Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 13 (1988)

Artikel: Seismic behavior of joint panels in mixed systems

Autor: Yamanouchi, Hiroyuki / Izaki, Yukio / Nishiyama, Isao

DOI: https://doi.org/10.5169/seals-13079

Seismic Behavior of Joint Panels in Mixed Systems

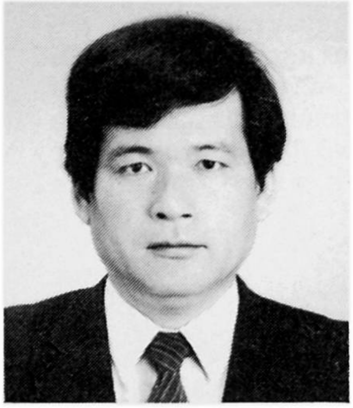
Comportement sismique des noeuds dans les systèmes de structure mixtes

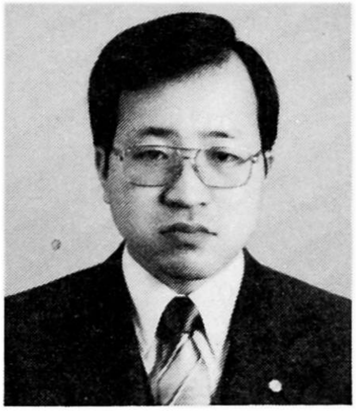
Verhalten von Rahmenknoten eines Mischbausystems unter Erdbebenbelastung

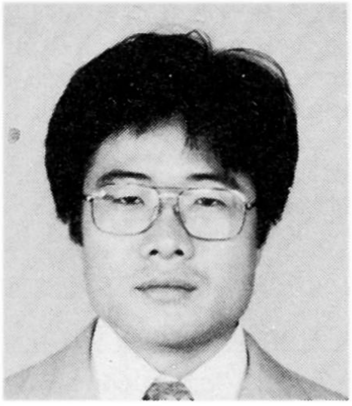
Hiroyuki YAMANOUCHI
Dr.-Eng.
Building Res. Inst.
Tsukuba, Japan

Yukio IZAKI
Structural Engineer
Sato Kogyo Co., LTD.
Atsugi, Japan

Isao NISHIYAMA
Dr.-Eng.
Building Res. Inst.
Tsukuba, Japan







Hiroyuki Yamanouchi, born in 1944, received his engi. degree and his doctrate from the University of Tokyo. Since 1972, he has been working in the Building Res. Inst., currently the Head of the Structural Dynamics Division. His major field is in earthquake engineering of building structures.

Yukio Izaki, born in 1951, received his masters degree of engineering from Nagoya Institute of Technology. Since 1976, he has been working at the Engineering Research Institute of Sato Kogyo Co., LTD. He, currently Chief, has involved mainly in seismic research on reinforced concrete structures.

Isao Nishiyama, born in 1953, received his engineering degree and his doctorate from the University of Tokyo. Since 1981, he has been working in the Building Res. Inst. Currently, he is Senior Research Engineer. His major field is in earthquake engineering of steel building structures.

SUMMARY
A new mixed structural system comprised of reinforced concrete columns and structural steel girders is proposed. In order to apply this mixed system to actual structures, a structural evaluation of "joint panels in mixed system" and a quantitative assessment compared to other structural systems were carried out. The investigation results show the advantages of the proposed mixed system for practical application.

RÉSUMÉ
Un nouveau système structural mixte avec des poteaux en béton armé et des poutres en acier est proposé. Une évaluation structurale ainsi qu'une estimation quantitative de l'ensemble ont été déterminées. Les résultats obtenus reflètent le bon comportement du système et font ressortir certains avantages par rapport aux autres systèmes.

ZUSAMMENFASSUNG
Ein neues Mischbausystem aus Stahlbetonstützen und Stahlträgern wird vorgestellt. Zur Abschätzung der Anwendungsvorteile dieses Mischbausystems in Prototyp-Bauwerken wurden konstruktive Untersuchungen und quantitative Auswertungen zum Vergleich mit anderen Bausystemen durchgeführt. Die Untersuchungsergebnisse zeigen die Vorteile des vorgestellten Systems für praktische Anwendungen.

1. INTRODUCTION

Although steel structures have their own advantages in weight, ductility, span length, term of the construction contract etc., compared with reinforced concrete structures, they are not always more competitive in the total construction cost, since the material of reinforced concrete is significantly cheaper than steel. Introduced in this paper is a challenging mixed structural system comprised of reinforced concrete columns and structural steel girders which utilizes both, the advantages of steel and reinforced concrete. In order to apply this mixed system to actual structures, a structural performance evaluation and a quantitative assessment compared to other structural systems are discussed in the following.

The first item discussed in this paper is the structural performance evaluation of the steel girder to reinforced concrete column joint panels. Results from half scale tests on perpendicular girder + column joint sub-assemblages are presented and discussed. The second one is to assess the advantages of the mixed structural system quantitatively and to find out the most effective practical applications, such as the optimal span length. For this purpose, design simulations and comparisons were carried out on a prototype 3x3 bay, three story build-ing, designed in steel, reinforced concrete and as a mixed structural system.

2. CYCLIC LOADING TESTS ON GIRDER-TO-COLUMN SUB-ASSEMBLAGES

2.1 Joint Panel Details

Typical joint panel details are shown in Fig. 1. Depicted are the details of the full-flange-type panel, in which two perpendicular structural steel I-girders penetrate the reinforced concrete column, see Fig. 1(a), with the main reinforcing bars (rebars) in the column corners passing through the panel zone, while center line rebars are welded to the top and bottom of the steel girders. Fig. 1(b) shows the details of the tapered-flange-type panels, in which girder flanges are tapered by cutting. The taper angle measures 45 degrees. These cut girder flanges assure reliable concrete casting in the panel zone.

2.2 Test Specimens And Loading

Five test specimens of one half scale girder-to-column sub-assemblages with short transverse girders were investigated. The ratio of the strength of columns to that of girders and the amount of the flange cutting of the steel girder in the panel zone were selected as test parameters. The shape of the specimens is shown in Fig. 2. The mechanical properties of steel, rebar and concrete are shown in Table 1. The specimens, whose columns are weaker than girders, are denoted by "A" and the specimens with strong column and weak girders are affixed with "B". The specimens with full-flange-type panels are denoted by "1", those with tapered-flange-type panels whose taper started from the rebar location are denoted by "2" and the specimen with the taper starting at the column face is denoted by "3". (see Fig. 2)

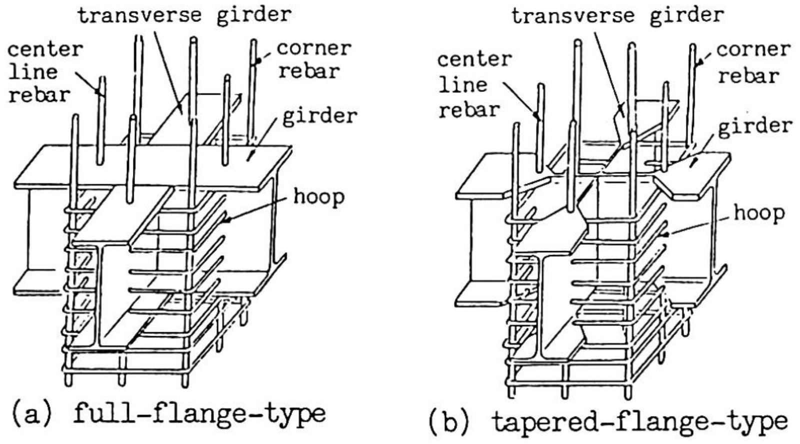


Fig. 1 Details of joint panels

The both ends of the girder were loaded inversely by two actuators simulating seismic forces with a constant axial column load of 620kN, as shown in Fig. 3.

Table 1 Mechanical properties

Spec-imen	Steel	σ_y	σ_t	Reinforcing bar size	σ_y	σ_t	concrete σ_c
A-1	flange	31.0	45.8	D16	35.6	51.8	2.12
	web	33.6	47.1	D13	37.7	55.4	
A-2	flange	30.1	43.6	D16	35.0	52.2	2.17
	web	33.8	45.2	D13	35.9	50.6	
B-1	flange	34.7	50.3	D16	35.6	51.8	2.10
	web	37.5	51.5	D13	37.7	55.4	
B-2	flange	33.1	44.8	D16	35.0	52.2	2.19
	web	38.6	47.2	D13	35.9	50.6	
B-3	flange	33.1	44.8	D16	35.0	52.2	2.15
	web	38.6	47.2	D13	35.9	50.6	

(unit:MPa)

2.3 Test Results

General Behavior:- First, flexural cracks were observed in the columns followed by subsequent diagonal cracking in the panel zone. Then, the shear yielding of the web plate of the steel girder in the panel zone occurred. Finally, in case of the specimens with full-flange-type panels ("1"), the center line rebars fractured close to the weld point on the top of the girder flange because of poor workmanship of the weld execution. This fracture brought about the spalling of the cover concrete in the panel zone. On the other hand, in case of the specimens with tapered-flange-type panels, the center line rebars did not fracture, forces were transmitted properly from steel girder to reinforced concrete column and the yielding of the tensile reinforcement occurred. Only minor spalling of the concrete cover was observed.

Hysteresis Behavior:- The hysteresis curves of the column shear force (Qc) vs. story drift angle (R) relationships are shown in Fig. 3. Each specimen showed quite stable loops. The maximum strength has the tendency to reduce as the amount of the flange cutting of the steel girder in the panel zone increases. Severe deterioration of load carrying capacity was observed in specimens with full-flange-type panels (A-1 & B-1) at the drift angle of 0.05 radian, where the severe spalling of cover concrete was observed in the panel zone because of the fracture of center line rebars fractured.

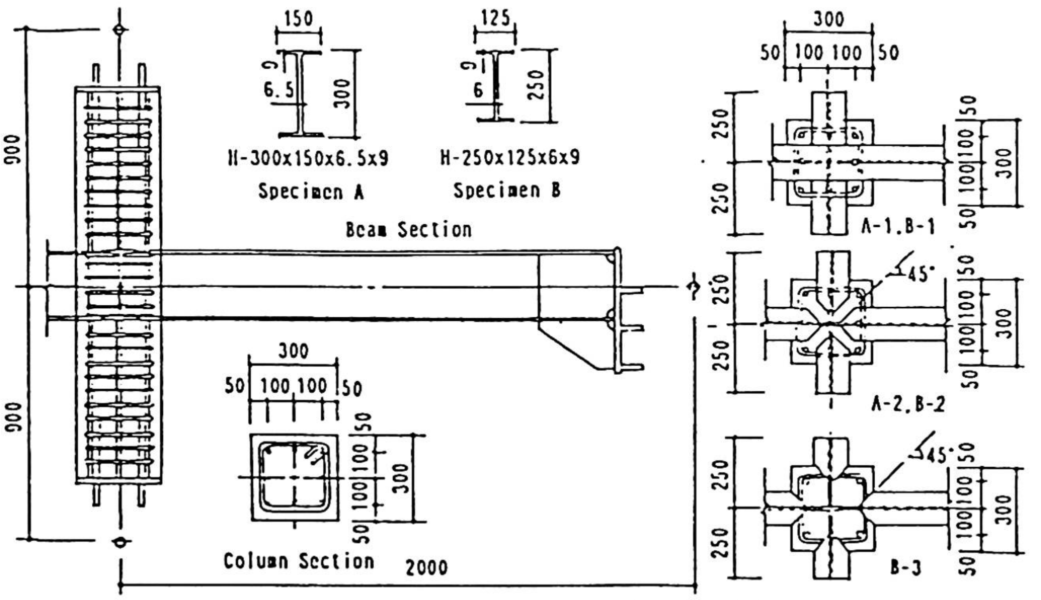


Fig. 2 Shape of specimens

Maximum Strength and Crack Initiation Strength:- The experimental and the calculated strengths of each specimen are summarized in Table 2. The experimental maximum strength to the calculated strength ratios are all larger than unity. This means that even tapered-flange-type joints well satisfy the required maximum strength criteria (eq.(1)) recommended by SRC Standard of AIJ [1],

$$jMu = cVe\ (\ jFs \cdot j\delta + rPw \cdot w\sigma y\ ) + 1.2\ sV \cdot sw\sigma y\ /\ \sqrt{3} \tag{1}$$

where, cVe=(b/2)·dc·db=effective panel concrete volume(mm3), b=width of column(mm), dc(db)=distance from centroid of compression steel to that of tension in column (girder)(mm), jFs=concrete shear strength which is smaller value of 0.12Fc or 1.76+(3.6Fc/100) (MPa), Fc=nominal design strength of concrete(MPa), $j\delta$=coefficient dependent on the joint shape (cross-shaped=3), rPw=aw/(b·x) =reinforcement ratio of hoops < 0.6%, aw=2 times area of the hoop rebar(mm2), x=spacing between hoops(mm), $w\sigma y$=tensile yield strength of hoops(MPa),

Table 2 Experimental and calculated strengths

Spec-imen	Maximum strength (kN)			Diagonal crack strength in panel zone (kN)		
	Exp	Cal	Exp/Cal	Exp	Cal	Exp/Cal
A-1	125.0	96.9	1.29	87.3	32.6	2.68
A-2	105.6	97.5	1.08	66.6	33.4	1.99
B-1	130.1	81.2	1.60	75.3	25.5	2.95
B-2	92.3	83.2	1.11	65.8	26.5	2.49
B-3	85.4	82.6	1.03	51.4	26.1	1.97

*1 Strengths in the above table are shown as column shear force.
*2 Maximum strength is calculated from eq.(1).
*3 Panel shear crack strength is estimated as Qcra= $\tau \cdot (b \cdot dc + 15tw \cdot dc)$, $\tau = 0.1Fc$.

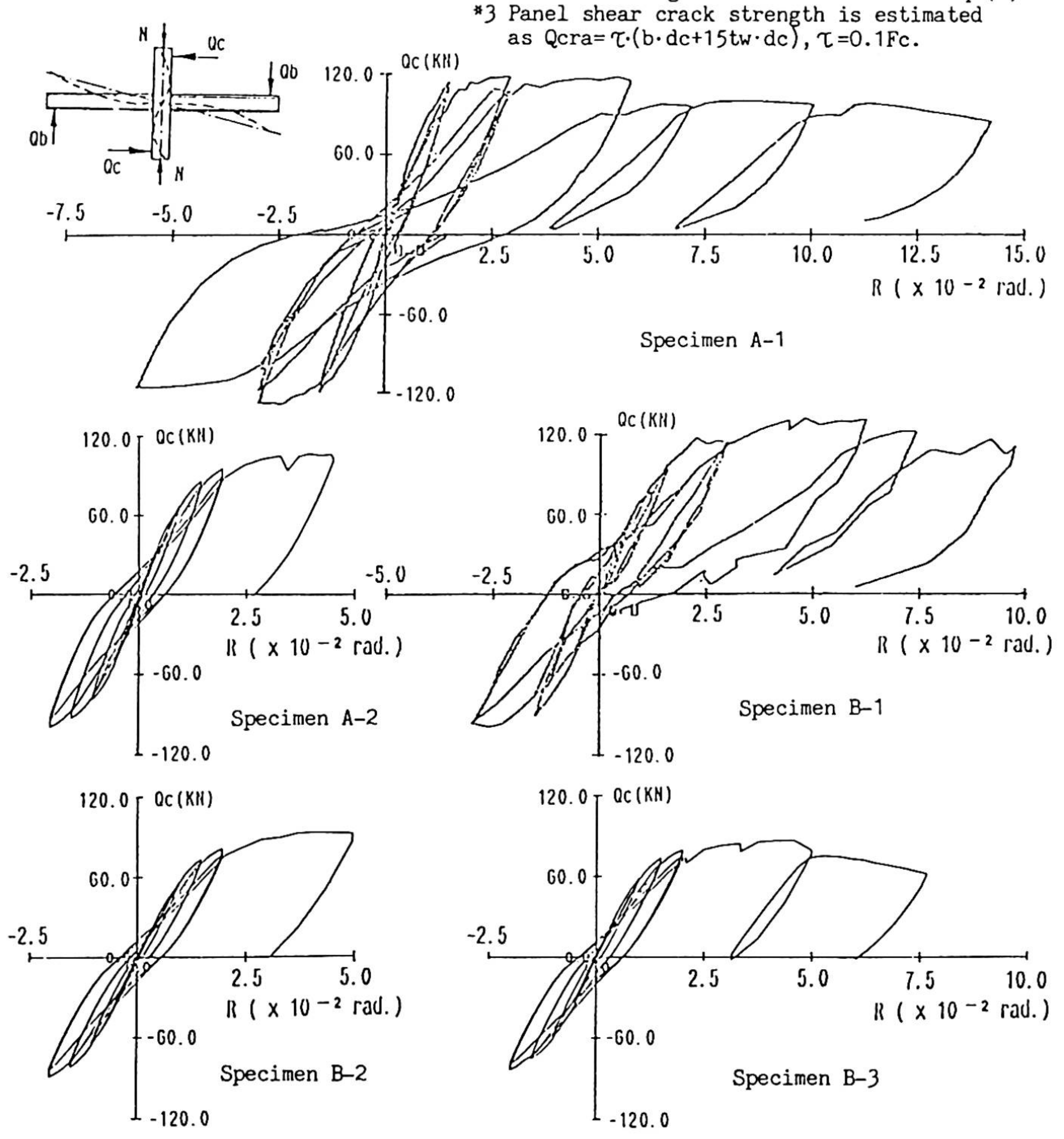


Fig. 3 Hysteresis curves (Qc-R relationships)

sV=db·dc·tw=effective panel steel volume(mm3), tw=thickness of steel web panel(mm) and swσy=tensile yield strength of the structural steel(MPa).

As for the crack initiation strength of the joint panels, the test results are two or three times higher than the calculated ones. The shear stress (τ) at the onset of diagonal cracking is taken as 0.1Fc in Ref.[1]. (see Table 2) Therefore, the experiments show that the crack initiation shear stress might be considered to be 0.3Fc in the case of full-flange-type panels and 0.2Fc in the case of tapered-flange-type panels.

Table 3 Design conditions

System	moment resisting frame (mixed, steel, reinforced concrete)
Dimen-sions	3x3 bay, 3 stories clear story height: 2.9m longitudinal span: 8,10,12,14m transverse span: 6m
Dead Load	floor mixed,steel metal deck + RC slab t=107.5mm reinforced concrete RC slab t=150mm miscellaneous interior/exterior wall, stairs, pent house and parapet are not considered
Live Load	roof floor 0.59kN/m2 2,3 floor 1.27kN/m2 (for seismic design)
Mate-rials	steel SS41(Japan Industrial Standard) rebar SD30(JIS) for slab SD35(JIS) for column concrete Fc=2.06MPa

3. DESIGN SIMULATION

3.1 Designed Buildings

Design simulations were conducted on a prototype 3x3 bay, three story building. This structure, shown in Fig. 4, was designed with mixed, steel and reinforced concrete structural systems. The span length in the longitudinal direction of the prototype, 8m, was changed to 10m, 12m and 14m. For these three additional model struc-tures, the same design simulations as that done for the prototype model were carried out to examine the effect of span length. The height of the story was set at 2.90m as the clear story height, i.e. the distance from the top of the floor slab to the bottom of the upper floor girder. All assumed design conditions are summarized in Table 3.

3.2 Results Of Simulation

Table 4 summarizes the various characteristics of the designed structures; the story height, the story drift, the total weight and the construction cost. The ratios of the calculated panel strengths by eq.(1) to the required panel moments are listed in Table 5.

Girder Height and Story Height:- The depth of the girders and the story height are almost the same in buildings designed with mixed and steel systems. The depth of the girders designed for the reinforced concrete system is not so different from those designed with mixed and steel systems in the case of 10m or less span length. However, as the span length becomes larger than 12m, the required girder depth significantly increases in the reinforced concrete system.

Story Stiffness:- The story drift angles of designed buildings subjected to seismic force of 20% of the building weight are summarized in Table 4. The inverse of the story drift angle of the mixed system is 70% of that of the reinforced concrete system and about 200% of that of the steel system.

Weight of Designed Buildings:- The weight per unit floor area is listed in Table 4, where the weight of interior and exterior walls, stairs etc. are not considered. The unit weight of the mixed system, 9.64-10.04kN/m2, is rather light compared to that of the reinforced concrete system, 13.02-16.95kN/m2, and is nearly equal to the unit weight of the steel system, 8.89-9.07kN/m2.

Construction Cost:- The construction cost per unit floor area are summarized in Table 4, where the following unit costs are used: concrete=12,300yen/m3, formwork=3,600yen/m2, rebar=8.57yen/N, structural steel=18.9yen/N, metal deck=17.3yen/N and fire protective covers=2,600yen/m2. The unit cost of the

Table 4 Summarized characteristics of designed buildings

Item	System / Span length (m)	Mixed 8	Mixed 10	Mixed 12	Mixed 14	Steel 8	Steel 10	Steel 12	Steel 14	Reinforced concrete 8	Reinforced concrete 10	Reinforced concrete 12	Reinforced concrete 14
Story Height	3rd	3.50	3.70	3.70	3.70	3.60	3.70	3.70	3.80	3.60	3.75	4.00	4.40
(Girder Depth)		(0.40)	(0.60)	(0.58)	(0.59)	(0.50)	(0.60)	(0.58)	(0.69)	(0.70)	(0.85)	(1.10)	(1.50)
	2nd	3.55	3.70	3.70	3.70	3.60	3.70	3.70	3.80	3.65	3.75	4.00	4.40
		(0.45)	(0.60)	(0.58)	(0.59)	(0.50)	(0.60)	(0.58)	(0.69)	(0.75)	(0.85)	(1.10)	(1.50)
(m)	1st	3.55	3.70	3.70	3.70	3.60	3.70	3.70	3.80	3.70	3.75	4.00	4.40
		(0.45)	(0.60)	(0.58)	(0.59)	(0.50)	(0.60)	(0.58)	(0.69)	(0.80)	(0.85)	(1.10)	(1.50)
Story Drift	3rd	1/447	1/596	1/633	1/602	1/324	1/376	1/411	1/474	1/829	1/791	1/1031	1/1406
Angle	2nd	1/375	1/438	1/467	1/480	1/214	1/282	1/307	1/340	1/645	1/577	1/741	1/864
(radian)	1st	1/543	1/527	1/541	1/582	1/307	1/306	1/301	1/328	1/705	1/594	1/722	1/809
Weight(kN/m2)		9.83	9.66	9.64	10.04	8.89	9.04	8.91	9.07	13.05	13.02	14.10	16.95
Cost(x10[illegible]yen/m2)		1.93	2.03	2.07	2.21	2.22	2.25	2.24	2.45	1.64	1.64	1.76	2.15

building designed as reinforced concrete system is the cheapest among three systems in all span length simulations. However the unit cost of the mixed system becomes close to that of the reinforced concrete system for buildings with longer span length.

Recommended Strength and Required Strength for Joint Panels:- The ratios of the calculated strength by eq.(1) to the required strength estimated from the ultimate strengths of adjacent members for the joint panels are summarized in Table 5. The ratios are all larger than unity. This means that the joint panels are not needed to be strengthened for practical use if eq.(1) is satisfied.

Table 5
Ratios of calculated strengths to required strength of joint panels in design simulations for the mixed system

Location		8	10	12	14
Roof Floor	y1x1	1.52	1.68	2.24	2.12
	y1x2	1.65	2.03	2.51	1.49
	y2x1	1.14	2.81	1.57	1.56
	y2x2	1.87	3.01	3.09	1.73
3rd Floor	y1x1	2.45	2.01	2.24	2.72
	y1x2	1.56	1.42	1.43	1.67
	y2x1	1.67	1.74	1.49	1.76
	y2x2	1.33	1.63	1.62	1.14
2nd Floor	y1x1	2.86	2.11	2.34	2.72
	y1x2	1.84	1.33	1.46	1.67
	y2x1	1.94	1.81	1.54	1.76
	y2x2	1.20	1.25	1.22	1.18

*1 The locations of joint panels are expressed by frame numbers in both x and y directions. Frame "1" means exterior frame and "2" means interior frame, where y direction is the longitudinal direction.

4. CONCLUSIONS

The strength of the joint panel decreases as the girder flange is cut in the panel zone. However, the strength satisfies the value recommended by SRC Standard of AIJ. Therefore the strength of the joint panel is not so critical for design applications. The ductility is quite large and it does not deteriorate at least up to a story drift of 1/20 radians.

The mixed system showed that it has both, the advantages of reinforced concrete and steel systems, in story height, story stiffness and total weight. It is somewhat inferior to the reinforced concrete system in construction cost, but there are many factors which can not be considered in the cost estimates, such as the terms of the construction contract.

The above mentioned conclusions show the high capability of the advanced mixed system proposed in this paper.

REFERENCE

[1] SRC Design Standard, Architectural Institute of Japan, 1987 (in Japanese).

Leere Seite
Blank page
Page vide