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A Road Map to Structural Alterations in the International Existing Building Code

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In a climate of constantly evolving building technologies and codes, the field of preservation faces the challenge of updating historic buildings to meet modern standards for occupancy. As buildings are upgraded for any number of reasons, including occupant comfort, energy performance, and changing code requirements, it is up to practitioners in the fields of design and preservation to adapt existing structural systems to enable historic buildings to meet modern needs. While such upgrades to meet code requirements can be costly and result in a significant loss of historic fabric, developing a thorough understanding of the design and performance requirements of the building code early in the design process allows owners and professionals to make informed decisions to optimize cost, schedule, and preservation considerations. Developing a comprehensive understanding of the code implications of design decisions early in a project allows the team to be proactive rather than reactive, and it can yield a dramatic payoff through the reduction of required structural interventions and retention of a building's historic integrity.

Impacts of Structural Intervention

Not only can structural upgrades be onerous, impacting cost and construction schedule; they can also have significant impacts on historic building fabric. In order to increase the capacity of a structure, one must either reinforce the existing structural elements themselves or insert a new structural system to supplement or bypass the historic structural system. Each approach comes with its own considerations and complications.

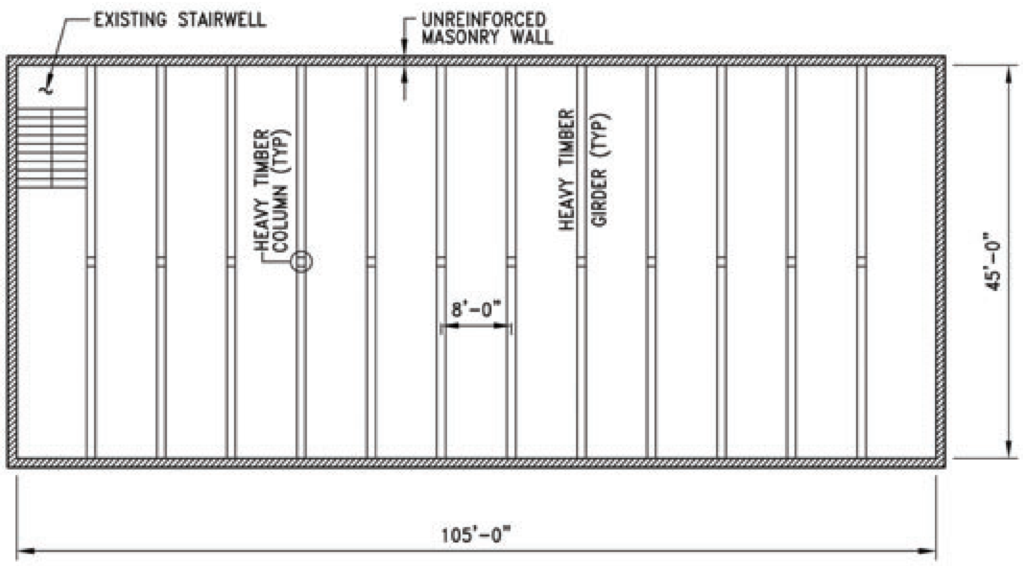


Fig. 1. *Hypothetical typical existing floor plan. All images by the authors.*

Reinforcing an existing structure could entail, for example, applying steel plates to the face of a heavy timber or steel beam or grouting solid a masonry wall. Reinforcing or strengthening allows the historic structural system to continue to serve as the load-carrying structure, frequently maintaining the load paths intended in the original construction, while providing the capacity needed to meet modern loading requirements. These interventions require an understanding of the performance of the existing system and an evaluation of material properties and conditions. In many cases, structural reinforcing will not increase the footprint of the structural system within a building, allowing existing floor-to-ceiling heights and square footage to be retained. However, gaining access to historic structural elements can often require the removal and loss of finish materials and decorative elements, and the reinforcing is frequently an irreversible intervention.

Inserting new structural components could involve anything from adding joists within an existing wood floor to inserting a new structural steel frame within a masonry bearing-wall building. This approach either reduces the load that must be carried by the existing structure, as in the case where supplemental wood framing is added to a floor, or removes all load except for the self-weight from the existing structure, as can be the case with a new structural frame. Inserting new structural elements can have less impact on the existing structural fabric and can be reversible; however, the new structural system can occupy significant amounts of space within the building. Installation still requires the removal of existing finishes and can result in loss of historic fabric.

Designing to the International Existing Building Code

Reuse of existing buildings is typically governed by some variation of the International Existing Building Code (IEBC), which has been adopted in part or in whole by 41 states in the United States.[1] While the applicable edition of the code may vary by jurisdiction, the structural requirements have remained largely the same in the 2009 and 2012 editions. The IEBC provides alternate paths for existing buildings to achieve code compliance without demanding that they meet the requirements of contemporary codes written for modern building materials and current performance objectives. Within the IEBC, there is a series of forks in the road that lead to varying levels of structural-performance requirements; at a high level, these trigger points are related to the percentage of the building that is being renovated, the degree of alteration to the structural system, how much load the structure must carry, and how much the structure's ability to carry loads is affected. It is important to note that the IEBC contains numerous subclassifications and exemptions and that each jurisdiction may modify and interpret the code differently. The process described here for navigating the IEBC represents the most commonly encountered and most impactful code sections, but it is in no way an exhaustive guide to the IEBC.

The IEBC is organized around three primary compliance methods: Prescriptive, Work Area, and Performance. Historic buildings, roughly defined as buildings or structures that are listed at a local, state, or national level, are allowed additional exemptions from code requirements outside of these three compliance methods to accommodate preservation of historically significant structures. While these provisions are valuable and can be used strategically with historic buildings, many projects that qualify within this category still follow one of the primary compliance methods to provide higher levels of life safety and property protection.

The Prescriptive Method, as the name implies, is defined by a series of prescriptive measures that must be met to achieve compliance. This method is frequently conservative, as it must apply to a broad range of items without in-depth professional analysis. It is thus restrictive for major renovation projects, so it is typically more appropriate for superficial work. The Performance Method prioritizes life safety, including fire safety and means of egress; compliance is achieved by evaluating 19 safety parameters to establish the minimum degree of life safety.

The Work Area Method categorizes projects by the amount of existing fabric that is impacted, breaking them into three alteration levels. This method is commonly preferred for major renovation projects and is the basis of discussion below. Separating requirements by level of alteration and requiring analysis by design professionals allow the code requirements to become more refined and project specific than with the Prescriptive Method. The increasing alteration levels require that progressively more stringent requirements be met; the greater the percentage of existing building that is impacted, the nearer the building must come to compliance with contemporary International Building Code (IBC) requirements.

Within the Work Area Method, there are a number of trigger points that determine a project's compliance requirements. The first trigger point as outlined by the IEBC is what total percentage of floor area is being impacted within the scope of a project. This area is defined as the building's work area. The IEBC divides projects into Alteration Levels 1, 2, and 3, each of which has requirements defined by a separate IEBC chapter. The Alteration Level is determined by the type of work and the work area:

- Alteration Level 1 corresponds to projects limited to finishes and fixtures.

- Alteration Level 2 includes projects involving the reconfiguration of spaces or systems with a work area of less than 50 percent.
- Alteration Level 3 includes all projects for which the work area is greater than 50 percent.

These work areas determine the analysis requirements of the existing structure and required design loads and are thus important trigger points to be cognizant of early in design.

Within a Level 2 alteration, the next significant trigger point comes with increasing loading or decreasing the capacity of structural elements. For gravity elements (elements not resisting seismic or wind load, such as floor joists), if the stress in an element is increased by greater than 5 percent, either by increasing the load (perhaps a concrete-topping slab is poured over an existing floor) or by decreasing that element's load-carrying capacity by more than 5 percent, that element must be able to carry full IBC gravity loads. If the element does not have the capacity to carry IBC loading, it must be reinforced to that capacity. If the stress is not increased by more than 5 percent, no analysis is required.

For lateral elements within a Level 2 alteration, the trigger point is when the demand-capacity ratio of an element is increased by greater than 10 percent. The demand-capacity ratio is the ratio of the amount of load imposed on an element to the total load-carrying capacity of said element. This 10 percent increase could be caused by increasing the demand on an element: for example, by increasing the weight of a building, thereby increasing the seismic load or by decreasing the capacity of an element, as would occur if a large opening were cut into a floor that was acting as a diaphragm. If the 10 percent demand-capacity threshold is not exceeded, no analysis or upgrades are required. If an element's demand-capacity ratio is exceeded by 10 percent, it must comply with the requirements of Alteration Level 3, described below.

Alteration Level 3 changes must comply with requirements for Levels 1 and 2; in addition, requirements are determined not only by the Work Area, but also by the structural work area, which is the floor area involved in a structural alteration. This can be more complicated to calculate; for example, when cutting in a new elevator shaft, in addition to the area of the footprint of the shaft itself, any framing or diaphragm elements tributary to the structure that is being removed will also count towards the structural work area. The trigger point occurs when the structural work area is greater than 30 percent. If the structural work area is less than 30 percent, the work is considered a Limited Structural Alteration; if it is greater than or equal to 30 percent, it is a Substantial Structural Alteration.

In a Limited Structural Alteration, the trigger point is exceeding a 10 percent increase to the demand-capacity ratio of any lateral element. If no elements reach this 10 percent trigger, analysis must show that the altered structure complies with load requirements applicable at the time of original construction (frequently none apply) or at the time of the most recent substantial alteration. If a 10 percent increase in demand-capacity ratio is exceeded in any element(s), such element(s) must meet reduced IBC loads as described within the IEBC, in addition to the whole building complying with the original load requirements as described above.

In a Substantial Structural Alteration, analysis must show that the altered building complies with full gravity and wind loading and with reduced IBC seismic loading. Projects within this classification are likely to require significant structural upgrades.

One of the largest considerations in renovating an existing building is the potential need for a seismic upgrade. Providing a new seismic-reinforcing system can be costly, time consuming, and result in substantial loss of historic fabric. Buildings constructed before the adoption of modern building codes were not designed with lateral force-resisting systems as they are now thought of, and it can be difficult to identify a "lateral system" within existing structures that can resist contemporary load requirements. Unreinforced-masonry structures pose great challenges with regard to seismic loading. Masonry structures are heavy, which correlates to high seismic loads, and typically they are designed to perform primarily in compression, meaning they resist lateral loading less efficiently. In addition to these attributes, unreinforced-masonry construction is highly restricted within the IBC, and there are limited standardized material properties or approved methods of analysis for historic masonry bearing-wall construction typologies. The combination of these factors requires the use of the IEBC and creative engineering to make code compliance a possibility. Appendix A1 of the IEBC outlines seismic requirements for unreinforced-masonry systems and provides options for materials testing and analysis methods. The materials testing required by this section can be costly and is often destructive, but it may provide the only opportunity to reuse existing fabric.

A Hypothetical Case Study

The following case study illustrates how the Work Area Method of the IEBC might be applied to a common existing-building typology. Figure 1 represents a typical floor plan for a hypothetical existing heavy-timber-framed mill building. The building has three floors, a roof, and no basement. Perimeter masonry-bearing walls support heavy timber girders that span to a central line of wood columns. Timber planking spans to the girders. There is a single stair; there is no elevator in the building. Perimeter windows provide the only means of natural light to the space.

Hypothetically, the owner would like to renovate the building into a work-share space with an open floor plan, more natural lighting, and potentially some double-height spaces along the perimeter walls. A second stair for egress and an elevator are also desired. An alternate approach involving the removal of the slab on grade and excavation for a basement under half of the current first floor plate needs to be considered. For the purposes of this case study, it is assumed that the perimeter bearing walls and all exterior windows and doors will remain unaltered. Utilizing the IEBC Work Area Compliance Method, this case study explores what Alteration Level will apply to the renovation and what design choices can be made early in the process to help inform the owner about decisions that will cause certain trigger points to be reached. Having a basic road map laid out early in the project can help the designers and the owner avoid these triggers if it is deemed desirable or necessary to do so. Since this is a hypothetical example, the statements below are also hypothetical.

The first step in evaluating the Alteration Level for the Work Area Compliance Method is to gather basic information about the existing building. An initial walk-through of the space showed that the timbers and masonry were in good condition and that only negligible areas of the structural flooring were damaged. Since the building was once used as a paper mill, the original floor load-ratings far exceed what is required for office use. This fact would mitigate any concerns about gravity-load upgrades on most of the base-building elements, including the bearing walls, columns, and footings. Therefore, the main focus in the initial study phase is on the lateral triggers.

Each floor plate measures 105 feet by 45 feet (4,725 square feet). With three floors and the roof, the initial gross area of the building is 18,900 square feet. The project will be either a Level 2 or Level 3 Alteration, as it entails more than finish-level upgrades. Also, at a minimum, work will encompass 100 percent of the first, second, and third floors, due to the need to add restrooms, partitions, and MEP systems throughout. This means that 75 percent of the floor and roof plates will be included in the work-area calculation (this number does not account for any potential skylight openings that may be considered). Therefore, the project is going to trigger the 50 percent work-area threshold and move it from a Level 2 to Level 3 Alteration. Based on the wide-open nature of the existing space, as well as limited amenities, few architectural solutions are available to avoid this classification. In fact, most buildings that go through “gut renovations” will fall into Level 3 Alterations when using the Work Area Compliance Method.

The next step is to determine how much of the structural area of the floors and roof are affected. This is a much more crucial trigger point, as anything more than 30 percent will put the renovation into the Substantial Structural Alteration category. Once this occurs, a full building analysis must be done to show compliance with current IBC gravity loading, current IBC wind loading, and a reduced IBC seismic loading. Given the nature of the existing structure (heavy timber-stacked columns or girders supported on unreinforced-masonry perimeter walls), there is a very good chance that this building would require a substantial intervention, such as new braced frames or shear walls, to carry the IBC-level lateral loads.

Figures 2 and 3 represent the minimum level of intervention for the base-building renovation: a new stair, elevator, and skylights. This will require removal of structural materials in these areas, and will all count towards the considered structural-work area. For the purposes of this case study, it has been assumed that the stair and elevator will require new rooftop bulkheads and will therefore impact the roof framing as well. In this situation, the structural work area is changed as follows:

Elevator contribution	
8 ft. x 10 ft. x 4 floors	320 sq. ft.
Stair contribution	
8 ft. x 14 ft. x 3 floors	336 sq. ft
Skylight contribution	
8 ft. x 71 ft. x 2 skylights	1,136 sq. ft.
Total structural work area	1,792 sq. ft.
Total gross floor area	18,900 sq. ft.
Change	9.5%

Based on the above analysis, this building would fall in the Level 3, Limited Structural Alteration category. Within this level, the code requirements focus on the performance of the specific elements that are being altered and how the alterations affect the demand-capacity ratio of these elements. In this case, where the new gravity loads are well within the capacity of the existing structure, the main focus would be on the lateral capacity, specifically the floor diaphragms, as no other structural lateral load-carrying elements are being altered. As the loads on the building are not being increased, the demand piece of the demand-capacity ratio would remain constant. Adding openings into the existing floors reduces the capacity of each floor to act as a diaphragm. The designer must evaluate whether the capacity of each diaphragm is being diminished to a point where the increase to the demand-capacity ratio exceeds 10 percent. If the ratio is increased by more than 10 percent, the designer can either reinforce the diaphragm or reduce or reconfigure the openings such that the capacity is not reduced to as great an extent. This can be an iterative process, but depending on how difficult or extensive the reinforcement is, it can often be worthwhile.

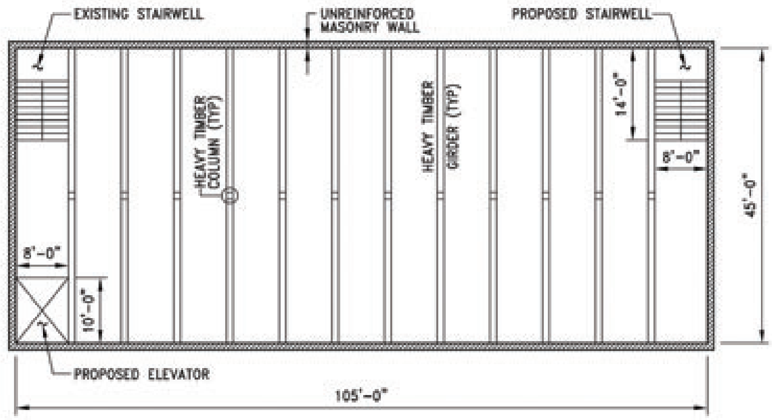
The next scenario evaluates what happens when additional floor areas are removed to create double-height spaces between the first and third floors and between the second floor and roof. Figure 4 depicts a schematic layout for these openings on the second floor that would be mirrored on the third floor, creating six equal-sized openings.

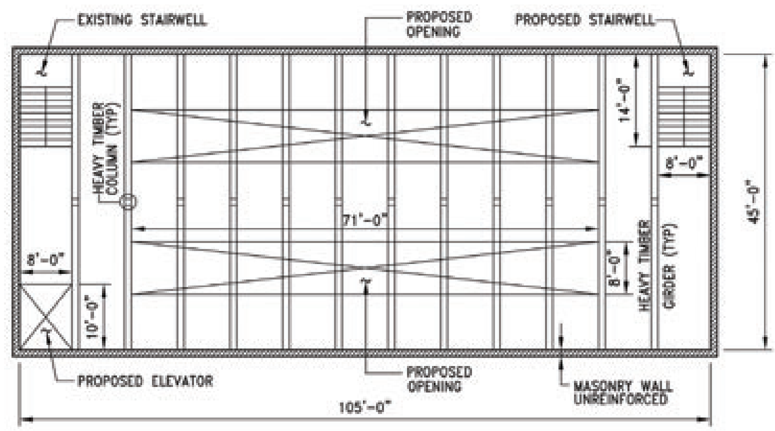
Based on the size of these openings, the structural work-area calculation would now look like this:

Elevator contribution	
8 ft. x 10 ft. x 4 floors	320 sq. ft.
Stair contribution	
8 ft. x 14 ft. x 3 floors	336 sq. ft
Skylight contribution	
8 ft. x 71 ft. x 2 skylights	1,136 sq. ft.
Double-height openings	
12.5 ft. x 23 ft. x 6 openings	1,725 sq. ft.
Total structural work area	3,517 sq. ft.
Total gross floor area	18,900 sq. ft.
Change	18.6%

Even with these openings, the overall percentage is well below the trigger point of 30 percent, and this building would still fall in the Level 3, Limited Structural Alteration category. Additionally, while in this example the demand-capacity ratios of the floor and roof diaphragms would almost certainly increase by more than 10 percent and would therefore require local reinforcement, there is still no need to provide a comprehensive upgrade to the entire building structure.

The final alternate assesses the possibility of excavating below half of the footprint of the first-floor level for basement storage. If this alternative were reviewed with all of the base-building requirements and the double-height opening alternative, the structural work-area calculation would now look like this:





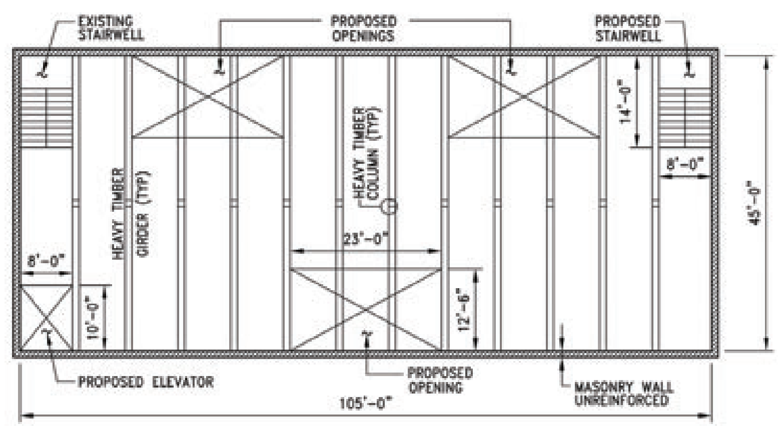


Fig. 2. *Hypothetical typical floor plan for base-building renovation.*

Fig. 3. *Hypothetical typical roof plan for base-building renovation*

Fig. 4. *Hypothetical alternate floor plan with additional floor openings.*

Elevator contribution	
8 ft. x 10 ft. x 4 floors	320 sq. ft.
Stair contribution	
8 ft. x 14 ft. x 3 floors	336 sq. ft
Skylight contribution	
8 ft. x 71 ft. x 2 skylights	1,136 sq. ft.
Double-height openings	
12.5 ft. x 23 ft. x 6 openings	1,725 sq. ft.
Basement below first floor	
0.5 x 4,725 sq. ft.	2,363 sq. ft.
Total structural work area	5,880 sq. ft.
Total gross floor area	18,900 sq. ft.
Change	31.1%

As can be seen, this last alternate brings the total percent change in structural work area to greater than 30 percent and would place the building in a Level 3, Substantial Alteration category. As previously noted, this trigger point would require the building to go through a comprehensive lateral analysis that could conclude that there is a need for a substantial upgrade to the base-building structure. Because the final percentage is close to the 30 percent mark, minor adjustments to the design of the double-height openings or the size of the basement could be made to bring the number back below the threshold level, making the overall project more feasible and far less costly.

Conclusion

In conclusion, the IEBC provides a series of paths for existing buildings to become structurally code compliant. As structural upgrades can be costly and destructive to historic fabric, it is critical to work collaboratively as early as possible to understand the code trigger points and the potential methods of reinforcement or strengthening that may be required. Understanding the basic trigger points of the IEBC and how they will impact the final design and reviewing the design options periodically throughout the design process are critical in making good decisions that will benefit both the cost and feasibility of any building-reuse project. Thoughtful investigation into the possible methods of reinforcement or strengthening and the impact on the existing building fabric can lead to solutions that achieve the required performance in a way that is appropriate for the building's original construction, its current use, and its level of historic significance. Ultimately, optimizing the process of designing within the IEBC provides the opportunity to save considerable historic fabric and minimize structural-upgrade costs while achieving code compliance.

Note

1. "International Codes-Adoption by State," International Code Council, last modified May 2016, https://www.iccsafe.org/wp-content/uploads/State-Local-Code-Charts.pdf.

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