Online Exclusive

Lessons Learned from Building Enclosure Delegated Design Disasters

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This paper was presented at the 2023 IIBEC Building Enclosure Symposium.

INTRODUCTION

As a means of achieving higher quality control, expedited installation, and adapting buildings for their next phase of use, more and more building enclosure systems are prefabricated and consolidated, and their designs require higher performance than ever before. Simply put, the building enclosure is no longer simply keeping water (liquid and vapor) out and achieving the overall exterior aesthetic while other systems manage the thermal, structural, and hygrothermal aspects of the overall building performance. The modern building enclosure has evolved into a complex design that not only manages and transfers structural loads while accommodating the permanent and dynamic main frame structural and thermal movements. The enclosure systems are also controlling the transfer of water vapor, managing liquid water, achieving the thermal performance to ensure occupant safety and comfort, all whilst providing an aesthetically beautiful, sustainable, and durable building enclosure.

For complex building enclosure systems, their overall design is often delegated to trades with specialized expertise and is typically performed under the trade responsible for their installation.[2] Common delegated-design systems include architectural precast panels, curtainwall systems, dimension stone cladding, metal or composite wall panels, fabric membrane roof systems, panelized roof systems, green/blue/purpose roof systems, etc. As the delegated design is independent from the coordinated building design that is performed under the supervision of the Designer-of-Record (DOR), the DOR does not assume the responsibility of the proper integration of the system's design with other systems of the building. Therefore, the system's delegated design is responsible for the integration with the other building systems. In most jurisdictions, only a portion of the actual delegated design requires a licensed design professional. As a result, an engineer contracted under the specialty trade typically provides structural design, which includes thermal and other movement accommodations. However, the other performance requirements, such as water-penetration and air-infiltration management, hurricane resistance, and specialty performance (such as fire, flood, and blast protection), are not the responsibility of a licensed professional. Instead, system performance testing (manufacturer or project specific) is compared to the performance requirements established by the building's DOR, and if it meets or exceeds them, then the system is accepted for incorporation into the building design.[3]

Herein lies a fatal flaw. Ultimately, the system's delegated design does not have a licensed professional responsible for its overall performance. The delegated design engineer is typically only responsible for a portion of the system's design; however, the entire system's performance is critical to the health and safety of the occupants and the public.[4] In addition, the trade responsible for efficient and effective system installation to achieve the project cost and schedule is also responsible for the system's design, resulting in a conflict of interest and requiring additional design coordination. Further, modification of a tested standard system or customization of a tested fabrication/installation that deviates from the standard means and methods must be vetted to understand possible impact on the system's previously tested performance. If

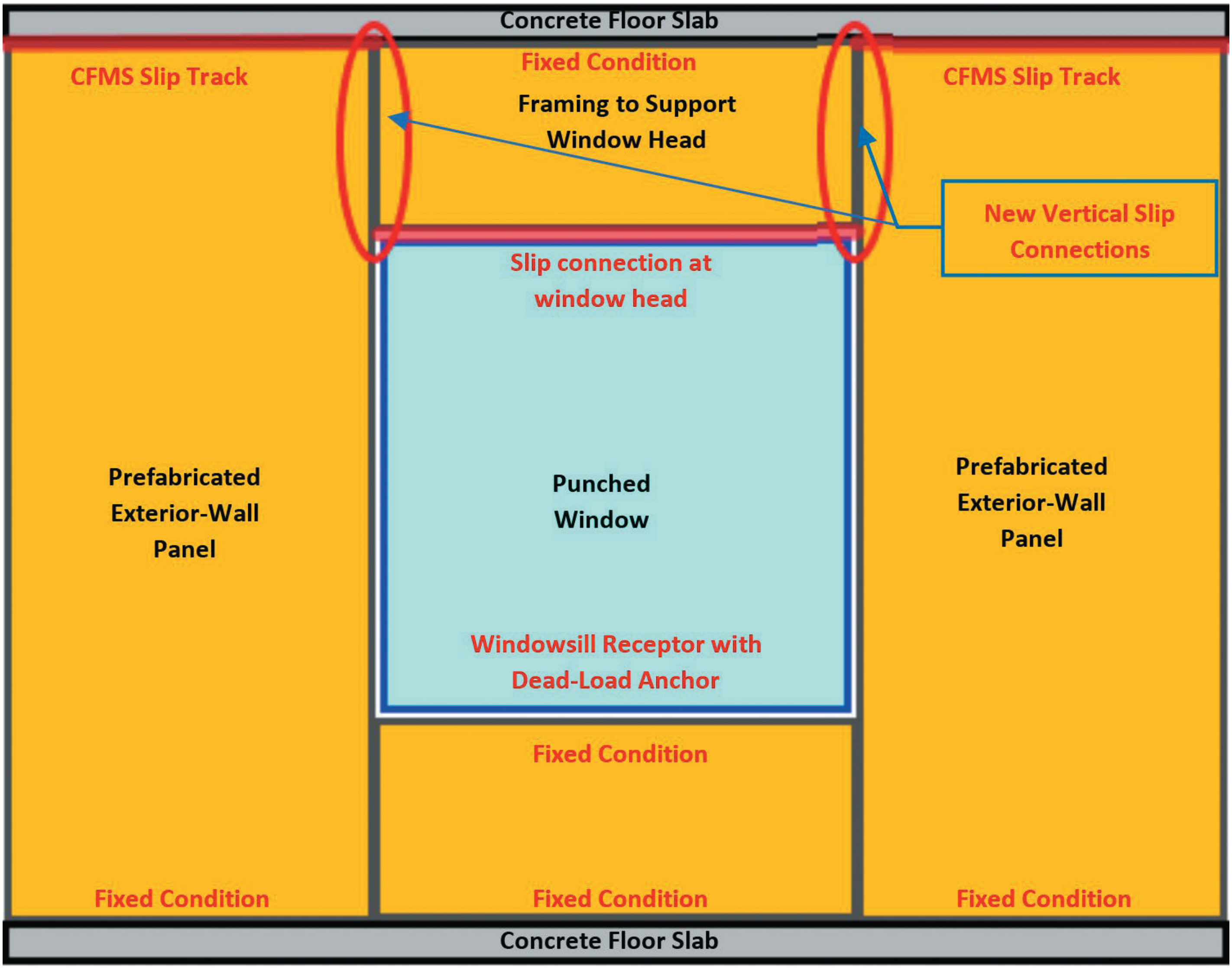

Figure 1. *Configuration of typical premanufactured exterior wall framing panel and punched window between floor lines with resulting unresolved vertical differential movements (circled).*

system customizations and modified means and methods are not integrated within the delegated design, then there can be significant consequences, the direst of which are structurally unstable systems or systems that don't meet the DOR's design requirements. This article discusses the complexity of modern building enclosure design and the possible problems resulting from complex delegated designs and their increased expectations for installation and performance through a series of case studies from the authors' personal experience.

CASE STUDY 1

Located in Texas, this building is a 32-story luxury residential high-rise with a concrete-framed structure containing 274 apartments. To meet an accelerated project schedule, prefabrication was considered for the building cladding and fenestration systems. As it was not feasible to prefabricate the traditional brick cavity wall veneer required for construction in the historic district where the building was located, the decision was made to prefabricate the exterior cold-formed metal stud (CFMS) framed walls, exterior sheathing, and air barrier, as well as the punched windows and window-wall systems. Therefore, once the prefabricated exterior backup walls and fenestrations were in place, the building would be dried in to accelerate the finish-out process.[5] However, as the delegated design of each prefabricated system was left to its respective team (the curtainwall contractor and the framing contractor), there was a lack of coordination that resulted in conflicts related to system performance and ultimately caused schedule delays for the project. Both the prefabricated exterior walls and fenestration systems were designed to accommodate movement as well as construction installation tolerance with movement joints along each floor line. The premanufactured framed exterior-wall panels (**Fig. 1**) were designed to fit between the floor lines with allowance for movement and construction tolerance at the head condition. For the punched windows, the same provisions were provided at the window heads. As the premanufactured components were submitted as two separate submittals, it was not apparent that the provisions for each conflicted with one another and resulted in a design issue that was not discovered until installation was underway. Specifically, it became apparent that to achieve proper load transfer from the punched windows, the

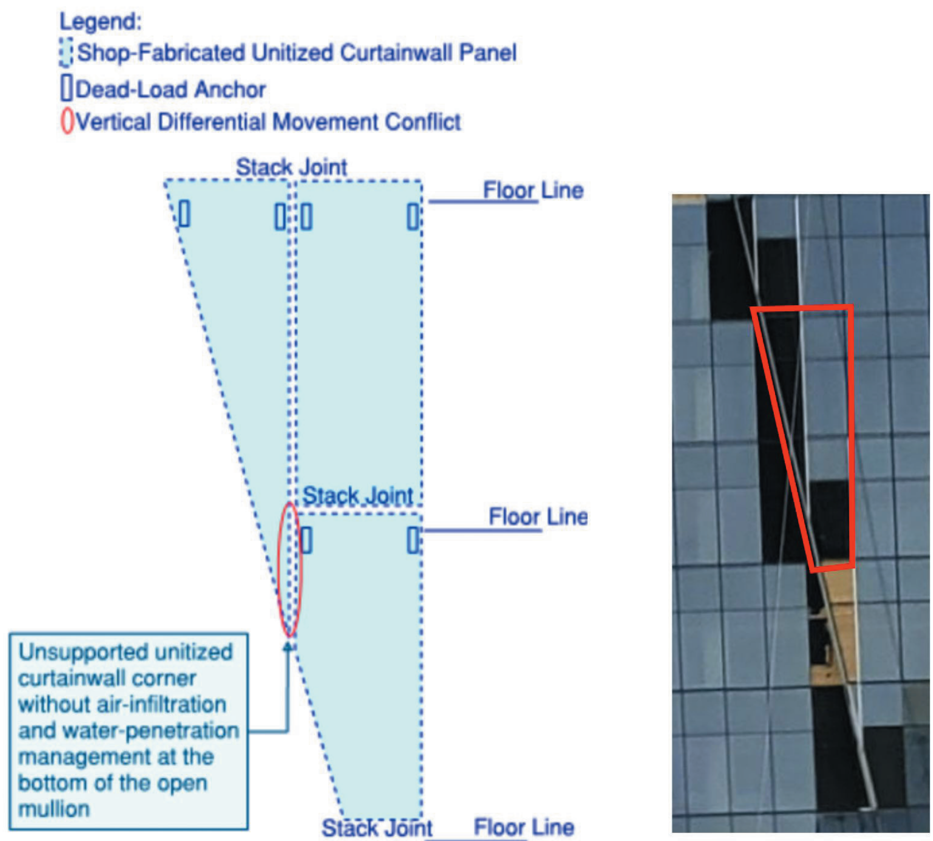

Figure 2. *Unitized curtainwall panelization layout on the left showing a triangular panel bypassing the floor line where the typical panel stack joint accommodates the installation tolerance and movements (see the resulting movement conflict along the two-part mullion circled). Photograph of the missing bypass panel on the right.*

framing supporting the window head required anchorage to the base of the overlying slab. However, the adjacent exterior-wall framing at each side was supported at the slab below. As a result, there was no provision for movement between the prefabrication framed panels and the framing supporting the window heads. To address the resulting movement between the two locations within each level, a new vertical slip joint at each side of the window head framing was required (circled in Fig. 1). The resulting redesign and rework to accommodate the coordination oversight between the adjacent systems caused increased project costs and schedule delays. This first case study provides an example of how independent delegated designs require proper integration to ensure the overall building enclosure performance.

CASE STUDY 2

This is a 19-story Class A office building in Texas, constructed as a part of a master-planned business district which includes aluminum and glass curtainwalls, metal panels, and architectural precast-concrete cladding systems with a signature angled feature on each building. The new tower consists of a concrete-frame structure clad with a unitized curtainwall system and metal wall panel accents, with an attached parking garage clad with architectural precast-concrete panels. The signature angled accents on three elevations are outset from the building face and supported by concrete framing and supplemental steel. The unitized curtainwall was a standard system by a large manufacturer that was customized to achieve the angled accent features and was modified by the installer for field-erection means and methods. The design was delegated to the curtainwall installer who retained an engineer to perform the structural design for the system. The engineer reviewed the curtainwall system shop drawings produced by the curtainwall installer to provide the associated framing and connection design. No fabrication or erection drawings were provided to the engineer. However, the curtainwall installer intended to splice adjacent units together side by side and across floor lines to achieve their desired panel erection layout. The result was unsupported/discontinuous triangular units that were omitted from the delegated design and were not coordinated with the adjacent components, supporting structure, building movements, and thermal expansion/contraction (**Fig. 2**) to achieve the project requirements. In addition, twin-span units were fabricated under the direction of the curtainwall installer to address constructability issues but were also omitted from the delegated design. Finally, the building design included entrance canopies, balconies, a garden roof plaza, and other horizontally intersecting features through the curtainwall. Like Case Study 1, floor-to-floor movements and thermal expansion/contraction changed between adjacent floor slabs at and adjacent to these features, resulting in conflicts for the continuity of vertical displacement between floor lines.

Other consequences resulted from the separation of the delegated design from the design team to that of the installer. The triangular glass units along the angled building features were not coordinated with the glass manufacturer's minimum dimensional production requirements. As a result, metal panels were utilized in lieu of glazing, which significantly impacted the overall building aesthetic along the signature angled features of the building facade. Also, the cut framing elements at the triangular units resulted in open and discontinuous framing intersections that did not conform to the manufacturer's tested curtainwall assembly for air-infiltration and water-penetration management of the standard curtainwall system.

Finally, where the triangular panels were spliced to panels at the overlying or underlying floor, the triangular panel was laterally unsupported and obstructed the adjacent continuous stack joint's movement and drainage above the floor line. Finally, the engineering requirements for the maximum framing spans, cantilevered framing distances, connection requirements, and fastener requirements were not coordinated between the engineered calculations and the field installation. As a result, following curtainwall installation, every framing span/cantilever, connection, and anchor required inspection for the entire project. Subsequently, many conditions were outside of the tolerance of the engineering requirements and required field modifications.

The delegated-design engineer was solely focused on the structural performance of the curtainwall without an understanding

Figure 3. *Excessive deflection of twin-span unitized curtainwall during erection.*

of the unit fabrication and erection layout, building features, and the corresponding structural movements and thermal expansion/contraction. Additionally, because the installer failed to coordinate between the installation and engineering requirements, field conditions did not meet the engineering requirements. Extensive repair design and field alterations were required to remediate the curtainwall system, which led to significant project cost and schedule overruns. This resulted in an unvetted, custom system that no longer resembled the standardized manufacturer system (that met the project requirements), and the curtainwall aesthetics did not meet the architect's and owner's desired intent for an integrated aesthetic of the master-planned business district. This case study serves as an example that delegated designers are responsible for the overall system design. The lack of coordination between the installer and its delegated designer can result in design deficiencies and construction defects that fail to meet the design intent.

SAMPLE STUDY 1: TRANSPORT AND INSTALLATION

In addition to design considerations for shop fabrication and field installation, the process of transportation, handling, and erection may also impact the delegated design of prefabricated building enclosure systems. For example, twin-span precast unitized curtainwall undergoes significant loading during transport and erection (**Fig. 3**). These loads can result in excessive deflections that can cause permanent deformation or breakage of the unit's components.

For architectural precast concrete and other large, unitized components (such as mega panels), the engineered panel size and layout must be coordinated with the erection methods, including crane capacity. Crane weight limitations may limit panel shapes and sizes, which can impact the overall aesthetic; therefore, coordination is necessary before the finalization of the delegated design. Another aspect commonly requiring delegated-design coordination is for installation of other adjacent systems. For example, large structural elements such as continuous concrete shear walls that bypass several floor and column lines will obstruct access for installation of the interior continuous-insulation and air-barrier systems. Also, the placement of panel structural connections should undergo review prior to finalizing the delegated design. Often, the delegated designer is more focused on the constructability and structural performance of the system and less concerned with the impact on the air- and water-management performance. Therefore, if not coordinated properly, flashing or integration between systems may be negatively impacted. A common example is with perimeter dual-joint sealants that are obstructed or discontinuous as a result of structural embed or connection placement. These examples illustrate that while delegate designers are not part of the design team, their designs still require coordination with the overall design.

SAMPLE STUDY 2: ROOF DECKS

During standard planned reroofing operations of a major hospital campus in the Texas Medical Center, review of the existing roof deck confirmed that while the new roof system was a manufacturer-tested assembly complying with the latest code-required wind-uplift pressures, the existing roof deck, which had been in place for over 50 years, was unable to meet the same requirements. Further engineering review confirmed that the metal roof decks throughout the campus required significant modification to accommodate the increased uplift capacity of modern codes; however, many of the roofs had already undergone replacement in the recent past. As a result, retrofit of the existing roofs at metal roof deck locations was required to enhance the roof deck capacity at corner and sometimes perimeter zones. On another Texas Medical Center reroof project, an evaluation for the removal of abandoned rooftop equipment confirmed that the incorporation of so many rooftop penetrations had compromised the shear diaphragm capacity of the roof deck. The evaluation also revealed significant areas of roof deck corrosion requiring replacement. The result was complete roof deck replacement and additional support at corner and perimeter zones, significantly impacting the overall project scope, budget, schedule, and hospital operations. These projects serve as a lesson learned that routine maintenance should include an engineer review to ensure that the roof deck or components supporting the roof system are able to meet the increased demands of modern building codes (and insurance requirements).

RECOMMENDATIONS

The following provisions, when properly coordinated and integrated with the project scope, have proven successful to mitigating delegated-design disasters.

1. Include building enclosure commissioning within the project scope from the conceptual design phase forward.
2. Incorporate specialty engineering design peer review for complex building enclosure delegated designs.
3. Perform third-party special inspections at the fabrication facility and in the field to support installer quality control and quality assurance (if not already required by the authority having jurisdiction).

Incorporate the following project requirements to ensure that the delegated

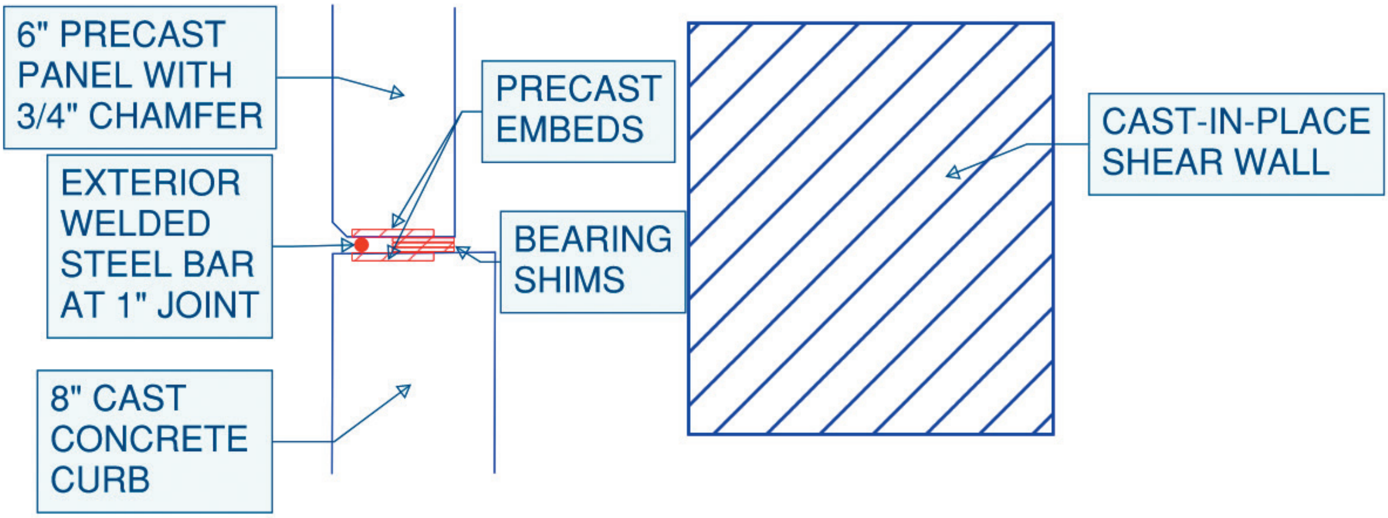

Figure 4. *Excessive deflection of twin-span unitized curtainwall during erection.*

design is comprehensive and coordinated with the other project requirements.

1. Loads: In addition to dead, wind, seismic, and other project-in-service loads, include the following:
   a. Transport- and erection-load analysis reflecting dynamic transport and erection methods
   b. Maintenance loads including at intermittent stabilization anchors and along horizontal projecting elements (such as sunshades)
   c. Sufficient load transfer and accommodation of movement across movement/expansion joints
   d. Inclusion of associated requirements, such as those for supplemental framing
2. Delegated-design engineering package: Professional engineer–sealed, coordinated, and comprehensive set, including structural calculations (framing, glazing, and structural-sealant glazing), shop-fabrication drawings and instruction, and field-elevation panelized layout and installation instructions. The field-elevation panelized layout should include the outline of each panel (single span, twin span, spliced-multiple wide units, etc.), dead-load and live-load anchor locations, clear indication for each starter and stack joint locations, etc.).
3. Delegated-design requirements: Coordination with other performance requirements, including but not limited to the following:
   a. Structural-engineering movements (creep, dead loads, live loads, etc.)
   b. Structural-engineering or wind-tunnel components and cladding pressures
   c. Review of complete and final delegated design to ensure system meets specified requirements (water management, air management, thermal, energy, fire, sound, etc.).
   d. For existing buildings, confirmation of as-built construction with updated code-required loads and associated requirements (area of openings, projectile risk, increased loads/ pressures, etc.)
4. Manufacturer's certification letter: Project-specific letter from the manufacturer (framing, glazing/infill system, structural-sealant glazing, etc.) certifying their review of the delegated-design engineering package to ensure that the system will meet the specified project requirements.
5. Site-inspection requirements for existing buildings:
   a. Confirmation of as-built construction
   b. Confirmation of existing conditions (distress, damage, etc.)
   c. Evaluation of as-built, existing capacity and coordination with requirements (including additional requirements such as shear diaphragm, shear walls, etc.)

Finally, during construction, include the following provisions.

1. Delegated-design meeting(s): Between the delegated-design team (specialty trade/installer and their engineer), owner, general contractor, structural engineer, architect, building enclosure consultant (prior to fabrication), and related manufacturers.
2. Field-erection set: Provide a set of field-installation/erection drawings that include the actual layout, dimensions, spans, anchor types, anchor requirements. The set should include the following:
   a. Maximum spans and cantilever framing lengths (anchor to stack/parapet/soffit hang-down, etc.) per system type/ component type
   b. Connection requirements, including maximum eccentricity (of anchors/ hooks), maximum shim depth/height, etc., for each connection and/or anchor (embedded versus field installed) type
   c. Fastener requirements, including minimum edge distances, minimum embedment depths, required torque, minimum thread engagement, etc.
   d. Allowable field modifications (such as cutting of lifting lugs) to accommodate setting of units
3. Quality control and quality assurance: Pre-fabrication laboratory performance mockup testing for custom or modified standard systems:
   a. Shop-fabrication inspections, including compliance with manufacturer's requirements
   b. Field verification of structural dimensions prior to installation (spans, embed locations, etc.)
   c Pre-setting inspection of units (for proper unit fabrication and confirming no damage)

d Post-setting inspection of units (for proper integration between units, stack/starter seal installation, etc.)
e. Fastener inspections to ensure compliance with requirements
f. Field air-infiltration and water-penetration testing

4. As-built set: Provide as-built record set, including all field fixes and supporting documents.

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