# Construction Issues

discussion of construction issues and techniques

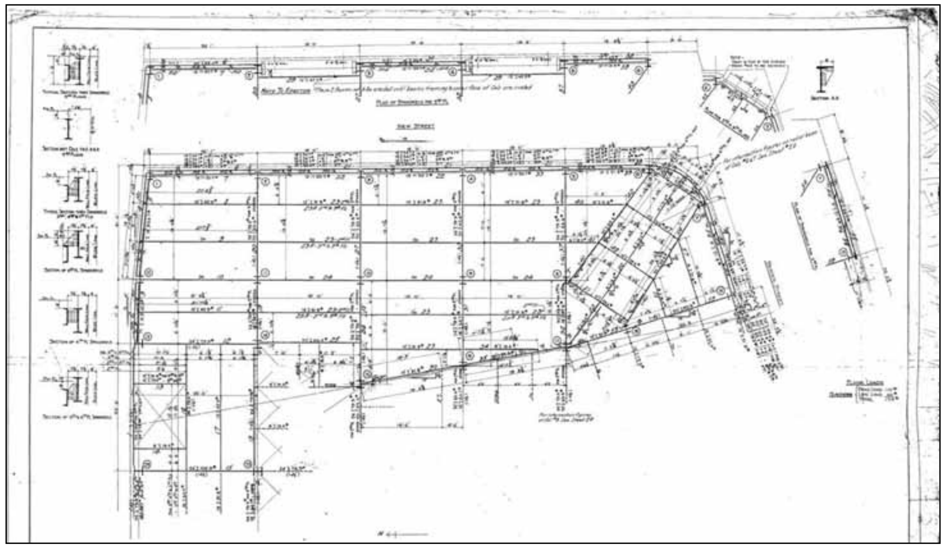

*Figure 1: (Documents review) Exploratory field work compensates for a lack of architectural sections and shop drawings.*

## From Old to New

### Navigating Adaptive Reuse Projects

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In many U.S. cities, the alteration of existing buildings has eclipsed design and development of new buildings in both number and dollar amounts. With more stringent credit and financing requirements, initiating new construction has become increasingly difficult. On the other hand, repairing and redeveloping older, existing buildings has become more attractive; not only are the initial costs lower, but intangible factors such as more limited demolition, political issues, and environmental concerns now play a broader role in the decision-making process. Furthermore, since prime locations in large cities are often designated as historic districts, new developments can be limited or prohibited, making adaptive reuse of existing structures the only viable alternative.

Repurposing of buildings, however, often requires special knowledge and effort on the part of the structural engineer. This article describes a number of issues a structural engineer faces during each of the typical four phases of an alteration project: document review, field investigation, structural analysis and design, and construction administration.

### Document Review

Unlike in new building designs, the unavoidable first step in the design process is to understand the existing structure. Initial research online or of public records can provide valuable insight at the onset of the project. The Certificate of Occupancy, the approximate date of construction, aerial and street photographs of the building, and history of previous alterations, as well as violations, are often available with the Department of Buildings online registry. Occasionally, additional data can be found in newspaper, library, or private archives (e.g. digitized historical maps, building elevations, historic facade ornaments, etc.). All of these sources can provide a glimpse into a specific area of interest, or into a specific aspect of the project, but the information is usually incomplete and insufficient. The most useful documents for an engineer, by far, are the original architectural and structural drawings. Even limited or partial sets of structural drawings, architectural drawings, or shop drawings are usually more beneficial than all other type of information that can be found in public records.

Unfortunately, for most "vintage" buildings, the original structural drawings can be rare. Very old buildings were often built without a developed set of drawings. When the drawings were produced, only a small percentage of the owners, or perhaps original architects, managed to keep them. Buildings change hands, documents get misplaced, entities cease to exist, natural disasters occur, and, as a result, architects and engineers are left to their own devices. "Detective" engineers search for drawings onsite and, if fortuitous, can find them rolled up or stuffed in a box somewhere in the building. Other times, the drawings are available and in good condition, but incomplete. In such cases, engineers need to fill in the blanks through field work (*Figure 1*).

Sometimes, even the information shown on the original structural drawings may not be sufficient or accurate. Heritage buildings have likely changed ownership or management several times and could have undergone significant alterations throughout the lifetime of the structure. Tracking the alteration history of a building is a daunting task, one that further complicates the structural assessment of a building. A condition survey, accompanied with spot-check probing, is usually a necessary step to confirm whether the information shown on the available drawings is accurate.

## Field Investigation

Unfortunately, after several decades in service, the original structural drawings for most buildings are usually nonexistent, lost, or hard to find. Invaluable information associated with archaic, hidden, or specialized structural systems can thus only be obtained through field investigation. Field work not only allows the engineer to determine or confirm load paths, and to identify visible signs of structural distress that may require remediation, it also allows gathering of key missing information relative to affected elements and systems (member sizes, reinforcement details, connections, etc.).

The engineer must often act like a detective, looking at small parts of the structure and putting pieces of the puzzle together to understand how the structure behaves and how proposed modifications may affect its behavior. Generally, this involves identifying, understanding, and carefully documenting structural elements and systems affected by the planned alteration or modification work. In more cases than not, this effort also requires exploratory probing through building finishes. Due to cost limitations, probing locations must be carefully selected to capture key information indicative of typical construction, as well as critical components (such as transfer girders, columns, and footings, especially those with a significant increase in total load).

In addition to exploratory probes, sampling of the materials, such as concrete cores, brick and mortar extraction, and steel coupons that are tested for their chemical and mechanical properties, can be used to determine strength, ductility, durability, and other properties. Engineers can also use non-destructive testing (NDT) to obtain structural information. NDT techniques can typically be used to quantify the type and extent of hidden distress, or to identify inaccessible structural elements like steel beams encased in concrete. The more common NDT techniques include chain dragging or hammer sounding to determine delamination or freeze-thaw damage in concrete decks and other elements, half-cell testing or galvanostatic pulse testing to determine the extent of corrosion, impact echo or impulsive response to determine structural discontinuities or obstructions, and ground-penetrating radar (GPR) to locate reinforcement or concealed steel elements in concrete elements. Lastly, engineers can perform in-situ testing to evaluate properties and performance of structural elements. Typically, in-situ strength tests are non-destructive; element or system properties are measured through, or quantified by, observation of predefined structural-performance parameters, such as deflection under known load.

*Figure 2: (Field investigation) Removal of finishes, concrete coring and other testing can reinforce available shop drawings and confirm structural details.*

Finding an optimal combination of visual observation, exploratory probing, destructive sampling, NDT, and in-situ testing is vital for a success of every alteration project. For example, once the size, configuration, and connections of a typical floor steel beam are confirmed through probing in discrete locations, the location and layout of the remainder of beams can be found from the topside through GPR scanning. Similarly, once the typical layout and configurations are confirmed, engineers can use their judgment to determine how many steel coupon samples and tests are needed to arrive at reliable material properties for the entire system (*Figures 2, page 13 and 3*).

In general, structural engineers have to balance their desire for detailed understanding of the existing structure at the early stages of the design process against potential cost implications. In-situ load testing, while a powerful technique, certainly cannot be performed on every project – cost and benefits of such tests should be carefully evaluated. Similarly, exposure of the majority of concealed structural elements through probing is not practical.

The cost and other secondary effects of the probing can also greatly influence the owners' and developers' preferred strategy. For instance, performing field work adjacent to occupied space may not be feasible because of tenant discomfort or adverse impact on operations. As a result, engineers frequently perform their detective work at off-hours, or relocate their probe from preferred areas to secondary locations.

Experienced engineers strive to streamline field investigations. They aim to obtain sufficient information for design at reasonable cost, while limiting exposure to costly change orders during construction when unexpected field conditions may be discovered. On most projects, however, some risk remains. Engineers must stress to ownership prior to starting the design phase that a more thorough understanding of the structure in the early phases of the project is the best protection against unexpected field conditions. A strategy that focuses on practical, upfront "discovery" of existing conditions often results in vast savings in both time and money during the construction phase.

Ultimately, the engineer must be cognizant that gaining a complete understanding of the structure through field investigation is not possible, and therefore, should design creative, adaptable solutions that can be modified to address unforeseen conditions. Not only should the design provide flexible solutions, but the engineer must be prepared to offer additional advice and solutions during the construction administration phase, when the inevitable hidden conditions are discovered.

*Figure 3: (Field investigation) In some instances, removals allow for new installations. Portions may not require removal, and ground-penetrating radar (GPR) can supply needed information.*

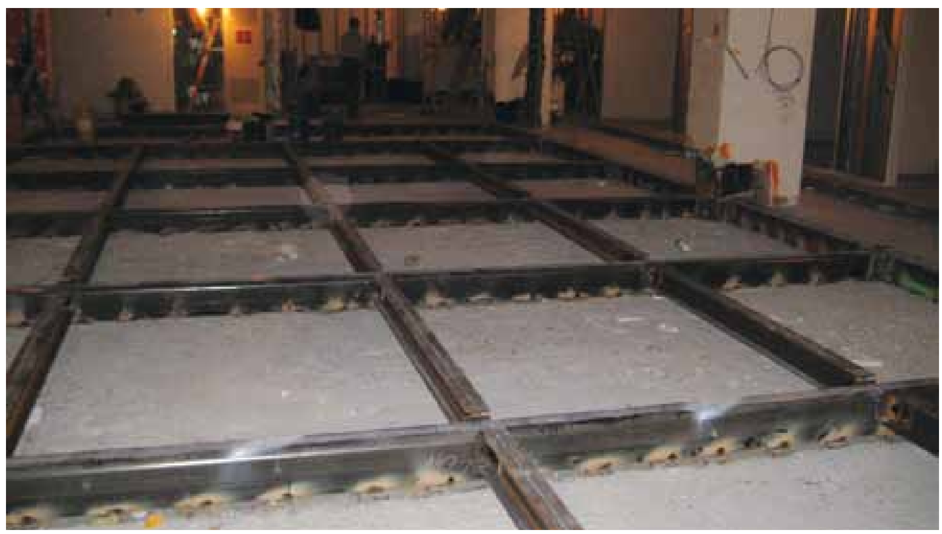

*Figure 4: (Structural analysis and design) When existing structural elements are inadequate, and access is not available, unique solutions are required. Here, designers trenched the concrete fill at the steel beams and welded tubes to their top flanges. Then a framework of filler beams was created that would support the track loads from the high-density file system. All beam topsides and tubes were hidden in a raised floor system.*

## Structural Analysis and Design

Available literature on historic and archaic structural systems can be very beneficial, whether used to supplement knowledge obtained in the field, or to help interpret the original drawings. For example, *Kidder-Parker Architects' and Builders' Handbook* by Frank E. Kidder and Harry Parker, and *Historical Building Construction* by Donald Friedman provide design tables for terra-cotta arch systems, as well as steel and wrought iron material properties dating back to the late 1800s. The American Institute of Steel Construction's (AISC) *Iron and Steel Beams – 1873 to 1952* provides detailed information on historical beam sections and properties. These and similar references eliminate a lot of the guess work and make the lives of adaptive-reuse engineers much easier. For example, if information on the slab span and terra-cotta depth, or the type of cinder concrete and the type of wire mesh is obtained in the field, design tables can effectively provide an estimate of the floor-system's capacity. Also, a comparison of incomplete field measurements to the historic data may allow identification of a full set of beam-section and material properties.

Even when the affected structural elements are fully understood and can be analyzed, finding creative structural-design solutions can be challenging. Because of occupancy, spatial, material,

*continued on page 16*

and other constraints associated with existing construction, common structural approaches used in new construction may not be feasible, and finding practical ways to supplement or strengthen affected structural elements may not always be straightforward. For example, floor structures that are not adequate to withstand the design live load associated with the new, proposed use cannot always be simply reframed, reinforced, sistered, or rebuilt due to access issues, height limitations, architectural requirements, or tenant considerations. In addition, work often involves fragile and "finicky" systems that are not easily modified, such as terra-cotta flat arches spanning to wrought-iron beams and cinder-concrete with draped-mesh reinforcement. Options like strengthening with tee sections or tubes welded to the top flange of existing steel beams and hidden in a raised-floor system (to avoid working from below), or replacing cinder fill with structural deck (to provide for a stronger system without changing the overall depth of the floor system) can be explored and made to work effectively (*Figure 4, page 14*). Yet, depending on the type of constraints and the fragility of the system, engineers may be left with few structural options. Creativity, experience, and confidence in the contractor performing the work are the keys to success.

Satisfying the code-mandated requirements for performance under lateral loads is an even larger challenge when it comes to alteration of existing buildings. Most pre-war buildings were not designed in accordance with modern-day building-code requirements, and may lack the detailing and, in some cases, even apparent systems and load paths to resist the lateral load demands. Building codes today, in an attempt to avoid stifling growth and development, allow limited structural modifications to existing buildings without requiring full compliance with modern-day lateral-load resistance requirements. Typically, the mandate for lateral-load upgrades depends on the cost of the performed alteration work, type of proposed use, and whether the existing lateral-load-resisting system (adequate or not) is weakened by the proposed work. The vigilance of building codes related to this issue often depends on the jurisdiction. For example, the *International Existing Building Code*, a widely accepted and referenced national code developed specifically to address issues related to alteration of existing buildings, provides solid guidance and definitive upgrade requirements for a variety of modification scenarios. On the other hand, the New York City *Building Code* still vastly relies on its 1968 version with respect to the modification of existing buildings, and its current requirements are often vague and confusing. As a result, engineers must use their judgment and interpretation to arrive at solutions that are both practical and feasible, but also robust and comprehensive enough to fulfill their professional and ethical obligations to provide the client with a safe and functioning building.

In some situations, it is particularly difficult to find middle ground – a solution that works for the client, but also satisfies the code and gives the engineer peace of mind. For example, owners and architects do not always understand why creation of openings in a masonry bearing wall may trigger a retrofit of the overall lateral-load system of the building, even if this masonry bearing wall is, perhaps unintentionally, the only lateral-load-resisting element in that direction for the building. Moreover, they may not understand why the addition of two stories to an existing six-story building may require not only column and foundation strengthening, but also the addition of an entirely new

*Figure 5: (Construction administration) Changes during construction also require unique solutions. Designers, working closely with the contractor, analyzed new conditions requiring the raising of a storefront elevation, resulting in the existing lintel system, which included a complicated shoring procedure.*

lateral load-resisting system, through the full height of the building. A classic example of the difficulty to find middle ground can occur if, on a high-rise window-replacement project, the engineer discovers that the façade brick veneer and the 4-inch thick concrete block backup are grossly insufficient to transfer the wind loads back to the building structure; yet, there are no signs of distress, and the building was constructed 40 years ago. Is upgrading the entire backup system prudent in this case?

In these and similar situations, engineers' decisions often rely on an assessment of load history, on a detailed assessment of the overall load paths, on evaluation of redundancy, importance, and expected performance of the affected lateral-load elements, etc. Some questions that might need an answer: Is there no distress because the structure has never been exposed to the design-level wind loads? Or, would openings in the masonry walls really weaken the overall lateral-load system if the weakest links in the load path are the existing connections between the floor diaphragms and the wall? In general, engineers should be sensitive to owner's expectations and should strive to find pragmatic solutions. Under no circumstances, however, should alterations weaken the existing lateral-load system, even if the building is grandfathered and its lateral-load-resisting system is already incapable to meet the current code requirements.

## Construction Administration

The construction administration phase concludes the project and often represents the stage in which the effectiveness of the engineer's solutions is finally tested, since all the existing conditions are unveiled as the construction proceeds. Some changes in the design are inevitable and, more often than not, they will have to be implemented at the 11th hour (*Figure 5*). This dynamic typically requires the design engineer to be extremely responsive, to work under pressure and to offer solutions on the fly, so as to allow the project to move forward without significantly affecting its budget and schedule. Possession of strong interpersonal skills to manage the expectations and to alleviate the potential for disputes is key.

Furthermore, because of the nature of the process, the potential for disputes is high. To what extent is the engineer responsible for accuracy of the information shown in the contract documents, if not given the opportunity to observe all the field conditions? To what extent is the contractor responsible for estimating the impact of unknown information and accounting for it in the final bid? It takes an experienced project team to guide the project and the owner through the process.

## Conclusion

For many reasons, ranging from financing to landmark constraints, alteration and adaptive reuse of existing buildings has become an attractive alternative to new construction. This type of work, however, introduces a new series of challenges to the engineer in all phases of the project; working with existing buildings is different and requires special knowledge and approach. The engineers' success often depends on their thoroughness and perseverance with document research, their capacity to organize a balanced, cost-effective field-investigation campaign (acceptable to the owners and yet one that provides sufficient information for the design), their ability to adopt creative solutions given a multitude of constraints and challenges, and their responsiveness in the construction-administration phase, when all the field conditions are uncovered. Creativity, experience, patience, and interaction amongst the design team members are paramount for the success of every adaptive-reuse project.▪

All photos courtesy of Simpson Gumpertz & Heger Inc.