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Lime addition chemical stabilization of expansive soil at Al- Kawamil city, Sohag region, Egypt

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Abstract. Soil is the fundamental element in the construction process. Soil problems affect the safety of the structures, even so the high quality of the structures and so, bad soil found the structures will affect the lifetime or even destroy the structures built on it. Therefore, the study of soil is an important step in the construction process and the investigation of the most effective characteristics of a special kind of soil (shale soil), i.e. Atterberg limits, swelling pressure, swelling potential and unconfined compression strength, are the most effective soil properties. A big projects will be constructed in new urban extension areas with expansive shale soils, like at Al-Kawamil and new Akhmim shale soils which associated with soil problems, treatment system should be used to ensure the stability of the soil under the structures foundations one of the most effective methods is by adding lime solution to the soil by specific quantities, which affect on the properties of the shale soil by decreasing the swelling and increasing the compressive strength of the treatment soils. Experimenting with the soil added to the lime, it was found that the addition of lime solution 6% improve c j the properties of the soil. The results of the tests showed the high effectiveness of using lime in the treatment of Al-Kawamil soil

Keywords: expansive soil; hydrated lime; unconfined compressive strength; heave; swelling pressure; swelling potential; Egyptian code

1. Introduction

Soil under the foundations of buildings or roads is a major part of transferring loads to the subsoil. Thus, the quality of the soil has a great impact on the type of structure and design (Kharade *et al*. 2014a, b).

Because of the environmental changes of the arid and semi-arid regions, it is a fundamental factor affecting the behavior of swelling soil (Ismaiel 2013). There are several ways to stabilize the soil,

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including mechanical stabilization as replacement of sand or made sand cushions, thermal stabilization, electrical stabilization, and chemical stabilization as lime (Kanawi and Kamel 2013). In the present study, the soil of Al-Kawamil was treated using chemical additives lime. The lime addition to the expansive soil resulted in a chemical reaction causing an improvement of the properties of soil due to the physical, chemical, and mineral changes of the soil (Indiana Dept. of Transportation 2008).

This interaction depends on the mineral composition of the soil fouling, PH and the proportion of lime added to treat the soil moisture content and temperature (Al-Mukhtar *et al.* 2010).

Several studies were conducted on the treated soil. For example, Malhotra and Naval improved the properties of expansive soil with lime in varying percentages. The stabilization of black cotton, called expansive soil, using lime (Modak *et al*. 2012a, b). Hesham used 5% of lime in soil treatment in Al-Kawthar area, Sohag. This decreased plasticity and increased water content (Ismaiel and Badry 2013). Lime was widely used in the 20th century to stabilize soil for structures and roads in Europe to change the properties of soil, decrease plasticity, swell capacity and increase water content (Laguros *et al*. 1956a, b, Lu *et al.*1957a, b, Lambe 1962, Compendium 1979). Al-Mukhtar treated the soil with lime by ≥ 6% on 7 days at a high temperature of 50°C and increased the percentage of unconfined compression (Al-Mukhtar *et al.* 2010). Sea Bell treated the soil with lime and depended on the temperature at which it was treated (Bell 1996). Emarah and Seleem treated the roads serving the wind farms at Zafarana region, Egypt on the Red using lime (7% of the soil weight) and the effect of using seawater instead of the potable water as mixing water for the lime-treated soil and its effect on the swelling behavior (Emarah and Seleem 2017). Lime was added to its seawater to treat the expansive soil (Rajasekaran and Narasimha 1997). In this paper, the Olympus Px51 optical-microscope of natural and treated stabilized soil to Scanning electron microscope samples studies. The tests used for the Egyptian code were carried out and units were used. Chemical stabilization is used by mixing or injection into the soil such as Portland cement, lime, asphalt, calcium chloride, and sodium chloride.

Yasuhara and Chang, 2017 provided four different articles with valuable findings and recommendations on innovative and eco-friendly soil treatment.

Yilmaz *et al.* 2018 provided a treatment method for high plasticity clayey with Portland cement and sodium hexametaphosphate, aluminum sulfate, sodium carbonate, and sodium silicate and applied unconfined compressive strength they concluded that the strength of the soil-cement mixture increased with cement values increased and for adding Chemical components with no significant effect on soil strength and vice versa increase such chemical components decreased the soil strength. Hu *et al.* 2018 studied organic-sandy soils and suggested cement treatment method and concluded that the optimal permutation of these influencing factors is suggested for the reinforcement of organic-sandy soils.

Younis *et al.* 2017 used cotton stalks as feedstock for biochar production to improve the soil characteristics.

Herrier *et al.* 2018, used lime treated of soil and concluded that lime used in embankment protect surfaces of erosion.

Kaur, and Singh, 2012 treated soil by lime and concluded that ability of the lime in stabilizing the soil increasing the optimum moisture contents with increasing % lime and the maximum dry density value decreases with increasing lime %, and increasing confined compressive strength with a certain % lime addition.

Afaf *et al.* 2013, used lime powder in Red Sea road soil and concluded that the water content increased by increasing % lime powder, the compressive strength increase and decrease maximum

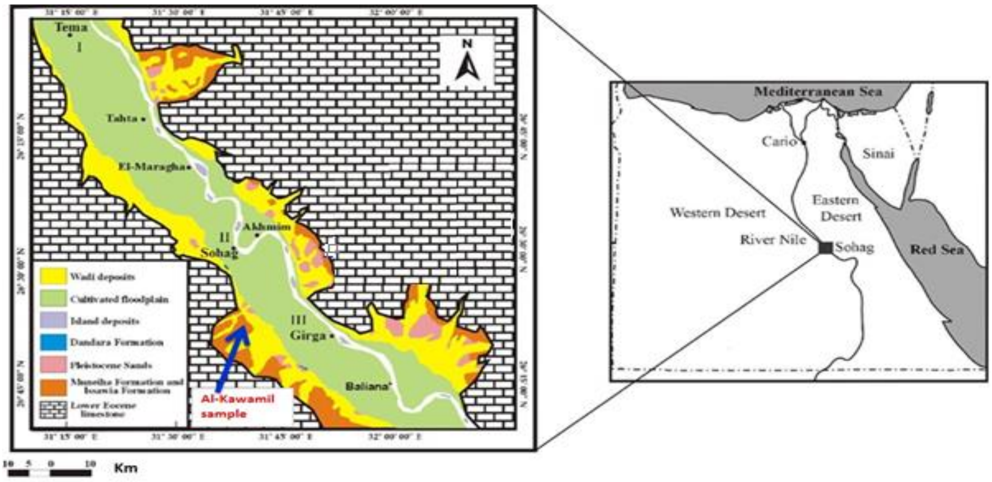

Fig. 1 Geological map of the studied area

dry density, so that treatment of soil cracks will be more effective when using lime powder especially when water leakage in such shale soils.

In this study, the geotechnical investigations were carried out to determine the properties of swelling soil in Al-Kawamil area, Sohag. The study mainly aimed to stabilize the soil using hydrated lime chemical to reduce the swelling of soil for roads and structures.

2. Location and geological properties of the studied area

The study was conducted at Al – Kawamil (New Sohag) lies 12 km to the southwest of the city, to the west of the Nile river.

It lies at latitude of 26˚ 27’ 23.76’’ and a longitude of 31˚ 40’ 58.62’’, where the clay sediments are distributed in the geological map in Fig .1. The case study is the green-colored expansive soil at New Sohag area defined Shale Fig.1.

3. Lime stabilization

Lime is defined as a product of high-temperature when its calcination occurs. Many studies explain how to improve the mechanical and hydraulic properties of the expansive soil after lime addition. Most of them focus on the changes associated with the Atterberg limits and the changes of soil in terms of swelling pressure, swelling potential and shear strength (Al-Mukhtar *et al*. 2012). Lime addition for soil clays provides an abundance of calcium ions ($Ca2^{+}$) and magnesium ions ($Mg2^{+}$). These ions tend to displace other common actions such as sodium (Na^{+}) or potassium (K^{+}), in a process known as action exchange replacement of sodium or potassium ions because calcium significantly reduces the plasticity index of the clay. Lime addition leads to decreased plasticity, decreased swelling of the soil, and increased pH of the soil, resulting in a change in the properties due to the interaction of lime with clay content. The ratio of adding lime (2-8%) of the soil weight

PH reached 12.4, which is the safest value (Chen 1975, Tensar Technical Note 1998). The graph is drawn between the value of the PH and the percentage of lime. The optimal lime content must be determined corresponding to the maximum PH value (Afaf and Hesham 2013, Ahmed Abbas Galal Abd Allah 2012).

4. Treatment methodology

In this study, the proposed treatment was the expansive Pliocene subgrade (expansive shell microfacies). Many parameters (including plasticity, compaction, swelling pressure, swelling potential and unconfined compression strength) were calculated.

5. Materials and methods

5.1 Materials

The experimental part of the study aimed to investigate the effect of lime addition on the soil and the treatment period on Atterbirg limits, confined strength, and microscopic analysis. The samples were collected from Al-Kawamil region. They were milled and removed from 40 sieves and heated at 50°C for 24 hours. Then, lime was added by weight (Eades and Grim 1966). The chemical analysis of lime was completed. Table (1) showed that it was mainly composed of the oxides of calcium, aluminium, iron, and silica. Hydrated lime is calcium hydroxide, Ca(OH)2. It is produced by reacting quicklime (CaO) with sufficient water to form a white powder.

High calcium quicklime + Water Hydrated lime + Heat CaO + H2OCa(OH)2+ Heat Hydrated lime that is used in most of the lime is sometimes used in lime stabilization applications such as dehydrated dolomitic lime, monohydrated dolomitic lime, and dolomitic quicklime (Tensar Technical Note 1998, Hassan Abdo Mohamed Abdel-Kader 2017).

5.2 Methods

The stabilization process takes several steps. First, chemical analysis (XRD, X-ray fluorescence) of both the sample and the hydrated lime was carried out, where the mineralogical analysis was carried out by X-ray for soil and XRF for lime. Second, the sample was milled and sieved in 40, dried at 50°C for 24 hours, and lime was added to it by 6% of weight; it is the suitable percentage according to PH test. Third, a compacted sample of the mixture at maximum dry density and optimum water content was prepared. For this test, unconfined compression (AASHTO 2010). Swelling test and free swelling were calculated (Egyptian code 2001). Finally, the structural changes of the soil were studied using the electron microscope before and after the treatment.

Table 1 Chemical analysis of lime

Chemical Elements	Mg	Al	Si	CI	K	Ta	Ti	Mn	Fe	P	Na	L.O. I
Percent (%)	1.9	.1	1.1	---	.27	62.6	0.01	---	1.4	0.01	.55	32

*LOI: Los of ignition

Table 2 XRD analysis of studied samples

Minerals	Gypsum	Total Clay	Quartz	Plagioclase	K - Feldspar	Calcite
Wt.%	2.6	51.4	20.3	20.8	0	4.9

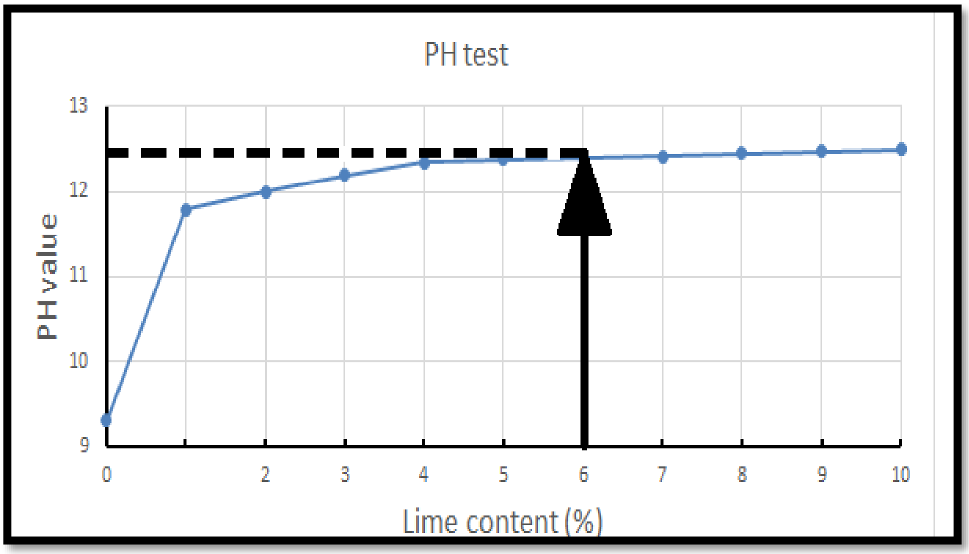

Fig. 2 Relationship between pH values and Lime content (%) to determine the optimum lime content of an expansive shell

Table 3 Values of pH and lime contents of lime

Lime Content%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
PH value	9.1	11.79	12	12.2	12.35	12.38	12.4	12.42	12.45	12.47	12.5

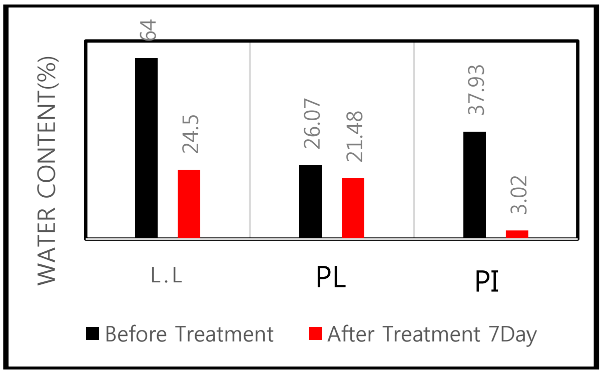

Fig. 3 Atterbirg Limits before and after treatment

Where:
L.L: Liquid Limit
PL: Plastic Limit
PI: Plasticity Index

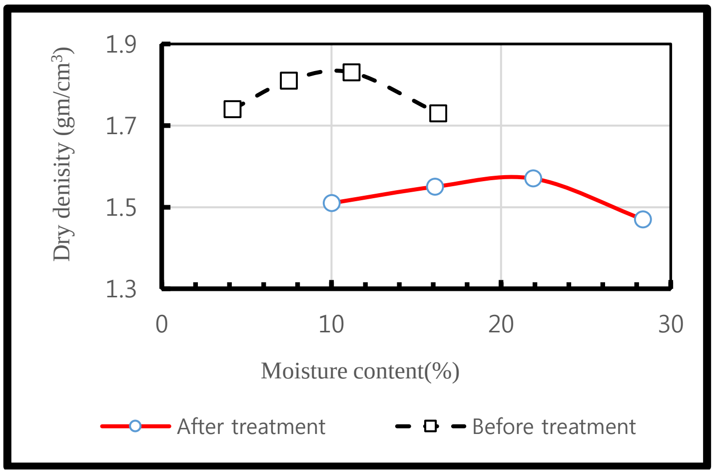

Fig.4 Compaction curves Before and After Treatment

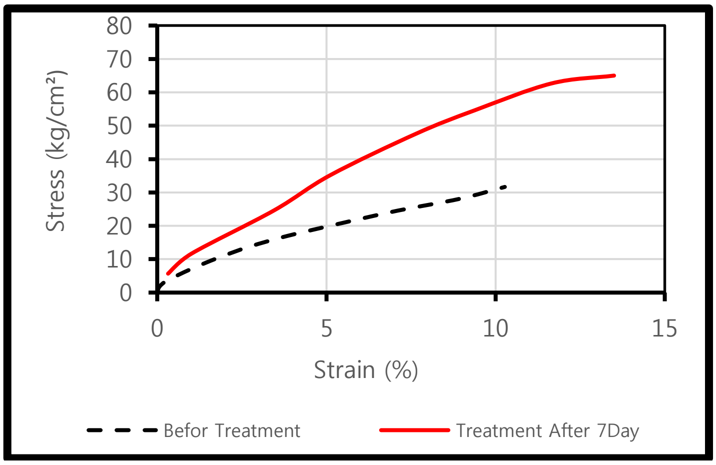

Fig. 5 Unconfined compression strength curves Before and After Treatment 7 days

6. Results

6.1 Results of mineralogical analysis and PH value

The mineralogical analysis results showed that the expansive soil is a basic constituent of clay, calcite, and quartz, as shown in table 2. The best ratio of pH obtained for soil treatment was 6% of lime ratio. Fig. 2 and Table 3 show the relationship between pH values and lime content.

6.2 Results of geotechnical tests

6.2.1 Atterberg limits

Fig.3 shows the values of Atterberg limits of the soil before and after the lime treatment, including (liquid limit, plastic limit and plasticity index) Fig. 3. The addition of lime reduced both L.I, P.L and PI from 64 to 24.5, from 26.07to 21.48, and from 37.93 to 3.02, respectively.

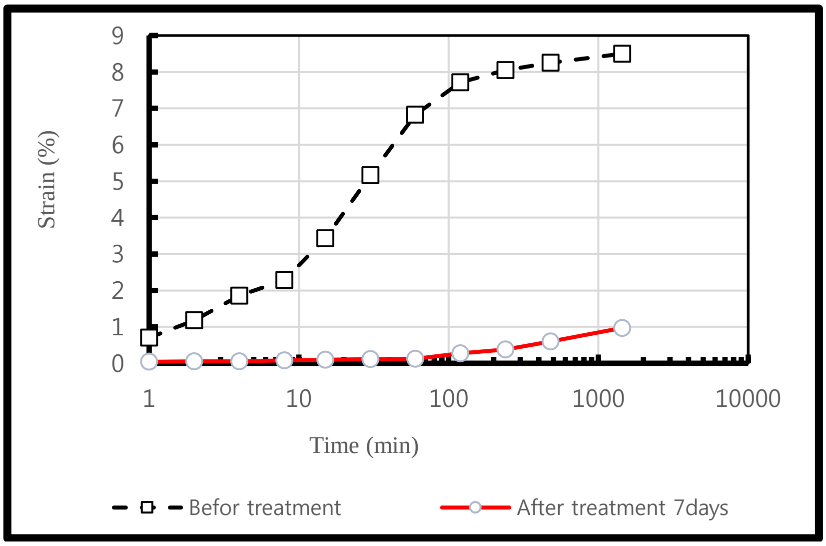

Fig. 6 Swelling Potential curves Before and After Treatment 7 days

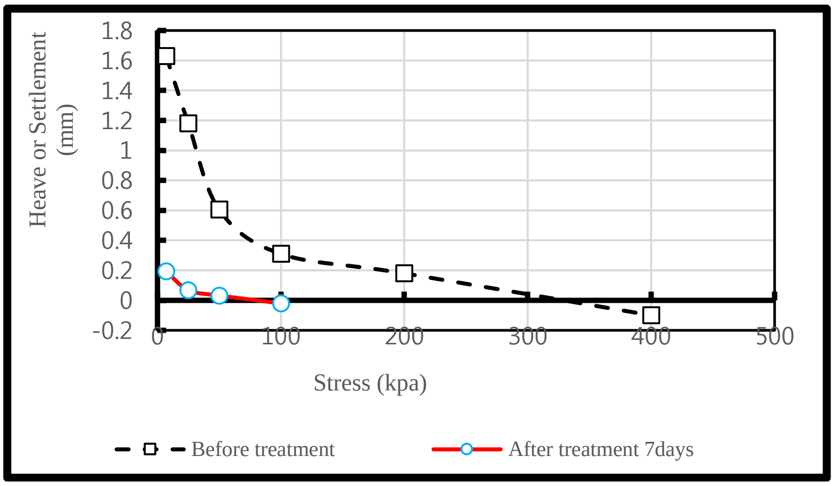

Fig. 7 Swelling Pressure curves before and after Treatment 7 days

6.3 Compaction test results

Results showed that the maximum dry density of soil before treatment increased from 1.83 to 1.9 and the optimum content water increased from 8.71 to 11.2. After treatment, the maximum dry density was 1.57 and the optimum content water was 21.9, as shown in Fig. 4. After the addition of the lime, the compacting of the sample in proctor reduced the dry density.

6.4 Unconfined compression test results

Fig. 5 shows the stress and strain curve of the unconfined compression before and after treatment with lime and the results showed an increase in the compression strength of the sample added to lime after7 days of the test from 31.65 without Lime to 65 kg/cm^2 with Lime.

Fig. 8a Scanning electron micrograph of natural soil

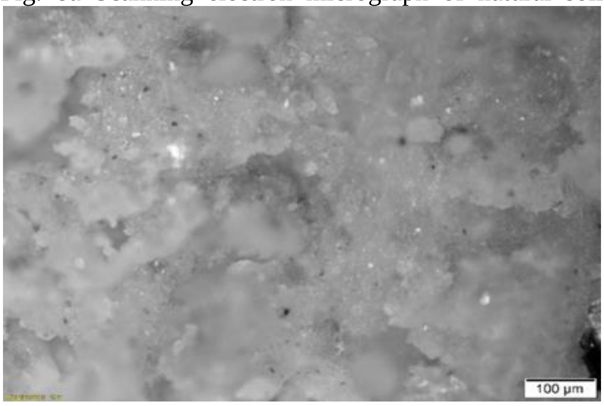

Fig. 8b Scanning electron micrograph of treatment lime 6% after 7days

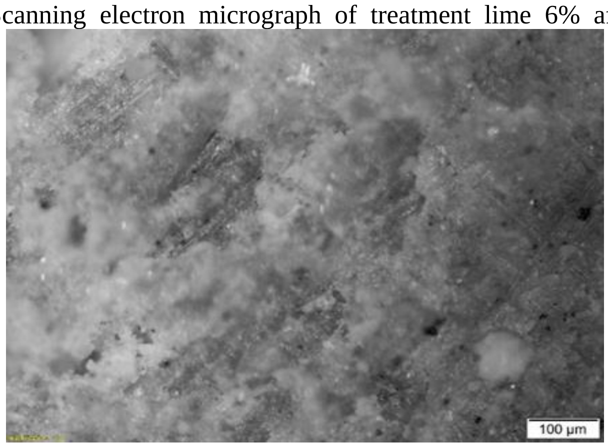

Fig. 8c Scanning electron micrograph of treatment lime 6% after 28 days

6.5 Swelling test results

6.5.1 Swelling potential

Fig. 6 shows the results of stress and time curve of the swelling potential before and after the treatment with lime. The results showed a decrease in the swelling sample with time. After 7 days of the test, the swelling potential became from 8.5% without lime to 0.97% with lime.

6.5.2 Swelling pressure

Fig. 7 shows the results of settlement (mm) and stress (KPa) curve of the swelling pressure before and after treatment with lime. The results showed a change in the vertical displacement of the lime-treated clay after the load is reduced heave with increased stress levels. Before treatment, the swelling pressure was 335 Kpa without lime and after (7) days of treatment it became 75 Kpa with lime.

6.6 Microstructural changes

Changes in the microscopic structure of the sample play a significant role in showing the improvement of the geotechnical properties before and after lime addition (Ismaiel 2006). Fig. 8a shows a microscopic picture of the soil in its natural state showing the arrangement of clay particles, silt and fine sand. Fig. 8b shows a microscopic image of the soil stability by 6% after 7 days of adding lime. The picture shows the reaction of lime with clay to the formation of particles of different sizes resulting in increased soil porosity. Fig. 8c shows a micrograph of the soil stability after 28 days of adding lime. The micrograph illustrates the aggregated arrangements due to flocculation and a formation of hydration reaction products coating and cementing the particles, that leads to reducing the porosity of the particles system.

7. Conclusions

The objective of this study was to stabilize shale soils to improve the geotechnical properties of these soils regions. The lime was used as solution to stabilize the soil properties, like plasticity, Atterberg limits, swelling potential, swelling pressure, and unconfined compression. The samples were prepared by adding 6% of the lime by weight of the soil and the following conclusions were drawn:

- The hydrated lime added to clay led to low plasticity index from 37.93% to 3.02%.
- The addition of lime led to increasing the optimum moisture content according to the Proctor test and reducing the maximum dry density as the water content increased from 11.2 to 21.9 % and the maximum dry density reduced from 1.9 to 1.57 gm/cm3.
- The unconfined pressure strength after 7days of treatment increased from 31.65 to 65 kg/cm2.
- The swelling pressure with increased stress levels decreased from 335 to 75 KPa.
- After 7 days of treatment, the swelling potential decreased from 8.15% to 0.97%.

Scanning electron microscope studies of the stabilized soil indicated that the microstructures of the tested mudstone microfacies changed due to lime-addition. The Olympus Px51 optical-microscope of natural and treated stabilized soils indicated the formation of new cementations compounds and mineral crystals as a pozzolanic reaction product through the long-term treatment.

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