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Design and calculation of test stand for testing personal fall protection equipment according to EN 364

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ABSTRACT

This paper presents the design and calculation of a test stand intended for testing personal fall protection equipment in accordance with the requirements of the international standard EN 364. The objective of the study was to develop a reliable, safe, and structurally adequate test stand capable of performing both static and dynamic tests on components of fall arrest systems, including different types of personal fall protection systems, fall-arresters, anchor lines, safety harnesses, lanyards, energy absorbers, and connecting elements. The paper analyzes the requirements of EN 364 and defines the functional and structural characteristics of the test stand. Particular emphasis was placed on the static strength of the supporting structure, which was designed to withstand the maximum prescribed test forces without permanent deformation or structural failure, ensuring an adequate safety factor under the most unfavorable loading conditions. Furthermore, the dynamic performance of the test stand was analyzed through the evaluation of its natural frequencies, in accordance with standard requirements. The obtained calculation results confirm that the designed test stand fully complies with the requirements of EN 364 and enables accurate, reliable, and safe testing of personal fall protection equipment, thereby contributing to improved occupational safety and compliance with relevant standards.

KEYWORDS

Personal fall protection equipment, Test stand design, EN 364 standard, Fall arrest system.

1. INTRODUCTION

Fall protection and the prevention of injuries resulting from falls from height are key elements of occupational safety, particularly in industries such as construction, maintenance, and industrial operations where working at height is frequent. Personal protective equipment designed for fall protection, such as full-body harnesses, lanyards, energy absorbers, anchor devices, fall-arresters, is intended to reduce the risk of serious injury during fall events and to ensure compliance with safety regulations and standards [1-3].

Standardized methods of experimental testing are essential for verifying the performance of fall protection equipment and ensure its reliability under both static and dynamic loads. The European standard EN 364 (Personal protective equipment against falls from a height - Test methods) defines procedures for static loading, dynamic impact tests, and other conditioning tests used to evaluate the structural and dynamic characteristics of personal protective equipment components and assemblies used in fall arrest systems [4]. The standard also provides a technical foundation for testing laboratories, manufacturers, and certification bodies to assess personal protective equipment performance, safety, and conformity. It specifies standardized test procedures including static strength assessments, dynamic impact tests using torso dummies, corrosion and environmental conditioning tests, and endurance tests. The standard also provides recommendations for specimen preparation and test scheduling to ensure repeatability and comparability of results.

Scientific research and publications in this field are relatively limited and primarily focus on numerical and experimental investigations of forces, energy absorption, and deformation in personal fall arrest systems under static and dynamic loading conditions. Pomares et al. [5] conducted dynamic tests on fall arrest lanyards and showed that high loading rates significantly reduce resistance compared with static tests, highlighting the need for dynamic test requirements in standards such as EN 354 and EN 364. Carrión et al. [6] conducted dynamic tests on models of Energy Absorber Lanyards from six manufacturers to study their real elongation behavior during fall arrest. Using image processing, they measured the total elongation (elastic and plastic) of each lanyard and determined the minimum clearance distance required to safely arrest a fall without hitting the ground. Pomares et al. [7] conducted both static and dynamic tests on various personal fall arrest devices to evaluate their performance under different fall factors and fall heights. The tests were carried out in accordance with EN 354, EN 355, EN 362, EN 363, and 364 standards, with the aim of analyzing the variables affecting system behavior and energy absorption during fall arrest. Pan et al. [8] developed a multibody dynamic model of a scissor lift and a human operator, and conducted manikin drop tests to evaluate lift stability and the performance of various fall-arrest harnesses and lanyards under simulated fall arrest conditions. The study quantified dynamic loading on the operator model, particularly to the head and neck, while constraining tests to flat surfaces to isolate the effect of manikin-lanyard interaction. Bižić and Petrović [9] provided a systematic overview of the methodology for testing guided-type fall-arresters with a rigid rail anchor line, following the EN 353-1 standard. Their study analyzed the physical, geometric, and mechanical characteristics of the equipment and detailed procedures for performing both static and dynamic tests, based on experiments conducted.

Thus, scientific studies, technical publications, and other literature provide comprehensive guidance on fall protection principles, hazard identification, personal protective equipment selection, and safety management practices [10]. While they emphasize standardized testing and the importance of test stands for evaluating fall protection equipment, practically no publications provide detailed designs or concrete solutions for test stands. Consequently, standards and academic research mainly define general requirements, leaving the practical design and implementation of robust test stands largely to manufacturers and testing laboratories.

In line with the above, this paper presents the design and structural calculation of a dedicated test stand for personal fall protection equipment, fully compliant with European standard EN 364. The test stand enables reproducible static and dynamic testing of various fall protection components, including harnesses, lanyards, energy absorbers, anchor lines, fall-arresters, and connectors. The study integrates both static strength verification and dynamic performance assessment, including evaluation of natural frequencies to prevent resonance during testing. The given test stand represents a practical, safe, and standards-compliant solution for laboratories, manufacturers, and certification bodies, thereby contributing to improved occupational safety and regulatory compliance.

2. MAIN REQUIREMENTS OF STANDARD EN 364

The test stand must be designed to ensure reliable, repeatable, and safe testing of personal fall protection equipment under both static and dynamic conditions. It shall comply with standard EN 10002-2 [11], while force measuring devices used during testing must be calibrated by an authorized accredited laboratory to ensure the required measurement accuracy [4]. The loading rate depends on the material type – for metallic materials, the rate prescribed in standard EN 10002-1 [12] shall be applied, whereas for textile components with a length of 1÷2 meters, the crosshead speed during tests should be 50÷150 mm/min. Controlling the loading rate is very important, as it affects the measured mechanical response of the material and ensures comparability between different tests.

Special attention should be given to the standard's requirements regarding the static and dynamic strength of the test stand's supporting structure. Namely, the structure must be designed so that the application of a 20 kN force at the anchorage point at the top of the test stand does not produce a vertical deflection greater than 1.0 mm. In addition, the natural frequency in the vertical direction at the anchorage point must not be less than 100 Hz [4]. These requirements minimize test stand deformation and dynamic interference, ensuring that test results accurately reflect the behavior of the tested personal protective equipment, rather than the test stand.The anchorage point shall be either a ring with a bore of 20±1 mm or a cross-sectional diameter of 15±1 mm, or a rod of the same cross-sectional diameter. The height of the rigid anchorage point must ensure that no part of the tested system or component, nor the torso dummy or rigid steel mass, comes into contact with the floor during testing.

3. DESIGN AND CALCULATION OF TEST STAND

For the purpose of testing personal fall protection equipment, a special test stand was designed in accordance with the requirements of the EN 364 standard. The supporting structure of the test stand was designed as a closed spatial frame – truss structure made of welded steel box sections. The designed height of the supporting structure, i.e. test stand, is 6.8 m, while the designed base dimensions are 3.0×2.2 m. The structural material specified for the test stand construction is structural steel S235JR. The total mass of supporting structure is about 1.3 t.

At the top of the supporting structure, a special crossbeam is designed, with an anchorage point located on its underside. The crossbeam is movable along its supports, and the element carrying the anchorage point is also movable along the crossbeam itself. In this way, the anchorage point can be positioned at any location within the base area of the test stand, which is of great importance for testing different types of personal fall protection equipment. It should be noted that the test stand is designed to be anchored to the floor at four points, as well as anchored to a fixed wall at the rear side. The appearance of the designed supporting structure of the test stand is shown in Fig. 1.

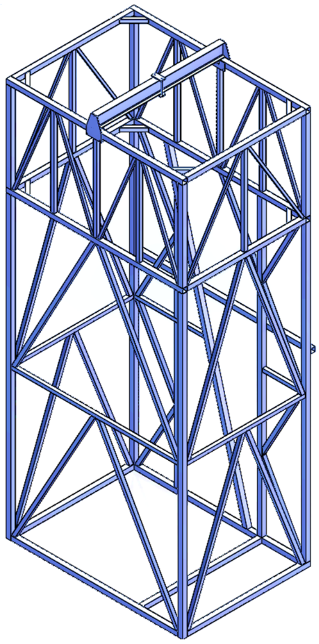

Figure 1: Designed supporting structure of test stand

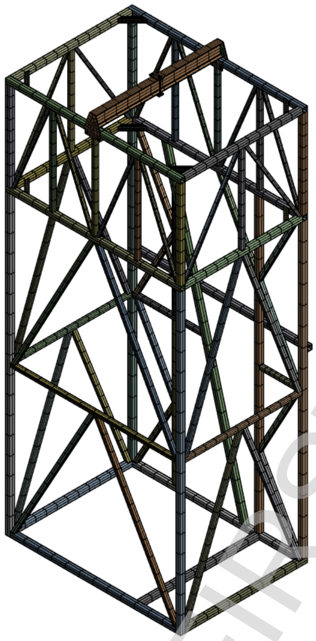

Figure 2: FEM model (65873 nodes, 10682 finite elements)

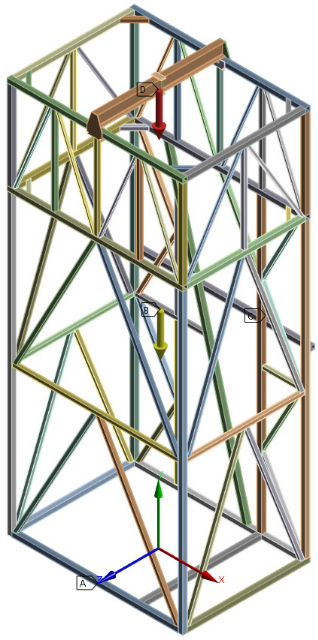

Figure 3: Loads and boundary conditions in model

In order to verify compliance with the requirements of the EN 364 standard, a structural analysis of the supporting structure of the test stand was performed using the finite element method (FEM). By spatial discretization of the supporting structure, a discretized model was created consisting of 65873 nodes and 10682 finite elements (Fig. 2). Boundary conditions in the FEM model were defined in accordance with the actual anchoring method of the test stand: the floor contact surface was modeled as fixed, the two rear wall anchor points prevented displacements normal and transverse to the wall while allowing vertical displacement, and all welded joints were treated as rigid connections.

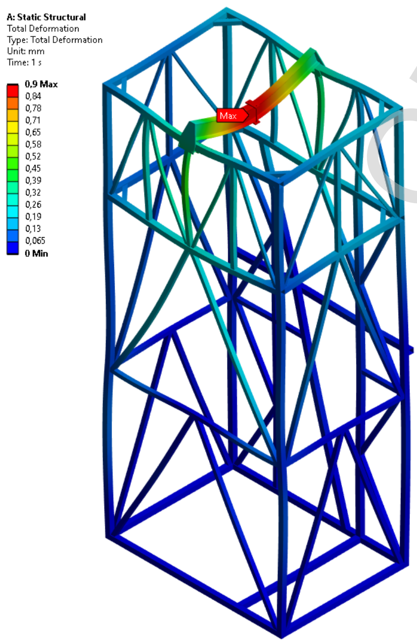

Figure 4: Total deformations of test stand supporting structure

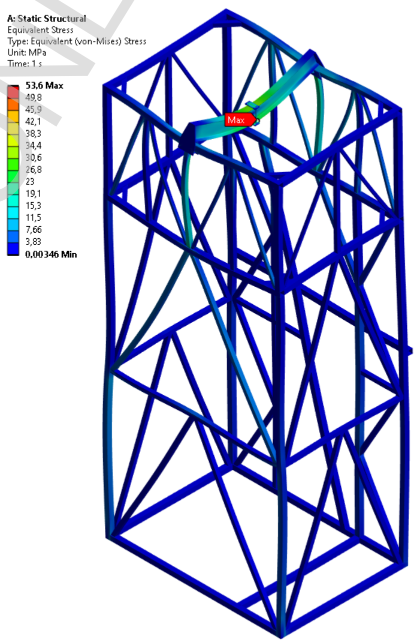

Figure 5: Equivalent stress of test stand supporting structure

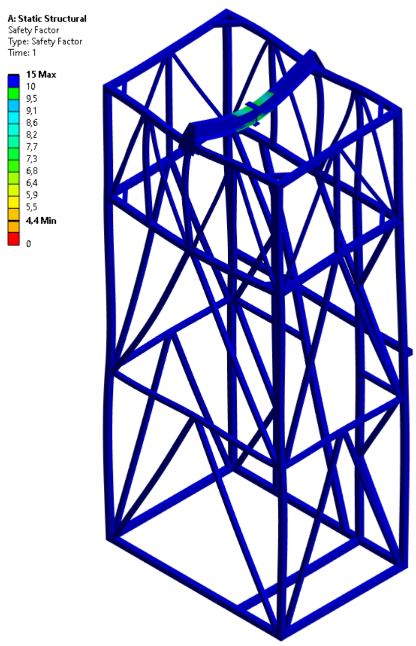

Figure 6: Safety factor of test stand supporting structure

The stress-strain analysis was performed for the critical loading case, where a force of 20 kN acts at the midpoint of the span of the load-bearing crossbeam, while the crossbeam is positioned at the center of the device (Fig. 3). The obtained FEM results for total deformations, stress distribution, and safety factor of the supporting structure of the test stand are presented in Figs. 4–6. For the specified critical loading case, the total deformation at the anchorage point is 0.9 mm in vertical direction, while the equivalent stresses in the supporting structure of the test stand are significantly lower than the allowable stresses; consequently, the safety factor is significantly greater than 1.

Subsequently, a modal analysis was performed to determine the natural frequencies of the first 30 vibration modes of the supporting structure of the test stand. The results of the analysis showed that there are no natural frequencies below 100 Hz for which the anchorage point exhibits dominant oscillations in the vertical direction. The part of the results of the modal analysis are presented in the following figs 7–21.

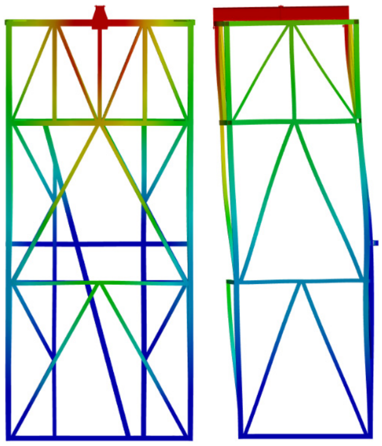

Figure 7: Vibration mode 1 (f_1=18.12 Hz)

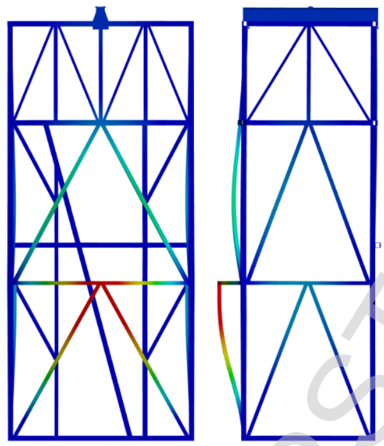

Figure 8: Vibration mode 2 (f_2=24.11 Hz)

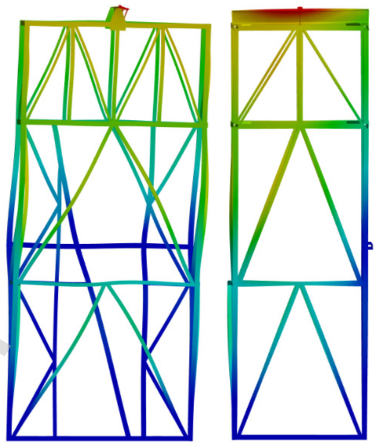

Figure 9: Vibration mode 3 (f_3=24.87 Hz)

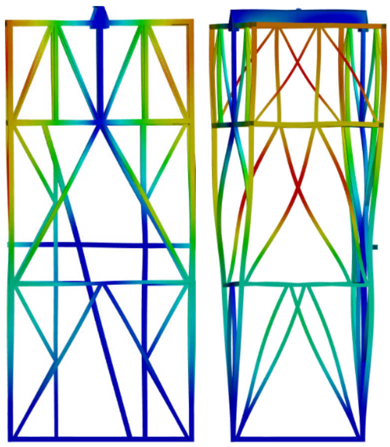

Figure 10: Vibration mode 4 (f_4=29.79 Hz)

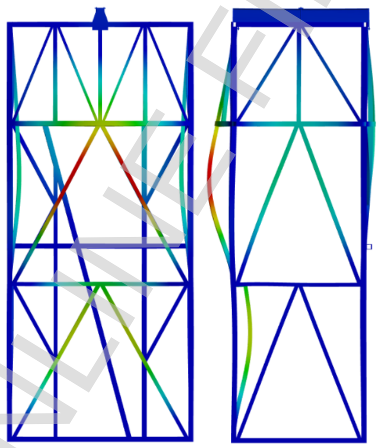

Figure 11: Vibration mode 5 (f_5=30.59 Hz)

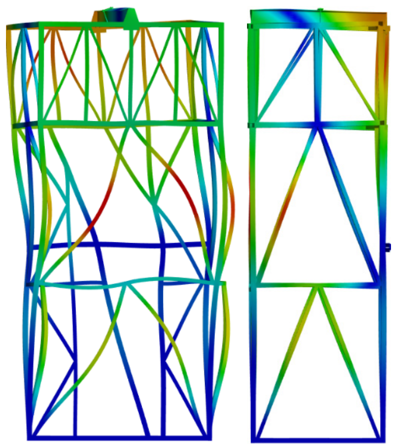

Figure 12: Vibration mode 6 (f_6=34.87 Hz)

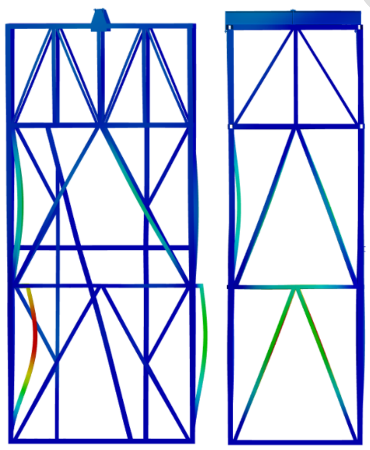

Figure 13: Vibration mode 7 (f_7=35.97 Hz)

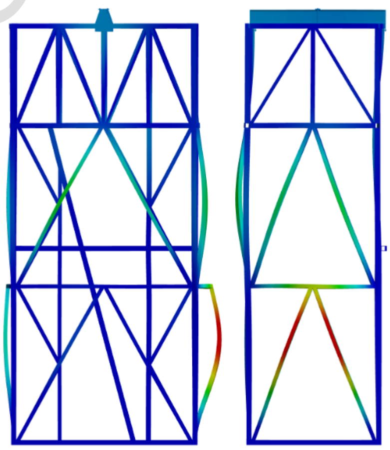

Figure 14: Vibration mode 8 (f_8=36.55 Hz)

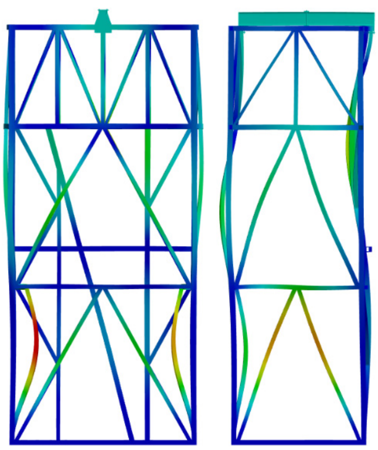

Figure 15: Vibration mode 9 (f_9=37.30 Hz)

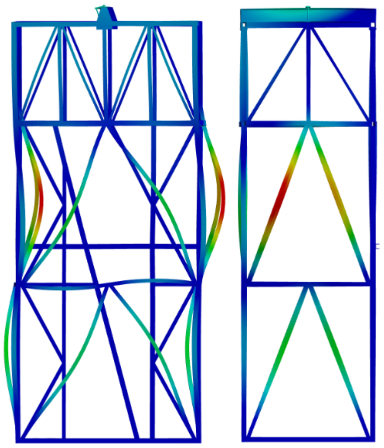

Figure 16: Vibration mode 10
(f_{10}=41.54 Hz)

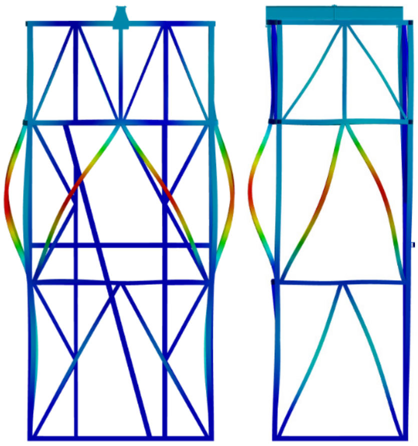

Figure 17: Vibration mode 11
(f_{11}=42.48 Hz)

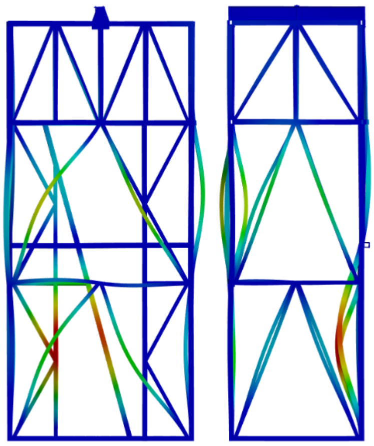

Figure 18: Vibration mode 12
(f_{12}=44 Hz)

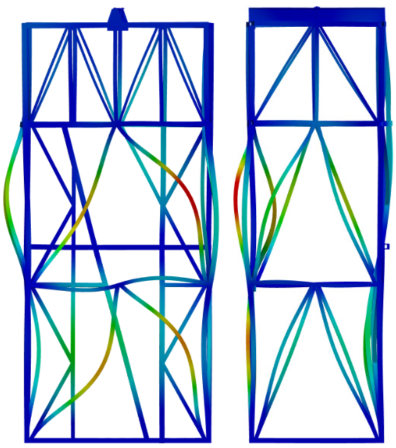

Figure 19: Vibration mode 13
(f_{13}=44.28 Hz)

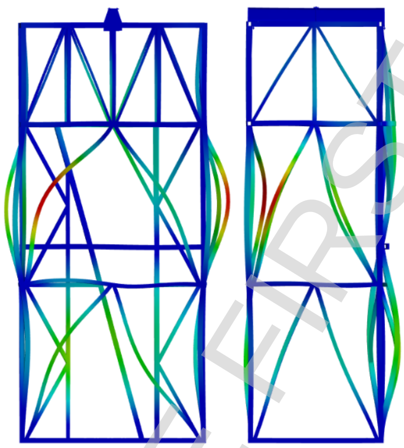

Figure 20: Vibration mode 14
(f_{14}=45.5 Hz)

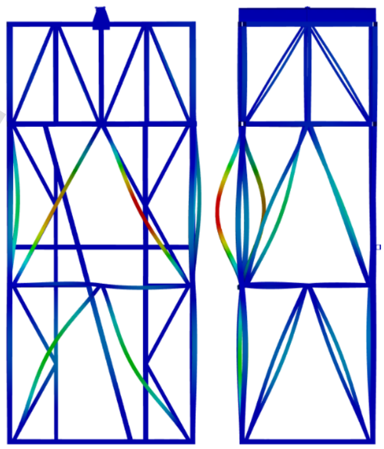

Figure 21: Vibration mode 15
(f_{15}=45.97 Hz)

4. REALIZED TEST STAND

The designed test stand was manufactured in accordance with the developed technical documentation. During fabrication, particular attention was paid to achieving a high structural quality of the test stand, including geometric accuracy, connection details, anchoring to the ground and wall, quality of welded joints, corrosion protection, etc.

Figure 22: Manufactured test stand in operational condition

The test stand is configured to enable safe and controlled execution of standardized tests of personal fall protection equipment. It is equipped with a lifting device for handling test masses and tested equipment, as well as all other necessary auxiliary equipment required for proper test preparation and execution. The geometry and layout of the structure ensure sufficient clearance for test masses and torso dummies, while the adjustable anchorage point allows adaptation to different test configurations. The manufactured test stand in its operational condition is shown in Fig. 22.

5. CONCLUSION

The design, structural analysis, and realization of the test stand for personal fall protection equipment have been successfully completed. The stand provides a safe, stable, and flexible platform for conducting both static and dynamic tests in full compliance with EN 364. Particular attention during fabrication ensured high structural quality, including geometric accuracy, connection details, anchoring, weld integrity, and corrosion protection. The inclusion of a lifting device and all necessary auxiliary equipment enables safe handling of test masses and tested components.

The realized test stand allows reproducible and controlled testing of various fall protection systems, including harnesses, lanyards, energy absorbers, anchor lines, fall-arresters, and anchor devices. By providing reliable and consistent testing conditions, it facilitates the verification of personal protective equipment performance and contributes to enhanced occupational safety.

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