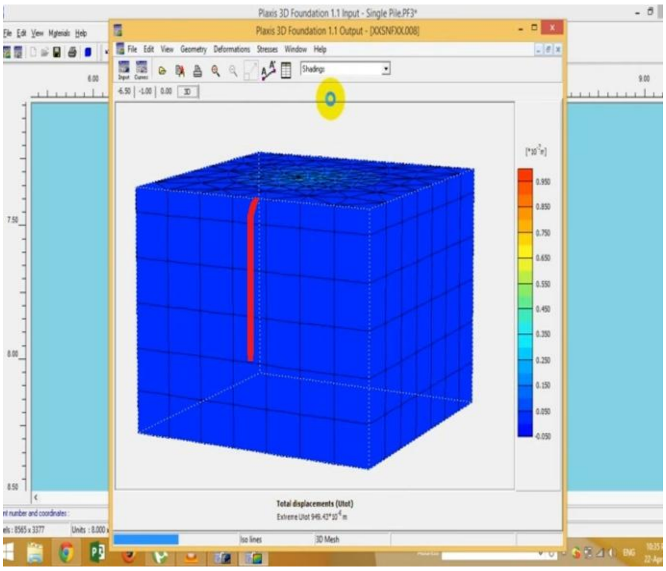

Fig-6: Horizontal displacement for 500 mm diameter pile.

The distinction of results, getting theoritically and analytically about load-displacement-depth are represented by Table-1 and 2 below.

Table – 1: Deatail results obtaining from IS: 2911-2010

Diameter of pile (mm)	IS Code		
	Allowable lateral load (kN)	Depth below cut off level (m)	Displacement (mm)
500	32	5.25	5
600	39	6.07	6
700	48	6.81	7
800	60	7.53	8

Table – 2: Deatail results obtaining from PLAXIS 3D

Diameter of pile (mm)	PLAXIS 3D		
	Allowable lateral load (kN)	Depth below cut off level (m)	Displacement (mm)
500	38	5.43	4.99
600	42	6.10	5.85
700	49	7.24	6.93
800	61	7.73	7.89

The divergence in behavioural response of different diameter piles (500 mm, 600 mm, 700 mm, 800 mm) are depicted graphically as per results of Table-1 and 2.

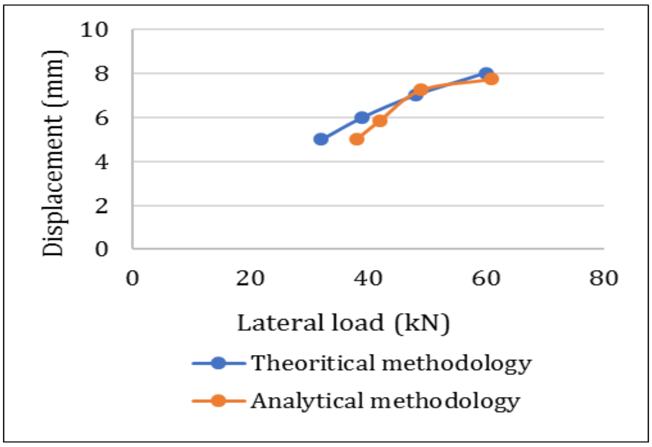

Fig-7: Displacement-load curve for different diameter of pile.

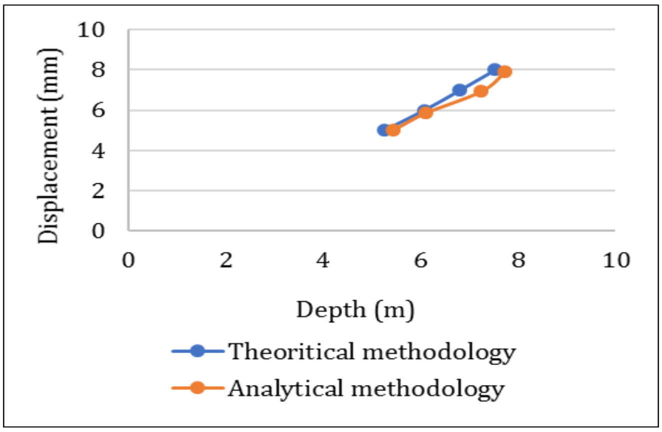

Fig-8: Displacement-depth curve for different diameter of pile.

4. CONCLUSIONS

Estimation of lateral load carrying capacity and simulation of lateral response of embedded pile in multi-layer earth structure is under taken in the current probe. Two alternative perspective are revealed as may be summarized below,

[1] The lateral load carrying capacity of several diameter (500 mm, 600 mm, 700 mm and 800 mm) embedded pile in multi-layer soil is obtaining by computation of code analysis in first scheme. The displacement values are esteemed as 1% of pile diameter, proposed by IS 2911:2010.

[2] Herein, the embedded pile model of different diameter is demonstrated in multi-layer soil for predicting the lateral response subjected to horizontal soil movement by employing PLAXIS 3D finite element software. It is an efficient articulation using line elements combination with elasto-platic line-to-volume and point-to-volume interfaces. The permissible load bearing capacity is evaluated with respect to the variation of response parameter that is horizontal response (displacement) and depth below cut off level. As respect to that values, the values of displacements are to be chosen which is less than 1% of pile diameter, is more accurate.

This paper describes a precise solution by the predicting the lateral response with respect to calculate the ultimate load bearing capacity of different diameter embedded pile. In this parametric study, the accuracy of propose analysis has been verified by graphical representation. The plotting shows that the incompatibility in behavioral mode of response. All the above revisions conclude that the pile behavior embedded in layered soil and the ultimate load carrying capacity of several diameter are more justifiable the numerical assessment than the theoretical assessment.

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