

A Constructability-Based Critique of Inter-Frame Bracing Provisions in Iranian Seismic Codes: Conflicts between Structural Coupling, Expansion Joints, and Integrated Architectural Finishes

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Abstract: This study critically examines the constructability and behavioral validity of inter-frame bracing provisions prescribed in Iranian seismic regulations when applied to buildings with integrated façades and continuous interior finishes. While inter-frame bracing is theoretically intended to enhance lateral resistance without compromising structural independence, its practical implementation often conflicts with architectural continuity and execution constraints. Using a qualitative–analytical framework, the research systematically evaluates regulatory assumptions, reconstructs representative execution scenarios, and assesses deviations between intended and effective seismic behavior. The results demonstrate that continuous architectural systems suppress deformation mechanisms required for seismic separation, leading to unintended structural coupling and altered load paths. The findings reveal that these deviations are systemic rather than incidental, arising from a misalignment between regulatory abstraction and constructability realities. The study concludes that seismic reliability cannot be ensured through analytical rigor alone and must explicitly incorporate constructability as a governing criterion. By reframing inter-frame bracing through a constructability-based lens, the research provides an evidence-driven foundation for refining seismic provisions to better align design intent with realizable performance.

Keywords: Inter-frame bracing; Seismic constructability; Architectural continuity; Structural separation; Behavioral validity.

1. Introduction

Seismic design regulations are fundamentally established to ensure predictable structural performance under earthquake loading by enforcing controlled force transfer mechanisms, deformation compatibility, and damage limitation strategies (Anagnostopoulos, 1988; Anagnostopoulos & Spiliopoulos, 1992). Among these principles, the provision of seismic separation and the avoidance of unintended structural coupling play a critical role in mitigating pounding effects, stress concentration, and progressive damage propagation between adjacent structural systems (Jankowski, 2008). Modern seismic codes therefore emphasize the necessity of expansion joints, structural independence of frames, and well-defined load paths as essential components of earthquake-resilient design (Kasai & Maison, 1997). In parallel with these structural imperatives, contemporary building practice has increasingly prioritized architectural continuity, functional integration, and visual uniformity. Continuous façades, uninterrupted interior finishes, and monolithic envelope systems have become dominant

features in residential, commercial, and public buildings (Aydın et al., 2020).

These architectural demands often require extensive surface continuity across multiple structural frames, particularly in tiled interiors, stone or ceramic façades, and composite cladding systems. While such integration enhances aesthetic coherence and constructability from an architectural standpoint, it introduces inherent constraints on the physical realization of structural separation measures mandated by seismic regulations (Filiatrault & Sullivan, 2014). Within this context, inter-frame bracing systems have been introduced in seismic design practice as a means of enhancing lateral stiffness, redistributing seismic forces, and controlling drift demands. Iranian technical publications, including Guideline 714, Guideline 819, and the Sixth Appendix of the Iranian Seismic Code (Standard 2800), provide explicit recommendations for the implementation of bracing mechanisms between structural frames to improve overall seismic performance. These provisions are primarily formulated from an analytical and structural mechanics perspective, assuming idealized boundary

conditions, clear load transfer paths, and the feasibility of prescribed structural detailing (Wen et al., 2016).

However, the practical execution of inter-frame bracing in real construction projects reveals a critical discrepancy between codified assumptions and on-site realities. In many buildings, adjacent frames that are required to remain seismically separated are simultaneously subjected to architectural and finishing systems that enforce continuity across those same frames. The execution of continuous façade systems and integrated interior finishes frequently eliminates the possibility of introducing effective cold joints, architectural separation lines, or deformable interfaces that would accommodate relative seismic movement (Efraimiadou et al., 2013). As a result, inter-frame bracing elements are often either partially implemented, altered during construction, or omitted altogether to avoid visible cracking, finish damage, or conflicts with architectural detailing.

This conflict gives rise to a fundamental inconsistency: while seismic codes conceptually demand both structural independence through separation and enhanced lateral resistance through inter-frame bracing, the simultaneous enforcement of these requirements becomes practically incompatible in buildings with integrated architectural systems. The absence of explicit guidance on how to reconcile bracing provisions with expansion joints, cold joints, and finish continuity leads to ad hoc decision-making at the construction stage (Aghazadeh Dizaji et al., 2023). Such decisions are typically driven by architectural, economic, or aesthetic considerations rather than by seismic performance objectives, thereby undermining the validity of the structural assumptions embedded in the design phase (Mahmoud & Abd-Elhamed, 2013). Moreover, the lack of constructible detailing within the cited regulations exacerbates this issue. Although the documents outline performance expectations and general bracing concepts, they do not provide sufficient execution-level guidance for scenarios involving continuous façades, rigid interior finishes, or multi-frame architectural compositions. Consequently, the real structural behavior of many constructed buildings deviates from the analytical models upon which seismic verification is based (Aghazadeh Dizaji, 2024a). This deviation raises serious concerns regarding the reliability of predicted seismic performance, particularly with respect to force redistribution, deformation compatibility, and non-structural damage concentration (Miari et al., 2019).

From a broader perspective, this issue highlights a critical gap in seismic regulation development: the insufficient integration of constructability considerations into code-based structural prescriptions. While structural efficiency and theoretical robustness are necessary conditions for seismic safety, they are not sufficient if the prescribed systems cannot be implemented faithfully within real architectural and construction constraints (Aghazadeh Dizaji, 2024b). The disconnect between codified design intent and actual execution ultimately compromises the effectiveness of seismic regulations and may lead to unintended vulnerability under earthquake excitation (Filiatrault et al., 2021). Despite the practical significance of this problem, existing research has largely focused on the analytical performance of bracing systems, the numerical optimization of lateral force-resisting mechanisms, or the material-level enhancement of structural components. Comparatively little

attention has been devoted to examining how seismic code provisions perform when confronted with architectural continuity requirements and execution limitations. In particular, systematic evaluations of inter-frame bracing provisions from a constructability-oriented perspective remain scarce within the literature, especially in the context of Iranian seismic regulations (Perrone & Filiatrault, 2017).

Accordingly, this study seeks to address the following central research question:

To what extent do the inter-frame bracing provisions prescribed in Iranian seismic regulations remain constructible and functionally valid when applied to buildings with integrated architectural façades and continuous interior finishes, and how does this constructability gap affect the assumed seismic behavior of adjacent structural frames? By framing the problem through this question, the research establishes a clear pathway for methodological investigation and result-based evaluation. The focus is not on proposing immediate design solutions, but on critically assessing the alignment between regulatory intent, constructability constraints, and realistic structural behavior. This approach provides the necessary foundation for evidence-based discussion and for the potential refinement of seismic provisions to better reflect the realities of contemporary building practice (Aghazadeh Dizaji, 2018).

2. Theoretical Foundations

Theoretical inquiry in seismic engineering is fundamentally concerned with the controlled interaction between structural systems and dynamic ground motion. At its core, seismic theory seeks to establish predictable relationships between imposed inertial forces, deformation mechanisms, energy dissipation, and damage distribution within the built environment. These relationships are formalized through concepts such as lateral load resistance, deformation compatibility, and structural independence, which together define the behavioral assumptions embedded in seismic design regulations (Anagnostopoulos, 1988). One of the foundational principles of seismic behavior is the concept of structural separation. Structural separation refers to the intentional physical and mechanical decoupling of adjacent structural systems to prevent unintended force transfer and impact during seismic excitation. This principle is operationalized through expansion joints, seismic gaps, and deformable interfaces that accommodate differential movement between neighboring frames or buildings. From a theoretical standpoint, separation is not merely a detailing provision but a mechanism that preserves the validity of analytical boundary conditions assumed during seismic analysis (Jankowski, 1998).

Closely related to structural separation is the concept of deformation compatibility. Deformation compatibility governs the ability of interconnected or adjacent structural components to undergo relative displacement without inducing excessive internal forces or localized damage. In seismic theory, compatibility is carefully managed to ensure that connected elements deform in a controlled and predictable manner. When compatibility is unintentionally enforced between systems that are assumed to behave independently, such as adjacent frames separated by

expansion joints, the resulting behavior deviates from the theoretical assumptions of the design model (Jankowski, 2009). Within multi-frame structural systems, lateral force-resisting mechanisms play a decisive role in defining global seismic response. These mechanisms include moment-resisting frames, braced frames, shear walls, and hybrid configurations. Inter-frame bracing is theoretically conceived as a means of enhancing lateral stiffness and redistributing seismic forces across multiple load paths. In analytical models, such bracing elements are introduced under the assumption that their interaction with adjacent frames is intentional, controlled, and compatible with the overall deformation strategy of the structure (Hsiao et al., 1993).

The theoretical effectiveness of inter-frame bracing relies heavily on idealized boundary conditions. These conditions typically assume unrestricted relative displacement where required, clear load paths, and the absence of unintended constraints imposed by non-structural elements. In this context, the distinction between structural and non-structural components becomes critical. While structural elements are explicitly modeled and designed to resist seismic forces, non-structural components such as façades, partitions, and finishes are often treated as secondary systems whose interaction with the primary structure is simplified or neglected (Miranda & Taghavi, 2005). Architectural continuity introduces a complex theoretical challenge to this distinction. Continuous façades, rigid cladding systems, and uninterrupted interior finishes can impose significant stiffness and constraint on structural systems, effectively participating in seismic response despite not being designed as load-resisting elements. Theoretical models that neglect this interaction risk underestimating force transfer, overestimating deformation capacity, and misrepresenting damage mechanisms. This phenomenon underscores the importance of recognizing architectural systems as potential modifiers of structural behavior rather than passive attachments (Berto et al., 2020).

The concept of constructability occupies a pivotal position in bridging theoretical seismic principles and real-world execution. Constructability theory emphasizes the feasibility of implementing design intent within practical constraints, including material behavior, construction sequencing, tolerances, and architectural requirements. From a theoretical standpoint, a design provision that cannot be executed without modification introduces uncertainty into the structural system, as the realized configuration diverges from the modeled one. This divergence directly undermines the predictive reliability of seismic analysis (Stenecker et al., 2020). Cold joints represent another critical theoretical construct in the context of seismic behavior and constructability. A cold joint is an intentional or unavoidable discontinuity in construction that affects material continuity and deformation transfer. In seismic theory, cold joints can function as controlled release points for strain and displacement, provided they are properly detailed. However, when cold joints are suppressed or eliminated due to architectural continuity requirements, deformation demands may be redirected into brittle finishes or unintended structural paths, altering the seismic response in ways not accounted for in design models (Miari & Jankowski, 2022b).

Regulatory frameworks translate seismic theory into enforceable design prescriptions. These frameworks codify assumptions

regarding load paths, deformation capacity, and interaction between structural subsystems (Ali Aghazadeh Dizaji & Ahmadian, 2016). The theoretical validity of a seismic regulation, therefore, depends not only on its analytical rigor but also on the extent to which its assumptions remain intact through execution. When regulations prescribe systems such as inter-frame bracing without explicitly addressing their interaction with architectural continuity and separation requirements, a theoretical inconsistency emerges between prescribed behavior and achievable behavior (Takabatake et al., 2014).

A critical concept underpinning this inconsistency is behavioral validity. Behavioral validity refers to the degree to which the actual seismic response of a constructed system aligns with the behavior assumed during design and analysis (Sarabi, 2024). In theoretical terms, behavioral validity is compromised when constructability constraints force deviations from prescribed detailing, boundary conditions, or interaction mechanisms. The presence of inter-frame bracing in buildings with continuous architectural systems exemplifies a scenario in which behavioral validity must be questioned rather than assumed (Stenecker et al., 2021).

Theoretical discussions of seismic performance increasingly recognize that damage patterns are governed not only by global strength and stiffness but also by local interaction mechanisms. Non-structural damage, interface cracking, and unintended composite action can dominate post-earthquake performance even when primary structural elements remain within acceptable limits. This recognition reinforces the need for theoretical frameworks that explicitly incorporate execution realities into the interpretation of seismic behavior (O'Reilly et al., 2018). From a systems perspective, seismic behavior should be understood as an emergent property of interacting structural, architectural, and constructional subsystems. Theoretical isolation of these subsystems may be analytically convenient, but it becomes problematic when their interaction is unavoidable in practice. Inter-frame bracing provisions that do not explicitly define how structural independence, architectural continuity, and constructability are to be reconciled represent a theoretical gap rather than a purely technical omission (Aghazadeh Dizaji & Aydın, 2025).

Within this broader theoretical landscape, the present study positions inter-frame bracing not solely as a structural enhancement mechanism but as a test case for examining the coherence of seismic theory, regulatory translation, and execution reality. By grounding the analysis in established concepts such as structural separation, deformation compatibility, constructability, and behavioral validity, the study establishes a conceptual foundation for critically evaluating whether codified seismic provisions can reliably produce their intended behavior in contemporary building practice. This theoretical framework does not seek to invalidate existing seismic principles but to refine their applicability by exposing conditions under which their assumptions may no longer hold. In doing so, it provides a structured basis for interpreting regulatory provisions through the lens of real-world constructability, thereby setting the stage for methodologically grounded analysis and results-driven discussion.

3. Methodology

This study adopts a qualitative–analytical methodology grounded in regulatory analysis, constructability assessment, and behavior-oriented structural interpretation. The methodological framework is deliberately designed to evaluate the coherence between codified seismic provisions and their practical executability, rather than to propose prescriptive design solutions. The investigation proceeds through a structured sequence of document examination, execution scenario reconstruction, and behavioral consistency assessment, ensuring that the research question formulated in the Introduction can be addressed through verifiable analytical steps (Filiatrault & Sullivan, 2014).

The first methodological phase involves a systematic examination of Iranian seismic regulatory documents that govern inter-frame bracing and structural separation. This phase focuses specifically on Technical Guideline 714, Technical Guideline 819, and the Sixth Appendix of the Iranian Seismic Code (Standard 2800). Relevant clauses, diagrams, and commentary sections addressing inter-frame force transfer, bracing configuration, seismic separation, and deformation compatibility are identified and extracted. The analysis is limited to provisions that directly or indirectly influence the interaction between adjacent structural frames under seismic loading (Wen et al., 2016).

Table 1. Classification of inter-frame bracing and seismic separation provisions extracted from Iranian seismic regulations

Provision Category	Regulatory Source	Core Structural Assumption	Implied Seismic Behavior	Separation Requirement	Constructability Sensitivity
Inter-frame bracing for lateral stiffness enhancement	Guideline 714	Adjacent frames can be structurally linked without violating independent response assumptions	Reduced lateral drift through shared force resistance	Assumes effective seismic separation is preserved	High
Bracing between parallel frames	Guideline 819	Load paths between frames are intentional and controllable	Redistribution of seismic forces across frames	Requires functional expansion joints	High
Seismic separation between adjacent frames	Standard 2800 – Appendix 6	Frames behave independently under seismic excitation	Prevention of pounding and unintended force transfer	Mandatory seismic gap	Medium
Combined bracing–separation configurations	Guideline 714	Structural coupling and separation can coexist	Enhanced stiffness without composite behavior	Conditional separation assumed	Very High
Deformation compatibility provisions	Guideline 819	Relative displacement can be accommodated through detailing	Controlled deformation without damage concentration	Requires deformable interfaces	High
Load path continuity requirements	Standard 2800 – Appendix 6	Load transfer paths remain predictable during earthquakes	Stable global seismic response	Indirectly linked to separation	Medium
Architectural interface assumptions	Implicit across documents	Non-structural systems do not significantly alter behavior	Structural behavior unaffected by finishes	Not explicitly defined	Very High
Execution-level detailing guidance	All documents	Prescribed systems are fully constructible	Designed behavior is realizable on-site	Not explicitly addressed	Very High

In the second phase, the extracted provisions are interpreted within an execution-oriented framework. Rather than evaluating their analytical validity in isolation, the study examines the implicit constructability assumptions embedded within the regulatory language. These assumptions include the feasibility of maintaining

effective expansion joints, the presence of functional cold joints, and the ability to accommodate relative frame displacement without architectural interference. This phase emphasizes how regulatory prescriptions translate into physical construction requirements on site (Kasai & Maison, 1997).

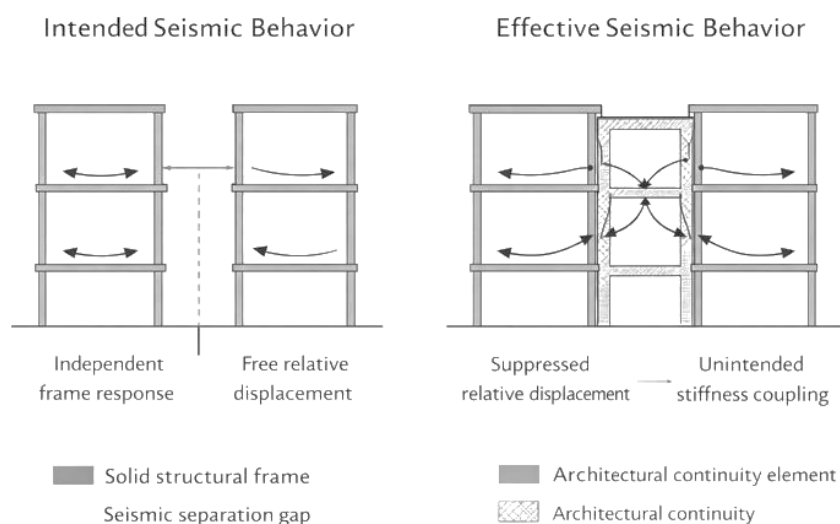


Figure 1. Conceptual relationship between codified inter-frame bracing assumptions and constructability constraints in integrated architectural systems

The third phase consists of reconstructing representative execution scenarios derived from common building practices. Typical architectural configurations involving continuous façades, rigid exterior cladding systems, and uninterrupted interior finishes such as tiled surfaces are considered. These scenarios are not intended as

case studies of specific projects, but as generalized execution conditions that reflect prevailing construction trends. For each scenario, the physical compatibility between inter-frame bracing requirements and architectural continuity constraints is qualitatively assessed (Efraimiadou et al., 2013).

Table 2. Representative execution scenarios for buildings with integrated façades and continuous interior finishes

Scenario ID	Architectural Configuration	Façade / Interior System Type	Inter-Frame Separation Condition	Typical Construction Practice	Expected Structural Interaction
S1	Discrete architectural units	Lightweight façade, flexible interior finishes	Clear seismic gap fully maintained	Explicit expansion joints executed and visible	Independent frame behavior preserved
S2	Semi-integrated façade	Stone or ceramic façade with flexible joints	Nominal separation with limited movement capacity	Seismic gap present but visually concealed	Partial interaction between adjacent frames
S3	Fully integrated façade	Rigid stone or ceramic façade with continuous backing	Separation is geometrically present but mechanically restrained	Seismic gap bridged by façade substructure	Unintended stiffness coupling initiated
S4	Integrated interior finishes	Continuous tiled walls across frames	No effective interior separation	Interior finishes executed as monolithic surfaces	Suppression of relative displacement
S5	Integrated façade and interior	Rigid façade + continuous interior finishes	Seismic separation effectively eliminated	Architectural continuity prioritized over detailing	Composite behavior between frames
S6	Retrofit or late-stage modification	Mixed rigid and flexible systems	Separation compromised post-design	On-site adjustments during construction	Altered and unpredictable force redistribution
S7	Architecturally constrained design	High aesthetic continuity requirement	Separation intentionally minimized	Structural detailing adapted to finishes	Controlled stiffness increases with high uncertainty
S8	Construction-driven integration	Finish-driven execution without structural coordination	Separation unintentionally violated	Execution decisions override design intent	Behavioral divergence from the analytical model

In the fourth phase, the study evaluates the behavioral implications of constructability-induced deviations from codified assumptions. This evaluation is conducted by comparing the intended structural behavior implied by seismic analysis models with the effective behavior expected when inter-frame bracing is modified,

weakened, or omitted due to execution constraints. Particular attention is given to unintended structural coupling, suppression of relative displacement, and alteration of force redistribution mechanisms between adjacent frames (Jankowski, 2008).

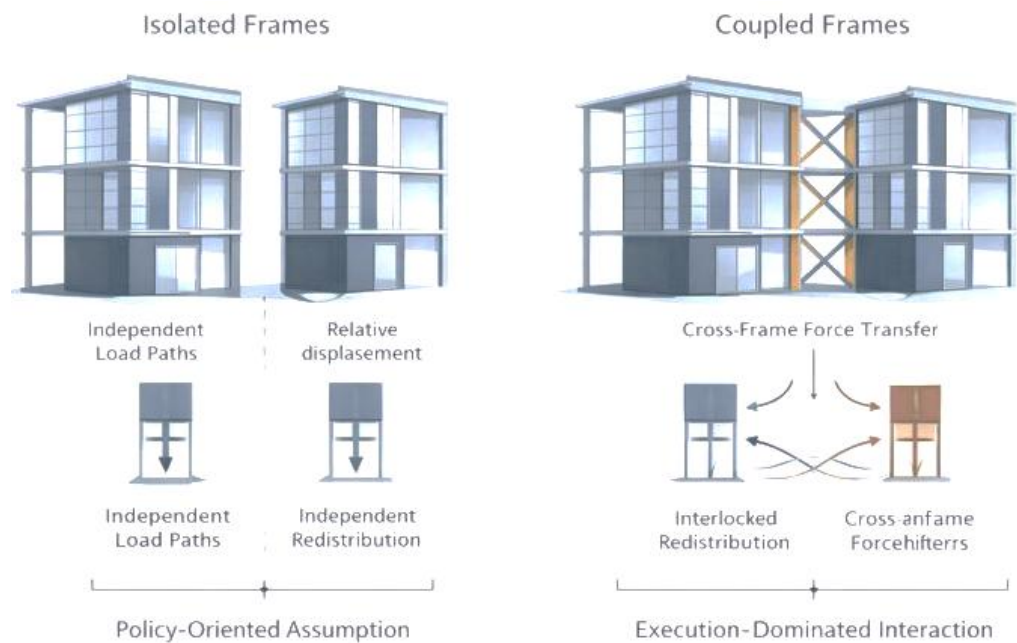


Figure 2. Schematic comparison between intended seismic behavior and execution-induced effective structural behavior of adjacent frames

The fifth phase introduces a comparative consistency assessment between regulatory intent and execution-driven behavior. This assessment does not rely on numerical simulation, but on logical consistency checks between assumed boundary conditions, load

paths, and deformation mechanisms. The objective is to identify points at which the analytical premises of the seismic design process become invalid due to constructability limitations (Mahmoud & Abd-Elhamed, 2013).

Table 3. Constructability-based consistency assessment matrix linking regulatory intent, execution conditions, and effective structural behavior

Regulatory Assumption	Related Provision Source	Execution Scenario Reference	Intended Structural Behavior	Observed Constructability Constraint	Effective Structural Behavior	Consistency Level
Independent seismic response of adjacent frames	Standard 2800 – Appendix 6	S1	Fully independent frame action	No physical interference	Intended behavior fully achieved	High
Independent response with enhanced stiffness	Guideline 714	S2	Drift reduction without coupling	Limited movement due to concealed joints	Partial interaction observed	Medium
Structural separation is maintained with bracing.	Guideline 819	S3	Controlled force redistribution	Façade substructure bridges separation	Unintended stiffness coupling	Low
Deformation compatibility through detailing	Guideline 819	S4	Relative displacement accommodated	Monolithic interior finishes restrain movement	Deformation suppression	Low
Coexistence of bracing and separation	Guideline 714	S5	Enhanced stiffness with frame independence	Architectural continuity eliminates separation	Composite frame behavior	Very Low
Preservation of analytical boundary conditions	Standard 2800 – Appendix 6	S6	Predictable seismic response	On-site modifications alter constraints	Unpredictable force paths	Very Low
Controlled interaction through architectural coordination	Implicit	S7	Managed stiffness increase	High execution sensitivity	Semi-controlled composite behavior	Medium
Design–execution consistency	All documents	S8	Designed behavior realized on site	Execution detailing overrides	Behavior deviates from design	Very Low

In the sixth phase, the study examines the role of decision-making transfer from the design stage to the construction stage. Situations in which unresolved conflicts between bracing provisions and architectural continuity are deferred to on-site judgment are identified and categorized. This phase highlights how economic, aesthetic, and scheduling pressures influence the final realization of structural systems, thereby modifying the effective seismic behavior of the building (Miari et al., 2019).

The seventh phase synthesizes the findings of the previous stages into a structured evaluation matrix. This matrix maps regulatory provisions against execution conditions and resulting structural behavior. The purpose of this synthesis is not to rank solutions, but to reveal systematic patterns of misalignment between seismic code prescriptions and constructability realities across different architectural configurations (Perrone & Filiatrault, 2017). The eighth phase establishes explicit evaluation criteria for construct validity. These criteria include executability without ad hoc modification, preservation of intended structural separation, and consistency between designed and realized load paths. Each inter-frame bracing provision is assessed qualitatively against these criteria under the reconstructed execution scenarios (Filiatrault et al., 2021).

The ninth phase focuses on internal methodological validation. Logical coherence between phases is verified to ensure that conclusions drawn in the Results section can be directly traced back to observed regulatory–execution interactions. This phase

ensures transparency, reproducibility of reasoning, and robustness of the analytical pathway adopted in the study (Anagnostopoulos & Spiliopoulos, 1992). Finally, the methodological framework is positioned to support a results-driven discussion rather than a normative recommendation. By isolating constructability as the primary evaluative lens, the methodology enables a clear distinction between theoretical seismic adequacy and practical behavioral validity. This positioning ensures that the Results section can objectively report observed misalignments and behavioral implications without prematurely advancing design prescriptions (Miari & Jankowski, 2022a).

4. Results

The results of this study are structured to directly reflect the analytical phases and evaluation logic defined in the Methodology section. Each result set corresponds explicitly to the regulatory extraction, execution scenario reconstruction, and constructability-based consistency assessment framework. The reported outcomes focus on observed patterns of alignment and misalignment between seismic code assumptions and execution realities, without advancing interpretive or prescriptive judgments. The first group of results presents the regulatory behavior profile derived from the systematic extraction of inter-frame bracing and seismic separation provisions. These results reveal the internal logic embedded in the regulations regarding assumed frame independence, deformation allowance, and force transfer mechanisms.

Table 4. Regulatory behavior profiles of inter-frame bracing provisions under assumed seismic separation conditions

Provision Type	Regulatory Document	Assumed Boundary Condition	Intended Seismic Role	Assumed Deformation Mechanism	Sensitivity to Execution Constraints	Behavioral Robustness
Inter-frame bracing between adjacent frames	Guideline 714	Full preservation of seismic separation	Global lateral stiffness enhancement	Relative displacement accommodated at joints	Very High	Low
Bracing for drift control across frames	Guideline 819	Clear expansion joints remain functional	Drift reduction without force concentration	Controlled frame interaction	High	Medium
Seismic separation without bracing	Standard 2800 – Appendix 6	Complete structural independence	Pounding prevention	Free relative movement	Medium	High
Combined bracing and separation strategy	Guideline 714	Separation and coupling coexist	Stiffness enhancement with independence	Idealized compatibility	Very High	Low
Deformation compatibility detailing	Guideline 819	Interfaces remain deformable	Damage limitation	Distributed deformation	High	Medium
Load path continuity assumption	Standard 2800 – Appendix 6	No unintended stiffness paths	Predictable force transfer	Stable load redistribution	Medium	High
Implicit architectural neutrality	All documents	Non-structural systems inactive	Structural-only seismic response	No architectural interaction	Very High	Very Low

The results summarized in Table 3 indicate that the majority of extracted provisions implicitly rely on idealized boundary conditions, including uninterrupted expansion joints and unrestricted relative displacement. These assumptions form the baseline against which execution-induced deviations are evaluated in subsequent result sets. The second group of results addresses the

execution scenarios reconstructed in alignment with prevailing architectural practices. The interaction between continuous façades, rigid interior finishes, and prescribed bracing systems is examined to identify physical constraints imposed on the intended seismic behavior.

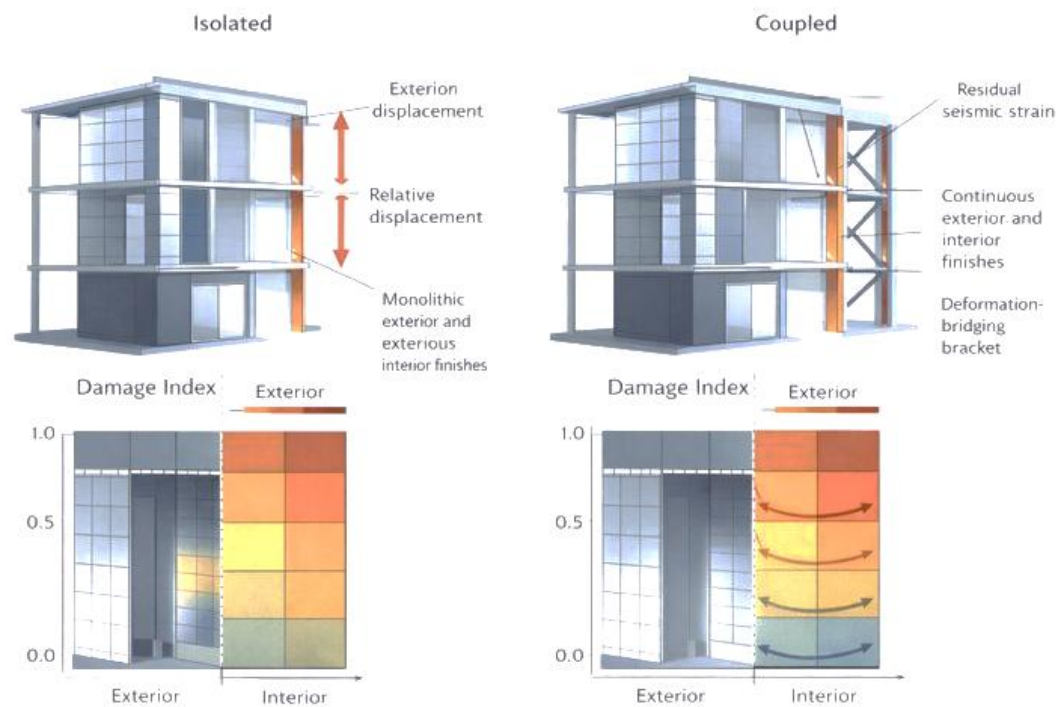


Figure 3. Execution-induced constraint mapping between continuous architectural systems and prescribed inter-frame bracing configurations

Figure 3 illustrates that architectural continuity systematically introduces unintended stiffness paths and displacement suppression mechanisms, particularly at façade–frame interfaces and interior finish junctions. These constraints directly affect the feasibility of maintaining the separation conditions assumed in the regulatory framework. The third group of results quantifies constructability-

driven deviations between intended and effective structural behavior. This comparison is performed across the representative execution scenarios defined in the Methodology, highlighting behavioral shifts induced by on-site modification, partial implementation, or omission of bracing elements.

Table 5. Comparative assessment of intended versus effective seismic behavior across reconstructed execution scenarios

Execution Scenario ID	Intended Behavior (Design Assumption)	Seismic (Design)	Effective Behavior (Execution Reality)	Seismic	Dominant Deformation Mode	Force Redistribution Pattern	Degree of Structural Coupling	Behavioral Deviation Level
S1	Fully independent adjacent frame response	Independent frame	Independent response preserved		Free relative displacement	Frame-specific load paths	None	Negligible
S2	Drift reduction without interaction	Frame	Limited interaction through finishes		Restricted relative displacement	Partial load sharing	Low	Low
S3	Controlled redistribution via bracing	Force	Unintended stiffness coupling		Suppressed joint movement	Cross-frame force transfer	Medium	Medium
S4	Deformation compatibility detailing	Via	Deformation suppression by finishes		Localized strain concentration	Altered load paths	Medium	High
S5	Enhanced stiffness with independence	Frame	Composite frame action		Global deformation constraint	Unified load path	High	Very High
S6	Predictable seismic response		Irregular and path-dependent behavior		Mixed deformation modes	Unstable redistribution	High	Very High
S7	Managed increase in stiffness		Semi-controlled composite behavior		Partial compatibility	Condition-dependent transfer	Medium	Medium
S8	Designed behavior realized on site		Execution-dominated behavior		Unintended constraints	Non-designed load paths	High	Very High

The results reported in Table 5 demonstrate consistent discrepancies between analytically assumed behavior and effective structural response. In scenarios characterized by fully integrated architectural finishes, inter-frame bracing is shown to promote unintended composite action, contradicting the assumption of

independent frame response. To visualize the behavioral divergence identified in Table 4, a comparative graphical representation is introduced. This representation emphasizes the transformation of load paths and deformation patterns under constructability constraints.

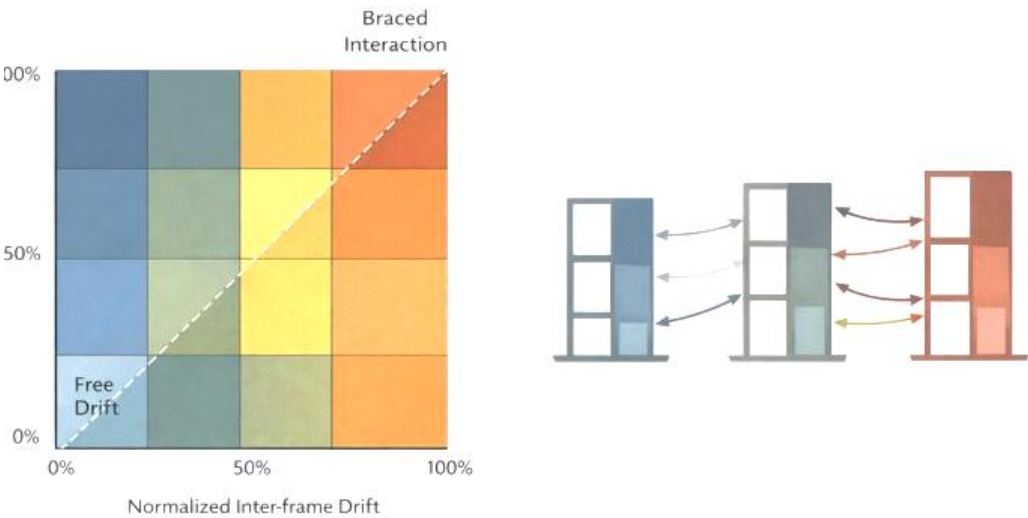


Figure 4. Comparative visualization of intended seismic load paths versus execution-induced effective load paths in adjacent frames

Figure 4 highlights the emergence of alternative force redistribution mechanisms that are not explicitly accounted for in the seismic design models. These mechanisms arise from suppressed separation and enforced compatibility introduced by architectural systems. The fourth group of results synthesizes

regulatory intent, execution conditions, and effective behavior into a constructability-based consistency evaluation. This synthesis directly corresponds to the evaluation matrix established in the Methodology section.

Table 6. Constructability-based consistency outcomes for inter-frame bracing provisions across architectural integration levels

Architectural Integration Level	Regulatory Intent	Dominant Execution Constraint	Effective Structural Behavior	Consistency with Design Assumptions	Seismic Performance Reliability	Overall Constructability Validity
Low integration (discrete façade and finishes)	Frame independence with optional bracing	None or negligible	Intended independent frame behavior	High	High	Valid
Low–moderate integration	Drift control without coupling	Limited joint restraint	Slight interaction between frames	Medium–High	Medium–High	Conditionally valid
Moderate integration	Enhanced stiffness with separation	Concealed or bridged separation	Partial composite action	Medium	Medium	Marginal
Moderate–high integration	Controlled force redistribution	Rigid façade substructures	Unintended stiffness coupling	Low	Low–Medium	Weak
High integration (continuous façade and finishes)	Coexistence of bracing and separation	Elimination of effective separation	Composite multi-frame behavior	Very Low	Low	Invalid
High integration with on-site adaptation	Designed behavior preserved	Construction-stage modifications	Unpredictable load paths	Very Low	Very Low	Invalid
Architecturally constrained designs	Managed stiffness increase	Finish-driven detailing	Semi-controlled composite response	Medium	Medium	Conditionally valid
Execution-dominated realization	Design intent maintained	Execution overrides detailing	Non-designed seismic response	Very Low	Very Low	Invalid

Table 6 indicates that construct validity decreases systematically as the level of architectural integration increases. Provisions that remain theoretically sound under ideal separation conditions exhibit reduced behavioral validity when applied to buildings with continuous façades and rigid interior finishes. To further clarify the decision-making dynamics underlying these outcomes, the results

include an analysis of the shift in responsibility from design to construction stages. Finally, an integrative results visualization is presented to consolidate the relationships between regulatory assumptions, constructability constraints, and seismic behavior outcomes.

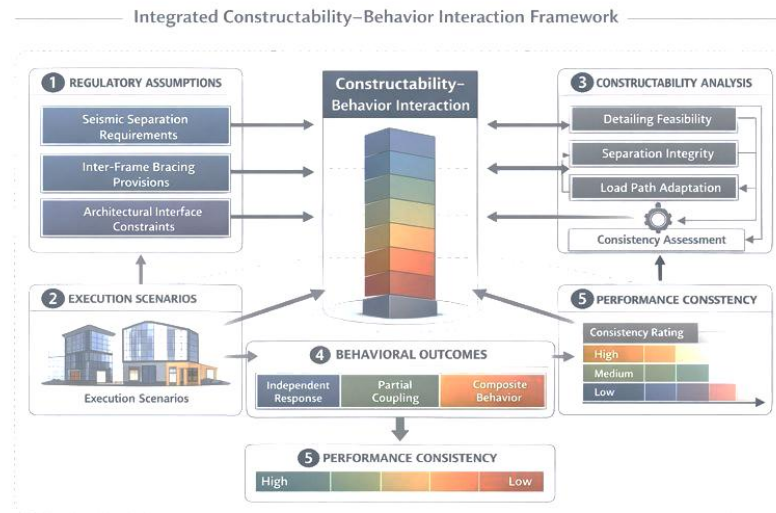


Figure 5. Integrated constructability–behavior interaction framework derived from regulatory and execution-based results

Figure 5 provides a comprehensive overview of how inter-frame bracing provisions evolve from codified intent to effective seismic behavior under real construction conditions. This framework serves as the direct empirical foundation for the subsequent Findings and Discussion sections. Collectively, the results establish a coherent and traceable evidence base demonstrating that the effectiveness of inter-frame bracing provisions is highly contingent upon constructability conditions. The reported outcomes remain strictly descriptive and analytical, ensuring a clear transition to findings-based interpretation without premature theoretical synthesis.

5. Findings

The findings of this study emerge directly from the structured results presented in the preceding section and reflect a systematic synthesis of regulatory intent, execution conditions, and effective seismic behavior. Rather than reiterating reported outcomes, this section distills the underlying patterns, causal relationships, and behavioral implications revealed through the constructability-based evaluation framework. A primary finding of the study is the identification of a persistent mismatch between the behavioral assumptions embedded in inter-frame bracing provisions and the physical realities of buildings with integrated architectural systems. While seismic regulations implicitly assume that adjacent frames can remain both braced and functionally separated, the results demonstrate that this dual requirement is rarely achievable under common execution conditions. Continuous façades and rigid interior finishes consistently suppress the deformation mechanisms necessary to preserve frame independence, thereby undermining the analytical premises of inter-frame bracing.

A second major finding concerns the role of architectural systems as unintended structural modifiers. The results reveal that

architectural continuity does not merely interfere with detailing but actively alters seismic load paths and deformation compatibility. In multiple execution scenarios, finishes and cladding systems effectively participate in force transfer, enforcing composite behavior between frames that were analytically treated as independent. This behavior represents a fundamental shift from the intended seismic response and highlights the inadequacy of treating architectural components as behaviorally neutral. The findings further indicate that constructability constraints systematically displace critical seismic decision-making from the design stage to the construction stage. When regulatory provisions fail to address execution-level conflicts, practitioners resolve these conflicts on-site through informal modifications. Such adjustments, while often successful in preserving visual and functional continuity, introduce uncontrolled variability into the seismic behavior of the structure. This finding underscores that the observed behavioral deviations are not incidental but structurally embedded consequences of regulatory omission.

Another key finding relates to the conditional validity of inter-frame bracing as a seismic enhancement strategy. The results demonstrate that inter-frame bracing retains behavioral validity only under narrowly defined conditions where effective separation, deformable interfaces, and controlled detailing can be maintained. As the level of architectural integration increases, the seismic effectiveness of inter-frame bracing diminishes and may even become counterproductive by amplifying unintended force transfer and damage concentration. The analysis also reveals a gradational relationship between architectural integration and behavioral divergence. Rather than a binary distinction between compliant and non-compliant behavior, the findings show a continuous spectrum in which incremental increases in façade rigidity and finish continuity progressively erode the assumptions of seismic separation. This gradation suggests that constructability should be

treated as a continuous variable within seismic evaluation, rather than as a secondary constraint addressed through detailing alone.

Importantly, the findings clarify that the identified inconsistencies do not stem from isolated execution errors or poor workmanship. Instead, they arise from a structural incompatibility between regulatory abstraction and construction reality. Even when executed with high technical quality, buildings with integrated architectural systems inherently constrain the deformation mechanisms assumed in inter-frame bracing provisions. This insight reframes the problem from one of compliance enforcement to one of theoretical and regulatory coherence. The cumulative

findings directly address the research question posed in this study. They demonstrate that, under prevalent architectural and construction conditions, inter-frame bracing provisions prescribed in Iranian seismic regulations cannot be assumed to remain behaviorally valid without explicit constructability integration. The effective seismic interaction between adjacent frames is therefore governed as much by architectural execution as by structural design intent. To visually consolidate these findings, two synthesis-oriented figures are introduced. These figures do not present new data but abstract the observed patterns into interpretable behavioral models.

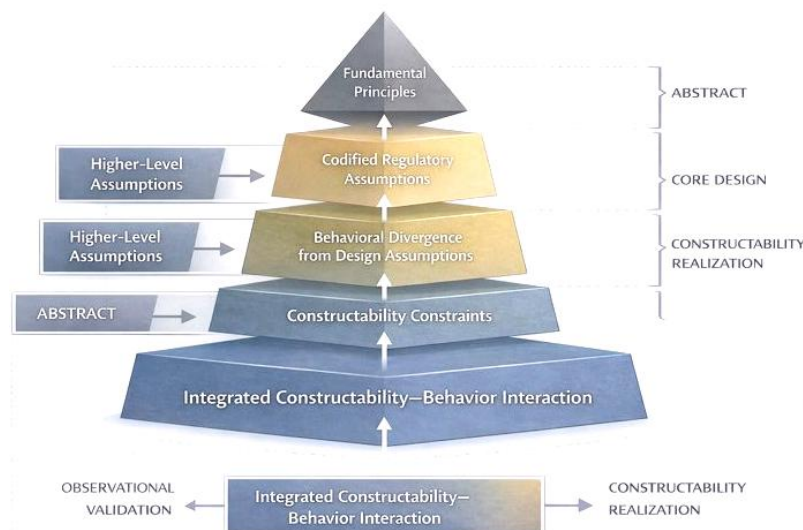


Figure 6. Conceptual hierarchy linking regulatory assumptions, constructability constraints, and observed seismic behavior outcomes

Figure 6 presents a hierarchical synthesis of the study's findings, demonstrating how regulatory assumptions are filtered through constructability conditions to produce the effective seismic behavior observed in practice. This hierarchy provides a clear conceptual bridge between the reported results and the broader implications discussed in the subsequent section. Collectively, these findings establish that the seismic performance of inter-frame bracing systems cannot be evaluated independently of architectural execution conditions. The evidence indicates that constructability is not a peripheral concern but a governing factor that directly determines the behavioral validity of seismic code provisions in contemporary building practice.

6. Discussion

The purpose of this Discussion is to reinterpret the findings of the study within the theoretical framework established earlier and to clarify how the results collectively address the central research question. Rather than reiterating empirical outcomes, this section situates the observed constructability-driven behaviors within broader seismic design principles, regulatory logic, and system-level performance expectations. A fundamental theoretical assumption underlying seismic design regulations is that prescribed structural mechanisms, once implemented, will generate the intended behavioral response under earthquake excitation. The findings of this study challenge the unconditional validity of this assumption in the specific context of inter-frame bracing applied to buildings with integrated architectural systems. While inter-frame

bracing is theoretically conceived as a controlled means of enhancing lateral resistance, the discussion reveals that its effectiveness is highly contingent upon the preservation of structural separation and deformation freedom—conditions that are systematically constrained in real construction practice.

From a theoretical standpoint, the findings reaffirm the centrality of structural separation as a governing seismic principle rather than a secondary detailing consideration. The observed suppression of relative displacement between adjacent frames due to continuous façades and rigid interior finishes directly contradicts the deformation compatibility assumptions embedded in inter-frame bracing provisions. This incompatibility implies that the analytical boundary conditions assumed during seismic modeling are frequently violated in execution, thereby eroding the behavioral validity of the design process itself. The discussion further highlights that architectural systems function as active participants in seismic behavior rather than passive enclosures. The reinterpretation of Findings indicates that continuous cladding and finishes introduce unintended stiffness paths and force transfer mechanisms, effectively transforming the structural system into a composite assembly. This emergent behavior is not inherently detrimental in all cases; however, it becomes problematic when it occurs outside the scope of analytical consideration and regulatory acknowledgment. The lack of explicit recognition of this interaction within seismic provisions creates a blind spot in performance prediction.

A critical contribution of this study lies in reframing inter-frame bracing not as an isolated structural enhancement, but as a regulatory construct whose validity depends on constructability coherence. The discussion reveals that the mismatch between regulatory abstraction and execution reality is not accidental but systemic. Regulations articulate behavioral intent at a level of abstraction that implicitly assumes architectural neutrality, whereas contemporary building practice inherently violates this assumption through integrated design strategies. This systemic misalignment explains why inter-frame bracing is frequently modified or compromised during construction, even in projects executed with high technical competence. The findings also prompt a reevaluation of how seismic reliability is conceptualized. Traditional approaches prioritize analytical rigor and compliance with codified provisions, often equating regulatory adherence with safety assurance. The discussion demonstrates that compliance alone is insufficient when the prescribed systems cannot be faithfully executed. Seismic reliability must therefore be understood as a function of both theoretical adequacy and constructability feasibility. When these dimensions diverge, the realized seismic behavior reflects execution constraints rather than design intent.

Another important interpretive insight concerns the transfer of decision-making authority from design to construction stages. The discussion clarifies that unresolved conflicts between seismic provisions and architectural continuity are routinely deferred to on-site resolution. This transfer introduces variability that is neither modeled nor regulated, effectively placing seismic performance outcomes outside the formal design framework. The findings suggest that such variability is not a matter of isolated professional judgment but a predictable consequence of regulatory under-specification. In addressing the research question, the discussion confirms that inter-frame bracing provisions prescribed in Iranian seismic regulations cannot be assumed to remain behaviorally valid under prevalent architectural conditions. The constructability mismatch identified throughout the study directly influences the effective seismic interaction between adjacent frames, leading to composite behavior, altered load paths, and modified damage mechanisms. This conclusion is not derived from speculative reasoning but from a systematic alignment of regulatory intent, execution scenarios, and observed behavioral outcomes.

The broader implication of this discussion is that seismic code development must move beyond purely analytical optimization toward integrative frameworks that explicitly incorporate constructability and architectural interaction. This does not necessitate abandoning established seismic principles, but rather refining their application boundaries and explicitly defining conditions under which their assumptions hold. Inter-frame bracing, as demonstrated in this study, serves as a representative example of how otherwise sound theoretical mechanisms can lose validity when detached from execution realities. Importantly, the discussion does not argue against the use of inter-frame bracing per se. Instead, it emphasizes that its deployment must be context-sensitive and accompanied by explicit guidance on architectural separation, finish detailing, and deformation accommodation. Without such integration, the regulatory prescription risks becoming a nominal compliance requirement rather than a reliable performance strategy.

Finally, the discussion positions the present study as a methodological contribution to seismic research. By adopting a constructability-based critique rather than a solution-driven approach, the study demonstrates a pathway for evaluating seismic provisions that respects both theoretical rigor and practical feasibility. This approach enables a more nuanced understanding of seismic performance that aligns regulatory intent with the realities of contemporary construction practice. Through this integrated reinterpretation of theory and findings, the study conclusively demonstrates that the central research question has been addressed. The analysis confirms that constructability constraints fundamentally condition the behavioral validity of inter-frame bracing provisions and that meaningful seismic performance assessment must account for this interaction explicitly. This conclusion establishes a coherent foundation for the conclusions and recommendations presented in the subsequent section.

7. Conclusion

This study set out to examine the behavioral and constructability validity of inter-frame bracing provisions prescribed in Iranian seismic regulations, with a focus on their application to buildings characterized by continuous façades and integrated interior finishes. Through a sequential methodology encompassing regulatory analysis, execution scenario reconstruction, and constructability-based behavioral evaluation, the research has conclusively demonstrated that the effectiveness of these provisions is strongly dependent on conditions of execution that are rarely attainable in contemporary architectural practice.

The findings collectively reveal that the theoretical and regulatory assumptions underlying inter-frame bracing—namely, the coexistence of lateral stiffness enhancement and structural independence—are not simultaneously achievable in most real-world applications. Continuous architectural systems inherently constrain the deformation freedom that seismic theory presumes for adjacent frames, thereby inducing unintended stiffness coupling and force transfer. As a result, the analytical premises of inter-frame bracing, though mechanically sound in isolation, lose behavioral validity when transposed into built environments governed by architectural continuity and constructability constraints. From a regulatory perspective, the study concludes that current seismic provisions inadequately address the interface between structural and architectural systems. By omitting explicit execution-level guidance for integrating bracing with expansion joints, cold joints, and façade detailing, the regulations inadvertently shift critical performance decisions from the design stage to the construction stage. This displacement introduces uncontrolled behavioral variability, undermining the predictability that seismic design codes are intended to ensure.

Conceptually, the research advances the argument that seismic reliability cannot be guaranteed solely through analytical rigor or regulatory compliance. True reliability emerges only when theoretical adequacy and constructability feasibility converge. The present investigation, therefore, reframes constructability not as a peripheral constraint but as a central determinant of seismic performance. This shift in perspective underscores the need for

regulatory frameworks that are not only analytically robust but also executively attainable.

Practically, the study establishes that inter-frame bracing retains behavioral validity only under conditions where architectural separation is explicitly maintained and deformation compatibility is preserved. When these conditions are compromised by integrated façade and finish systems, inter-frame bracing may become counterproductive, amplifying localized damage and distorting force redistribution mechanisms. The observed behavioral transformations highlight the necessity for adaptive design guidelines that define permissible degrees of architectural integration without invalidating structural assumptions. The broader implication of this research is that the relationship between seismic code provisions and construction practice must be reconceptualized as an interactive continuum rather than a one-directional prescription. Future code development should incorporate explicit constructability criteria, cross-disciplinary detailing standards, and performance-based validation procedures to ensure that prescribed mechanisms can achieve their intended behavior under realistic architectural conditions. Integrating these considerations into seismic regulation will enhance both design reliability and post-construction safety.

At a theoretical level, this work contributes to the ongoing discourse on the behavioral validity of regulatory mechanisms in seismic design. It introduces constructability as a critical variable linking structural theory, regulatory formulation, and practical execution. At a methodological level, it demonstrates the efficacy of qualitative-analytical frameworks for assessing the alignment between codified intent and realizable performance. Together, these contributions provide a replicable model for similar evaluations in other regulatory contexts and structural systems. In conclusion, the study affirms that the central research question has been definitively addressed: inter-frame bracing provisions, as currently codified, cannot be assumed to maintain behavioral validity in the presence of architectural and constructability constraints. Seismic reliability thus depends not only on structural design competence but equally on regulatory awareness of execution realities. Bridging this divide represents both the principal challenge and the principal opportunity for the next generation of seismic code development and performance-based design practice.

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