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Autor(en): **Nagai, Y. / Yamagata, Y. / Karatsu, T.**

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Fatigue Testing of Reinforced Concrete Beam to Column joints

Essais de fatigue sur des joints poutre-colonne en béton armé

Ermüdungsversuche an Träger-Stützen-Verbindungen aus bewehrtem Beton

Y. NAGAI
Manager of Techn. Research
Kobe Steel Ltd.
Kobe, Japan

Y. YAMAGATA
M. Eng.
Kobe Steel Ltd.
Kobe, Japan

T. KARATSU
M. Eng.
Kobe Steel Ltd.
Kobe, Japan

SUMMARY

This paper presents experimental studies relating to the fatigue strength of reinforcing bars and anchorages in concrete structures. Beam to column joint specimens were given up to 10 million cycles of loading to study bar strength and enable the development of a reliable mechanical anchorage for repeated severe loads.

RESUME

Cet article présente des études expérimentales sur la résistance à la fatigue de barres d'armature et d'ancrages dans les structures en béton. Des échantillons de joints poutre-colonne ont subi jusqu'à 10 millions de cycles de charges pour étudier la résistance des barres et permettre le développement d'un ancrage mécanique sûr pour des charges répétées.

ZUSAMMENFASSUNG

In diesem Artikel werden Ermüdungsversuche an Armierungsstäben und an Verankerungen in Betonkonstruktionen beschrieben. Probekörper von Träger-Stützen-Verbindungen wurden bis zu 10 Millionen Mal belastet, um das Ermüdungsverhalten der Armierungsstäbe zu untersuchen. Zudem wurde versucht, eine mechanische Verankerung für wiederholte Belastungen zu entwickeln.

1. INTRODUCTION

Thread-like deformed bars which are formed by hot-rolling are anchored by a mechanical method. Anchor plates and anchor nuts are used in this method. Anchorage of reinforcing bars is the result of a coupled effect which consists of bond stress and bearing stress. Under the tensile stress state of reinforcing bars bond stress occurs between the bars and the concrete, and bearing stress on the concrete occurs through anchor plates and anchor nuts.

The method described above is different from conventional ones, such as bending or hook anchorage, and it is very useful for rationalization and saving on the expense of the field practice of reinforcement. When there are many frames with the same dimensions and details in concrete structures, for example the frames of overhead railroad bridges, this mechanical method may be of good use. Here, fatigue, caused by trains' passing through, should be discussed. However, there has as yet been little research on the fatigue of reinforced concrete structures under cycles as high as 10^7 cycles.

The purpose of this research is to investigate the applicability of this mechanical anchoring method to concrete structures under dynamic loads by carrying out fatigue tests, using reinforced concrete L-shaped frames with the mechanical anchors in beam-column joints.

2. OUTLINE OF TEST

2.1 Specimens

To investigate the fatigue behaviour of mechanical anchorage in beam-column joints of reinforced concrete L-shaped frames, six specimens for the fatigue test at six stress levels, and a specimen for the static test were prepared. Through the static test the stress of reinforcing bars imbedded in concrete and deflections of the beams were determined for the fatigue test.

The details of specimens, the list of specimens and the mechanical properties of reinforcing bars are shown in Fig. 1, Table 1 and 2, respectively.

Dimensions of the beams were 290mm x 470mm (defined as a model with about one third the scale of actual structures). The flexural tension reinforcement ratio was 0.89% (four thread-like deformed bars with a nominal diameter of 25mm). Dimensions of the columns were 500mm x 500mm. The flexural tension reinforcement ratio was 1.9% (twelve thread-like deformed bars with a nominal diameter of 35mm). Because of the placement of the bars, when the stress on the main bars in the beams reached 1,800 kgf/cm^2 at the critical section, the stress on the main bars in the columns went under 500 kgf/cm^2 at the critical section. This is the reason why it was considered that the stress on the main bars in the columns was to be under a quarter of the allowable stress of reinforcing bars (f_t) ignoring the effects of fatigue in the design of the overhead bridges of super express "Shinkansen" railroad (under 500 kgf/cm^2 in case of Grade SD35, f_t=2,000 kgf/cm^2).

2.2 Loading and Measuring

The loading point was near the end of the beams as shown in Fig. 1. In the static test for specimen No. D-AS, load reversals were controlled by the stress at the end of the top reinforcements of the beams ($_s\sigma$) and the deflection at the loading point (δ), that is, five cycles at $_s\sigma$ = 1,800 kgf/cm^2, five cycles

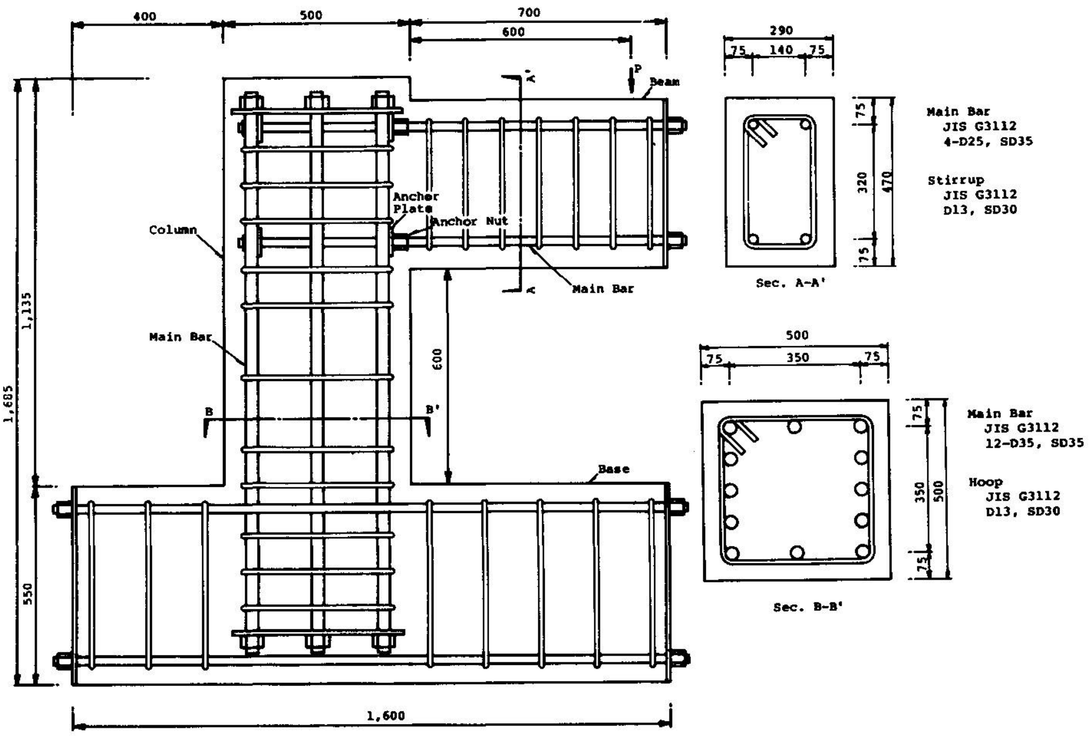


Fig. 1 Details of Specimens (in mm)

Table 1 List of Specimens

		Beam				Column			
Specimen No.	Loading pattern	Main bars	Flexural tension rein-forcement ratio (%)	Stirrups	Web rein-forcement ratio (%)	Main bars	Flexural tension rein-forcement ratio (%)	Hoops	Web rein-forcement ratio (%)
D-AS	Static	4-D25 Thread bar	0.89	D13 Spacing 100 mm	0.88	12-D35 Thread bar	1.91	D13 Spacing (mm) Upper 100 Mid. 200 Lower 100	Upper 0.51 Mid. 0.25 Lower 0.51
D-A1∿6	Partial pulsating fatigue								

Table 2 Mechanical Properties of Reinforcing Bars

Size	Grade	Section area (cm^2)	Yield strength (kgf/cm^2)	Tensile strength (kgf/cm^2)	Elonga-tion (%)	Young's modulus ($\times 10^6$ kgf/cm^2)
D35	SD35	9.57	3,950	5,750	32.4	2.06
D25	SD35	5.07	4,090	6,000	27.8	2.07
D13	SD30	1.27	3,520	5,410	28.1	2.10

at $_s\sigma = \sigma_y$ (σ_y = yield stress of reinforcing bars), to $\delta = 7\delta_y$ (δ_y = yield deflection defined as the deflection corresponding to yielding of top reinforcements).

In the fatigue tests for specimens No. D-A1 ∿ A6, repeated loads by partial pulsating were applied at six stress levels by the electro-hydraulic fatigue testing machine (Photo. 1).

Deflections at the loading point, strains in the reinforcing bars and crack patterns were measured.

3. TEST RESULTS AND DISCUSSION

3.1 Static Test

Fig. 2 shows the load-deflection relationship obtained from the static test for specimen No. D-AS. Fig. 3 shows the measured strain distribution through the main bars of the beams and the columns ((a): at $_s\sigma$ = 1,800 kgf/cm^2, (b): $_s\sigma = \sigma_y$). Fig. 4 shows the crack patterns under the yielding state of the beam (at $\delta = 4\delta_y$).

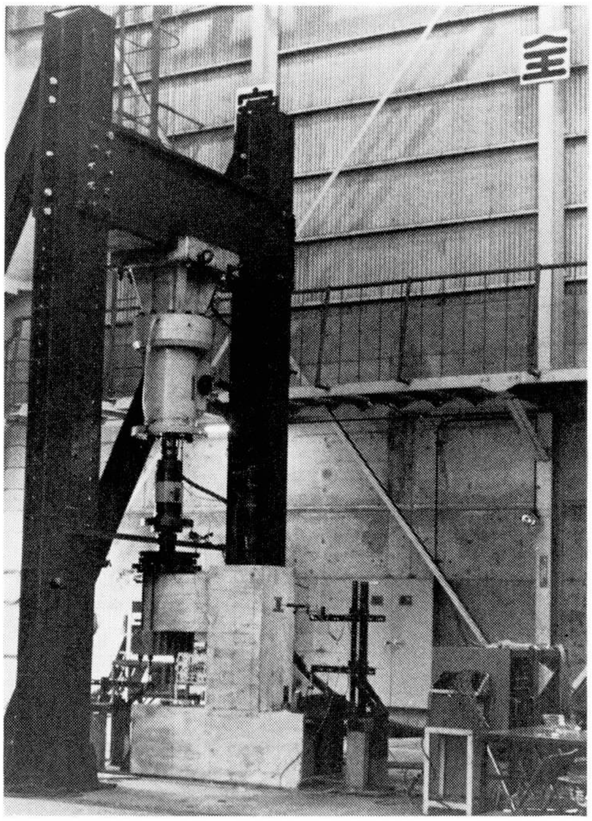


Photo. 1 Test Set-up

Typical flexural behaviour is represented in the load-deflection curve (Fig. 2). That is to say, the stiffness decreased a little when flexural tension cracks appeared. Yielding of the top reinforcements of the beam occurred and simultaneously the beam yielded. After that the frame showed much ductility.

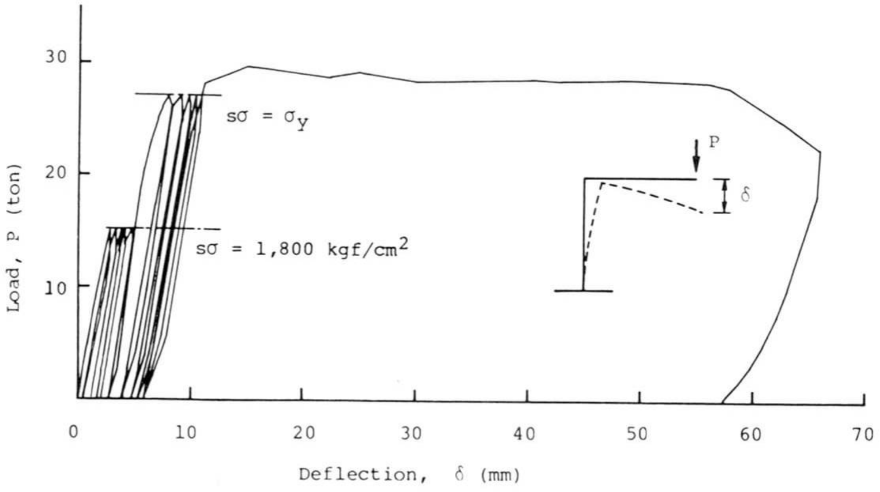
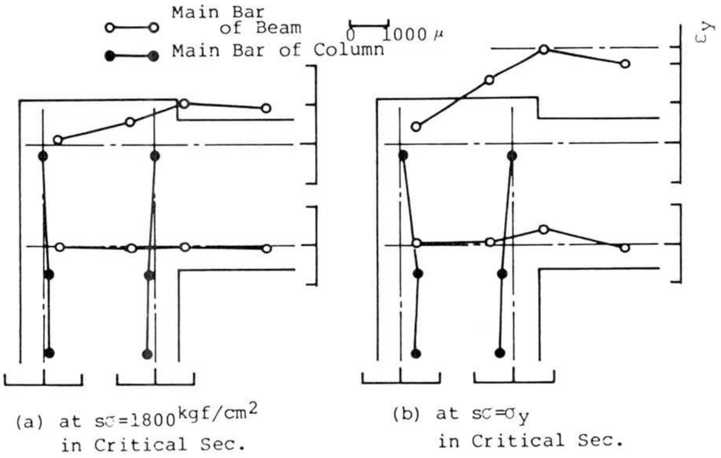


Fig. 2 Load-Deflection Curve (Static Test)

The strains in the top reinforcements in beam-column joints show triangular distribution which indicates almost no stress at the anchor nut. This proves that the anchorage of reinforcements was performed completely under cyclic loading at either $_s\sigma = 1,800$ kgf/cm^2 or $_s\sigma = \sigma_y$. And the strains in the main bars of the column remain at the level of 200×10^{-6} ($_s\sigma < 500$ kgf/cm^2) when the stress of the beam was 1,800 kgf/cm^2 (Fig. 3). This shows very clearly that the stress transmission from the beam to the column was performed smoothly by this mechanical anchorage.



(a) at $_s\sigma$=1800kgf/cm^2 in Critical Sec.

(b) at $_s\sigma$=σ_y in Critical Sec.

Fig. 3 Strain Distribution through Main Bars in Static Test

3.2 Fatigue Test

Table 3 indicates the results of the fatigue tests for specimens No. D-A1 ∿ A6 which were carried out at six amplitude levels.

The stress on the bars was determined by using the results of specimen No. D-AS and the results of the standard tensile test of reinforcing bars in the air. Table 4 indicates the results of the fatigue tests for reinforcing bars with a nominal dia. of 25mm and Grade SD35 in the air as compared to in concrete.

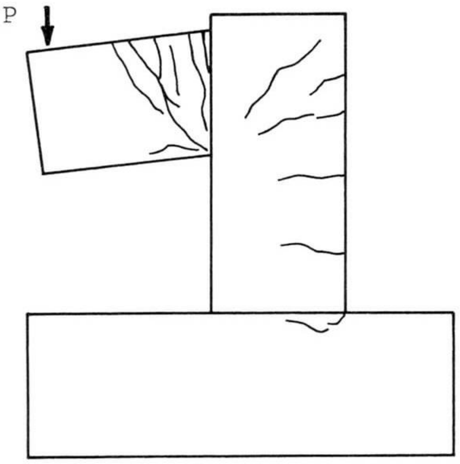


Fig. 4 Crack Pattern (at $\delta=4\delta_y$)

Several cracks were observed in the beams of each specimen and their distribution was almost the same. Diagonal cracks did not appear in the concrete web panels of the joints. As a matter of course the top reinforcements of the beams fractured near the critical section (see Photo. 2).

Photo. 2 Fracture Surface of Bar

Fig. 5 shows the S-N relationship between stress amplitude (σ_R) in ordinate and number of cycles to failure (N) in abscissa. In the diagram the '●' shows the test results in concrete and the '○', those in the air.

The fatigue strength of bars imbedded in concrete was 18.0 kgf/mm^2 at 2 x 10^6 cycles, and 17.0 kgf/mm^2 at 10^7 cycles. There is no significant difference between the test results in concrete and those in the air.

Fig. 6 shows the strain distribution through the top and bottom reinforcements in the beam of specimen No. D-A2, which was measured at the upper limit stress of the first, of the 50 x 10^{3}th, then of the 100 x 10^{3}th and finally of the 200 x 10^{3}th cycle. According to Fig. 6 the strains in the reinforcing bars in the joints were nearly constant, independent of the increase in the number of cycles and they were about zero at the end of anchorage. This shows that the deterioration of the performance of the anchorage in the joints never occurred and the reinforcing bars didn't slip even under dynamic-repeated loads.

It may be concluded that this mechanical anchorage with thread-like deformed bars, anchor plates and anchor nuts is excellent and appropriate from the point

Table 3 Results of Fatigue Tests (in Concrete)

Specimen No.	Concrete compressive strength (kgf/cm^2)	Load (ton)		Stress of bar at critical section (kgf/mm^2)			Repetition frequency (Hz)	Number of cycles to failure ($\times 10^3$ cycle)
		P max.	P min.	σ max.	σ min.	σ_R		
D-A1	409	22.6	1.0	28.17	1.17	27.00	1.5	172
D-A2	360	20.0	1.0	24.89	1.17	23.72	1.5	559
D-A3	413	17.1	1.0	21.19	1.17	20.02	1.5	798
D-A4	364	16.3	1.0	20.17	1.17	19.00	1.5	1,470
D-A5	428	15.4	1.0	19.16	1.17	17.99	2.5	8,380
D-A6	416	13.5	1.0	17.17	1.17	16.00	2.5	over 10,000

Table 4 Results of Fatigue Tests (in the Air)

Specimen No.	Section area (mm^2)	Load (ton)		Stress of bar (kgf/mm^2)			Repetition frequency (Hz)	Number of cycles to failure ($\times 10^3$ cycle)
		P max.	P min.	σ max.	σ min.	σ_R		
S-A1	506.7	15.0	0.1	29.6	0.2	29.4	5	224
S-A2		14.2	0.1	28.0	0.2	27.8	5	289
S-A3		13.2	0.1	26.0	0.2	25.8	8	428
S-A4		12.0	0.1	23.7	0.2	23.5	8	692
S-A5		11.2	0.1	22.1	0.2	21.9	8	1,226
S-A6		10.3	0.1	20.3	0.2	20.1	10	over 2,220

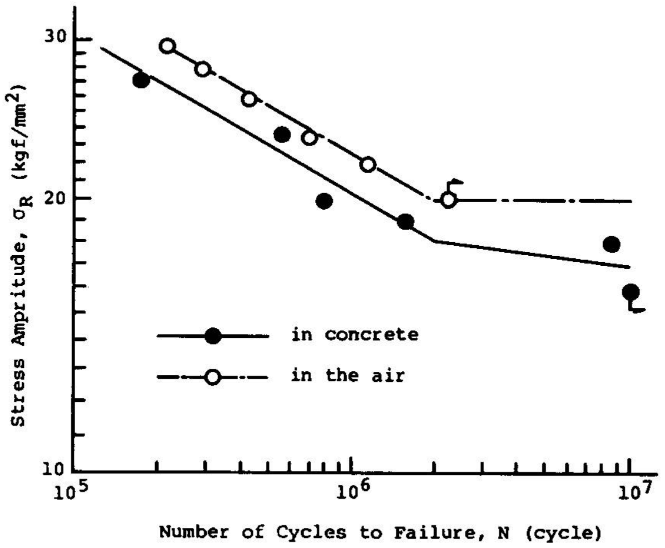


Fig. 5 S-N Diagram

of view of structural performance, and that the mechanical device for anchoring reinforcements is applicable to structures under repeated loading, such as overhead railroad bridges, as a result of the high efficiency in field practice.

4. SUMMARY AND CONCLUSIONS

The fatigue tests using reinforced concrete L-shaped frames with mechanical anchors in the beam-column joints were carried out in order to make clear the fatigue strength of bars and performance of anchorage in concrete structures under dynamic loads. On the basis of the test results presented herein, the following conclusions can be made;

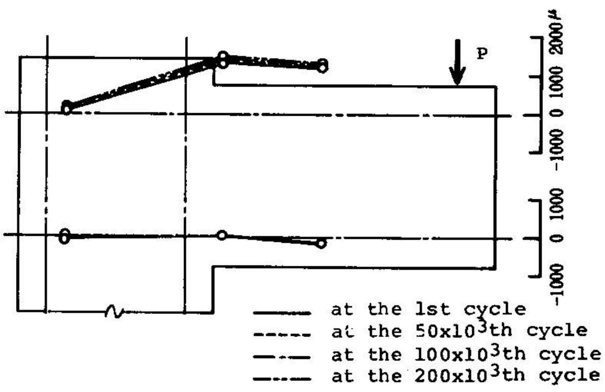


Fig. 6 Strain Distribution through Main Bar of Beam (Fatigue Test)

- The mechanical anchoring method conducted surely the L-shaped frames to the mode of flexural failure in the beams.
- The fatigue strength of the bars imbedded in concrete is nearly equal to that of those tested in the air.
- The fatigue strength of the bars imbedded in concrete is 17.0 kgf/mm^2 at 10^7 cycles.
- The deterioration of the performance of the anchorage in the joints never occurred.

- It was clarified that the mechanical anchoring method was applicable to concrete structures subjected to dynamic loads.

NOTATIONS

P	applied load	ε_y	strain in steel bar at yielding
N	number of cycles to failure	σ	stress
f_t	allowable stress of steel bar	${}_s\sigma$	stress on steel bar
δ	deflection at loading point	σ_y	yield stress
δ_y	yield deflection	σ_R	stress amplitude

REFERENCES

MIYAZAKI, S., INOUE, H.: Building Requirements of Concrete Structures in TOHOKU-SHINKANSEN, Building Code of JNR, No.37, Mar., 1971.