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FRACTURE DUCTILITY OF STRUCTURAL ELEMENTS AND OF STRUCTURES

Minoru YAMADA[1], Hiroshi KAWAMURA[1], Akinori TANI[1], Katsunobu IWANAGA[2], Yasuo SAKAI[3]
Hiroshi NISHIKAWA[4], Akitoshi MASUI[5], Minoru YAMADA[6]

[1]Department of Architecture, Faculty of Engineering, Kobe University, Nada-ku, Kobe, Japan
[2]Maeda Construction Co. Ltd., Osaka, Japan
[3]Asahi Chemical Industry Co. Ltd., Kita-ku, Osaka, Japan
[4]Shimizu Corporation, Minato-ku, Tokyo, Japan
[5]Fujita Corporation, Shibuya-ku, Tokyo, Japan
[6]Ministry of Construction, Chu-bu Branch, Naka-ku, Nagoya, Japan

SUMMARY

Ductility has been considered as an evaluation base of aseismic capacity of structures. However, structural ductility has not yet been sufficiently clarified by experiments. This paper intends to present the overall fracture ductilities of various kinds of multi-span, multi-story rigid frames with special reference to the fracture ductilities of their component elements (members). Test results of overall structures, stories, members and elements are illustrated and it becomes possible to evaluate and compare the aseismic capacity of various kinds of structural systems in the same scale.

INTRODUCTION

Ductility is discussed often as an evaluation base or measure of aseismic capacity of structures. Theoretically the definition of ductility or ductility factor is very clear as perfectly elastic - perfectly plastic behaviours. However, it is not so clear this concept for the practical application, because of the differences from the real behaviours with hardening or softning processes after yielding and deterioration and fracture processes after maximum resistances especially by the difficulty of the definition of fracture. Aseismic capacity of structures are often discussed at different loading levels but it must be based upon the same measure so this paper aims to make clear the relationships among such behaviours or ductilities of overall structures, stories, members or elements of them by experiments and to present the bases of discussions of aseismic capacity of structures.

OBJECTIVES AND SCOPES

Ductility is generally regarded as an evaluation measure of aseismic capacity of structures. This concept was introduced at first by Tanabashi in 1937, by Housner in 1956 as an energy dissipation capacity and then based upon them by Veletsos and Newmark as quantative measure "Ductility Factor" more clearly in 1960 (Ref. 1). The presenting author had proposed in 1969 the low cycle fatigue fracture limit of structural members, especially by the cyclic bending tests of beam-columns, as the evaluation base of aseismic capacity of structures, because of the unclearness of the definition of "Ductility Factor" in the behaviours of real structural members and of the differences from their real behaviours (Ref. 2). The objectives of this paper is to make clear the relationships among the ductilities of overall structures, stories, members, elements and materials, and to present the predominant factors of aseismic capacity of structures.

DUCTILITY AND FRACTURE

Structural Ductility Aseismic capacity of structures are based upon their overall structural behaviours. Horizontal loading tests are carried out on the multi (3) span, multi(3,6,9) story Steel(S), Steel Profile Encased Reinforced Concrete (SRC) and Reinforced Concrete(RC) rigid frames with or without resisting cores (i.e. Bracings for S, and Cantilever Shear Walls for SRC and RC) of 1/10 scale models under the action of constant axial loads such as shown in Fig. 1 (Ref. 3).

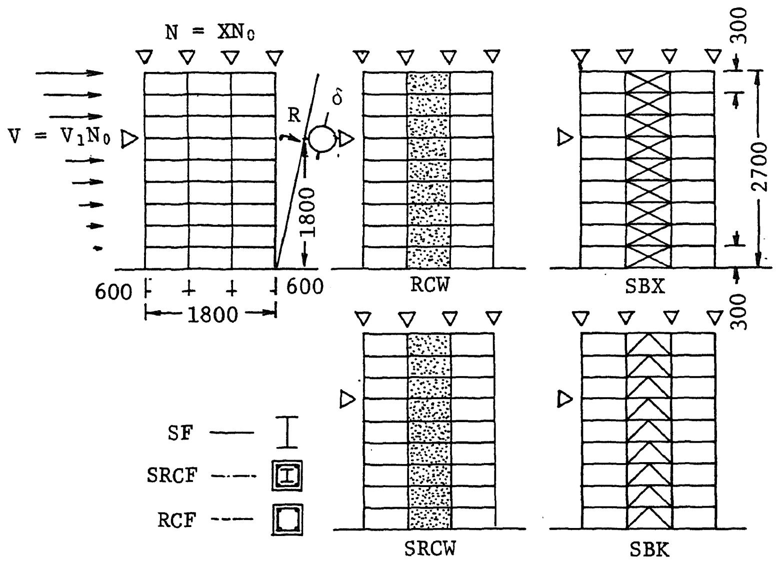


Fig. 1 Testing and Resisting Systems

The horizontal load ratio V_1 (i.e. the ratio of the horizontal load V to the ultimate strength of column N_0 (Ref. 4)) versus sway angle R relationships are illustrated by their envelope curves of horizontal cyclic loading test results in Fig. 2. These figures show the sway characteristics and fracture ductilities of various kinds of structural frameworks with and without resisting cores under incremental cyclic sway amplitude tests. Structural collapses occure at swaying angles R of about 0,040 in S, 0,030 in SRC and 0,025 in RC frames without core and of about 0,100 in S, 0,015 in SRC and 0,005 in RC frames with cores.

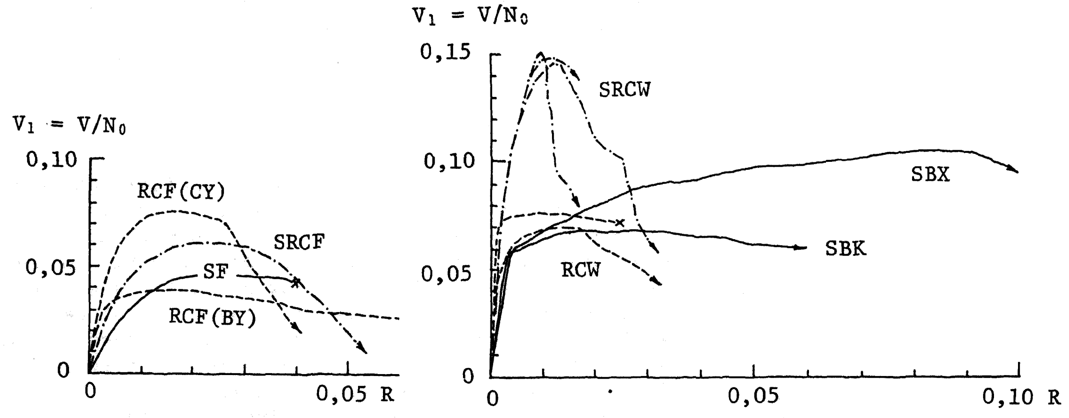


Fig. 2 Horizontal Load Ratio V_1 - Sway Angle R Relationships (Envelope Curves of Incremental Cyclic Sway Loadings)

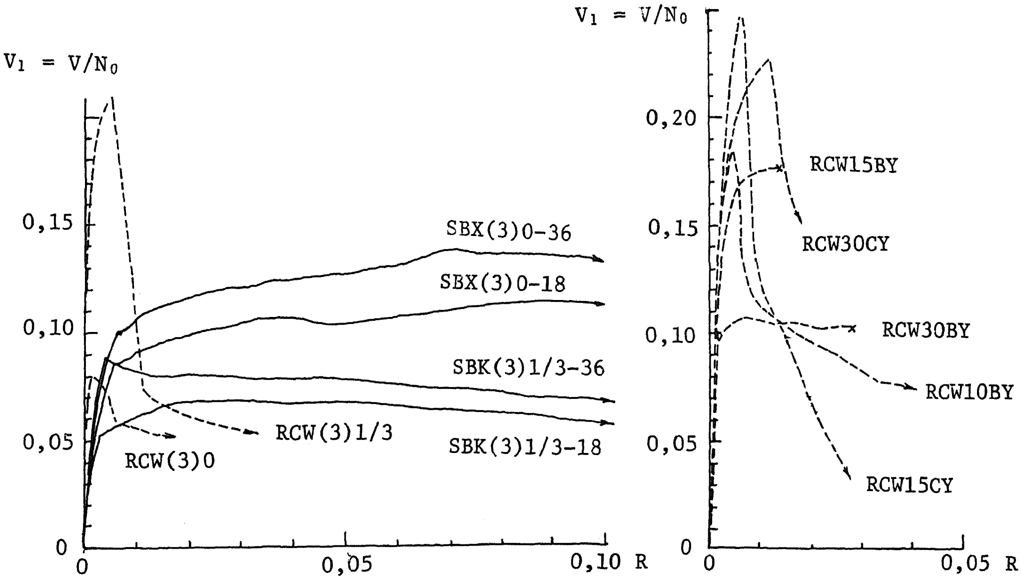


Fig. 2 Horizontal Load Ratio V_1 - Sway Angle R Relationships
(Envelope Curves of Incremental Cyclic Sway Loadings)

Story Ductility Under the action of horizontal loading, structural frameworks show such deformations as illustrated in Fig. 3. After the initial elastic states plastic hinges are formed gradually at the ends of beams and columns according to their cross sectional characteristics of such members. Finally structures become a hinged system consisted of rigid members with plastic hinges at their both ends. The largest story sway angle occures at a certain story and this story collapse initiates the fracture of overall structure. Fig. 4 shows the relationship between overall structural sway V_1-R and story sway V_1-R_i at the i-th (i=2) story as an example.

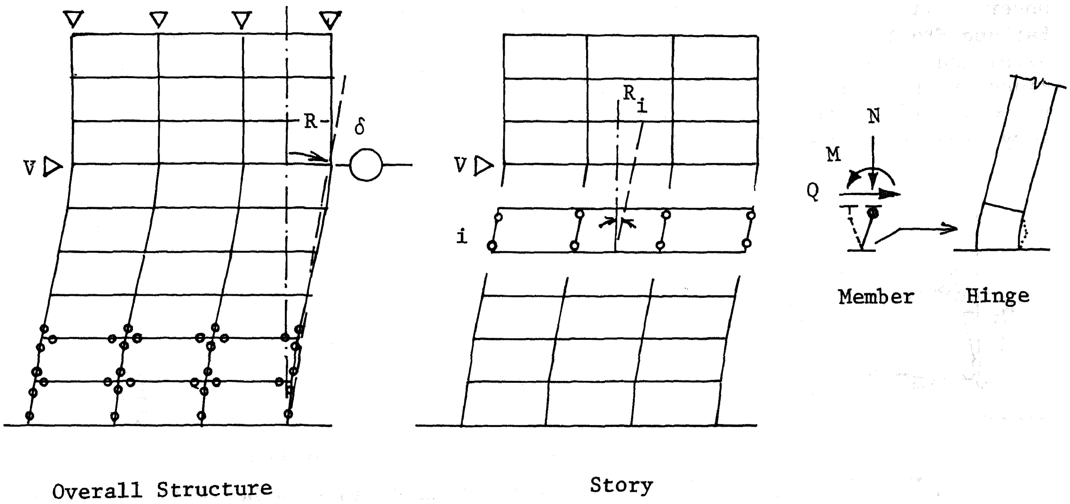


Fig. 3 Idealized Ultimate State of Frameworks

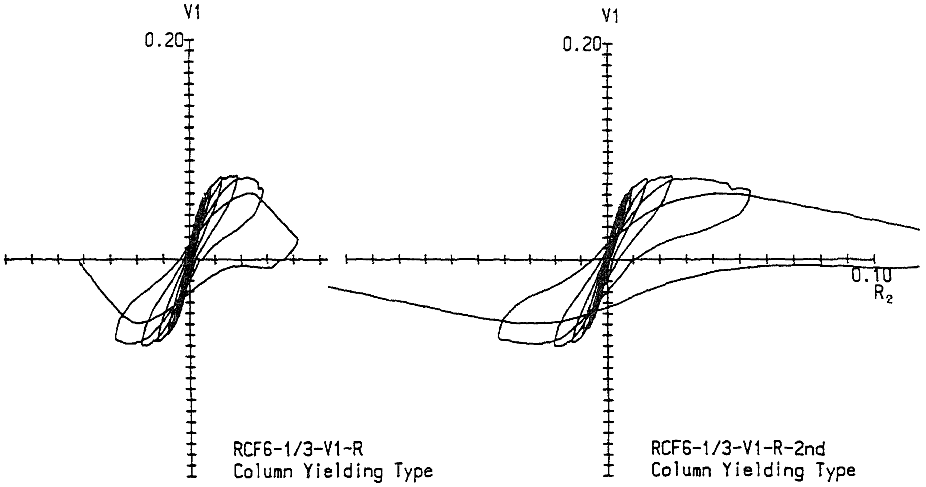
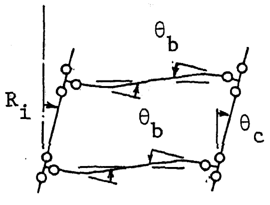


Fig. 4 Overall Structural Sway V_1 - R and Story Sway V_1 - R_2 at the 2 nd Story, RCF(CY)

Member Ductility Structural members are connected rigidly at their both ends except some special cases. Plastic hinges are usually, therefore, formed at their both ends at the ultimate state. Vertical members, i.e. columns and braced frames or shear walls, are fixed rigidly at their top and bottom by very rigid reinforced concrete floors, so that they are forced to deforme by the same story sway value. The story sway angle R_i at the i-th story is the same value of each vertical members and at the same time approximately equal to the deformation angles of beams at the ultimate state such as shown in Fig. 5. Fig. 6 shows the horizontal load ratio V_1 versus deflection angle R relationships of beam-colums of Wide Flange Steel (b/t = 10, 20, 30), Steel Box (b/t = 17, 24, 35), SRC and RC under the same constant axial load level ratio 1/3 of their yield or ultimate axial strength N_0 with the same scale of overall structures in Fig. 2 for comparison. The ductility or deformability of consisting members of stories indicate at the same time the ductility of stories. Ultimate deformability or ductility of structural members under cyclic bending like earthquake excitation are indicated as the Low Cycle Fatigue Fracture Limit of such structural members under the action of the constant axial loads. Fig. 7 illustrates the Low Cycle Fatigue Fracture Limits of various kinds of structural members under the action of the same constant axial load level ratio X = 1/3 of their yield or ultimate axial strength N_0. This figure presents very clearly the deformation limits i.e. ductility of such structural members.



$\theta_b \cong \theta_c \cong R_i$

Fig. 5 Rotation Angles

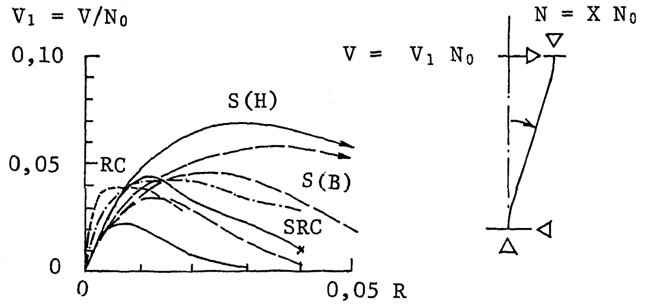


Fig. 6 Horizontal Load Ratio V - Deflection Angle R of Beam-Columns (cf. Fig. 2)

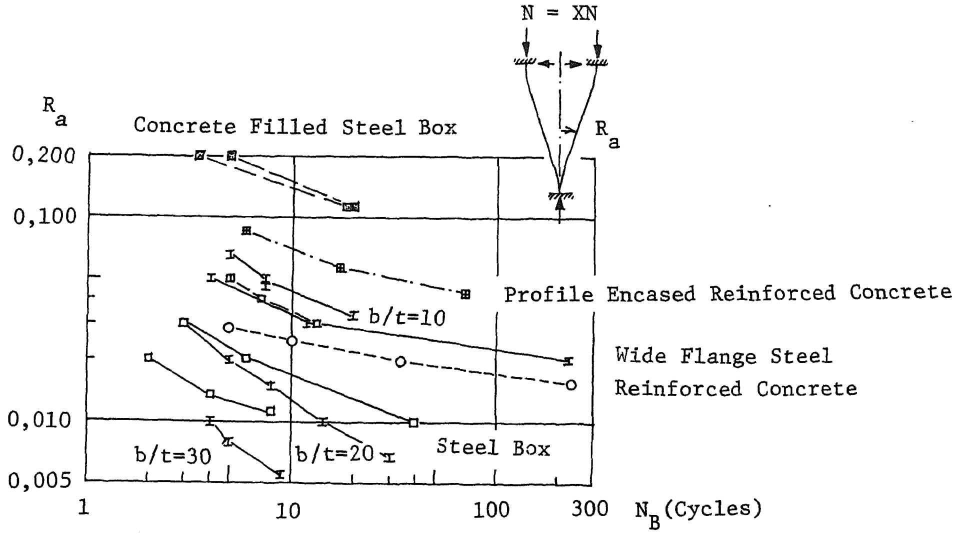


Fig. 7 Low Cycle Fatigue Fracture Limits of Beam-Columns (X=1/3)

Element Ductility Cross sections of structural members are consisted of many elements, i.e. flange and web in S, tensile reinforcement and compressive concrete in RC. The resisting mechanisms of such flange or web elements are idealized into plate elements under the cyclic axial compression or tension in their plane. The Low Cycle Fatigue Fracture Limit of such plate elements are illustrated in Fig. 8.

Plastic hinges are formed at the both ends of members with a certain length. This length had named by the presenting author as "Plastic Hinge Length" in 1958 (Ref. 5) and varies under the conditions i.e. axial load level ratios X, moment gradients etc.. However this length is usually approximately equal to the depth D of cross section of the member. Therefore, if it is assumed that the plastic hinge length l_z to be approximately equal to the member depth D, then the extreme fiber strain ε in the plastic hinge at the ends of member approximately equal to the member sway angle R as shown in Fig. 9. Then it becomes possible to discuss on the same basic data of elements in Fig. 8 and members in Fig. 7. Fig. 10 shows such extreme fiber strains in plastic hinges at each stories of S, SRC and RC frames under such assumption.

Material Ductility Low Cycle Fatigue Fracture Limits of structural steels are gotten under the cyclic tension - compression tests as the fundamental mechanical properties of materials and this limits are gotten as the critical case with the shortest specimens in Fig. 8.

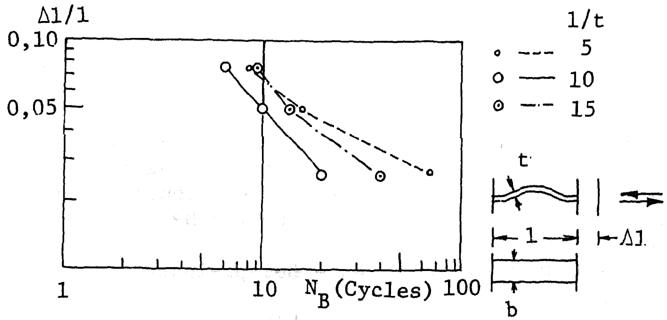


Fig. 8 Low Cycle Fatigue Fracture Limits of Steel Plates

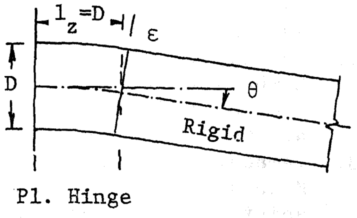


Fig. 9 Exterme Fiber Strain in Plastic Hinge

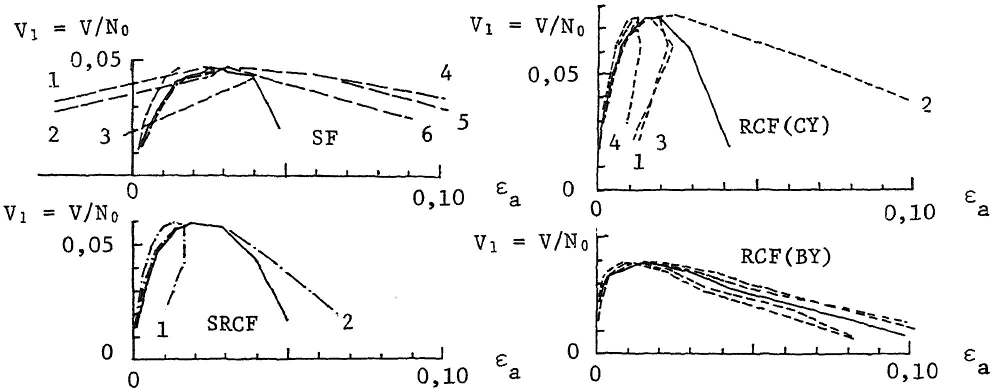


Fig. 10 Extreme Fiber Strains in Plastic Hinges at Each Story

RELATIONSHIPS AMONG DUCTILITIES

As discussed and illustrated in the preceeding sections, there are many ductility concepts according to their objects such as overall structures, stories, members, elements or materials. This paper illustrates roughly their relationships among them. The most important or predominant ductility may be the story ductility at the critical story and it will be roughly indicated by the characteristics of component elements i.e. columns with the same sway amplitudes by the low cycle fatigue fracture limits of beam-columns shown in Fig. 7. And that, this value is roughly related to the low cycle fatigue fracture limits of steel plate elements shown in Fig. 8.

CONCLUDING REMARKS

Ductility and fracture limits of overall structures, stories, members, elements and materials of Steel(S), Steel Profile Encased Reinforced Concrete(SRC) and Reinforced Concrete(RC) are presented and the relationships among them are generally illustrated in Figs. 2, 6, 10. The Low Cycle Fatigue Fracture Limits of beam-columns of various kinds of structural members are presented in Fig. 7 and of steel plate elements in Fig. 8 as basic data. On these general view, it may become possible to discuss and to extend the aseismic safety of structures upon the same common base.

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