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FRACTURE AND FATIGUE STRENGTH OF SLABS REPAIRED WITH D-RAP METHOD

H.Matsushima
Dainichi Consultant Inc., Gifu, Japan
T. Watanabe
Japan Highway Public Corporation, Nagoya, Japan
M. Yasui
Nagoya Road Maintenance Co., Nagoya, Japan
W. Koyanagi
Department of Civil Engineering, Gifu University, Gifu, Japan
T. Aoki
Department of Civil Engineering, Aichi Institute of Technology, Nagoya, Japan

Abstract
Reinforced concrete slabs on the steel girders of old highway bridge get damage occasionally. Various repairing methods of damaged deck slab have been developed and adopted in site. A new repairing method of the damaged RC slabs named D-RAP method was developed where double layered pre-fabricated panels were glued on the top surface of concrete by epoxy resin mortar.

Though it is not clear how they can be fractured under static and dynamic load. However, various tests were made on the mechanical behavior of beams and slabs reinforced by this method. It were also made by fatigue tests of full scale model slabs on two alternative points. It was found that D-RAP method increased load-carrying capacity and fatigue strength as high as newly constructed slabs. These test results showed that D-RAP method is an effective reinforcing method of deteriorated slabs.
Key words: Repair, Reinforced concrete slabs, D-RAP method, Fatigue, epoxy resin mortar, pre-fabricated panels

1 Introduction

We often observe that reinforced concrete slabs get damaged occasionally. Many cracks appear at the botom of the slabs and in some cases, partial punching damage can be seen. These are caused as a result of fatigue by mainly heavy traffic load. Seepage of rainwater into concrete slabs makes the damage more serious. Various repairing methods of damaged deck slab have been developed and adopted in site. They are classified into two types. One is so-called the bottom face reinforcing method such as epoxy bonded steel plate method and epoxy bonded carbon fiber sheet method. The other is so-called the top face reinforcing method such as slab depth increase method by in-situ concrete placing where steel fiver concrete is always used.

Recently, we proposed D-RAP method newly. Figure 1 shows D-RAP method. It belongs to the top face reinforcing method, where after removal of asphalt pavement, deteriorated concrete slab surface is cut out and then pre-fabricated panels are glued on the deck slab in two layers with epoxy resin morter. Gluing epoxy resin mortar layer plays also the roll of water proofing layer on the slab and it gives the slabs a long fatigue life. "D-RAP" means Deck Restoration by Adhesive Panels. Various tests were made on the mechanical behavior of beams and slabs reinforced by this method. Small size model beam tests were made and the effects of the panel arrangement and those of ambient temperature up to 60℃ were examined. The effects of the imperfection of gluing and of the change of loading point were tested in the small size model beam tests. Fatigue tests of full scale model slab on two alternative points were also made. The property for panels and gluing morter was also examined. These test results showed that the D-RAP method is an effective reinforcing method of deteriorated slabs. It increases load-carrying capacity and fatigue strength as high as newly constructed slabs. It can also minimize the removal of old damaged slab portion. The method has been applied in several deteriorated bridge deck restoration in Japan Highway. Fundamental test results will be presented.

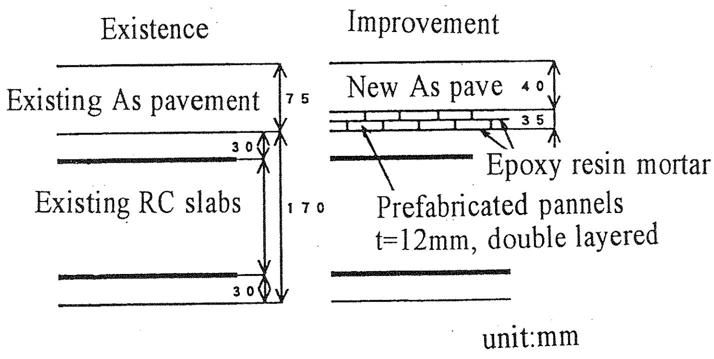

Fig.1 D-RAP method

2 Materials and methods

2.1 The purpose of this experiment

The question we have to ask here is whether pre-fabricated panels can peel off in-situ concrete before other portions destroy. We would like to examine the unification of pre-fabricated panels and in-situ concrete under static and dynamic load.

The second point that requires clarification is that there existed unclear points of materials and construction in D-RAP method. We would like to examine the following matters.

1. The effects of reinforcing by D-RAP method.
2. The effects of the pannel arrangement and joint spacing of pannel.
3. The influence of ambient temperature up to 60℃ for temperature dependence of epoxy resin mortar.
4. The effects of the imperfection of gluing.
5. The effects of the change of loading point.
6. The efects of swelling of water absorption for pannels.
7. The effects of repetition of drying wetting conditions for pannels.
8. The effects of wet ratio on contact area between pannels and concrete.

We suggest that we exmine these matters under static load and do the effects of reinforcing by D-RAP method under fatigue test using dynamic load.

2.2 Materials of static bend test

Table 1 shows the concrete mix-design. Strength of Concrete was 33.7MPa. Yield stress of reinforcing bars was 360MPa and tensile strength was 508MPa. Pre-fabricated panels were non-asbestos board with non-autoclave curing. They were 0.6×15cm in cross section and 20cm in length. The ultimate flexural strength was 29.4MPa. Glue was epoxy resin mortar that mix proportion was 3:1:8 (resin, hardening, sand) by weight.

Pannel layers were double. The joint of upper pannels shifted the joint of lower pannels each other.

Table 1. Mix design of concrete

W (kN)	C (kN)	W/C (%)	S (kN)	G (kN)	Slump (cm)
1.54	27.0	57.0	7.43	10.5	10.0

Table 2. Dimensions for specimens of small beam

Specimen	Dimension unit : cm				Reinforcing Bars
	width	Depth	Effective depth	length	
Normal concrete beam(1)	15	10	6.5	120	D10
Normal concrete beam(2)	15	11.5	8.0	120	D10
Concrete beam by D-RAP Method	15	11.5	8.0	120	D10

2.3 Static bending test

Table 2 shows the dimensions for test specimens of small beams. The span of these simply supported beams is 1.0m, subjected to two equal concentrated loads situated at L=0.375m and 0.625m respectively.

We used sticker on the pannels for the effects of the imperfection of gluing. Fig.2 shows the detail of imperfection of gluing for pannels. For the effect of swelling of water absorption for pannels, we put the specimen that had been glued by pannels into the pool for 2 days. We examined the specimen as soon as we took out them from the pool. For the effects of repetition of drying wetting conditions for pannels, we put the specimen into the pool for 24 hours and took out and left for 24 hours. We examined after their repetition of ten times and keeping the specimen dry.

We examined for the effects of wet ratio as follows. We glued pannels as soon as drying the top surface of concrete by heater. Wet ratio on the concrete was about 7%. We glued pannels as soon as drying the top surface of concrete by rubbing with a cloth. The wet ratio was 12% and it was 3% for dry specimen.

Fig3. shows static load testing method. In static test, the load was increased gradually to failure with measuring of deflection and strain of longitudinal bar and concrete, together with the observing propagation of cracks.

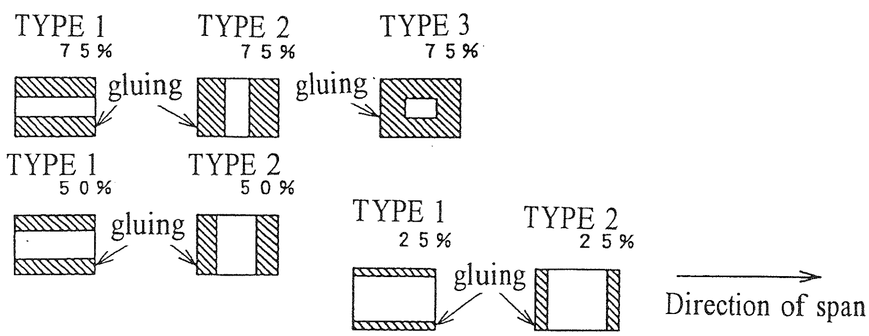

Fig.2 The detail of imperfection of gluing

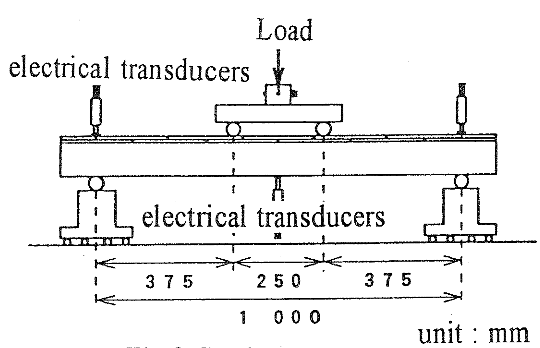

Fig.3 Static load test

2.4 Materials of fatigue bend test

Fig.4 and Table 3 shows the dimensions for test specimens of full scale slabs reinforced by D-RAP method. Srength of concrete was 31.9 MPa. Yield stress of reinforcing bars was 361 MPa and tensile strength was 529 MPa. Pre-fabricated panels were non-asbestos board with non-autoclave curing. They were 1.2×30 cm in cross section and 45cm in length. The ultimate flexural strength was 29.4 MPa. Glue was expoxy resin mortar that mix proportion was 3:1:8 (resin, hardening, sand) by weight. Pannel layers were double and the joint of upper pannels shifted the one of lower pannels each other.

2.5 Fatigue test

Each slab was simply supported on the steel round bar and the longitudinal span length was 1.5m. Transverse edges were unsupported. We applied cyclic loading of sine variation with a freguency of 4 Hz by a servo controlled fatigue testing machine with hydraulic actuators controlling the load. The vertical load on two alternative points was about 9.8kN for the minimum load. The maximum load was varied considering the failure of each test. We designed to simulate the actual traffic loads with the vertical loads on two alternative points. We also placed the water on the slabs for the confirmation of the effect of water proof. We measured the deflections, the strain of reinforcing bar and the observing propagation of cracks and penetration of water. We also applied static loading using test specimens of full scale slabs for comparison of fatigue test.

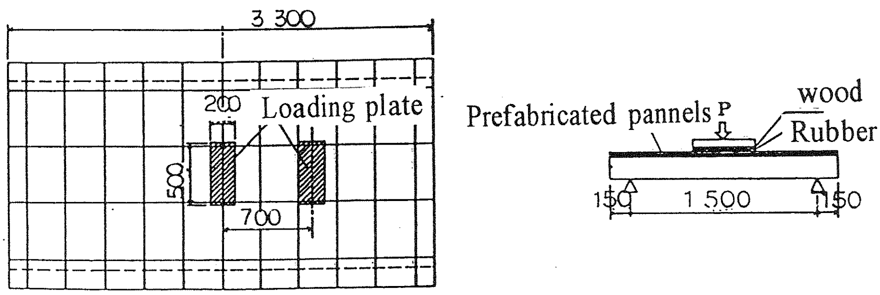

Fig.4 Full scale slabs

Table 3. Dimendions for specimens of full scale model

Specimen	characteristics	Dimension width	Depth	Effective depth	unit : cm length	Number of Specimen
1-1,2	Normal concrete	330	17	14	180	2
2-1,2	Normal concrete	330	20	17	180	2
3-1	Normal concrete	330	22	19	180	1
4-1,2,3,4,5	by D-RAP method (t=3 cm)	330	17 (20)*	14	180	5

* : total depth by D-RAP method.

3 Results and discussion of static bend test

3.1 Failure bahavior of D-RAP Method

Table 5 shows the summary of flexural loading test results. Puc was calculated for yield load. The point of stripping in failure was interior of pannels and not the bond failure between pannels and exposy resin mortar without exception. Fig.5 shows load deflection curves. Fig.6 shows the side view of the final crack patterns. Flexural test of D-RAP method indicate similar flexural behaviors as those of plain concrete without D-RAP method, excepting super development of deflection before the beam failure.

3.2 The loading arrangement

We compared the change of loading point which a=100mm, 250mm and 500mm. A=100mm means that two egual concentrated loads situated at L=0.45m and 0.55m. A=500mm means that situated at L=0.25m and 0.75m. It was found that Pyu/Pyuc were nearly same.

3.3 The effect of ambient temperature

It was known that the expoxy resin mortar had temperature dependence. We would like to know the failure behavior after unification by D-RAP method. The ultimate loads up to 40℃ were similar to one obtained in the testing condition of 20℃ but the ultimate loads in case of a higher temperature up to 60℃ decreased to 90% of the referenced result(20℃).

3.4 The effect of imperfection of gluing

The following approach was employed on the influence of enclosed air during construction. We used 3 patterns of imperfection of gluing that the ratios of gluing area were 75%, 50% and 25%. The arrangement of gluing area was classified Type 1, Type 2 and Type 3. The imperfection of gluing decreased load-carrying capacity when the ratio of gluing was 25%.

3.5 Swelling of water absorption for pannels

It is most important to emphasize that the failure mode was the stripping and that the interior of pannels changed to many layers.

3.6 Repetition of drying wetting conditions

The ultimate loads decreased to 90% of another one.

3.7 Wet ratio on contact area

It is essential to see that the failure mode was shear as soon as the stripping between pannels and concrete. It is likely that the wet ratio of 7% and 12% will cause to decrease the load carrying capacity.

3.8 Joint spacing

The ultimate loads are similar to another one. It is not clear what the different of joint spacing. We would like to emphasize that the joint spacing of pannels is weekpoint.

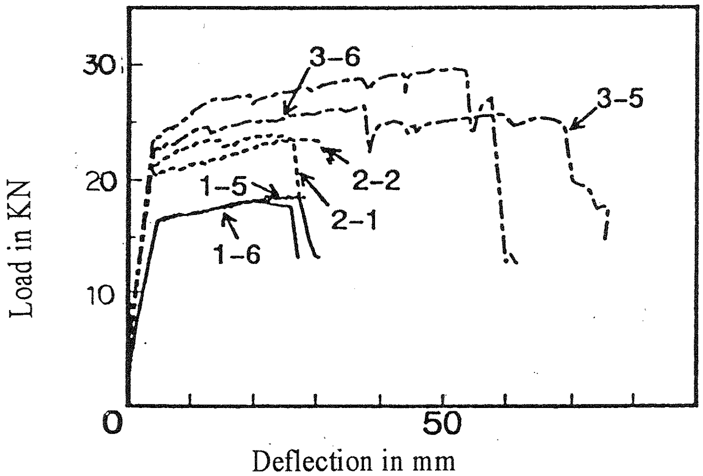

Fig.5 Load deflection curves

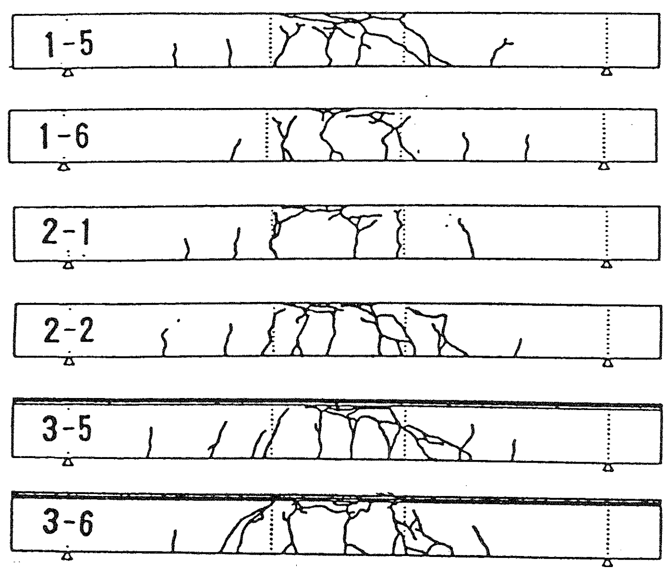

Fig.6 Final crack pattems

Table 4. Experiment cases

Specimen	Characteristics of test	Number of Specimen
1-1,2,3,4,5,6	Normal concrete beam(1)	6
2-1,2	Normal concrete beam(2)	2
3-1,2,3,4,5,6	Concrete beam by D-RAP Method	6
4-1,2	The change of loading point (a=100mm)	2
5-1,2	The change of loading point (a=500mm)	2
6-1,2	Ambient temperature up to 40℃	2
7-1,2	Ambient temperature up to 60℃	2
8-1,2	Imperfection of gluing (75%, Type 1)	2
9-1,2	Imperfection of gluing (75%, Type 2)	2
10-1,2	Imperfection of gluing (75%, Type 3)	2
11-1,2	Imperfection of gluing (50%, Type 1)	2
12-1,2	Imperfection of gluing (50%, Type 2)	2
13-1,2	Imperfection of gluing (25%, Type 1)	2
14-1,2	Imperfection of gluing (25%, Type 2)	2
15-1,2	Swelling of water absorption for pannels	2
16-1,2	Repetition of drying wetting conditions	2
17-1,2	Wet ratio on contact area (7%)	2
18-1,2	Wet ratio on contact area (12%)	2
19-1,2	Joint spacing (same point in double layer)	2
20-1,2	Joint spacing (non-joint)	2

Table 5. Summary of flexural loading test results

Specimen	Yield load Py in kN	Ultimate loads Pu in kN	Pu/puc	Deflection in mm	Failure mode
1-1,2	13.4	14.1	1.12	20.1	Compression at upper edge
1-3,4,5,6	16.3	18.5	1.14	26.0	Compression at upper edge
2-1,2	20.8	23.3	1.14	24.0	Compression at upper edge
3-1,2	17.2	20.5	1.26	38.2	Stripping with compression
3-3,4,5,6	21.7	24.5	1.30	43.0	Stripping with compression
4-1,2	14.6	18.1	1.26	38.2	Compression at upper edge
5-1,2	25.7	30.6	1.18	31.9	Stripping with compression
6-1,2	19.3	25.6	1.24	58.6	Stripping with shear
7-1,2	18.3	24.0	1.16	54.0	Stripping with shear
8-1,2	17.3	21.2	1.23	32.6	Compression of joint
9-1,2	16.8	20.4	1.15	37.6	Compression of joint & stripping
10-1,2	17.1	21.8	1.26	40.6	Compression of joint & stripping
11-1,2	20.0	24.8	1.20	59.6	Stripping with compression
12-1,2	20.2	25.3	1.22	42.7	Stripping with shear
13-1,2	20.2	24.9	1.20	24.7	Stripping with shear
14-1,2	19.4	23.4	1.13	26.2	Stripping with shear
15-1,2	17.3	19.1	1.11	32.7	Stripping
16-1,2	21.3	25.5	1.25	50.5	Stripping with shear
17-1,2	20.6	23.3	1.14	27.3	Stripping with shear
18-1,2	20.3	23.5	1.15	26.1	Stripping with shear
19-1,2	16.7	20.0	1.16	40.4	Stripping
20-1,2	17.3	21.1	1.22	33.8	Stripping

4 Results and discussion of fatigue test

Table.6 shows the test results. In the static loading of full scale models, them aximum static load of the slabs reinforced by D-RAP method increased the one of plain concrete slab of 17cm depth. The failure mode was punching shear after the development of crack radially. The deflection of D-RAP method also increased. In the fatigue test, we observed the following results. All of the slabs failed by the punching shear. Fig.7 shows the S-N curve. The ultimate strength ratio in Fig.7 is defined by the ratio of the residual static ultimate strength of the slabs. It shows that the relation between upper load ratio and number of cycles to failure. It is most important to emphasize that the failure mode is similar to that of reinforced concrete slabs. The fact suggests that design of D-RAP method is available to the design of reinforced concrete.

5 Conclusions

We made various tests on the mechanical behavior of beams and slabs reinforced by D-RAP method. The flexual loading test of beams result indicates as follows:

(1) The D-RAP method increased load-carrying capacity as high as newly constructed beams of same depth.

(2) It may be presumed that the ambient temperature up to 60℃ decreased

Table 6. Summary of test results of full scale model

Specimen	Load method	Ultimate strength in kN	Number of cycles	Failure mode
1-1	static	584	———	punching shear
4-1	static	663	———	punching shear
1-2	Fatigue	upper load 304	180,000	punching shear
2-1	Fatigue	363 431 490	2,000,000 1,500,000 250,000 sum=3,750,000	punching shear
2-2	Fatigue	431 490	2,000,000 337,000 sum=2,337,000	punching shear
3-1	Fatigue	363 431 490	2,000,000 2,000,000 3,000,000 sum=7,000,000	not failure
4-2	Fatigue	235 304 363	2,000,000 250,000 115,000 sum=2,365,000	punching shear
4-3	Fatigue	304 363 431	4,000,000 1,000,000 58,000 sum=5,058,000	punching shear
4-4	Fatigue	363 431	2,000,000 115,000 sum=2,115,000	punching shear
4-5	Fatigue	431 490	2,000,000 18,000 sum=2,018,000	punching shear

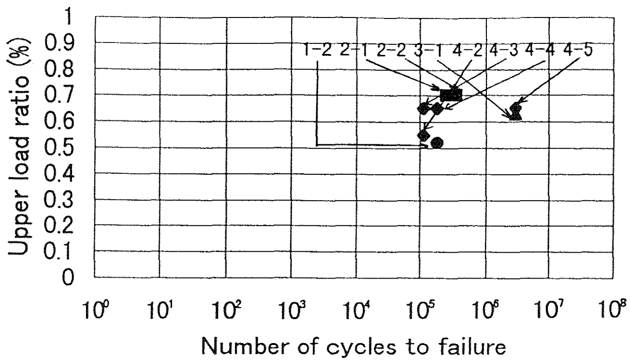

Fig.7 S-N curve

load-carrying capacity.

(3) It is clear that the imperfection of gluing decreased load-carrying capacity.

(4) The following datum is the evidence that we need to care the construction of D-RAP method during rainy day. The effects of wet ratio on contact area between pannels and concrete decreased load-carrying capacity in proportion to wet ratio.

(5) Joint spacing of pannels is week point compared with non-joint. We would like to focus attention on effective sifted double layers.

In the fatigue test of full scale slabs, we obtained the following results.

(1) The slabs reinforced by D-RAP method increased load-carrying capacity that is equivalent to newly slabs of same depth.

(2) Fatigue strength of D-RAP method is highter than that of plain concrete slab of 17cm depth and is similar to the slabs of 20cm depth.

6 Acknowledgments

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