

## RESEARCH ARTICLE

## AN INTEGRATED SUBSURFACE CHARACTERISATION FOR FOUNDATION COMPETENCE IN ODA TOWN, AKURE, SOUTHWESTERN NIGERIA

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## ABSTRACT

A foundation investigation was carried out at a proposed site for a residential building in Oda Town, Akure, Nigeria. The research is aimed at evaluating the competence of the sub-soil as foundation materials. Geophysical and geotechnical techniques were employed to characterise the subsurface foundation properties of the soil. A total of 8 Vertical Electrical Soundings and 6 disturbed soil samples were collected to aid the study. The geophysical results revealed three geo-electric sections, comprising the topsoil, weathered basement and rock head/basement. The topsoil is composed of compacted sandy-clay. The geo-electric sections further revealed the undulating nature of the rock head/basement. However, there is no evidence of faulting within the bedrock which can cause subsidence in the area. The geotechnical results revealed that the soil has a relatively low clay content. The soils within the study area are expected to exhibit low to medium swelling potential as deduced from the consistency tests. From these results, it can be conclusively stated that the subsoils within which the building or any engineering structure is to be founded are competent but generally, deeper foundations are recommended due to the prevailing H-curve across the vertical profiles for the soils examined.

## KEYWORDS

Geophysical, Geotechnical, Vertical Electrical Sounding, Foundation Competence, Subsur-face Characterisation

## 1. INTRODUCTION

Over the years, the cases of foundation failure and general building subsidence has been an issue not just in Africa, but in the entire world. The causes of such failures have been blamed on so many things like the poor quality of building materials used, salinity, old age of buildings, carelessness, poor workmanship, poor supervision, poor materials and quackery (Oba et al., 2024). Less frequently mentioned are the subsurface conditions on which the buildings are erected or sited. The design of a structure which is safe, durable and has low maintenance costs depends upon an adequate understanding of the nature of the ground on which such building is located (Unamba et al., 2024). A foundation can be seen as that element of architectural structure which connects it to the ground and transfers load from the structure to the ground.

Foundations are designed to have an adequate load capacity depending on the type of subsoil supporting the foundation. The primary design concerns of a foundation are settlement and bearing capacity. According to a study, when considering settlement, total settlement and differential settlement is normally considered (Adamu et al., 2024). Differential settlement is when one part of a foundation settles more than another part. This can cause problems to the structure which the foundation is supporting. Expansive clay soils can equally cause some major problems. Hence, it is pertinent to evaluate a site and characterize effectively using the basic and advanced methods of geotechnical survey and applied geophysical methods. The properties of soil have the major influence on the design, stability and sustainability of foundations to make it perform its functions (Ehidiamen et al., 2023). From the studies conducted a good foundation should meet both geophysical and geotechnical conditions in

order to ensure the durability of the building (Sanusi, 2023). Different soil types have different load bearing capacity and this is as a result of the mineral matter that make up the soil. Hence, foundations sited on a poor soil presents only a disaster waiting to occur. The fields of geology, geotechnics and geophysics are aspects of Engineering geology that are often imbibed by the civil engineers to ensure that the subsurface foundation is worthy of the proposed buildings or other engineering structures that would be sited on them.

Foundation failure has been ever present problem that when not considered as a major factor, it can cause loss of life and valuables including the financial implication. Although the study area is located in the basement complex, the site of the proposed building is on a soil that does not seem to be evenly distributed in terms of competence (Oba et al., 2024). Upon physical inspection some areas on which the foundation is sited appear to have a 'subsiding' characteristic. The soil appears to be a bit marshy further down east. However, the front of the proposed building seems to present a different perspective, as the ground appears competent enough to carry the proposed load. Although the proposed building is a bungalow, if sited on a poor clayey-laden soil material, the building will not stand the test of time and the rigors of non-uniform load that it will put on the soil. Hence, the motivation behind this research as it seeks to investigate ground stability for foundation competence for a residential building or any other engineering structure based on the Geophysical and Geotechnical tools deployed.

## 1.1 Study Area

The study area is located between Latitude  $7^{\circ}10.526'N$  and Longitude  $5^{\circ}14.394'E$  and it has an elevation of 335m above sea level, it is located in

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Oda Town in Akure (Figure 1). The area is accessible through motorable road network, well-connected footpaths and with excellent urban

drainage system. The location of the study area is presented with the aerial photograph captured in Figure 2.

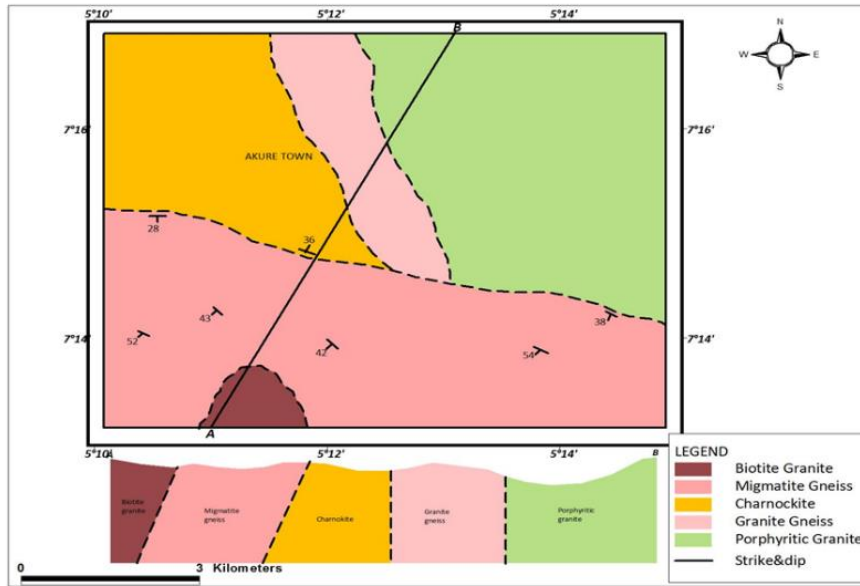


Figure 1: Geological Map of Akure (after Afolabi, 2010)



Figure 2: Aerial photograph of the study location showing the sampled points

## 2. MATERIALS AND METHODS

It made use of the ABEM Digital Terrametre SAS 3000 model. This was done using the electrical resistivity method that incorporates the VES methodology. By gathering data at ground level, electrical resistivity surveys are often used to calculate the electrical resistivity of subsurface materials (Mayange et al., 2018). For VES work, two common electrode arrays are those from Wenner and Schlumberger (Sharma, 1997). The Schlumberger array's potential electrode spacing should not be greater than 40% of the spacing between the current electrodes (AB) (Anakwuba et al., 2014).

Schlumberger electrodes were used, and their maximum current electrode spacing (AB/2) was 100m. The apparent resistivity and depth penetration of this array are both 0.125AB. This served as the primary tool. Both the receiver and transmitter circuitry are currently housed in the box. During data collection, extras such cable reels, stainless steel electrodes, and meter tapes were also used (Hardianshah and Adul Rahim, 2013). The geotechnical analysis involved collection of an undisturbed soil samples from dug holes one and two located close to stations 5 and 9 respectively. The samples were taken at a depth 0.5m and 1.0m respectively. The geotechnical test carried out include Moisture content, Specific gravity, Grain size analysis, Atterberg limit and Shear test using the standard established procedures (Ashioba and Nelson, 2024).

## 3. RESULTS AND DISCUSSION

Geophysical and geotechnical techniques were deployed to investigate the

failed foundations in this study in order to infer the likely reason for the failure. The results of the geophysical survey carried out at the study area is presented as sounding curves, tables, and geo-electric sections while that of geo-technic analysis carried out are: plastic limit, liquid limit, specific gravity, moisture content test and shear test and are represented as graphs and tables.

### 3.1 Vertical Electrical Sounding of the Soil

Eight (8) VES points were located in the study area (Table 1). The result from the analysis depicted H curve type (Figure 3) for all the VES of the soil. The H curve has the following characteristics; it is mostly water-saturated, with low resistivity, high porosity, low permeability and low specific yield which typically indicates a competent top layer overlying a weak, low-resistivity middle layer (often a clay or saturated/weathered material), underlain by a more resistive competent basement (Ilevbare and Ogundana, 2023; Fadele et al., 2013; Emmanuel et al., 2011). The depth to the rock head ranges from 3.1m (VES 7) to 10.0m (VES 10). The topography of the bedrock from the geophysical study revealed that the bedrock is not levelled results of the interpreted VES results are portrayed in Table 5. Also from the generated Geo-electric sections, three layers have been delineated, each having varying resistivity values. These layers include the top soil, the weathered basement and the rock head/crystalline basement. Resistivity values are lowest in the weathered layer; hence the layer is the most conductive of all layers. The top soil has high resistivity values ranging from 631.8 ohm-m (VES 3) to 1624 ohm-m (VES 1), it may be indicating that the soil type is of a sandy (fine to coarse sand) with very little amount of silt/clay composition.

| Table 1: VES 1 of the sampled soil |                     |           |            |
|------------------------------------|---------------------|-----------|------------|
| VES STATIONS                       | RESISTIVITY (ohm-m) | DEPTH (m) | Curve type |
| 1                                  | 1624.0/50.5/463.5   | 0.5/4.2   | H          |
| 2                                  | 859/48.1/3938.2     | 0.7/3.7   | H          |
| 3                                  | 631.8/35.1/2365.7   | 1.3/4.3   | H          |
| 4                                  | 641.9/94.8/2251.4   | 1.2/7.7   | H          |
| 5                                  | 1167.1/103.4/3804.4 | 0.9/5.2   | H          |
| 6                                  | 1134.5/137/3712.2   | 0.9/8.8   | H          |
| 7                                  | 802.3/39.1/5077.7   | 0.9/3.1   | H          |
| 8                                  | 1050/484.1/1622     | 2.5/10    | H          |

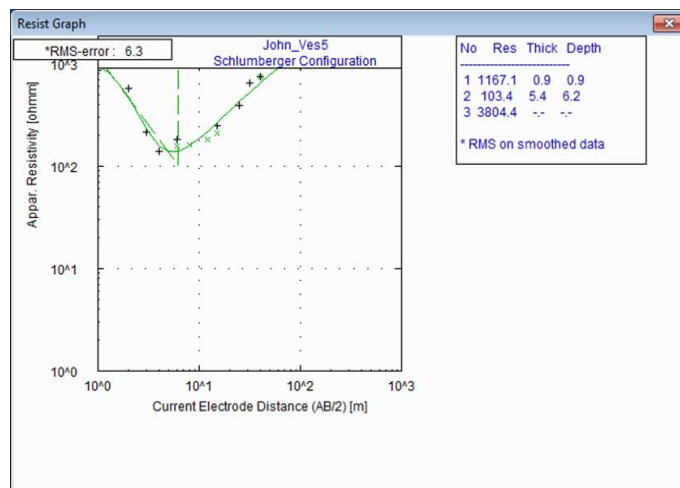


Figure 3: H-type resistivity curve

The geo-electric section 1 (Figure 4) consists of VES 1 to VES 6 in NNE/SSW direction. The horizontal distance interval between each of the station is 8m. The depth to bedrock ranges from 3.7m (VES 2) to 8.8m (VES 6), table 5. The rock underneath has high resistivity values ranging from 463.5 ohm-m (VES 1) to 3938 ohm-m (VES 2), and this is presumably the rock head or basement. The topsoil resistivity ranges from 631.8 ohm-m (VES 3) to 1624 ohm-m (VES 1) and the depth to the surface ranges from 0.5m (VES 1) to 1.3m (VES 3). The second layer has resistivity ranging from 35.1 ohm-m (VES 3) to 137 ohm-m (VES 6). The depth ranges from 3.7m (VES 2) to 8.8m (VES 6). The topsoil may be a compacted sandy-clay. The geo-electric section 2 is made up of VES 7 and VES 8 in NNE/SSW axis. The horizontal distance interval is 10m. The topsoil has resistivity ranging from 802.3 ohm-m (VES7) to 1050 ohm-m (VES 8), with depth ranging from 0.9m (VES7) to 2.5m (VES 8), table 5. The second layer has resistivity ranging from 39.1ohm-m (VES7) to 484.1 ohm-m (VES 8) and being delineated as weathered layer.

The geo-electric section cuts across the site making comparison between the array of VES points in front of the site and the VES points at the back of the site. The topsoil has resistivity ranging from 802.3 ohm-m (VES 7) to 1167.1 ohm-m (VES 5). The depth of the topsoil is 0.9m at both VES points. The weathered basement has a resistivity ranging from 39.1 ohm-m (VES 7) to 103.4 ohm-m (VES 5). The rock head has a resistivity ranging from 3804.4 ohm-m (VES 5) to 5077.7 ohm-m (VES 7) with depth ranging from 3.1m (VES 7) to 5.2m (VES 5). The depth to bedrock is shallow for VES point 7 as compared to the deeper VES point 5.

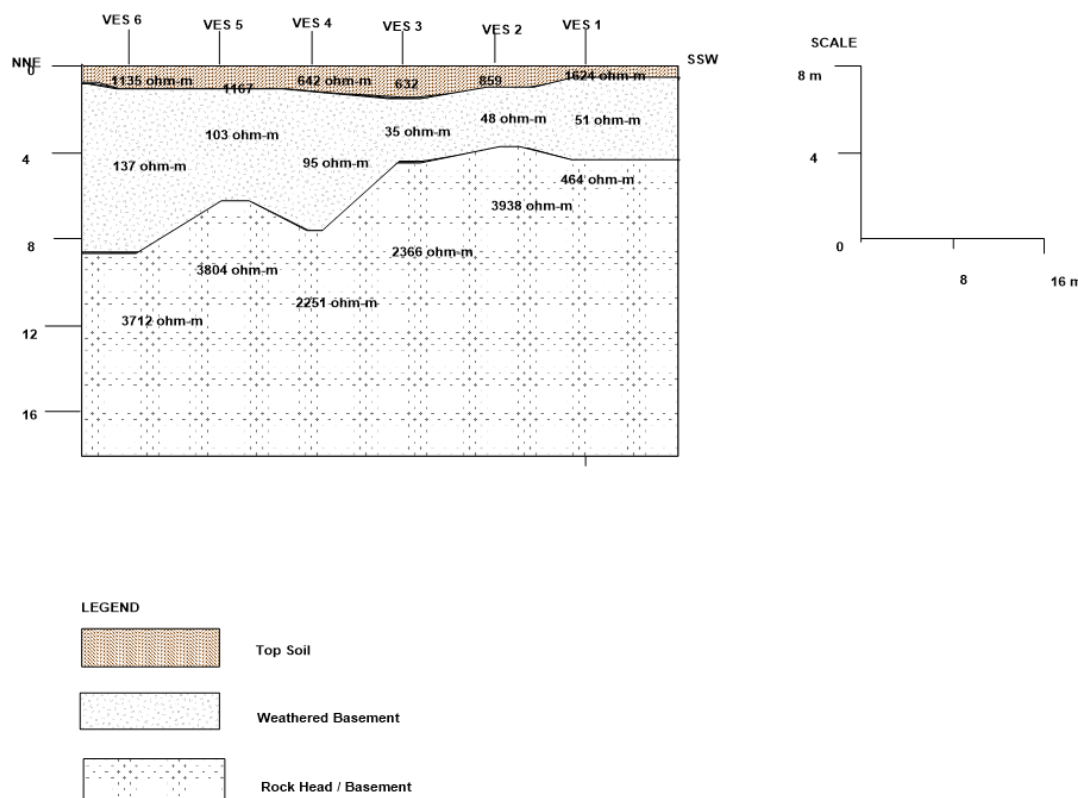


Figure 4: Goelectric Section 1

### 3.2 Geotechnical Properties of the Soil

#### 3.2.1 Natural Moisture Content of the Soil

The Natural moisture content from the analysed samples, the moisture content ranges from 16.77-34.64%, average being 23.8%. This shows a close range of the values except for disturbed samples taken from DH4 and DH3 whose values were far off from the other four. This shows that the natural moisture content of the soil in the area is relatively low at its natural state. Moisture variation is generally determined by intensity of rain, depth of collection of sample and texture of the soil (Oladipupo, 2025). A soil that absorbed too much moisture can result in soil collapsing which outrightly affects any building upon it. Natural moisture contents

for soil are below 60%. The soil samples analysed indicate that the soil is a uniform natural soil that supports foundation. At a depth of 1.10m, DH6 has the lowest moisture content and at 1.05m, DH4 has the highest moisture content. DH3 has the second highest moisture content of 28.87%. A liquid soil has little or no bearing capacity. Moisture content is vital to proper compaction, moisture acts as the lubricant within soil, sliding the particles together, too little moisture means little compaction and neither is too much moisture favourable and weakens the bearing capacity. If the soil is adequately saturated, there is an apparent cohesion that acts to bind the soil particles together. Cohesion is also a function of particle size, having an inverse relationship (Ilevbare and Edegbai, 2022). However, one geotechnical test cannot on its own be used to estimate the competence of the soil and soil moisture content cannot solely on its own

be used to evaluate a soil competence when faced with the test of time as a foundation material. The result of the moisture content is expressed in the table below;

**3.2.2 Specific gravity determination of the Soil**

Soils containing organic material and porous particles may have specific gravity values below 2.0, and soils having heavy materials usually have specific gravity values above 3.0. From the analysis, specific gravity ranges from 1.8 to 3.5 average being 2.26. As such, the soil has little or no organic content and traces of heavy particles. This value indicates soil with relatively low density, often associated with organic content or highly weathered materials. This suggests reduced unit weight, low bearing capacity and increased compressibility. Consequently, such soils are prone to excessive and differential settlement, posing risks to foundation stability (Oba et al., 2024).

**3.3.3 Atterberg Consistency limit of the Soil**

According to a study, a soil with high liquid and plastic limits is widely regarded as poor foundation materials (Sanusi, 2023). A plastic or liquid soil has little or no bearing capacity. The maximum value recommended by the Federal Ministry of Works and Housing (FMWH), 1972 is 20% plasticity index for any given soil sample to be regarded as a good foundation material, hence it shows a good engineering property since the higher the plastic index of a soil, the less the competency of the soil as a foundation material. The tested soil samples are of medium consistency limits indicating low percentage of clay content in the soil. From the analysed samples, the plasticity index ranges from 2.5-11.55% (Table 2).

According to a study, this plasticity index range shows a low to medium plastic soil, silty or clayey (Adamu et al., 2024). Such soils have moderate cohesion, low compressibility and limited swellings potential. For foundations, they are generally stable but may still experience minor moisture-related strength variations.

The results for each consistency limit test are represented (Table 4).

**Table 2: Atterberg Limit of the sampled soil**

| Sample location | Liquid limit (%) | Plastic limit (%) | Plasticity index (%) |
|-----------------|------------------|-------------------|----------------------|
| DH1             | 23               | 18.5              | 4.5                  |
| DH2             | 26.5             | 17                | 9.5                  |
| DH3             | 30.75            | 19.2              | 11.55                |
| DH4             | 41.4             | 30.5              | 10.5                 |
| DH5             | 24               | 20.01             | 4.0                  |
| DH6             | 17               | 14.5              | 2.5                  |

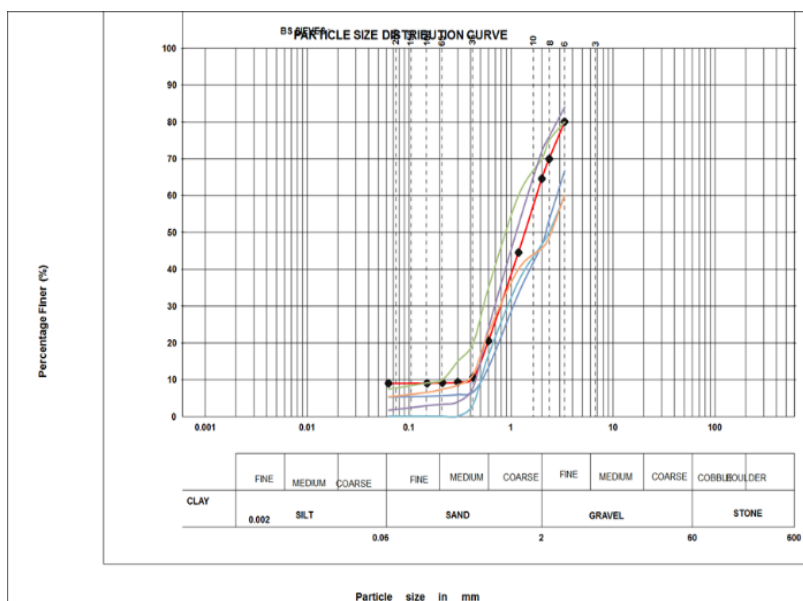
**3.2.4 Grain Size Characteristics of the Soil**

Fine particles are prone to volume change with time, thus if the analysed samples fall within the fine percentage range, there would be lots of questions asked about its competence as a foundation material. From the grading curves the soils can be classified as well graded soil. From the grading curve (Figure 3), the soil particle size ranges from the coarse silt to fine gravel, which satisfies the classification recommended by Federal Ministry of Works and Housing (FMWH) (1972) for a foundation material, hence; the soils can be generally rated as fair to good sub-grade foundation material.

The lower boundary of the soil particle size is in the coarse silt range and the upper boundary belongs to coarse gravel, thus leaving a great part of the soil collected from different sample points in the fine to coarse sand region (Table 5). The soils that are largely made up of fine particle are likely to have poor geotechnical properties as foundation materials than soils that are largely made up of coarse particle (Ilevbare and Edegbai, 2022).

**Table 3: Grain Size Distribution of the sampled soil**

| Sieve size (mm) | Mass of empty sieve (g) | % passing |       |      |      |      |       |
|-----------------|-------------------------|-----------|-------|------|------|------|-------|
|                 |                         | DH1       | DH2   | DH3  | DH4  | DH5  | DH6   |
| 3.35            | 570                     | 80        | 66.7  | 80   | 84   | 60   | 60    |
| 2.36            | 540                     | 70        | 53.37 | 75   | 76   | 50   | 48.6  |
| 2.00            | 520                     | 64.6      | 46.7  | 70   | 72   | 46.7 | 45.71 |
| 1.18            | 490                     | 44.6      | 33.37 | 60   | 52   | 36.7 | 40.01 |
| 0.600           | 480                     | 20.6      | 13.37 | 35   | 24   | 16.7 | 22.9  |
| 0.425           | 420                     | 10.6      | 6.67  | 20   | 8    | 3.4  | 11.44 |
| 0.300           | 410                     | 9.3       | 5.97  | 15   | 4    | 0.1  | 8.58  |
| 0.212           | 400                     | 9.2       | 5.7   | 20   | 3.36 | 0.1  | 7.44  |
| 0.150           | 390                     | 9.1       | 5.5   | 9.15 | 2.96 | 0.1  | 6.58  |
| 0.63            | 400                     | 9.0       | 5.3   | 7.45 | 1.72 | 0.1  | 5.35  |



**Figure 5: Particle Size Distribution Curve**

#### 4. CONCLUSION

The geophysical results revealed three geo-electric sections which comprise of the topsoil, weathered basement and rock head. The topsoil is generally thin (<2.5m) and composed of sandy clay. From the geo-electric section, the rock head is between 3.7m to 10m, and shows no evidence of intensive geologic structure such as a fault which can also aid subsidence in the area. The geotechnical results show that the soil has a relatively low natural moisture content. Since the Plastic Index of the soils within the area are less than 20%, the soil can be adjudged to be low to medium plasticity, hence, the soils are expected to exhibit low to medium swelling potential. The specific gravity shows that the soil has little or no fine particles, thus conforming to the geophysical results for the topsoil layer. The grading curve shows that the soil is well graded and mostly in the sandy region.

The higher the geotechnical parameters of a soil, the lesser the competence of the soil as a foundation material. The Federal Ministry Work and Housing (FMWH), (1972) recommend 50%, 30% and 20% Maximum for the Liquid Limit, Plastic Limit and Plastic Index respectively for a good foundation material. The geotechnical properties of the topsoil are relatively good as most of soil samples taken within the topsoil fall within FMWH, (1972) recommendation. It can however be concluded that the subsoils on or within which engineering structures will be founded within the study area are fairly competent. The deduction from the above is that, the topsoil Formation may be rated as relatively good as a foundation material. The foundation of the proposed civil structure can be hosted by this formation. The uneven nature of this layer has to be considered in the design of the Foundation.

#### RECOMMENDATION

The implication of the H curve from the Geophysical studies is that the intermediate low-resistivity layer is usually compressible and may cause differential settlement or instability under load. Shallow foundations may be unsafe if placed above or within this layer. Therefore, deep foundations extending to the competent third layer or ground improvement techniques are often required to ensure structural stability and adequate load bearing capacity.

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