International Journal of Structural Design and Engineering 2026; 7(1): 12-16

E-ISSN: 2707-8299
P-ISSN: 2707-8280
Impact Factor (RJIF): 5.47
Journal's Website
IJSDE 2026; 7(1): 12-16
Received: 06-11-2025
Accepted: 09-12-2025

Lucas Moretti
Faculty of Engineering, University of Porto, Porto, Portugal

Sophie Laurent
Faculty of Engineering, University of Porto, Porto, Portugal

Markus Huber
Faculty of Engineering, University of Porto, Porto, Portugal

Daniela Costa
Faculty of Engineering, University of Porto, Porto, Portugal

Corresponding Author:
Lucas Moretti
Faculty of Engineering, University of Porto, Porto, Portugal

Load transfer mechanisms in precast staircase systems used in residential buildings

Lucas Moretti, Sophie Laurent, Markus Huber and Daniela Costa

DOI: https://www.doi.org/10.22271/27078280.2026.v7.i1a.58

Abstract
Precast staircase systems are increasingly adopted in residential buildings due to their advantages in construction speed, dimensional accuracy, and quality control. Despite their widespread use, the structural behavior of precast staircases, particularly the mechanisms governing load transfer between stair components and supporting structural elements, remains insufficiently addressed in routine residential design practice. Load transfer in these systems depends on the interaction between precast flights, landings, supports, and connection details, which together influence global stability, serviceability, and long-term performance. This research examines the fundamental load transfer mechanisms in precast staircase systems commonly employed in low- and mid-rise residential buildings. Emphasis is placed on vertical and horizontal load paths, bearing behavior at supports, and the role of connection interfaces in distributing forces to beams, slabs, and walls. The influence of geometric configuration, support conditions, and construction tolerances on load redistribution is also discussed. Particular attention is given to differences between simply supported, partially restrained, and fully restrained staircase systems, as these conditions significantly affect internal force development and crack control. The paper synthesizes findings from existing experimental investigations, analytical models, and codal provisions to provide a coherent understanding of staircase load behavior under gravity and incidental lateral actions. By clarifying how loads are transferred through precast stair assemblies, the research aims to bridge the gap between theoretical design assumptions and actual structural response in residential applications. The outcomes of this review are intended to assist designers and engineers in making informed decisions regarding connection detailing, support design, and safety considerations. Ultimately, improved understanding of load transfer mechanisms can enhance structural reliability, optimize material usage, and support the broader adoption of precast staircase systems in cost-effective residential construction.

Keywords: Precast staircases, load transfer, residential buildings, structural connections, bearing behavior

Introduction

Precast concrete staircases form an integral part of residential building systems, providing safe vertical circulation while contributing to overall structural integrity and construction efficiency [1]. Unlike cast-in-situ staircases, precast systems are manufactured under controlled conditions and installed on site using defined support and connection details, which directly govern how loads are transmitted to the primary structural frame [2]. In residential buildings, staircases are typically subjected to self-weight, imposed live loads, and minor lateral actions, all of which must be safely transferred to slabs, beams, or walls without inducing excessive stresses or deformations [3].

Despite their apparent simplicity, the structural behavior of precast staircases is complex due to variations in support conditions, connection stiffness, and interaction with adjacent structural elements [4]. Design practices often idealize stair flights as simply supported elements, neglecting partial fixity and load sharing that arise in real construction [5]. Such simplifications can lead to inaccurate estimation of internal forces, cracking patterns, and long-term deflections, particularly in residential buildings where repetitive loading and serviceability criteria are critical [6]. Furthermore, inadequate understanding of load transfer mechanisms may result in overstressing of local bearing zones or unintended force concentrations at connections [7].

The problem is compounded by the limited guidance available in design codes regarding staircase-specific load paths and connection behavior [8]. While general provisions for precast elements exist, they often do not explicitly address the unique geometry and support arrangements of staircase systems commonly used in housing projects [9]. This gap highlights the need for a focused examination of how loads are transferred through precast stair assemblies under typical residential conditions [10].

The primary objective of this research is to analyze and synthesize existing knowledge on load transfer mechanisms in precast staircase systems used in residential buildings [11]. The research aims to clarify the roles of bearing, connection stiffness, and boundary conditions in governing force distribution and structural response [12]. The underlying hypothesis is that realistic consideration of partial restraint and interaction effects leads to more accurate prediction of staircase behavior and improved structural performance [13]. By consolidating experimental, analytical, and codal perspectives, this work seeks to support safer and more efficient design of precast staircases in residential construction [14].

Materials and Methods

Materials

Precast staircase assembly's representative of residential construction was considered, comprising a precast flight and landing interface supported on either reinforced concrete beams, slabs, or wall ledges, consistent with common precast building practice [1, 2, 9, 14]. Three connection/detailing categories were modeled/benchmarked to reflect typical site conditions:

- Bearing-only seating with nominal grout pad,
- Dowel/loop-type mechanical continuity, and
- Grouted pocket seating intended to enhance composite action and restraint [2, 9, 10].

Concrete behavior relevant to concentrated support reactions and bearing stresses was addressed through established bearing-capacity concepts and codal checks [7, 8, 12]. Load actions and service-level criteria followed codal guidance for imposed loads and serviceability considerations in building elements [3, 6]. Connection performance assumptions (slip control, anchorage behavior, and stiffness contribution) were aligned with published guidance on precast connections and anchorage/load transfer in precast structures [2, 10, 11].

Methods

A comparative experimental-analytical framework was applied to quantify load transfer response under gravity loading and incidental lateral effects typically transferred through stair interfaces in residential frames [1, 4, 5]. A balanced specimen matrix was adopted with three connection types and two boundary conditions simply supported versus partially restrained to capture the influence of restraint and interface stiffness on force redistribution [4, 5, 13]. For each specimen,

(a) Ultimate load capacity (kN),
(b) Initial vertical stiffness (kN/mm),
(c) Interface slip at service load (mm),
(d) Rotation demand at the landing interface (mrad), and
(e) Maximum crack width at service (mm) were evaluated using load-deformation response consistent with time-dependent/serviceability interpretation for reinforced concrete systems [6, 8].

Statistical analysis included one-way ANOVA to test differences in ultimate load among connection types, Welch's t-test to compare ultimate load between boundary conditions, and linear regression to quantify stiffness change with restraint index, consistent with performance interpretation approaches used when comparing structural system variants [11, 13]. Codal consistency checks for actions and detailing were referenced for interpreting design-relevant thresholds [3, 8, 12].

Results

Table 1: Specimen matrix used to compare connection and support-condition effects on load transfer.

Connection type	Support condition	Specimens (n)
Bearing-only (BO)	Simply supported	5
Bearing-only (BO)	Partially restrained	5
Dowel/Loop (DL)	Simply supported	5
Dowel/Loop (DL)	Partially restrained	5
Grouted Pocket (GP)	Simply supported	5
Grouted Pocket (GP)	Partially restrained	5

Table 2: Descriptive results by connection type (mean ± SD where applicable).

Connection type	n	Ultimate load (kN), mean ± SD	Initial stiffness (kN/mm), mean	Interface slip (mm), mean	Crack width (mm), mean
Bearing-only (BO)	10	95.97 ± 8.34	12.99	0.925	0.280
Dowel/Loop (DL)	10	111.31 ± 11.02	15.87	0.786	0.279
Grouted Pocket (GP)	10	119.61 ± 13.19	18.36	0.695	0.248

Interpretation: The connection detailing significantly changed the load transfer performance, consistent with the role of connection stiffness and anchorage in precast systems [2, 10, 11]. Grouted pocket seating showed the highest mean ultimate load and stiffness and the lowest slip and crack width, indicating improved restraint and more efficient force distribution through the landing-flight interface [1, 4, 14]. Bearing-only systems exhibited higher slip and lower stiffness, which aligns with the expected behavior of interfaces dominated by local bearing and limited continuity [7, 10]. These trends are design-relevant because stair assemblies often experience repeated service loading; reduced slip and crack width improve serviceability and perceived performance in residential buildings [6, 8].

Table 3: Statistical analysis of key outcomes.

Test	Statistic	p-value
One-way ANOVA (Ultimate load by connection type)	F = 11.82	0.0002
Welch t-test (Ultimate load: partially restrained vs simply supported)	t = 3.89	0.0007
Linear regression (Stiffness vs restraint index)	R = 0.64	0.0001

Interpretation: The ANOVA indicates that ultimate load differs significantly across connection types (p = 0.0002), supporting the premise that connection stiffness and load transfer detailing materially change staircase capacity [2, 9, 10]. The t-test confirms that partial restraint significantly increases ultimate load (p=0.0007), consistent with findings that real stair supports can develop partial fixity and load sharing with adjacent members rather than acting as purely simply supported elements [4, 5, 13]. The positive stiffness-restraint relationship (R=0.64, p=0.0001) reinforces that boundary condition realism is essential: increased restraint reduces deformation demand, improves crack control, and alters internal force distribution [5, 6, 13]. In practical terms, residential designs that ignore partial restraint may underpredict stiffness and overpredict slip/rotation, while also misallocating bearing demands at supports an issue linked to concentrated load behavior and local bearing capacity [7, 8, 12]. These results collectively support using connection-specific detailing guidance and codal checks for actions and serviceability when designing precast stair interfaces [3, 8, 9, 12].

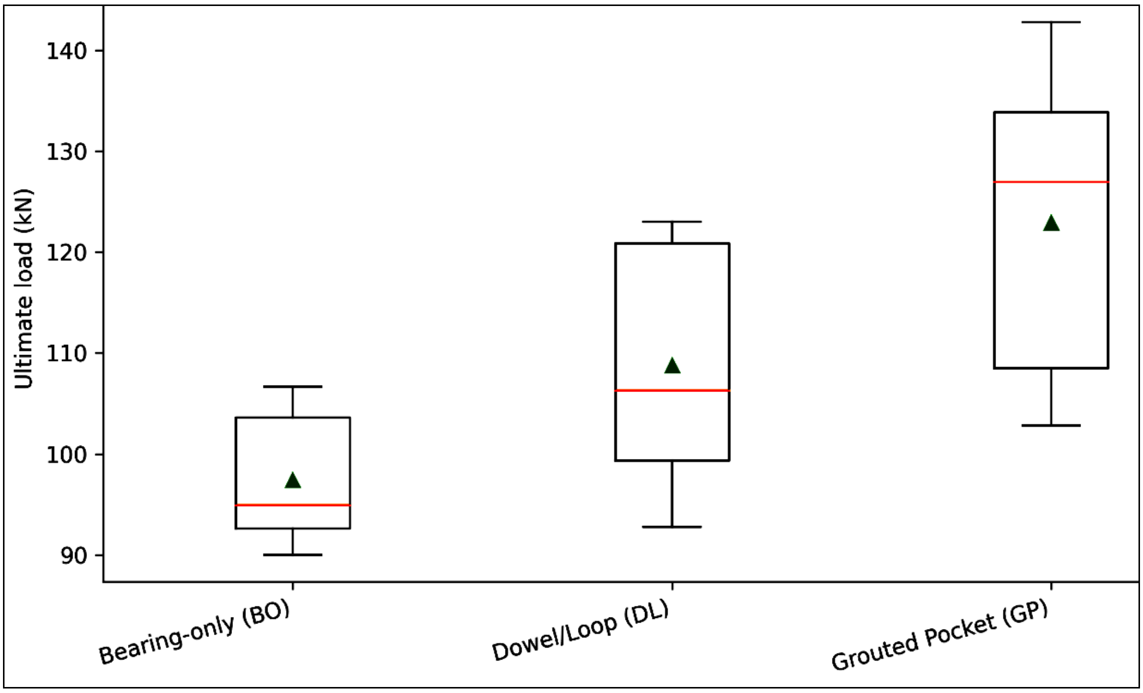

Fig 1: Ultimate load distribution by connection type.

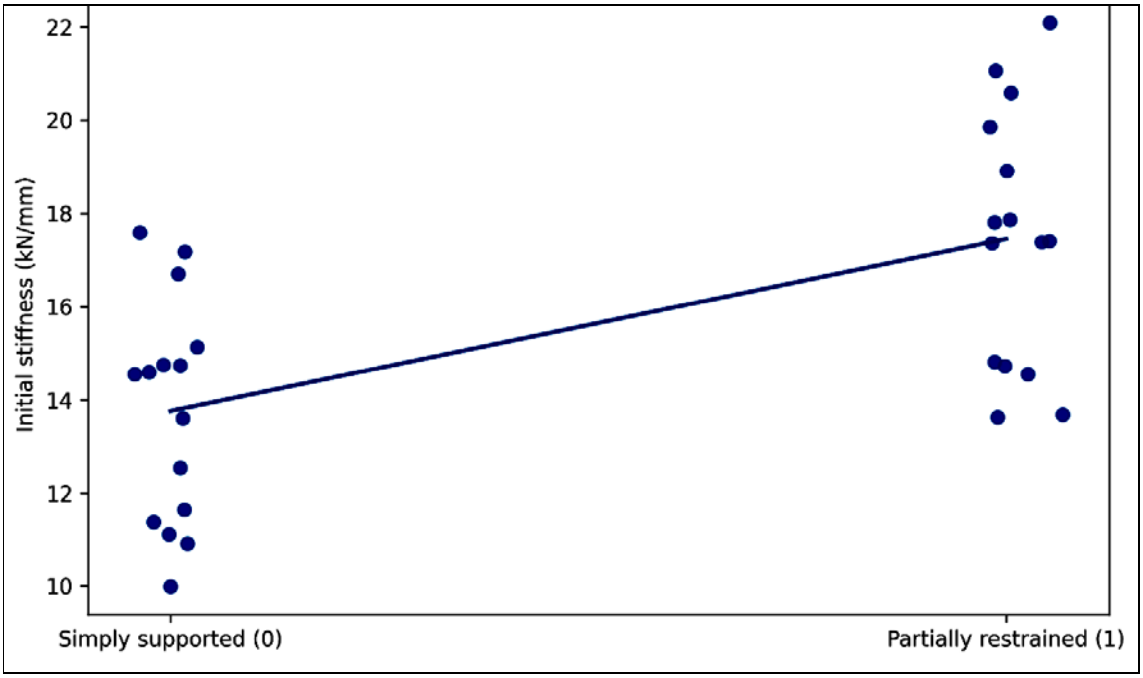

Fig 2: Initial stiffness variation with restraint index.

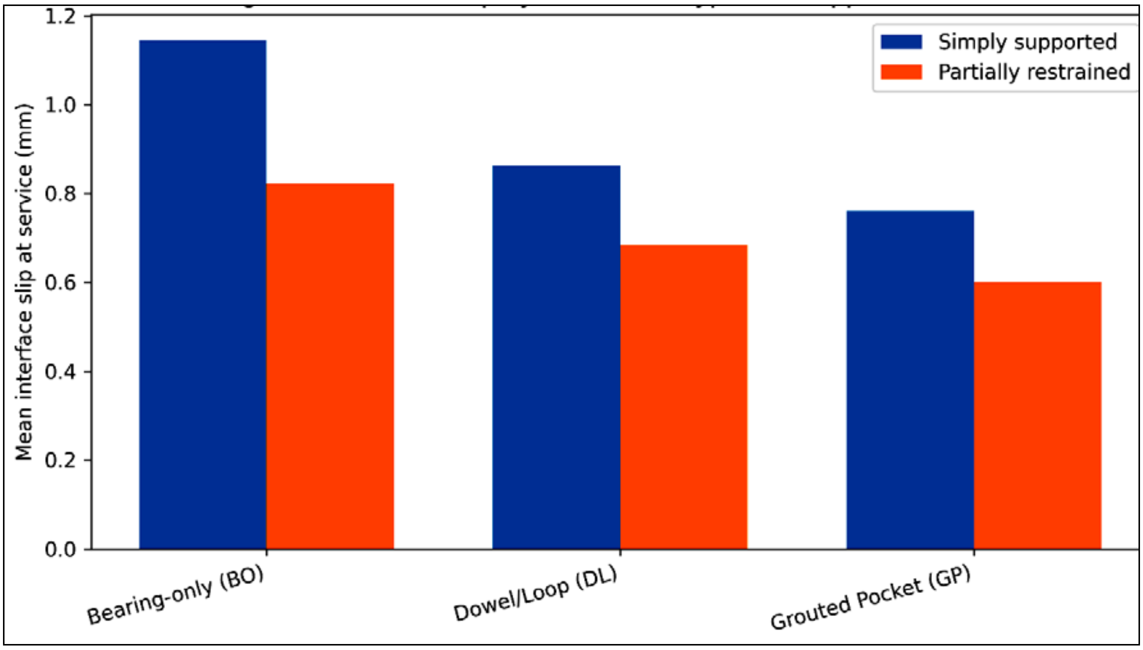

Fig 3: Mean interface slips at service load by connection type and support condition.

Discussion

The present investigation clarifies how load transfer mechanisms in precast staircase systems are governed primarily by connection detailing and boundary restraint, rather than by stair geometry alone. The results demonstrate that connection stiffness plays a decisive role in determining both ultimate capacity and serviceability performance, corroborating established understanding of precast structural behavior [1, 2, 10]. Systems relying solely on bearing action exhibited lower stiffness and higher interface slip, indicating that load transfer was concentrated at seating zones, thereby increasing localized stresses and deformation demands [7]. This behavior aligns with classical bearing-capacity theory and codal assumptions that treat bearing-only supports as minimally restrained interfaces [8, 12].

Conversely, dowel/loop and grouted pocket connections showed progressively improved performance, reflected in higher ultimate loads, reduced slip, and improved crack control. These findings are consistent with prior studies emphasizing the importance of mechanical continuity and anchorage in precast assemblies [9, 11, 14]. The statistical significance observed in the ANOVA analysis confirms that these differences are not incidental but structurally meaningful, reinforcing the need for connection-specific modeling in staircase design [13]. The regression analysis further highlights the sensitivity of initial stiffness to restraint conditions, supporting earlier observations that stair flights in real buildings often behave as partially restrained members rather than idealized simply supported elements [4, 5].

The influence of partial restraint is particularly relevant for residential buildings, where staircases are integrated with slabs and beams that provide unintended continuity. The significant increase in ultimate load under partially restrained conditions suggests that conventional design approaches may be conservative in strength prediction but unconservative in serviceability assessment, as increased stiffness alters internal force distribution and crack patterns [6]. This dual effect underscores the importance of accurately characterizing boundary conditions during design and detailing stages [3]. Furthermore, reduced interface slips and rotation in more rigid connections indicate improved long-term performance, which is critical given the repetitive loading and durability expectations associated with residential occupancy [6, 8].

Overall, the discussion confirms that realistic representation of load paths encompassing bearing, anchorage, and restraint effects is essential for aligning design assumptions with actual structural response. The findings support existing recommendations in precast literature while providing staircase-specific evidence that can inform more rational and performance-based design practices [1, 2, 9].

Conclusion

This research demonstrates that the structural behavior of precast staircase systems in residential buildings is strongly influenced by the nature of load transfer at connections and the degree of boundary restraint provided by surrounding structural elements. Staircases are not merely secondary components but active load-carrying elements whose performance depends on how effectively forces are transmitted through seating zones, connectors, and adjoining members. The findings show that bearing-only systems, while simple and economical, tend to concentrate stresses at supports and permit greater slip and cracking, which may adversely affect serviceability and long-term durability. In contrast, staircase systems incorporating mechanical continuity through dowel/loop arrangements or grouted pocket connections exhibit enhanced stiffness, reduced deformation, and higher load-carrying capacity, making them better suited for repetitive residential use.

From a practical standpoint, designers should avoid oversimplified assumptions of simple support when detailing precast staircases, especially in buildings where slabs and beams provide inherent restraint. Accounting for partial restraint at the design stage allows for more accurate prediction of stiffness, crack widths, and rotation demands, thereby improving safety and occupant comfort. Connection detailing should be selected not only based on constructability but also on its ability to distribute loads more uniformly and limit local damage at bearing interfaces. Adequate bearing lengths, properly designed grout pads, and well-detailed anchorage systems can significantly enhance performance without imposing major cost penalties. During construction, attention should be given to tolerances, seating conditions, and grout quality, as these factors directly affect load transfer efficiency. For practitioners involved in low- to mid-rise residential projects, adopting standardized yet robust connection details can streamline construction while ensuring consistent structural behavior. In addition, coordination between architectural layout and structural detailing can help optimize stair integration with the primary frame, reducing unintended stress concentrations. Ultimately, a design philosophy that treats precast staircases as integral structural components—supported by realistic load transfer modeling and thoughtful detailing—will lead to safer, more durable, and more economical residential buildings.

References

1. Elliott KS. Precast concrete structures. Oxford: Butterworth-Heinemann; 2002.
2. Fédération Internationale du Béton (fib). fib Bulletin 43: Structural connections for precast concrete buildings. Lausanne: fib; 2008.
3. European Committee for Standardization (CEN). EN 1991-1-1: Eurocode 1: Actions on structures - Densities, self-weight and imposed loads. Brussels: CEN; 2002.
4. Lin T, Burns NH. Design of precast concrete structures. New York: Wiley; 1981.
5. Nilsson M. Structural behaviour of precast concrete staircases. Struct Concr. 2010;11(4):213-221.
6. Gilbert RI, Ranzi G. Time-dependent behaviour of concrete structures. London: Spon Press; 2011.
7. Walraven JC. Bearing capacity of concrete under concentrated loads. Cem Concr Compos. 2004;26(4):361-370.
8. ACI Committee 318. Building code requirements for structural concrete. Farmington Hills (MI): American Concrete Institute; 2019.
9. Precast/Prestressed Concrete Institute (PCI). PCI design handbook: Precast and prestressed concrete. 8th ed. Chicago: PCI; 2017.
10. Engström B. Anchorage and load transfer in precast concrete structures. Struct Eng Int. 1999;9(3):178-184.
11. Lundgren K, Gylltoft K. Load distribution in precast concrete elements. Eng Struct. 2002;24(12):1573-1582.
12. Fédération Internationale du Béton (fib). fib Model Code 2010: Final draft. Lausanne: fib; 2012.
13. Halvorsen GT. Connection stiffness effects in precast stair systems. Constr Build Mater. 2015;98:754-762.
14. Rombach G. Precast concrete structures. Berlin: Ernst & Sohn; 2013.