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Effects of End Restraint on Steel Deck Reinforced Concrete Floor Systems

Influences des conditions d'encastrement sur les planchers en béton armés par des plaques métalliques ondulées

Einfluss von Endsteifungen an profilblechbewehrten Betonplatten

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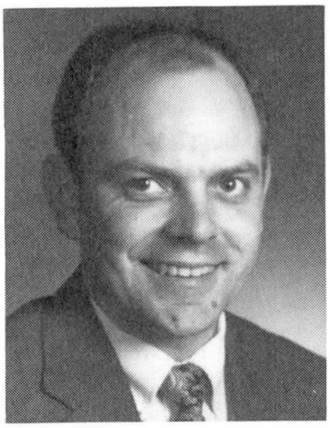

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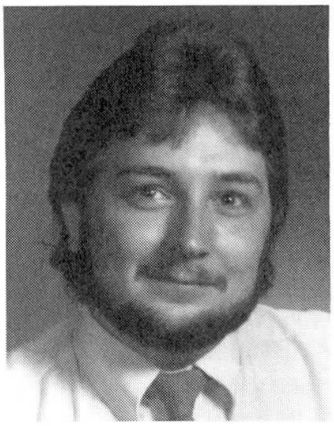

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SUMMARY

This paper describes results to date of a current research program: the project concerns full scale multi-span tests of composite floor systems. A primary objective of the research is to asses the strength of steel deck reinforced concrete floor slabs that are constructed to simulate actual field conditions, with respect to details at the intermediate supports and at end spans. In particular, the influence of adjacent spans and typical pour stop details are considered.

RÉSUMÉ

Cette communication décrit les derniers résultats d'un programme de recherche centré autour d'essais grandeur nature de planchers mixtes à travées multiples. Un objectif primaire de la recherche consiste à évaluer la résistance des planchers en béton renforcés par des plaques métalliques ondulées, et construits pour simuler les conditions réelles des travées extrêmes et des supports intermédiaires. En particulier, on a tenu compte de l'influence des travées adjacentes et des détail typiques d'arrêt de bétonnage.

ZUSAMMENFASSUNG

Der Beitrag beschreibt die bisherigen Ergebnisse einer fortschreitenden Arbeit. Das Projekt beinhaltet die Untersuchung von profilblechbewehrten mehrfeldrigen Betondecken. Die Ergebnisse der ersten drei Experimente werden vorgestellt und mit analytischen Ergebnissen verglichen. Erste Schlüsse werden gezogen und zükunftige Experimente sind beschrieben.

1. INTRODUCTION

Cold-formed steel decking has been part of floor systems in buildings since the late 1940's. Initially, the deck was used strictly as a stay-in-place or permanent form. Not long after the first uses, engineers recognized the potential for utilizing the steel deck as tensile reinforcement.

As the desire to use the deck as reinforcement grew, so did the need to perform design calculations. Predicted strengths based on ultimate strength reinforced concrete theory did not agree with laboratory tests of the slab elements. Continued attempts to develop analytical methods, which are not dependent on experimental testing, have thus far not been completely successful.

Instead, the current design standard in the United States is based on a testing program that produces data from which statistical coefficients are obtained [1]. These coefficients are then used, along with design parameters, to arrive at design live loads. This method resulted from an extensive research program at Iowa State University that was initially sponsored by the American Iron and Steel Institute [2]. The approach, in similar form, is used in the European and Canadian design communities.

The test method in the U.S. standard is uses a single span, single panel width specimen set-up. This arrangement, while convenient for the testing agency, has several significant limitations, which do not accurately reflect field conditions. One such limitation is the lack of proper representation of end span and adjacent span details. Due to this aspect of the set-up, the dominant mode of failure is shear bond, characterized by a breakdown of the bond between the steel deck and concrete in the shear span. The concrete is then essentially free to slip relative to the deck. Pour-stop, or closure angle details, and adjacent spans have a significant influence on inhibiting or preventing the shear bond mode of failure.

2. OBJECTIVE AND SCOPE OF RESEARCH

The primary objective of this study is to determine the influence of typical field details on the strength of composite floor systems. To achieve this objective, a series of full-scale tests are being preformed. To date three tests have been completed and the program is ongoing.

Several specimen configurations are being used. A three span set-up (Figure 5) permits the center span to be tested with the influence of adjacent spans being studied. Or the outer two spans can be tested to evaluate different pour stop details. To date, one center span test and two end span tests have been completed.

3. EXPERIMENTAL PROGRAM

3.1 Test Setup

Specimen configuration for test numbers SDI-1-1, SDI-2-1, and SDI-2-2 consisted of three equal, double panel width continuous spans. The length of each span was 2.44 meters center to center of supports and total width was 1.83 meters. End constraints consisted of a hot rolled angle (L127mm X 127mm X 6.35mm) on one end and a cold formed angle (L127mm X 127mm X 1.22mm) on the other end.

The angles were both attached to the support members by 25 mm welds placed at 305 mm intervals along the toe of the attached leg. Intermittent tack welds were also placed along the heel of the angles to prevent distortion of the member during the welding process.

Fifty-one mm deep, 20 gage, galvanized steel deck was used for each of the three tests. A sketch of the deck cross-section is given in Figure 4. The two sheets were attached to by crimping on approximately 250 mm centers along the full length. The deck was placed directly on the flanges of the support members. The deck was not attached in test SDI-1-1. For tests SDI-2-1 and SDI-2-2, the deck was attached to the support members using puddle welds at each flute, along each support.

Test SDI-1-1 was a center span test (boundary conditions of adjacent spans on each end), test SDI-2-1 was a hot rolled angle test (boundary conditions of one adjacent span and one hot rolled angle), and test SDI-2-2 was a cold-formed angle test (boundary conditions of one adjacent span and one cold-formed angle).

Strain gages were placed on the underneath side of the deck at the middle of each of the three spans. To measure the strain variation on the cross section, gages were placed on the bottom flange, the web, and on the top flange. Deflection transducers were placed at midspan and at the quarter points of the span being loaded. Additionally, transducers were placed at midspan of the two spans that were not being loaded. Dial gages were placed at the end of the east and west spans to measure slip between the frame and pour stop.

Concrete was placed 127 mm deep, measured from the bottom of the deck to the top of the slab. Over the interior supports, a control joint was made to facilitate cracking at that location (no negative moment reinforcement or shrinkage and temperature steel was provided) and to prevent the cracks from progressing into adjacent spans. The concrete was covered and kept moist for seven days and then allowed to air cure. Form-work along the edges was removed after seven days. Air temperature was not allowed to drop below 18 °C for the duration of the cure period.

During the placement of the concrete, the strain gages were monitored and an average strain of 120 micro strain was recorded at the bottom flange of the center span and 290 micro strain at the bottom flange of the two end spans. Data was only collected for the SDI-2 series.

Loading was applied with a hydraulic cylinder connected to the test frame. Load was measured by a load cell at this location. The point load of the cylinder was distributed by a spreader beam onto two beams which distribute the load to the slab as two line loads transverse to the span. The line loads were located 764 mm from the middle of the supports for the span being loaded. The weight of the spreader beam system was considered part of the total applied load.

All instruments were zeroed with only the dead load of the slab acting. This becomes the zero point of the measurements. The first load point consisted of the weight of the spreader beams and associated plates and pads.

3.2 Test Results

3.2.1 SDI-1-1

Concrete compressive strength, on the day of the test was determined to be 29.9 MPa.

The loading program proceeded by beginning at the first load point as described above. After this, load was increased by the hydraulic ram in approximately 4.44 kN increments until it became necessary to proceed in increments of deflection (approximately 98.75 kN). Load was then applied in

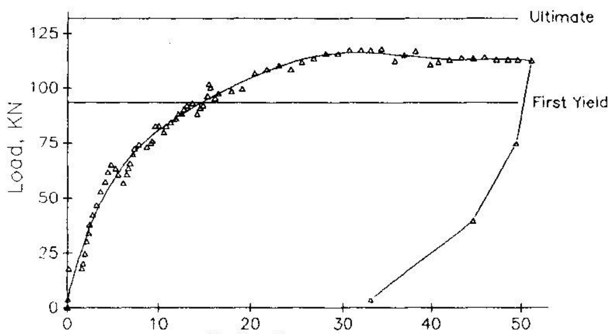

Figure 1: Load vs. Midspan Deflection for SDI–1–1

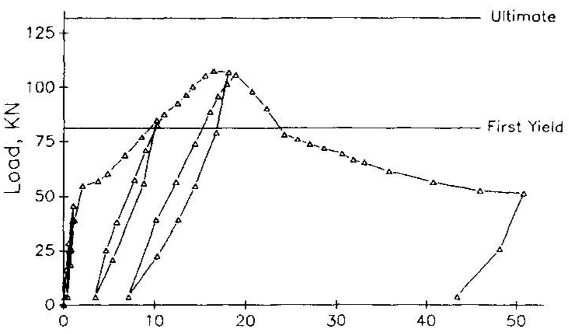

Figure 2: Load vs. Midspan Deflection for SDI–2–1

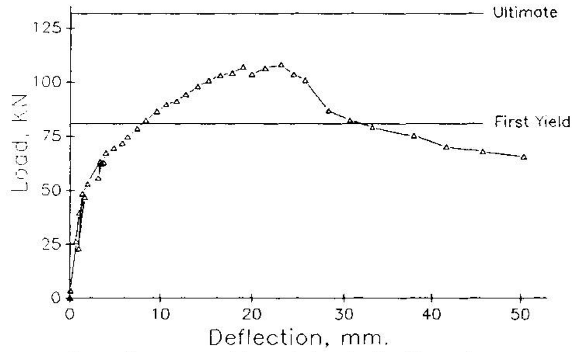

Figure 3: Load vs. Midspan Deflection for SDI–2–2

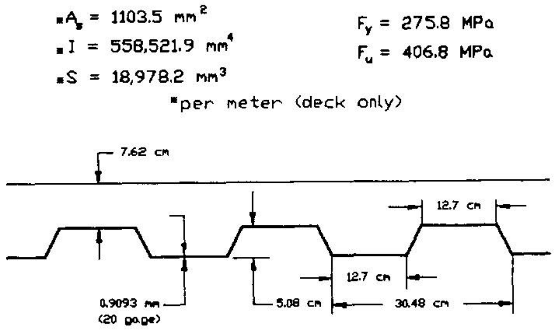

Figure 4: Deck Cross-section and Properties

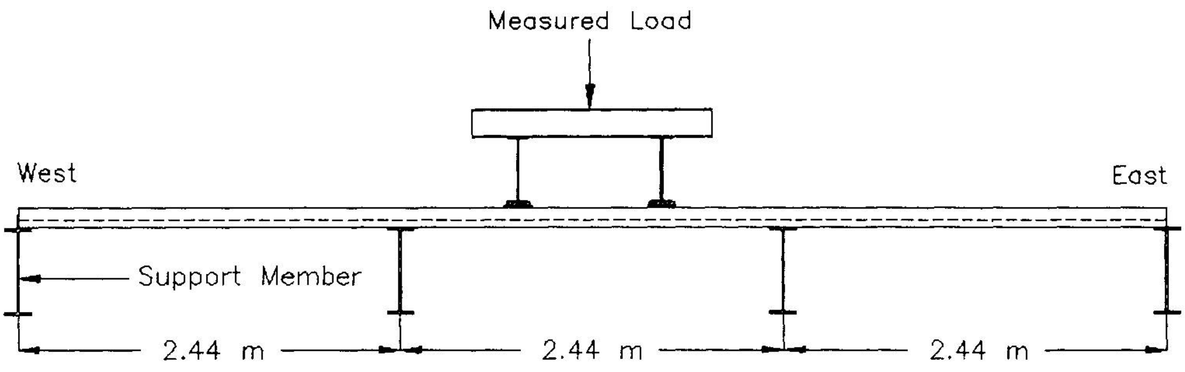

Figure 5: Test Setup

stages as to cause a 1.25 mm change in deflection. This continued until 50.8 mm of deflection was recorded. At this point, the test was stopped and unloaded.

Cracking over the supports was observed at a load of 17.3 kN. At a load of 65.4 kN, cracking under the spreader beams occurred but no slippage at the ends of the slab was measured. Separation of the deck and concrete, between the spreader beams (the concrete and deck were in contact between the spreader beams and the support members), was observed at a load of 93.4 kN with slip measured at 0.025 mm inward at the west end (hot rolled angle) and 0.05 mm inward at the east end (cold-formed angle). Maximum applied load was 118.8 kN with the measured movement at the ends of 0.025 mm inward at the west end and 0.66 mm inward on the east end. These recorded values can be attributed to support member rotation due to the fact that no noticeable slip occurred between the deck and concrete. Termination of the loading occurred when 50.8 mm of centerline deflection was measured. See Figure 1 for a load verses deflection plot.

3.2.2 SDI-2-1

Compressive strength for the concrete for this slab was determined to be 32.5 MPa.

The loading pattern for this test was very similar to SDI-1-1 except that the load was raised in 13.3 kN increments until a load of 99.2 kN was reached then increments of 1.25 mm deflection were used to control the loading. Loading was terminated when 50.8 mm of deflection was recorded. As in SDI-1-1, no slip between the deck and concrete occurred until after ultimate load.

Cracking over the supports was present before the loading process began. At a load of 54.7 kN separation of the concrete and hot rolled angle occurred. At a load of 57.8 kN cracking under the load points occurred, and at a load of 67.6 kN cracking between the spreader beams occurred. At a load of 107.6 kN separation of the deck and concrete between the spreader beams was noticed. At several points along the loading process, the slab was slowly unloaded and then reloaded. The different stiffness values of each unloading can be seen in the plot of load verses displacement. See Figure 2 for a load verses deflection plot.

3.2.3 SDI-2-2

Compressive strength of the concrete for this test was determined to be 32.5 MPa.

The loading pattern followed the same pattern as SDI-2-1 with the exception that no unloading occurred. The transition from loading in steps of 13.3 kN to loading in steps of 1.25 mm occurred at load of 108.1 kN. As in SDI-1-1 and SDI-2-1, no slip between the deck and concrete occurred until after ultimate load.

Cracking over the supports was present before the loading process began. At a load of 70.2 kN cracking under the spreader beams occurred without the normal drop in load. An ultimate load of 108.1 kN was obtained with a corresponding center displacement of 23.2 mm. After ultimate load, at a load of 100.1 kN, separation of the pour-stop and concrete occurred suddenly. See Figure 3 for a load verses deflection plot.

4. ANALYTICAL COMPARISONS

Comparisons between the test results and predicted strengths were made. The theoretical ultimate load was calculated using ultimate strength reinforced concrete theory. This value was then reduced to account for the dead load due to the slab. The first yield line represents the theoretical first yield of the bottom fibers of the steel deck. In calculating this value, the strain induced in the bottom fibers of the deck due to the concrete placement was accounted for. Average measured values from the second casting (SDI-2) were used.

Figures 1, 2, and 3 show the predicted strength for both limit states. In each test the experimental capacity exceeded the predicted load corresponding to first yield, but did not reach the predicted ultimate strength. This behavior is indicative of partial composite action.

5. SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

Three full-scale composite slab tests have been performed and the partial results reported. These tests are part of a research program, in which the effects of various pour-stop and adjacent span details are being studied.

The first test was performed by loading the center span, which was done to study the effects that adjacent spans have on resisting the shear bond mode of failure. The second and third tests examined at two different pour stop details, a cold-formed angle and a hot rolled angle, to determine their influence on restraining the shear bond failure.

Predictive strength were calculated based on ultimate strength and first yield of the bottom steel fiber limit states. Both pour stop configurations prevented slip from occurring at the ends. Initial results indicate that predicted strength based on first yield or perhaps a partial composite behavior has merit.

Future testing will focus on additional pour stop details, in order to identify those that are both practical and are efficient in preventing the premature shear bond failures. Analytical studies will focus on developing or verifying design approaches that are independent of full scale testing, except in a confirmatory mode.

6. ACKNOWLEDGEMENTS

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