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Autor: Yamada, Minoru / Kawamura, Hiroshi / Kondoh, Kazuo

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IV

Elasto-Plastic Cyclic Horizontal Sway Behaviours of Reinforced Concrete Unit Rigid Frames subjected to Constant Vertical Loads

Comportements élasto-plastiques de cadres en éléments de béton armé soumis à des charges verticales constantes lors de mouvements cycliques horizontaux

Elastoplastisches zyklisches horizontales Schwingungsverhalten von Stahlbetonrahmen unter konstanter vertikaler Belastung

Minoru YAMADA
Professor Dr.-Ing.

Hiroshi KAWAMURA
Wiss. Ass. Dipl.-Ing.

Kazuo KONDOH
Dipl.-Ing.

Department of Architecture, Faculty of Engineering
Kobe University
Kobe, Japan

1. INTRODUCTION

To make clear the fundamental cyclic deformation behaviors of reinforced concrete rigid frames, various constant deflection amplitude tests are carried out on reinforced concrete unit rectangular rigid frames subjected to constant vertical loads. "The Critical Strain-Point Method"[1) with the idealized cross section and the idealized material properties are applied for analysis. The computed values are compared with tested results.

2. TESTS

2-1. Test Specimens

The test specimens of reinforced concrete unit rectangular rigid frames are shown in Fig.1 (a) and (b). The length of span and height of the frames are 120cm, 60cm, respectively, and the cross section of the columns and beams are 12.5cm x 12.5cm, with reinforcement ratios of:

Series (a) p_{Beam}=1.6%, p_{Column}=0.3%;

Series (b) p_{Beam}=0.9%, p_{Column}=0.9%.

The mix proportion of the concrete is 1:2.55:3.34 with a water-cement ratio of 60% by weight with high quality portland cement and river gravel aggregate. The mechanical properties of concrete and reinforcing steels are indicated in Tables 1 and 2.

2-2. Loading and Measureing System

The test specimens are loaded in such a mechanism as shown in Fig.2. The cyclic lateral forces P are loaded by oil jacks with load cells through diagonal high tensile strength bars, and constant vertical load N is loaded by testing machine through needle roller bearings with a friction coefficient of 1/1000. The lateral sway displacement of frames are measured by dial gages fixed upon the measureing frames which are set upon the test piece at the center of the corner through knife edges and supported by roller at the opposite corner.

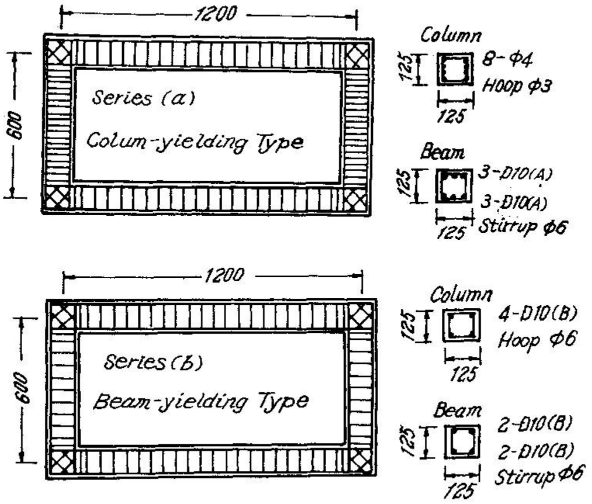

Fig.1 Test Specimen

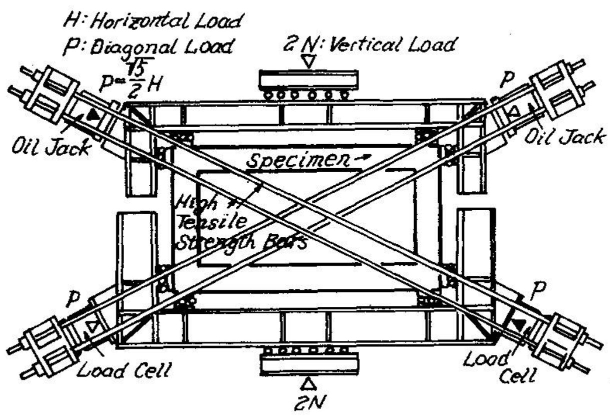

Fig.2 Loading System

2-3. Test Results

Tests are carried out on both series (a) and (b) in order to make clear the effects of constant vertical load levels and the effects of displacement amplitudes upon the deformation and fracture behaviors.

The constant vertical load level, it is selected here 1/3No and 1/6No, where No is the ultimate strength of centrally loaded column, and as displacement amplitudes ±0.100h, ±0.050h, ±0.033h, ±0.025h, where h is story height.

Test results are shown in Fig.3, the lateral sway displacement δ (in mm) or relative story displacement angle $R(=\delta/h)$ in abscissa and the lateral load $H(=\frac{2}{\sqrt{5}}P$, P:diagonal load) in ordinate.

The mark X represents the point at which the vertical resistance, i.e. the constant vertical load of column, become unable to sustain the definite constant value, namely, the collapse of frames (Figs.3 (a)-1,2,5; (b)-1,4).

CTC, CCC indicate the formation of the tensile cracks and compressive cracks at column's surface, BTC, BCC the tensile cracks and compressive cracks at beam's surface and PSC the shear cracks at the frame corner, respectively.

The deformation characteristics, cracking patterns and the fracture moodes are distinguished into two types;
Series (a) the column-yielding type,
Series (b) the beam-yielding type.

Table 1 Mechanical Property of Concrete

Specimens	$c\sigma_c$ (kg/cm²)	$c\sigma_t$ (kg/cm²)	Series
RCR:B16C03:1/3No:Ra=±0.100	340	25.8	
RCR:B16C03:1/3No:Ra=±0.050	323	25.6	Series (a)
RCR:B16C03:1/3No:Ra=±0.025	363	31.8	Column-
RCR:B16C03:1/6No:Ra=±0.100	321	26.0	yielding
RCR:B16C03:1/6No:Ra=±0.050	341	29.1	Type
RCR:B16C03:1/6No:Ra=±0.025	329	25.0	
RCR:B1C1 : 1/3No:Ra=±0.100	331	26.3	Series (b)
RCR:B1C1 : 1/3No:Ra=±0.033	317	29.9	Beam-
RCR:B1C1 : 1/6No:Ra=±0.100	320	28.9	yielding
RCR:B1C1 : 1/6No:Ra=±0.033	338	30.2	Type

Table 2 Mechanical Property of Steel

Reinforcing Bar	$s\sigma_y$ (kg/cm²)	$s\sigma_{max}$ (kg/cm²)
D-10 (A)	3900	5920
D-10 (B)	3730	5370
Φ-6	2350	3250
Φ-4	3700	4810
Φ-3	3110	4420

D: Deformed Bar Φ: Round Bar

3. ANALYSIS

3-1. Assumptions

For the deformation analysis the "Critical Strain-Point Method"[1], which was introduced by the authors, is applied. The reinforced concrete cross section is idealized into 3-Point-Model (Fig.4). The Stress-Strain relationships of concrete and reinforcement are idealized into poly-linear models (Fig.5 (a),(b)).

3-2. Bending Moment-Curvature Relationships

Bending moment-curvature relationships of reinforced concrete cross section is deduced from the critical strain point such as shown in Fig.6. As an example series (a) column-yielding type, RCR:B16C03:1/3No:Ra=±0.050, is shown.

3-3. Load-Displacement Relationships

From the moment-curvature relationships (Fig.6), the load-displacement relationships are able to be computed as a total deformation of the rotation increments of plastic hinged region and elastic deformation of other parts such as shown in Fig.7. Fig.8 shows the strain states in a cross section at column ends (hinged part). The numerals in circles in Figs.6,7 and 8 correspond to each other. The stress states in 3 parts in the cross section expressed by critical strain point in Fig.7 are indicated in Fig.8 with corresponding numerals. From these figures, the stress states in arbitrary deformation states are clearly shown.

3-4. Computed Results

The computed results by the above mentioned critical strain-point method are indicated by dotted lines in Fig.3 (a),(b) for comparison.

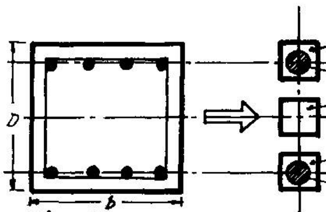

Fig.4

Idealization of Reinforced Concrete Cross Section

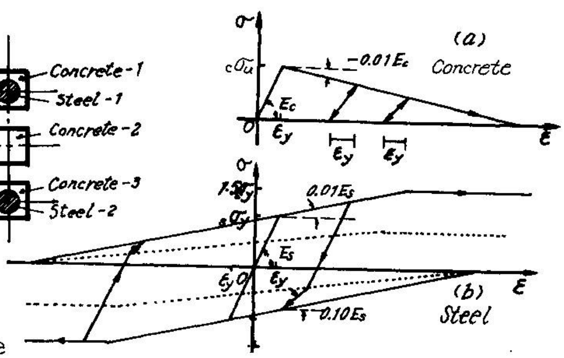

Fig.5 Stress-Strain Relationships

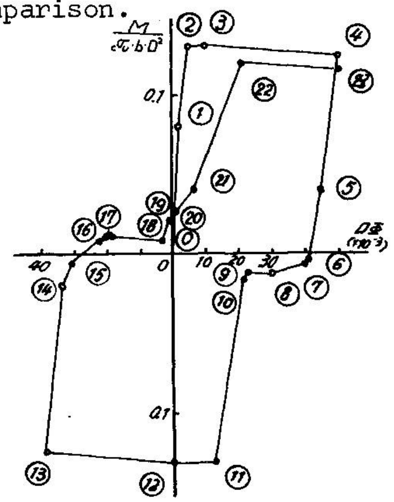

Fig.6 M-Φ Relationships

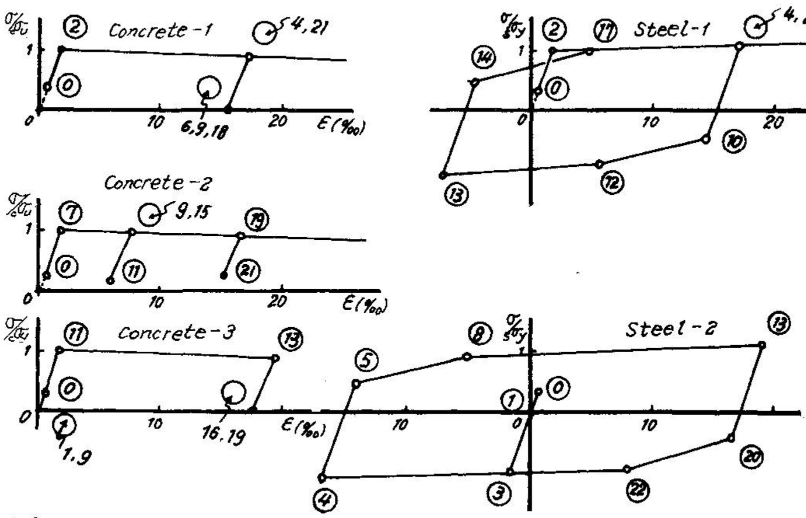

Fig.8 Process of Stress-Strain Relationships

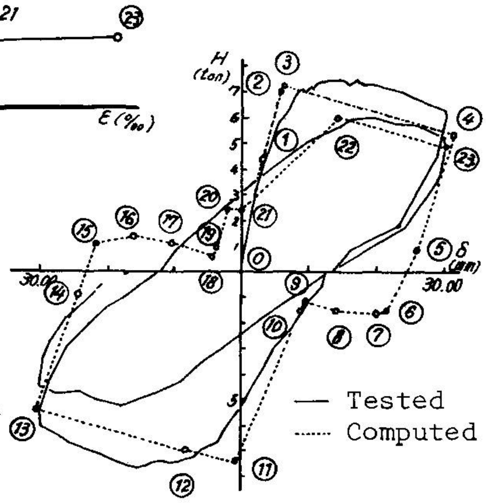

Fig.7 H-δ Relationships

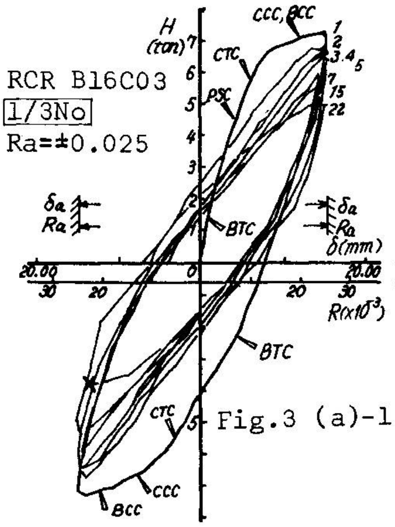

Fig.3 (a)-1

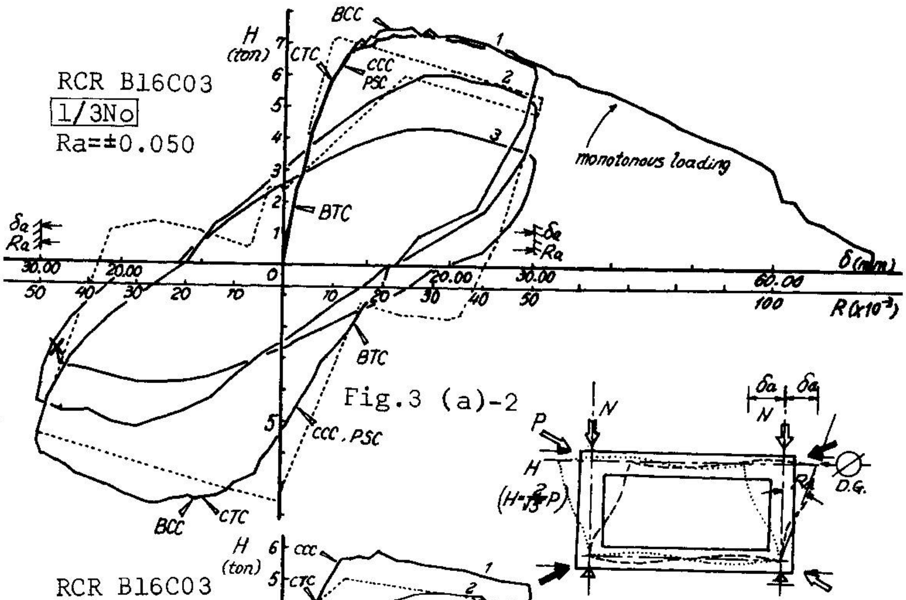

Fig.3 (a)-2

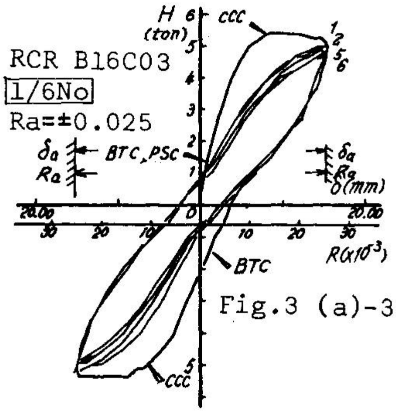

Fig.3 (a)-3

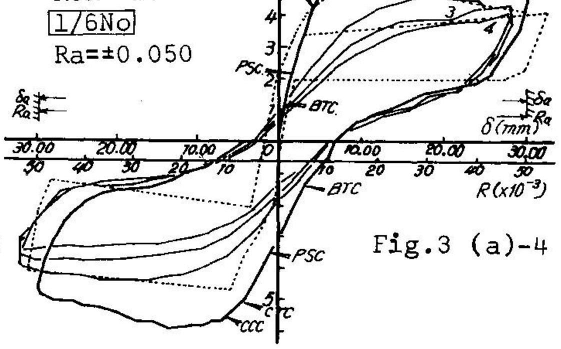

Fig.3 (a)-4

— Tested
······ Computed

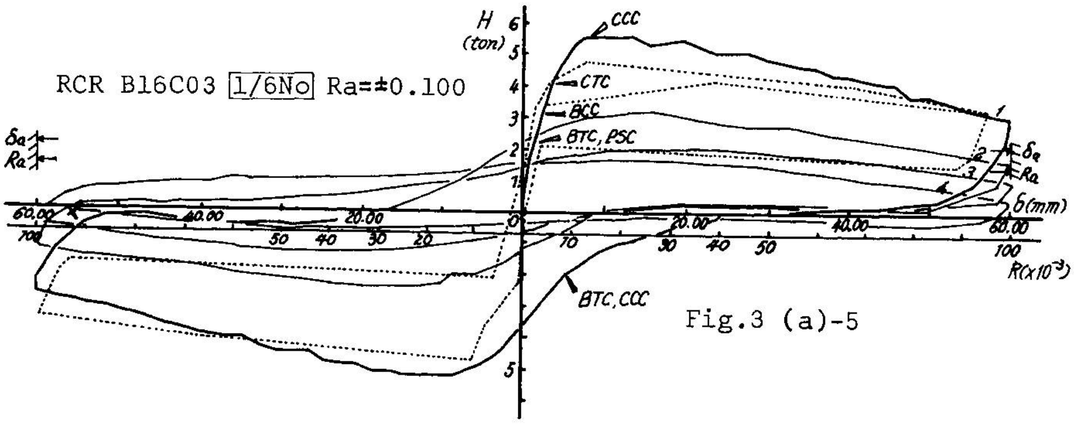

Fig.3 (a)-5

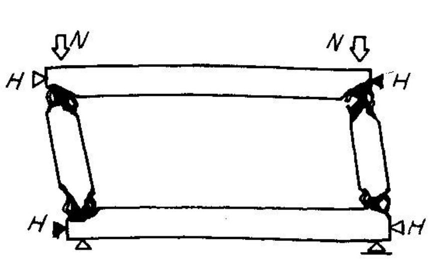

Fig.3 (a)-5** Final State

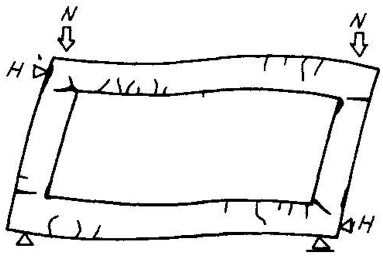

Fig.3 (a)-5* Cracking Patterns at the End of Virgin Cycle

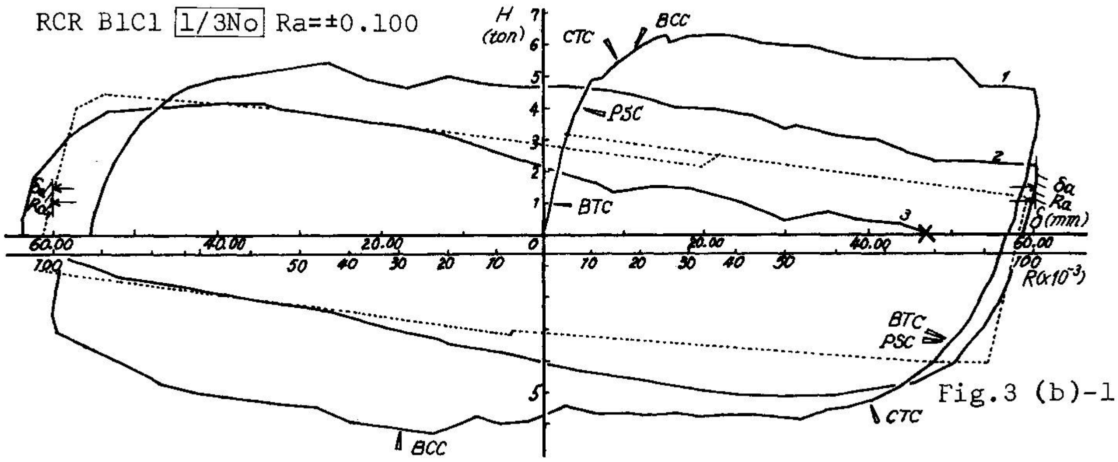

Fig.3 (b)-1

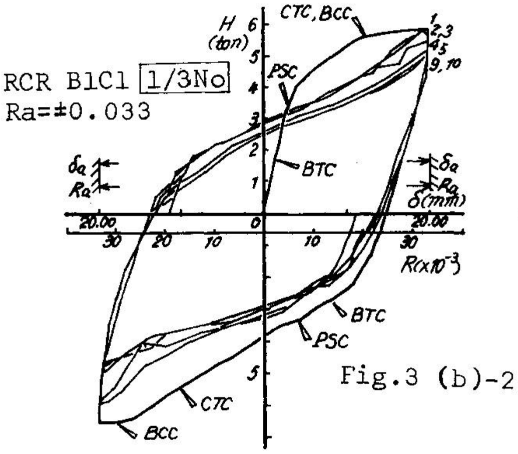

Fig.3 (b)-2

— Tested
······ Computed

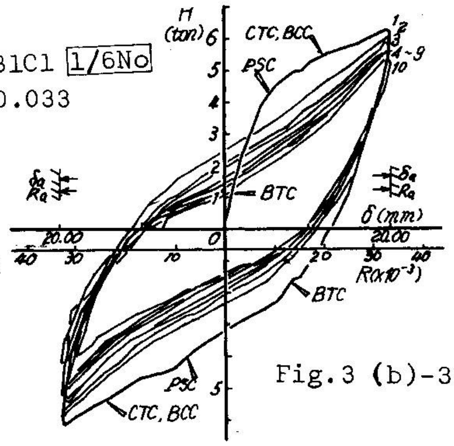

Fig.3 (b)-3

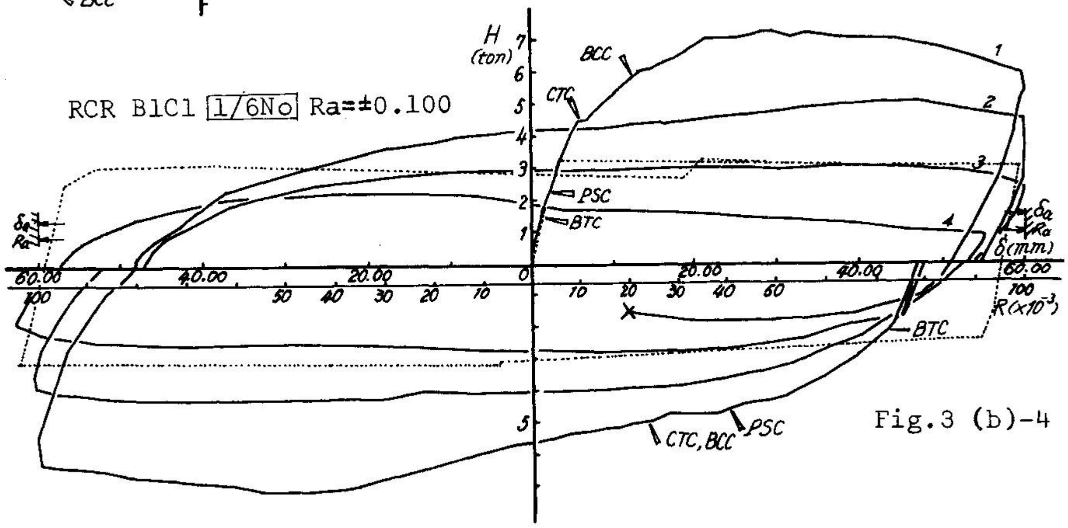

Fig.3 (b)-4

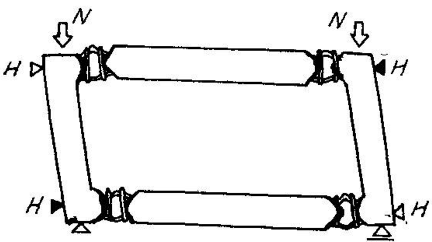

Fig.3 (b)-4** Final State

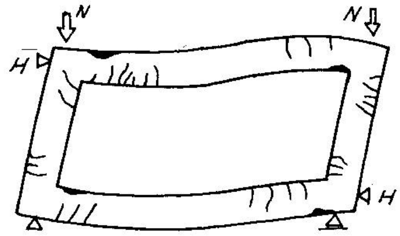

Fig.3 (b)-4* Cracking Patterns at the End of Virgin Cycle

4. DISCUSSIONS AND CONCLUDING REMARKS

In the case of the column-yielding type (a) under the constant vertical load level of 1/3No, H-δ loops show softening type and resisting capacity (H) deteriorates with the increase of the number of cycles, caused by the fatigue at the ends of columns, Figs.3 (a)-1,2.

Under the vertical load level of 1/6No, with smaller displacement amplitude such as 0.025h, H-δ loops show softening type and become steady state after several cycles (Figs.3 (a)-3). However, with larger amplitudes, 0.050h and 0.100h, H-δ loops show slipping type, and resisting capacity (H) deteriorates with the increase of the number of cycles, caused by the fatigue at the ends of columns (Figs.3 (a)-4,5).

On the other hand, in the case of the beam-yielding type (b) with larger amplitude such as 0.100h, H-δ loops show softening type, and resisting capacity (H) deteriorates with the increase of the number of cycles, caused by the fatigue at the ends of beams (Figs.3 (b)-1,4). With smaller displacement amplitude such as 0.033h, H-δ loops show hardening type, and become steady state after several cycles (Figs. 3 (b)-2,3). The differences of constant vertical load level (1/3No, 1/6No) are not so remarkable in this type (b).

In this research, the fundamental elasto-plastic deformation characteristics of reinforced concrete unit rectangular rigid frames are made clear experimentally, and the physical meanings of the load-displacement hysteresis loops are well explained by the analysis, too.

5. REFERENCES

1) . Yamada,M., Kawamura,H. :Elasto-plastische Biegeformänderungen der Stahlbetonsäulen und -balken(einseitige Biegung unter Axiallast), Abh., IVBH, Bd. 28/1, 1968, Zürich, S.193/220.

SUMMARY

Constant sway displacement amplitude tests on reinforced concrete unit rectangular rigid frames are carried out. The effects of vertical load level and displacement amplitudes upon the hysteresis loop characteristics are clarified on two series ((a) column-yielding type and (b) beam-yielding type) (Figs. 3 (a), (b)). Analytical values computed by the "Critical Strain-Point Method" are compared with test results. The coincidence between them are reasonable.

RESUME

On présente des essais effectués sur des cadres en éléments de béton armé soumis à des mouvements cycliques horizontaux. Les influences de l'intensité de la charge verticale et de l'amplitude des déplacements sur les caractéristiques de la boucle d'hystérésis sont classées en deux groupes: a) type colonne en domaine d'écrouissage, b) type poutre en domaine d'écrouissage, (Fig. 3 (a), (b)). Les valeurs analytiques obtenues par la méthode du point de déformation critique sont comparées aux résultats des essais. La coïncidence avec ces derniers est acceptable.

ZUSAMMENFASSUNG

Es werden Versuche mit konstanter Schwingungsamplitude an Einheits-Stahlbetonrahmen ausgeführt. Die Wirkungen der vertikalen Last- und Verformungsgrössen auf die Hysteresis-Schlaufe werden in zwei Serien geklärt: a) Typ des Stützen-Versagens und b) Typ des Balken-Versagens, (Fig. 3 (a), (b)). Nach der "Critical Strain-Point Method" gerechnete Werte werden mit Versuchsresultaten verglichen. Die Uebereinstimmung der Werte ist vernünftig.