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Behavior of Partially Concrete-Filled Steel Columns

Comportement des colonnes d'acier partiellement remplies de béton

Verhalten von teilweise mit Beton gefüllten Stützen

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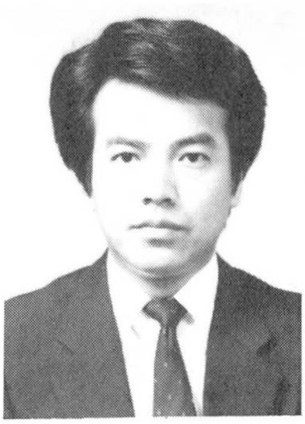

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SUMMARY
Concrete is filled inside the lower colums of two-storied rigid frame piers of Kansai International Airport Bridge located within Osaka Bay. This paper presents the results of a bi-directional loading tests performed to understand the behavior of partially-concrete-filled steel colums.

RÉSUMÉ
Le béton est coulé dans la partie inférieure des piles d'un pont à cadre rigide à 2 niveaux. Cet ouvrage dessert l'aéroport international de Kansai situé dans la baie de Osaka. Ce document présente les résultats d'une analyse de chargement bidirectionnel permettant de comprendre le comportement des piles d'acier partiellement remplies de béton.

ZUSAMMENFASSUNG
In die unteren Stützen eines zweistöckigen Rahmens wurde Beton eingefüllt. Die Brücke befindet sich in der Nähe des Kansais-Flughafens. Dieser Bericht stellt die Resultate einer Übergewichtsprüfung vor, im das Verhalten der mit Beton gefüllten Stützen zu erklären.

1. Introduction

Kansai International Airport(KIA) Bridge is now under construction by KIA Co. Ltd. to be a 3.75km dual purpose (road and railway) route connecting the airport island with Osaka area. The superstructure of the KIA Bridge has three main sections. The type of superstructure over open water is 3-span continuous steel truss with equal span length of 150m. The type of superstructure for each approach ends is 3-span continuous steel box girder with equal span length of 109m. The type of the KIA Bridge pier is two storied rigid frame steel structure as shown in Fig. 1. The lower column of the frame was designed to provide high ductility and load carrying capacity against the seismic force by filling concrete partially. It was already verified that wholly-concrete-filled steel columns have high ductility and load carrying capacity[1]. However, no study on the behavior of partially-concrete-filled steel columns is reported yet. For this reason, Public Works Research Institute(PWRI), Ministry of Construction, carryied out two directional loading test for model specimens of partially-concrete-filled steel columns in collaboration with KIA Co. Ltd. This paper presents the outline of the results of this loading test.

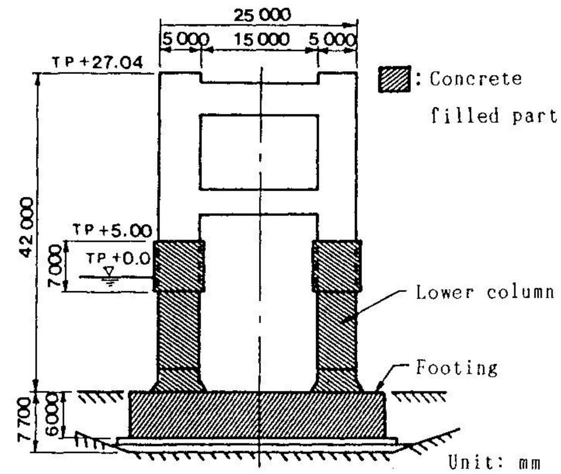


Fig. 1 Shape of Kansai International Airport Bridge Pier

2. Test method

2.1 Specimens

Three specimens which are almost 1/5 scale model of the lower column of the KIA Bridge pier, were fabricated using steel plates of grade SM41. The concrete was filled by up to half depth from the bottom for every specimen. They have same height of 350cm and same cross section of 90×90cm. Fig. 2 shows their dimensions. Lateral diaphragms were provided for every specimen in the same manner as those of the KIA Bridge pier in order to expect the composite action between the concrete and the steel column. A closed type lateral diaphragm was

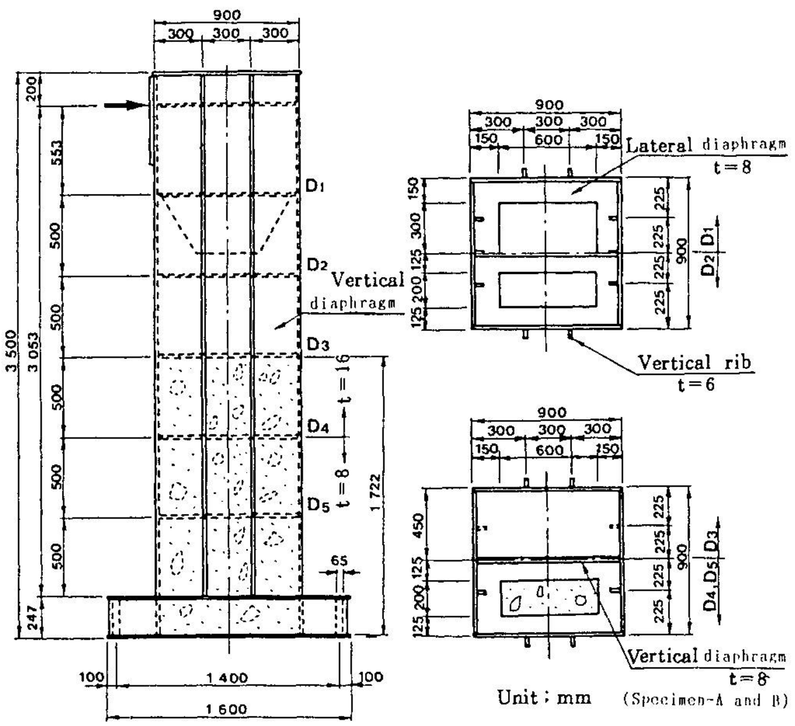


Fig. 2 Configuration of specimens

Table 1 Strength of steel (SM41)

Thickness(mm)	8	16
Yield point(kgf/cm²)	3,540	2,950
Tensile strength(kgf/cm²)	4,770	4,480

Table 2 Properties of concrete
(concrete cylinder: 10×20cm)

Specimen	A	B	C
Compression Strength(kgf/cm²)	267	260	253
Tensile Strength (kgf/cm²)	26.1	21.6	23.4
Young's modulus(×10^5 kgf/cm²)	2.27	2.17	2.14

placed at the boundary between concrete-filled part and non-concrete-filled part to impart the vertical load to the filled concrete, while hollow type lateral diaphragms were used to other parts. A vertical diaphragm was placed in Specimen-A and Specimen-B to expect the smooth stress flow at tansition zone of concrete-filled part and non-concrete-filled part.But Specimen-C does not have a vertical diaphragm. The concrete was so mixed that the compression strength(240kgf/cm²) of the concrete can be obtained. Table 1 and Table 2 show material properties of the concrete and the steel plate obtained from the material tests, respectively.

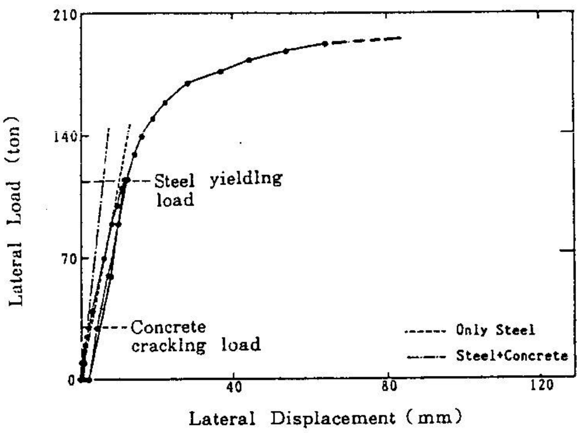
2.2 Loading method

The lower edge of specimens was fixed to the bed of the loading machine with bolts. The lateral load was statically applied to the point of 20cm lower from the upper edge under constant vertical load of 100ton for Specimen-A and Specimen-C, 500ton for Specimen-B. The vertical stress under the vertical load of 100ton is almost same as that in the KIA Bridge pier. In the loading test, the vertical and lateral displacement of specimens as well as strains in the steel plate of the steel column and the vertical diaphragm were measured. The strains inside the filled concrete was also measured by mould gages embeded inside the steel column.

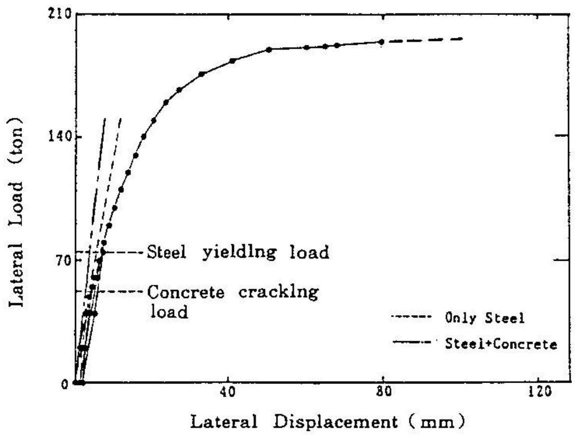
3. Test results

3.1 Load-displacement relationship

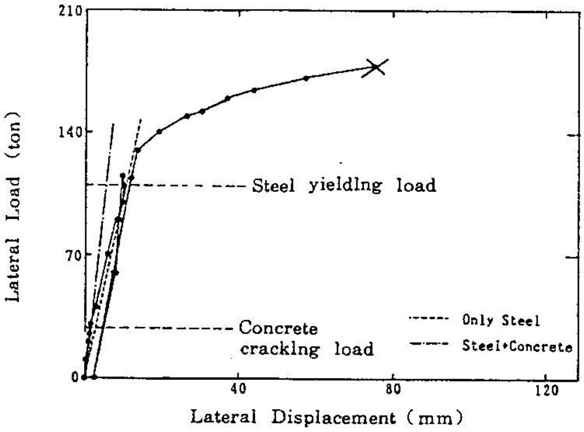
Fig. 3 (a)~(c) show the relationship between lateral load and lateral



(a) Specimen-A (Vertical Load; 100ton)



(b) Specimen-B (Vertical load; 500ton)



(c) Specimen-C (Vertical load; 100ton)

Fig. 3 Load-displacement relationship

displacement at the loading point for every specimen. In every specimen, a bending crack of the filled concrete firstly might have occured in the tension side of the lower edge according to the strain measured by mould gages, and subsequently the yielding and small local buckling of the steel column occured in the compression side of the lower edge. Maximum lateral load for every specimen was observed after these phenomena with high ductility. Two lines in Fig. 3 (a)~(c) which indicate the theoretical load-displacement relationship are based on the elastic theory. A dashed line is based on the assumption of the flexural rigidity of steel column only, while a dot-dashed line is based on the assumption of the combined flexural rigidity of the steel column and the filled concrete.

From these figures, it is noticed that the flexural rigidity of the filled concrete leads to the increase of the flexural rigidity of specimens particularly before the occurrence of the bending crack of the filled concrete, because measured displacements of every specimens increase almost along dot-dashed lines. Although the lateral loading for Specimen-A and Specimen-B were performed taking into account the capacity of the loading machine until their lateral displacements reach respectively about 5.3 and 11.3 times the yielding one, their failure points were not observed. On the other hand, Specimen-C lost its resistance due to the crack of the steel column in the tension side of the lower edge when the ratio of the lateral displacement to the yielding one was about 6.3.

3.2 Load carrying capacity

Table 3 lists the concrete cracking load and the steel yielding load at lower edge as well as the maximum load. Theoretical values are based on the the assumption of the strain distributions in cross section as shown in Table 4. The theoretical concrete cracking load(Pcc) was based on the assumption that the crack occurs when the stress in the filled concrete reaches the splitting tensile strength. The value Ptys expresses theoretical steel yielding load in the case that only steel column resists the lateral load, while the value Ptysc indicates theoretical steel yielding load in the case that both the steel column and the filled concrete resist the lateral load. The value Puh expresses theoretical maximum load based on the calculation method[2] proposed for wholly-concrete-filled steel columns, while the value Pup indicates theoretical maximum load corresponding to the full plastic resisting bending moment in which the effect of the strain hardening of the steel plates is not considered.

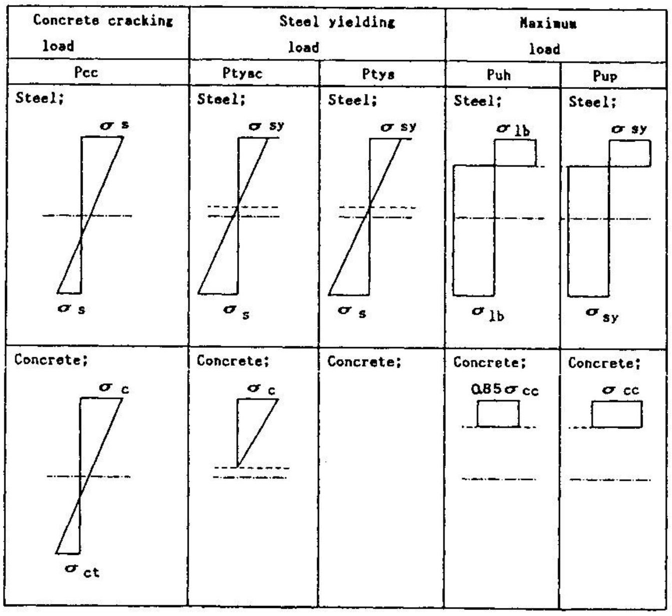
Table 3 Test results (concrete cracking load, steel yielding load and maximum load)

unit: tonf

Specimen			A	B	C
Vertical load			100	500	100
Concrete cracking load	Measured value Pcm		29.7	54.7	30.0
	Theoretical value Pcc		32.2	47.5	29.7
	Pcm/Pcc		0.92	1.15	1.01
Steel yielding load	Measured value Pym		114.6	74.7	109.8
	Theoretical value	Ptys	108.3	73.0	98.3
		Ptysc	141.2	137.3	128.9
	Pym/Ptys		1.06	1.02	1.12
	Pym/Ptysc		0.81	0.54	0.85
Maximum load	Measured value Pmm		192.6	194.5	184.6
	Theoretical value	Puh	169.4	168.9	150.1
		Pup	178.3	201.0	158.2
	Pmm/Puh		1.14	1.15	1.22
	Pmm/Pup		1.08	0.97	1.17

Test results for every specimen show that the measured concrete cracking load(Pcm) agrees well with the theoretical value, but the measured steel yielding load(Pym) is smaller than the value Ptysc and almost equal to the value Ptys. On the other hand, the measured maximum loads(Pmm) exceed the value Puh and almost agree with the value Pup. Thus, it is realized that partially-concrete-filled steel columns do not entirely behave as a composite structure in the elastic region, but do not lose its resistance abruptly after the steel yielding. Futhermore, it is understood that the load carrying capacity of partially-concrete-filled steel columns tends to become smaller by the effect of vertical load, because Pmm/Pup(=0.97) of Specimen-B is smaller than the ratio(=1.08) of Specimen-A and the ratio(=1.17) of Specimen-C.

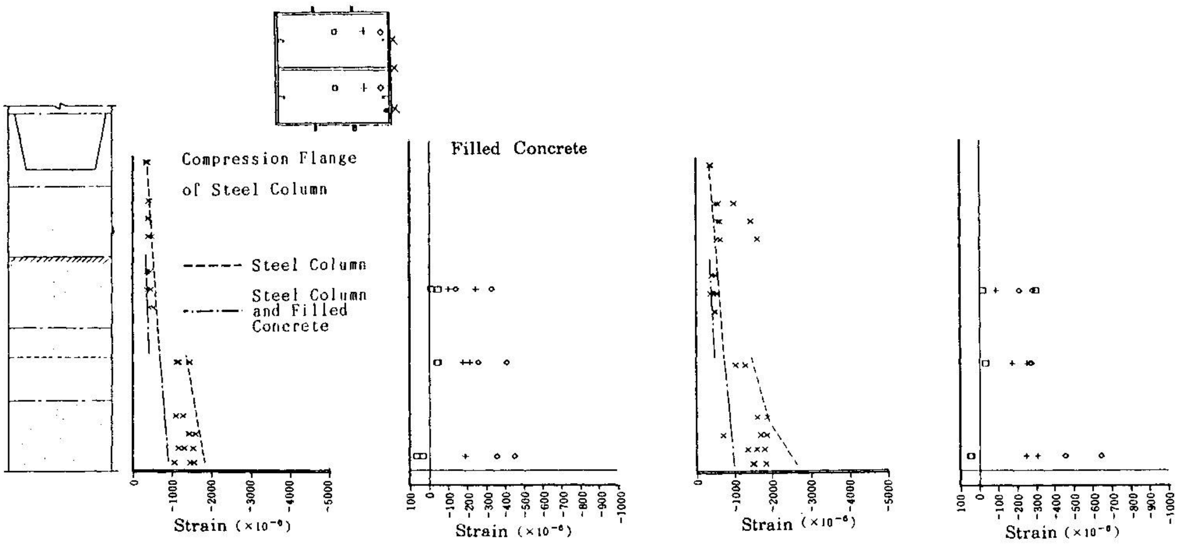
Table 4 Assumed stress distributions in cross section



σct: Tensile strength of concrete
σsy: Yield point of steel
σlb: Local buckling strength of steel
σcc: Compression strength of concrete

3.3 Characteristics of strain distribution

Fig. 4 (a) and (b) show the longitudinal strain distribution of the steel column and the filled concrete for Specimen-A and Specimen-C to understand the effect of the vertical diaphragm on the stress flow around the boundary between concrete-filled part and non



(a) Specimen-A (Lateral load: 114.5ton) (b) Specimen-C (Lateral load: 114.8ton)

Fig. 4 Longitudinal strain distribution

-concrete-filled part. In these figures, dashed lines are based on the assumption that only steel column resists the lateral load, while dot-dashed lines are based on the assumption that both steel column and the filled concrete resist the lateral load.

It is observed from these figures that longitudinal strains for Specimen-C exist widely around the boundary between concrete-filled part and non-concrete-filled part compared with that for Specimen-A. Thus, it is understood that the vertical diaphragm has the effect of making smooth stress flow around the boundary between concrete-filled part and non-concrete-filled part.

4. Concluding remarks

It was found that partially-concrete-filled steel columns do not exhibit substantial local buckling after the steel yielding, and have high load carrying capacity corresponding to almost full plastic resisting bending moment. It was also understood that the stress flow near the boundary between concrete-filled part and non-concrete -filled part become smooth by providing a vertical diaphragm.

[Reference]

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