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Advancements in the Use of Micropile Slab Brackets

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Abstract- This paper begins by reviewing the two primary methods used to restore slabs on grade that have experienced differential displacement: removal or installation of micropiles fashioned with exterior brackets spaced at 5 foot (1.5 m) centre. This paper then introduces recent advancements in interior slab bracket technology and presents the research used in development. These advancements have led to a new generation of interior slab bracket capable of being installed through a smaller diameter hole and providing a far greater reach. With a greater reach and less damage to the slab interior slab bracket spacing's can be increased up to 10 foot (3 m) centres. Thereby enabling designers to reduce the number of interior brackets by 50% and eliminate the need to gut interior finishes and features.

***Keywords*:** Interior Slab Bracket, Slab Bracket, Slab Underpin, Slab Micropile, Micropile, Underpin, Slab on Grade, Slab Restoration

1. Introduction

Historically when faced with restoring slabs on grade experiencing differential displacement the options included replacement or the limited use of micropiles. In both of these cases, removal or the use of micropiles (fashioned with exterior brackets installed at very close spacing's), the interior's finishes and features required gutting or removal. This paper introduces recent advancements in interior slab bracket technology and the research used in development that has yielded a new generation of interior slab bracket.

2. Historical Methods used to Restore Slabs on Grade Experiencing Differential Displacement

Historically the two most common methods used to restore slabs on grade that had experiencing differential displacement were either replacement of the slab or the limited use of micropiles (Bullivant, 1996). Replacement, the most invasive of these two options, involved gutting of a structure's interior followed by demolition of that portion of the interior slab requiring restoration. Once removed the ground surface could be modified, the slab poured back (ACI, 2005) and the interior of the structure reconstructed.

The second of these options included the use of a standard exterior support bracket placed beneath the slab and atop a micropile (Brown, 1997). Figure 1 shows a standard exterior support bracket that is placed beneath the slab. While effective this technology was also invasive given that the maximum spacing between piles was 5 feet (1.5 m). This method also required limited gutting of a structure's interior followed by coring 20 to 30 inch (51 to 76 cm) diameter holes through the interior slab. Figure 2 shows a typical slab installation utilizing exterior support brackets placed at 5 foot (1.5 m) centers.

3. Advancements

In order to advance the restoration of slabs on grade having experienced differential displacement, the number of piles used needed to be reduced and their method of installation made far less invasive. In order to accomplish this, a method for providing a uniform support for the slab and a method for increasing the influence area of support would be required. Therefore a multi-arm collapsible slab support bracket (referred to as an interior slab bracket), was developed. This interior slab bracket represents advances in operation, a significant reduction in size, and an even greater improvement in the amount slab that is able to be support thereby reducing the number required.

Fig. 1. Standard exterior support bracket

Fig. 2. Photograph of slab cores for the installation of conventional underpins

3. 1. Slab Bracket Operation

The interior slab bracket is a multi-arm unit equipped with pivoting arms. The arms fold against the main body of the bracket which makes it lighter and enable it to be installed through a much smaller hole in the slab. Figure 3 shows the interior slab bracket in its fully open position.

Fig. 3. Interior slab bracket

3. 2. Slab Bracket Size

Similar to the historical method, the interior slab bracket is installed atop a micropile. However, unlike the historical method, the folding arms allow the interior slab bracket to be installed through a much smaller diameter hole in the slab, typically less than 12 inches (30 cm) in diameter. By reducing the diameter of the core hole less of the slab is affected and less of the structure requires gutting.

3. 3. Slab Bracket Reach

Unlike the historical method, the three folding arms of the new interior slab bracket allow for a uniform load distribution to the underside of the slab thereby creating a circular influence area of support. The linear influence zone of the historical method is what limited its spacing to a maximum of 5 feet (1.5 m). The circular zone of influence of the interior slab bracket was found to enable it to support more of the slab with a circular zone of influence thereby allowing the brackets to be spaced further apart than the historical methods. In particular, for a 4 inch (10 cm) nominal slab the interior support brackets can be spaced from 8 to 12 feet (2.4 to 3.6 m) on centre.

4. Research

After first designing and building it, the capabilities of the interior slab bracket had to be established starting with its maximum allowable spacing and then determining its maximum load capacity.

In order to determine the allowable spacing of the interior slab bracket, full scale testing of existing concrete slabs was conducted. This testing served to determine what the influence area was. As part of the research, finite element analysis and numerical computation was also performed to confirm the results achieved from the full scale testing.

4. 1. Maximum Allowable Spacing

Full Scale Testing: The full scale testing was performed on existing cast-in-place concrete slabs on grade that had been in service for over 20 years. In all, three slab sections were tested with each measuring 17 feet by 17 feet (5.2 m by 5.2 m).

The testing commenced by first sampling each of the three sections so as to establish their specific material properties (ASTM, 2010). Then a 10 inch (26 cm) diameter hole was cored through the center of the slab and a helical pile installed. The piles were installed to an average depth of 30 feet (9 m) below ground surface. These piles achieved a support capacity of 15 kip (6.8 metric ton) axial load. Once the piles were in place, the slab brackets were installed atop the piles and beneath the slabs. In order to capture the strains on the top surface of the slabs, they were instrumented with strain gages. Figure 4 shows one of the slab test specimens.

Fig. 4. Interior slab bracket test specimen

Prior to commencing the test, a load cell was installed so as to capture and record the load being applied to the bracket via the hydraulic ram. The hydraulic ram used for the testing was rated at 50 kips (22.7 metric tons). Prior to applying pressure to the hydraulic ram, all the strain gages were calibrated and zeroed. The sequence of loading was incremental and was accomplished by providing 1 kip (0.45 metric ton) load increments to the slab bracket with limited time between each load application. The elevation readings at each strain gage location and along the perimeter of the slab was collected with the use of the water level (manometer). By capturing the lifting force, the surface strains and the relative elevation we were able to capture the exact performance of each test specimen in 3-dimensions.

The test on the slab continued by applying load incrementally until the center of the slab displaced at least 3/8 of an inch (1 cm) and the edges of the perimeter of the slab completely separated from the supporting soils.

Post Processing- Relative Elevation Surveys: The relative elevation surveys for each slab were accomplished through the use of a calibrated manometer. These elevation reading were taken at the location of each strain gage, at the center of the slab adjacent the hole and along the perimeter. Figure 5 shows a 3-dimensional image of one of the test specimens.

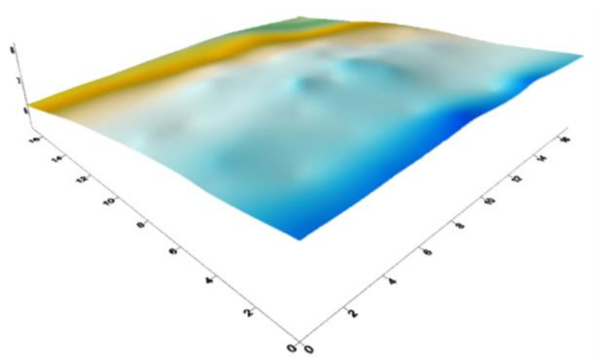

Fig. 5. 3-D Representation of the Slab at the End of the Lifting Sequence

Post Processing- Strain Measurements: The strain measurements were captured by the use of strain gages and data acquisition hardware. These strain measurements were then converted to stress measurements by multiplying the strain output by the modulus of elasticity of the concrete. It was noted that as the slab began to lift off the supporting ground a radial pattern developed about the center ultimately reaching 80 psi (5.6 kg/cm^2) at a radial distance of approximately 8 feet (2.4 m) from the center of the slab along the slab edges. The 80 psi (5.6 kg/cm2) recorded was significantly less than the fracture stress (7.5(f'c^1/2) for concrete, which for this slab was approximately 414 psi (29.1 kg/cm^2). Figure 6 shows the stress map for Test Slab #1 in pounds per square inch.

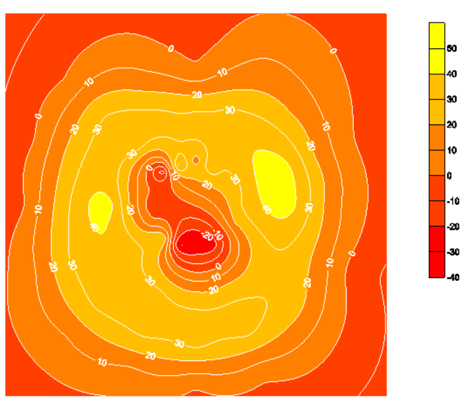

Fig. 6. Stress Map for Test Slab #1

Based on the data collected; the elevation differential patterns, the strain distribution throughout the surface of the slab during the lift, and our visual assessments, a determination was made as to the area of slab influenced by the interior slab bracket. Although the entire surface of the slab was influenced by the lifting of the slab, the area of the slab within the area which evidenced the transition of stresses would be classified as the affected influence area. Therefore, based on the tests performed and a correlation between the elevation patterns and the stress distribution, the affected influence area of the slab ranged between 8 to 12 feet (2.4 to 3.6 m).

Post Processing- Finite Element Analysis: In order to evaluate the results of the full scale testing, a finite element analysis of the slabs was performed. This analysis was performed for each of the three specimens using each specimen's material properties and would replicate the actual conditions of the slab specimen.

Given that the slab specimens measured 17 feet by 17 feet (5.2 m by 5.2 m) with a prescribed thickness, a plate analysis was performed with the thickness of the plate being the thickness of each slab specimen. In order to mimic the 10 inch diameter circular hole at the center of the slab, an opening in the plate surface was created by inserting a polygonal opening in the parametric model. Once this opening was created, the parametric model had to be meshed with the base model. In order to replicate the full scale slab test, the three (3) arms of the slab bracket were created beneath the slab. Once the arms were created, they were fixed in the X and Z direction and were only allowed translation in the Y direction. The same conditions were set for the perimeter of the slab.

Once the model was created, a loading scenario was developed. Given that the amount of load which was applied to the bracket was known, this load was converted to a linear load applied to each arm beneath the slab. This conversion was made for each loading case which ranged from 2,000 to 22,000 pounds (0.9 to 10 metric tons) on the bracket. The slab load was also taken into account with the analysis. Once the model was complete and the loading scenarios set up, the analysis was performed. The results which were assessed were the maximum top (principal major stress) in psi.

Once the results of the finite element analysis were determined, a correlation was made to the stress topographies generated from the strain data collected from the full scale slab tests. In general, the patterns of stress distribution of the stress topographies correlated with the patterns of the finite element model. Therefore, the finite element model confirmed that the affected influence area of the slab ranged between 8 to 12 feet (2.4 to 3.6 m). Figure 7 shows the finite element stress map for Test Slab #1. Note the correlation between the stress ranges and the distribution patterns.

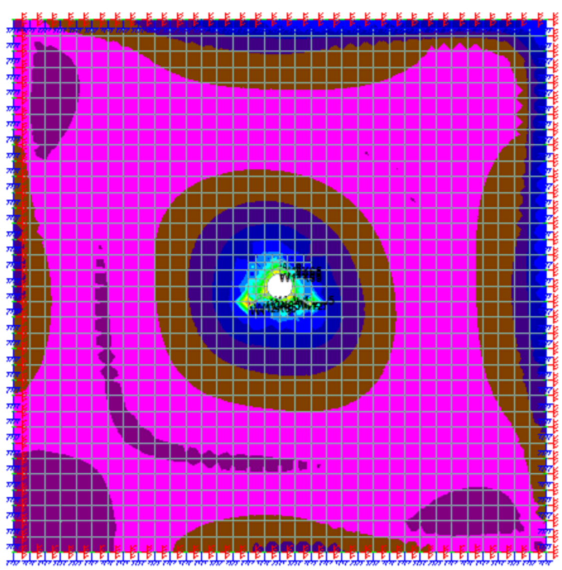

Fig. 7. Finite Element Stress Map for Test Slab #1

4. 2. Maximum Load Capacity

Load Testing: Subsequent to the full scale slab testing that was performed two of the interior slab brackets were tested to failure so as to establish their maximum load capacity. This test was performed in compression on two brackets at the University of South Florida's, Tampa, Florida campus. The ultimate strength was determined to be 91.02 kips (41.3 metric tons). Figure 8 shows the loading curve of one of the interior slab brackets tested.

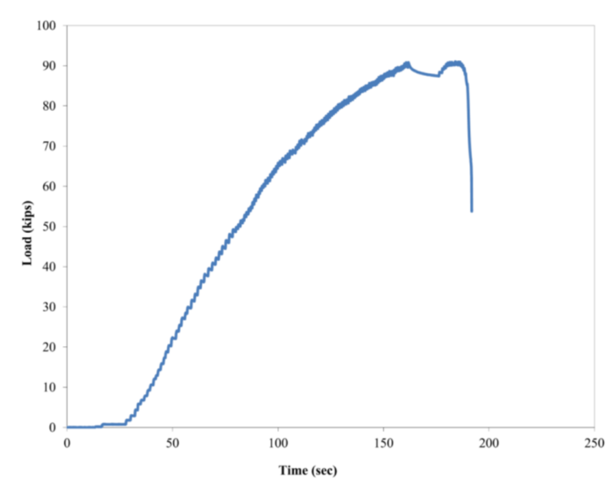

Figure 8. Interior Slab Bracket Loading Curve

The testing confirmed that the maximum spacing of the interior slab brackets would almost always be controlled either by the bending capacity of the slab (Nilson, 2004) or the axial capacity of the micropile. The post-processing established that effective finite element modeling can be developed for atypical slabs or slab with properties other than those used in this study.

5. Comparison between Technologies

When compared with the historical methods used to restore slabs on grade experiencing differential displacement, the interior slab bracket reduce the number of piles needed resulting in a far less invasive impact on the structure. To illustrate this point, two micropile layouts were developed; one using standard exterior brackets and one using the newly designed interior slab bracket. Figures 9 and 10 show the respective layouts. As can be seen, the design using the interior slab bracket, given is much greater spacing uses only 30 brackets and micro piles whereas the design using the standard exterior bracket used 129 brackets and micropiles.

6. Conclusion

It was concluded, after performing full scale testing, ultimate load testing, stress analysis, computation and finite element analysis, that the influence area of support provided to a cast-in-place concrete slab by the multi arm interior slab bracket is greater than previous support methods. Therefore, the required spacing between interior slab supports when the multi arm slab bracket is utilized is significantly increased and the amount of interior supports needed is reduced. With this reduction of interior supports, the disturbance of the existing structures is minimized.

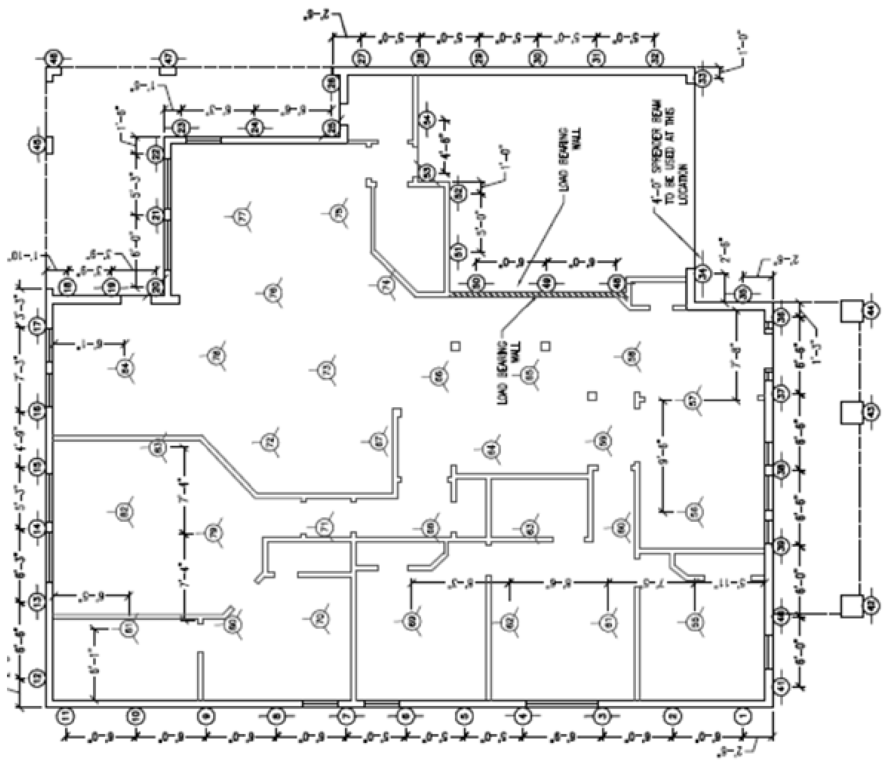

Fig. 9. Interior Slab Bracket Micropile Layout

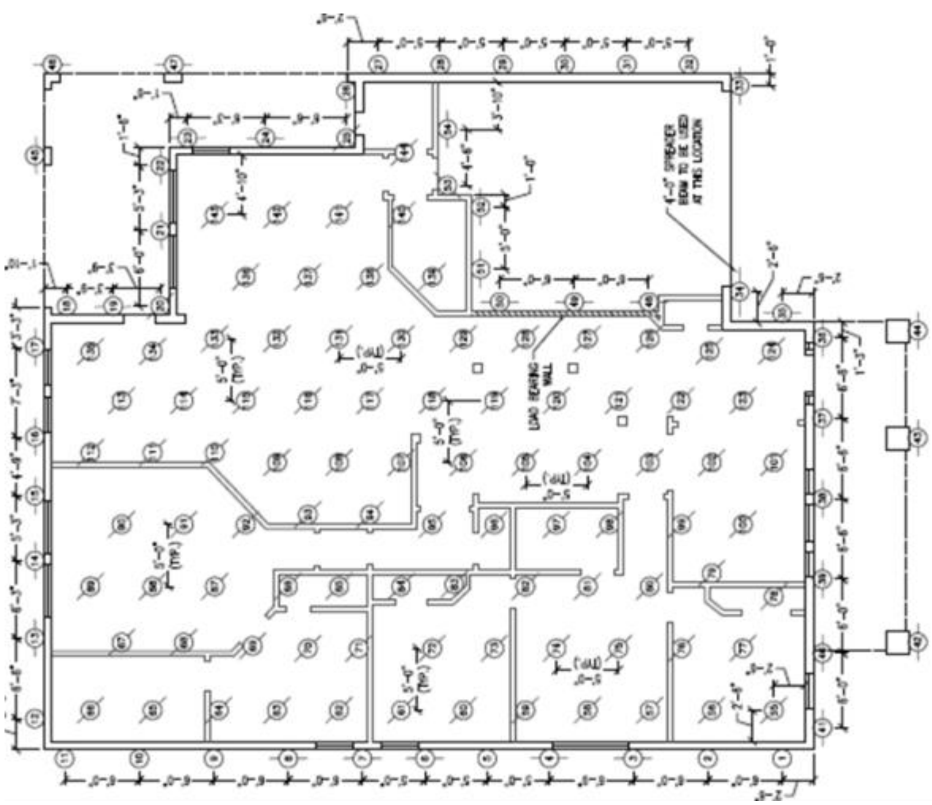

Fig. 10. Standard Exterior Bracket Micropile Layout

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