Resolving Impaired Performance Caused by Conduit Congestion in Concrete Slabs

by Charles C. Thiel Jr. and K. Dirk Bondy

Traditionally, the structural performance issues posed by placing conduits in concrete slabs were limited mostly to electrical conduits for lighting, which seldom presented structural performance issues if they were in the middle one-third of the slab. The advent of electric vehicles (EVs) and the necessity to provide charging stations have increased the potential for diminished structural integrity caused by embedded conduits. EV installations require as much conduit as photovoltaic (PV) installations, although the latter tend to be more localized to the roof.

All new parking structures in California are required to be wired for PV installations, resulting in conduit quantities that have overwhelmed the traditional design assumptions and shown them to be inadequate. The structural and construction communities need more reliable design procedures to evaluate and design slabs with embedded conduits. As demonstrated in Fig. 1 to 4, there is a need for the concrete industry and code communities to address this concern.

The California State University (CSU) system's Seismic Review Board (SRB) developed interim requirements for CSU projects. This article shares their interim requirements with the structural engineering community, concrete industry, and model-building code community in the hope that the issue will receive broader consideration, and that consensus technical requirements will be developed.

The reason for the change is the imperative to put PV collectors on roofs and EV charging stations throughout garages. Mandatory requirements for such have been enacted and are being enforced without addressing the structural engineering issues, other than weight and attachment, which are part of the code, without addressing the resulting conduit problems. Other electrical systems requiring conduit include lighting, data, Wi-Fi, power outlets, ventilation and fans, security video, carbon monoxide sensors, methane sensors, gate sensors, telephones, and so forth. Because mechanical/electrical/plumbing (MEP) and structural engineering (SE) permits are often separately considered, effective coordination between these specialties is required to avoid the negative implications of conduit congestion. Cumulatively, the conduit requirements have become excessive for some slabs. These conditions can seriously impair the structural load path and create an unanticipated structural hazard.

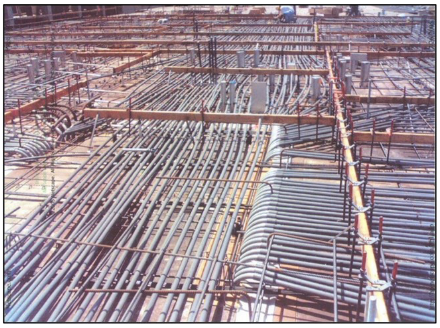

Fig. 1: An example of the congestion of conduits in a slab

Framing the Problem

The images in Fig. 1 to 4 make it clear that the concentration of conduits could have serious consequences if they occur in areas of high diaphragm shear and bending moment in the load path. This includes the full spectrum of loads seen in all environments for gravity, live loads, and natural hazards. Of particular concern is the potential that this conduit will impair the punching shear of a column in a flat-plate system. Suppose a conduit occupies 2 in. (50 mm) of depth in a 7 in. (178 mm) deep flat plate. In that case, the slab has only 71% of the calculated punching shear capacity, and the conduit introduces the possibility that horizontal cracking could be initiated here and propagate to other sections if there are not regular vertical ties between the reinforcing bar curtains. Most long-span parking structures use only 5 in. (127 mm) thick

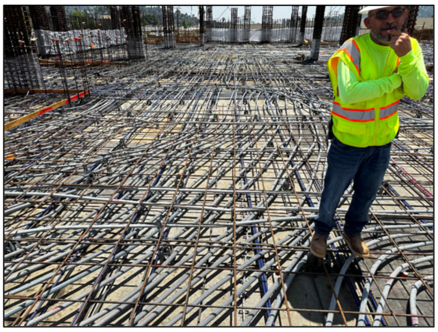

Fig. 2: A second example of the congestion of conduits in a slab. The curvilinear silver elements are conduits, the blue elements are post-tensioning cables, and the brown elements are mild steel reinforcing bars. Photo taken after the top side reinforcement was placed to moderate the conduit impact after observation of installation

Fig. 3: A close-up of the reinforcement. Here, the top curtain of added reinforcement is more visible. Note from the shadows on the conduit that many of these appear to be within 1 in. (25 mm) of the reinforcing bar curtain

Fig. 4: A close-up of the reinforcement at the edge of a shear wall to be cast where the vertical bars at the right of the image are (photo taken in 2024). Note from the shadows on the conduit that many of these appear to be within 1 in. or less of the top reinforcing bar curtain in the slab

one-way slabs. The middle one-third comprises only 1.66 in. (42 mm) of usable space for conduit, which precludes stacked conduits to meet the old requirements and effectively necessitates the external placement of conduit. Therefore, the focus of concern is on two-way flat plates. Engineering mechanics and judgment affirm the need to avoid concentration of stress, such as that caused by closely spaced large conduits. If such concentration of conduit is unavoidable, then the design of the slab should include added reinforcing bars designed to ensure that shear and bending moment can be transferred reliably through these sections of the slab.

No specific standards or building code requirements address this problem, except that maintaining the load path integrity for shear and moment capacity transfer is integral to good practice. So, it falls within the purview of the design professional. Claiming that the referenced codes and standards did not require consideration of embedded conduit congestion is unlikely to be a defense strategy if serious consequences should occur. Current practice allows the conduits to be placed in a slab to be indicated only schematically on the electrical design drawings—the preparation of design details is typically a deferred item. It is far from common for the structural engineer of record (SEOR) to review conduit layouts to discover if there is congestion.

The solutions for conduit congestion in a slab are less expensive to deal with when they are identified in the design phase rather than addressed during construction. During the design phase, the option of placing the conduits exterior to the slab is still possible. For these reasons, the CSU SRB acted as discussed herein.

While these issues were first found by the authors during peer reviews as posing a seismic issue, the problem is apparent in all types of loading conditions, including column punching. EV charging stations and PV installations are universal and have no regional concentration.

Interim Recommendations for Structural Engineering Practice-Based Actions

A section on conduit placement is in the process of being incorporated into CSU's Seismic Requirements document.[1] CSU has been directed by its Board of Trustees to meet good-practice norms that may not be required by applicable codes or standards. The following are stated as requirements but should be considered as recommendations for consideration by the structural engineers who propose to use them in their general practice:

- Each individual conduit must be drawn with the outside diameter specified and its complete path of travel. It is not acceptable to draw a single line and call out multiple conduits. In two-way slabs, prestressed or nonprestressed, conduits shall not be placed within 3 ft (0.9 m) of any column face or within the field of headed shear stud reinforcement protruding from a column;
- In post-tensioned slabs, the conduit shall not exist within 24 in. (610 mm) of the bearing face of an anchor;
- Conduit locations must be within the middle one-third of the slab, except for right-angle turns where they penetrate the horizontal planes of the slab;
- Conduits should be constructed of plastic or steel. Aluminum conduit is not allowed. Plastic polyvinyl chloride (PVC) conduit can be ridged instead of smooth. The maximum outside diameter of the conduit shall be 1.0 in. (25 mm) for slabs less than or equal to 6 in. (152 mm); 1.25 in. (32 mm) for slabs between 6 and 10 in. (152 and 254 mm); and 1.5 in. (38 mm) for slabs greater than 10 in;
- The conduit seems to act as a weak bonded reinforcement at low levels of loading (service), and the cracking that we might expect with this number of voids does not typically appear. For this reason, consideration should be given when using PVC conduits with ridges as opposed to being smooth where conduits are allowed in the slabs;

- All conduits must be chaired independently of the slab reinforcement (bonded reinforcement or post-tensioning);
- Crossing of conduits should be avoided or minimized. Where it cannot be avoided, all conduits must exist within the middle one-third of the slab. When this cannot be achieved, the adjacent crossovers should be not less than one slab thickness apart. Often, this problem is accentuated as the conduit converges at the electrical room. That's a good reason for having multiple electrical rooms on the floor;
- The required spacing of the conduit in the slab must be shown and shall not be less than three times the conduit diameter governed by the largest of the adjacent conduits;
- Added reinforcement (top and bottom) should be used at congested locations of conduits to minimize cracking and maintain the integrity of the slab as a vital component in the structural load path of the lateral-load-resisting system. Where vertical conduits exist that penetrate the horizontal planes of the slab at the bottom or top, there must be added reinforcement at the top and/or bottom of the slab so that every fourth such vertical conduit has added reinforcement perpendicular to the plane of the conduit extensions, as well as added bars so that the bundle of conduits is enclosed in a reinforcing bar rectangle;
- The SEOR shall include inspection of conduits in the special inspections to address conduit and structural elements by the inspector of record (IOR) to verify that these requirements are met;
- The SEOR shall observe the construction of the slabs as needed to verify that initial physical layouts of conduits are consistent with the design intent and, if necessary, require modification of the placements or the structural design to accommodate the placements to maintain the structural integrity of the slab;
- The structural peer reviewer, if one is engaged, shall examine the electrical conduit plan and structural drawings to confirm no excessive conduits are in any proposed design whose structural issues are unresolved; and
- The SEOR shall instruct the IOR to review the reinforcement of **all** concrete slabs before placing concrete to ensure these rules are followed.

Recommended Responsibility Assignments

We have observed that many inspectors claim that it is not in their purview to inspect or comment on electrical conduits. When inspections are requested by the SEOR, common responses include:

- "I am not certified nor trained to inspect electrical elements";
- "My scope of work only includes inspecting the rebar and the post-tensioning"; or
- "I am only taking samples of the concrete to test slump and make cylinders for testing."

Even if there is an inspection of the electrical system, those inspectors are not looking at nor commenting on congestion as a structural issue.

Our experience is that requirements on the structural drawings about conduit placement will not be reviewed in enough detail to observe if congestion is a problem or not. When it occurs, the feasible fix is an added mat of reinforcing bars in congested areas, but nobody will direct the elimination or relocation of the conduit until the SEOR comes to the site and writes an observation report—usually 1 or 2 days before the placement.

The CSU inspectors have been tasked by peer reviewers with inspecting and commenting on conduit congestion, interference, and placement. But in the general construction community, inspectors are rarely focused on these issues or adding conduit observations to their daily reports.

Experience indicates that city inspectors have shut down placements when they recognize problems, but this typically happens the day before the concrete placement and well after all the reinforcement and conduits are tied in place. When this is the case, the city inspector makes an emergency request and mandates that the SEOR comes to the site and writes a letter either accepting or rejecting the conduit. This puts the SEOR in a very awkward position. The design and construction community needs to have a better system than this to identify the conduit problems earlier when they can be easily resolved.

Based on our collective experience, the CSU SRB has made the following recommendations for action for various members of the design/construction/supervision groups on their projects. Again, these should only be taken as recommendations for consideration by the design team:

Building official

- Building officials should identify this problem during permit applications as a practice deficiency not covered by the current codes but potentially leading to major structural response issues.

Inspector

- Inspectors observing pre-placing slabs for approval are to notify the SEOR if conduit conditions are present that need consideration. Often, the placement of conduits is not covered in the permit drawings but becomes a deferred construction issue, which, if **not** called to the attention of the structural SEOR, may not be addressed, and a deficient slab may be the consequence.
- The SEOR shall inform the inspector of what conduit congestion entails and how it can be identified.

Design and construction team

- The SEOR shall inform the design team of the issues of conduit congestion and inspect the initial installation to confirm that the contractor and designers are following good practices where congestion occurs.

- The peer reviewer shall identify where these issues are apparent and direct engineering resolution. The peer reviewer should be particularly concerned about such problems developing during construction where conduit placement is often a deferred submittal that is not reviewed by the SEOR.
- The design/construction team should do a cost comparison of embedding conduit within the slab, along with the added nonprestressed reinforcement required, versus surface-mounting conduit below the slab or in predesignated chases or shafts. Unless the surface-mounted conduit presents an unacceptable architectural feature to the structure, most of the PV and EV conduit should be surface-mounted.
- During the design phase, multiple electrical rooms shall be considered on each floor where PV and EV conduit will be placed in the slab. A single electrical room where all conduits converge shall be avoided.
- We urge all structural engineering peer reviewers to consider these recommendations and identify projects where the designers have created such issues and seek to resolve them as a good-practice imperative to achieve the building code objective of providing structures that meet the safety imperative of the building code provisions.
- We urge all design teams to understand that while these issues have been seen in parking structures, the same PV and EV forces for development apply in offices and residential buildings.

Others with a vested interest

- We recommend that the technical community consider the development of design standards for conduit congestion. We are particularly interested in addressing retrofit actions before this becomes an imperative.
- We recommend interested researchers explore the impact on structural performance caused by conduit congestion in slabs to provide a knowledge base on how best to address them.
- We recommend that concrete and post-tensioning standards communities take steps to prepare requirements that can be incorporated into the model codes to resolve the professional and construction practice difficulties identified in this paper as quickly as practical.

CSU enforces these conditions as the owner of the structures, and the SRB confirms that the mitigation steps, if taken, maintain the structural integrity of the gravity and lateral-load-resisting system. The SRB is required by trustee directions to review all aspects of the seismic design of a building before the building official approves a permit to proceed, and their duties are not completed until the occupancy permit is issued.

Acknowledgments

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Reference

1. "CSU Seismic Requirements," California State University, Long Beach, CA, Feb. 15, 2024, 56 pp., https://www.calstate.edu/csu-system/doing-business-with-the-csu/capital-planning-design-construction/Documents/CSU_Seismic_Requirements.pdf.

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