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Practical ductility assurance of structures for aseismic design

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ABSTRACT: For practical aseismic design of structures, the existence of sufficient ductility in structures must be verified. However there are not yet established any reliable method of assurance or generalized standard assessment method to evaluate the ductility. In this paper, as a practical method to assure the ductility of structures, the low cycle fatigue fracture limits of reinfoeced concrete- or steel unit rigid frames are presented. The low cycle fatigue fracture limits of their component beam-column members are presented for comparison and compared with them and with the ultimate sway deformations of multi-story, multi-span reinforced concrete and steel rigid frames at their fracture states. Then, based upon these comparison, the low cycle fatigue fracture limits of their component reinforced concrete or steel beam-columns are proposed as the most reliable practical ductility assurance values of structures for aseismic design.

1 INTRODUCTION

In order to present a practical method for the evaluation of ductility of structures for aseismic design, the author (1969,1984, 1988) had already proposed to use the low cycle fatigue fracture limits of component beam-column members. Multi-story structures and their component stories are composed of columns and special aseismic elements like shear walls in reinforced concrete and bracings in steel structures. Multistory structures show the integrated behaviours of the component stories and beam-columns,

In this paper, it will be presented at first the low cycle fatigue fracture limits of unit rigid frames with or without special aseismic elements and then compared with the corresponding low cycle fatigue fracture limits of component beam-columns and with the ultimate sway deformation states of multi-story, multi-span reinforced concrete and steel rigid frames at fracture. Based upon the comparison of these experimental results, the practical evaluation method of story ductility of structures and their aseismic safety may be discussed numerically.

2 DUCTILITY AND LOW CYCLE FATIGUE FRACTURE LIMITS OF UNIT RIGID FRAMES

Behaviours of multistory frames may be integrated from the component stories. Therefore, at first, it may be presented the low cycle fatigue fracture limits of reinforced concrete or steel unit rigid frames with or without special aseismic elements like reinforced concrete shear walls or steel bracings. Fatigue fracture tests are carried out with various various prescribed constant story sway amplitudes under the action of constant axial loads.

2.1 Ductility and low cycle fatigue fracture limits of reinforced concrete unit rigid frames

Low cycle fatigue fracture limits of reinforced concrete unit rigid frames are illustrated in Fig. 1(a). Story sway angle amplitudes R_a are in ordinate and number of cycles until fracture N_B in abscissa. Solid line show the low cycle fatigue fracture limits of reinforced concrete unit rigid frames of column yoielding type under a constant axial load level ratio of 1/3 of ultimate axial strength of columns by Yamada, Kawamura, Kondoh (1972) and dotted line shows the low cycle fatigue fracture limits of reinforced concrete unit rigid frames with infilled reinforced concrete shear walls under the same constant axial load level ratios by Yamada, Kawamura, Katagihara, Moritaka (1977).

2.2 Ductility and low cycle fatigue fracture limits of steel unit rigid frames

Low cycle fatigue fracture limits of steel unit rigid frames are illustrated in Fig. 1 (b). Solid line shows the low cycle fatigue

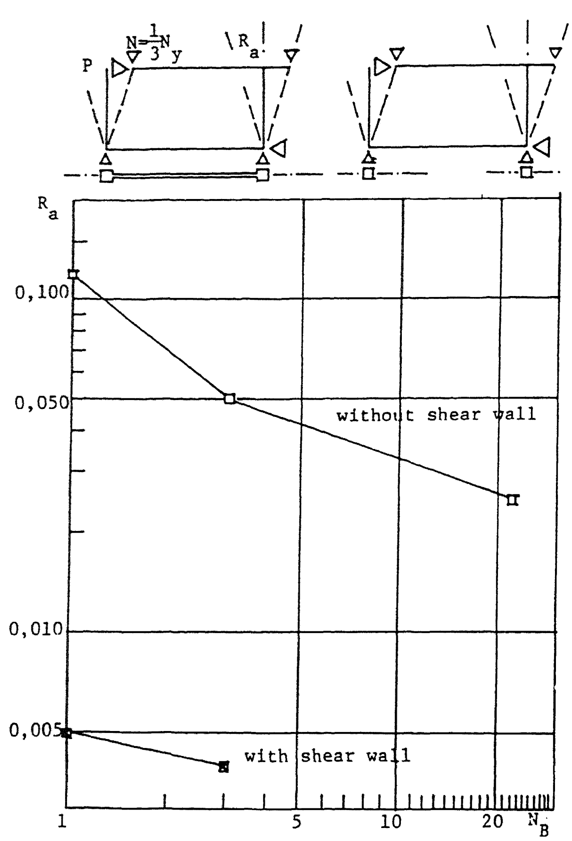


Figure 1(a). Low cycle fatigue fracture limits of reinforced concrete unit frames.

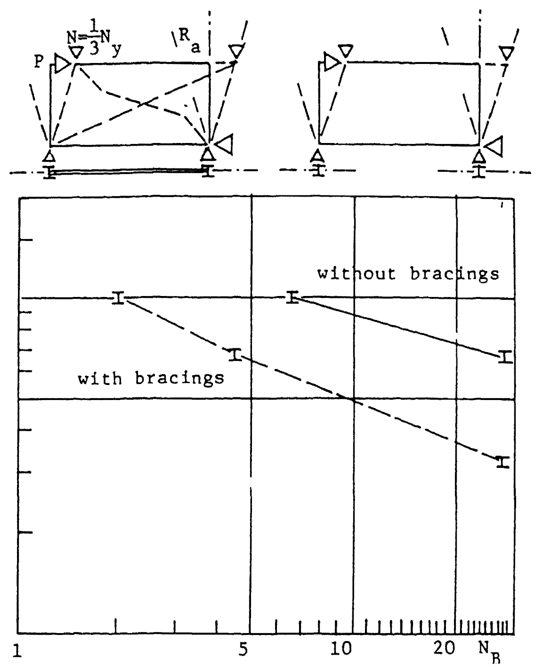


Figure 1(b). Low cycle fatigue fracture limits of steel unit rigid frames.

fracture limits of unit rigid frames under a constant axial load level ratio of 1/3 of axial yielding strength by Yamada, Tsuji, Murazumi (1973), Yamada, Tsuji, Asagawa (1981a), and dotted line shows the low cycle fatigue fracture limits of unit steel frames with bracings under the same constant axial load level ratio by Yamada, Tsuji, Tsubakimoto (1981b).

3 DUCTILITY AND LOW CYCLE FATIGUE FRACTURE LIMITS OF BEAM-COLUMNS

Fundamental fracture limits of resisting elements may be expressed by the low cycle fatigue fracture limits of beam-columns. Fatigue fracture tests are carried out by the various prescribed constant sway amplitudes under the action of the various prescribed constant axial loads. Fracture of the member are able to be defined very clearly as the loss to maintain the prescribed axial resistance or as the loss of horizontal resistance.

3.1 Ductility and low cycle fatigue fracture limits of reinforced concrete beam-columns

Low cycle fatigue fracture limits of reinforced concrete beam-columns are illustrated in Fig. 2(a), sway angle amplitude R_a in ordinate and the number of cycles until fracture N_B in abscissa. Solid lines show the cyclic bending fatigue fracture of reinforced concrete beam-columns of a shear span ratio (H/D) of 8,75 under the action of constant axial load level ratios of 1/6, 1/3, 2/3 by Yamada, Kawamura, Furui (1966) and dotted lines show the cyclic shear fatigue fracture limits of reinforced concrete short columns of a shear span ratio (H/D) of 2,00 under the action of constant axial load level ratios of 1/6, 1/3 by Yamada, Yagi (1973).

3.2 Ductility and low cycle fatigue fracture limits of steel beam-columns

Low cycle fatigue fracture limits of steel beam-columns are illustrated in Fig. 2(b), sway angle amplitude R_a in ordinate and the number of cycles until fracture N_B in abscissa. Tested cross sections of steel beam-columns are wide flange profile around the strong as well as weak axis with various (b/t) ratios of 10, 20, 30 and box profile

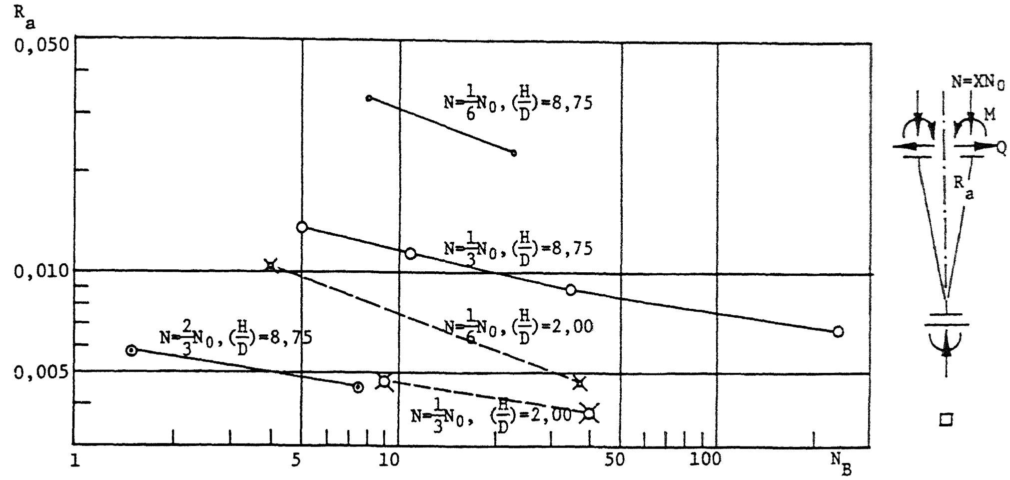


Figure 2(a). Low cycle fatigue fracture limits of reinforced concrete beam-columns

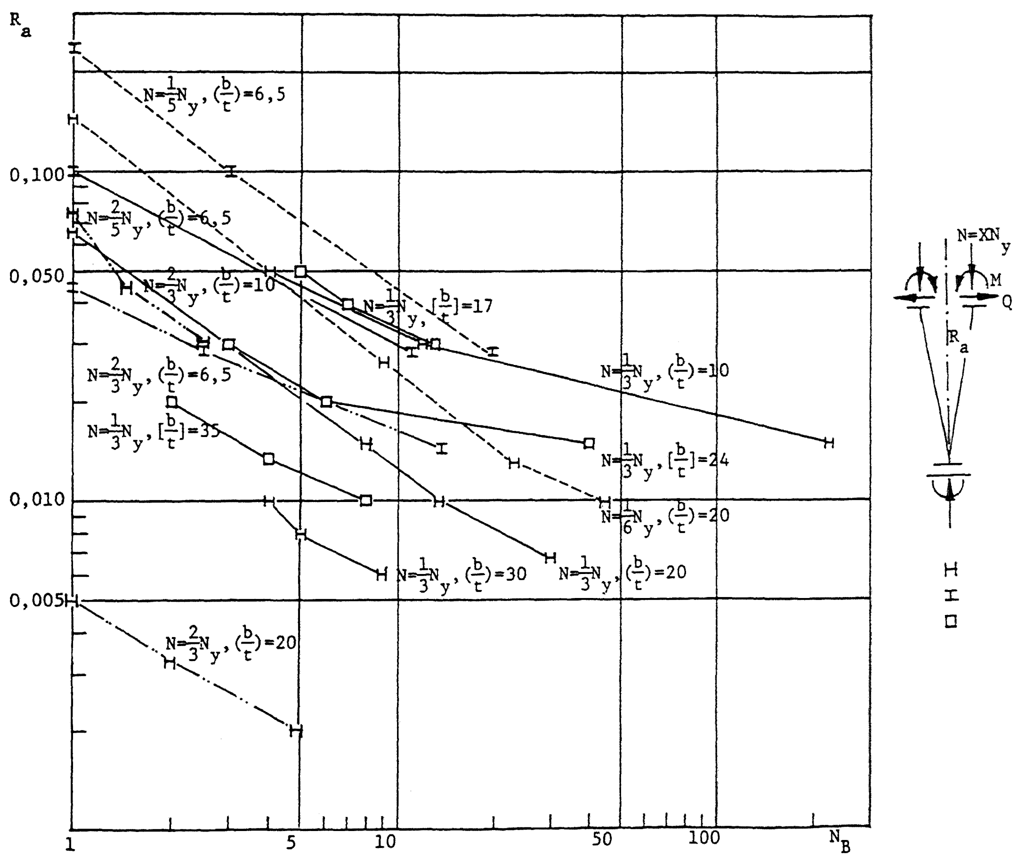


Figure 2(b). Low cycle fatigue fracture limits of steel beam-columns.

with various (b/t) ratios of 17, 24, 35. Tests are carried out under the action of various constant axial load level ratios of 1/6, 1/3, 2/3 by Yamada, Shirakawa (1971), Yamada, Kawabata, Yamanaka (1989). Suppliment Tests are carried out by Yamada, Tsuji, Kobayashi (1980) for weak axis and by Yamada, Kawamura, Tani, Isaka, Komiya, Kikuchi.

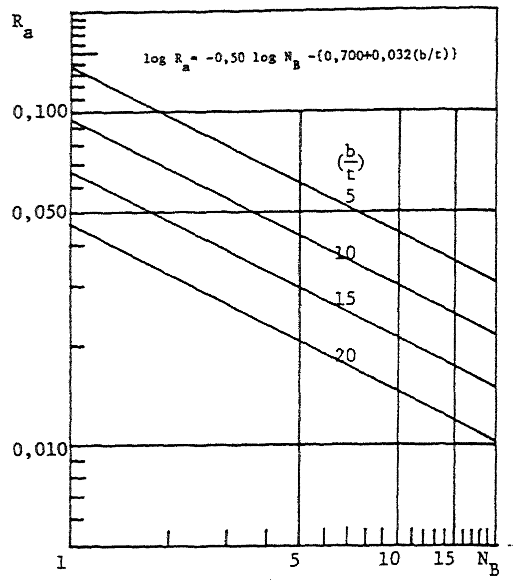


Figure 3(a). Low cycle fatigue fracture limits of wide flange beam-columns under $(1/3)N_y$ for design.

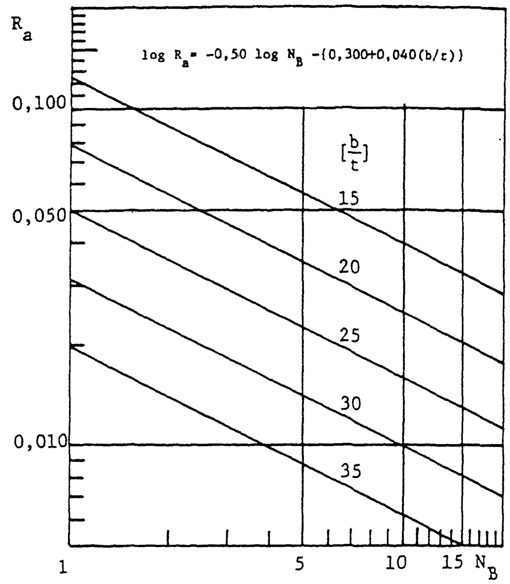


Figure 3(b). Low cycle fatigue fracture limits of steel box beam-columns under $(1/3)N_y$ for design.

As the measure of the low cycle fatigue fracture limits of steel beam-columns, the author has proposed under the action of a constant axial load level ratio of 1/3 of yield resistance:
for wide flange steel beam-columns,

$$\log R_a = -0{,}50 \log N_B - \{0{,}700+0{,}032(b/t)\} \quad (1),$$

for box steel beam-columns,

$$\log R_a = -0{,}50 \log N_B - \{0{,}300+0{,}040(b/t)\} \quad (2),$$

where
R_a: sway angle amplitude,
N_B: number of cycles until fracture,
b : width of the cross section,
t : thickness of flange.
Fig. 3 shows these proposed values for practical design by Yamada (1991).

4 FRACTURE DUCTILITY OF MULTI-STORY, MULTI-SPAN RIGID FRAMES

For the bases to discuss the required and existing fracture ductility of whole structures, test results on multi-story (10), multi-span (3) reinforced concrete as well as steel rigid frames are presented to enable to compare with the test results of the low cycle fatigue fracture limits of unit rigid frames and component beam-columns. Tests are carried out under the action of constant axial load level ratios of 1/3 of their ultimate axial strength N_0 or N_y. Horizontal load P are normalized by the ultimate axial strength N_0 or N_y as $V_1 = P/N_0$ by Yamada (1980), and the relationships between the horizontal load ratio V_1 and the structural sway angle R at the loading story i.e. 2/3 of the whole heights are illustrated for comparison. In the figures of deformation of frames, the measures of story sway angles $R_{\text{each story}}$ of each story are also indicated.

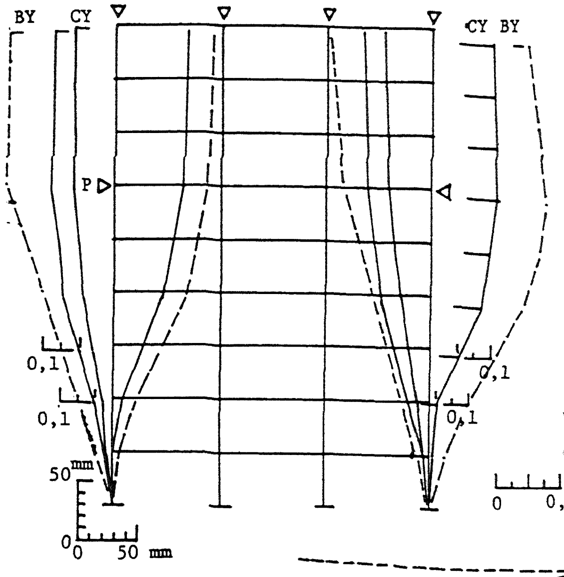
4.1 Fracture ductility of 10-story, 3-span reinforced concrete rigid frames

Fracture deformation characteristics of 10-story, 3-span reinflrced concrete rigid frames without shear walls at the ultimate states are illustrated in Fig. 4(a). Solid lines show the test results of so called column-yielding type by Yamada, Tani, Niwa (1991) and dotted lines show the test results of so called beam-yielding type by Yamada, Kawamura, Tani, Toyoda (1992).

Column yielding type rigid frame RCFCY shows the maximum resistance $V_1 = 0{,}063$ at $R = 0{,}01 \sim 0{,}03$ and occures sudden column fracture in 4th. story at a frame sway angle R of 0,03 and then a story sway angel $R_{e.s.}$ reachs 0,07 to 0,10 and more at the fourth at the final fracture. Beam yielding type rigid frame RCFBY shows the maximum resistance of $V_1 = 0{,}028$ at $R = 0{,}01 \sim 0{,}02$ and story sway angle reachs 0,07 at the final fracture states.

4.2 Fracture ductility of 10-story, 3-span steel rigid frames

Frame deformation characteristics of 10-story, 3-span steel rigid frame without bracings at the ultimate states are illustrated in Fig. 4 (b). Until the frame sway angle R reachs 0,03 at the maximum resistance V_1 = 0,045, the deformation processes are symmetric but after the maximum frame resistance, at a frame sway angle R = 0,04, the whole framework shows the bifurcation phenomenon as system. Story sway angle at the 4th. story exceeds R > 0,05 and reachs R > 0,16 by Yamada, Iwanaga (1987).



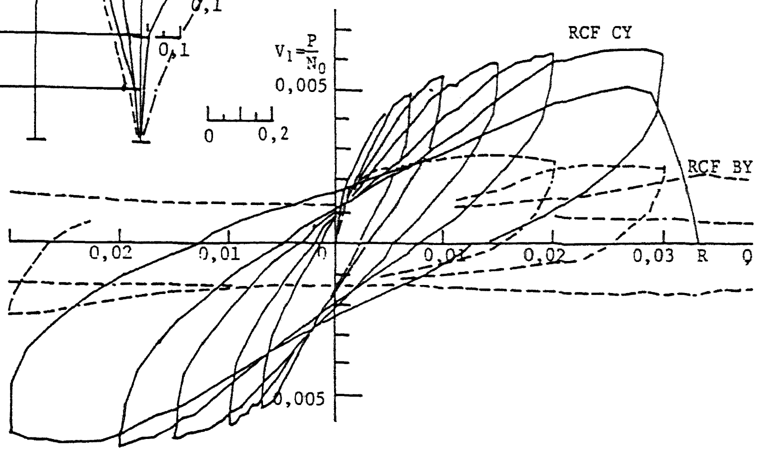


Figure 4(a). Ultimate deformation of 10-story 3-span reinforced concrete rigid frames at fracture.

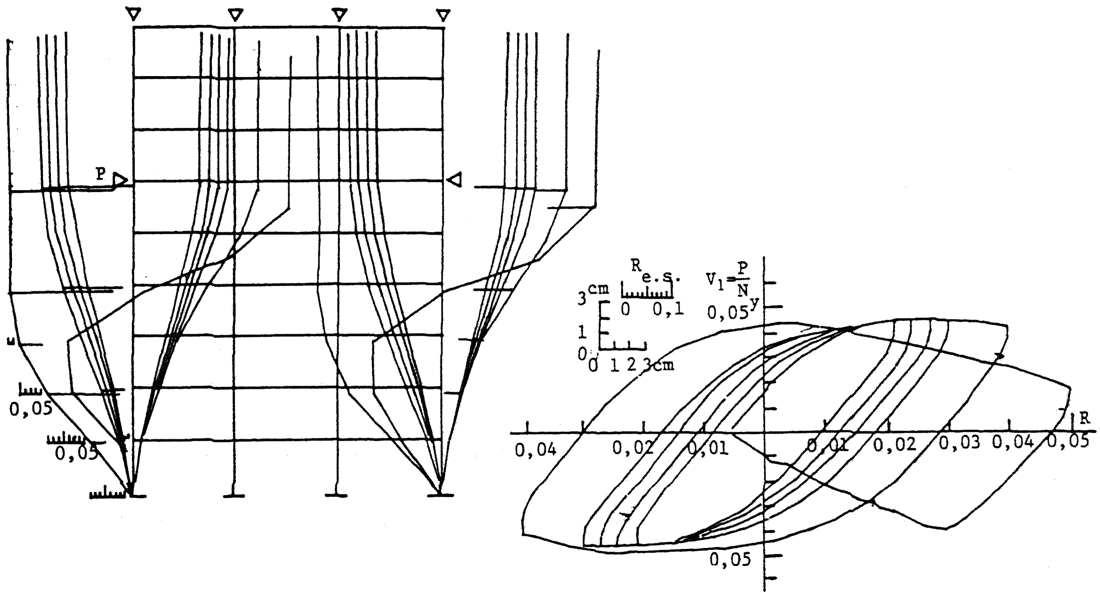


Figure 4(b). Ultimate deformation of 10-story 3-span steel rigid frame at fracture.

5 DISCUSSIONS

In order to present an evaluation base of ductility assurance of structures for aseismic design, the low cycle fatigue fracture limits of reinforced concrete and steel beam-columns are presented in Fig. 2 and compared with the low cycle fatigue fracture limits of corresponding unit rigid frames with or without special resisting elements like reinforced concrete shear walls or bracings in Fig. 1. Comparison between these fatigue fracture limits shows that the low cycle fatigue fracture limits of unit rigid frames in Fig. 1 lie always somewhat over that of the component beam-columns in Fig. 2, because of the most severe testing conditions are applied to the tests of beam columns i.e. under fixed ended and on the contrary the real sway angle of columns in frames are larger than fixed ended columns through the rotation of adjacent beams.

Comparison of the fracture ductility of multi-story, multi-span rigid frames in Fig. 4 with the low cycle fatigue fracture limits of unit rigid frames in Fig. 1 and that of the beam columns in Fig. 2, the low cycle fatigue fracture limits of component beam-columns in Fig. 2 covers the required ultimate story ductility in Fig. 4 and excess of this fatigue fracture limit, it may be occure the structural fracture.

Therefore, the low cycle fatigue fracture limits of component beam-columns may be available as the most reliable practical assessment condition of minimum ductility criteria.

6 CONCLUSION

Structural ductility are composed of their component story sway ductility, and story sway ductility are composed of component beam-columns. Therefore, the low cycle fatigue fracture limits of beam-columns play the most important roll on the structural ductility. For the aseismic assurance of story sway ductility, the low cycle fracture limits of beam-columns are available not only several cyclic but also monotonous one way sway deformation at $N_B = 1$ too.

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