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SOME ASPECTS OF THE ANALYSIS AND DESIGN OF AN EMBEDDED PILE WALL

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Summary

This paper presents some aspects of the design and analysis of an embedded pile wall.The wall is represented by a row of reinforced concrete piles with 60cm diameter and 13m length. The embedment depth is 8.5m.The calculations are carried out using different methods: conventional methods which consist in the limit equilibrium analysis and the calculations are normally performed by the simple earth pressure formula.; beam spring analysis performed through program ETABS; full numerical analysis (FEM) performed through program PLAXIS. The results of the above methods have been compared with each other. The differences between the results are present because each method consider different factors in the calculation.

Key words

Pile, embedded wall, numerical analysis, ETABS, earth pressure, PLAXIS,

1. THEORITICAL SUMMARY OF THE DIFFERENT USED METHODS

1.1. Limit equilibrium analysis

Limit equilibrium analysis are normally performed by the simple earth pressure formula. Figure 1 shows the diagram of pressure distribution around a pile wall. The water table is at a depth L_1 below the top of the wall. The intesity of the net pressures σ_1' and σ_2' are given by the eqs (1) and (2)

$$\sigma_1' = \gamma L_1 K_a \quad (1)$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2) K_a \quad (2)$$

where K_a = Rankine active earth pressures coefficent $= \tan^2(45 - \varphi'/2)$, Υ = unit weight of soil above the water table

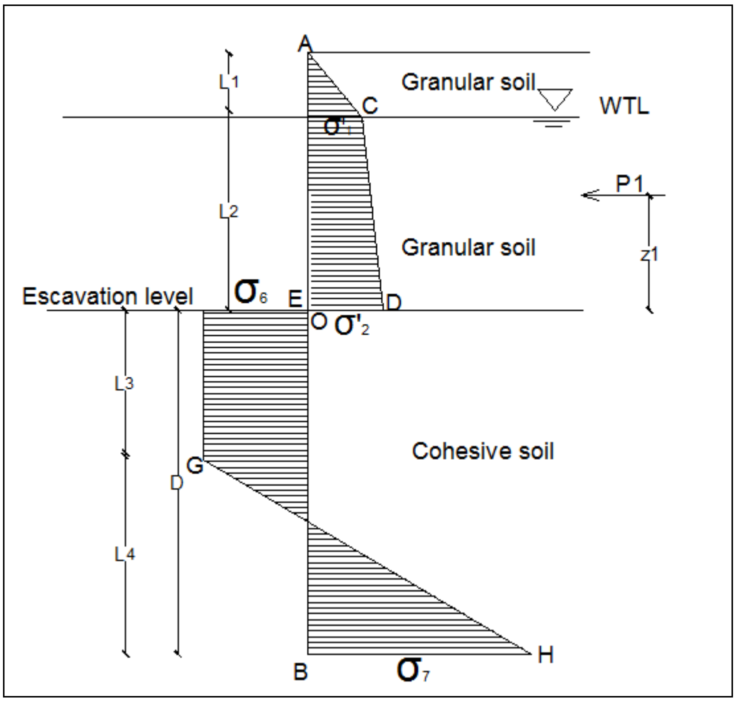

Figure 1 Diagram for pressure distribution

At any depth greater than L_1+L_2 for $\varphi=0$, the Rankine active earth pressure coefficient K_a = 1. Similarly, for $\varphi=0$, the Rankine passive earth pressure coeffcient (K_p)=1. Thus above the point of rotation (point O in the Figure 1) the active pressure from right to left is

$$\sigma_a = [\gamma L_1 + \gamma' L_2 + \gamma_{sat}(z - L_1 - L_2)] - 2c \quad (3)$$

Similarly, the passive pressure from left to the right may be expressed as

$$\sigma_p = \gamma_{sat}(z - L_1 - L_2)] + 2c \quad (4)$$

Thus the net pressure is

$$\sigma_6 = \sigma_p - \sigma_a = 4c - (\gamma L_1 + \gamma' L_2) \quad (5)$$

At the bottom of the pile the net pressure is

$$\sigma_7 = \sigma_p - \sigma_a = 4c + (\gamma L_1 + \gamma' L_2) \quad (6)$$

For the equilibrium analysis $\Sigma F_H = 0$. Now, taking the moment about point B ($\Sigma M_B = 0$) and after solving the equation (7) we obtain the theoretical depth of penetration D.

$$D^2\left[4C-(\gamma_1\cdot L_1+\gamma'_2\cdot L_2)\right]-2DP_1-\frac{P_1(P_1+12\cdot C\cdot \bar{z}_1)}{(\gamma_1\cdot L_1+\gamma'_2\cdot L_2)+2C}=0 \quad (7)$$

1.2. Finite Element Method

1.2.1. Beam spring approaches

Beam-spring calculation methods cover a variety of models, ranging from simple uncoupled springs with constant stiffness to semi-empirically based spring stiffness with maximum capacities superimposed. The most suitable engineering method for calculation the static interaction between pile and soil is the Winkler model in which the soil reaction to pile movement is represented by independed springs distributed along the pile (Figure 2).

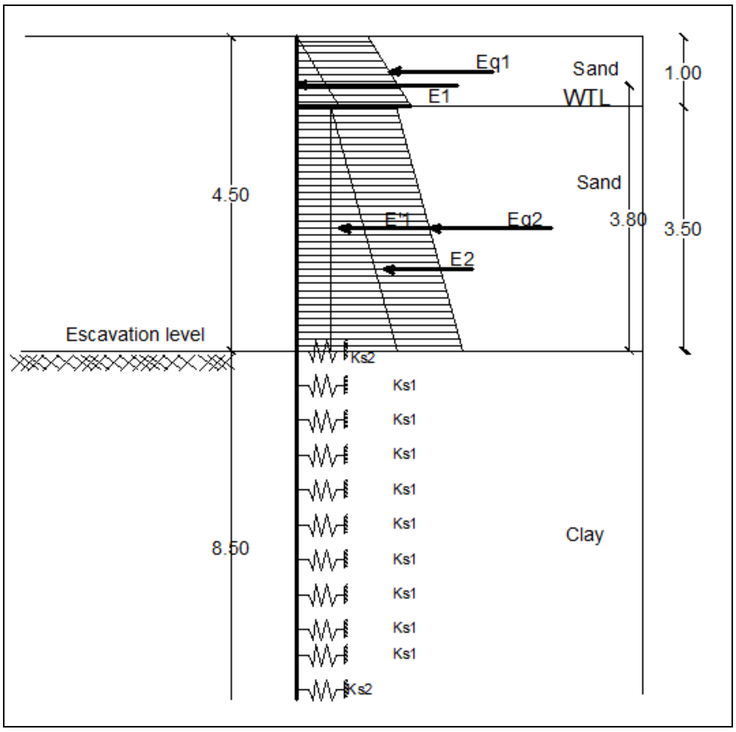

Figure 2 Soil modeled as springs

Assumption of the model is that the deflection (Y) of the soil medium at any point on the soil-structure boundary is directly proportional to the stress (P) applied at that point and independent of stresses applied at other locations. The force-displacement relationship can be directly related to the stress-strain relationship and be expressed by P=K.Y. The response of the surrounding soil is represented by systems of springs characterised with constant (K). The existing analytical formulation used in investigation of laterally loaded piles suggests that the modulus of subgrade reaction (K) for a given soil is independent of width. The stiffness can be derived theoretically (Vesic, eq (8)) or be determined experimentally using p-y curves.

$$k_s=\frac{0.65}{D}\sqrt[12]{\frac{E_s\cdot D^4}{E_P I_P}}\cdot\frac{E_s}{1-\mu_S^2} \quad (8)$$

In this model the finite element analysis is done by using ETABS. The modulus k_s is taken as constant.

1.2.2. Full numerical analysis

A two-dimensional finite element programme PLAXIS 2D has been used to model the pile. (Figure 3).

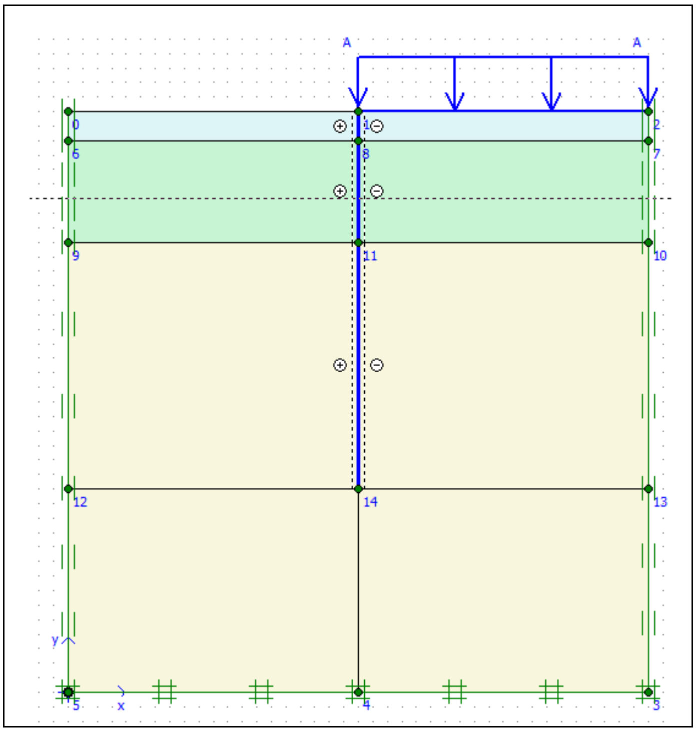

Figure 3 2D Finite element model in Plaxis

Plane strain as two-dimensional modeling: In PLAXIS 2D, selection of plane strain condition results in a two-dimensional finite element model with only two translational degrees of freedom per node. The 15- noded triangle provides a fourth order interpolation for displacements and the numerical integration involves twelve Gauss points. Beam elements as single pile: Plates elements in the two-dimensional finite element model are composed of beams elements (line elements) with three degrees of freedom per node: two translational degree of freedoms (Ux, Uy) and one rotational degree of freedom (rotation in the x-y plane and about the out-of plane axis, fz).When using a 15-noded soil elements, 5-noded beam elements are used. Therefore, this allows for beam's deflection due to shearing as well as bending. Beam elements can become plastic if a prescribed maximum bending moment or maximum axial force is reached. Bending moment and axial forces are evaluated from the stresses at the stress points.

Mohr-Coulumb as soil's model: Mohr-Coulumb's model (Figure 4) can be considered as a first order approximation of real soil behavior. This elastic perfectly-plastic model requires 5 basic input paramaters, namely a Young's Modulus, E, a Poisson's ratio, n, a cohesion, c,a friction angle, f and a dilantacy angle, y. This is a well-known and a basic soil model.

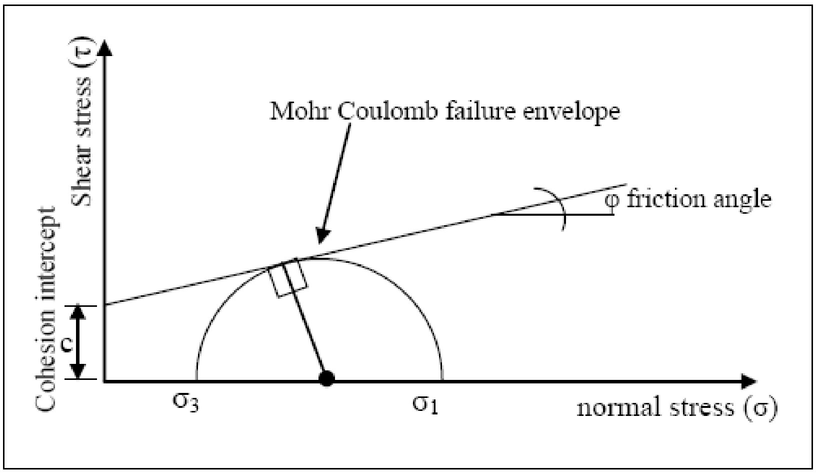

Figure 4 Mohr Coulomb model

2. RESULTS OF USED METHODS

2.1 Geotechnical properties of the soil

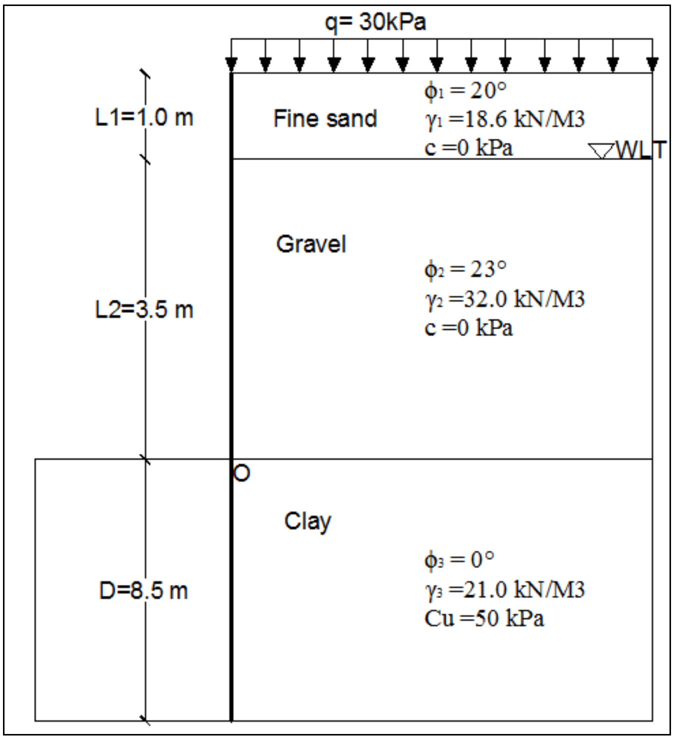

Figure 4 Geotechnical properties

2.2 Classic earth pressure calculations

The net pressure at the point of rotation is calculated using eq (5)

$\sigma_6 = \sigma_p - \sigma_a = 4c - q - (\gamma L_1 + \gamma' L_2)$ = 49.63 kN/m^2 / pile

At the bottom of the pile the net pressure is calculated using eq (6)

$\sigma_7 = \sigma_p - \sigma_a = 4c + (\gamma L_1 + \gamma' L_2 + q)$ = 230.37 kN/m^2 / pile

For the equilibrium analysis $\Sigma F_H = 0$.

$$P_1 - \sigma_6 \cdot D + \frac{1}{2} \cdot L_4 \cdot [\sigma_6 + \sigma_7] = 0 \tag{9}$$

The moment about point B ($\Sigma M_B = 0$) is

$$P_1(D + z_1) - \sigma_6 \cdot \frac{D^2}{2} + \frac{1}{2} \cdot L_4 \cdot (8c) \cdot \frac{L_4}{3} = 0 \tag{10}$$

After solving the system of equations (9), (10) we obtain the theoretical depth of penetration D.

$D_{theoretical} = 5.45$ m

D $=5.45 \cdot 1.4=7.63$ m

2.3 Finite element methods calculations

2.3.1 Beam spring analysis using ETABS

The stiffness is calculated using eq (8). The modulus k_s is taken constant and for the pile dimensions it is

$$K_{s2} = K_s \cdot d \cdot l / 2 = 1701 \text{ kN/m} \tag{11}$$

$$K_{s1} = K_s \cdot d \cdot l = 3402 \text{ kN/m} \tag{12}$$

The results after the finite elements analysis are presented in Figure 5:

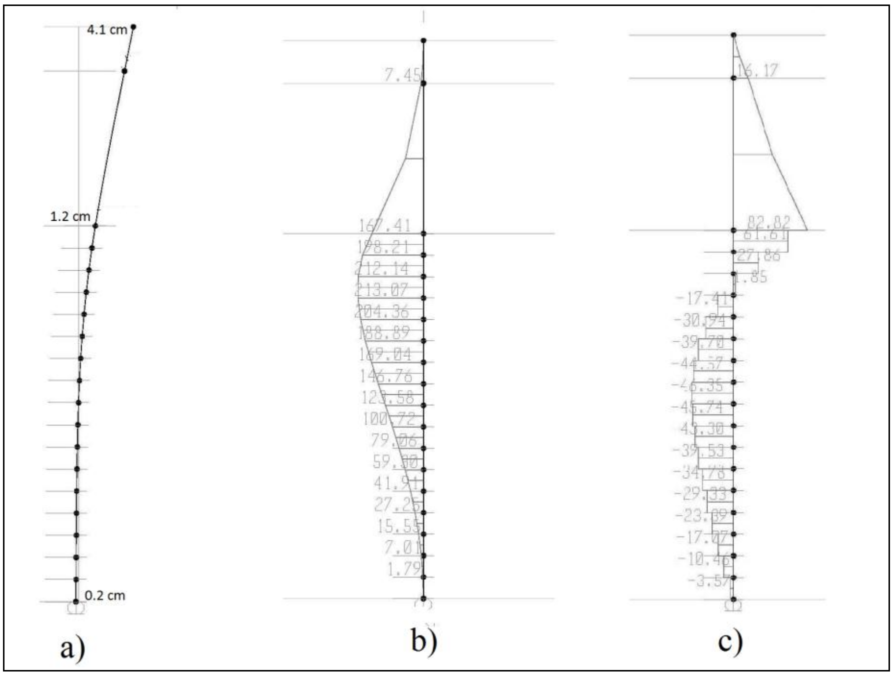

Figure 5 Results of ETABS analysis.: a)horizontal displacements umax=4.2cm b) bending moment Mmax=213.07kNm c) shear force Qmax=82.82kN

2.3.2 Full numerical analysis using PLAXIS 2D

The deformed mesh after the calculations is shows in Figure 6:

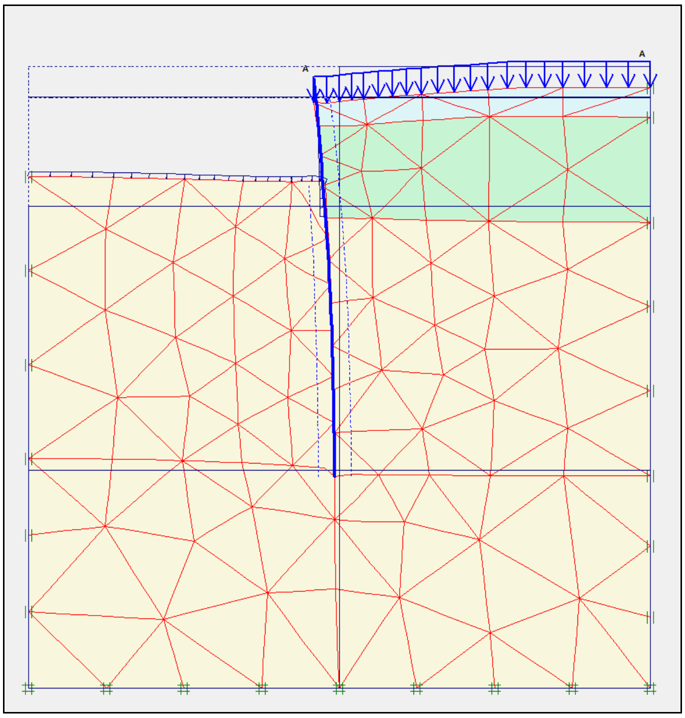

Figure 6 Deformed mesh

The internal forces are presented in Figure 7:

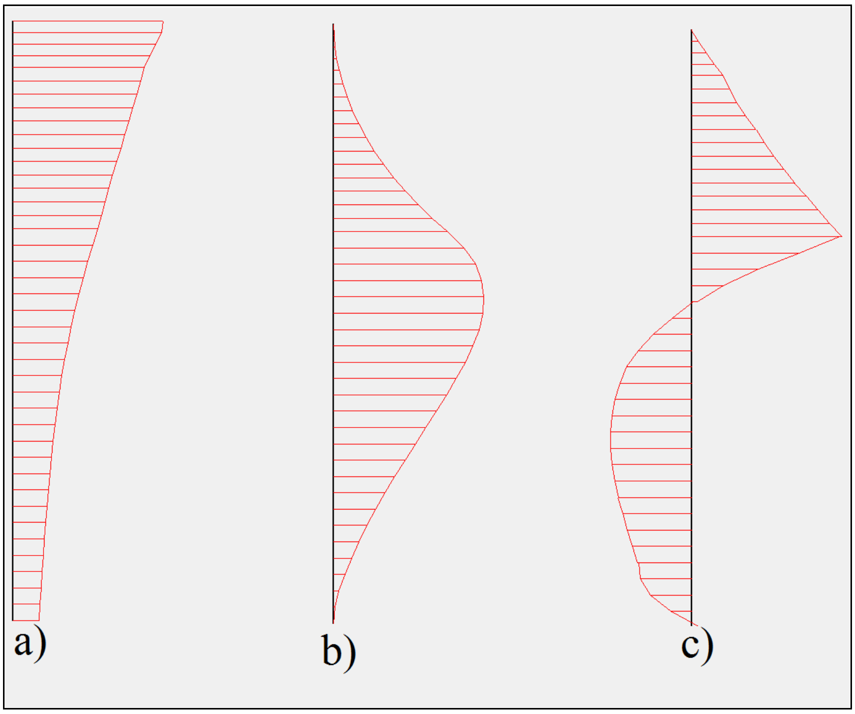

Figure 7 Results of PLAXIS analysis.: a)horizontal displacements umax=4.1cm b) bending moment Mmax=212.7kNm c) shear force Qmax=77.62 kN

3. DISCUSSIONS ABOUT THE RESULTS AND CONCLUSIONS

3.1 Comparisons of the results

In the table below are the results from both methods:

Table 1 Results from both methods

Internal forces	Soil modeled with springs	Plaxis
Mmax (KN*m)	213.07	212.7
Qmax (KN)	82.82	77.62
Δ (cm)	4.1 1.2 0.2	4.1 2.3 0.7

In the figure 8 are presented the comparisons of the results from both methods:

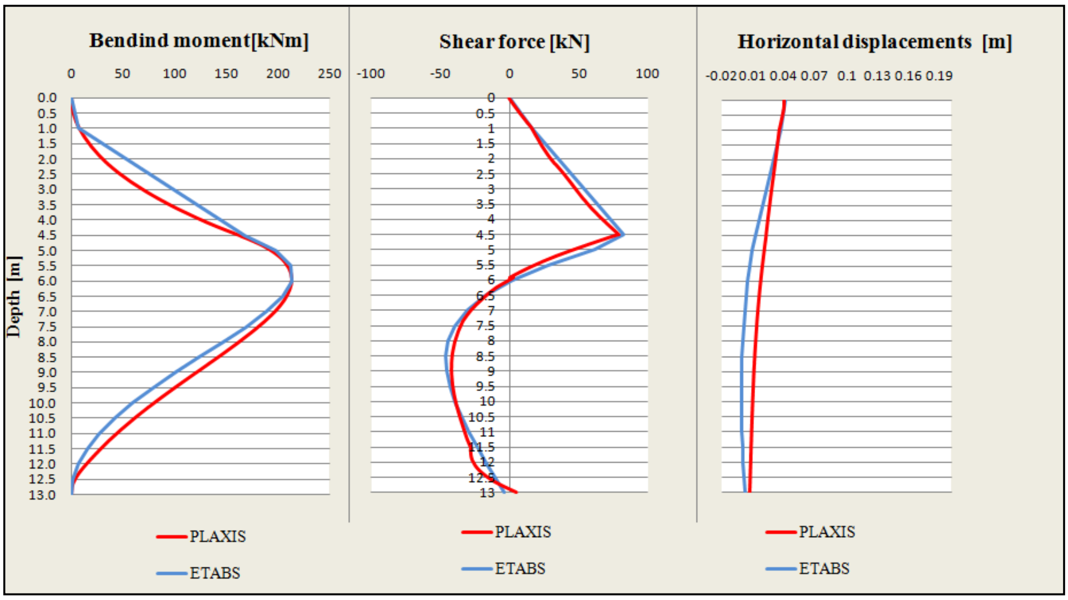

Figure 6 Comparisons of the results from both methods

3.2 Conclusions

We see that internal forces are almost the same from the two models. The model in which the soil is modeled with springs uses a lower number of parameters and is simpler to perform. Winkler formulation are well accepted because: (1) their predictions are in good agreement with results from more rigorous solutions; (2) they can easily incorporate variation of soil properties with depth and with radial distance from the pile; and (3) they required smaller computation effort than finite and boundary element procedures.Finite-element analysis offers and excellent alternative to model single-pile under lateral loading to study the pile-soil interaction. Since in a two dimensional environment, the single pile is modeled as an infinitely long wall, the shear flows of soil around the pile tend to be neglected, hence underestimating the maximum moment acting along the pile. Plaxis gives more accurate results, so we conclude that displacements from plaxis are more exact.

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