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EARTHQUAKE DAMAGE RESULTING FROM SLAB-ON-GROUND TRENCHING

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Abstract

A code review of current requirements for trenching, or sawcutting of existing slabs-on-ground to accept utilities, was performed for buildings in seismic zones and areas susceptible to liquefaction and differential settlement. The resulting review shows that there are few requirements or recommendations for this practice for existing buildings. A generalized code amendment is suggested in an effort to ensure that proper detailing and design are implemented. Architects, mechanical engineers, and plumbers are often performing trenching procedures with very little input from structural engineers. The resulting trench results in slabs that may perform poorly in large earthquakes where soil settlement occurs and the ability of the slab to accommodate differential settlement is compromised due to the poorly detailed slab and underlayment at trenching locations. Common details currently used by structural and other engineers are evaluated and critiqued for resistance to liquefaction and differential settlement, and a detail is suggested. This paper stems from the authors' experience in investigating damage following earthquakes, including the recent Napa earthquake in California, where significant (and costly) damage was encountered due to poorly detailed subbase/subgrade systems and patches in slabs-on-ground at trenching locations.

Keywords: Slab-on-Ground; Trenching; Liquefaction; Differential Settlement; Earthquake Damage Assessment



1. Introduction

Trenching through concrete slabs-on-ground is a common practice performed to place mechanical or electrical utility lines underneath existing slabs-on-ground. A typical trenching procedure is to full-depth sawcut the concrete slab-on-ground, including any embedded reinforcing, and remove the concrete from the area between sawcuts. The trenching can result in long strips of slab removal that can run from one end of a building to another; often the trenches intersect and branch out, creating a patchwork of slab removal (Fig. 1). After slab removal, the subbase and subgrade is removed and the pipes or conduits are placed. The trench is then backfilled with soil and new concrete is cast.

There are currently very limited requirements for the design of the repairs of trenched areas, which are often detailed by mechanical, electrical or other parties involved in the utility placement that have limited knowledge of structural behavior of reinforced concrete slabs-on-ground or geotechnical behavior of underlying soils. Even when detailed by a structural engineer, many details we have reviewed have weaknesses in the delivery of important information to ensure good behavior of the patch. Furthermore, the subbase and subgrade of the slab-on-ground is often designed by a geotechnical engineer for initial construction; however, these guidelines are often not considered when the subbase and subgrade are removed and replaced during trenching activities.

In locations with weak soils, ground shaking due to earthquakes can produce differential settlement of soils and liquefaction. At these locations, where there is a high risk of liquefaction or differential settlement of the soil, it is desirable to have slab-on-ground patches that are detailed to act integrally with the surrounding existing slab and not result in significant vertical offsets after significant ground shaking (Fig. 2). Trenching locations where a designed subbase/subgrade underlayment has been removed and another underlayment system has been installed can be more at risk for differential settlement. Although damage to slabs-on-ground after earthquakes in areas of weak soils has been documented [1-3], in virtually all cases it is considered non-structural damage. It can also be difficult to distinguish earthquake cracking damage from pre-existing commonplace shrinkage cracking in slabs-on-ground. Although differential settlement of a previously trenched slab after an earthquake does not create a life safety hazard, it may prevent the immediate functioning of the business after an earthquake and may lead to expensive remediation costs. In locations where the slab-on-ground is relied on to transfer seismic forces to the soil, improper removal and replacement of long strips of slab could lead to structural damage after a large earthquake.



Fig. 1 - Trenching through existing slab-on-ground

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Fig. 2 - Vertical offsetting at a slab-on-ground joint due to earthquake-induced settlement

2. Code Provisions

In general, the governing codes in the United States do not provide requirements for the detailing and design of trenching through slabs-on-ground in areas subject to liquefaction or differential settlement. The 2015 International Building Code (IBC) [5] only discusses slab-on-ground foundations in relation to expansive soils where the *WRI/CRSI Design of Slab-on-Ground Foundations* [6] document is referenced. In IBC section 1808.2, settlement is briefly addressed with a statement that foundations should be designed so that that differential settlement is minimized; however, does not provide any further guidance of how this should be achieved. Trenching and the removal and replacement of subbase/subgrade is not addressed even though in our experience the trenching efforts undertaken by contractors are given little guidance or oversight. The IBC mentions general requirements for supporting soil properties for shallow foundations in section 1804.6 where the requirement for compacted fill is 90% of the maximum dry density; however, this is only the case for compacted fill material 12 inches or less in depth. Trenches for utilities are often deeper than 12 inches. In these cases, the IBC requires that the subbase/subgrade comply with an approved geotechnical report.

The IBC currently has very little guidance on the design of the slabs-on-ground. The WRI/CRSI document referenced in the expansive soils section about slabs-on-ground was originally published in 1981 with an update in 1996. It outlines design procedures for all slabs-on-ground, not only in expansive soil conditions. This document also explicitly states that the design procedure considers loss of support and the center and edges, in effect, differential settlement. Therefore, this document would be well-suited for the design of slabs-on-ground in areas of liquefaction and differential settlement and should be used as the design standard for these areas.

The American Concrete Institute (ACI) Standard 318 [7] contains design requirements of concrete foundations; however it specifically excludes requirements for slabs-on-ground that are not structural slabs. The provisions in ACI 318 for slabs-on-ground only apply when they are used as part of the lateral force resisting system or in areas that directly transmit code level forces through the slab to the soil, commonly referred to as structural slabs. Since structural slabs are required to be designed in accordance with "applicable provisions" of the ACI 318 document, they have been omitted from consideration in this paper. The ACI 318 explicitly states "This Code does not apply to design and construction of slabs-on-ground, unless the slab transmits vertical loads or lateral forces from other portions of the structure to the soil." The commentary for this statement refers to the ACI 360R [8] document for the design of slabs-on-ground that are not considered structural slabs.



ACI 360R states that "Stresses in slabs-on-ground result from applied loads and volume changes of the soil and concrete. The magnitude of these stresses depends on factors such as the degree of slab continuity, subgrade strength and uniformity..." Specifically, it notes that subbase/subgrade uniformity and continuity of the slab are important. These two items are often compromised during trenching activities. The ACI 360R addresses the issue of trenching in concrete slabs in section 4.4.7: "Lack of uniform support can cause slab cracks. On some projects, a well-constructed subgrade has been compromised by utility trenches that were poorly backfilled. The importance of providing uniform support cannot be overemphasized. Inspection and testing of controlled fills should be mandatory." However, this statement does not place any specific requirement for the subbase/subgrade nor does it address detailing of the concrete patch.

3. Review of Current Trenching Details

A common practice in the United States is for a structural engineer to have a standard detail for a slab-on-ground patch that is used interchangeably between projects. This detail remains the same from project to project despite differing subbase/subgrade conditions or project specific susceptibility to liquefaction and differential settlement. Furthermore, often a structural, civil, or geotechnical engineer is not involved in the detailing of the slab-on-ground trenching and concrete patch, since other parties, such as contractors, are often solely involved in pipeline and conduit work. This further emphasizes the need for a standard detail, or other provisions, for a concrete slab-on-ground trenching patch in areas of weak soil that can be used by all parties involved in the work.

A good detail should ensure that the behavior of the concrete patch material and adjacent existing slab-onground acts integrally and the sawcut joints are able to transfer shear, tension, and moment forces. Also, the subbase/subgrade should provide uniform support and strength to the patch and existing slab-on-ground.

Several example details have been obtained from anonymous engineers. Below these details are evaluated for strengths and weaknesses to achieve the aforementioned behavior, specifically in locations susceptible to liquefaction and differential settlement. In the next section a detail is suggested that draws from the strengths of the example details to more completely achieve the desired behavior.

3.1 First example detail

The first example of a detail of a trench patch repair from a structural engineer can be seen in Fig. 3, below.



Fig. 3 – First example structural slab-on-ground trenching patch detail



The detail in Fig. 3 provides information on the patch reinforcing and how it is attached to the existing slab-on-grade. Proper attachment of the new reinforcement to the existing slab with epoxy dowels ensures that forces are transferred across the sawcut joint. However, this detail does little to address the existing subbase/subgrade conditions and does not make any efforts to match the newly placed material with existing. While there are numerous elements of this detail that are intended to address force transfer at the sawcut joint, this could be improved by requiring the joint to be roughened prior to new concrete placement. Furthermore, the strength and type of the concrete infill is not stated, however, this can have a significant effect on the performance of the patch.

3.2 Second example detail

The second example of a detail of a trench patch repair from a structural engineer can be seen in Fig. 4, below.



Fig. 2 – Second example structural slab-on-ground trenching patch detail

The detail in Fig. 4 provides information for new dowels to be placed and attached to the existing slab-ongrade, which will provide the transfer of forces across the sawcut joint. Information is also provided for the reinforcing of the patch itself. A note is included in this detail that indicated to roughen the surface of the concrete which will aid in the existing concrete and patch behaving more integrally. In this detail, the steel that is placed across the sawcut joint is a dowel, which may imply a smooth bar. A smooth bar does not have the same ability to impart loads into the concrete when in tension and therefore the joint is inherently weaker in tension and bending moment than if a deformed bar were used. In a fully supported condition, shear transfer through the joint would be the primary concern, however, in areas of liquefaction or differential settlement the slab may be required to span a void, thus needing to have a moment capacity. The detail shows the subbase/subgrade and shows that it is the same in the area under the patch as the adjacent, however, does not explicitly indicate what it is.

3.3 Third example detail

The third example of a detail of a trench patch repair from a structural engineer can be seen in Fig. 5, below.



Fig. 5 – Third example structural slab-on-ground trenching patch detail

This detail addresses the continuity and patch of the under-slab moisture barrier, something that previous details did not. The backfill in this detail is indicated as compacted sand or gravel which may or may not match the existing soil profile. The detail also appears to show that the bottom of the patch is inset, therefore making it thinner, and inherently weaker, than the surrounding areas. Surprisingly, this detail also provides no longitudinal reinforcement in the direction of the trench; this is even with a width of the trench that sets no maximum.

3.4 Civil and electrical engineer example details

Project specific example details provided by electrical and civil engineers were reviewed. These details were found to have detailed information regarding the subbase/subgrade and very limited detail of the concrete slab-on-ground, as expected. The subbase/subgrade detail is likely partially attributable to the project-specific nature of the details, which are likely more detailed than a standardized detail. Despite this, there is a clear indication that the slab-on-ground detailing is overlooked on the details. For the sake of anonymity, the reviewed electrical and civil details are not shown in this paper.

4. Recommended Trenching Detail

As expected, the details researched vary distinctly. It is understandable that the electrical and civil engineer details are more concentrated on the subbase/subgrade system than the slab above. Likewise, the structural engineer details concentrated on the slab itself and generalize the subbase/subgrade. The civil and electrical engineer details were researched from specific jobs may not necessarily be a good representation of a standard. Nonetheless, the details were all useful insight in development of a suggested detail.

Considering all the details studied, the detail in Fig. 6 below is a suggestion of a standard generalized detail that could be used in various projects, including in high seismic zones with liquefaction and differential settlement risk. The detail presents the subbase/subgrade in general terms, however, requires that replacement of the existing system in kind, if it is known. If the existing system is not known, the detail gives a minimum guideline. The moisture barrier, if exists, is shown to be patched prior to placement of the concrete. A note is included indicating that the depth of the concrete patch must be at least the same depth as the existing concrete to ensure that a weak point is not created. Furthermore, a minimum concrete strength is indicated to ensure that the quality is acceptable. Embedded deformed bars and a significantly roughened surface of the sawcut ensures that there is a good bond and force transfer through the joint. A maximum width is established for the trench and a note is added indicating that a structural engineer should be retained for larger trenches. This ensures that the patch is designed for project specific conditions if it is large.



It is suggested that a more specific detail be developed, whenever possible, considering project-specific conditions. This would be especially important if a subbase/subgrade system was designed by a geotechnical or civil engineer for the project.



Fig. 3 – Suggested slab-on-ground trenching patch detail

5. Code Change Recommendation

An investigation into the current code provisions found no guidelines regarding repair of trenching activities at slabs-on-ground in areas susceptible to liquefaction or differential settlement. A simple addition to the code could be added in order to establish requirements for slab-on-ground design, and inherently also patch details for trenching, at these areas. The following is a suggested code modification to the 2015 IBC:

1808.X Design for liquefiable soils or differential settlement. In *Seismic Design Category* D, E, or F, in locations that are known to contain subsoils with the potential of liquefaction or localized settlement, foundations should be designed in accordance with Section 1808.X.1.

1808.X.1 Slab-on-ground foundations. The design of slab-on-ground foundations, including patch sections due to trenching or other operations, shall be designed in accordance with the *WRI/CRSI Design of Slab-on-Ground Foundations or ACI 360R-10 Guide to Design of Slabs-On-Ground*. It shall be permitted to analyze and design such slabs by other methods that account for soil-structure interaction, the deformed shape of the soil support, the plate or stiffened plate action of the slab as well as both center settlement and edge settlement conditions. Such alternate methods shall be rational and the basis for all aspects and parameters of the method shall be available for peer review.

The above passage is limited to slabs-on-ground and does not include considerations for other foundation types, which may be necessary, however, are beyond the scope of this paper.

6. Conclusions

An added code section has been suggested in an effort to establish requirements for the design of slabs-onground in high seismic zones susceptible to liquefaction and differential settlement. A detail has also been suggested that draws from the strengths of several engineer's standard details. The detail attempts to obtain



better behavior of slab-on-ground patches due to trenching operations, in the event of underlying soil liquefaction or differential settlement.

Implementation of both these recommendations would help to reduce damage caused from liquefaction and differential settlement due to poor detailing of trenching through slabs-on-ground, by requiring that a design standard be followed in these areas and providing an example of an acceptable detail.

7. References

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