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Autor: Udagawa, Kuniaki / Mimura, Hiroaki

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Stiffness and Strength of Composite Beams in Frames

Rigidité et résistance de poutres mixtes dans des cadres

Steifigkeit und Widerstand von Verbundträgern in Rahmen

Kuniaki UDAGAWA
Prof.
Tokyo Denki University
Tokyo, Japan

Hiroaki MIMURA
Prof.
Tokyo Denki University
Tokyo, Japan

1. INTRODUCTION

A composite beam in a frame under loadings which occur during an earthquake has a positive and a negative moment regions simultaneously. Hence, the composite beam becomes a sort of a beam with changes in cross section and presents complex dynamic behavior. This poster describes the evaluation of stiffness of composite beams based on frame experiments and a frame analysis using the accurately calculated stiffness of the composite beams. The stiffness evaluation is made by replacing two kinds of moment of inertia of a composite beam under positive bending and negative bending with a single equivalent moment of inertia. Also, regarding the strength, story shear force capacity of the frames and positive bending moment capacity of the composite beams upon crushing of concrete slabs are discussed in the poster.

2. EQUIVALENT MOMENT OF INERTIA OF COMPOSITE BEAMS

The test was performed in six steel frames each with a fully composite beam and one frame with a steel beam (see Table 1). Specimens were designed so that a composite beam may fail prior to steel columns. Figs. 1 and 2 illustrate the details of a specimen and the loading apparatus, respectively. Circles in Fig. 4 represent the experimental elastic story stiffness ($P/{}_sP_p/u/{}_su_p$) of the frames (see Fig. 3). In the figure, t_c means the thickness of concrete slabs. On the other hand, the flexural stiffness matrix of a composite beam of Fig. 5 is given as Eq.(1) from the accurate analysis.

$$\begin{Bmatrix} M_{AB}/{}_sM_p \\ M_{BA}/{}_sM_p \end{Bmatrix} = \begin{bmatrix} 0.57\beta + 0.10 & 0.16\beta + 0.17 \\ 0.16\beta + 0.17 & 0.14\beta + 0.52 \end{bmatrix} \begin{Bmatrix} \theta_A/{}_s\theta_p \\ \theta_B/{}_s\theta_p \end{Bmatrix} \quad \cdots\cdots\cdots\cdots\cdots \quad (1)$$

where ${}_sM_p$: full plastic moment of steel beam, ${}_s\theta_p = {}_sM_pL/6E_sI$, E: Young's Modulus, ${}_sI$: moment of inertia of steel beam, β: ratio of moment of inertia of composite beam under positive bending moment to moment of inertia of steel beam. Story stiffness of the frames shown in Fig. 4 as a solid line are calculated by employing Eq.(1). In this calculation, an effective width of concrete slabs of the test frames was determined as follows: The longitudinal stress distribution in width direction within the concrete slab was assumed to be a trapezoid distribution $\triangle$ ABDC in Fig. 6. To obtain the effective width, a rectangular distribution $\square$ EFHG in the same figure was considered. The effective width $\overline{EF}$ was determined by equalizing two areas of $\triangle$ ABDC and $\square$ EFHG. As a good agreement between the story stiffnesses from the experiments and the analysis was shown, an attempt was made to substitute a single equivalent moment of inertia, ϕ_sI, for the moment of inertia of the composite beam consisting of two kinds of moment of inertia. The equivalent coefficient, ϕ, was determined on the condition that a story stiffness of a frame with a composite beam, whose flexural stiffness is predicted by Eq.(1), is equal to that of a frame with an equivalent beam.

3. STORY SHEAR FORCE CAPACITIES AND POSITIVE BENDING MOMENT CAPACITIES

Story shear force capacity of the frames (see Fig. 3) and positive bending moment capacity of the composite beams (see Fig. 7) upon crushing of concrete slabs in the tests are indicated with circles in Figs. 8 and 9, respectively. In the same figures, a solid line represents calculative values. The story shear forces were obtained by assuming one end of the composite beam in the frame as the full plastic moment under positive bending and the other as the full plastic moment under negative bending. On the other hand, bending moment capacities in the calculation mean the full plastic moments themselves under positive bending. The width of the concrete slabs used in the calculation of the full plastic moments is the same as the afore-mentioned effective width of the concrete slabs.

4. CONCLUSIONS

The equivalent coefficients, ϕ, which represent the equivalent moment of inertia, $\phi_S I$, of the composite beam range from 1.53 to 1.78 for one-bay one-story frames tested. The equivalent moment of inertia is also found to be about 70 % of the moment of inertia of the composite beams under positive bending regardless of the thickness of the concrete slabs. The story shear force capacities upon the crushing of concrete slabs nearly coincide with the story shear forces calculated by the method mentioned under Chapter 3. The experimental positive bending moment capacity of the composite beams upon the concrete slab crushing are nearly as large as the full plastic moments under positive bending.

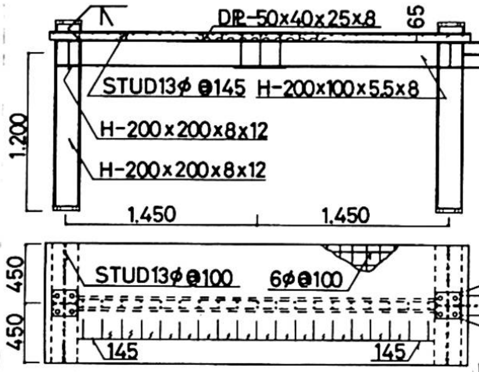

Fig. 1 Test Specimen

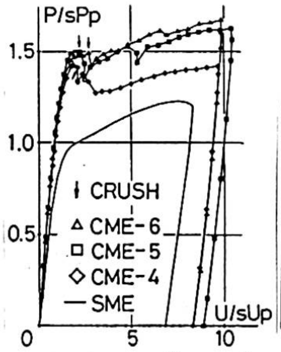

Fig. 3 Story Shear Force - Displacement

Table 1 Moment of Inertia and Full Plastic Moment of Beams

Specimen	sI	cIn	cIn'	sMp	cMp	cMp'
S M E	1792	—	—	795	—	—
CME-4	1788	3690	2086	741	1140	802
CCE-4	1809	3703	2106	748	1146	809
CME-5	1802	4252	2159	730	1181	797
CCE-5	1781	4147	2124	721	1195	787
CME-6	1802	4670	2193	772	1348	842
CCE-6	1797	4679	2189	770	1349	840

sI,cIn,cIn' : [cm⁴] sMp,cMp,cMp' : [tcm]

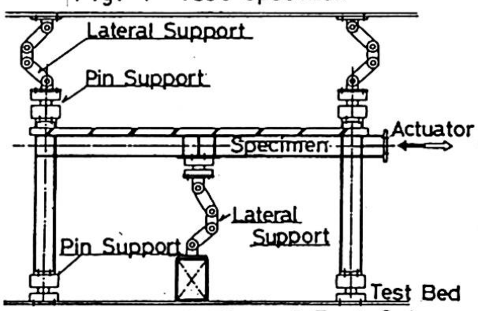

Fig. 2 General View of Test Setup

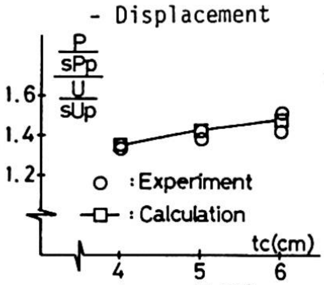

Fig. 4 Story Stiffness of Frames

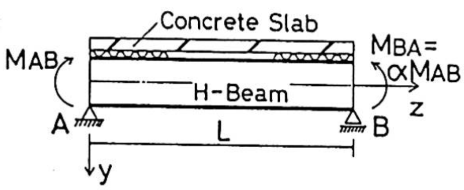

Fig. 5 Composite Beam for Analysis

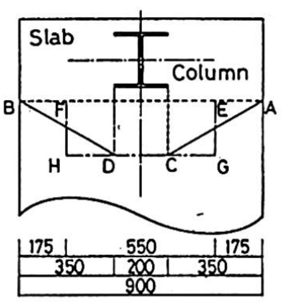

Fig. 6 Effective Width of Concrete Slab

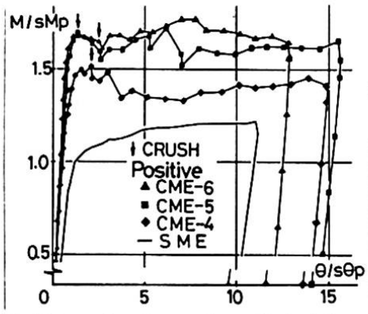

Fig. 7 Moment - Rotation of Beams

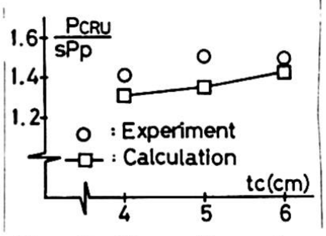

Fig. 8 Story Shear Force upon Concrete Crushing

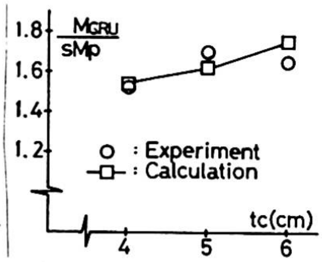

Fig. 9 Moment upon Concrete Crushing