Japan-U.S. Science Seminar
August 23-27, 1971
Seattle, U.S.A.

On Special Types of Lapped Joints of Deformed Bars to be Used for Precast Slabs

By Hideo YOKOMICHI[1], and Yoshio FUJITA[2]

Synopsis

The effect of U type and V type lapped joints of deformed bars, which were proposed by the authors for the purpose of decreasing field concrete of a precast slab bridge, on fatigue behavior and statical strength of reinforced concrete beams was investigated. Beams with conventional lapped joints of bars and with no-joint bars were also tested for comparison. The results showed that the proposed types of lapped joints were available enough for practical use. The allowable strengths of the joints were presented in steel stresses of deformed bars for statical and repeated loadings.

Keywords: lapped joint of bar; deformed bar; flexural strength; fatigue; deflection; cracking; reinforced concrete; beam; precast slab.

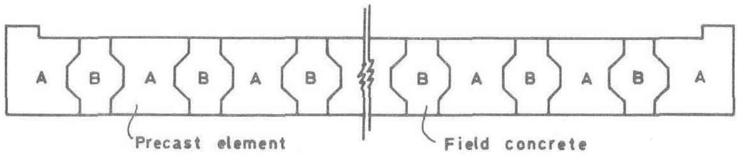
Introduction

A number of precast concrete slab bridges were constructed in Hokkaido since twenty years ago by a construction system which was developed by the author and others (1) (Fig.1 and Fig.2). In this system U-shaped lapped joints as shown in Fig.3 were adapted for the purpose of decreasing field concrete. The authors carried out investigation (2) (1956) on statical flexural behavior of the reinforced concrete beams using U type and V type (Fig.4) lapped joints for a round bar of nominal yield point of $24kg/mm^2$, and showed their availability as the joints of transverse reinforcements of precast slabs. The present paper describes the flexural test results on the reinforced concrete beams using the above mentioned types of no-hook lapped joints for a high strength deformed bar concerning fatigue and statical strength, deflection and cracking of beam.

Materials and Test Procedure

The early strength Portland cement was used. Seashore sand of 3.19 fineness modulus and river gravel of 25mm maximum size were used. The concrete used in the test had a gravel/sand ratio of 1.94 by weight, a weight of cement of $280kg/m^3$ concrete, a water/cement ratio of 0.55 and compressive strength of 348

1., 2. Professor of Concrete and Reinforced Concrete Engineering, Hokkaido University



Fig,1 Section of precast concrete slab bridge

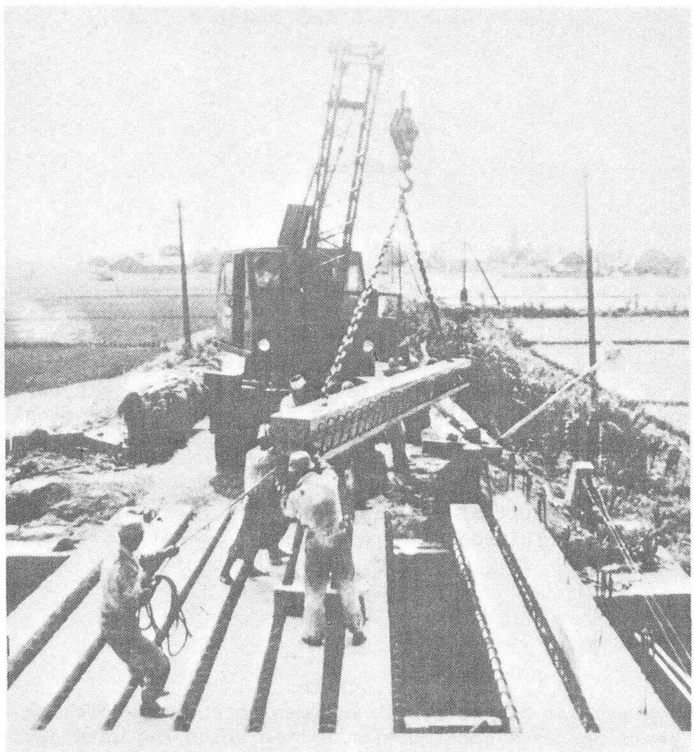


Fig.2 Precast concrete slab bridge under construction

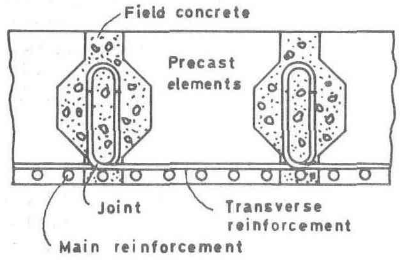


Fig.3 U-shaped lapped joint

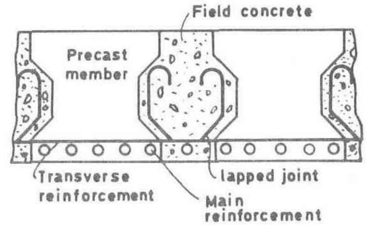


Fig.4 V type lapped joint

to 455kg/cm^2 at the beam tests, the age varying from 35 to 130 days.

Table 1 Bond test results on bottom bar of ASTM (bar dia.:16mm, concrete strength:400kg/cm^2)

Reinforcing bar	Mean bond stress as far as loaded end slip of 0.25mm (kg/cm^2)	Max. bond stress (kg/cm^2)
Twisted bar	77	141
Deformed bar with transverse ribs	67	143
Deformed bar with oblique ribs	70	145

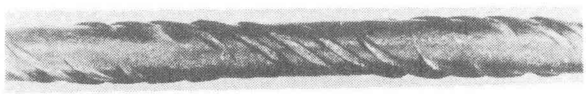


Fig.5 Tested bar

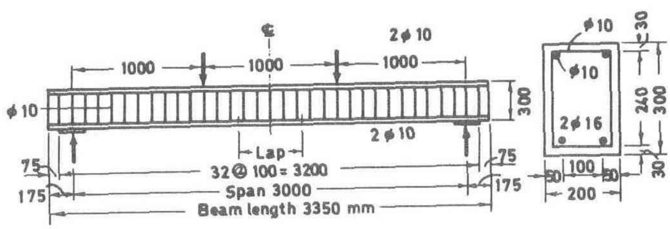


Fig.6 Test beam

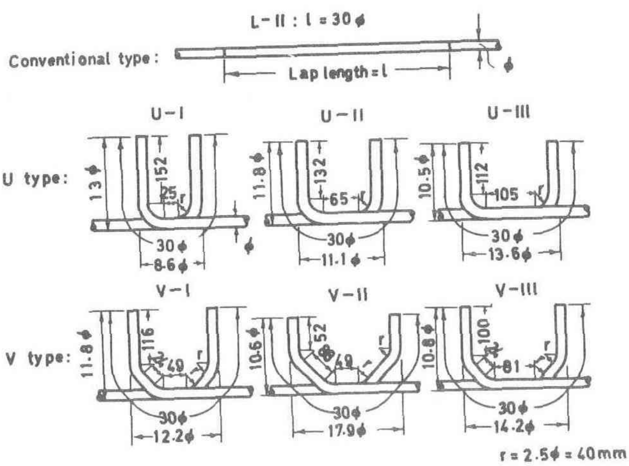


Fig.7 Details of bar joints

As the reinforcement in the test, in order that ultimate strength of beams may be controlled by the bond failure of the bar splices used in the beams, the author employed twisted bar which had the highest strength, nominal yield point of 40kg/mm^2, among deformed bars produced in Japan. Its pattern was shown in Fig.5. Bond strength of the twisted bar which was tested on bottom bar of ASTM was shown in Table 1 and was the same class as compared with some types of deformed bars having typical patterns in Japan.

As shown in Fig.6 16 beams, in total, having a rectangular section of 20 × 30cm, an effective depth of 27cm and a span of 3m were tested with loads at third points of the span as simply supported beams. All the test beams had 2 bars of 16mm diameter as the reinforcements.
16 beams had a lapped joint in each bar at the span center.
2 beams without any bar joint were also tested

for comparison.

As shown in Fig.7 the bar joints used were no-hook U type lapped ones which varied in lap length, and V type lapped ones which varied in length of both horizontal and diagonal parts of lap. The total length of bar of joints was kept constant at 30 times ϕ, where ϕ is the bar diameter. The conventional no-hook lapped joint whose lap length was 30 times ϕ was also tested for comparison. The above mentioned lap length of 30 times ϕ corresponds with the value at allowable bond stress of 27kg/cm² and allowable steel stress of 2400kg/cm² in the calculating formula of

$$l = \frac{a\ \sigma_{sa}}{3/4\ u\ \tau_{oa}} = \frac{\sigma_{sa}}{3\ \tau_{oa}}\ \phi$$

where l is the lap length, a is the cross section and u is the circumference of the individual bar, and σ_{sa} is the allowable steel stress.

The test beams were cured in a water tank for 2 weeks, the temperature being regulated at 20°c, and then were took out and stored in the test room until tested at any age from 38 to 130 days.

Beam tests were carried out by Losenhausen type fatigue machine. Eight beams were statically loaded and the others were tested under repeated loading at the rate of 250 cycles per minute. In fatigue tests, the ratio of minimum load to maximum load was set to 0.25. The maximum range of loads was set first to any of 2200, 2600, 3000, and 3400kg/cm² in steel stress and subsequently it was raised by 400kg/cm² every 10^6 cycles of repeated loading until fracture.

Test results and considerations

FLEXURAL STRENGTH

First, statical test results were as shown in Table 2 which showed that conventional lapped joint (L-II) and V type lapped joints except V-I had scarcely effect on the strength of reinforced concrete beam. In cases of U type lapped joints and V-I lapped joint, however, the bond failure of lapped joint was

Table 2 Statical beam test results

Test beam No.	Joint		Concrete Strength	Yielding load		Ultimate load
	type	lap length (in dia)	(kg/cm²)	My (tm)	calculated steel stress σ_{sy}(kg/cm²)	Mult (tm)
4016	no joint		396	4.89	5220 1)	5.85
4021	L- II	30	433	4.69	4980 1)	5.52
4024	U- I	8.6	434	(2.95)	3140 3)	2.95
4026	U- II	11.1	448	(3.60)	3880 3)	3.60
4028	U- III	13.6	387	(3.67)	3880 3)	3.67
4030	V- I	12.2	424	(4.00)	4280 3)	4.00
4032	V- II	17.9	413	4.69	5000 2)	5.00
4034	V- III	14.2	430	4.39	4630 2)	4.65

1) fracture of concrete in compressed surface
2) do, accompanied with slip of lapped bar
3) bond failure of lapped bar

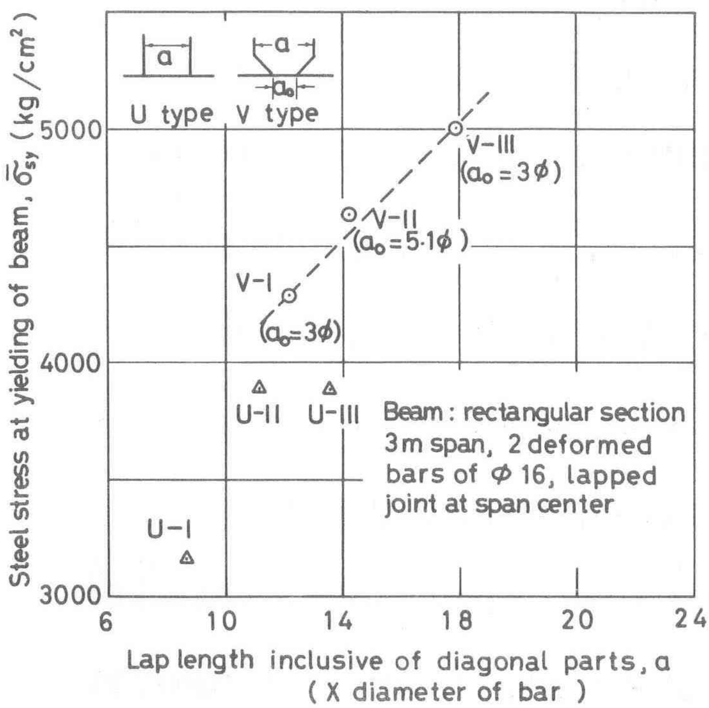


Fig.8 Relationship between beam strength and lap length of V type joint

observed, and therefore they affected considerably the strength of beam, apparent difference between yielding load and ultimate load of beam being scarcely observed. Furthermore, Table 2 shows that in case of V type joint there existed a linear relationship between beam strength in steel stress $\bar{\sigma}_{sy}$ and lap length of joint inclusive of diagonal parts of lapped bars as shown in Fig.8. This shows that the diagonal parts of bars of joint were effective to be taken as parts of lap length.

Second, fatigue test results and the view of beams after failure were as shown in Table 3 and Fig.9 respectively. Similarly as in case of statical test the conventional lapped joint and V type joints except V-I had scarcely any effect on the fatigue strength of beam, while the U type joints and V-I joint were fractured due to the bond fatigue failure of joint. Except the case where the bond failure of joint was observed the faitigue failure of beam was always caused by the fatigue fracture of deformed bar as typically shown in Fig.10.

Reffering to the authors' previous test results (3) and neglecting the effect of stress history, $\sigma_0 - N$ diagrams were drawn as shown in Fig.11, where σ_0 is maximum steel stress and N is cycles at failure. From this figure the fatigue strength of steel $\bar{\sigma}_f$ at 2 million cycles for stress ratio of 0.25 was assumed for each beam and shown in Table 3.

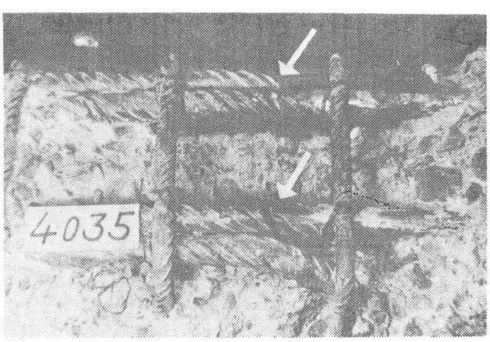
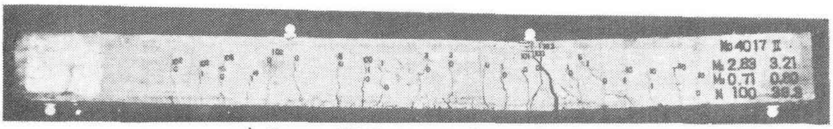


Fig.10 Fatigue fracture of deformed bars

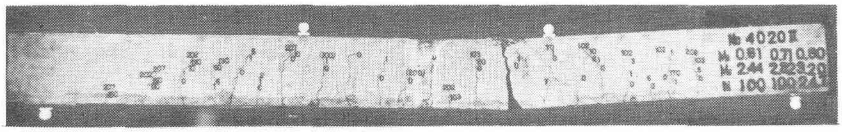
ALLOWABLE STEEL STRESSES

Table 4 shows the allowable strength of bar joint in steel stress of deformed bar. This table is calculated as follows:

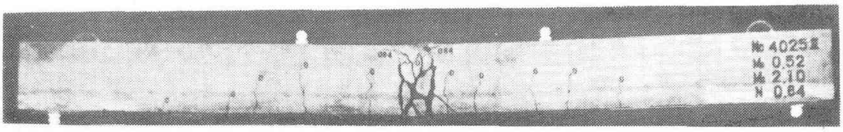
In regard to statical load, allowable stress of deformed bar is calculated by $\bar{\sigma}_{sy}/F$, where $\bar{\sigma}_{sy}$ is steel stress at yielding of beam, which is shown in



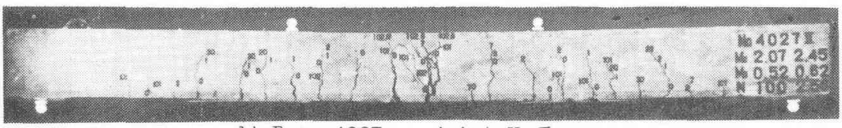
a) Beam 4017 no joint



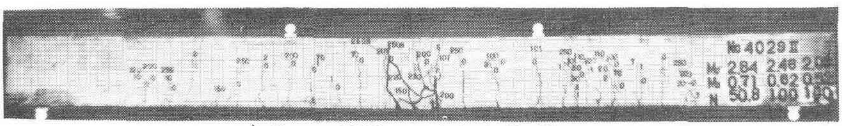
b) Beam 4020 joint L-II



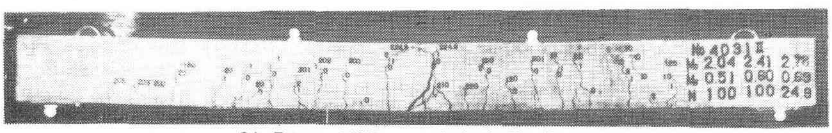
c) Beam 4025 joint U-I



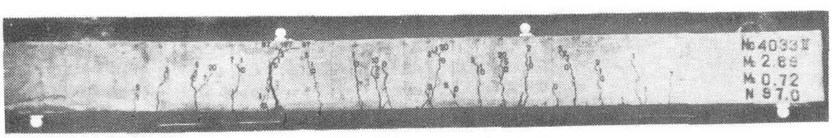
d) Beam 4027 joint U-II



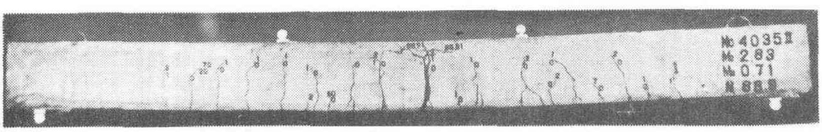
e) Beam 4029 joint U-III



f) Beam 4031 joint V-I



g) Beam 4033 joint V-II



h) Beam 4035 joint V-III

Fig.9 View of test beams after fatigue failure

Table 3 Fatigue beam test results

Test beam No.	Joint type	Joint lap length (in dia)	Concrete Strength (kg/cm^2)	Cycles of repeated load (10^3), Max. Steel Stress σ_o (kg/cm^2): 2200	2600	3000	3400	Assumed fatigue steel strength at $2\ 10^6$ cycles (S=0.25): $\bar{\sigma}_f$ (kg/cm^2)	range of stress $2\sigma_a$ (kg/cm^2)
4017	no joint		382			1000	393*	3080	2310
4020	L- II	30	409		1000	1000	247*	2980	2230
4025	U- I	8.6	383	64**				—	—
4027	U- II	11.1	455	1000	256**			2200	1650
4029	U- III	13.6	348	1000	1000	508**		2840	2130
4031	V- I	12.2	476	1000	1000	249**		2650	1990
4033	V- II	17.9	437			970*		2940	2200
4035	V- III	14.2	439			889*		2940	2200

* fracture of reinforcing bar
** bond failure of lapped joint

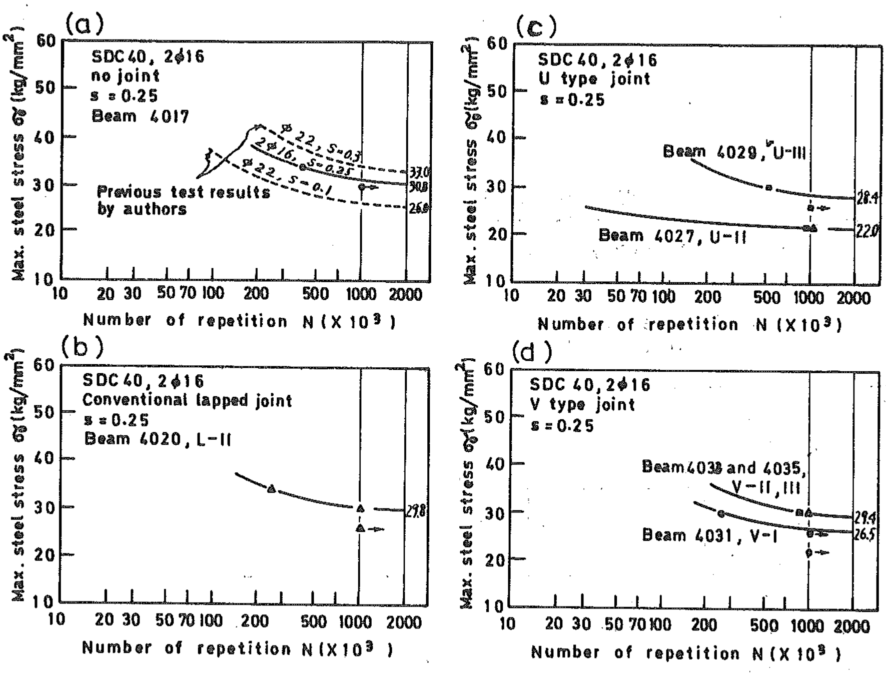


Fig.11 Fatigue test results, σ_o-N diagrams

Table 4 Allowable strength of joint in steel stress of deformed bar calculated from Table 2 and Table 3

Type of joint	Static load			Repeated load		
	$\bar{\sigma}_{sy}$ (kg/cm^2)	safety factor F	allowable steel stress $\bar{\sigma}_{sy}/F$ (kg/cm^2)	σ_f (kg/cm^2)	safety factor F	allowable steel stress σ_f/F (kg/cm^2)
U- I	3140	2.0	1570	—	—	—
U- II	3880	2.0	1940	1650	1.15	1430
U- III	3880	2.0	1940	2130	1.15	1850
V- I	4280	2.0	2140	1990	1.15	1730
V- II	5000	1.67	3000	2200	1.10	2000
V- III	4630	1.67	2770	2200	1.10	2000

Table 2, and F is safety factor. As the value of F, 2.0 and 1.67 are taken for the types of joints whose bond failure are observed and the other ones respectively.

In regard to repeated load, allowable stress is calculated by σ_f/F , where σ_f is fatigue steel strength for stress ratio of 0 and can approximately be taken as equal to range of stress, $2\sigma_a$, which is shown in Table 3. As the value of F, 1.15 and 1.10 are taken for the types of joints whose bond fatigue failures are observed and the other ones respectively.

Reffering Table 4, the allowable steel stress for U type or V type joint is proposed by the authors as shown in Table 5.

DEFLECTION

Fig.12 shows the deflection of beams under repeated loads which had a same tendency in the range of practical steel stress irrespective of existence of lapped joints. The tendency to the deflection of beam increased only in the

Table 5 Proposed allowable steel stress for U-type or V-type bar joint (bar diameter ≦ 32mm)

No-hook lapped joint		Statical load		Repeated load	
type	lap length (in dia)	allowable steel stress (kg/cm^2)	available steel quality in symbol	allowable steel stress (kg/cm^2)	available steel quality in symbol
U- I	8.6	1400	SD24	—	—
U- II	11.1	1800	SD30	1400	SD24
U- III	13.6	1800	SD30	1800	SD35
V- I	12.2	2100	SD35	1700	SD30
V- II	17.9	2400	SD40, SDC40	2000	SD40, SDC40
V- III	14.2	2400	SD40, SDC40	2000	SD40, SDC40

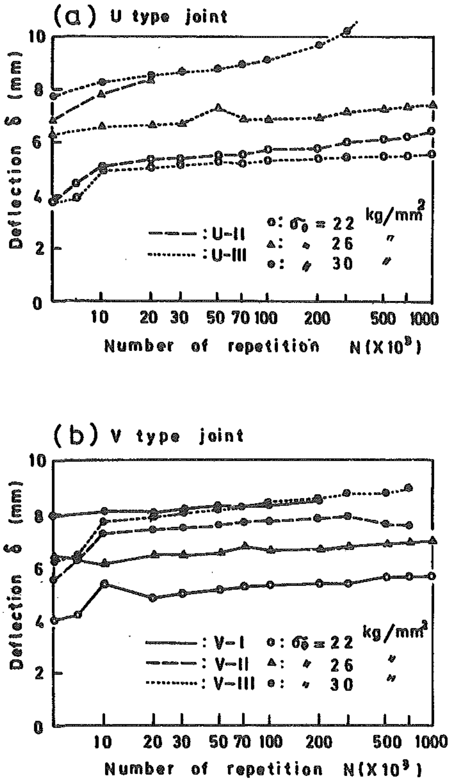


Fig.12 Deflection of beam under repeated load

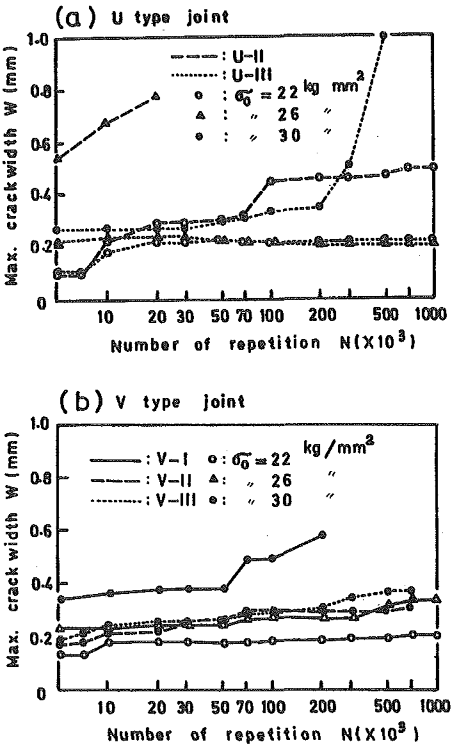


Fig.13 Maximum crack width in beam under repeated load

range below 10^4 cycles of repeated loading, but thereafter it kept balance up to just before the fracture of the beam.

CRACKING

States of crackings of beams after fatigue failure were as shown in Fig.9. The variation of the maximum crack width with repetition of loading were as shown in Fig.13. This shows that the remarkable increase of crack openings was hardly observed in beams with any type of lapped joint under repeated loads, when the maximum stresses σ_0 were kept under practical stresses.

Conclusions

It is certified that the no-hook lapped joints of U type and V type with the dimensions shown in Fig.7 can be applied to the allowable stresses shown in Table 5. The diagonal parts of bars of joints in case of V type are effective to be taken as parts of lap length. There exists a linear relationship between the lap length of V type joint inclusive of diagonal parts of bars and the statical strength of beam as shown in Fig.8. The deflection and cracking behaviors of beams having joints of U type and V type for deformed bars are stable under repeated loads, when the maximum stresses are under practical stresses.

References

(1) H.Yokomichi, M.Hayashi and K.Kitamura; On Precast Concrete Slab Bridges, Bulletin of Civil Engineering Research Institute of Hokkaido Development Bureau No.6, 1952

(2) H.Yokomichi and Y.Fujita; On Special Types of Lapped Joints of Reinforcements, CAJ Cement Gijitsu Nenpo X , 1956

(3) H.Yokomichi, Y.Fujita and T.Nishibori; Fatigue Test of Reinforced Concrete Beams using Deformed Bars, The 2nd Symposium on Deformed Bars, JSCE Concrete Library No.14, Dec. 1965