

Jointless industrial floor using synthetic macro fibre-reinforced concrete: a Hungarian case study

Péter Károly Juhász^{1,2}, Márton Kispál³, Anna Bencze⁴

¹ : Chief engineer in JKP STATIC Ltd, Budapest, Hungary.

² : Adjunct lecturer in Budapest University of Technology and Economics, Budapest, Hungary.

³ : Head of R&D and Design at HelloParks – Futureal Group

⁴ : Head of Sustainability at HelloParks – Futureal Group

Abstract

In jointless industrial floors, in addition to conventional service loads, structural behaviour is significantly influenced by tensile stresses induced by concrete shrinkage and by friction between the slab and the subgrade. At present, no generally accepted design guideline exists for the assessment of these effects, and current design practice relies largely on empirical recommendations.

Synthetic macro fibres, even at relatively high dosages, typically exhibit strain-softening behaviour, which raises the question of their effectiveness in mitigating crack localisation in jointless floor slabs. Nevertheless, the economic and sustainability advantages of synthetic fibres are evident, making their application increasingly attractive in industrial floor construction.

The design of the presented jointless industrial floor was preceded by an extensive experimental programme. In addition to determining the residual strength of the fibre-reinforced concrete, the influence of fibres on early-age shrinkage was investigated over a range of fibre dosages. Alongside the mechanical strength parameters of the concrete, the time-dependent shrinkage behaviour was also characterised. Prior to structural design, a finite element parametric study was conducted to analyse crack formation under various loading scenarios and fibre dosages.

Based on the obtained experimental and numerical results, the structural design was carried out for a 24 × 24 m jointless industrial floor slab with a thickness of 190 mm, dimensioned for a predefined rack-leg layout using experimentally derived material parameters. Following construction, continuous diagnostic monitoring is being performed, enabling verification and further development of the numerical model.

This paper presents the design and construction process of the jointless industrial floor, with particular emphasis on the finite element modelling approach and the material parameters employed.

Keywords

Mixing model, stochastic modelling, fibre distribution, fibre-moment, quality control

1 Introduction

From a structural design perspective, industrial floor slabs are generally not classified as primary load-bearing structural elements; therefore, their design is not necessarily required to follow the Eurocode design methodology (Lohmeyer and Ebeling, 1999). Nevertheless, these slabs represent critical components of industrial facilities and must satisfy strict serviceability requirements. In particular, the slab surface must maintain a high level of flatness, while differential movements at joints must remain limited in order to ensure the reliable operation of manufacturing equipment and forklift traffic. In addition, surface crack widths are typically required to remain below approximately 0.2–0.3 mm.

With the increasing application of jointless industrial floors, the risk of deterioration associated with saw-cut contraction joints can largely be eliminated. However, the significantly larger panel dimensions introduce additional challenges, particularly with respect to slab edge curling and the development of larger crack widths.

In the industrial developments of HelloParks, in addition to load-bearing capacity and serviceability requirements, sustainability focused design, construction and operation have become key objectives, with particular emphasis on the reduction of embodied carbon. Based on these requirements, a jointless industrial floor optimisation programme was initiated. As a result, using industrial floor solutions and construction materials available in Hungary, a highly optimised floor structure was developed that satisfies both structural performance and sustainability requirements. The design of the optimised floor system was supported by extensive laboratory material testing and numerical analyses. This paper presents the optimisation methodology and the performance of the constructed floor systems.

2 Designing of industrial floor with advanced finite element analysis

Industrial floor design is governed by several guidelines (e.g. TR34, 2013; ACI360, 2010; ÖVBB, 2008a), which are mainly based on empirical and semi-analytical approaches, considering different load cases (point, line, distributed loads) and support conditions. The design methods can be grouped into manual (guideline-based), linear finite element (FEA), and nonlinear FEA approaches. The main advantage of guidelines is their simplicity and ease of use, but their drawbacks include strong simplifications, conservative assumptions, and limited ability to represent real structural behaviour (e.g. cracking, shrinkage, complex load interactions). In addition, some important phenomena (such as shrinkage effects, joint behaviour, or interaction of multiple point loads) are either poorly addressed or not covered at all.

FEA, on the other hand, allows a more realistic representation of floor behaviour, including subgrade response (e.g. nonlinear springs), material nonlinearity, and cracking. Especially nonlinear FEA can capture post-cracking behaviour and stress redistribution, which guidelines cannot adequately describe. Therefore, FEA is particularly useful for complex loading conditions, high-performance floors, or when optimization (avoiding overly conservative design) is required.

2.1 Material parameters

At HelloParks, particular emphasis is placed on sustainability and reducing the carbon footprint of industrial floor construction. Accordingly, material selection has focused on solutions that provide both high structural performance and low embodied carbon. Fibre-reinforced concrete has a long and well-established track record in industrial flooring, demonstrating reliable performance and broad industry acceptance.

From a sustainability perspective, low-carbon synthetic macrofibres were identified as the most suitable reinforcement option. To support the selection process, a comprehensive comparative testing program was carried out. Mechanical performance was evaluated using three-point bending beam tests (3PBBT) in accordance with EN 14651 (Table 1), while the influence of fibres on crack formation was assessed through ring tests based on the Austrian guideline (ÖVBB, 2008b). Beams were produced using identical concrete mixes and fibre dosages representative of the actual floor application, ensuring direct comparability of results.



Figure 1. 3PBBT according to EN 14651 in JKP STATIC Concrete Laboratory

The selection criteria included residual strength performance, crack control efficiency, carbon footprint, and practical applicability on site. Based on these combined considerations, BarChip MQ58, a synthetic embossed polyolefin macro fibre, was selected as the optimal reinforcement solution. The adopted dosage of 3 kg/m³ (approximately 0.33 vol.%) provided the required residual strength while minimizing the embodied carbon of the floor system.

Table 1: Mean flexural tensile and residual strength parameters obtained from EN 14651 three-point bending tests

Parameter	$f_{ct,L}$	$f_{R,1}$	$f_{R,2}$	$f_{R,3}$	$f_{R,4}$
Strength [MPa]	3.3	1.5	1.2	1.2	1.2

The obtained residual strengths satisfied the requirements defined for the proposed industrial floor application and were subsequently used for calibration of the constitutive model.

2.2 Constitutive model

Numerical analyses were performed using the ATENA finite element software (Cervenka Consulting, 2026), which is a well-established and validated tool specifically developed for nonlinear analysis of concrete structures. To improve computational efficiency, double symmetry was applied, allowing a reduction in the total number of finite elements without compromising accuracy.

The modelling approach was initiated with the representation of the subsoil and bedding system. The subsoil beneath the bedding layer was modelled using nonlinear compression-only springs, capturing the stiffness and nonlinear response of the ground. The bedding layer itself was described using a Drucker–Prager material model, enabling a realistic representation of its elastic-plastic behaviour. Material parameters for both soil and bedding were calibrated based on settlement data provided by geotechnical investigations.

The interaction between the concrete slab and the bedding layer was modelled using nonlinear contact elements. This approach allows separation (uplift) of the slab as well as horizontal displacements after detachment, governed by a defined friction coefficient. Such modelling is essential for accurately capturing curling effects and load transfer mechanisms.

The concrete slab was modelled using nonlinear material laws, with the William–Menétrey (1995) failure criterion applied in compression and the Rankine criterion (Cervenka, 2008) in tension. The post-cracking behaviour of fibre-reinforced concrete was incorporated using the modified fracture energy approach (Juhász, 2019; *fib* Bulletin 117, 2025). The constitutive model was calibrated using experimentally determined material properties. In particular, the tensile response was calibrated from the residual flexural strengths and fracture energy obtained from EN 14651 three-point bending beam tests, while the compressive behaviour was defined using the measured compressive strength. Crack development was represented using the crack band theory proposed by Bažant and Oh (1983), ensuring mesh-objective energy dissipation. Compressive strength was measured on cube specimens in accordance with EN 12390-3:2019. Flexural tensile strength and residual tensile strength were obtained from 3PBBT conducted according to EN 14651:2007+A1:2008. The modulus of elasticity and Poisson’s ratio were determined based on the provisions of the Eurocode.

Standard isoparametric eight-node linear brick elements with full integration (Gaussian quadrature with eight integration points) were employed. Mesh objectivity was ensured through the crack band approach, where the crack band width was determined as the projection of the finite element size in the direction normal to the crack. As a result, the crack band size varies between integration points depending on the associated concrete volume and crack orientation. The element size of the concrete slab was selected as $5 \times 10 \times 10$ cm. This discretization was determined based on previous studies (Juhász and Schaul, 2023) and validated through mesh sensitivity analyses. The mesh satisfies the requirement of having at least four elements through the slab thickness, while maintaining element aspect ratios below the recommended maximum of 1:4. For the soil domain, two elements were applied through the thickness.

The analysis was carried out in two loading stages. First, the self-weight of the slab and a uniformly distributed load were applied incrementally in 20 steps. Subsequently, shrinkage effects were introduced using an equivalent temperature gradient approach. The temperature load was applied over 300 increments as a linear gradient through the slab thickness, based on the previously conducted shrinkage analysis. The maximum shrinkage strain was 480×10^{-6} , based on previous shrinkage tests conducted in accordance with ASTM C157/C157M.

2.3 Results of numerical analysis

The load-bearing capacity of the floor is difficult to define in terms of the Ultimate Limit State (ULS), as a clearly identifiable failure mode is not straightforward to establish. Therefore, the required slab thickness for the given loading conditions was determined in accordance with the TR34 guideline, considering both bending and shear capacity.

In contrast, deformation and cracking behaviour were evaluated entirely through finite element analysis. As both deformation and crack width are Serviceability Limit State (SLS) criteria, characteristic load values and mean material properties were adopted in the analysis. Accordingly, the finite element model was used primarily to evaluate shrinkage-induced cracking, curling and deformation under serviceability conditions.

The rack system placed on the slab was well defined; therefore, both the positions and dimensions of the rack legs were precisely known. Several loading scenarios were investigated; however, the governing case was identified as the fully loaded slab condition, where all loads act simultaneously. An important aspect of the analysis was the time-dependent application of loads. Shrinkage-induced deformations occurring under unloaded conditions result in lower friction forces; therefore, it is beneficial if operational loads are applied at a later stage, typically after at least three months of curing.

Crack patterns in the slab are presented in Fig. 2a, while vertical displacements are shown in Fig. 2b. The effect of modelling the slab with joints was also investigated, resulting in reduced vertical displacements. The governing criterion was taken as the vertical displacement at the free edge of the slab.

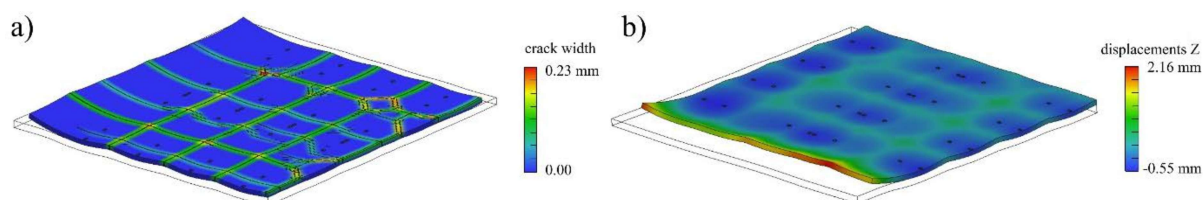


Figure 2. Results of the FEA a) crack width b) displacements

3 Carbon footprint calculation

The real estate sector accounts for approximately 38% of greenhouse gas emissions within the European Union, according to World Green Building Council (2019). As such, it is considered the largest emitting sector, making its decarbonization essential for achieving the climate targets set by the European Union (see European Green Deal).

In the case of buildings, achieving these targets requires assessing the carbon footprint generated throughout the entire life cycle of the asset, with the ultimate goal of reaching carbon neutrality.

The life-cycle carbon footprint can be divided into two main categories: operational and embodied carbon. Operational carbon refers to emissions associated with energy consumption during the use phase of the building. Embodied carbon, on the other hand, arises from the

extraction and production of construction materials, their transportation, the energy demand of construction processes, as well as maintenance, repair, and replacement activities during the life cycle, and finally from demolition, waste treatment, and disposal processes at the end of the building's life.

Over the past decade, regulatory changes have primarily focused on reducing operational carbon, with only limited and mostly indirect consideration of embodied carbon emissions. However, in the case of new buildings – largely due to improved energy efficiency – the balance has shifted significantly towards embodied carbon.

Upcoming European Union regulations will explicitly integrate the assessment and reduction of embodied carbon, representing a major shift in industry priorities. By 2027, all Member States will be required to develop detailed roadmaps for new buildings, including Whole Life Carbon (WLC) targets and limit values, thereby driving continuous reduction across the sector. As a next step, from 2028 onwards, Whole Life-Cycle Global Warming Potential (WLC GWP) calculations will become mandatory for all buildings with a floor area exceeding 1000 m², and these results must be incorporated into the building energy performance certificate. Binding national limit values are expected to come into force from 2030.

The construction sector is characterized by long project lead times, with development, design, and execution often spanning several years. As a result, timely preparation for forthcoming regulatory changes is essential. In this context, assessing, understanding, and reducing embodied carbon is a necessary step both to ensure future compliance and to achieve measurable emission reductions. In Hungary, the systematic consideration of embodied carbon is not yet standard practice, therefore early engagement with the topic – such as that undertaken by HelloParks – contributes to its broader recognition and integration into industry practice.

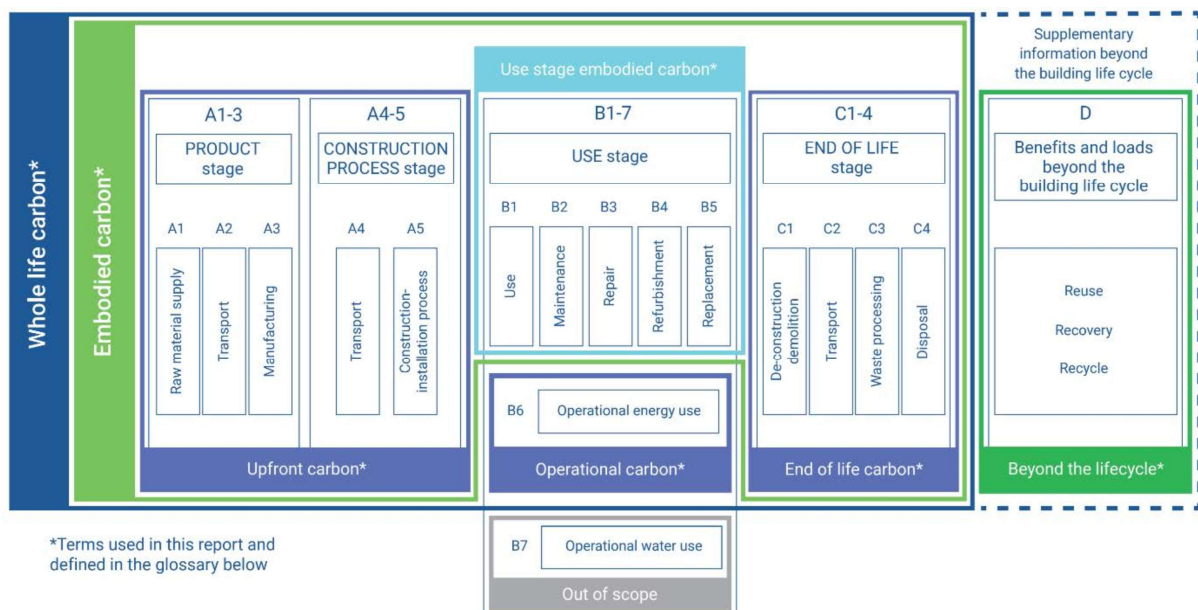


Figure 3. Terminology defined in EN 15978 (World Green Building Council, 2019)

In Europe, the EN 15978 standard defines the methodology for assessing the environmental impacts of buildings over their entire life cycle. The standard divides the building life cycle into the following stages and modules, as shown in Fig. 3 (World Green Building Council, 2019).

In 2022, HelloParks carried out a detailed life-cycle assessment for its standard building typology, which resulted in a distribution of 59% embodied carbon and 41% operational carbon. The following figures present the breakdown by life-cycle stages as well as the temporal distribution of emissions, clearly highlighting the importance of addressing embodied carbon in the case of new buildings.

The analysis further revealed that, considering embodied carbon alone, the largest contributor is the industrial floor, accounting for 13% of the total embodied carbon footprint. It was therefore evident that optimizing the industrial floor and reducing its carbon footprint could yield significant results.

Several carbon reduction measures were identified, and their combined application resulted in a significant 10.62% reduction for a standard building geometry. The achieved savings are attributable to one optimization measure and two interventions related to material type and composition. The full package of measures was gradually implemented during 2023 and 2024 and has since been incorporated into the technical standard.

The optimization of the floor thickness to 19 cm, presented in the previous sections, provides a clear example of reducing unnecessary carbon emissions arising from overdesign (see Table 2). The replacement of steel fibres with synthetic fibres represents a targeted intervention in another carbon-intensive component (see Table 3). The most significant reduction, however, was achieved through the substitution of the cement component in the concrete mix with a higher blast furnace slag content (see Table 4).

Tables 2–4 present the detailed changes in carbon footprint associated with each measure, demonstrating their reduction potential by comparing the standard HelloParks building with the updated standard incorporating the modified technical specifications.

Aggregating the partial results, the three measures together result in a total embodied carbon reduction of 1,925,232.8 kgCO_{2e} for a standard HelloParks building, corresponding to a decrease of 42.78 kgCO_{2e} per square metre. This represents a 10.62% reduction compared to the original standard baseline.

The optimisation measures presented in this section were not considered independently but formed the basis of the final floor design described in Sections 2 and 4. The reduction of slab thickness from 200 mm to 190 mm was enabled by the experimentally validated material model and nonlinear FE analysis, while the use of synthetic macro fibres contributed simultaneously to the required structural performance and the reduction of embodied carbon.

Table 2: Optimization – cost savings from reducing industrial floor thickness from 20 cm to 19 cm

Section	Result category	Savings (kg CO ₂)	Savings (kg CO ₂ /m ²)	Savings (%)
A1-A3	Construction materials	333 369.43	7.4082	2.09%
A4	Transportation to site	9 781.04	0.2174	1.64%
B1-B5	Material replacement and refurbishment	-	-	0.00%
C1-C4	End of life	11 796.90	0.2622	1.38%
TOTAL		354 947.37	7.8877	1.96%

Table 3: Carbon reduction – 19 cm FRC industrial floor with synthetic fibres instead of steel fibres

Section	Result category	Savings (kg CO ₂)	Savings (kg CO ₂ /m ²)	Savings (%)
A1-A3	Construction Materials	529 046.04	11.7566	3.32%
A4	Transportation to site	3 354.85	0.0746	0.56%
B1-B5	Material replacement and refurbishment	-	-	0.00%
C1-C4	End of life	149.17	0.0033	0.02%
TOTAL		532 550.06	11.8344	2.94%

Table 4: Carbon reduction – CEM III/A vs. CEM II/B-S cement

Section	Result category	Savings (kg CO ₂)	Savings (kg CO ₂ /m ²)	Savings (%)
A1-A3	Construction Materials	870 014.41	19.3337	5.46%
A4	Transportation to site	-	-	0.00%
B1-B5	Material replacement and refurbishment	-	-	0.00%
C1-C4	End of life	167 720.96	3.7271	19.67%
TOTAL		1 037 735.37	23.0608	5.72%

4 Implementation and construction

Since the founding of HelloParks in 2020, and after the completion of nearly a dozen warehouse buildings with a total floor area exceeding 500,000 m², the path that led to the development of the floor design presented in this study has become clearly visible. In the case of HelloParks' first building, the floors were constructed with 20 cm thick slabs in line with standard Hungarian construction practice. However, the sustainability objectives and the continuous optimisation of the technical concept led to the development of the 190 mm thick jointless synthetic macro fibre-reinforced industrial floor presented in this paper.

The floor was completed in April 2024 and consists of 72 jointless panels, each with plan dimensions of 24 × 24 m. Since then, the last three completed projects, with a total floor area of more than 150,000 m², have been built using this new industrial floor solution. A completed floor area before installation of the warehouse equipment is shown in Fig. 4.

Achieving a technically sound result requires strict quality control throughout the entire construction process. During the sub-base preparation phase, load tests were carried out at high frequency on every layer, and the laboratory evaluation results were reviewed at multiple levels

during construction. The use of synthetic macro fibres did not require any major modification of conventional industrial floor construction technology. During finishing, the most common technology-related, yet easily remedied, problem is surface defects caused by plastic fibres protruding from the plane of the floor. In some cases, the partially protruding fibres are rotated by the circular motion of the power trowel, creating flower-shaped marks on the surface. These can be removed with a torch without damaging the fresh concrete. No significant fibre-related construction problems, such as fibre balling or segregation, were observed.

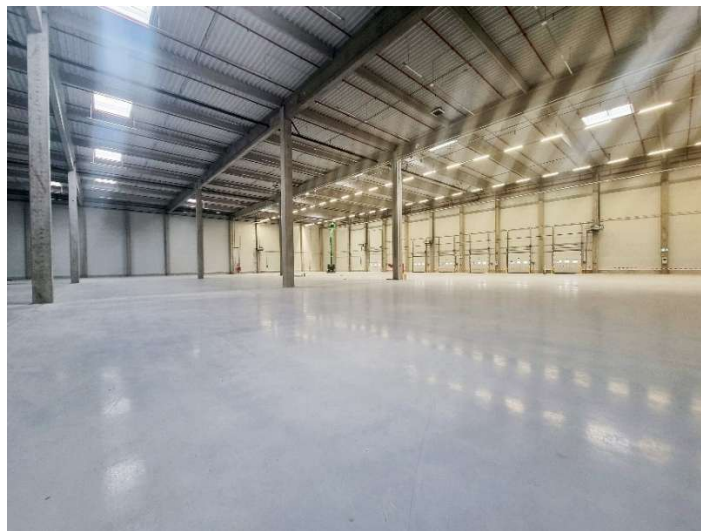


Figure 4. Completed jointless industrial floor before installation of warehouse equipment

Approximately two years have elapsed since completion. During this period, no surface cracks visible to the naked eye have been observed on the jointless floor panels, and no detrimental curling has been detected. The only measurable shrinkage-related movement occurred at the steel expansion joints separating the building dilatation units, where an opening of approximately 5 mm was observed, as shown in Fig. 5. This movement occurred at the structural expansion joint rather than within the individual 24×24 m jointless panels.



Figure 5. Opening of the steel expansion joint at a column line after shrinkage deformation

The warehouse has since been fully equipped with high-bay racking systems and has been operating under normal service conditions, as illustrated in Fig. 6. No functional limitations or serviceability problems related to the floor have been reported. The observed field performance is therefore consistent with the numerical predictions, which indicated controlled shrinkage deformation without excessive crack width or unacceptable curling.

To further validate the numerical model, a long-term monitoring programme has been initiated on one representative dilatation unit. The monitoring system measures the horizontal movement of the floor with high precision, allowing the time-dependent shrinkage and temperature-related movements to be quantified under real service conditions. These results will be used for further calibration of the finite element model.

The successful performance of the constructed floors confirms that synthetic macro fibre-reinforced concrete can be applied in large jointless industrial floor panels while maintaining the required serviceability performance. The observed field performance also indicates that further optimisation may be possible. In particular, the numerical analyses suggest that a slab thickness of 17 cm may be achievable without compromising comparable load-bearing performance.



Figure 6. High-bay racking system installed on the jointless industrial floor

5 Concluding remarks

This study demonstrates that industrial floor design can be significantly improved by combining advanced FEA with targeted material optimisation. Nonlinear FEA enables a more realistic representation of structural behaviour, allowing the reduction of conservative assumptions and avoiding overdesign. As a result, slab thickness could be reduced without compromising structural performance or serviceability.

The application of synthetic macro fibres proved to be an effective alternative to conventional steel fibre reinforcement. Despite their strain-softening behaviour, both the EN 14651 test results and numerical results confirmed their suitability for crack control in jointless

industrial floors. In addition, their lower embodied carbon and practical advantages make them a favourable solution from both sustainability and construction perspectives.

From an environmental standpoint, the results highlight that industrial floors represent a key leverage point for reducing embodied carbon in logistics buildings. The combined measures investigated in this study resulted in a meaningful reduction, demonstrating that significant improvements can be achieved through integrated engineering and material decisions.

Overall, the presented approach illustrates that sustainability-driven optimisation does not require compromises in performance. On the contrary, the integration of advanced finite element modelling and innovative materials provides a robust pathway towards more efficient and lower-carbon industrial floor solutions.

The next stage of the research will focus on the further development of the numerical model through a sensitivity analysis of the governing modelling parameters. Particular attention will be paid to the influence of subgrade properties and slab-subgrade interface parameters. The results will be validated against long-term monitoring data collected from the full-scale industrial floor presented in this study.

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