Frequently Asked Questions (FAQ) About Structural Modifications to Existing Reinforced Concrete Buildings

Introduction

CRSI routinely receives inquiries regarding structural modifications to existing reinforced concrete buildings. A collection of frequently asked questions (FAQ) are addressed, which mainly came from structural engineers, architects, code enforcement officials, and contractors.

This Technical Note includes general guidelines and recommendations for common types of structural modifications. The information is not meant to be comprehensive; it is simply not possible to cover every type of structural modification that can be made to a reinforced concrete building.

Questions and responses are provided below for cast-in-place concrete buildings with nonprestressed reinforcement; structures with post-tensioned reinforcement are not covered. Guidelines for creating openings and penetrations in existing concrete slabs with unbonded post-tensioning reinforcement can be found in Reference 1. Detailed information on repair and strengthening methods for reinforced concrete members is also not included; requirements for assessing, repairing, and rehabilitating existing concrete structures are given in Reference 2, and a number of strengthening systems and methods for concrete structures can be found in References 3 and 4. Finally, no specific information is provided on the means and methods of making modifications.

Modifying existing buildings can be very challenging; a great deal depends on the structural information that is available, the nature of the proposed modifications, operational constraints, and restrictions related to access of space and constructability, to name a few. Unlike new construction, structural solutions are subject to more constraints and limitations in existing buildings. Because of the inherent continuity in reinforced concrete construction, minor modifications and certain types of major modifications can often be made without the need to strengthen the existing structural members. Regardless of the scope of the modifications, a thorough understanding of the existing structure and the inherent constraints and limitations are essential to achieve safe and cost-effective solutions.

Building Codes

What building codes must be used when modifying reinforced concrete buildings? Before starting any project, it is always good practice to check with local building officials regarding the applicable code requirements that must be satisfied when performing modifications to an existing reinforced concrete building.

Many jurisdictions have adopted the provisions in the International Existing Building Code (IEBC), with or without amendments (Reference 5). The provisions of the IEBC apply to alterations, repairs, additions, relocations of structures, and changes of occupancy (see Section 302.1 of that document). The definitions in IEBC Section 202 that are related to structural modifications are given in Table 1.

According to Sections 502, 503, and 506 of the IEBC, additions, alterations, and changes in occupancy made to any building must comply with the requirements of the International Building Code (IBC) for new construction (Reference 6). The conditions under which the provisions of the IBC are applicable are given in the IEBC sections noted above.

Table 1 – Definitions in the IEBC Related to Structural Modifications

<table>
<thead>
<tr>
<th>Addition</th>
<th>An extension or increase in floor area, number of stories, or height of a building or structure</th>
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<tr>
<td>Alteration</td>
<td>Any construction or renovation to an existing structure other than a repair or addition</td>
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| Change of occupancy | • A change of occupancy class  
|                   | • A change from one group to another group within an occupancy classification  
|                   | • Any change in use within a group for which there is a change in application of the requirements of Reference 5 |
Section 1901.2 of the IBC requires that structural concrete be designed and constructed in accordance with the provisions of Chapter 19 of the IBC and the 2014 edition of ACI 318 (Reference 7) as amended in IBC Section 1905. Thus, ACI 318 is part of the IBC and its provisions must be satisfied, where applicable, in jurisdictions where the IEBC is adopted.

Review of Existing Information

What existing information is needed prior to performing any structural modifications? It is very important to have a thorough understanding of every aspect of the existing reinforced concrete structure prior to any structural modifications. Where design strengths of the existing structural members must be determined because of the nature of the modifications, the following information is required: span lengths, member sizes, material properties of the concrete and reinforcing steel, reinforcing bar size and distribution, and superimposed loads. For relatively minor modifications, determining design strengths may not be required, so acquiring some or all of the aforementioned information may not be necessary.

Existing documentation. Existing structural drawings are an invaluable resource on any modification project and usually contain some or all of the following information: (1) plans and sections of the existing structure, (2) member sizes and reinforcement (bar size, number of bars, bar spacing, and bar length), (3) properties of the concrete (unit weight and compressive strength) and reinforcing steel (yield strength), and (4) design loads. Specifications, structural calculations, concrete test reports, reinforcing steel mill reports, placing drawings, and architectural drawings are other useful sources of information (architectural drawings of older buildings sometimes contain a wealth of structural information). An extensive list of information sources for existing buildings is given in Section 2.1 of Reference 8.

The older the building, the less likely that existing drawings and other sources of information are available. If the client does not have existing drawings, the local building department or the original design firms (if known or still in existence) may have them on file.

Field survey of as-built construction. When existing documentation is not available, a survey of the existing structure must be performed in the areas that will be directly affected by the proposed modifications. The existing framing system must be documented, which includes measuring member cross-sections and lengths. Slab thickness can be obtained at existing openings or by making a small core at a judiciously-chosen location in the slab.

A field survey should be performed even when existing documentation is available to confirm that the information in the documents matches the as-built conditions; this is especially important in cases where the modifications are relatively extensive or extreme. Another benefit of performing a field survey is that damaged or deteriorated structural members, which otherwise would remain unknown, are often discovered during the survey. The type and extent of the damage or deterioration dictates the kind of repair that needs be made.

Material properties. The standard test methods in Table 2 can be used to estimate the in-place compressive strength of concrete when such information is not available from existing documentation. These tests do not directly measure compressive strength; instead, some other property is measured that has been found to have an empirical correlation with compressive strength. Specific information on each test is given in the corresponding ASTM standards listed in Table 2.

The most accurate way of determining in-place concrete compressive strength is by selecting, removing, and testing core samples of the concrete in accordance with Reference 2. Reference 15 provides information on how to evaluate concrete strength test results.

Where documentation is not available or where coring of the existing concrete is not possible, the default concrete compressive strengths in Table 6.3.1a of Reference 2 can be used. The historical data in that table are adapted from Reference 16 and can be applied to reinforced concrete buildings constructed from the 1900s to present-day.

The size, number, and location of reinforcing bars can be determined using a variety of nondestructive methods if such information is not available from existing documentation. Electromagnetic devices, radiography, and ground-penetrating radar are nondestructive methods that can be used to determine the size and location

<table>
<thead>
<tr>
<th>Test</th>
<th>ASTM Standard</th>
<th>Reference No.</th>
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<tr>
<td>Rebound number</td>
<td>C805</td>
<td>9</td>
</tr>
<tr>
<td>Probe penetration</td>
<td>C803/C803M</td>
<td>10</td>
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<tr>
<td>Pulse velocity</td>
<td>C597</td>
<td>11</td>
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<td>Pullout test</td>
<td>C900</td>
<td>12</td>
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of reinforcing bars within the concrete (see Reference 17). Concrete cover should be removed from appropriate structural members and exploratory openings should be carefully made within the structure (and then subsequently restored where required) to verify the accuracy of the information obtained from the nondestructive methods wherever necessary.

Where material properties of the reinforcing steel are not known, coupon samples of the reinforcement can be obtained from the existing structure in accordance with Reference 18. Test methods to determine yield stress and tensile strength are also given in that reference. Reference 19 contains a wealth of information on sizes, material properties, and systems of steel reinforcement that were prevalent in the early 1900s. Default tensile and yield strength properties for steel reinforcing bars from various time periods are given in Tables 6.3.1b and 6.3.1c of Reference 2 and in Reference 20. Reference 21 provides a broad overview of the major items that need to be addressed when determining the load capacity of a structure where existing information is not available.

**Strength Evaluation**

What is the procedure to evaluate the strength of reinforced concrete members in an existing building? Provisions to evaluate whether the members of an existing structure satisfy the strength requirements of ACI 318 are given in Chapter 27 of that document. An analytical method or a load test are permitted to evaluate strength, and the conditions under which these methods are applicable are covered below.

An analytical strength evaluation is permitted when all the following items are determined (Section 27.3.1):

1. **Dimensions of the structure.** Cross-sectional dimensions and lengths of the members must be field measured.

2. **Locations and sizes of the reinforcement.** Amount, size, arrangement, and location of reinforcing bars must be measured in the field. In lieu of measurements, it is permitted to use existing construction documents provided the information on the documents is verified in the field at representative locations. According to Section R27.3.1.2, determination of this information for approximately 5 percent of the reinforcement at each critical region is generally sufficient for large structures. The properties of the reinforcement are permitted to be determined using tensile tests of representative samples of the reinforcing bars in the structure.

3. **Concrete compressive strength.** The estimated equivalent compressive strength of the concrete is permitted to be determined based on analysis results of cylinder tests from the original construction or cores removed from appropriate locations in the structure.

The test methods discussed previously can be used to determine the required information in items 2 and 3.

Once the above information has been determined, the structure is analyzed for the effects from the proposed modifications. The design strength of existing structural members affected by the modifications must be greater than or equal to the required strength using the load combinations in ACI Table 5.3.1. When determining design strength, the strength reduction factors, $\phi$, in ACI Table 27.3.2.1 are permitted to be used instead of those in Chapter 21 when the as-built conditions are verified in accordance with Section 27.3.1 (see Table 3). These strength reduction factors are larger than those in Chapter 21 because in-place member dimensions and field-obtained material properties are used in the analysis, that is, there is less variability in the design strength where member dimensions and material properties are verified in the field.

Where verification of as-built conditions in accordance with Section 27.3.1 is not possible or is not done, a load test in accordance with Section 27.4 may be performed. Section 27.4 contains provisions on test load arrangement, load combinations, test load application, response measurements, and acceptance criteria. Performing a load test can be risky and is usually expensive; it is typically used as a last resort to determine the load-carrying capacity of an existing structure.

**Guidelines and Recommendations for Structural Modifications**

**Slab Openings**

How are one-way slabs analyzed for the effects of new openings? The effects of new
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openings in existing one-way slab systems depend on the size, number, distribution, and location of the openings. Relatively small core penetrations for plumbing risers or electrical conduit can usually be made in the slab at essentially any location without having to strengthen the slab (see Figure 1). It is good practice to locate the flexural reinforcing bars prior to cutting the opening(s) and to adjust the location of the opening(s), if possible, to avoid cutting any of the bars. Where the opening location is fixed and one or more existing flexural reinforcing bars must be cut, the design flexural strength of the slab must be checked by analysis; for relatively small openings, the flexural strength of the slab will usually be adequate.

Where a number of core penetrations are aligned and spaced relatively close to each other, the slab edges adjacent to the openings become essentially free and the slab sections on either side of the openings can be conservatively modeled as cantilevers (see Figure 2). In such cases, strength and serviceability requirements must be checked and analysis will indicate if strengthening of the slab is required.

A situation similar to that depicted in Figure 2 occurs where a relatively large rectangular opening is made in a portion of the span (see Figure 3). The orientation of the opening is also important. If possible, the opening should be oriented with the long side parallel to the span of the one-way slab (Opening A) because it is likely that fewer flexural reinforcing bars will need to be cut compared to the case where the opening is oriented with the long side perpendicular to the span (Opening B).

Where the entire slab between supports is to be removed, the span or spans adjacent to the opening, which were interior spans prior to the opening, become end spans and the structure must be checked accordingly, including checking the beams at the edges of the opening for torsion (see Figure 4). The top flexural reinforcing bars that resist the negative bending moments at the beams will be removed with the slab. In order to resist the redistributed negative moments at these critical sections, these bars must be fully developed in tension. It is common to provide slab overhangs parallel to the span of the one-way slab that are long enough to fully develop these bars, that is, the length of the overhang must be equal to at least the tension development length $l_d$. Slab overhangs may also be needed for openings like the ones in Figure 3.

Openings that require removal of a portion of the supporting members of a one-way slab (such as beams, joist ribs, or walls) are not recommended. Strengthening the

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**Figure 1 – Core penetration for a pipe in a one-way slab (photo courtesy of TGRWA Structural Engineers).**

**Figure 2 – Aligned core penetrations in a one-way slab.**

**Figure 3 – Rectangular openings in a one-way slab.**

**Figure 4 – Slab removal between supports in a one-way slab.**
remaining portions of the affected supporting members may not be possible or may be inordinately expensive.

How are two-way slabs analyzed for the effects of new openings? Just like one-way slabs, the effects of new openings in existing two-way slab systems depend on the size, number, distribution, and location of the openings (Reference 22). Provisions for openings in two-way slabs are given in ACI 8.5.4. According to ACI 8.5.4.1, openings of any size are permitted provided an analysis is performed that shows all strength and serviceability requirements are satisfied (see Figure 5). This provision is applicable to new openings in existing two-way slab systems.

The requirements in ACI 8.5.4.2(a) through (c) must be satisfied for openings common to intersecting middle strips, intersecting column strips, and the intersection of one column strip and one middle strip, respectively. These provisions are basically intended for new construction because of the reinforcement detailing requirements that must be satisfied (which are generally impractical or impossible to implement when introducing new openings in existing slab systems).

New openings are commonly specified adjacent to columns in existing two-way slab systems. For flat plate systems, these openings can have a direct impact on the critical shear perimeter, \(b_o\), that is available to resist shear forces. According to ACI 8.5.4.2(d), the effects of openings on \(b_o\) must be considered where the opening is at the following locations (see Figure 6):

- A distance less than 10 times the slab thickness, \(h\), from a concentrated load or reaction area
- Inside of a column strip

For slabs without shearhead reinforcement, \(b_o\) must be reduced by a length equal to the projection of the opening that is formed by two lines that extend from the centroid of the column, concentrated load, or reaction area and are tangent to the boundaries of the opening (ACI 22.6.4.3). The ineffective portions of \(b_o\) for flat plate systems are illustrated in Figure 6 (also see ACI Figure R22.6.4.3 and Figure 2 in Reference 22 for flat slab systems). A reduction in \(b_o\) results in a reduction in two-way design shear strength and the existing slab must be checked considering this reduction (see ACI 22.6.5). Similar requirements for slabs with shearhead reinforcement are given in ACI 22.6.9.9.

If possible, new openings in existing flat plate systems should be located greater than 10\(h\) from the column or outside of a column strip so that the full two-way design shear strength can be utilized. Slab overhangs, which are described above for one-way slabs, may also be needed for two-way slabs depending on the size and location of the opening(s).

Where are the best locations for new stair openings in an existing building? In general, a stair opening can be made at any location in an existing floor system provided all the required strength and serviceability requirements are satisfied for the existing structural members that are affected by the opening and the stair structure, including the members that directly and indirectly support the loads from the stringers and any landings (see Figure 7). Depending on a number of factors, existing structural members may need to be strengthened and/or new structural members may be required around the perimeter of the opening. It is not recommended to locate the stair opening where major existing structural elements like beams, columns, or walls would have to be cut.

An existing structural member may lose lateral support provided by the slab if a stair opening (or any other type of opening, such as an escalator opening) is located next to it. Consider the interior column in Figure 8 that is adjacent to an existing opening. If a new stair opening is positioned as shown in the figure, this column will no longer have lateral support in the east-west direction, and it essentially becomes a two-story column in that direction. Additionally, a major portion of the critical
New slab openings that are made adjacent to existing vertical elements of the LFRS can have a significant effect on in-plane force transfer to these elements. Depicted in Figure 9 are new openings adjacent to an existing wall, which is designated as part of the LFRS. It is evident that these openings drastically reduce the amount of shear transfer that can occur between the diaphragm and the wall, so this wall would no longer be able to resist its portion of the total lateral force at any level in the building where these openings occur (unless it can be determined by analysis that the portion of the slab in line with the wall can act as a collector that transfers the in-plane forces directly into the ends of the wall). This means the existing diaphragms, the vertical elements of the LFRS, and the corresponding connections must be checked for redistributed lateral forces. Additional information on analysis and design of reinforced concrete diaphragms, including openings, can be found in Reference 24.

**Beam Openings**

How are beams analyzed for the effects of new openings? Where mechanical, electrical, or plumbing ducts or pipes cannot be routed horizontally beneath existing reinforced concrete beams, it may be possible to route them through new openings in the beam webs. Regardless of the size and location of an opening, an analysis must be performed to ensure that strength and serviceability requirements are satisfied. The analysis will also indicate whether the beam needs to be strengthened or not.

It is strongly recommended to locate openings in beams so that the top and bottom flexural reinforcement are not cut anywhere along the length of the beam, if possible. It is also recommended to position the opening between stirrups and outside of regions where the shear forces are relatively large, such as at the ends of the member.

At locations where the ducts or pipes are routed vertically, openings should be made in the adjoining slab and not in the web of a beam, regardless of the size or location of the opening.

Openings should be avoided in beams that are part of the LFRS. Relatively large openings can reduce the stiffness of a moment frame considerably, resulting in...
a redistribution of lateral forces to the elements of the LFRS. Where the beam is part of an intermediate or special moment frame, which are required in buildings assigned to SDC C and to SDC D, E, or F, respectively, openings should not be made within regions where yielding is expected; these regions are assumed to occur over a length equal to 2h at each end of the beam measured from the face of the column towards midspan where h is the overall depth of the beam (see Sections 18.4.2.4 and 18.6.4.1 of ACI 318).

Additional information on effects of creating openings in existing reinforced concrete beams can be found in Reference 25.

**Wall Openings**

**How are walls analyzed for the effects of new openings?** The first step is to determine whether the wall is load bearing and/or is part of the LFRS. For interior non-loadbearing walls that are not part of the LFRS, relatively small openings can be located anywhere in the wall and strengthening is usually not required. For relatively large openings, the wall must be able to support its own weight above the opening without excessive deflection; in such cases, new lintels are usually required. Out-of-plane strength and serviceability requirements must be checked where openings are proposed in exterior non-loadbearing walls that are subjected to wind pressure perpendicular to the face of the wall. If possible, openings should be located between the longitudinal and transverse reinforcement. Where reinforcing bars must be cut, an analysis must be performed to determine whether strengthening the wall is required or not.

An analysis is required where openings are proposed in loadbearing walls and/or walls that are part of the LFRS. The in-plane stiffness of a wall can be significantly reduced by relatively large openings, which means the lateral forces may have to be redistributed to the vertical elements of the LFRS. The analysis will indicate whether strengthening of any of the LFRS elements is required due to the redistribution of forces.

Because relatively large tension and compressive forces can occur at the ends of a wall due to bending from lateral forces, openings should be avoided at these locations. In the case of special structural walls, which are required in buildings assigned to SDC D, E, or F, openings should not be made within regions where yielding is likely to occur or within the boundary elements at the ends of the walls (see ACI 18.10.6.2 and 18.10.6.4, respectively).

**Changes in Occupancy**

What are the main issues that need to be addressed when a change in occupancy is proposed on one or more floors of any existing reinforced concrete building? When a proposed occupancy change is such that

the required live loads in accordance with IBC Section 1607 are greater the live loads that the structure was originally designed for and the risk category of the building in accordance with IBC Table 1604.5 remains the same, a structural analysis must be performed to check the strength and serviceability requirements of the existing structural members directly impacted by the occupancy change, including (1) the members in the floor system that support the larger live load, (2) the vertical members that support these floor members, and (3) the corresponding foundations. Existing structural members may need to be strengthened; however, it is not always feasible or cost-effective to strengthen columns, walls, or foundations. Where the live loads due to the occupancy change are less than the original live loads, the design strength of the applicable structural members should be checked to ensure that the original design is adequate for the prescribed loads (for example, the original members may have been under-designed for one reason or another).

Where a change in occupancy results in a building being assigned to a higher risk category in IBC Table 1604.5, the floor live load may not be the only load that needs to be increased. In such cases, roof elements must be designed for the design snow loads in IBC Section 1608, where applicable, and the LFRS must be designed for the wind loads in IBC Section 1609 and the seismic loads in IBC 1613. IBC Sections 1608, 1609, and 1613. These sections in the IBC reference ASCE/SEI Chapters 7, 26 to 30, and 11, 12, 13, 15, 17 and 18 for the determination of snow, wind, and seismic loads, respectively. The importance factors in ASCE/SEI 7 Table 1.5-2 are used in determining these loads; these factors are larger for higher risk categories. which means the corresponding loads will be larger. Analyses must be performed to determine whether the affected structural members need to be strengthened or not.

Vibration is often not an issue for reinforced concrete floor systems because of inherent mass and stiffness. However, with certain types of occupancy changes, rhythmic excitations like those generated by fitness equipment (especially treadmills) or by aerobics or jumping can cause vibration problems on elevated floors in existing buildings. A vibration analysis must be performed in such cases to determine whether the existing floor system satisfies the applicable acceptance criteria or not.

Floor vibrations must also be checked where sensitive equipment such as microscopes, magnetic resonance imagers, or microelectronics manufacturing equipment, to name a few, must be supported on existing elevated floors. Equipment may not operate properly where the expected maximum velocity of the floor system is greater than the limiting vibrational velocity of the equipment.

Remediating the effects from vibration in an existing
building can be quite challenging depending on the circumstances. Where a large difference occurs between the actual conditions and the acceptance criterion, a solution to remediate the vibration may be possible, but, more often than not, it is impractical, too costly, or both to implement. Feasible solutions include relocating the vibration source to a slab on grade or to a more vibration-resistant floor system. Locating sensitive equipment away from corridors and other traffic pathways or closer to columns and walls can reduce or eliminate vibration issues. Comprehensive information on vibrations in reinforced concrete floor systems can be found in Reference 26, including analysis methods for various types of floor systems and strategies for mitigation and remediation.

**Bay Removal**

**Can entire bays be removed in an existing concrete building?** It is possible to remove entire bays in an existing reinforced concrete building (see Figure 10). One or more of the following issues need to be considered depending on the location of the bay removal and the existing conditions.

- Loss of lateral support of existing columns or beams. Removal of the end bay in the existing floor system in Figure 11 results in the loss of lateral support for the spandrel beam and the affected edge column. The beam must be checked for gravity load effects due to self-weight and façade weight, where applicable, and for lateral load effects without lateral support provided by the slab. The column must be analyzed as a two-story column in the north-south direction, which must include the possible effects due to slenderness. Depending on the circumstances, loss of lateral support of interior beams or columns can also occur.

- Redistribution of gravity load effects. Where a bay is removed, the bays adjacent to the new opening become end bays. This causes a redistribution of gravity load effects in those bays, and the structure must be checked accordingly (see the discussion above for one-way slabs).

- Change in diaphragm stiffness and distribution of lateral forces. The introduction of a relatively large opening in an existing floor system can have a significant impact on the stiffness and behavior of a diaphragm and on the distribution of lateral forces to the vertical elements of the LFRS. As discussed previously, structures that meet the diaphragm discontinuity irregularity criteria in ASCE/SEI Table 12.3-1 must satisfy certain design and detailing requirements for buildings assigned to Seismic Design Category (SDC) D, E, and F. Also, in-plane force transfer from the diaphragm to vertical elements of the LFRS can be significantly affected where the diaphragm is removed adjacent to the vertical elements. This results in redistribution of lateral forces to all the elements of the LFRS, and the existing structure must be checked accordingly. For the situation depicted in Figure 11, in-plane shear transfer from the diaphragm to the wall has been eliminated on one side of the wall due to the bay removal, which results in a redistribution of lateral forces.

**Column Removal**

**Can columns be removed in existing reinforced concrete buildings?** Removal of one or more columns in an existing reinforced concrete building is possible. Careful planning and coordination with the contractor is essential for this type of modification, particularly in the means and methods of removal.

The location of the column and the magnitude of the gravity load it supports usually dictate whether removal is feasible or not. For example, corner columns should not be removed. It is generally not possible to remove a column that supports a relatively large axial force because of the logistics associated with removing the existing axial force from the column prior to removal (which entails jacking the existing structure) and subsequently transferring this force to existing columns or walls via a...
new transfer beam. The required size of a transfer beam may not be feasible for strength or construction reasons.

Where column removal is feasible, the axial force from the removed column can be supported by a new transfer beam that has been constructed below the column above. This beam, in turn, transfers the axial force to existing columns or walls adjacent to the column that is being removed. These columns, walls, and foundations must be checked for the increased forces and must be strengthened, where required. As noted previously, it is not always feasible or cost-effective to strengthen columns, walls, or foundations in an existing building.

It is not recommended to remove columns that are part of the LFRS, especially columns that are part of intermediate and special moment frames, which are required in buildings assigned to SDC C and to SDC D, E, or F, respectively.

Additional Floors

Can one or more floors be added to an existing reinforced concrete building? It is possible to add one or more floors to an existing reinforced concrete building. Expanding the building vertically can often pose significant engineering challenges. The extent of vertical expansion depends on a number of factors, the most important of which is the load-carrying capacity of the existing structural members, particularly the vertical members and the foundations.

If possible, it is strongly recommended to connect the new columns and walls in the expansion directly to the existing columns and walls; by doing so, the existing horizontal roof framing is not subjected to any transfer loads and no new transfer members are required. The existing columns and walls over the entire height of the building and the foundations must be checked for the increase in gravity load. Where design strength is exceeded, it may be possible to strengthen these elements, but doing so is not always feasible or cost-effective, especially for existing foundations. The use of lightweight aggregate concrete in the expansion helps reduce the dead load that needs to be supported by these members.

The structural members at the existing roof level must be checked for the required live load that is associated with the new occupancy at that level. The live load from IBC Table 1607.1 will more than likely exceed the live load that the roof members were originally designed for. The increase in live load may be partially offset by the reduction in dead load due to the removal of roofing material. Where design strength is exceeded, existing structural members need to be strengthened accordingly.

An increase in building height and weight due to vertical expansion signifies an increase in wind and seismic forces, respectively. The existing LFRS must be checked for these larger forces. If possible, the members of the new LFRS for the expansion should be connected directly to the members of the existing LFRS.

Strengthening Methods

What strengthening methods are available for reinforced concrete members? Numerous methods are available to strengthen existing reinforced concrete members. Selecting the most suitable method depends on a number of factors, the most important being the type of structural member that needs to be strengthened. Section 2.0 of Reference 3 contains a list of engineering issues that should be carefully considered when selecting a strengthening method. Chapter 4 in Reference 4 contains numerous strengthening methods for reinforced concrete buildings. In summary, a thorough understanding of the structure, the work area where the modifications are to be made, and pertinent restrictions and limitations are essential before a feasible strengthening method can be selected and implemented. Two common types of strengthening methods are briefly discussed below.

Section enlargement. Section enlargement is a strengthening technique where additional concrete and reinforcing steel is added to an existing structural member (slabs, beams, columns, and walls) to increase member strength and stiffness. The main items to consider in this method are the following:

- Section enlargement may not be possible due to existing ducts and pipes adjacent to the member. Rerouting these items to accommodate the enlargement may be an option but doing so is usually very expensive and time consuming.

- The existing section and the enlargement must act as a monolithic member, and details must be provided on the construction documents that show how this is to be achieved. The enlarged section cannot resist existing dead loads unless such loads are removed prior to the installation of the enlargement (such as by shoring and jacking); only live loads and new superimposed loads can be resisted by the enlarged section where existing loads are not removed.

- Where enlarged sections are part of the LFRS, the increased stiffness must be accounted for in the lateral load analysis.

Supplemental supports. Supplemental support strengthening is a technique where the load effects on an existing structural member are reduced or the design strength of an existing structural member is increased by adding one or more new structural elements.
at judiciously-chosen locations in the existing structure. This strengthening method can also be used to decrease deflections or to improve the vibration characteristics of an existing floor system. A supplemental support system can consist of a single column, several beams and columns, or bracing members.

The main items to consider in this method are the following:

- A new load path through the structure is likely to occur because of the introduction of new supports. The corresponding load effects must be thoroughly investigated at all locations in the structure and in the foundations.

- The location of supplemental supports can have a major impact on the redistribution of load effects in an existing member. Consider the existing reinforced concrete beam in Figure 12 where a new column has been added below the beam at midspan, the purpose of which is to decrease the shear forces and bending moments along the span. This support introduces a negative bending moment at this location, which the beam was not originally designed for. In this case, no top flexural reinforcing bars are available to resist this bending moment. When considering supplemental supports, it is important to study the existing conditions and subsequent effects on the existing structure.

- Supplemental supports cannot resist existing dead loads unless such loads are removed prior to the installation of the supports (such as by shoring and jacking); only live loads and new superimposed loads can be resisted by the supplemental supports where existing loads are not removed. It is common for a supplemental member to be installed with a small gap between it and the existing member (trying to achieve an “exact fit” between the new and existing members is not feasible for a number of reasons). A non-shrink grout is then dry-packed into the gap. This method of construction essentially ensures that superimposed loads will be directly transferred into the supplemental members. If the gap is not filled, the existing member would have to deform before the supplemental member could be engaged, which would not occur if the gap is too large.

References


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Historical: Not applicable

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