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Seismic in-plane shear resistance of steel-deck concrete composite slabs with a bottomless trench duct

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ABSTRACT: In cold-formed steel-deck concrete composite floor slab systems, cellular raceway systems having bottomless trench ducts have been increasingly used for office buildings. Since almost no theoretical and experimental explanations are given about the seismic in-plane shear transfer mechanism of this type of composite floor system, experimental studies are conducted by using ten different full-scale test specimens with and without a bottomless trench duct. During the test, alternately repeated in-plane lateral forces are applied to those specimens on a laboratory test floor, and complete hysteresis loops for load and deformation relations are obtained. Test results indicate that the composite floors with a bottomless trench duct have an adequate initial stiffness and strength in case when the steel-decks are sufficiently welded onto the steel supporting beams. Main conclusion obtained is that this type of composite floor slab is applicable practically into actual building floor systems without any horizontal floor bracing.

1 INTRODUCTION

In recent years, cold-formed steel-deck concrete composite floor slab systems have become more popular in office building constructions. In this type of floor systems, cellular raceway systems having bottomless trench ducts as shown in Fig.1 have been increasingly used especially in the United States and Japan. In the United States, a number of extensive studies have been conducted on the in-plane shear resistance of composite floor diaphragms without any trench ducts, and design formulas have been also proposed based on these studies. Among these, the Tri-Service method are empirical formulas which are widely used to predict the stiffness and strength of composite floor diaphragms. In addition, the Iowa State University method proposed by M.L.Porter and L.F.Greimann is a reasonable approach for predicting the initial stiffness and ultimate strength of the composite floor diaphragms and therefore has good potential as a design tool.

On the contrary, there are quite few studies on the in-plane seismic shear resistance of composite floor slabs which have cellular raceway systems with a bottomless trench duct. Since any concrete is not cast completely along through the trench headers, its structural behavior seems to be rather different from that of an ordinary composite floor diaphragm without any trench duct. Although design formulas for the composite slabs with a trench header is presented in a report by the ICBO, these are based on the test results obtained from only two test specimens.

Main objective of the present study is to investigate the in-plane seismic shear-force transfer mechanism of steel-deck concrete composite floor slabs having a bottomless trench duct experimentally.

2 TEST SPECIMENS

Ten different full-scale specimens listed in Table 1 were designed and tested. Each of the test specimen is composed of five sheets of cold-formed steel-decks, three of which have an ordinary steel-deck cross-section and other two are cellular decks to provide passageways for electrical wiring and other utilities as shown in Figs.2 and 3. Note that the steel-deck panels used for Specimens CD-3 through CD-6 are made in Japan(Type-B) and their panel widths are 27mm smaller than other panels, which are made in the United States(Type-A).

Among these specimens, six specimens from CD-1 through CD-6 in Table 1 are composite slabs with a bottomless trench duct, two specimens of C-1 and C-2 are without any duct and last two specimens, S-1 and S-2, are plain steel deck slabs on which any concrete is placed.

Fig.3 shows an illustration of a composite slab specimen (CD-3) together with the test setup used in the experiment. Along all edges of the specimens except for CD-5 and CD-6, steel-decks and, supporting- and edge-beams were connected each other by 25 mm diameter puddle welds, the spacing of which is given in Table 1 and Fig.3, while in Specimen, CD-5, studs (or shear connectors) were provided instead of using puddle welds. Along the South and North edge beams of CD-6, steel-deck plates were not connected to those two beams but were only placed on the top-flanges of the beams although West and East edges were connected by puddle welds. Steel-deck panels for Specimens CD-3 through CD-6 were connected each other by button-punches spaced 60cm, while other deck panels were welded each other by seam welds spaced 90cm on center using 38 mm electrodes.

Width of the bottomless trench ducts is 60cm for all the specimens and location of the duct is also shown in Table 1 and Fig.3. Concrete of the composite slab specimens were reinforced by welded-wire fabrics with 6 mm diameter smooth wires spaced 150 mm on

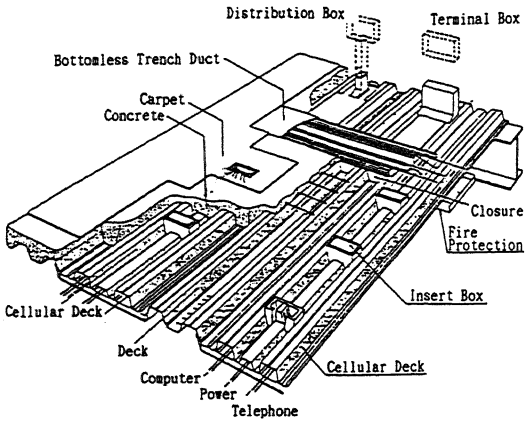

Figure 1. Steel-deck concrete composite floor system with a bottomless trench

Table 1. Summary of parameters for test specimens

Test group	Specimen Number	Span Length (mm)	Yield Strength (MPa) Steel-deck	Yield Strength (MPa) Cellular-deck	Compressive Strength of Concrete (MPa)	Puddle Welds or Studs* Steel-deck	Puddle Welds or Studs* Cellular-deck	Puddle Welds or Studs* Longitudinal Edge(mm)
Composite Slab with a Bottomless Duct	CD-1 CD-2	2750 2200	307	328	17.7 19.6	3-Welds per panel	4-Welds per panel	@212 @200
	CD-3 CD-4	2750	339	354	21.2			@212
	CD-5		318	343	26.8	2-Studs per panel	3-Studs per panel	9-Studs @300
	CD-6					3-Welds per panel	4-Welds per panel	Non
Composite Slab without a Bottomless duct	C-1 C-2	2750 2200	307	328	21.6			@212 @200
Steel-deck Slab	S-1 S-2	2750 2200			-			@212 @200

* Stud size used is 19mm in diameter and 120mm in length.

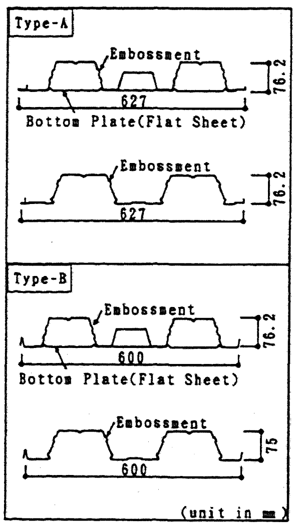

Figure 2. Cross-sectional details of steel-deck panels

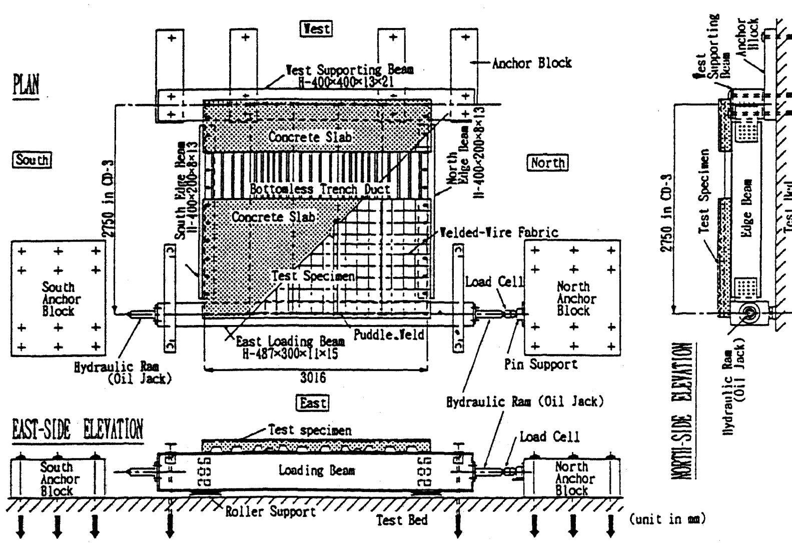

Figure 3. Test setup and composite test specimen with a bottomless trench duct

center. Thickness of concrete above the up corrugation is 80 mm for all the composite specimens. Material properties for all the test specimens are also listed in Table 1.

3 TEST SETUP AND INSTRUMENTATION

Test setup used in the present study is shown in Fig.3 together with Specimen, CD-3. Each specimen is placed on the West and East supporting beams and the North and South edge beams. The West supporting beam is fixed on the test floor, while East supporting beam which acts as a loading beam is placed on roller supports. Webs of both ends of the edge beams are connected to the North and South supporting beams by means of flexible T-shape elements.

Alternately repeated lateral in-plane shear forces were applied by using two hydraulic rams with 490kN capacity. In the early stage of loading, applied load was gradually increased and then loading program was changed to the displacement-controlled procedure. Those Lateral loads applied to the test specimens were measured by using load-cells and displacement measurements were made by displacement transducers. In addition, single- and three-gage rosette strain gages was used to measure the strains on the steel-deck and concrete surfaces. All informations obtained during the loading reversals were sent to a personal computer and were processed simultaneously.

4 EXPERIMENTAL RESULTS

In Figs.4, 5 and 6, in-plane lateral forces (Q) applied to CD-4, CD-5 and CD-6 specimens are respectively plotted against relative in-plane floor displacements (δ) between West- and East-beams. All envelop curves and ultimate strengths obtained from the Q-δ relations during positive (North to South) loading are summarized in Figs.7 and 8.

Specimens, CD-1, CD-2 and CD-3 showed a quite similar structural behavior and failure mode to CD-4 as shown in Fig.4, where in the early stage of loading, first major cracking (vertical cracks) occurred at around corners of the concrete slab. When lateral load was more than 220kN, relative displacements between concrete and steel-decks initiated to occur along the West and East edges. Cracking along the bottomless duct initiated by additional loading, however did not propagate significantly. Just before reaching the ultimate strength, considerable relative displacements occurred between concrete and steel-decks which caused steel-deck "fold-over", and then horizontal cracks propagated through up corrugation surfaces. Final failure mode was the interfacial shear failure between concrete and steel-decks along the West and East edges of the concrete slab. It can be noted that any fracture did not occur at the puddle welds.

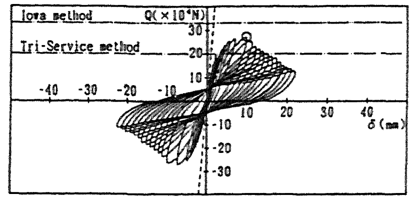

Figure 4. Q-δ relation of Specimen, CD-4

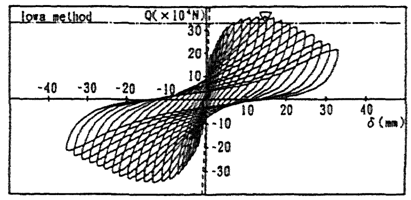

Figure 5. Q-δ relation of Specimen, CD-5

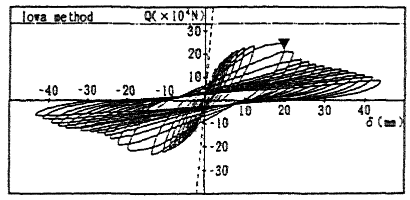

Figure 6. Q-δ relation of Specimen, CD-6

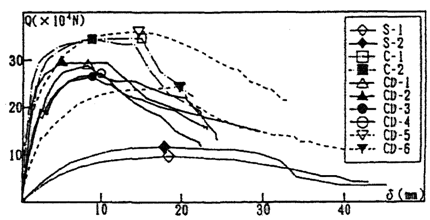

Figure 7. Envelop curves for all Q-δ curves

Specimen, CD-2, which had a shorter span-length than CD-1, showed a slightly higher strength than CD-1. Little difference in ultimate strengths were observed between CD-1 and CD-3. Structural behavior including ultimate strength and failure mode in CD-3 was almost the same with CD-4.

Specimen, CD-5, had just the same size and shape, and cross-sectional details with CD-3 except that the higher concrete was cast and adequate number of studs were provided along the perimeters of its floor slab. Up to the ultimate strength of this specimen, most of the significant cracking concentrated along the bottomless trench duct, and its failure mode was a interfacial shear failure between

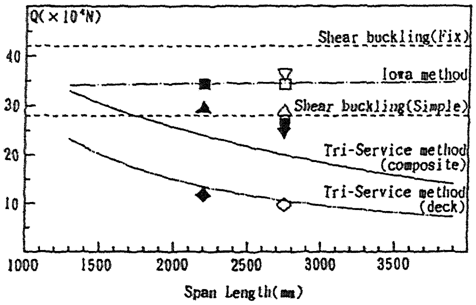

Figure 8. Ultimate lateral strengths

concrete and bottomless duct. This specimen showed the highest lateral stiffness and ultimate strength among all the test specimens (see Figs.5, 7 and 8).

Along the South and North edges of CD-6, steel decks and edge beams were not connected each other. In the early stage of loading for this specimen (Fig.6), cracking occurred along the West and East edges, and also along both side of the bottomless duct. When lateral load was more than 220kN initial buckling was observed on the web-plate elements of the deck panel. And just before reaching the ultimate load (Qu=245kN), buckling occurred on bottom plates of the cellular deck panel. Due to further increase of repeated displacements, however, buckling waves did not become pronounced, but both of the fastener and interfacial shear failures were finally observed along the West and East edges.

Specimens, C-1 and C-2 had no bottomless ducts. These specimens showed about 50kN higher than the ultimate strengths of CD-1 and CD-2, but failure modes of these two specimens were interfacial shear failures and were same with CD-1 through CD-4.

Two specimens of S-1 and S-2 are plain steel-decks having no concrete fill.

5 DISCUSSIONS

For all the tested specimens, initial stiffness and ultimate strengths were calculated by using both of the Tri-service and Iowa State University methods. Dashed straight lines in Figs.4 through 6 are initial stiffness determined by the Iowa method based on the assumption that the bottomless duct is not provided within the composite slab. Initial stiffness determined by this method falls within the error ranging from -35% to +65% for all the composite test specimens.

In Fig.8, ultimate strengths obtained from the present experiment are compared with the predicted values determined by the Tri-Service and Iowa State University methods. Since there are no established formulas to predict the ultimate strength of composite floor diaphragm with a bottomless duct, theoretical approach was made by considering the shear buckling and/or yielding of the horizontal plate elements located within the bottomless duct. Results are presented in Fig.8, where two cases when longitudinal edges of each plate element are simply supported or fixed are respectively shown by dashed lines.

In case when any bottomless duct is not located within the composite slabs, both of the ultimate strengths and failure modes can be well predicted by the Iowa method as is observed in C-1 and C-2 in Fig.8.

While in test specimens with a bottomless duct, failure modes in CD-1 through CD-4 are well predicted by the Iowa method, but their ultimate strengths are about 20% lower than the predicted values by the Iowa method because no bottomless ducts are assumed to be provided in to the slab. However it is noted from the test result on CD-5 that, if higher concrete and adequate number of studs are used instead of puddle welds, ultimate strength of the composite slab with a bottomless duct becomes considerably higher than CD-1 through CD-4 specimens. Also it is worthy of note that a rough calculation based on the elastic buckling theory gives a good approximation for the ultimate strength of CD-6.

6 CONCLUSIONS

(1). Steel-deck concrete composite floor systems with a bottomless trench duct have adequate initial stiffness and ultimate strength even if slab-edges are connected only by puddle welds.

(2). Ultimate strength of this type of composite slabs becomes higher if higher concrete and adequate number of studs are provided to prevent the slab-edges from interfacial shear failures.

(3). The Iowa State University method gives good predictions for initial stiffness, failure mode and ultimate strength of the composite specimens, while the Tri-Service method gives a very conservative strength predictions.

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