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# A New Steel-Concrete Composite Building with Double-floor System

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**Summary**

In order to create a better residential environment in human life, it is necessary to offer a higher quality of apartment building which has sufficient storage spaces and adequate sound transmission insulation between adjacent two stories. Herein, a new steel reinforced concrete (SRC) apartment building having double-floor system is proposed to satisfy these requirements within a limited floor space, and SRC inverted T-shape and L-shape specimens are tested to develop a better reinforcing method within slab-to-beam connections of the double floor system.

## 1. Introduction

According to the latest investigation report by the Ministry of Construction of Japanese Government, more than 50 percent of one-hundred thousand householders jointing this investigation have their dissatisfactions on narrow storage spaces and noisy sound transmission from the upper-story residents [1]. In order to solve these problems within a limited floor-space area and to offer a higher quality for dwelling environment in multi-story residential buildings, a new type of apartment building having double-floor system was already proposed by authors, and the first reinforced concrete (R/C) building with seven stories was built in 1994 in Oita City, Japan [2,3].

Fig. 1 shows a schematic illustration of the double-floor slab system adopted in a thirteen-story steel reinforced concrete (SRC) apartment building which was completed in 1996 in Fukuoka City, Japan. This building has nearly the same floor area with ordinary apartment buildings widely constructed in Japan, but the only one difference in structural system is that this has a double-floor slab system to insulate the sound transmission from upper-story residents and to provide satisfactory storage spaces between top and bottom floor slabs. Each of the top floor of this double-floor system is a lumber decking which is composed of plywoods and light-gage steel sub-beams without any intermediate supports. On the contrary, each bottom floor is an R/C suspended slab which has an inverted T-shape or L-shape cross-section at the R/C-slab to SRC-beam connections. In this type of inverted T-shape slab-to-beam connections, however, systematic experimental study about the effect of reinforcing details on its structural behavior has not been conducted sufficiently.

Main objective of the present study is to examine the structural behavior of inverted T-shape and L-shape suspended slabs experimentally and to propose a better reinforcing method for strength and ductility of this type of suspended slab system.

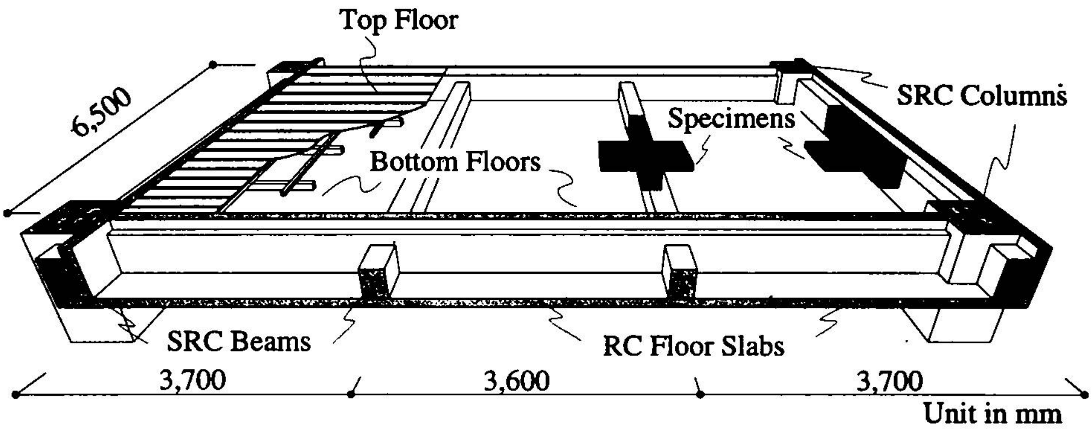


*Fig. 1 Double-floor slab system*

In the present experimental study, five different full-scale specimens with inverted T-shape and L-shape slabs were tested under monotonic vertical loads and test results were compared with those obtained from the ordinary T-shape specimen.

## 2. Test Specimens

A total of six full-scale specimens with different slab-to-beam connection details were designed and constructed. Five specimens have suspended slabs with inverted T-shape and L-shape cross-sections, and only one specimen has an ordinary T-shape cross-section. Each specimen is composed of one SRC beam element and one or two R/C slab elements connected each other at the top of the beam for the T-shape specimen and the bottom of the beam for the inverted T-shape and L-shape specimens, respectively. Fig. 2 shows size and shape of the inverted T-shape and L-shape specimens, which correspond to slab-beam segments as shown in Fig. 1.

Reinforcing details for all the specimens are listed in Table 1 together with the material properties of concrete and Re-bars, and the details of all the specimens are respectively shown in Fig. 3. Specimen (SRC-OT) in Fig. 3 is a model of ordinary T-shape beam-slab subassemblage in case

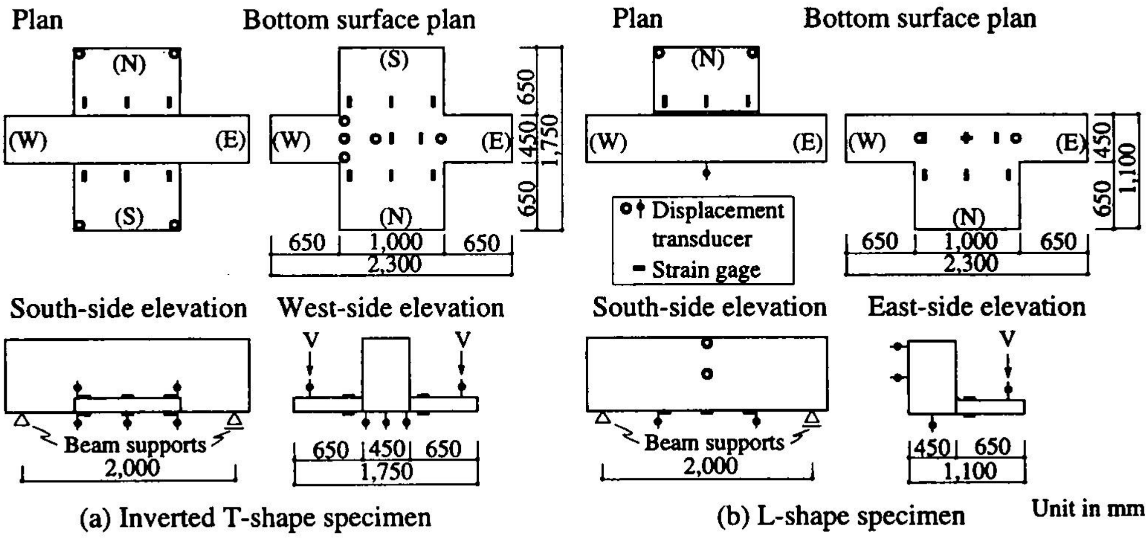


*Fig. 2 Size and shape of inverted T-shape and L-shape specimens*

*Table 1 List of specimens*

| Specimens | Reinforcement | | | Compressive Strengths of Concrete [kgf/cm²] | Yield Strengths of Slab Re-bars | |
|---|---|---|---|---|---|---|
| | Slab Re-bars | | Slab-to-beam Connection | | Bar Size | |
| | Top Bars | Bottom Bars | Diagonal Re-bars | | D13(#4) [kgf/cm²] | D10(#3) [kgf/cm²] |
| SRC-OT | D13(#4) D10(#3) Alternate @200 | D10(#3) @400 | None | 275 | 3760 | 3710 |
| SRC-IT | | | | 252 | | |
| SRC-ITH1 | | | D13(#4) @200 | 277 | | |
| SRC-ITH2 | | | | 211 | | |
| SRC-LH | | | | 251 | | |
| SRC-LHS | | | | 246 | | |

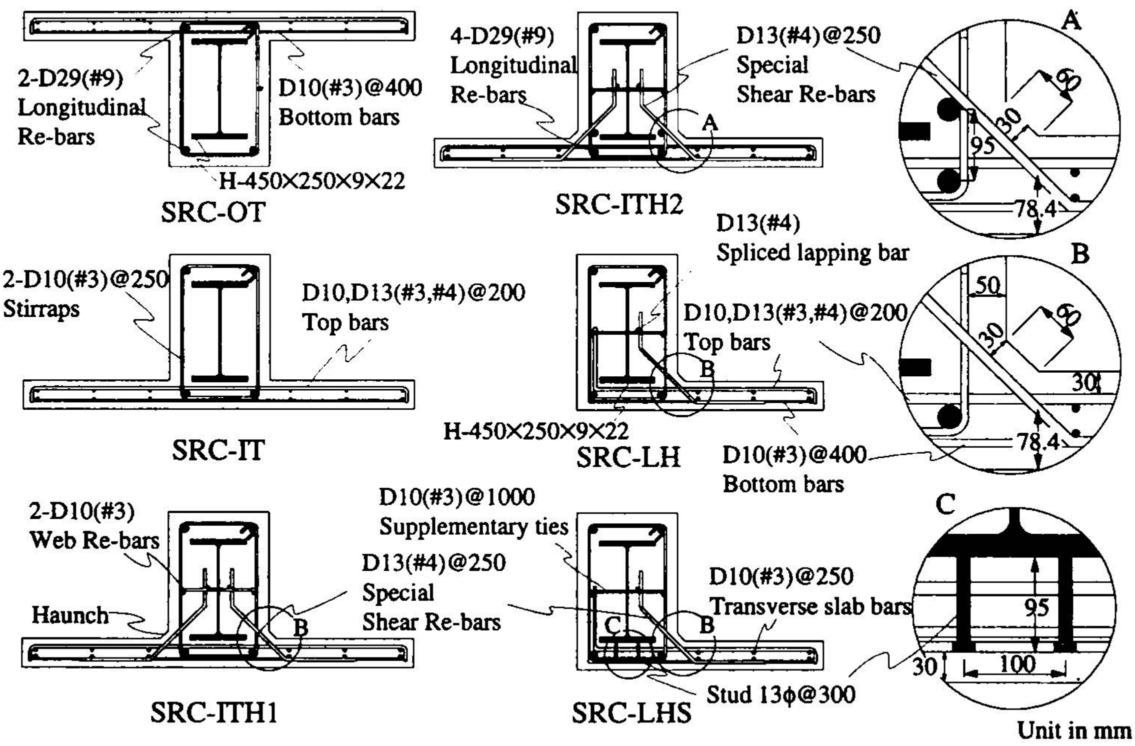


*Fig. 3 Reinforcing details in slab-to-beam connection*

when floor slabs of the similar building shown in Fig. 1 are designed by using an ordinary T-shape slab system, where required amount of reinforcement and connection details are designed in accordance with the current structural design standard in Japan [4].

Other three specimens in Fig. 3 are inverted T-shape specimens with different reinforcing details. Slab-to-beam connection of Specimen (SRC-IT) has the same reinforcing details with Specimen (SRC-OT) except that the slabs are located at the bottom of the beam. In addition to this slab-to-beam connection detail, special diagonal shear reinforcements and haunch are provided in Specimens (SRC-ITH1) and (SRC-ITH2) as shown in Fig. 3. Only one difference between reinforcing details of Specimens (SRC-ITH1) and (SRC-ITH2) is the total number of longitudinal Re-bars provided at the bottom of each beam. Specimen (SRC-ITH2) was adopted to investigate the effect of congestion of reinforcement on the structural behavior of slab-to-beam connection.

In Specimens (SRC-LH) and (SRC-LHS), only one slab is provided along the bottom of spandrel beam. Slab-to-beam connection of Specimen (SRC-LH) has the corresponding reinforcing details to those of Specimen (SRC-ITH1) in Fig. 2. Specimen (SRC-LHS) has the same reinforcing details with Specimen (SRC-LH) except that some studs are welded at the bottom of wide flange surface in the steel H-shape beam.

## 3. Test Setups

Experiments for the ordinary T-shape, inverted T-shape and L-shape specimens were respectively conducted by using the test setups shown in Figs. 4(a), (b) and (c). All the test specimens were simply supported at both ends of their beam. Vertical load to the slab-end, V, was applied as a concentrated line load, the loading point of which was 50 cm from the beam face as shown in Figs. 4(a), (b) and (c). Application point of this vertical loading was determined so as to be equivalent when the same slabs were subjected to design dead plus live loads specified in the Building Code and Standard of Japan [4,5].

"Displacement Controller (or Pantograph)" shown in Figs. 4(a) and (b) was designed and installed in order that both of the vertical displacement at the North and South loading points can be kept equal all through the experiment. "Reaction Beam" shown in Fig. 4(c) was to prevent the rotational movement of the beam.

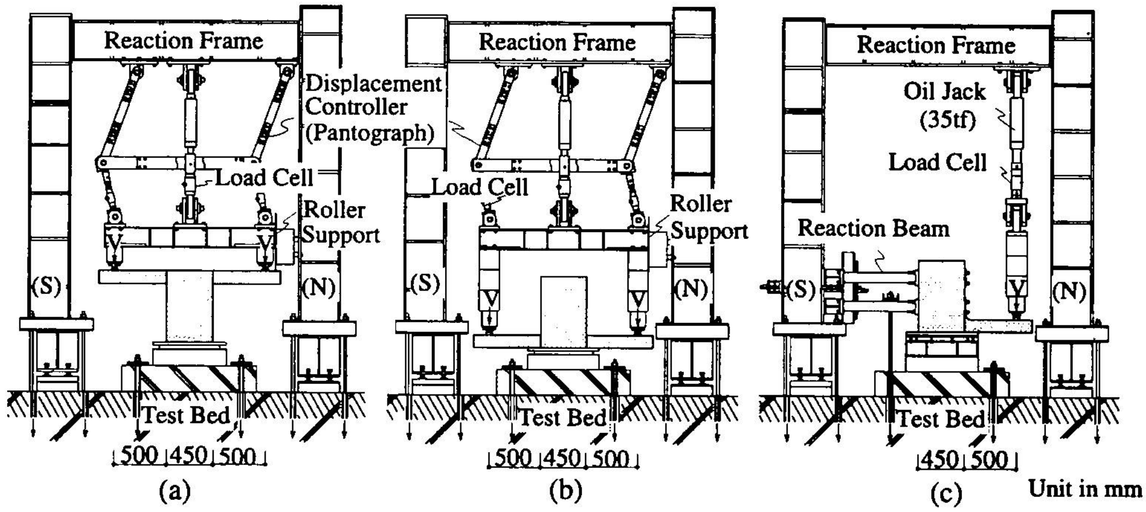


*Fig. 4 Test setups for (a) ordinary T-shape, (b) inverted T-shape and (c) L-shape specimens*

## 4. Test Results and Discussions

Fig. 5 represents the applied vertical load (V) versus corresponding vertical displacement relations for all the specimens. In the figure, bending moment (M) applied to each of the slab-end is also presented. For the T-shape and inverted T-shape specimens, these values of V and M are the averages of two measurements, and $\delta$ is the average of four measurements at the North and South slabs. Along each curve of the V-$\delta$ relations in Fig. 5, information obtained from the strain-gage measurements or visual observation is also given by using the open circle, open square and solid triangle, which mean the initiations of tension-yielding in top and bottom bars for slab main reinforcement and crushing of compression-concrete at the slab-to-beam connections, respectively. Also in this figure, the allowable strengths for long-term loading [4] and the ultimate strengths

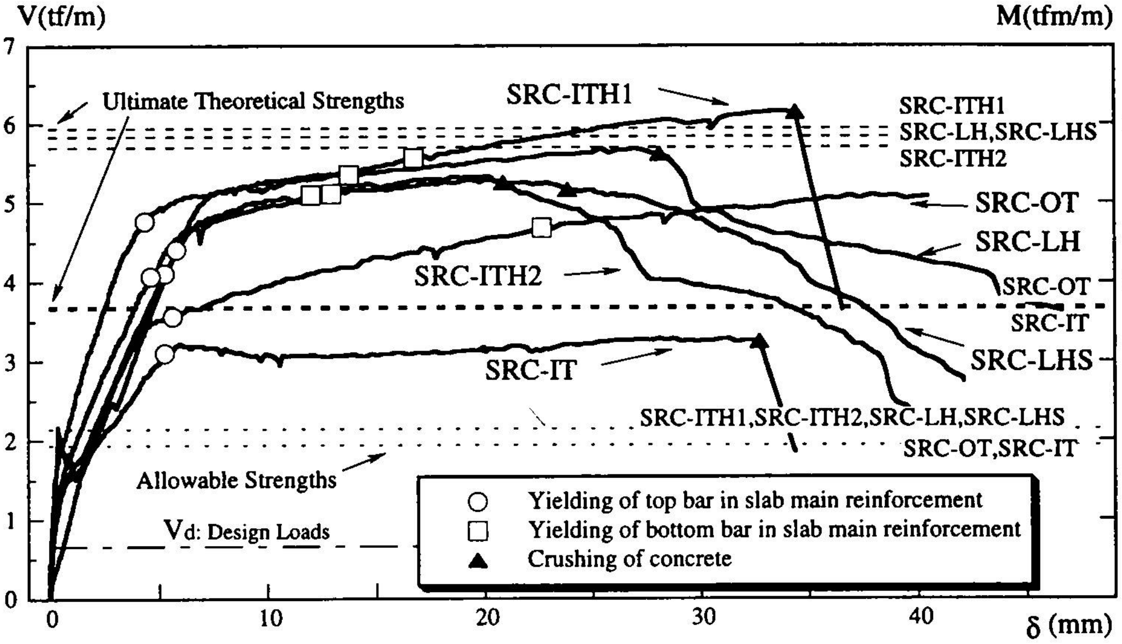


*Fig. 5 Vertical load (V) versus displacement (δ) relation*

*Table 2 Allowable strengths and ultimate strengths*

| Specimens | Theoretical Predictions | | | | Test Results | |
|---|---|---|---|---|---|---|
| | Allowable Strengths for Long-term Loading | | Ultimate Flexural Strengths | | Observed Ultimate Strengths | |
| | Flexure Mall [tfm/m] | Shear Vall [tf/m] | Flexure Mu [tfm/m] | Shear Vu [tf/m] | Flexure Mutest [tfm/m] | Shear Vutest [tf/m] |
| SRC-OT | 1.07(0.86*) | 2.14(1.71*) | 1.95 | 3.89 | 2.65 | 5.30 |
| SRC-IT | | | 1.93 | 3.86 | 1.75 | 3.49 |
| SRC-ITH1 | | 2.34(1.87*) | 2.81 | 6.14 | 2.91 | 6.37 |
| SRC-ITH2 | | | 2.70 | 5.90 | 2.54 | 5.54 |
| SRC-LH | | | 2.77 | 6.06 | 2.70 | 5.89 |
| SRC-LHS | | | 2.77 | 6.04 | 2.52 | 5.50 |

* Based on specified yield strength of Re-bars($f_y$=3000kgf/cm$^2$), and design compressive strengths of concrete ($f'_c$=270kgf/cm$^2$).

determined by a theory [4] are presented by dotted lines and dashed lines, respectively. In addition, the design loads ($V_d$) based on the current Japanese Standards are given in the figure. Each of the theoretical strengths and ultimate strengths obtained from the experiment are also listed in Table 2.

Summarizing the test results obtained;

(1). The observed ultimate strengths ($V_{utest}$) of all the test specimens are more than 4.1 to 7.4 times as large as the design load ($V_d$), and more than 1.6 to 2.7 times as large as the allowable strength for long-term loading ($V_a$).

(2). The ordinary T-shape Specimen (SRC-OT) could develop its ultimate flexural moment capacity ($V_u$) and has excellent deformability without any concrete crushing.

(3). Specimen (SRC-IT), which is the inverted T-shape specimen having the same slab reinforcing details with the ordinary T-shape Specimen (SRC-OT), could almost develop its ultimate flexural moment capacities determined by the approximate equation [4], in which Re-bars at the bottom of slabs are not taken into consideration, but was not able to develop its theoretical ultimate flexural strength ($V_u$). In a large deformation area, brittle shear failure occurred at the fixed end of the slabs, and then rapid deterioration in load-carrying capacity took place. This type of failure was also observed in the experiment using R/C beams and inverted T-shape and L-shape slabs specimens [2,3], but could not be expected by an existing design method such as used for designing ordinary R/C slabs with T-shape cross-section [4].
(4). The special diagonal shear reinforcements, which are provided in Specimens (SRC-ITH1), (SRC-ITH2), prevented the brittle shear failure such as observed in the Specimen (SRC-IT) and could increase their ultimate strengths considerably. Finally both specimens failed in shear failure mode in slab concrete, where shear cracks were running from the bottom of slab end toward the loading point. A minor difference of strength and ductility between these specimens would be caused by the slight difference on compressive strengths of the concrete.
(5). In Specimens (SRC-LH), (SRC-LHS), the special diagonal shear reinforcements contributed to increase the ultimate strength, and prevented the occurrence of brittle shear failure at the fixed end of the slabs in a large deformation area.

## 5. Concluding Remarks

In order to create a higher quality of residential environment, a SRC new apartment building with double-floor system was proposed, and some experimental studies were performed to develop the better reinforcing method for slab-to-beam connection details. From the test results, it can be concluded that the special diagonal shear reinforcements are quite effective to prevent the brittle flexure-shear failure and crushing compression-concrete in large deformation area in the slab-to-beam connection of the inverted T-shape floor slabs in SRC building structures, as well as R/C structures, and to develop the ultimate flexural strength and the large ductility.

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