Determination of Composite Slab Strength Using a New Elemental Test Method

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Abstract: Composite slabs utilizing cold-formed profiled steel decks are commonly used for floor systems in steel framed buildings. The behavior and strength of composite slabs are normally controlled by the horizontal shear bond between the steel deck and the concrete. The strength of the horizontal shear bond depends on many factors and it is not possible to provide representative design values that can be applied to all slab conditions a priori. Thus, present design standards require that the design parameters be obtained from full-size bending tests, which are typically one or two deck panels wide and a single span. However, because these full-size tests can be expensive and time consuming, smaller size specimens, referred to as elemental tests, are desirable and have been the subject of a great deal of research. Details for a new elemental test method for composite slab specimens under bending are presented. Test results consisting of maximum applied load, end slips, and failure modes are presented and compared with the results of full-size specimens with similar end details, spans, etc. It is shown that the performance of the elemental test developed in this study is in good agreement with the performance of the full-size specimens. Application of test data to current design specifications is also presented.

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Introduction

A composite slab comprised of structural concrete cast on cold-formed profiled steel deck is the most popular type of floor system used in steel framed buildings. The system is well accepted by the construction industry due to the many advantages over other types of floor systems. Designers typically work with design aids generated and published by deck manufacturers. The manufacturers rely on a combination of experimental test programs and approximate calculation procedures to generate design load tables. A typical test configuration consists of a single, simple span that utilizes one or two deck sheets, thus the specimen generally varies in width from 610 to 1,830 mm. The focus of this paper is on a new experimental test configuration that provides a more economical solution than the typical configuration and that addresses key shortcomings in existing elemental test configurations.

Background

In most practical cases, the behavior and strength of a composite slab is governed by horizontal shear bond at the interface of the steel deck and the concrete. The strength of the horizontal shear bond depends on many factors, among which include the shape of the steel deck profile, type and frequency of embossments, thickness of steel sheeting, arrangement of load, length of shear span, slenderness of the slab, and type of end anchorage. Because of these many influencing factors, it is not possible to provide representative design values that can be applied to all slab conditions. As such, present design specifications require that design parameters be obtained from full-size bending tests (ASCE 1992; BSI 1994; ECS 1994; CSSBI 1996). These test specimens are typically one or two deck panels wide with a single, simply supported span of various lengths. Two concentrated line loads are placed symmetrically along, and perpendicular to, the slab span at locations between 1/5 and 1/3 of the slab span from the supports. This configuration of a simple span with two concentrated line loads has been used to evaluate the strength of composite slabs since the early days of testing (i.e., early 1960s). The configuration has been used to simulate a portion of the one-way slab behavior in actual construction.

Design methods using data from numerous full-size tests suffer drawbacks such as being expensive and time consuming. This becomes obvious when many types of deck profiles are involved, and thus composite slabs built with each of them have to be tested separately due to their different characteristics. Because of these reasons, a smaller, simpler and more economical test has been needed and has been the focus of work for many researchers (Airumyan et al. 1990; An 1993; Burnet 1998; Daniels 1988; Patrick and Poh 1990; Plooksawasdi 1977; Porter and Ekberg 1978; Stark 1978; Tremblay et al. 2002; Veljkovic 1996; Zubair 1989).

Despite the variety of tests developed by those researchers, the configurations are conceptually similar in that direct shear loading was applied to narrow and short specimens, as illustrated schematically in Fig. 1. These types of tests, which are usually referred to as *elemental or push tests*, have a similar shortcoming in

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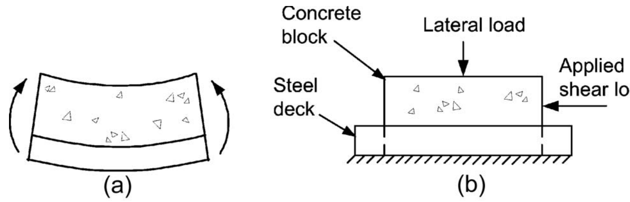


Fig. 1. (a) Slab bending; (b) a typical push test, sometimes with application of lateral load

that the complex interactive behavior between the concrete and the steel deck under bending action is not reflected in the test specimens. Curvature and natural clamping at the deck–concrete interface, slab slenderness, loading arrangement, tensile strain in the steel sheeting, natural frictional resistance at supports, and other phenomena associated with slab bending cannot be simulated in a push test. Some of the push tests involved fixing of steel sheeting to test beds or to opposite decks (Plooksawasdi 1977; Jolly and Zubair 1987; Patrick and Poh 1990; Veljkovic 1996), whereas in some other tests, lateral loads were applied perpendicular to the shearing force (Daniels 1988; Patrick and Poh 1990; Stark 1978; Tremblay et al. 2002). For these tests, fixing of the steel deck and the application of lateral loads exerts constraint to the relative movement of the concrete and the steel sheeting and hinders them from separating as naturally happens in actual slab bending.

A block bending test to simulate the bending effect was developed by An (1993). However, because of the shortness of the specimen and the nature of the test setup, effects due to bending as mentioned earlier still could not be simulated accurately. Wright and Veljkovic (1996) consider the block bending test to be similar to the push test. The block bending specimen is also relatively complicated to construct.

The major weakness of the push tests is that the effect of bending is not incorporated, thus the test data cannot be used to design composite slabs in accordance with present specifications (ASCE 1992; BSI 1994; ECS 1994; CSSBI 1996). As a result, design methods in these specifications use data that must be obtained from full-size bending tests. A more detailed review of the various elemental tests is given by Abdullah (2004).

Objective and Scope

The objective of this experimental study is to develop a new method for conducting an elemental bending test for composite slabs. The prime interest is that the test setup be simple, economical and easy to conduct, whereas the procedure and the performance of the test specimen should be comparable to the full-size tests as prescribed in the present specifications. Hence the results of the elemental tests can be used directly in the present design methods, namely the *m-k* (ASCE 1992; BSI 1994; ECS 1994) and the partial shear connection (PSC) methods (ECS 1994). Additionally, load versus interfacial slip data were collected so that the new elemental tests can also be used to obtain the information necessary for numerical modeling. The details and applications of this data collection and the numerical modeling are presented by Abdullah (2004), but are not presented or discussed further herein.

The elemental test developed in this study is a bending test conducted on a narrow specimen measuring 305 mm wide, which is one rib of a typical trapezoidal deck profile. The span length and the concrete thickness were selected within the range of typical construction practice. Shear studs, which are normally used in composite beam construction, were not used to anchor the slabs to the support beams. Rather, all attachments were made using arc-spot welds.

Methodology

A series of full-size bending tests were conducted earlier in a separate investigation (Abdullah and Easterling 2003.) The results of these tests were used to verify the performance of the new elemental test developed in this study. The elemental test was developed by performing two series of tests. The first series was conducted to determine the effect of web curling and end conditions, which are the main factors that influence the behavior and the strength of the elemental bending specimens. Once the effect of these factors was determined, a second series of elemental specimens was built and tested. The details of the second series were chosen based on the performance of the first series tests. The parameters considered in the second series were similar to the full-size tests so that their performance could be directly compared.

Experimental Program

Full-Size Bending Test

Twenty-four full-size specimens that were 1,830 mm wide and constructed in a three-span configuration were tested as part of an earlier program (Abdullah and Easterling 2003). These specimens are referred to by Abdullah and Easterling as Tests 1–12, with Spans A and B for each test, resulting in a total of 24 specimens. Experimental parameters that were considered included deck depth, sheeting thickness, span length, and concrete thickness. The specimens were built with two pieces of steel deck per span

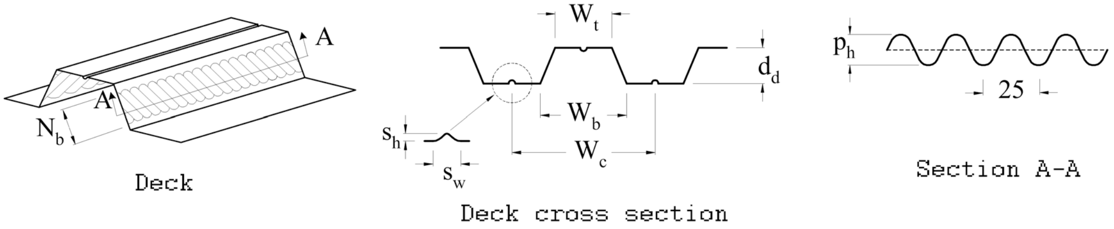


Fig. 2. Trapezoidal type deck

Table 1. Deck Section Dimensions and Properties (from Abdullah and Easterling 2003)

Deck type	W_t (mm)	W_b (mm)	W_c (mm)	d_d (mm)	Sheeting thickness (mm)	Weight (N/m^2)	N_b (mm)	P_h (mm)	s_h (mm)	s_w (mm)	A_s (mm^2/m)	I_p (mm^4/m)	S_p (mm^3/m)	F_y (MPa)	F_u (MPa)
3–20	120.7	184.2	304.8	76.2	0.9	102.5	66.0	7.0	12.7	20.3	1,257	1,280,922	29,731	370	440
3-18	120.7	184.2	304.8	76.2	1.2	136.0	66.0	7.0	12.7	20.3	1,666	1,708,351	42,742	330	440
3-16	120.7	184.2	304.8	76.2	1.5	171.4	66.0	7.0	12.7	20.3	2,102	2,157,630	54,462	350	410
2-20	127.0	177.8	304.8	50.8	0.9	94.3	36.7	7.0	10.2	31.8	1,156	570,816	19,086	360	430
2-18	127.0	177.8	304.8	50.8	1.2	125.0	36.7	7.0	10.2	31.8	1,530	760,633	27,527	340	410
2-16	127.0	177.8	304.8	50.8	1.5	157.5	36.7	7.0	10.2	31.8	1,930	96,1374	35,107	320	400

Note: Deck designation is in the form of "*i*-*j*," where *i* denotes the deck depth in inches and *j* denotes the steel thickness in gauge number. Yield and ultimate strength, F_y and F_u, were obtained by coupon tests.

arranged side by side. The deck details and parameters are shown in Fig. 2 and Table 1. Separate pieces of deck were used to form the three spans, thus a simple span configuration was obtained for the flexural evaluation. The test set up is illustrated in Fig. 3. The exterior supports were anchored with lipped cold-formed steel pour stop. The pour stop thickness was 1.2 mm and was welded to support beams. Note that these tests were not conducted in the typical single span configuration. The three, single span arrangement was used to study the effect of end restraint.

The concrete was placed continuously on the three spans, but no reinforcing steel was placed in the slab. Both exterior spans were tested to failure, whereas the intermediate spans were not tested. Two concentrated line loads, symmetrically placed, were used to load the specimens. The intermediate spans were used to simulate typical interior spans which provide restraint against in-plane movement of the concrete at interior supports. The slab details were chosen to reflect typical construction practice. Maximum applied loads, vertical deflections, relative end slips, failure modes, and strain response in the steel deck were investigated and recorded. The test procedure generally followed the ASCE (1992) standard. The details of the full-size tests are reported in Abdullah (2004) and Abdullah and Easterling (2003).

Elemental Bending Tests

The elemental bending tests were conducted in two separate series, which are referred to as Series 1 and Series 2. Series 1 tests were conducted to study the effect of web curling. Test results from Series 1 were used as a basis for the selection of details for Series 2, so as to create elemental specimens whose behavior was comparable with similarly configured full-size test specimens. Sixteen specimens were tested in Series 1 and 32 specimens were in Series 2, of which two tests were conducted for each parameter.

In the following sections, the discussion is first focused on the two major factors that influence the performance of the elemental specimens, namely web curling and end constraint, and then followed by the details of the specimen and test procedure.

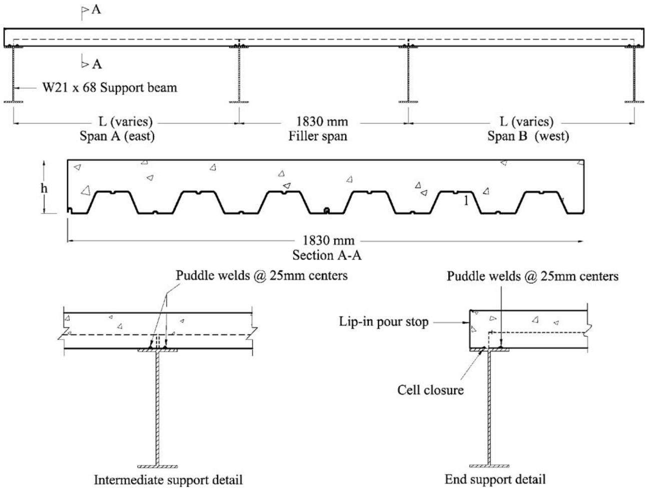


Fig. 3. Full-size (three-span) test configuration

Edge Web Curling

Edge web curling is a major factor that affects the performance of the elemental specimen. As was recognized by Stark (1978), web curling occurs in edge webs as depicted in Fig. 4. In a bending test, once the concrete starts to slip, the presence of embossments along the webs can create a reaction force that pushes the webs away from the concrete. Thinner steel sheeting and deeper webs are more vulnerable to flexing and curling. Because of this flexibility, the shear bond resistance between the concrete and the steel sheeting in elemental, or more accurately narrow, specimens is reduced significantly. The problem is more pronounced in elemental tests than in full-size tests because both webs in an elemental test are "edge" webs and thus susceptible to curling. A full-size specimen has four, or perhaps ten if it is two panels wide, webs that are not at the edge, as illustrated in Fig. 4(b). In this study the web curling effect was reduced by using straps fixed to the bottom flanges of steel decks. The strapping details are discussed in a subsequent section. The effect of edge web curling has not been explicitly addressed in prior studies involving full-

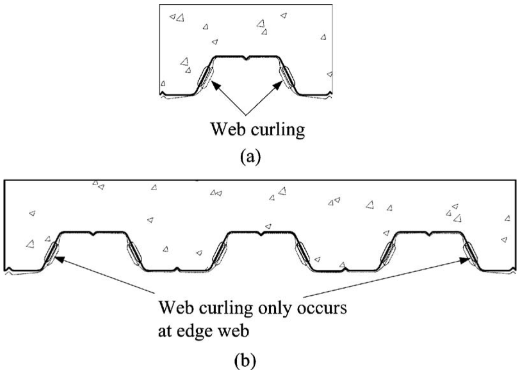


Fig. 4. Edge web curling due to concrete slipping against embossments on the web surface: (a) elemental specimen; (b) full-size specimens

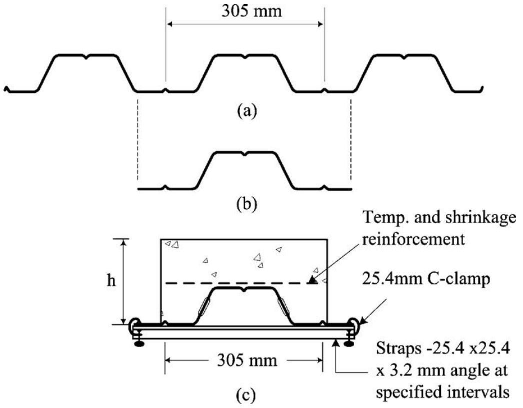


Fig. 5. (a) One deck panel; (b) a cut from the middle rib; and (c) specimen cross section

size tests. The behavior has been noted and was part of the justification for using two panel wide tests versus one panel wide tests (Easterling and Young 1992; Terry and Easterling 1994). The increased number of webs in a given specimen minimizes the effect, given that a smaller percentage of the total number of webs in a specimen are at the edge of a two panel test as compared to a single panel test. As mentioned, the effect is most severe for a specimen with a single rib, or cell, such as used in the new elemental test, because all (both) webs are at the edge.

End Constraint

Construction details at supports also contribute to slab behavior and strength. Studies on the effect of end details were reported by Chen (2003), Easterling and Young (1992), and Terry and Easterling (1994). The types of end details not only influence the performance of test specimens, but also the actual slab behavior in the field. In practice, the slab ends are usually anchored, typically by welding the decks to the support beams or in the case of composite beam construction, the slab may be anchored with shear studs. For exterior supports, pour stops are welded to support beams and then permanently left in place. The pour stops become part of the slab system during service. Elimination of these details in test specimens will reduce the horizontal shear resistance and hence significantly reduce the strength of the specimens. Designs based on the test data of specimens without end constraints can be too conservative and uneconomical. This happens with the use of the ASCE (1992) and Eurocode 4 (ECS 1994) standard test procedures, in which the specifications do not specify the use of typical support details. The effects of anchorage by end pour stop and the type of support were considered in this study.

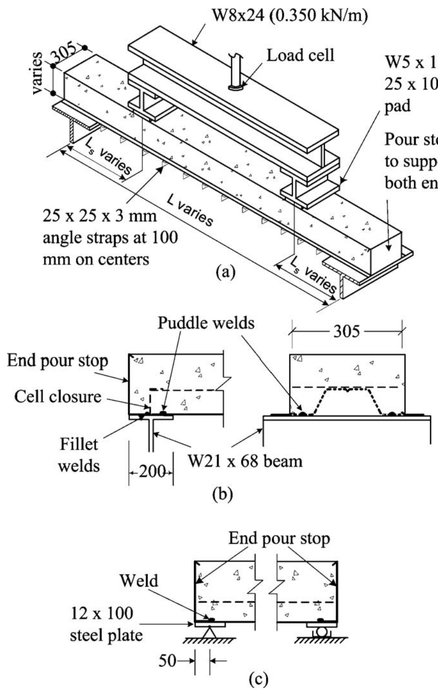


Fig. 6. (a) Series 2 test setup; (b) support details; and (c) support detail for Specimen 26 of Series 2

Other factors that can affect the specimen strength and behavior are shear span and concrete thickness. For narrow specimens, the orientation of the embossments can also affect the test results. These factors were also considered in the study but are reported elsewhere (Abdullah 2004).

Description of Small-Scale Specimens in Series 1

As illustrated in Fig. 5(a), one rib of the steel deck, with a typical dimension of 305 mm, was cut from a deck panel. The bottom flanges were cut slightly wider than 305 mm as shown in Fig. 5(b). to facilitate the fixing of angle straps. The specimens were constructed in single spans where the decks were simply rested on the support beams at both ends. The deck was not

Table 2. Test Parameters for Series 1

Test number	Span length (mm)	Total concentration thickness (mm)	Shear span (mm)	Straps
13	2,340	190	560	150 mm interval along shear spans only
14	2,340	190	560	No straps
15	2,340	190	660	100 mm interval along shear spans and 200 mm the constant moment region
16	2,340	190	660	No straps
17	2,340	190	760	100 mm interval along shear spans and 200 mm in the constant moment region
18	2,340	190	760	No straps
19	2,400	165	560	100 mm interval along shear spans and 200 mm in the constant moment region
20	2,400	125	560	100 mm interval along shear spans and 200 in the constant moment region

Note: Deck type is 3-16 with F_y=230 MPa and concrete f'_c=29 MPa.

Table 3. Test Parameters for Series 2

Test number	Deck type	Span length measured from center of support (mm)	Total concrete thickness (mm)	Shear span (mm)	Conc. comp. strength f'_c (MPa)
21	3-20	2,440	190	810	35
22	3-20	3,350	125	1,020	35
23	3-18	2,440	190	810	35
24	3-18	3,960	125	1,320	31
25	3-16	1,220	190	410	35
26	3-16	2,440	190	810	31
27	3-16	2,440	190	810	31
28	3-16	3,050	190	970	35
29	3-16	3,660	125	1,120	35
30	3-16	4,270	125	1,320	31
31	2-20	2,130	165	710	35
32	2-20	2,740	100	970	31
33	2-18	2,130	165	710	35
34	2-18	3,350	100	1,070	35
35	2-16	2,130	165	710	35
36	2-16	3,660	100	1,170	31

shored during concrete placement. The deck ends were not anchored and no permanent pour stop was provided. Except for width, other details were in accordance with the ASCE (1992) specification. Welded wire fabric was placed in all specimens as shrinkage and temperature control reinforcement. The construction process and quality control were similar to the comparable full-size specimens.

After casting, the specimens were moist cured and covered with plastic sheets for seven days. After seven days, they were left uncovered at room temperature until tested. Concrete cylinders were also prepared and cured in the same manner. Test parameters are listed in Table 2.

When a specimen was ready to be tested, the side and end forms were removed. The specimen was placed on pin and roller supports. Steel straps (L25×25×3 mm) were then fixed using 25 mm C-clamps to the bottom flanges of the deck at specified intervals along the span. The purpose of the angles was to simulate the restraining effect of adjacent ribs in a complete deck profile. The clamps were hand-tight but the clamping force was not measured. The specimen cross section is shown in Fig. 5(c). Specimens without straps were also tested to compare the effect of web curling.

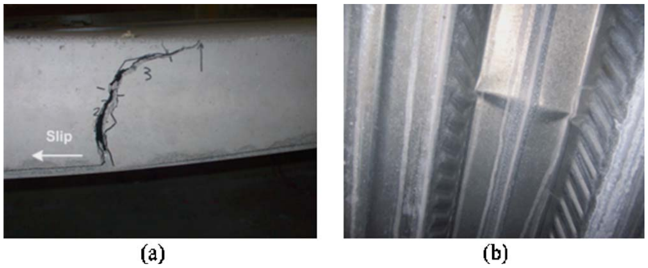


Fig. 7. (a) Major crack due to horizontal slip failure; (b) buckling of deck top flange

Fig. 8. Vertical separation: (a) end of slab; (b) side of slab

Description of Small-Scale Specimens in Series 2

Based on Series 1 test results, it was decided that the specimens in Series 2 were to be built in single spans but with both end conditions similar to the full-size tests. The test set up and end details are depicted in Fig. 6, whereas the test parameters are listed in Table 3. To facilitate comparison between different end conditions, two otherwise identical specimens (Test 26 in Table 3) were constructed with the decks and the pour stops welded to 12 mm thick by 100 mm wide steel plates at both ends. The plates were rested on pin and roller supports as depicted in Fig. 6(c). All specimens in Series 2 were built using steel deck from the same bundle as used for the full-size tests and therefore the yield and tensile strengths were taken to be the same as previously measured. Because of space limitation, the specimens in Series 2 were cast and tested in two separate batches. They can be recognized by different values of concrete compressive strengths as listed in Table 3. The construction process and quality control were similar to the full-size and Series 1 specimens.

Test Procedure

The test was carried out by applying point loads incrementally first by load control, and when the cracking was significant, by displacement control. The loads were applied using a hand operated hydraulic ram against a reaction frame and were measured by a load cell. Each load increment was held for at least 2 min to ensure that the slab was stabilized before the reading was recorded. Vertical displacements at mid span and under point

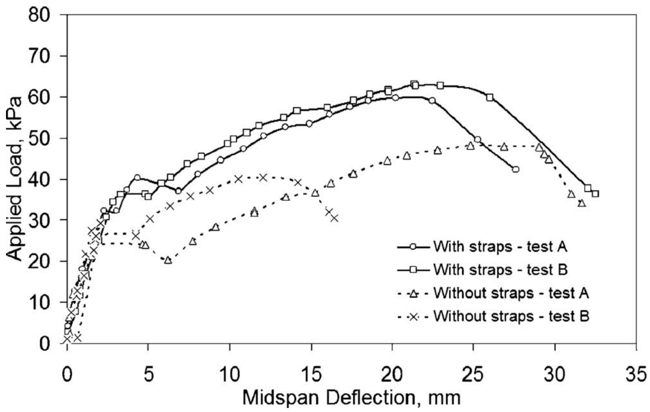


Fig. 9. Comparison of results for specimens with and without straps with 560-mm shear span—Tests 13 and 14

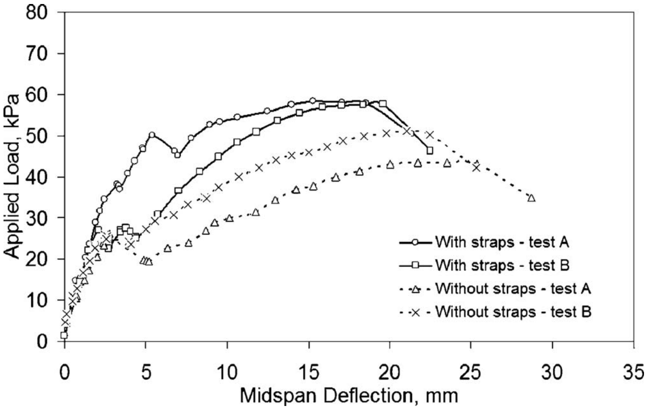


Fig. 10. Comparison of results for specimens with and without straps with 660-mm shear span—Tests 15 and 16

loads, and relative slips at the slab ends and near point loads were recorded using potentiometers and wire pot displacement transducers.

Test Results

Test Observations—General

All specimens in Series 1 and 2 failed by shear bond with significant slips recorded at one end and major cracks occurred at critical sections below one of the two point loads, as illustrated in Fig. 7(a). The relative slip recorded at the slab ends and near major cracks was almost identical. Small cracks due to bending were also observed in the constant moment region. Shortly after reaching peak loads, the deck top flange began to buckle at critical sections under one of the point loads, as illustrated in Fig. 7(b). At displacements greater than the displacement at peak load, the composite action was lost and the load resistance was completely attributable to the steel deck alone.

No attempt was made to measure the vertical separation. However, it was observed that the concrete and the decks were separated vertically as a result of concrete overriding as shown in Fig. 8. Specimens with fewer straps, namely 13 in Series 1 exhibited larger vertical separation than those with more straps in the same series. Due to this observation, it was decided that the straps in Series 2 would be spaced at 100 mm intervals along the entire span length.

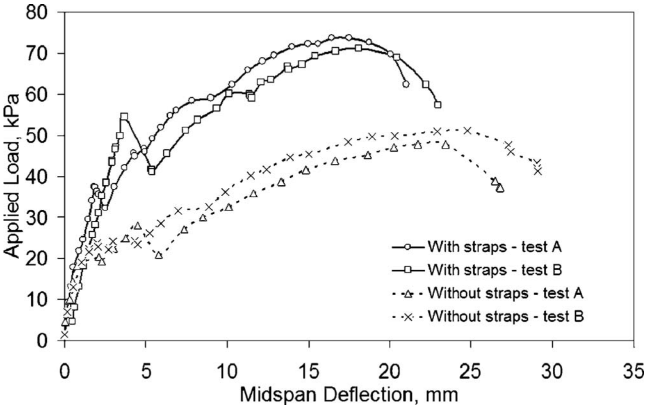


Fig. 11. Comparison of results for specimens with and without straps with 760-mm shear span—Tests 17 (with straps) and 18 (without straps)

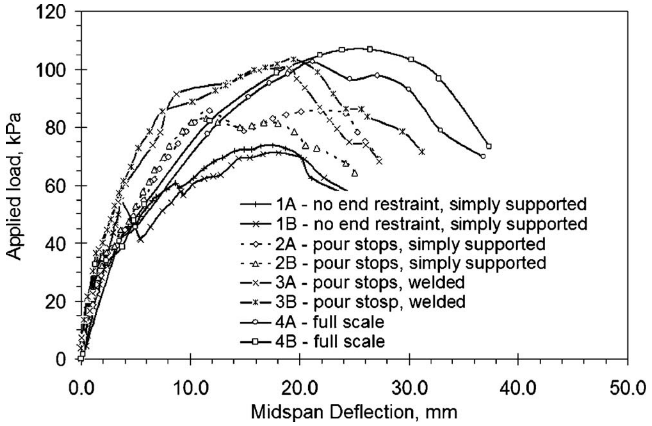


Fig. 12. Results of specimens with different end constraint

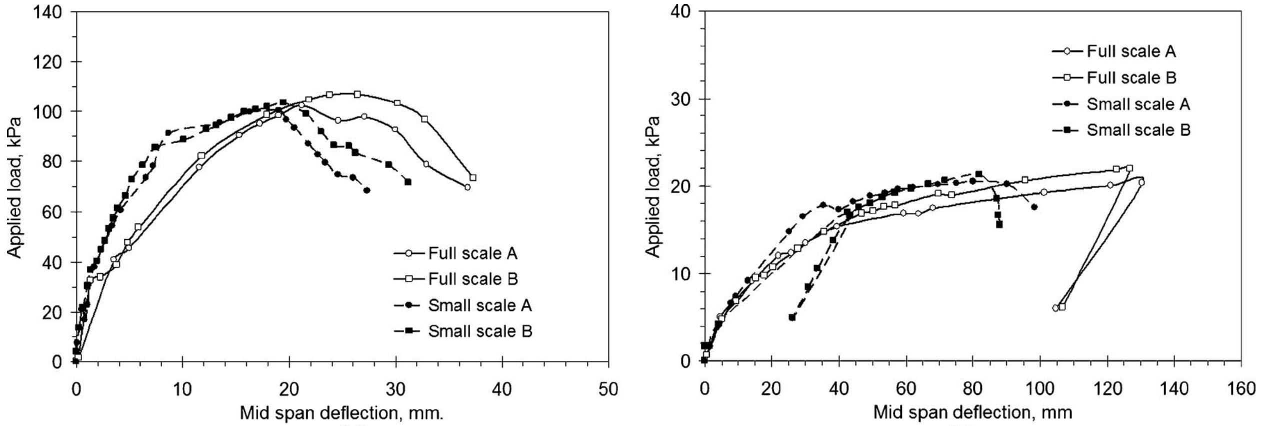
The observed behavior suggested that most elemental specimens in Series 2 failed earlier (i.e., at lesser deflection) and hence were more brittle than the full-size specimens. However the maximum loads of the elemental specimens were similar to the maximum loads of the full-size specimens. The observed amount of vertical separation along the sides of the elemental specimens in Series 2 was generally less than that in Series 1. It was also observed that the pour stop welding in the compact specimens of Series 2 failed in a sudden manner, especially for the specimens with 50 mm decks. After this failure, the slabs rapidly lost their strength. For short and thick specimens, those with 50 mm decks, in general, lost strength in a more abrupt manner than the ones with 76 mm decks.

Effect of Web Curling

The effect of restraining the webs from curling using angle straps for elemental specimens in Series 1, which were tested at different shear spans, are illustrated in the load-deflection graphs in Figs. 9–11. The loads were presented as equivalent uniform loads which were obtained by equating maximum moments from the tests to maximum moments of uniformly distributed simply supported beams. The graphs show that the lateral restraint of the profile using angle straps significantly increased the strength of the slab specimens. The average increase of the maximum load ranged between 30 and 48%.

Effect of End Constraint due to Different Support Details

End details can affect the response of composite slab tests (Easterling and Young 1992; Terry and Easterling 1994; Chen 2003). Specimens with identical geometries namely Test 17 of Series 1, 26, and 27 of Series 2 and one from the full-size tests were compared to illustrate the effect of different details at supports. Specimens 17 were supported by pin and roller at their ends and without pour stop. Specimens 26 had pour stops welded to steel plates but rested on pin and roller supports, as illustrated in Fig. 6(c), whereas Specimens 27 were anchored with pour stops at both ends similar to other specimens in Series 2. The compan-

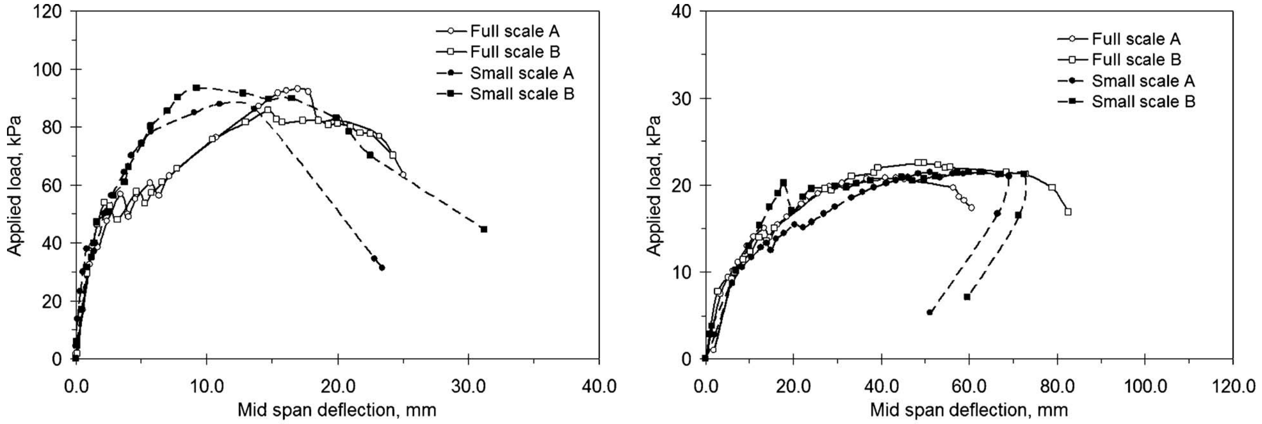


(a) (b)

Fig. 13. Equivalent uniform applied load versus mid span deflection: (a) Test 27 (compact); (b) Test 30 (slender)

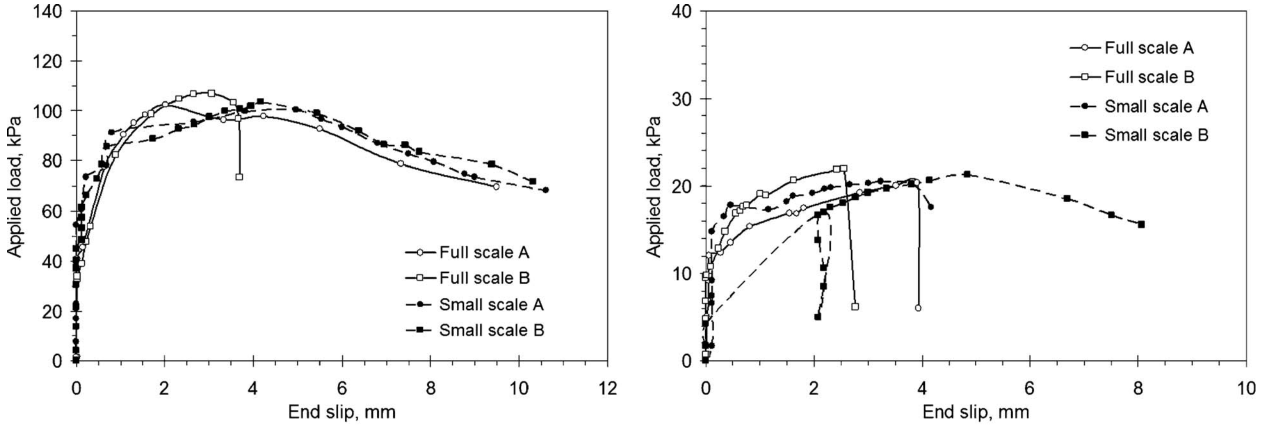
ion specimens from full-scale tests had the same end details as Specimen 27 at one end and were restrained by continuous concrete at another end (interior support).

The graphs of load versus mid span deflection for these specimens are shown in Fig. 12. The average maximum loads for Tests 16, 17, and 26 expressed as a fraction of the average maximum load of the full-scale specimens are 0.69, 0.81, and 0.97, respectively. This indicated clearly that the end details could exert a significant effect on the performance of the slab specimens. Further, both elemental and full-size specimens, whose end supports were identical, exhibited almost equal strength except that the elemental specimens were slightly stiffer in the beginning



(a) (b)

Fig. 14. Equivalent uniform applied load versus mid span deflection: (a) Test 33 (compact): (b) Test 34 (slender)



(a) (b)

Fig. 15. Equivalent uniform applied load versus end slip: (a) Test 27 (compact); (b) Test 30 (slender)

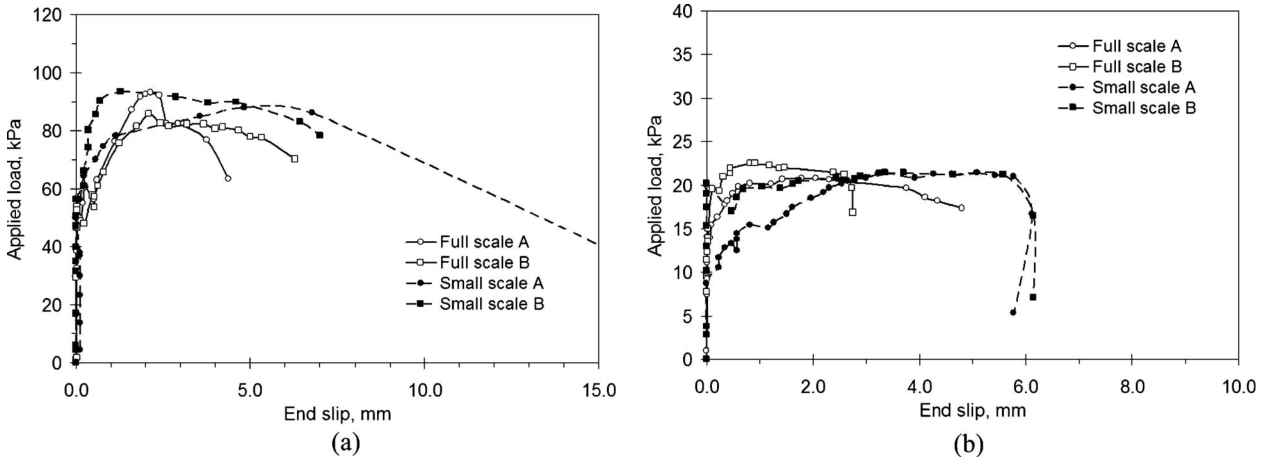


Fig. 16. Equivalent uniform applied load versus end slip: (a) Test 33 (compact); (b) Test 34 (slender)

and failed at a smaller displacement than the full-size specimens. This can be attributed to the elemental specimens being anchored by pour stops at both ends, whereas the full-size specimens had anchors at exterior supports only.

Comparison between Elemental Series 2 and Full-Size Tests

Maximum Loads and End Slips

Selected graphs of load versus midspan deflection for compact (short and thick) and slender (long and thin) specimens are shown in Figs. 13 and 14, whereas graphs of loads versus end slips for the same specimens are in Figs. 15 and 16. A summary of results in the form of maximum loads is given in Table 4. The average maximum loads of elemental tests were compared with those from full-size tests and are also presented in Table 4. The values indicate that the performance of elemental tests was comparable with the full-size tests. Most results were within 10% difference, except for Tests 21 and 23, which were weaker than the full-size specimens by 17%. This difference can be attributed to the comparable full-size specimens being tested first using an airbag as explained in Abdullah and Easterling (2003). Test 35 was 18% stronger than its full-scale counterpart. The difference was particularly due to outlying results of test A of the full-scale specimen which was unexplainably weak compared to Test B.

Table 4. Maximum Load for Full-Size and Elemental Specimens

Test number	Average maximum load from full-size tests, W_{uf} (kN/m^2)	Average maximum load from elemental tests, W_{us} (kN/m^2)	Ratio of W_{us}/W_{uf}
21	80	66	0.83
22	21	22	1.06
23	87	73	0.84
24	19	20	1.06
25	—	455	—
27	105	102	0.97
28	—	61	—
29	—	29	—
30	19	21	1.10
31	72	74	1.03
32	23	23	1.00
33	89	91	1.01
34	22	22	1.00
35	102	120	1.18
36	23	23	1.02
	Mean		1.01
	Standard deviation		0.10

Failure Modes

Based on the first recorded end slip of 0.5 mm (Veljkovic 1998), failure modes were determined in accordance with the Eurocode 4 (ECS 1994) definition and are compared with full-size data in Table 5. All elemental specimens, except Specimen A of Test 35, exhibited a ductile failure. Results were similar for the full-size test specimens.

Design Application

The elemental test data were used to calculate the strength of the composite slabs using the *m*-*k* method according to ASCE (1992) and Eurocode 4 (ECS 1994). The same data were also applied to the PSC method available in the Eurocode 4 (ECS 1994) to predict the strength of the slabs. The calculated strengths were compared with those from the full-size tests and plotted in Fig. 17. From the plot, it can be seen that most calculated capacities using the elemental test data were within ±20% of the full-size test values. The data plotted in Fig. 17 has a mean ratio of full-size test strength to calculated strength using the ASCE *m*-*k* method and the elemental test results of 1.04 with a standard deviation of 0.16. The Eurocode *m*-*k* method yields a mean of 1.00 and standard deviation of 0.11 and the PSC method yields a mean of 1.05 and a standard deviation of 0.14. These results indicate that the data from the elemental bending tests can be used to predict the capacity of full-size specimens, and hence the actual slabs, reasonably well using the established design procedures.

Conclusions

A new method for testing of the composite slab in bending in an elemental (narrow) configuration has been developed. If the same

Table 5. Failure Mode of the Specimens

		Full-size tests				Elemental tests			
Tests number	Span[a]	Failure load, W_{uf} (kN/m^2)	Load at first slip, W_s (kN/m^2)	W_{uf}/W_s	Failure mode	Failure load, W_{us} (kN/m^2)	Load at first slip, W_s (kN/m^2)	W_{us}/W_s	Failure mode
21	A	80	67	1.19	Ductile	67	55	1.21	Ductile
	B	79	62	1.27	Ductile	66	53	1.25	Ductile
22	A	20	15	1.35	Ductile	24	17	1.46	Ductile
	B	22	—	—	Ductile	20	15	1.28	Ductile
23	A	86	57	1.49	Ductile	71	56	1.27	Ductile
	B	88	51	1.74	Ductile	75	58	1.29	Ductile
24	A	19	14	1.34	Ductile	20	17	1.17	Ductile
	B	19	14	1.34	Ductile	20	13	1.56	Ductile
25	A	—	—	—	—	487	426	1.14	Ductile
	B	—	—	—	—	422	335	1.26	Ductile
27	A	102	69	1.48	Ductile	101	76	1.32	Ductile
	B	107	65	1.65	Ductile	103	73	1.42	Ductile
28	A	—	—	—	—	65	49	1.31	Ductile
	B	—	—	—	—	57	40	1.43	Ductile
29	A	—	—	—	—	29	24	1.22	Ductile
	B	—	—	—	—	29	24	1.20	Ductile
30	A	18	13	1.36	Ductile	21	18	1.16	Ductile
	B	20	16	1.24	Ductile	21	8	2.75	Ductile
31	A	74	57	1.28	Ductile	77	67	1.14	Ductile
	B	70	53	1.33	Ductile	71	58	1.21	Ductile
32	A	22	17	1.31	Ductile	23	16	1.45	Ductile
	B	23	18	1.26	Ductile	22	20	1.10	Ductile
33	A	93	57	1.62	Ductile	88	68	1.29	Ductile
	B	86	57	1.49	Ductile	93	83	1.13	Ductile
34	A	21	—	—	Ductile	22	13	1.61	Ductile
	B	23	—	—	Ductile	22	17	1.25	Ductile
35	A	89	86	1.03	Brittle	125	120	1.05	Brittle
	B	114	91	1.25	Ductile	114	91	1.26	Ductile
36	A	23	20	1.14	Ductile	23	17	1.34	Ductile
	B	23	17	1.34	Ductile	24	13	1.79	Ductile

[a] A and B refer to nominally identical specimens for a given test.

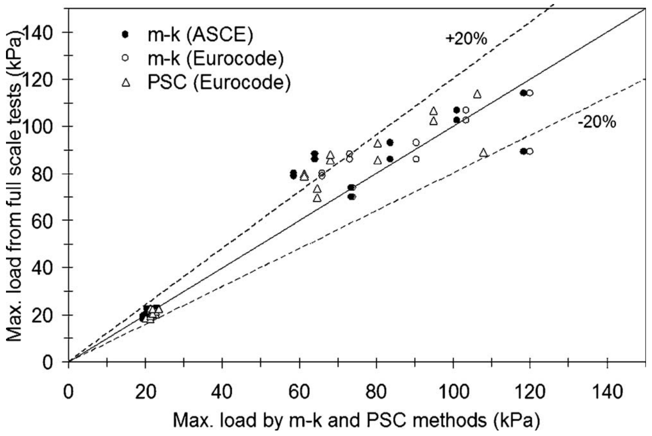


Fig. 17. Comparison between maximum load of full-size tests and maximum capacities using *m-k* and PSC methods

end details are utilized in both elemental and full-size specimens, the elemental tests can produce comparable results with the full-size specimens.

Edge web curling, end anchorage details, and type of support have significant influence on the slab specimen strength and behavior. Angle straps can provide sufficient restraint to the edge web, thus enabling elemental specimens to behave in a manner similar to full-size specimens. The use of angle straps at a spacing of 100 mm and end conditions that are comparable to a given full-size specimen enable the use of the elemental specimen developed in this experimental study to be used as an alternative to the full-size specimen.

The elemental tests developed in this investigation are simple and easy to construct. The side formwork, angle straps and C-clamps are reusable, which make the testing more economical. Four elemental specimens can be set up in the same space needed for one full-size specimen that is 1,830 mm wide, with almost an equal amount of material.

The calculated slab strengths using the elemental test data were within acceptable accuracy compared to the full-scale test results. Because the elemental test is conducted in bending, where the span length and the concrete thickness similar to a traditional full-size test can be used, the data from the elemental tests can be applied directly to the present design specifications, namely the *m*-*k* and the PSC methods in the ASCE (1992) and Eurocode 4 (ECS 1994).

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