HARMONIZATION OF DESIGN PROCEDURES FOR CONCRETE PAVEMENTS AND INDUSTRIAL FLOOR SLABS IN THE CONTEXT OF EN 206, EC 2 AND NATIONAL REGULATIONS

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Concrete pavement structures in Serbia and throughout the Western Balkans are still designed according to standards published more than 30 years ago, relying on material models derived from PBAB 87. Industrial floor slabs, although structurally almost identical to concrete pavements, are often designed according to foreign guidelines, using material properties determined in accordance with EN 206 and EC 2. Modern national regulation, including the Regulation on Technical Requirements for Concrete, SRPS EN 206:2021, SRPS U.M1.206:2023, and EC 2, requires a unified approach to defining concrete properties for all concrete structures. As a result, a significant discrepancy arises: structures exhibiting the same mechanical behavior are designed using different material models, with different values of tensile and flexural strength, modulus of elasticity, and compressive strength. This paper provides an overview of current design practice for concrete pavements and industrial floor slabs, with special emphasis on manipulation–traffic slabs used on industrial platforms. Concrete properties according to PBAB 87 / SRPS U.E3.020 are compared with those defined in EN 206 / EC 2, accompanied by a discussion on how this choice affects structural design. Since the second generation of EC 2 does not cover slabs on ground, the need to harmonize national road engineering standards with EN 206 is emphasized, as well as the need for the third generation of Eurocodes to introduce specific provisions for concrete pavements and industrial slabs.

Keywords: Concrete pavement, industrial floor slab, EN 206, Eurocode 2, flexural tensile strength, pavement design

1. INTRODUCTION

Concrete slabs-on-ground represent a broad group of engineering structures that include road pavement structures, concrete slabs of airport surfaces, as well as industrial floor slabs and manipulation–traffic slabs within logistics, transshipment, and industrial complexes. Whether they are traffic-bearing surfaces exposed to heavy axle loads or industrial platforms intended for truck manoeuvring, forklift operation, and storage of goods, the essential mechanical behaviour of these structures is the same: a cast concrete slab resting on a deformable subgrade and subjected to concentrated, cyclic, and dynamic wheel loads, accompanied by additional effects of temperature gradients, shrinkage, and restrained movements due to friction at the slab–subgrade interface.

Despite the clearly expressed structural similarity, design practice in Serbia and the region has evolved in two separate directions. Concrete pavement structures are still designed according to road engineering standards SRPS U.C4.014 and SRPS U.E3.020, based on the material models originating from PBAB 87. In contrast, industrial floor slabs are most commonly designed according to foreign guidelines where concrete properties are determined in accordance with standards EN 206 and EC2. As a consequence, for structures exhibiting the same mechanical behaviour, different systems of values for tensile strength, flexural strength (modulus of rupture), and modulus of elasticity are often used, resulting in different design outcomes and inconsistencies in engineering practice.

Modern national regulation further emphasises this discrepancy. The Regulation on Technical Requirements for Concrete, together with SRPS EN 206:2021, SRPS U.M1.206:2023, and SRPS EN 13670, prescribes the mandatory application of unified criteria for defining concrete properties and controlling its quality. Eurocode 2 also represents a mandatory basis for the design of all concrete structures, including those exposed to corrosion, frost, chlorides, and abrasion. This indirectly imposes the requirement that both concrete pavements and industrial slabs be designed using the same system of material parameters.

The aim of this paper is to:

- present the existing design practices for concrete pavement structures and industrial floor slabs in domestic and international contexts;
- compare the material models according to PBAB 87 and EN 206/EC 2 used in the design of slabs-on-ground;
- analyse the influence of differences in concrete properties on design results;
- consider the normative implications and the need for harmonizing national standards;
- point out that the 2nd generation of EC2 does not cover slabs-on-ground and propose potentials for development of standardization in this field.

2. EXISTING DESIGN PRACTICES FOR CONCRETE SLABS-ON-GROUND

Concrete slabs-on-ground used in traffic and industrial surfaces are designed based on the stress–strain behaviour of concrete supported by a subgrade defined through the subgrade reaction modulus “k”. Regardless of whether the structure is a pavement slab or an industrial floor, the key mathematical–physical model originates from Westergaard’s theory of an elastic plate on a semi-elastic foundation. However, road engineering practice and industrial practice have developed in different directions and today rely on different sets of standards and material models. The following sections present the actual state of design methodologies, insofar as they are based on SRPS standards and international guidelines such as TR34, ACI 360, and PCA.

2.1 CONCRETE PAVEMENT STRUCTURES ACCORDING TO SRPS U.C4.014 AND SRPS U.E3.020

In Serbia, concrete pavement structures are designed according to the standards U.C4.014 and U.E3.020, which are based on the classical Westergaard theory of a plate on an elastic foundation. Its fundamental assumptions are:

- concrete is idealized as a homogeneous, isotropic, and linear-elastic body of constant thickness;
- the subgrade provides a vertical reaction proportional to the deflection, whereby the reaction per unit area is given by $q = k \cdot w$, where q is the subgrade reaction pressure [kN/m²], k is the modulus of subgrade reaction [kN/m³], and w is the vertical deflection of the slab;

- the subgrade reaction modulus k is treated as a constant (Winkler idealization);
- the load is transferred uniformly over a circular (in the more recent version elliptical or square) contact area when the load acts inside the slab or at a corner, and over a semicircular (semi-elliptical) contact area when the load acts at the slab edge.

In accordance with the classical Westergaard approach, the standards define three characteristic load positions:

- interior loading – wheel load "sufficiently far from the edges" (distance ≥ *l* + *a*);
- edge loading – load position on the slab edge, sufficiently far from the corner (≥ *l* – *a*);
- corner loading – point of application in the corner, at a distance ≈ *a* from both edges.

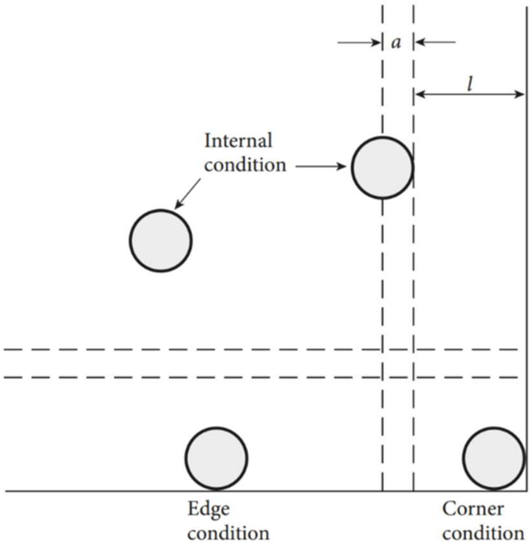

Figure 1. Characteristic load positions

Using Westergaard's method, the following stresses are determined:

- σ_i – interior flexural stresses;
- σ_e – edge flexural stresses;
- σ_c – corner flexural stresses.

These expressions explicitly originate from Westergaard's differential equations for plates on a Winkler foundation and represent the basis of the methodology for designing concrete pavement structures.

The material properties of concrete in these standards are based on the PBAB 87 concrete classes, which include higher values of modulus of elasticity and flexural strength compared to the values defined by EN 206 and Eurocode 2.

2.2 INDUSTRIAL FLOOR SLABS ACCORDING TO TR34, ACI 360 AND PCA

For industrial floor slabs, international methodologies are applied, among which TR34 (Concrete Society), ACI 360R-10, and PCA methods for slabs-on-ground are the most prominent. These guidelines also originate from Westergaard's theory but introduce the modern concept of limit state design (ULS and SLS), as well as a more detailed treatment of contact stresses, storage loads, and load transfer across joints.

The basic elements of the TR34 approach include:

- design of ultimate limit states (ULS) for bending, shear forces, and corner bearing (Meyerhof and Hetenyi);
- serviceability limit states (SLS) covering stress and deformation limitations (Westergaard);
- defining contact areas and pressures depending on the type of industrial vehicle (VNA forklifts, heavy forklifts, low-platform transporters);
- stress calculation for wheel passage across construction, contraction, and expansion joints;
- analysis of the influence of storage loads (rack columns, pallets, containers).

The subgrade reaction modulus in TR34 is determined based on plate load testing or on geotechnical parameters/moduli (Evd, Ed, Ms, E, etc.), with corrections depending on load width and subgrade layering. Fatigue is treated analogously to road engineering methods, through reduction of allowable stresses depending on the number of cycles, without the use of advanced damage models.

Industrial floor slabs are designed using concrete properties defined according to EN 206 and EC 2, including mean and characteristic tensile strength, flexural strength, and modulus of elasticity.

ACI 360R-10 defines industrial floor slabs as slabs on an elastic foundation, with emphasis on selecting the slab type (plain concrete slab, jointed slab, slab with dowels, slab reinforced for crack control). Unlike TR34, the ACI methodology does not introduce limit state design but uses the allowable stress concept based on Westergaard stress formulas, PCA recommendations, and empirical coefficients. It focuses on:

- determining the minimum slab thickness;
- controlling the width and layout of construction and contraction joints;
- selecting reinforcement for crack control;
- load transfer across joints (dowels).

The ACI 360 approach is more conservative regarding joint width but defines contact stresses and wheel crossing over joints less rigorously compared to TR34.

The Portland Cement Association's (PCA) method represent the oldest classical approach for designing floor slabs and concrete pavement slabs, based exclusively on Westergaard's theory. PCA design provides the minimum slab thickness based on:

- edge, interior, and corner stresses;
- subgrade reaction modulus *k*;
- fatigue calculation through reduction of allowable stresses.

Unlike TR34, PCA does not introduce limit state design nor contact models for modern industrial vehicles, but remains within the domain of classical elastic analysis. In practice, it is still used as a reference for minimum slab thicknesses in the USA and Canada.

2.3 COMPARISON OF DESIGN APPROACHES FOR CONCRETE PAVEMENT STRUCTURES AND INDUSTRIAL FLOOR SLABS

Although the design systems for concrete pavement structures and industrial floor slabs have evolved within different standards and technical guidelines, both approaches are based on the same mechanical foundation—the bending behaviour of an elastic concrete slab supported by a subgrade defined by the subgrade reaction coefficient *k*. The load positions considered in the analysis (interior, edge, and corner loading) and the basic stress expressions derived from Westergaard's theory are common to both methodologies. The differences arise from the following aspects:

- material models: pavement design standards apply values from the PBAB 87 system, whereas industrial floor slab design uses concrete properties according to EN 206 and EC 2;
- types of loading: industrial floor slabs are subjected to additional point and storage loads (forklifts, rack column loads, container units), while pavement structures are predominantly exposed to heavy traffic and environmental effects;
- limit state design: industrial methodologies implement ultimate limit states (ULS) and serviceability limit states (SLS), pavement structures in domestic standards are formally based on limit state theory; however, their practical design is governed primarily by serviceability limit state criteria, where flexural tensile strength is treated as a limiting stress value.

These differences are crucial for understanding inconsistencies in the selection of material models and represent the basis for the analysis presented in the next chapter.

3. MATERIAL MODELS: PBAB VS. EN 206 / EUROCODE 2

The design of concrete slabs-on-ground directly depends on the flexural tensile stress capacity of the concrete slab, the modulus of elasticity of concrete, and the way characteristic and design material parameters are defined. In domestic practice, the standards for designing concrete pavement structures are based on the values from PBAB 87, whereas industrial floor slabs predominantly use values determined according to EN 206 and EC 2. This difference in the selection of material models leads to a inconsistency in the design of structures that are mechanically and functionally similar.

3.1 PROPERTIES OF CONCRETE ACCORDING TO PBAB 87 / SRPS U.E3.020

The PBAB 87 / SRPS U.E3.020 methodology defines concrete grades (from MB 10 to MB 60) through nominal compressive strength, with specified values of modulus of elasticity, tensile strength under axial loading, and flexural tensile stress values obtained empirically:

$$f_{bzm} = 0.25 \cdot \sqrt[3]{f_{bk}^{\,2}} \quad (1)$$

where:

f_{bzm} –mean value of concrete tensile strength under axial loading

f_b – design compressive strength of concrete (taken from Table 15 of PBAB 87)

MB – concrete grade, from which the nominal compressive strength of concrete (f^{bk}) in MPa is derived, based on the characteristic cube strength at an age greater than 28 days.

$$E_b = 9.25 \cdot \sqrt[3]{f_{bk} + 10} \quad (2)$$

Eb – mean value of the modulus of elasticity of concrete

f_{zs} – flexural tensile strength (taken from Table 2 of SRPS U.E3.020)

According to Article 75 of PBAB 87, the design of reinforced concrete elements is based on ultimate and serviceability limit state verification. For concrete pavement structures, particularly airport slabs, design practice is predominantly governed by serviceability limit state criteria, where—both in PBAB 87 and in EN 206 / Eurocode 2—the calculations are performed without applying partial safety factors. Differences in design outcomes mainly arise from the different definitions of characteristic flexural tensile strength of concrete and the associated acceptance criteria.

3.2 PROPERTIES OF CONCRETE ACCORDING TO EN 206 AND EC 2

EN 206:2021 and Eurocode 2 define concrete properties through a system of characteristic and mean strength values. For the purposes of slabs-on-ground-particularly external manipulation and traffic-bearing surfaces—the most important parameters are:

C – concrete strength class, cylinder/cube.

f_{ck} – characteristic compressive strength of a concrete cylinder at 28 days (taken from Table 3.1 of SRPS EN 1992-1-1:2015)

$f_{ck,cube}$ – characteristic compressive strength of a concrete cube at 28 days (taken from Table 3.1 of SRPS EN 1992-1-1:2015)

f_{cm} – mean compressive strength of concrete cylinder

$$f_{cm} = f_{ck} + 8\,\text{MPa} \quad (3)$$

f_{ctm} – mean value of concrete tensile strength under axial loading

$$f_{ctm} = 0.30 \cdot f_{ck}^{(2/3)} \quad \text{za} \le C50/60 \quad (4)$$

$$f_{ctm} = 2.12 \cdot \ln(1 + (f_{cm}/10)) \quad \text{za} > C50/60 \quad (5)$$

E_{cm} – secant modulus of elasticity of concrete

$$E_{cm} = 22 \cdot [f_{cm}/10]^{0.3} \quad (6)$$

$f_{ctm,fl}$ – characteristic value of concrete flexural tensile strength

$$f_{ctm,fl} = (1.6 - h/1000) \cdot f_{ctm} \quad (7)$$

f_{cd} – design compressive strength of concrete

$$f_{cd} = \alpha_{cc} \cdot f_{ck} / \gamma_c \quad (8)$$

α_{cc} - coefficient accounting for long-term effects and unfavorable load application conditions

γ_c - partial safety factor for concrete

Thus, EN 206/EC 2 introduces a strictly defined statistical basis for characteristic values, which directly influences safety factors and design stress values.

3.3 COMPARISON OF CONCRETE PROPERTIES ACCORDING TO PBAB / SRPS U.E3.020 AND EN 206 / EC2

Table 1 presents the differences between the two systems of concrete properties used in the design of slabs-on-ground.

Table 1. Comparison of concrete properties according to PBAB 87 / SRPS U.E3.020 and EN 206 / EC2 (example: MB35 vs. C30/37)

Concrete parameter	PBAB 87/ SRPS U.E3.020	EN 206/ EC 2	Note
f_{bk} / $f_{ck,cube}$	35 MPa	37 MPa	partially compatible in compression
f_{bzm} / f_{ctm}	2.67 MPa	2.90 MPa	approximate values
f_{zs} / $f_{ctm,fl}$	4.5 MPa	4.0 MPa	always lower per EC2
E_b / E_{cm}	32.9 GPa	32.8 GPa	similar values
f_b / f_{cd}	23 MPa	17 MPa	always lower per EC2

Differences in the definition of characteristic tensile-strength values lead to differences in allowable and ultimate flexural stresses and, consequently, in determining the minimum required slab thickness. PBAB 87 uses higher flexural tensile strength values, while EN 206 / EC2 introduces consistently defined characteristic values and safety concepts. In practice, this means that under the same subgrade conditions, the same wheel load, and the same load position, the design thickness may differ depending on which material model is applied. This difference will be quantitatively analysed in the following section.

4. NUMERICAL ANALYSIS OF THE INFLUENCE OF THE MATERIAL MODEL ON SLAB DESIGN

To assess the influence of the concrete material model on the results of Westergaard's slab-on-ground analysis, a comparative study was carried out for concrete slabs with thicknesses of 18, 20, 22, and 24 cm, designed using concrete class MB35 according to PBAB 87 and C30/37 concrete according to EN 206 and EC 2. The analysis includes calculation of subgrade reaction modulus, Westergaard's radius of relative stiffness, characteristic flexural stresses in the edge loading position, and comparison with the concrete strength limits according to both models. It is performed through the following steps:

- determination of input parameters and material properties;
- calculation of the subgrade reaction modulus *k*;
- determination of Westergaard's radius of relative stiffness *l*;
- calculation of the equivalent contact radius *r*;
- calculation of flexural stresses for characteristic load positions;
- comparison with the ultimate concrete strengths according to PBAB and EC2;
- presentation of results in tabular form.

4.1 INPUT DATA FOR THE ANALYSIS

Descriptions of the parameters are given below.

- Load:
  - Tractor unit with semi-trailer
  - Design axle load: 115 kN
  - Number of wheels per axle: n = 4
  - Tire pressure: p = 650 kPa
  - Tandem wheel spacing: Sd = 0.373 m
  - Radius of the equivalent circular contact area: r = 0.216 m
  - Load per dual wheel: $Q_k/2$ = 57.5 kN

- Subgrade:

The subgrade reaction modulus *k* is determined using Vesić's method:

$$k = \frac{0.65 \cdot E_s}{B \cdot (1 - \nu_s^2)} \cdot \sqrt[12]{\frac{E_s \cdot B^4}{E_c I}} \tag{9}$$

where:

- E_s – modulus of elasticity of the soil/subgrade
- B – characteristic slab width – 1.0 m
- ν_s – Poisson's ratio of the soil/subgrade
- E_c – modulus of elasticity of concrete

- Concrete:

The following models are compared:

- MB35 (PBAB 87)
- C30/37 (EN 206 / EC2)

Relevant values from Table 1 are introduced into the calculation for each slab thickness.

4.2 WESTERGAARD'S RADIUS OF RELATIVE STIFFNESS AND FLEXURAL STRESSES

Westergaard's radius of relative stiffness is calculated as:

$$l = \left(\frac{E_c \cdot h^3}{12k \cdot (1 - \nu_c^2)} \right)^{1/4} \tag{10}$$

with Poisson's ratio of concrete ν_c = 0.15.

The radius of the equivalent wheel-contact area depends on the load and the tire–slab contact characteristics, while the ratio ℓ/a enters directly into Westergaard's expressions for stresses.

For the edge loading case (critical for a slab without dowels), the flexural stress is calculated using:

$$\sigma_e = \frac{3 \cdot (1+\nu_c) \cdot PE}{\pi \cdot (3+\nu_c) \cdot h^2} \cdot \left[\ln\left(\frac{E_c \cdot h^3}{100k \cdot a^4} \right) + 3.84 - \left(\frac{4 \cdot \nu_c}{3} \right) + \frac{(1 + 2 \cdot \nu_c) \cdot a}{2 \cdot l} \right] \tag{11}$$

This stress is compared, for each slab thickness, with the ultimate concrete strengths according to the two models:

- PBAB 87: flexural tensile strength, f_{zs}

- EC2: characteristic value of flexural tensile strength, $f_{ctm,fl}$

4.4 COMPARATIVE ANALYSIS

Table 2 presents the key parameters and calculation results for all analysed slab thicknesses and both material models. The table includes the subgrade reaction modulus, Westergaard's radius of relative stiffness, calculated flexural stresses σe, ultimate concrete strength values, and the fulfilment of criteria. The results indicate consistent differences between the two approaches:

- the concrete modulus of elasticity has a very small influence on the subgrade reaction coefficient and therefore on Westergaard's radius of relative stiffness;
- differences in ℓ further affect the logarithmic component of Westergaard's equations and thus the magnitude of the edge stress σ_e;
- the flexural and tensile strengths of concrete define the ultimate stress values, whereby PBAB uses higher limit values of flexural tensile strength, while EC2 defines lower characteristic flexural tensile strength values $f_{ctm,fl}$ dependent on slab thickness;
- the combined effect of these differences leads to different required slab thicknesses depending on the selected concrete material model.

Table 2. Comparative overview of key parameters and calculation results according to PBAB and EN 206/EC2

Slab thickness h (cm)	Concrete model	Edge stress σ_e (MPa)	Ultimate stress value (MPa)
18	PBAB	4.623	4.500
18	EC2	4.621	4.113
20	PBAB	3.910	4.500
20	EC2	3.909	4.055
22	PBAB	3.555	4.500
22	EC2	3.354	3.997
24	PBAB	2.915	4.500
24	EC2	2.914	3.939

5. DISCUSSION

The results of the numerical analysis show that the stress states in the concrete slab are practically identical regardless of whether material parameters according to PBAB 87 or EN 206/EC2 are used. Differences in the edge stress σe amount to only 0.002–0.2 MPa, depending on slab thickness and concrete grade/class, which represents a negligible deviation in the context of the overall accuracy of Westergaard's model. This outcome is a consequence of the fact that the elastic moduli E in both approaches have very similar values, and that the calculation of the subgrade reaction modulus and Westergaard's radius of relative stiffness yields almost identical results.

Although the mechanical part of the calculation produces virtually the same response, a significant difference appears in the concrete strength criterion. The PBAB methodology is based on a flexural strength $f_{zs} \approx 4.50$ MPa, which is taken as constant and independent of slab thickness. In contrast, EN 206/EC2 uses the characteristic value of concrete flexural tensile strength $f_{ctm,fl}$, which is lower than f_{zs}. Therefore, the difference in ultimate stress values is much larger than the difference in calculated stresses. For all analysed slab thicknesses, PBAB 87 allows higher stresses (4.50 MPa), while the characteristic values according to EC2 range from 4.11 to 3.94 MPa, resulting in lower available capacity in the EC2 approach.

Despite the fact that stresses are practically equal, the EC2 strength criterion leads to a greater required slab thickness compared to PBAB. This means that the difference in design outcomes originates almost exclusively from the different philosophies of defining concrete ultimate strengths, rather than from any difference in the mechanical model of a slab on an elastic foundation.

This finding is particularly important in the context of standard harmonisation, as it indicates that the transition from the PBAB model to the EN 206/EC2 framework does not change the stress state in the concrete slab; instead, it introduces a stricter and statistically defined serviceability-and subsequently ultimate-strength criterion. This ensures consistency with contemporary European standards, but in practice results in the need for greater slab thicknesses, especially for external manipulation and traffic-bearing surfaces exposed to cyclic and climatic effects.

6. CONCLUSION

This paper presents an analysis of the differences in the design of concrete slabs-on-ground arising from the application of two different concrete material models: PBAB 87 (MB35) and EN 206/EC2 (C30/37). The objective was to quantify the influence of differences in defining the mechanical properties of concrete on the results of Westergaard's calculation and on the serviceability and ultimate limit state criteria of the structure.

The results show that the differences in calculated flexural stresses between the two approaches are negligible. The subgrade reaction modulus and Westergaard's radius of relative stiffness remain practically unchanged when switching from PBAB 87 to EC2, leading to almost identical stress values in the critical load positions. This indicates that the choice of material design model does not significantly influence the mechanical response of the slab within the framework of Westergaard's theory.

However, the key difference arises in the strength criterion. PBAB 87 uses the flexural tensile strength f_{zs} as the allowable value, which is relatively high and independent of statistical parameters. In contrast, EN 206/EC2 defines concrete tensile strength through characteristic values. As a result, even with identical stresses, the available structural capacity according to EC2 is nominally lower.

Consequently, for the same loading and subgrade conditions, the PBAB 87 methodology yields thinner slabs compared to the EC2 approach. For external manipulation and traffic-bearing surfaces, where cyclic loading, frost, and chlorides are dominant influences, the application of EC2 provides a more conservative and reliable result, requiring greater slab thickness relative to our practice.

The findings indicate that the transition to European regulation does not change the fundamental mechanics of slab-on-ground design but introduces a modern and statistically based strength criterion that ensures a higher level of structural safety. In this sense, the harmonization of design standards for concrete pavements and industrial slabs with EN 206/EC2 represents a logical step toward unifying practice and increasing the reliability of engineering solutions.

It is worth noting that the draft of the second-generation Eurocode 2 does not introduce specific design models for concrete slabs-on-ground, nor does it modify the definition of characteristic or design tensile strengths that would be relevant for such structures. Accordingly, the differences identified between the PBAB 87 and EN 206/EC2 approaches, as well as the conclusions drawn in this paper, remain fully applicable in the context of the forthcoming EC2:2025 revision.

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