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Study on crack formation and crack mitigation in post-tensioned mat foundations and slabs

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ABSTRACT

Crack formation in reinforced concrete structures can significantly affect the performance and lifespan of buildings. Usually, when developing the structural design of a building, deflection-induced cracking is analyzed and measures to prevent serviceability issues regarding deflection are considered in the design of concrete structures. However, crack formation in concrete structures is developed by other causes apart from deflection effects, such as the case of restrain-to-shortening effects. (Aalami and Barth, 1988) Inexperienced structural engineers can often disregard the inclusion of restraining crack mitigation details and processes in their designs. This paper has the purpose of studying the restraining effects that can lead to cracking in post-tensioned mat foundations and slabs, and proposes a series of mitigation measures that can be indicated during the design process to prevent the appearance of such cracks.

1. INTRODUCTION

Crack formation in reinforced concrete structures can significantly affect the performance and lifespan of buildings. Usually, when developing the structural design of a building, deflection-induced cracking is analyzed, and measures to prevent serviceability issues regarding deflection are considered in the design of concrete structures. However, crack formation in concrete structures is developed by other causes apart from deflection effects, such as the case of restraint-to-shortening effects influenced by drying shrinkage, temperature changes, creep, and elastic shortening specific of prestressed slabs. Inexperienced structural engineers can often disregard the inclusion of restrain-induced crack mitigation details and construction processes in their designs. This paper has the purpose of studying the different restraining effects that can lead to cracking in post-tensioned mat foundations and slabs and its possible mitigation measures.

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2. RESTRAINT CRACK CAUSES AND MITIGATION MEASURES IN POST-TENSIONED SLABS.

2.1. Causes for crack formation

When shortening takes place in a slab, the stiffness from the columns and walls connected to it can produce a restraining force, pulling the slab apart in opposite directions, and leading to crack formation in the central area of the slab. When the tensile stress exceeds the tensile strength of the concrete, a restraint crack occurs. (Nawy, 2008)

Due to the bonding influence of rebar in non-prestressed reinforced concrete slabs, the formed cracks tend to be shorter, but more in quantity and distributed along the central section of the span. However, cracks produced in unbonded post-tensioned slabs tend to be much less in quantity, but with more depth, and extend longer along the span of the slab. Because in this case, cracks could be open throughout the depth of the slab there is an increased risk of leak formation.

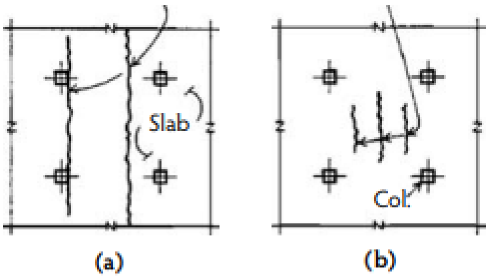

Fig.1. Reflected ceiling view of slabs illustrating crack formation in (a) post-tensioned slab; (b) reinforced concrete slab. (Nawy, 2008)

2.2. Mitigation strategies

Restraint crack formation in concrete slabs can be mitigated, with adequate member sizing, and an adequate architectural layout. It is important to avoid massive columns or massive supporting walls connected to a thin slab. Regarding the architectural layout, it is suggested to locate the members that could induce the most restraint forces (bearing walls, elevator or stair shafts) near the central part of the slab to minimize the ‘pulling’ effect.

The kind of cement or admixtures used to make the concrete mix can also significantly influence the formation of cracks due to shortening. In a study of drying shrinkage effects of concrete slabs on ground, concrete using calcium sulfoaluminate cement (CSA) showed to be very stable with no long term shrinkage, cracking or warping, while typical portland cement concrete (PCC) and high-strength concrete (HSC) can continue to show crack growth at over two years of age. (Shadravan, Ramseyer, and Kang, 2015)

The inclusion of a closure strip, also called pour strip, which consists on leaving a portion of the slab open to be filled once the most expected shrinkage of concrete would have occurred, is also a commonly used crack mitigation measure.

In the cases where the architectural layout cannot be modified to further minimize the effects of restrains, and if no required shear strength or stiffness is minimized as a result, release detail implementation is also recommended. The release of restrains consists on partially detaching the slab area that is expected to be most influenced by restrain forces, from the restraining elements, to allow free movement. (Aalami and Barth, 1988) These releases can be permanent, or temporary, depending on the designer and builder's consideration.

There is an advantage that can be taken from post-tensioned slabs. If the tendons are laid out in a way that deposits additional compression in regions where strength losses are expected to be highest, crack appearance can be prevented.

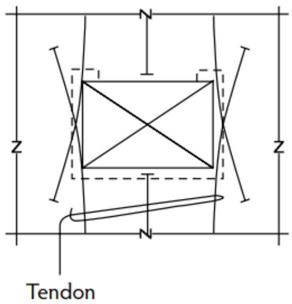

Fig.2. Arrangement of tendons as to prevent the formation of cracks around an opening. (Nawy, 2008)

All these recommendations should be considered along with the use of a strategically placed amount of bonded reinforcement in the unbonded post-tensioned slab.

3. RESTRAINT CRACK CAUSES AND MITIGATION MEASURES IN POST-TENSIONED FOUNDATION SLABS.

3.1. Causes for crack formation

In foundation slabs, volumetric changes due to shrinkage, temperature effects, and creep of the concrete are restrained both by subgrade friction and by restraining elements below and above the foundation. (Aeberhard, Marti, and Schuler, 1988) Because of the below-grade location of foundation slabs, few temperature and drying shrinkage effects might occur.

However, as the top fiber of the concrete foundation slab is exposed to an open environment, while the bottom fiber is directly influenced by the soil's humidity, a moisture difference is generated between the top and bottom surface of the slabs. This, together with the stresses by soil friction, cause a shrinkage gradient to develop into the slabs, and therefore warping, along with cracking, can occur. (Shadravan, Ramseyer, and Kang, 2015)

Fig.3. Warping effect on foundation slabs. (Aeberhard, Marti, and Schuler, 1988)

Even though the temperature changes occurring during the hydration process of concrete slabs can generate internal self-induced stresses, due to their low impact they are often disregarded. However, in the case of massive foundation slabs, these effects could be more influential at an initial phase, and the stresses caused by these effects might have to be taken into consideration. (Klemczak, Żmij and Azenha, 2017).

3.2. Mitigation strategies

The use of post-tensioning in foundation slabs can already result in cracking and warping resistance and reduce the need for expansion joints. However, in order to improve the cracking behavior, a certain minimum amount of bonded reinforcement is normally placed at the surfaces of prestressed foundations. (Aeberhard, Marti, and Schuler, 1988)

In the case of foundation slabs and slabs-on-ground, details aimed at reducing subgrade friction have frequently been used for pavements and slabs on grade, having a similar aim as the previously mentioned release details for slabs-above-ground. However, their effectiveness in connection with building structures is reduced, because the addition of gravity loads during construction results in an increase of subgrade friction. (Aeberhard, Marti, and Schuler, 1988)

4. CONCLUSION

The effects of restraint-cracking induced by shortening can be expected to be more significant in slabs above ground than in foundation slabs, where the restraint effects are mostly caused by the friction created between the weight of the structure and the subgrade supporting it, and the humidity and temperature differences between soil and environment. Both of these cases differ in mitigation measures, the case of slabs-above-ground having more measures than the case of slabs below ground level. However, for both it is suggested to have a sufficient amount of bonded reinforcement in specific locations to prevent the formation of cracks, along with the prestressing tendons.

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