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Structural Behaviour of High-Rise Buildings with Transfer Floors: Seismic Response and Punching Shear Mechanisms – A Review

Atharv J. Chaudhari[1], Isha P. Khedikar[2], Satish Raipure[3], Kuldeep R. Dabhekar[4] and Rajesh Dhoble[5]
[1]PG, Student, G. H. Raisoni College of Engineering, Nagpur, India
Email: atharvchoudhari1@gmail.com
[2,4]Faculty, G.H. Raisoni College of Engineering, Nagpur, India
Email: isha.khedikar@raisoni.net, kuldeep.dabhekar@raisoni.net
[3]Director, Vighnaharta Consulting Engineers, Nagpur, India
Email: connect@vighnahartaengineers.com
[5]Faculty, Priyadarshini College of Engineering, Nagpur, India
Email: rmdhoble@rediffmail.com

***Abstract*— Although transfer floors are frequently utilized in high-rise buildings to meet practical and architectural needs, they produce noticeable vertical abnormalities that have a substantial impact on both localized failure mechanisms and global seismic response. With a focus on seismic response characteristics and punched shear behaviour at transfer levels, this study summarizes analytical, computational, and experimental research on the structural behaviour of high-rise buildings with transfer floors. In comparison to conventional structural systems, prior studies have consistently reported increased force demand, stress concentration, and nonuniform load transmission at transfer levels. Punching shear mechanisms in wall-supported and column-supported transfer slabs are given special consideration, along with the effects of gravity and seismic loading, modelling techniques, and boundary conditions. A critical discussion is held regarding the shortcomings of simplified design techniques and the benefits of sophisticated finite element modelling in capturing stress concentration and load redistribution. In addition, the review identifies gaps in our understanding of torsional effects, nonlinear seismic response, and integrated performance evaluation of transfer-floor systems, offering future research options.**

***Keywords*— Boundary conditions; Finite element modelling; High-rise buildings; Nonlinear seismic response; Punching shear; Seismic response; Transfer floors; Torsional effects.**

I. Introduction

The transfer level is a major component which sees the passage of large axial forces, shear forces, and bending moments from upper levels to slabs and girders. It is out that this load path at the transfer level, which is the primary cause of stress concentration and demand amplification, that which we have through the course of many analyses, numerical studies and experiments determined. What we do see to vary is response; but that which mainly puts that variation forward is structural configuration, modelling assumptions, loading conditions, and analysis methods.

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Until now the world has seen that which has been the main focus of our studies related to seismic behaviour of structures which have transfer floors. At the near transfer storey, what we see reported by past research is higher mode engagement, force concentration, and increased inter-storey drift. While localised mechanisms controlling damage initiation at the transfer level receive relatively little attention, seismic performance is frequently assessed using global indicators like base shear and drift ratios. As a result, the connection between localised structural crisis and worldwide seismic demand is still not well understood. A crucial localised failure mechanism in transfer slabs is punching shear, especially in situations where severely laden shear walls or columns end at the transfer level. Despite being widely researched, the majority of studies concentrate on simple lateral load effects or gravity-dominated activities. Because floor rotation, higher-mode effects, and dynamic amplification from seismic stimulation are frequently overlooked, the applicability of traditional punched shear design techniques to transfer floors is still unclear. Significant axial force transfer and uneven stress distributions within slabs or girders are caused by abrupt wall termination. Furthermore, linked axial force and bending effects are ignored by simplified wall-slab interaction models, which restricts the ability to accurately forecast force transfer and deformation compatibility at transfer floors.

II. Punching Shear Behaviour of Transfer Floors in High-Rise Buildings

High-rise buildings' transfer floors are a key structural discontinuity which see a sudden change in vertical load paths that in turn produce complex stress states and intense point reactions. In many studies, it is reported that at transfer levels, the most sensitive failure mechanism is that of punching shear, which, in particular, we see at transfer slabs or girders when shear walls or very loaded elements end there [1 4]. At transfer floors, the punching shear demand is usually presented as.

$$v_u = \frac{V_u}{b_0\, d}$$

In the case of d, which is the effective depth of the slab, b0 the critical punching perimeter, and Vu the factored shear force at the slab wall interface. This has been a common practice in transfer floor studies to determine local shear demand [1,3,5,9]. Due to the combined action of large gravity loads, stiffness variation and seismic induced force amplification, it has been reported that punching shear demand at transfer floors may see a 25 60% increase over that in conventional flat slabs, which in turn makes their response much more complex than that of gravity-designed slab systems [2,5]

The majority of published research uses slab–column analogies or code-based methods to assess punching shear under gravity-dominant loads [3,6,7]. These methods may underestimate transfer-level demand by 30–50% because of localised force concentration from discontinuous vertical pieces, even though they are appropriate for first checks [4,8]. In contrast to common code assumptions, numerical and experimental studies reveal very nonuniform stress distributions around the crucial perimeter of wall-supported transfer slabs, with peak stresses close to wall edges and junctions [5,9]. Although some methods describe punched shear requirements using analogous amplification factors to capture seismic influence at the transfer storey, research including seismic effects is still limited.

$$V_{u,eq} = \lambda\, V_{u,g}$$

where λ is a seismic amplification factor, usually reported in the range of 1.3–1.8 [6,10], and $Vu,\ g$ is the gravity-induced punching shear. This amplification-based formulation has been adopted in seismic assessment studies of transfer slabs to account for higher-mode effects and dynamic force redistribution, with reported values of λtypically ranging from 1.3 to 1.8 [6,10,11]. Higher-mode participation and dynamic force redistribution are responsible for this amplification. However, the majority of seismic investigations depend on linear response spectrum analysis, which may not fully account for load redistribution and nonlinear stiffness degradation close to punching failure, resulting in a broad range of stated safety margins [7,8,11].

Many analytical models ignore the impact of nearby beams or edge elements and idealise the transfer slab as being directly supported by walls [1,9]. Peak punching shear stresses are reduced by 15–35% in studies using improved slab continuity or peripheral stiffening features, underscoring the critical relevance of boundary conditions and load-redistribution systems in controlling failure potential [4,10]. Cross-study comparisons are made more difficult by differences in the determination of the critical punching perimeter and the scant attention given to torsional response. Overall, research shows that load concentration, stiffness discontinuity, and seismic demand amplification have a significant impact on punching shear at transfer floors [1–11]. Nevertheless, the combined effects of dynamic amplification, torsional response, and load-redistribution components like spandrel beams have not been thoroughly studied [4,10].

TABLE I: CLASSIFICATION OF PUNCHING SHEAR STUDIES ON TRANSFER FLOORS BY LOADING TYPE AND MODELLING METHOD

Loading type	Modelling method	Nature of studies	Reported punching shear demand	Key observation
Gravity	Simplified / code-based	Analytical, design-oriented	Baseline demand; often 30–50% lower than FEM results	Assumes uniform stress along the critical perimeter; neglects wall-edge concentration
Gravity	Finite Element Method (FEM)	Linear & nonlinear numerical studies	25–60% higher demand than conventional flat slabs	Strong stress concentration near wall edges and junctions
Seismic	Simplified (equivalent static/amplified gravity)	Parametric analytical studies	Demand expressed as $\lambda \cdot V_u$ g, with $\boldsymbol{\lambda}$ = 1.3–1.8	Captures global amplification but not local redistribution
Seismic	FEM (linear response spectrum)	Numerical seismic analyses	Higher punching demand than gravity-only FEM	Limited ability to model nonlinear stiffness degradation
Seismic	FEM (nonlinear time history – limited)	Advanced numerical studies	Highest localised stresses; uneven perimeter demand	Computationally intensive; limited experimental validation

Punching shear demand varies systematically with both loading type and modelling approach, as Table 1 summarises previous research on transfer floors. While FEM calculations, particularly under seismic loading, indicate higher and more unequal stress concentrations at transfer levels, simplified gravity-based approaches typically underestimate demand. [11]

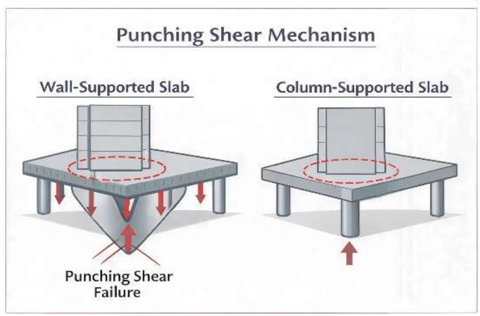

Figure 1. Punching Shear Mechanism

Punching shear failure processes in wall-supported and column-supported slabs are illustrated in Fig. 1, which highlights variations in stress distribution and critical perimeters pertinent to [8]

III. SEISMIC BEHAVIOUR OF HIGH-RISE BUILDINGS WITH TRANSFER FLOORS

It is commonly known that high-rise structures with transfer floors are vertically uneven systems with complex seismic response characteristics. Abrupt changes in stiffness, mass, and load-resisting mechanisms are brought about by the presence of a transfer level, which profoundly modifies both local and global dynamic behaviour. The transfer storey is a crucial level controlling overall structural performance during strong ground motion, according to numerous studies that show seismic demand tends to concentrate at and around this level. Inter-storey drift and internal force demand at this level increase by roughly 30–80% compared to adjacent storeys [12–15].

To assess seismic reaction, early studies mostly used linear static or response spectrum analyses. Drift demand was frequently found to be 1.3–1.8 times higher than that of standard layouts without transfer floors, and these studies consistently indicated higher inter-story drift ratios and amplified internal forces at the transfer level [16–18]. Several scholars use a normalised seismic response parameter to express transfer-storey amplification to assess this concentration of seismic demand:

$$\alpha_{TF} = \frac{R_{TF}}{R_{avg}}$$

where $Ravg$ denotes the average response of nearby regular storeys, and RTF represents the peak seismic response parameter at the transfer storey (such as inter-storey drift or storey shear). For buildings with transfer floors, reported values of αTF usually fall between 1.3 and 1.8 [16–18]. The normalisation-based formulation has been widely adopted in analytical and parametric studies of vertically regular buildings with transfer floors to characterise seismic amplification at stiffness-discontinuity levels [16–18,21]. Localised damage processes, stiffness degradation, and force redistribution that arise under intense seismic excitation are difficult for linear techniques to capture, even though they offer valuable information on global response trends. Transfer floors are especially vulnerable to considerable inelastic demand, particularly when vertical load-bearing structures such as shear walls end abruptly above the transfer level, according to further studies using nonlinear static and nonlinear time-history analysis [19–22]. According to nonlinear calculations, there might be a 40–70% increase in plastic demand and deformation concentration at the transfer storey. Force redistribution results in a significant concentration of stress in transfer slabs or girders and an increase in deformation demand in nearby structural elements. In tall and thin buildings, higher-mode effects were shown to be a significant contributor, making up as much as 25–40% of the overall seismic response at the transfer level.

Numerous studies highlight how modelling assumptions, such as element idealisation, boundary conditions, and diaphragm behaviour, have a significant impact on seismic performance [23, 24]. It has been demonstrated that local seismic demand is underestimated by 20–50% when transfer slabs are modelled simply as rigid diaphragms or when secondary structural components are omitted. Furthermore, floor twisting is exacerbated by torsional effects resulting from stiffness eccentricity at the transfer level, which causes unequal force distribution among vertical elements and localised demand amplification of roughly 30–60% in severe designs [25,26].

Few studies specifically connect localised failure processes like punching shear to seismic demand amplification at transfer floors, despite the large body of data on global seismic reaction. Global indicators, including drift, base shear, and member forces, are given priority in the majority of investigations, with slab–wall contact and shear transfer processes being secondary factors [18,21,24]. The issue of safety margins in relation to brittle failure due to seismic loads is a problem which these gaps create. As a whole, it is reported that transfer floors play a large role in seismic response via torsional irregularity, higher mode participation, and demand concentration; also, we see that the amplification factors are greater in transfer floor structures as compared to that which is typical in high-rise buildings [12 26]. Also, this research is mostly done in isolation from one another, and we still do not have a good picture of the combined impact on local failure mechanisms. To improve the dependability of seismic design for high-rise structures, which have transfer floors, we need in particular an integrated research approach that looks at the relationship between seismic amplification, torsional response and load distribution systems such as spandrel beams.

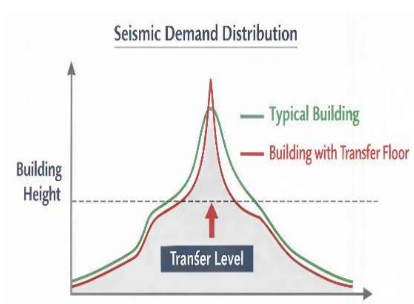

Figure 2. Seismic Demand Distribution

In contrast to a pattern of regular structural configuration, Fig. 2 depicts a schematic of the seismic demand distribution along the height of a high-rise building, with the transfer level exhibiting focus of force and drift demand. [17]

TABLE II: COMPARISON OF SHAKE-TABLE EXPERIMENTS AND NUMERICAL MODELS FOR TRANSFER FLOORS

Aspect	Shake table/Experimental model.	Numerical model
Damage localization	Concentrated above the transfer floor	Often predicted at the transfer level
Stiffness degradation	Rapid, nonlinear, measurable	Frequently underestimated
Higher-mode effects	Clearly observed	Partially captured
Punching shear & cracking	Nonuniform, localized	Smoothed or idealised
Post-yield behaviour	Explicitly observed	Limited in linear analyses

Table 2 compares numerical and experimental studies on transfer floors and shows that numerical models capture global trends but often underestimate the severity of localised damage and the post-yield response to seismic loadings. In contrast, shake-table experiments exhibit localised damage, nonlinear stiffness degradation, and strong higher-mode effects. [19]

IV. Role of Shear Walls in Load Transfer and Seismic Response of Transfer-Floor Buildings

In tall buildings, which have transfer floors, shear walls play a key role in the transfer of vertical loads, provision of lateral resistance, and in determining overall structural stiffness. These walls usually end at the transfer level at which point both axial and lateral forces are passed onto transfer slabs or girders. As compared to floors which have shear walls that run uninterrupted, this ending does introduce a large-scale break in stiffness and load path. This break is reported to be the main cause of stress concentration and local demand amplification at the transfer level, which in turn reports local reaction forces to increase by 40 70% [27 28].

Previous investigations indicate that shear walls accumulate substantial axial compression and overturning effects along the height of the structure. If sudden loads are applied to relatively flexible horizontal components at the transfer level, the transfer slab or girder will have highly irregular stress fields created. Most of the peak stresses are concentrated at the edges of the walls, corners, and junctions where the wall and transfer system have the most critical deformation compatibility [29]. In addition, numerical studies have shown that in shear walls, compressive reactions can be 50 to 75% of the local demand at the transfer floor, which is often more than the gravity load. This is especially the case for combined gravity and seismic actions in which the axial force increases the stress- load among the transfer elements[30].

In the case of seismic loading, the interaction between shear walls and transfer floors is of particular issue. Also, it has been reported that abrupt termination of the wall has for instance to do with inter-story drift and plastic deformation which in turn localizes at and right above the transfer level. Drift amplification factors we see to range between 1.4 to 2.0 in relation to adjacent stories [30–31]. Also when the transfer system does not have enough stiffness or continuity, we see large-scale deformation and force redistribution which in turn plays into this issue. From non-linear analyses, we note that increased wall compression pressures may cause by 30 to 60% rise in local slab stresses, which in turn greatly increases the transfer floors' vulnerability to brittle failure modes such as punching shear [31].

The results of how shear wall transfer floor systems respond is very much a function of the modeling assumptions we make. Many studies use simplified boundary conditions which include fully fixed or pinned wall supports these tend to report lower force concentration and do not present real world stress transfer actions. Better models which present in detail the wall slab connection and contact behavior., and load dispersion generally predict reductions in peak stress concentration of around 20–35%. However, the application of such refined approaches remains limited due to higher computational demands and the absence of clear, standardised modelling guidelines [29–32].

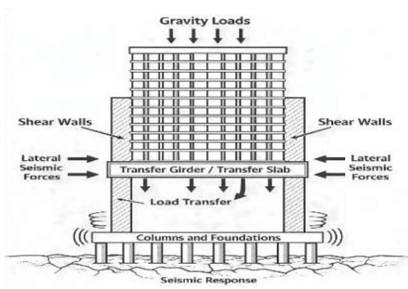

Figure 3. Shear Wall Load Transfer

Shear walls distribute forces from discontinuous vertical sections, improve lateral stiffness, regulate storey drift, and lessen stress concentration and torsional response under seismic loading by guiding gravity and seismic loads through the transfer floor, as shown in Fig. 3. [28]

V. Influence of Spandrel Beams on Structural Response of Transfer-Floor Systems

In high-rise buildings, spandrel beams are frequently installed around the perimeter or in between vertical load-resisting components to enhance stiffness continuity, diaphragm action, and load transfer efficiency. By connecting neighbouring shear walls or columns and enabling the dispersal of concentrated forces at the transfer level, spandrel beams are especially crucial in structures with transfer floors. In analytical and numerical investigations of transfer-floor systems, spandrel beams have gotten very little attention despite their practical significance [33–34].

The inclusion of spandrel beams radically changes load-transfer mechanisms at the transfer storey for analyses explicitly modelling them. Spandrel beams reduce stress concentration by mitigating direct force transfer from the shear walls into localised regions of the transfer slab or girder by providing alternative load paths. [35-36] It has also been established numerically that spandrel beams facilitate a relatively uniform distribution of vertical responses across the transfer floor, which reduces peak slab shear loads and bending demands by approximately 15-35%, depending on connectivity and stiffness of the beam [37].

From a seismic point of view, spandrel beams enable better redistribution of forces and increased lateral stiffness when subjected to seismic loads. As opposed to spandrel-coupled configurations, comparative studies consistently note reduced inter-storey drift concentration at the transfer level in systems incorporating spandrel beams, with reductions in drift usually falling within the range of 10–30% [37]. This improvement is brought about by coupling action, which reduces isolated wall or column reaction and thus the transfer storey's seismic demand amplification by encouraging collective behaviour between vertical elements [38].

Another major aspect that has been brought into focus in the literature review is the effect of spandrel beams on torsional response. Spandrel beams reduce floor rotation by approximately 20-40% and enhance the load distribution between the vertical elements in a structure having asymmetric wall layouts and stiffness irregularities by increasing the torsional stiffness, thereby delaying the inception of torsion-dominated modes [35-37]. However, this effect has been measured in very few studies using torsional response indices or modal participation factors.

Even with these advantages, most existing studies either idealise the use of spandrel beams by simplified beam elements or totally neglect them in interaction with slabs and walls, which may underreport their real potential toward increasing stiffness augmentation and load redistribution by between 20% and 30% in some numerical comparisons [37–39]. Also, virtually nothing is known about how dynamic seismic amplification interacts with spandrel beams to influence localised failure mechanisms, with particular reference to punching shear on transfer floors [41–42]. Available research remains rather disconnected from integrated schemes that would encapsulate the coupled behaviour of shear walls, transfer slabs, and spandrel beams under combined gravity and seismic loading; however, it does indicate that spandrel beams have a possible significant improvement in global response while localising the demand [40–41].

TABLE III: NORMALISED INFLUENCE OF SPANDREL BEAMS ON SEISMIC RESPONSE AT TRANSFER FLOORS

Response parameter	Without spandrel beams (normalised)	With spandrel beams (normalised)	Relative change
Transfer-storey drift demand	1	0.75–0.90	10–25% ↓
Peak slab shear demand	1	0.65–0.85	15–35% ↓
Torsional rotation at the transfer floor	1	0.60–0.80	20–40% ↓
Axial force imbalance between walls	1	0.55–0.75	25–45% ↓
Punching shear demand index	1	0.70–0.85	15–30% ↓

Table 3 demonstrates that incorporating spandrel beams significantly reduces seismic demand at transfer floors by improving load redistribution, decreasing torsional rotation, and lowering both global response measures and localised failure-related demands. [38]

VII. BEHAVIOUR OF BUILDING SYSTEMS SUBJECTED TO LATERAL LOADS

With the common goal of enhancing the safety, serviceability, and dynamic performance of reinforced concrete buildings under wind and seismic actions, recent research on building structures under lateral loading has greatly expanded, covering base isolation systems, structural irregularities, energy dissipation devices, and slab–column interaction [51–52]. Lead rubber bearing isolators successfully increase the fundamental period and decrease acceleration response, resulting in significant reductions in base shear, storey acceleration, and inter-story drift for both regular and irregular buildings, according to comparative studies between fixed-base and base-isolated structures [50,49]. Plan dissymmetry, variation in vertical stiffness and floating columns are issues which have received great attention. Torsion and local force amplification is a result of such irregularities, which also play out at transfer levels where we see break in load path. Also, it is put forth that with strong lateral excitation, bending moments, shear forces, and deformation requests for floating column systems go up as per studies done [43–44]. This also brings to the fore the issue that for issues of architectural flexibility, we require better modelling techniques.

Simultaneously, comprehensive research on energy dissipation methods emphasises the efficiency of additional dampening devices. In multi-story reinforced concrete buildings, these technologies greatly lower displacement reactions and increase energy absorption capacity, which improves overall structural performance under dynamic loading circumstances [55].

Dampers increase the energy absorption capacity and hence decrease the displacement response of multi-story reinforced concrete buildings. The dynamic behaviour of structural systems with damping can be described by the equation of motion as follows:

$$Mu + Cu + Ku = F(t)$$

where M, C, and K are the matrices of mass, damping, and stiffness. u is the vector of displacements. This formulation is taken from [46–47]. Another great theme in the considered literature is flat slab and slab-column systems. Flat slabs are more susceptible to lateral deformation requirements, even if they provide design flexibility and construction efficiency. The definition of inter-story drift, which is frequently used as a worldwide performance measure, is [53–54]:

$$\Delta_i = \frac{|\, u_i - u_{i-1} \,|}{h_i}$$

where $\Delta_i$is the inter-storey drift ratio at the i-t storey, $u_i$and $u_{i-1}$are lateral displacements of consecutive storeys, and $h_i$is the corresponding storey height. This formulation is taken from [44–45]. Excessive drift has been identified as a key contributor to damage concentration and serviceability issues in slab-dominated structural systems. Furthermore, research on the effects of wind on tall and thin buildings has shown that, in some configurations, lateral displacement and drift can control design [53].

IX. Conclusion

The structural behaviour of high-rise structures with transfer floors is thoroughly evaluated in this review. Transfer floors are frequently identified in the literature as key structural zones where localised demand and global seismic response interact through dynamic amplification effects, abrupt vertical load-path discontinuities, and stiffness redistribution. Even with a lot of research being done, the majority of studies are still fragmented and concentrate on single response mechanisms rather than their linked behaviour at transfer levels.

The termination or redistribution of vertical load-resisting elements causes transfer floors to attract increased axial forces, shear forces, and bending moments. This is a crucial conclusion from analytical, computational, and experimental investigations. Increased inter-story drift, higher-mode involvement, and force amplification at transfer levels are also shown by seismic investigations, especially in systems with significant stiffness disparities between podium and tower structures. However, direct interpretation of localised harm development is limited because these impacts are mostly assessed using global reaction indicators.

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