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# A NUMERICAL STUDY ON BEARING CAPACITY OF STRIP FOOTING ON LAYERED SOIL SYSTEM

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**Abstract:** Foundation is a connecting member between the structure and the ground which supports it or is the part of a structure which transmits the weight of the structure to the ground. All civil engineering structures whether they are buildings, dams etc. are build on soils. The most conventional method of foundation design is based on the concept of bearing capacity theories. Since the soil strata on which the foundations rests are not homogenous always, the bearing capacity determination of foundations on layered soil system is more significant than homogenous soil system. Hence this study on bearing capacity of strip footing on layered soil system plays a significant importance in geotechnical engineering. In this work, the effect of embedment and effect of top layer thickness on the ultimate bearing capacity of strip footing in two layered soil system is studied. The bearing capacity increases and the settlement of footing decreases, as the thickness of top layer increases to an optimum value beyond which there is no substantial increase in bearing capacity. An numerical study were conducted in order to understand the effect of top layer thickness and footing embedment on bearing capacity and settlement of strip footing on layered soil system with and without geotextile at the interface. The numerical study were conducted using PLAXIS 3D.

**Keywords:** Bearing capacity, strip footing, layered soil, top layer thickness, footing embedment.

## 1. Introduction

Foundation is the structure which transfers the load coming from the superstructure to underlying soil sub grade without any shear. Broadly speaking, foundations are divided into two categories namely shallow foundations and deep foundations. The words shallow and deep refer to the depth of soil in which the foundation is placed. Shallow foundations are used for small, light weight buildings, while deep ones are for large, heavy buildings. A shallow foundation system generally used when the soil close the ground surface has sufficient bearing capacity to withstand the load, and underlying weaker strata do not result in undue settlement. The shallow foundations are most commonly used and most economical foundation systems. There are of several kinds such as strip footing, spread or isolated footing, combined footing, strap or cantilever footing and mat or raft foundations. Strip footings are commonly found and act as a long strip that supports the weight of an entire wall. These are used where the building loads are carried by entire walls rather than isolated columns, in older buildings made of masonry. A bearing capacity failure is defined as a foundation failure that occurs when the shear stresses in the soil exceeds the shear strength of the soil on which the foundations rest. Bearing capacity failures of foundations can be grouped into three categories, they are general shear failure, local shear failure, punching shear failure. Traditional bearing capacity theories for determining the ultimate bearing capacity of shallow foundations assume that the thickness of the bearing stratum is homogenous and infinite. However, actually this is not true in all cases. Multilayered soils are commonly encountered in practical cases. It is possible to encounter a rigid layer at shallow depth or the soil may be layered and have different shear strength parameters (Bowles, 1988). The best estimation of bearing capacity and settlement on layered soil are possible only, if the pressure-settlement characteristics of the foundation-soil are known for the specific size of the footing.

Naturally occurring soils are often deposited in different layers. Within each layer in the soil may, typically, be assumed to be homogeneous, although the strength properties of adjacent layers are generally quite different. If a foundation is placed on the surface of a layered soil system for which the thickness of the top layer is large compared with the width of the foundation, then realistic estimates of the bearing capacity may be obtained using conventional bearing capacity theory. However, this approach may not be appropriate, if the thickness of the top layer is not large compared to width of the foundation. A layer of deposits below shallow foundation which influences the bearing capacity is known as subsoil. The present study involves the subsoil of two types shown in figure.1.

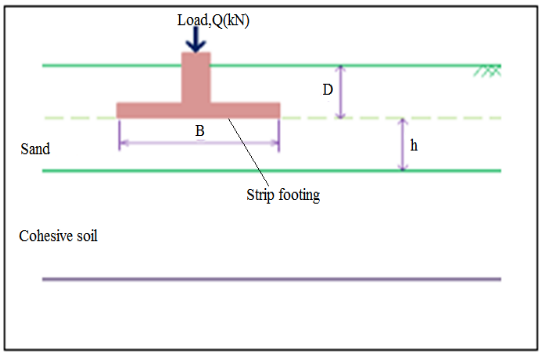


Figure 1: Subsoil layers

In the present investigation attempt has been made to study the ultimate bearing capacity of strip footings in layered soil system using numerical modeling in finite element software package PLAXIS 3D. Now-a-days numerical analysis program has wide-spread applications in Geotechnical Engineering. There are various Finite Element Method software packages available such as PLAXIS, ABAQUS, GEOSTUDIO, FLAC etc. These finite element software packages are worldwide used for numerical modeling and analysis of any geotechnical problem and are popular for their robust and accurate simulation techniques. Bearing Capacity analysis of shallow footing in layered soil can be conveniently carried out by PLAXIS 3D software. It is a three-dimensional finite element program especially developed for the analysis for foundation structures in geotechnical engineering. It combines simple graphical input procedures, which allow the user to generate complex finite element models, with robust calculation procedures and advanced output facilities. Thickness of the top layer (h) is one of the key factors in evaluation of bearing capacity in layered soil. The objective of the work is to study the effect of thickness of top layer of soil and depth of footing embedment on bearing capacity and settlement of strip footing on layered soil system under vertical central loading using numerical approach. Thickness of the top layer is expressed in terms of the ratio h/B and depth of footing embedment in terms of D/B, where B is the width of footing and D is the depth of footing embedment. In the present study thickness of the top layer (h) has been varied as 0B, 0.5B, 1B, 2B, 3B, 4B and the embedment depth (D) has been varied as 0B, 0.5B, 1B, 2B, 3B, 4B.

## 2. Previous Research

The numerical and experimental researches were conducted by numerous investigators in the past years. In the case of layered soils, depending on the depths and strengths of the layers, the lower layer may affect the UBC of strip shallow footing.When the thin top soil becomes increasingly weaker than the underlying strong soil, the contribution by the bottom soil layer to the bearing capacity increases. The value of bearing capacity ratio(η) increases with the increase of h/B ratio. Further increase of h/B does not show significant increase and becomes nearly constant, where h is the top layer thickness and B is the width of footing. The bearing capacity increased with an increase in the footing size. For small values of Cu/(γB), η increases continuously with an increase in h/B up to a certain optimum thickness h(opt) of the sand layer beyond which η becomes almost constant where Cu is the undrained cohesion and γ is the unit weight of soil. Maximum value of η corresponding to h(opt). η increases continuously with decreases in Cu/(γb) and increases in ϕ and q/ (γB), where ϕ is the angle of internal friction of sand and q is the surcharge load. When the thickness D of the upper layer is small or comparable to the footing width B, the shape of the failure envelops is not unique and the size of the failure envelops increases with increasing strength ratio.

## 3. Materials and Methodology

Two soil types were used in the study. Type 1: Locally available sand and Type 2: cohesive soil. The Index and Engineering properties of these soils were determined as per IS specifications. The sand was collected from Pavaratty, Thrissur and the cohesive soil was collected from Puthur, Thrissur. The dimension of mild steel tank is fixed as 0.5m x 0.5m x 0.6m. Model strip footing of dimensions 0.5m x 0.05m x 0.025m was used in the study. The properties of collected samples were shown in table 1 and table2.

**Table 1: Properties of sand**

| PROPERTIES | VALUE |
|---|---|
| Specific gravity | 2.66 |
| Particle size distribution<br>Percentage of gravel (%)<br>Percentage of sand (%)<br>Percentage of fines (%) | <br>0<br>96.5<br>3.5 |
| Angle of internal friction(degree) | 36 |
| Relative density(%) | 40 |
| Minimum dry density(kN/m$^3$) | 14.84 |
| Maximum dry density(kN/m$^3$) | 17.66 |

**Table 2: Properties of cohesive soil**

| PROPERTIES | VALUE |
|---|---|
| Natural water content (%) | 21 |
| Specific gravity | 2.75 |
| Particle size distribution<br>Percentage of Gravel (%)<br>Percentage of Sand (%)<br>Percentage of Fines (%) | <br>0<br>35<br>65 |
| Atterberg's limits<br>Liquid limit (%)<br>Plastic limit (%)<br>Shrinkage limit (%)<br>Plasticity index (%) | <br>35<br>22<br>15<br>13 |
| Compaction test<br>Optimum moisture content (%)<br>Maximum dry density (kN/m$^3$ ) | <br>20<br>16.92 |
| Unconfined compressive strength (kN/m$^2$) | 96 |

## 4. Finite Element Analysis

The three dimensional approach using PLAXIS 3D was used in the study to model the behavior of footing in the layered soil system. To simulate the behavior of soil, different constitutive models are available in the software. In the present study the soil behavior is simulated by Mohr- Coulomb model. A plane strain model is adopted in the analysis, since model strip footing is used. Meshing is done automatically. Medium meshing is adopted in all the simulations.
The input parameters of soil used in the test are shown in the table 3 and the input parameter for model plate strip footing are shown in table 4.

**Table 3: Input parameters of soil**

| PROPERTIES | VALUES |
|---|---|
| **SAND** | |
| Modulus of elasticity ,E( $kN/m^2$) | 30000 |
| Poisson's ratio(μ) | 0.3 |
| Cohesion, C ($kN/m^2$) | 1 |
| Angle of internal friction,ϕ (degree) | 36 |
| Dilatancy angle,ψ (degree) | 6 |
| **COHESIVE SOIL** | |
| Modulus of elasticity ,E ($kN/m^2$) | 4000 |
| Poisson's ratio(μ) | 0.4 |
| Cohesion, C( $kN/m^2$) | 32 |
| Angle of internal friction,ϕ( degree) | 34 |
| Dilatancy angle,ψ( degree) | 4 |

**Table 4: Input parameters of model strip footing and geotextile**

| PROPERTIES | VALUES |
|---|---|
| **MODEL STRIP FOOTING** | |
| Thickness(m) | 0.025 |
| Modulus of elasticity ,(E) $kN/m^2$ | $2x10^8$ |
| Poisson's ratio(μ) | 0.2 |
| **GEOTEXTILE** | |
| Axial stiffness, EA () | 1300 |

The soil geometry obtained in the analysis using PLAXIS 3D was shown on figure 2.

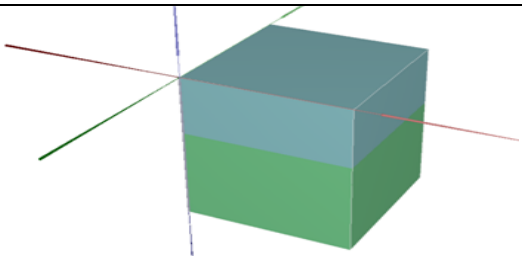

Figure 2: Soil geometry in PLAXIS 3D

The loading arrangements for strip footing of the layered soil were shown in figure 3 for the analysis of effect of top layer thickness and in figure 4 for the analysis of effect of depth of footing embedment.

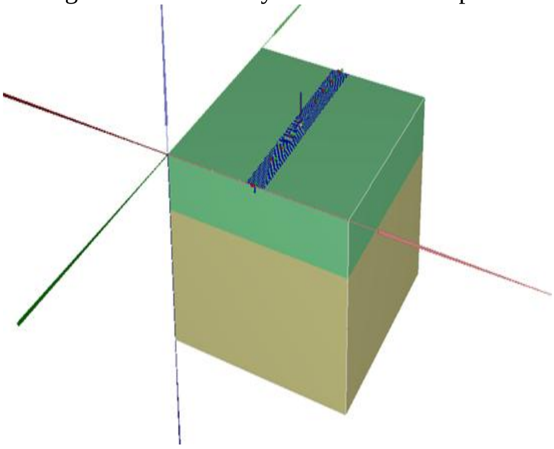

Figure 3: Loading arrangement for the analysis of effect of top layer thickness

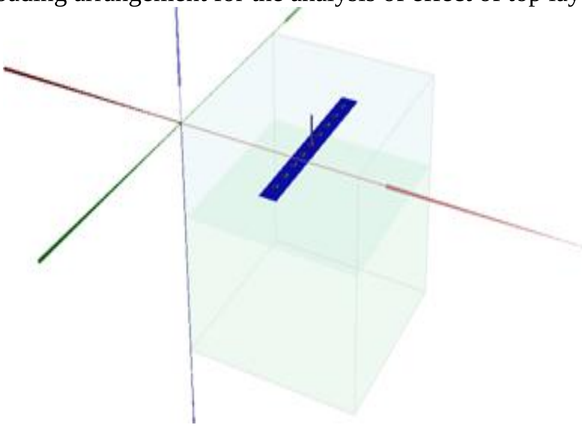

Figure 4: Loading arrangement for the analysis of effect of depth of footing embedment

The meshes obtained in the analysis of effect of top layer thickness were shown in figure 5 and for the analysis of effect of depth of footing embedment were shown in figure 6.

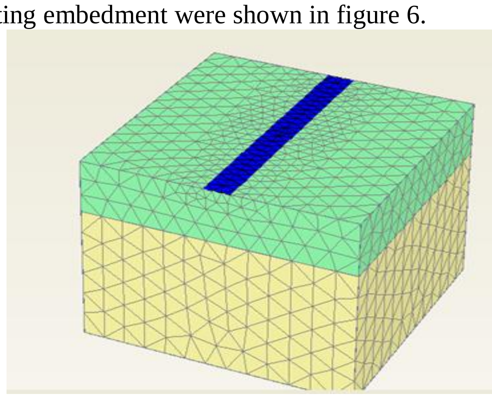

Figure 5: Mesh obtained in the analysis of effect of top layer thickness

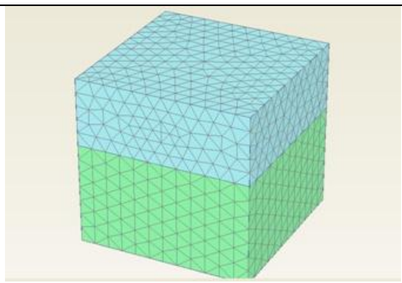

Figure 6: Mesh obtained in the analysis of effect of depth of footing embedment

Figure 7 and figure 8 shows the pattern of deformation produced in the system under a particular load for the analysis of effect of top layer thickness and depth of footing embedment respectively.

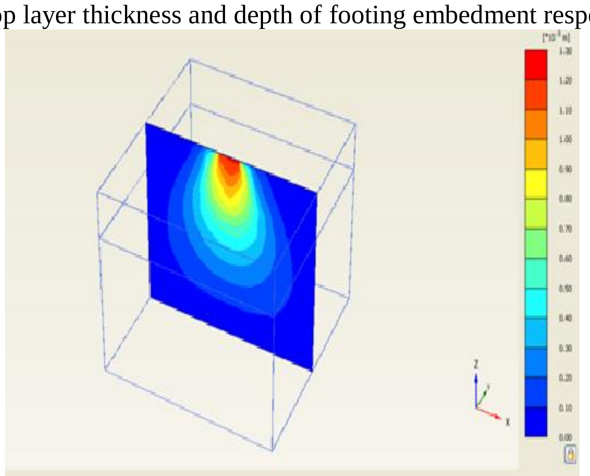

Figure 7: Pattern of deformation produced under a particular load for the analysis of effect of top layer thickness

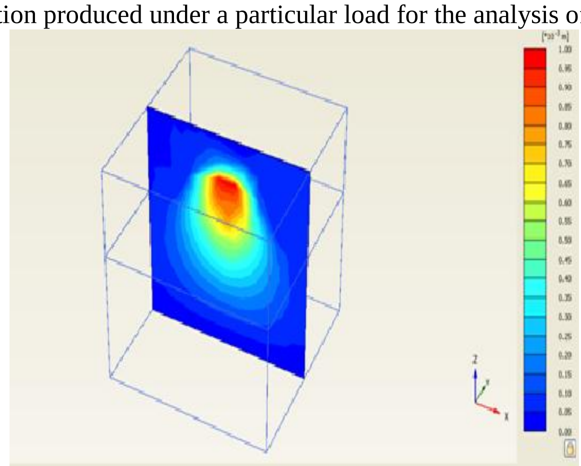

Figure 8: Pattern of deformation produced under a particular load for the analysis of effect of depth of footing embedment

## 5. Finite element results and discussion

### 5.1 Foundation soil without geotextile at the interface

#### 5.1.1 Effect of top layer thickness

The analysis in PLAXIS 3D were conducted by putting appropriate input parameters. The bearing capacity values obtained for h=0B, h=0.5B, h=1B, h=2B, h=3B and h=4B are 84.85kPa, 96.970kPa, 141.41kPa, 169.69kPa, 202.02kPa and 202.02kPa respectively for the system without geotextile at the interface. The settlement obtained in the analysis is shown in the table 5. The load- settlement curves are shown in figure 9.

**Table 5: Settlement obtained in different h/B ratios for the analysis of effect of top layer thickness**

| Test result | h/B | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **0.5** | **1** | **2** | **3** | **4** |
| Settlement (mm) | 1.9 | 2.03 | 2.86 | 3.33 | 3.62 | 2.01 |

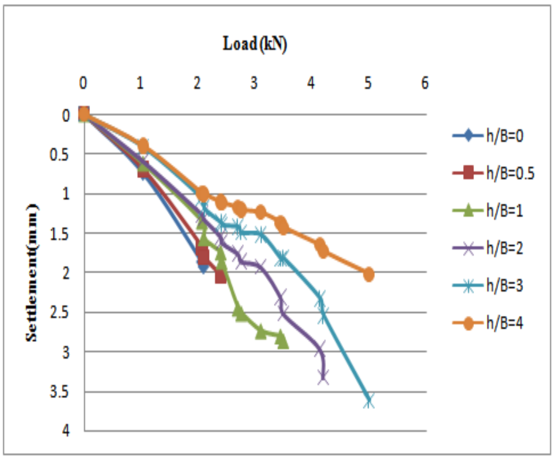


Figure 9: Load-Settlement curve for different h/B ratios without geotextile at the interface

### 5.1.2 Effect of depth of footing embedment

The bearing capacity of the soil without geotextile at the interface for D=0B, D=0.5B, D=1B, D=2B, D=3B and D=4B are 202.02kPa, 222.22kPa, 250.50kPa, 311.11kPa, 339.39kPa and 339.39kPa respectively. The settlement obtained in the analysis is shown in the table 6. The load- settlement curves are shown in figure 10.

**Table 6: Settlement obtained in different D/B ratios for the analysis of effect of depth of footing embedment**

| Test results | D/B | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **0.5** | **1** | **2** | **3** | **4** |
| Settlement (mm) | 2.01 | 4.12 | 4.78 | 5.50 | 6.42 | 6.92 |

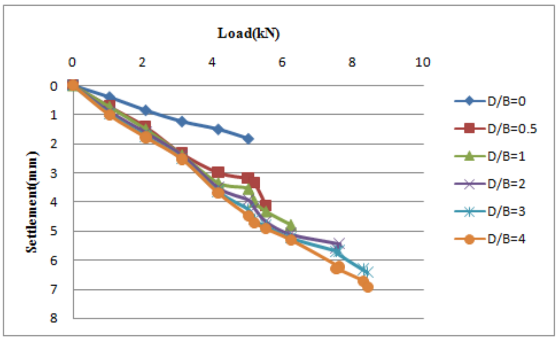


Figure 10: Load-Settlement curve for different D/B ratios without geotextile at the interface

## 5.2 Foundation soil with geotextile at the interface

### 5.2.1 Effect of top layer thickness

The bearing capacity values obtained for h=0B, h=0.5B, h=1B, h=2B, h=3B and h=4B are 133.33kPa, 161.62kPa, 238.38kPa, 303.03kPa, 303.03kPa, 303.03kPa and 303.03kPa respectively for the system with geotextile at the interface. The settlement obtained in the analysis is shown in the table 7. The load- settlement curves are shown in figure 11.

**Table 7: Settlement obtained in different h/B ratios**

| **Test results** | **h/B** | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **0.5** | **1** | **2** | **3** | **4** |
| Settlement (mm) | 1.83 | 2.03 | 3.23 | 3.61 | 3.62 | 3.62 |

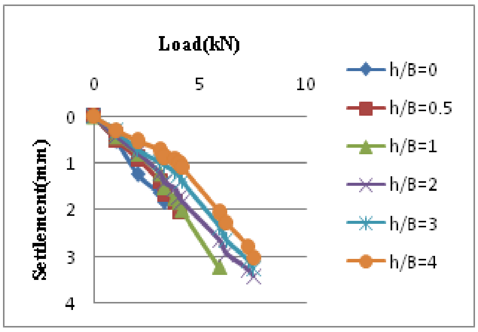


Figure 11: Load-Settlement curve for different h/B ratios without geotextile at the interface

### 5.2.2 Effect of depth of footing embedment

The bearing capacity of the soil with geotextile at the interface for D=0B, D=0.5B, D=1B, D=2B, D=3B and D=4B are 303.03kPa, 343.43kPa, 391.92kPa, 492.92kPa, 492.92kPa and 492.92kPa. The settlement obtained in the analysis is shown in the table 8. The load- settlement curves are shown in figure 12.

**Table 8: Settlement obtained in different D/B ratios**

| **Test results** | **D/B** | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **0.5** | **1** | **2** | **3** | **4** |
| Settlement (mm) | 3.63 | 4.02 | 5.64 | 6.31 | 6.58 | 6.76 |

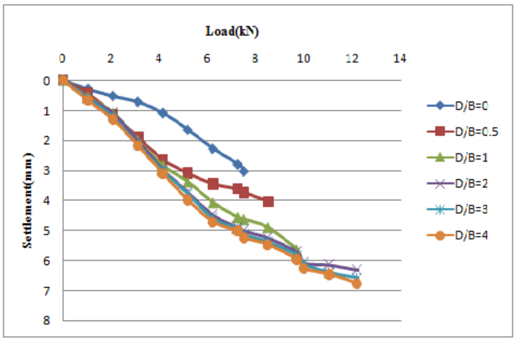


Figure 12: Load-Settlement curve for different h/B ratios without geotextile at the interface

From the test program it was observed that for without geotextile at the interface system, an increase in the thickness of the sand layer resulted in an increase in the load carrying capacity and a corresponding reduction in settlement of the layered soil. It is also observed that introduction of geotextile layer at the sand-cohesive soil interface further improves the performance of footing. The bearing capacity of the layered system increases with the increase in thickness of sand layer up to a certain value of h/B. Beyond this value, there is no substantial improvement in the ultimate bearing capacity. The value of h/B at which maximum bearing capacity is achieved is designated as $h/B_{cr}$. The steady increase in bearing capacity of the non-geotextile system can be attributed to the increase in the bearing resistance offered by the frictional granular soil as the fill thickness was increased. A thicker fill tends to spread the load over a wider area on the cohesive soil, thus increasing the ultimate bearing capacity of the footing. The failure surface at small h/B values the shear failure zones of soil developed below footing extended in to the cohesive soil and shows low bearing capacities. With an increase in fill thickness, an increasing portion of the shear failure zone was developed within granular fill, thus accounting for the improvement in performance. For strip footing in layered soil without geotextile at the interface, when thickness of the sand layer reached a value of h/B =4, the entire shear failure surface was developed and contained within the sand layer, at which the bearing capacity reached the maximum value with a small amount of settlement. Therefore, any further increase in sand thickness did not result in any additional improvement in bearing capacity and the settlement become almost constant value, as the failure surface was always confined within the sand layer. For geotextile at the interface soil system, when the thickness of sand layer reached a value of h/B=2, the bearing capacity reached the maximum value with small amount of settlement. Therefore, any further increase in sand thickness did not result in any additional improvement in bearing capacity. For the embedded footing there will be the effect of surcharge, hence the bearing capacity increases with the increase in footing embedment. For strip footing in layered soil without geotextile at the interface, when depth of footing embedment reached a value of h/B =3 bearing capacity reached the maximum value with small amount of settlement and for with geotextile at the interface, when depth of footing embedment reached a value of h/B =2 bearing capacity reached the maximum value.

## 6. Conclusion

The Index and engineering properties of the both the collected samples are determined according to the specified IS codes. The effect of top layer thickness and depth of footing embedment on bearing capacity of strip footing layered soil system were investigated using Plaxis 3D with and without geotextile at the interface. From the analysis, without geotextile at the interface, the optimum top layer thickness is obtained as four times the width of footing and the optimum depth of footing embedment is obtained as three times the width of footing. With geotextile at the interface, the optimum top layer thickness is obtained as two times the width of footing and the optimum depth of footing embedment is obtained as two times the width of footing. The inclusion of geotextile at the interface increases the bearing capacity of soil and decreases the optimum values of top layer thickness and depth of footing embedment The results obtained in the model tests were found to be very conservative with FE results in this study.

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