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A CYCLIC FLEXURAL LOADING TEST OF COMPOSITE BRIDGE COLUMN

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ABSTRACT

The ductility capacity and composite action between steel tubes and concrete have been studied with using beam type test specimens reinforced by ordinal longitudinal reinforcement and steel tubes and by high strength strand laterally windings. From the test study, followings are concluded: 1)Maximum loading capacity can be predicted by the plane strain assumption based theory assuming perfect bond action between steel tubes and concrete. 2)Sufficient ductile performance is assured due to effective confinement through strand windings. 3)Existence of steel tube assures prevention of brittle failure even in dominant shear stress condition. 4)The modified superposed equation is proposed for loading capacity assessment of the practical ductility design.

KEYWORD

Composite bridge column, Steel tube, High strength strand winding, Composite action, Ductility capacity

INTRODUCTION

Composite bridge column with steel tubes combined with ordinal steel reinforcement, has been developed aiming at not only high speed construction but skilled labor savings as well especially for high columns with 40 to 100m height (Fig.1). This type column has significant features, i.e. several steel tubes placed in the section and high strength strand windings in stead of ordinal lateral reinforcement. It is expected that these features lead well structural behaviors especially from seismic design point of view. So far, authors have conducted preliminary experimental test for superior hysteresis characteristic demonstration of this new type structure with using column type specimen with single tube in it(T.Meta. et alt 1994). Nevertheless different composite action is considered between single tube and multiple tube structures.In the past, no useful experimental test has been also conducted with new type column such as the present structure particularly forcusing on hysteretsis characteristics. In addition, superposed ultimate loading capacity equation is available for a composite beam and column with single steel member in it(AIJ.1987), but not with multiple steel tubes in it. In these background, present study focuses on composite action and ductility performance of the proposed composite bridge column with conducting cyclic loading tests using beam type model specimens.

CYCLIC LOADING TEST AND MODEL SPECIMEN

Test parameters are tabulated in Tab.1. Test specimens consist of general type for No.1 to No.3 all of which have similar flexural loading capacity and shear stress dominant type for No.4 and No.5 with and without grout in steel tube. General type is designed on the basis of preliminary designed 40 to 80m height bridge columns, while shear stress dominant type with twice of flexural loading capacity of general type. 0.04% lateral reinforcement by high strength strand is commonly provided among all specimens, that is equivalent to 0.2% reinforcement for ordinal strength steel bar (specified as minimum requirement in the design

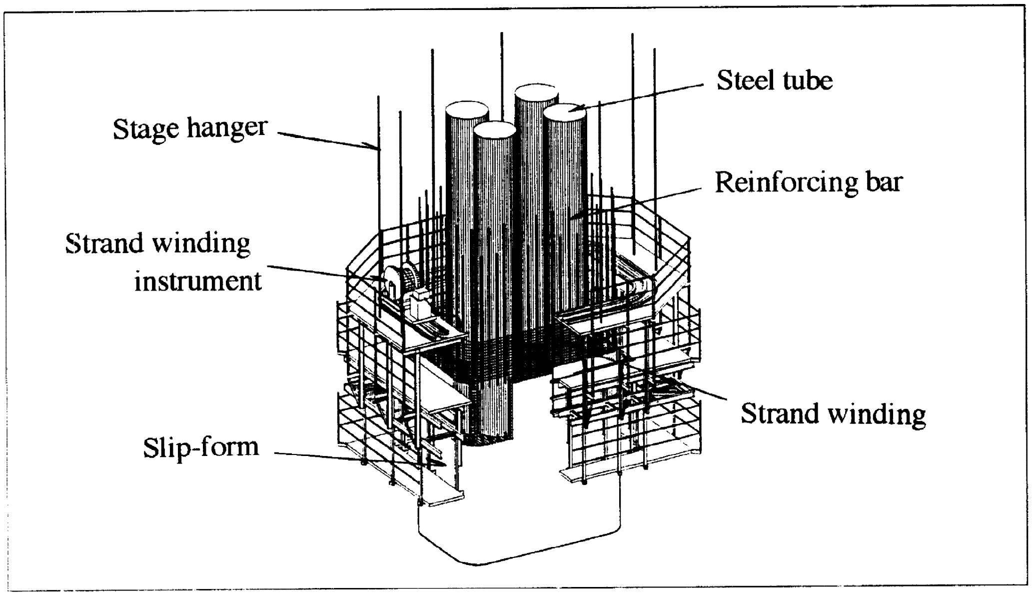

Fig.1 The new type bridge column for high speed construction

Tab.1 Test parameters

Specimen	Steel tube					Steel rebar			Lateral reinforcement
	Diameter (mm)	Thickness (mm)	Number of tubes	Reinforcement ratio =At/bh (%)	Inside grouting	Bar size	Number of rebars	Reinforcement ratio =Ar/bh (%)	High-strength strand 2-Φ 2.9mm @100mm
No.1	140	4.5	4	2.13	Yes	D16	12	0.66	
No.2	102	3.2	8	2.20	Yes	D16	12	0.66	
No.3	102	3.2	4	1.10	Yes	D22	12	1.29	
No.4	102	3.2	8	2.20	Yes	D25	20	2.82	
No.5	102	3.2	8	2.20	No	D25	20	2.82	

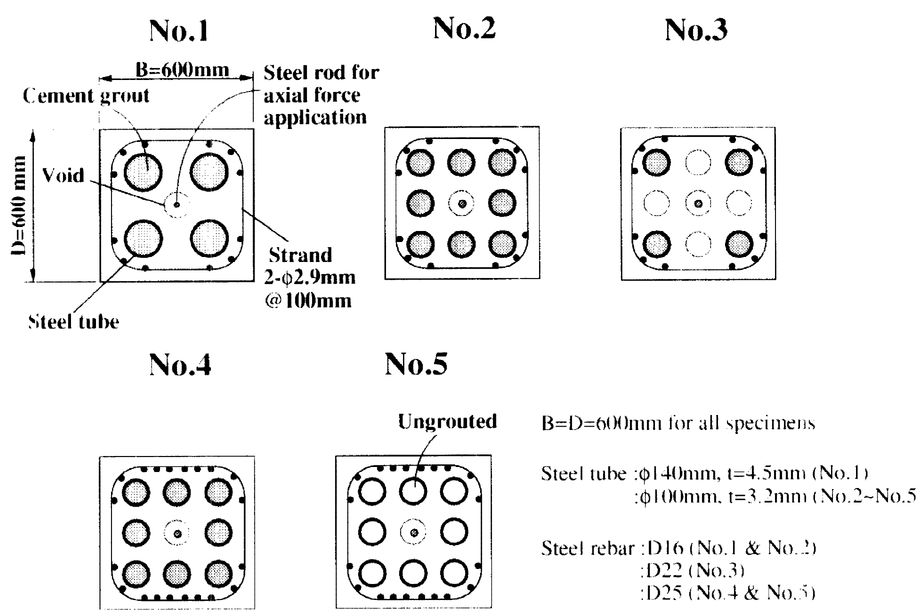

Fig.2 The cross section of test specimen

code(JSCE.1990) when considering tensile strength ratio between these materials.

Cross section of test specimen is illustrated in Fig.2. Test parameters are 1) dimension and layout of steel tubes for No.1 to No.3 and 2)steel tubes with or without grout in it. Inside of steel tube is generally grouted except No.5 specimen, because in the plastic hinge region of actual structure, concrete is required to be filled

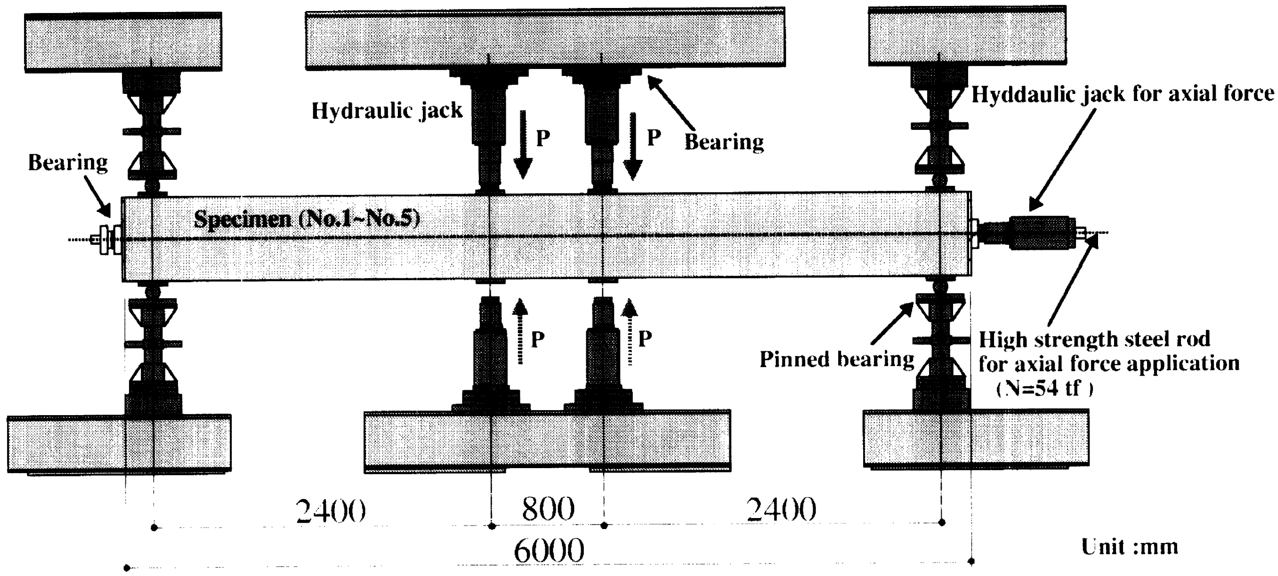

Fig.3 Flexual testing set up

Tab.2 Concrete mix proportion

W(kg)	C(kg)	W/C(%)	S/a(%)	Fine aggregate S(kg)	Coarse aggregate G(kg)
175	300	58.3	48.9	878	924

Air content : 4.5% Air entraining and high-range water reducing agent : C× 3.0%
Additive for increasing viscocity : 0.51 kg/m^3 Maximun size of coarse aggregate : 13mm

Tab.3 Material properties for concrete Unit : kgf/cm^2

Specimen	No.1	No.2	No.3	No.4	No.5
Conpressive strength	367	375	343	388	3818
Tensil strength	24.1	27.0	33.0	23.3	23.3
Elastic modulus	2.56×10^5	2.29×10^5	2.56×10^5	2.30×10^5	2.30×10^5
Tested Age (day)	28	42	35	70	70

Tab.4 Material properties for steel rebar, steel tube and strand Unit : kgf/cm^2

	Steel rebar			Steel tube		Strand
	D16	D22	D25	Φ140	Φ102	2-Φ2.9mm
Yield strength	3830	3930	3900	2970	3740	19100
Ultimate strength	5980	5910	5790	4250	4600	20590

at inside of steel tubes with considering buckling prevention. Steel rebar is welded to the end plate, but steel tubes not because of potential bond slip acceptance.

Four point flexural loading set up is illustrated in Fig.3. With constant axial stress of 15kgf/cm^2 , two cyclic loadings are applied in each drift angle range of R=1/200, 1/100,.........5/100 and finally monotonic loading up to R=8/100.

As for specimen production, because of difficulty of vibrating instrument utilization, highly workable concrete with specified surfactant and water reducing admixture was poured into complicated reinforcement layout section including multiple steel tubes. Concrete mix proportioning is tabulated in Tab.2 and material properties are in Tab.3. Similarly material test results are provided in Tab.4 for steel rebar, steel tube and strand.

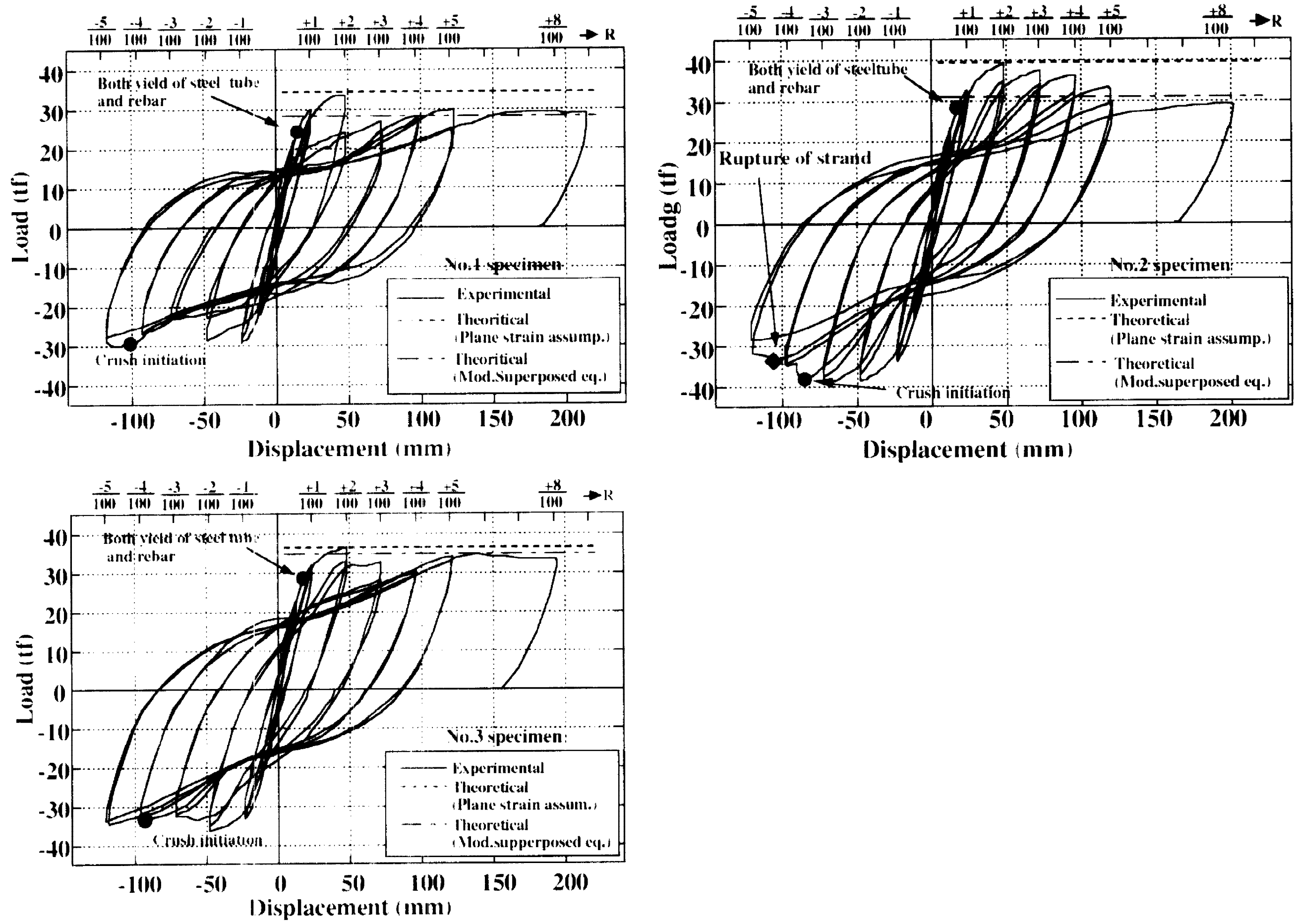

Fig.4 Load-displacement relationship(specimen No.1~No.3)

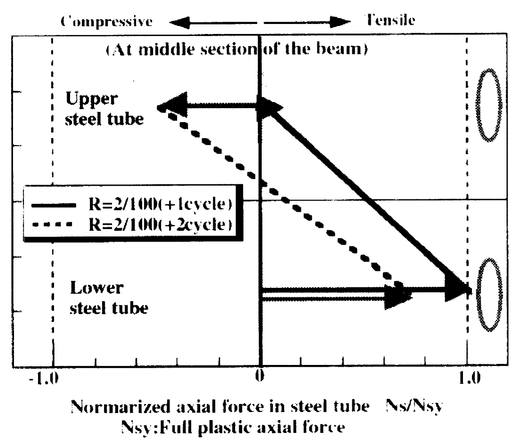

Fig.5 Axial force variation uo to bond slippage (No.1)

HYSTERESIS CHARACTERISTICS

Test results for No.1 to No.3 specimens are illustrated in Fig.4. All the specimens have maximum loading capacity at 1st loading cycle of R=2/100 which is approximately equal to the theoretical value as shown in the figure. Here the theoretical value is provided based on plane strain assumption with assuming steel tube as longitudinal reinforcement and perfect bond with concrete. Some reduction in loading capacity is observed in the 2nd loading cycle. Fig.5 represents variation of axial force to the steel tube between 1st and 2nd loading cycle, where it is calculated based on the experimentally obtained strain distribution and assumed stress-strain hysteresis. In the 1st cycle tensile tube approximately attains full plastic range, while in the 2nd cycle it reduces down to 70% of that and so compressive tube because of bond slip occurrence between concrete and steel tubes. This bond degradation dependent phenomena seems to correspond with loading capacity difference between 1st and 2nd cycle. Also shown in Fig.6 is strain distribution for representative No.1 specimen. In the phase of R=1/200 when rebar and steel tube are both in elastic, it seems to remain linear, while in that of R=2/100, it does not.

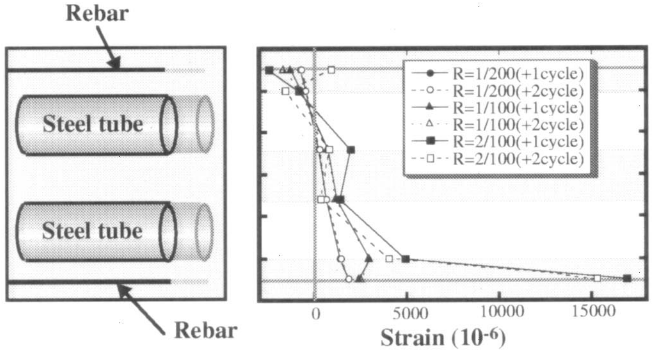

Fig.6 Strain distribution (Specimen No.1)

In the larger displacement range, the loading capacity increases but does not reach the experienced maximum value of that. Above reduction in loading capacity is largest in the No.1 specimen which has largest ratio of cross section area to perimeter of steel tube.

All specimens have 74 to 86% loading capacity of max that even in the ultimate displacement range of R=8/100. In the No.2 specimen with less recovery in loading capacity, rupture of strand leads loss of confinement to concrete and rebar buckling. In the No.3 specimen with less steel tubes, post maximum load reduction is less and its recovery in the larger displacement range is larger, because less steel tubes affects less load reduction due to bond degradation. These loading capacites in the ultimate displacement range tend to reach 2nd theoretical value shown as the modified superposed strength which will be proposed later. Final failure where significant difference is not observed between these three specimens, is represented in Photo.1.

Load-displacement relationships for shear stress dominant type specimen are illustrated in Fig.7. No.4 specimen with grouted tube provides closer max. load with the plane strain assumption based theoretical value, while No.5 specimen does not. Because of larger amount of rebar, steel-tube-bond-degradation dependent load reduction is less compared with general type specimens No.1 to No.3. In both specimens, strand ruptured in the compression side of cross section just outside of central pure flexure zone. Loss of confinement leads less load capacity, however No.4 with grouted steel tubes , leads still load capacity increase in the larger displacement range. Existence of steel tubes seems to assure prevention of shear failure due to

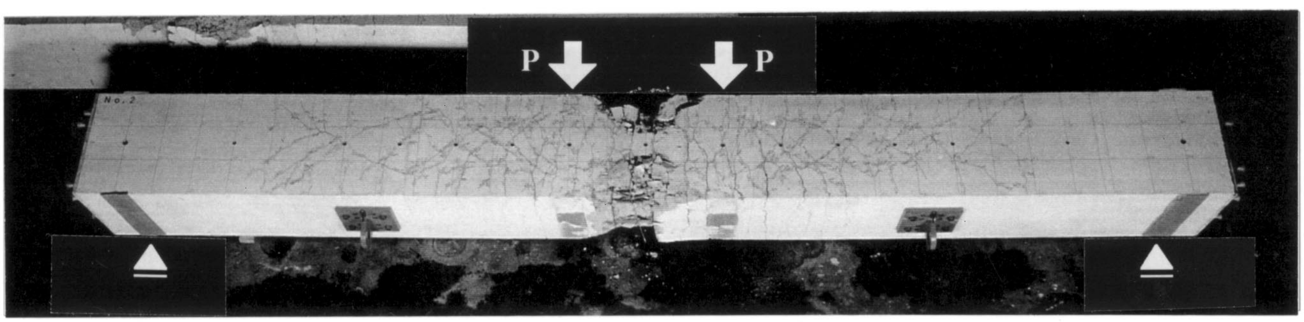

Photo 1 (Specimen No.2)

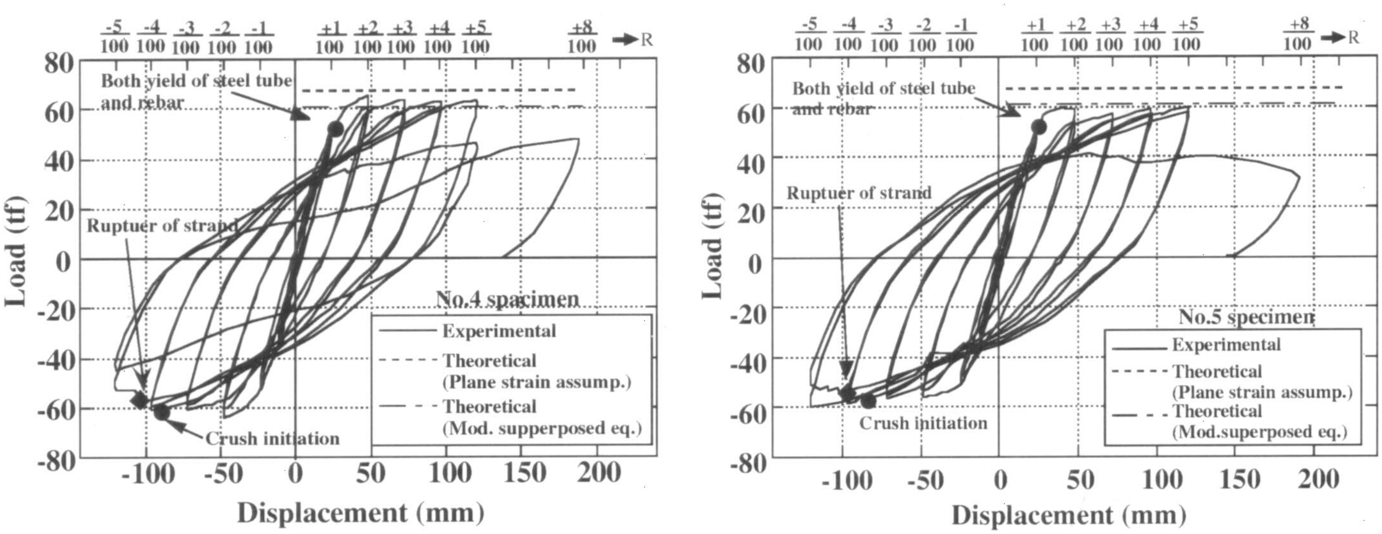

Fig.7 Load-displacement relationship (speciman No.4, No.5)

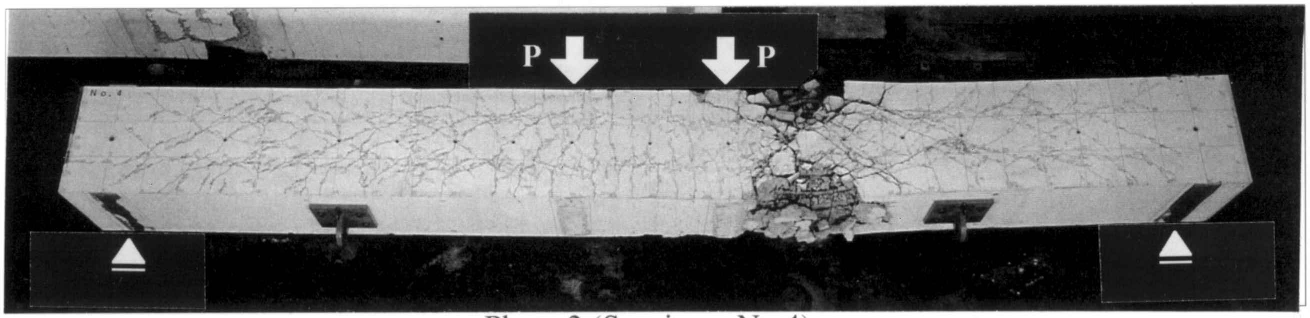

Photo.2 (Specimen No.4)

loss of shear resistant mechanism expected in the ordinal reinforced concrete member. Photo.2 represents final failure pattern.

LOADING AND DUCTILITY CAPACITIES

Experimental and calculated yield and maximum loading and ductility capacities are tabulated in Tab.5. Experimental yielding load of rebar is slightly less than plane strain based theoretical one, because at around that loading range, tensile stress in steel tube is redistributed onto rebar with bond slippage occurrence. That load of steel tube, which is defined as outer fiber yielding, is generally 10% less than theoretical value. No significant difference is observed in rebar yielding load between No.4 and No.5 specimens, but is in steel tube yielding load. Axial and circumferential strains at tensile tube are plotted to displacement in Fig.8 for No.4 and No.5 specimen. In No.4 specimen with grouted steel tube, as the increase in tensile axial strain, so does in compressive circumferential strain. However in No.5 specimen without grouting, strain decrease is observed

Tab.5 Loading and ductility capacity

Unit : tf , mm

Specimen	Yielding load of steel rebar			Yielding load of steel tube			Maximum loading capacity			Yield displacement δy	Ultimate displacement δ_u	Ductility capacity $\mu = \frac{\delta u}{\delta y}$
	Exp.	Theo.	Exp./Theo.	Exp.	Theo.	Exp./Theo.	Exp.	Theo.	Exp./Theo.			
No.1	23.9	27.6	0.87	23.2	24.3	0.95	33.4	34.3	0.97	16.0 (18.1)	>207	>12.9 (>11.4)
No.2	27.6	30.3	0.91	26.4	28.7	0.92	39.1	39.4	0.99	17.5 (20.4)	153	8.8 (7.5)
No.3	27.3	29.4	0.93	26.4	28.8	0.92	36.5	36.3	1.01	16.9 (20.1)	>191	>11.3 (>9.5)
No.4	50.6	54.0	0.94	48.9	54.7	0.89	65.2	67.4	0.97	23.1 (28.0)	96	4.2 (3.4)
No.5	50.9	54.0	0.94	54.4	54.7	0.99	59.3	67.4	0.88	26.7	120	4.5

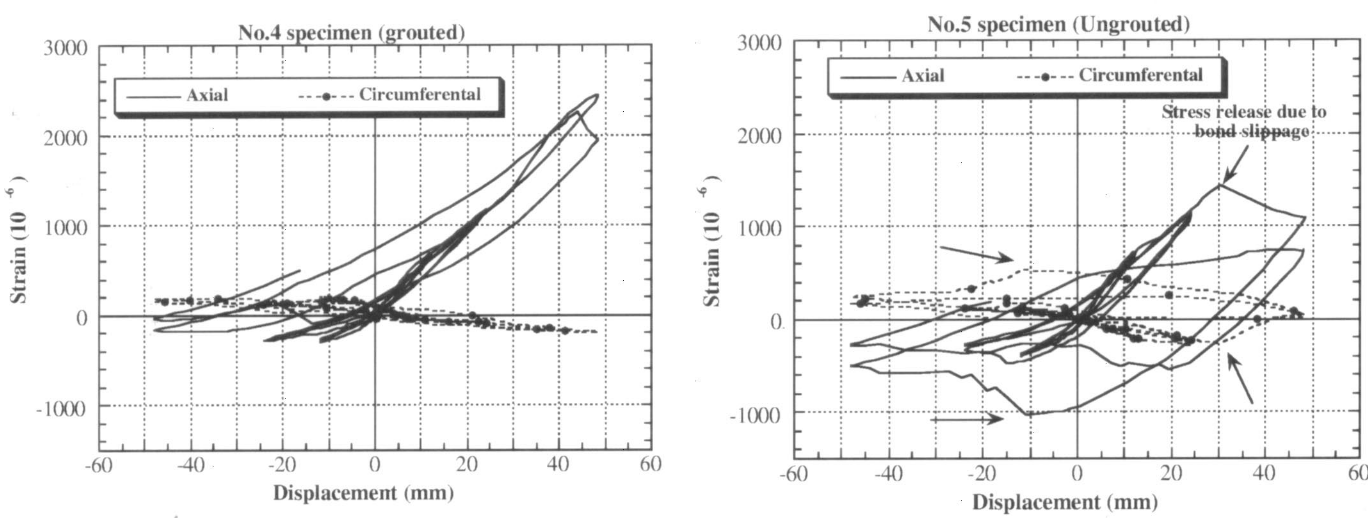

Fig.8 Axial and circumferential strain at tensil tube

in larger than 30mm ranges. That is because longitudinal extension encourages larger radial contraction in ungrouted steel tube and as the result, bond degradation is enhansted. This fact leads delay of steel tube yielding and less maximum loading capacity attained compared with theoretical value.

When comparing maximum loading capacity with plane strain based theoretical value, good approximation can be obtained for No.1 through No.4 specimens all with steel tube grouted except ungrouted No.5 specimen. In other words, in case of steel tube grouted, maximum loading capacity can be calculated on the basis of plane strain assumption.

At latter part of Tab.5, obtained yielding and ultimate displacement and ductility capacity are provided. The yielding displacement is defined as that when both rebar and steel tube yieldings are initiated, while ultimate one as that when loading capacity descend down to 80% of maximum and ductility capacity is defined as the ratio of former to latter. In the bottom part at each row, those values with yielding displacement defined as that when both rebar and steel tube at middle position yield. Among general type specimens, even No.2, least ductile specimen can possess 8.8(7.5) for ductility capacity. On the other hand, in case of shear stress dominant specimens, less ductility capacity is obtained due to strand rupture at shear span.

DESIGN PROPOSAL FOR FLEXURAL LOADING CAPACITY

Flexural loading capacity in the ultimate displacement range can be predicted in superposed equation, which is proposed as addition of that due to rebar-effective concrete section and that due to steel tubes section as shown in Fig.9. Latter part is provided as integrated full plastic axial force multiplied by arm length between middle position of steel tube and central axis of cross section. This equation should be identically proposed as modified superposed equation since past superposed equation(AIJ, 1987) was proposed for beams and columns with single steel member in cross section.

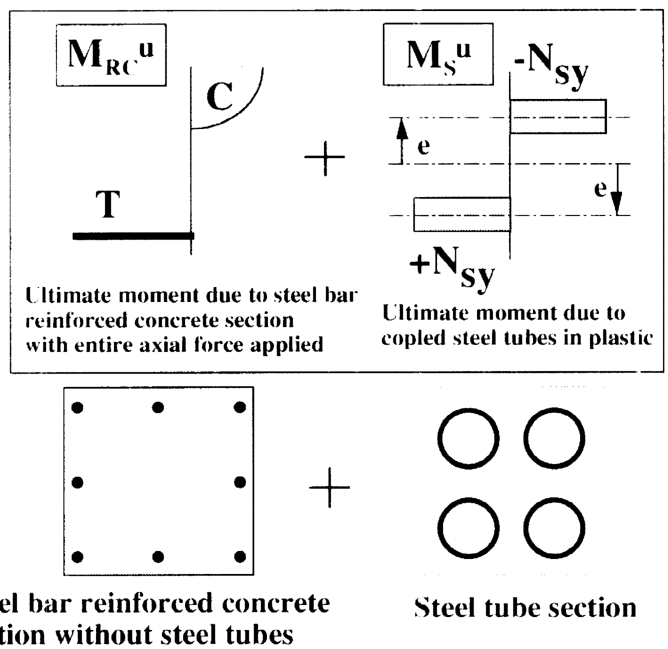

Fig.9 Idealized model of modified superposed equations

$$M_{S+RC}^{u}=M_S^{u}+M_{RC}^{u}$$

where,

M_{S+RC}^{u} : flexural loading capacity for entire section

M_S^{u} : flexural loading capacity for steel tubes (ΣN_{sy} e)

N_{sy}: full tensile or compressive plastic axial force

e: arm length between middle position of steel tube and central axis of cross section

M_{RC}^{u} : flexural loading capacity for rebar-effective concrete section

Good approximation can be provided between predicted and experimental values already as shown in Fig.4 and Fig.7. This proposed equation can be conservatively utilized for ultimate loading capacity assessment especially in the ductility design.

CONCLUDING REMARKS

Based on experimental tests, followings are concluded.
From the test results of general type specimens designed on the basis of typical bridge columns,
1) Maximum loading capacity can be approximately predicted by the plane assumption based theory assuming steel tube as one of longitudinal rebars.
2) Bond degradation of steel tubes in load reversal enhances reduction in loading capacity especially in the post maximum load range.
3) Confinement action through high strength strand windings assures significant ductility capacity, where its quantity is provided as code specified minimum reinforcement assuming full strength action of the material.
4) The modified superposed equation for ultimate loading capacity assessment is proposed for ductility design practice.

And from the test results of shear stress dominant type specimens,
5) If grouted in steel tube, maximum loading capacity can be also approximately predicted by the plane strain assumption based theory.
6) Existence of steel tube practically assures prevention of brittle failure even in loss of shear resistance mechanism provided by concrete and lateral reinforcement.

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REFERENCES

T. Meta, K. Yamagata, H.Ohuchi, Y.Inokuma, K.Irisawa, Y.Kobatake 1994
A Horizontal Loading Test of Steel Tubes - Reinforced Concrete Composite Bridge Column - Bridge High Piers by an InnovativeConstruction Hybrid-Slip Form Method,*Seismic Design and Retrofitting of Reinforced Concrete Bridges, Proc. of 2nd Intl. Workshop,New Zealand*,pp.387-pp.399
AIJ: *Standard for Structural Calculation of Steel Reinforced Concrete Structures*, 1987 Revised Version
JSCE: *Design Standard for Reinforced Concrete Structures*, 1990