Steel profile encased reinforced concrete composite frames

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Portique mixte en profilés d'acier enrobés de béton armé

Rahmentragwerke in Verbundbauweise

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Minoru Yamada, born 1930, received his doctor's degree 1959 from Kyoto Univ. Japan. His research findings on the shear explosion effect in short reinforced concrete columns in 1966 was later verified in the Tokachi-Oki earthquake in 1968. He has been professor of structural engineering, Kobe University, Japan, since 1964.

SUMMARY

Tests on steel profile encased reinforced concrete composite 3-span, multistorey rigid frame systems with or without shear walls of models have been carried out until fracture and compared with ordinary steel or reinforced concrete rigid frames with or without bracings or shear walls. The medium initial sway rigidity gives a more favorable state than steel, and the medium ultimate resistance and high ultimate fracture ductility result in a more adequate behavior of high rise buildings against earthquakes.

RÉSUMÉ

Des essais ont été effectués jusqu'à la rupture sur un portique rigide mixte en profilés d'acier enrobés de béton armé, à 3 travées et à plusieurs étages, avec ou sans voiles de contreventement. Les résultats ont ensuite été comparés à ceux obtenus sur un portique rigide ordinaire à ossature métallique ou en béton armé, de forme analogue. La rigidité moyenne initiale au déplacement horizontal du premier système est plus satisfaisante que celle de la structure métallique; la résistance moyenne ultime à la rupture et la forte aptitude à la déformation ultime à la rupture donnent aux bâtiments élevés un comportement mieux approprié aux tremblements de terre.

ZUSAMMENFASSUNG

Versuche an mehrstöckigen dreifeldrigen Rahmen in Verbundbauweise wurden mit und ohne aussteifende Wände bis zum Versagen des Systems durchgeführt. Die Resultate werden mit Stahl- und Stahlbetonrahmen mit oder ohne Aussteifungen verglichen. Die Anfangssteifigkeit ist höher als bei Stahlskelettbauten, die mittlere Tragfähigkeit wird bei grosser Duktilität mobilisiert und erlaubt ein besseres Erdbebenverhalten des Tragwerks.

1. INTRODUCTION

In order to make clear the structural characteristics of Steel Profile Encased Reinforced Concrete Composite structural systems, which were originnated by Prof. Emperger [1], Hawranek [2] and developed widely as high rise buildings in these half century in Japan, Tests on 1/10 scale models of 3-span, 9-story rigid frames with or without shear walls are carried out from elasto-plastic state until structural fracture. Test results are compared with that of the ordinary steel- or reinforced concrete rigid frames with or wothout bracings or shear walls with the same scale model and through this comparison structural characteristics of this steel profile encased reinforced concrete structural system may be clarified.

2. EXPERIMENT

2.1 Test Specimens and Loading System

2.1.1 Test Specimens

Test specimens are 1/10 scale model with a 40 mm x 40 mm x 4 mm x 2 mm wide flange cold formed steel section enbeded in 60 mm x 60 mm reinforced concrete cross section with 4-Ø4 (p_t=0,58%) as longitudinal reinforcements and Ø2 as hoops or stirrups in 20 mm pitchs (p_w=0,50%) such as illustrated in Fig.1. Model frames are composed of 3-span, 9-story with beams of 600 mm length and columns of 300 mm height, therefore total width of 1,80 m and total height of 2,70 m. Bases of the specimens are enbeded in a large base panel, which are fixed to loading bed. The maximum aggregate size is 5 mm.

2.1.2. Loading System

Loading system are illustrated in Fig.1. Vertical loads N are loaded at the top of each columns at the value of 1/3 of ultimate axial strength of column member $N_0 = f_c A_c + {}_r f_y\, {}_r A_s + f_y A_s$, where f_c: concrete strength, A_c: cross sectional area of concrete; ${}_r f_y$: yield stress of reinforcement, ${}_r A_s$: cross sectional area of reinforcement ; f_y: yield stress of steel profile, A_s: cross sectional area of steel profile. This value is maintained at constant value throughout the tests, therefore, the left hand side and the right hand side axial load values are always checked and adjusted according to the increments of horizontal displacements.

Horizontal loads V are loaded at the height of 2/3 of total height, which simulates the horizontal distribution of earthquake excitation as triangle by concentrated load at the center of gravity of trianguler distribution.

2.2 Test Series

Test series are composed of composite rigid frameworks without shear wall and composite rigid frameworks with reinforced concrete shear wall at the middle span with a wall thickness t of 20 mm, 30 mm and 40 mm with wall reinforcements of Ø3 mm in 50 mm pitchs (wall reinforcement ratios ${}_w p$=0,88%, 0,66%, 0,44% respectively).

2.3 Loading Process and Measureings

Loadings are carried out by alternately repeated cyclic horizontal loading by incremental displacement amplitudes. Horizontal and vertical displacements of each crossing points of beams and columns are measured by dial gauges.

2.4 Definition of Structural Fracture

It is very important to define fracture. Structural fracture of this test series is defined as the loss of the prescribed constant axial load level i.e. to become unable to sustain the axial load at the prescribed constant value $(1/3)N_0$.

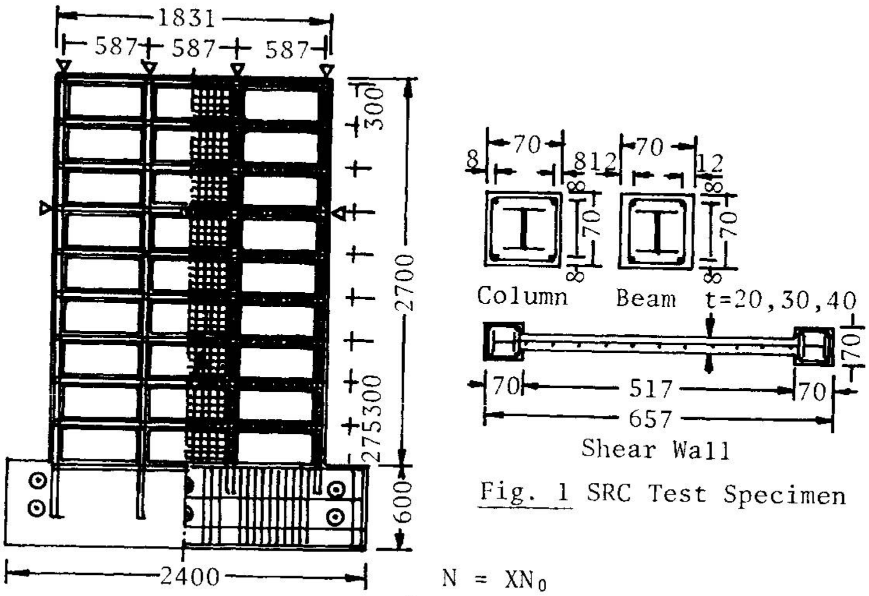

Fig. 1 SRC Test Specimen

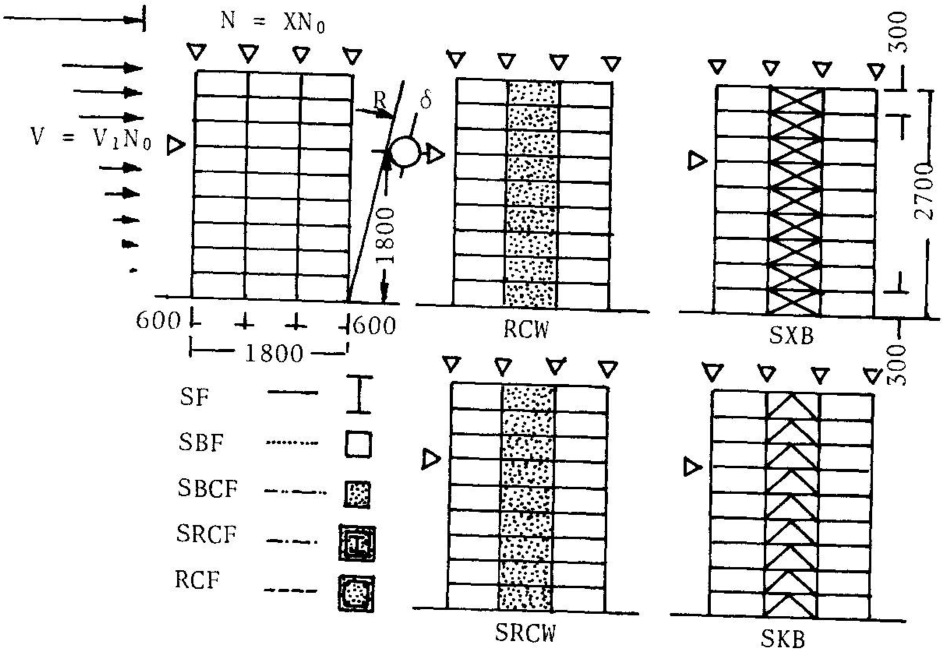

Fig. 2 SRC and other Resisting Systems

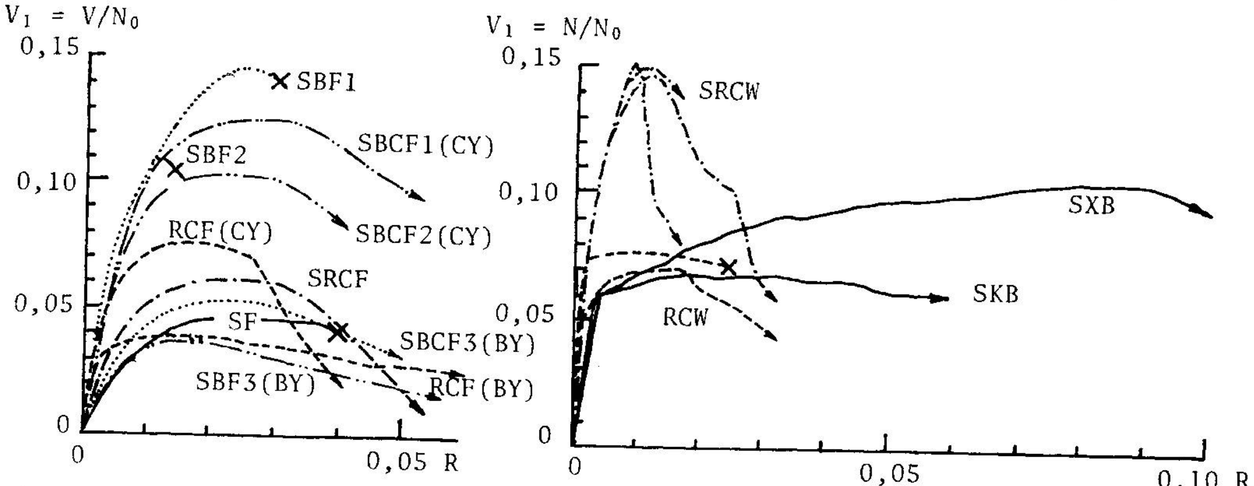

Fig. 3 Horizontal Resistance Ratio V_1 - Sway Angle R Relationships

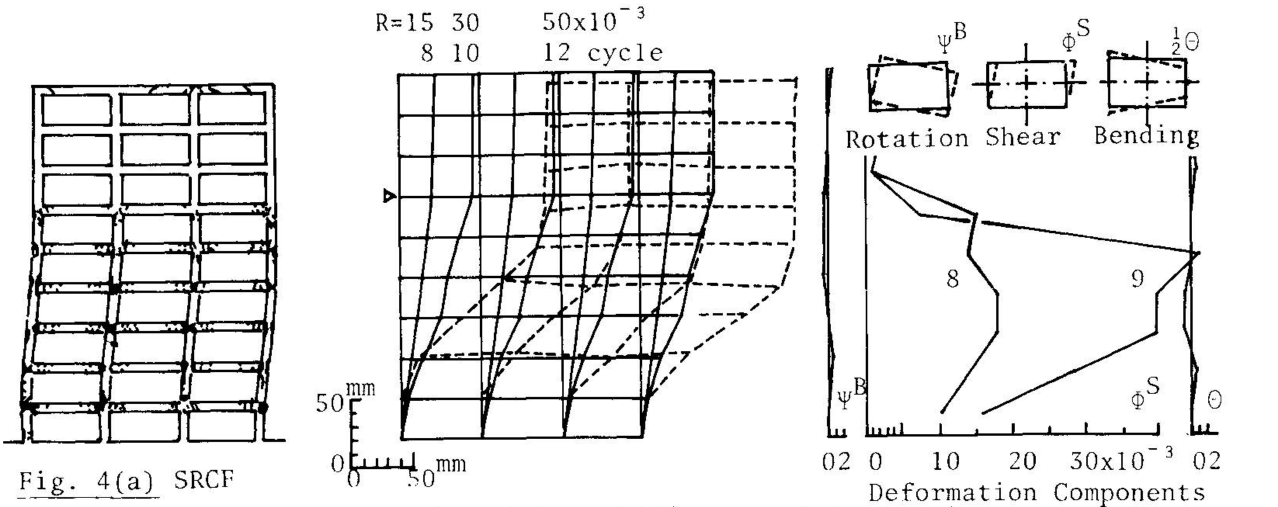

Fig. 4(a) SRCF

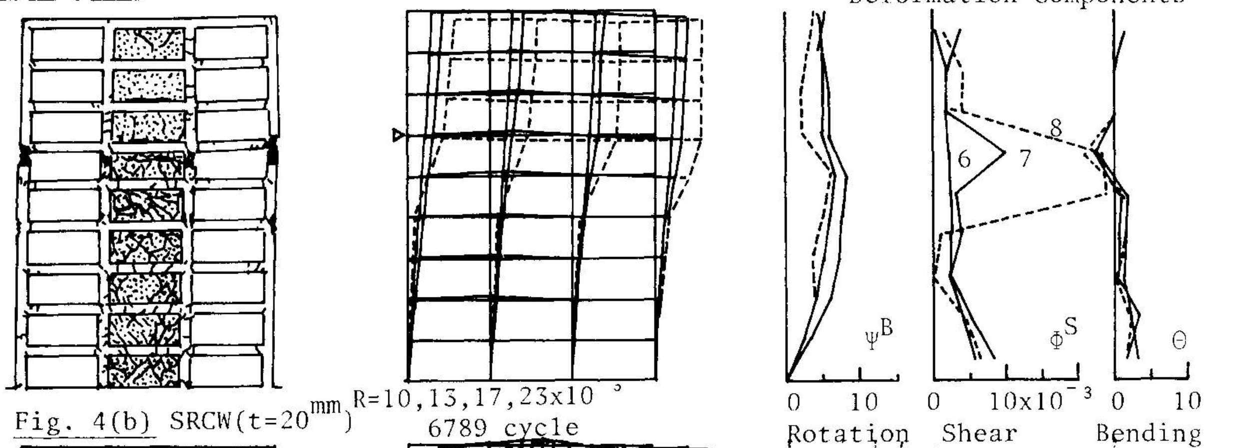

Fig. 4(b) SRCW(t=20mm) R=10,13,17,23x10⁻³ 6789 cycle

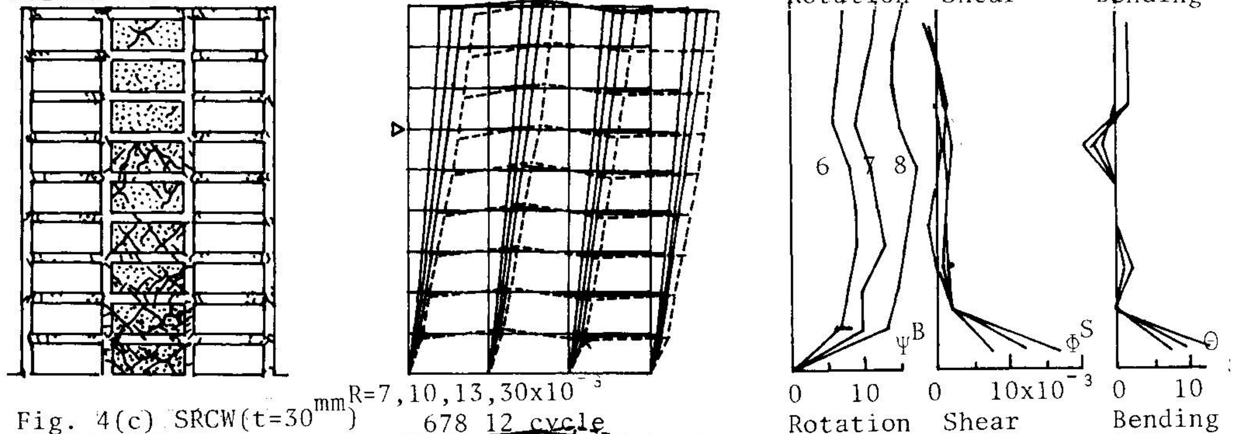

Fig. 4(c) SRCW(t=30mm) R=7,10,13,30x10⁻³ 678 12 cycle

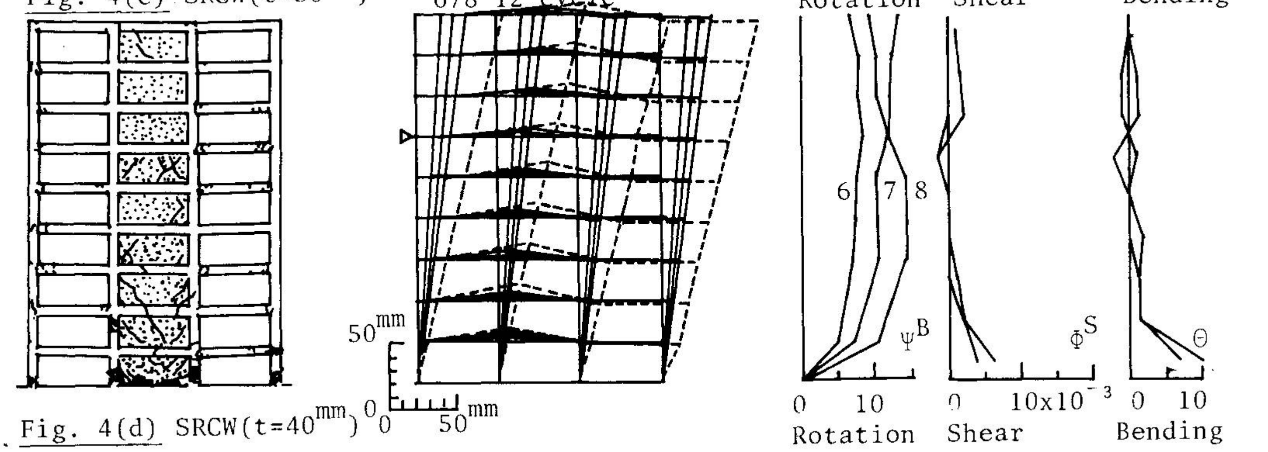

Fig. 4(d) SRCW(t=40mm)

2.5 Test Results

2.5.1 Horizontal Load V - Displacement δ - Relationships

Horizontal load V - horizontal displacement δ - relationships at the loading point are shown in Fig.3 by displacement angle R.

2.5.2 Deformation Process

Deformation process of each tested frames are shown in Fig.4 at the ultimate resisting states by solid lines and the final states by dotted lines in comparison with fracture modes with cracked patterns such as illustrated in Fig.4.

2.5.3 Distribution of Deformation Components

Distribution of deformation components in each story i.e. rotation component Ψ_i^B shear component Φ_i^S and bending component θ_i are shown in Fig.4.

3. DISCUSSION

3.1 Deformation Characteristics of this Composite System

Elasto-plastic deformation characteristics of these steel profile encased reinforced concrete rigid frame systems are illustrated in Fig.4 at their ultimate resisting states. Rigid frame without shear wall shows typical shear deformation almost no rotation and bending components as is the case of rigid frames in general. However the composite rigid frames with reinforced concrete shear walls show fairly strong bending deformation at the bottom story and moderate shear deformation at the upper stories by the stronger counter action of bending and shear through the adjacent beams than the cases of reinforced concrete shearwalls, at which there are no diagonal cracks in the upper shear walls.

3.2 Comparison with Other (Steel and Reinforced Concrete) Systems

3.2.1 Horizontal Resisting Ratio V_1

In order to compare the resisting characteristics of these composite frame systems with another structural systems like steel- or reinforced concrete systems not only qualitatively but also quantatively, the author had already introduced [3] a non dimensional value, horizontal load ratio V_1 as the ratio of horizontal load V to the ultimate axial load N_0 of columns in total i.e. $V_1 = V / N_0$.

By this non dimensional value V_1 the relationships between horizontal load ratio V_1 - horizontal sway angle R at the loading point are illustratee in Fig.3 in comparison with other systems [4][5][6] such as shown in Fig.2.

3.2.2 Initial Stiffness V_1/R

From these figures it may be concluded that steel profile encased reinforced concrete rigid framework system without shear walls (SRC) shows a medium initial horizontal sway stiffness of V_1/R =8,5 compareing with stiffnesses of reinforced concrete (RC)-frameworks of V_1/R =17 and of Steel (S)-frameworks V_1/R =4,5 at the initial resisting state. Concrete filled steel box column (SBC)-frameworks show V_1/R =17. This moderate initial stiffness of (SRC) presents a comfortable state for usual function of high rise buildings and causes a moderate response at earthquake excitation. Through the stiffening by reinforced concrete shear walls, this value of (SRC) becomes V_1/R =35 (SRCW) and of (RC) V_1/R =55 (RCW), and by bracings of (S) V_1/R =15 (SFB).

3.2.3 Ultimate Resistance V_{1_u}/N_0

Ultimate horizontal resistance ratio V_{1_u}/N_0 i.e. a ratio of ultimate horizontal resistance V_u to the ultimate vertical resistance N_0 of frameworks are 0,06 for (SRC), 0,04 $\div$ 0,07 for (RC) and 0,05 for (S)-frameworks without shear walls.

Concrete filled steel box column (SBC)-frameworks show ultimate resistance ratios 0,103-0,127, corresponding steel box (SB)-frameworks without concrete filling 0,112-0,142.

These values are increased to 0,15 for (SRCW), 0,04-0,07 for (RCW) and 0,07-0,10 for (SFKB)(SFXB)-frameworks with shear walls or bracings.

3.2.4 Horizontal Sway Fracture Ductility of Systems

Horizontal sway fracture ductility R_u are 0,030 for (SRCF), 0,020-0,025 for (RCF) 0,04 for (S)-frames. Concrete filled steel box column (SBCF)-frameworks show 0,035-0,040 and more, however, the corresponding steel box column (SBF)-frameworks show only 0,015-0,030 with the sudden loss of axial load resistance by the total frame buckling.

Through the stiffining by reinforced concrete shear walls, this sway fracture ductility becomes 0,01-0,015 for (SRCW), 0,02 for (RCW) and 0,06-0,09 for (SFKB) (SFXB) with bracings.

4. CONCLUSION

Ultimate structural characteristics of typical steel profile encased reinforced concrete rigid frames as system, are clarified by a series of 1/10 scale model tests on 3-span, 9-story frameworks with various wall thicknesses of reinforced concrete shear wall at the central span as main parameter. Test results are compared with steel or reinforced concrete framework systems of the same scale models. Initial stiffness and ultimate horizontal resistance of these composite systems show medium value between corresponding steel or reinfroced concrete framework systems. This may enable to present a comfortable states for usages of high rise buildings. Enough fracture ductility as system may enable to realize an effective resisting system against earthquakes.

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