- Technical Paper -

IMPROVEMENT OF FATIGUE DURABILITY OF RC SLABS BY EXPANSIVE AGENTS

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ABSTRACT

Usage of chemical agents to reduce crack occurrence and propagation in concrete members is well known. Due to crack inhibition they seem to be one solution for bridge decks where high durability is of prime importance. The authors selected expansive agents and PVA as suitable agents. Fatigue tests using the Wheel Load Running Machine were carried out for both types of concrete specimens.
Keywords: expansive agents, PVA, fatigue durability, Wheel Load Running Machine

1. INTRODUCTION

Movement of traffic induces fatigue loading on bridges. The most fatigue loaded elements of bridges are the deck slabs. The high number of load cycles lead to progressive damage of deck slabs resulting in spalling of bottom concrete and ultimately punching shear failure [1, 2]. The failure mechanism of RC bridge decks has been documented by fatigue tests using the wheel load running machine by Matsui [1]. Crack occurrence in concrete is a prerequisite to initiate failure under fatigue loading. These cracks occur in the form of early age cracks due to drying shrinkage and also when extreme fiber stresses exceed the modulus of rupture of concrete under external loads.

Cracking of concrete structures often seriously compromise not only structural integrity, but also durability and long-term service life [3]. In evidence, a large number of chemical agents are available to reduce crack occurrence and propagation in concrete. Expansive agents have the unique ability to provide a volumetric expansion during early setting in order to compensate for plastic and drying shrinkage. Poly vinyl alcohol (hereinafter, PVA) in contrast increases the air void content, apparent fluidity and importantly the bond strength between coarse aggregate and cement matrix [4]. Although extensively used in crack mitigation, the effect of expansive agents and PVA on fatigue durability of concrete slabs has not been studied.

The authors carried out wheel load running tests to investigate the fatigue durability of expansive and PVA concrete slabs and compared their performance under fatigue loading with normal reinforced concrete slabs, made without the addition of crack mitigating chemical agent.

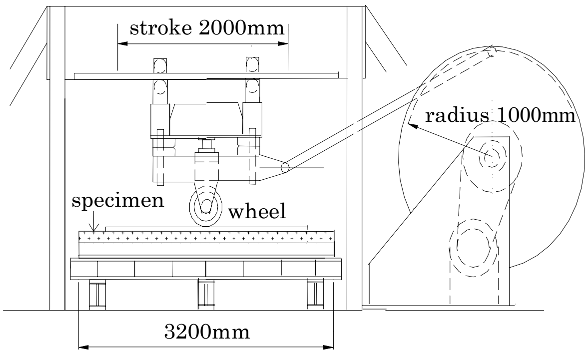

Fig. 1 Wheel Load Running Machine

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2. EXPERIMENTAL PROCEDURE

An outline of the wheel load running machine is shown in Fig. 1. The test specimens were models of real bridge slabs. Fig. 2 illustrates the reinforcement details and dimensions of the slab. A general mix design that adheres to manufacturer specifications was used and is given in Table 1. The expansive agent was added in place of equal cement content, whereas PVA was added in place of equal water content in the respective mix.

Each type of concrete was cast and cured for 10 days. The sides of the slabs were waterproofed to prevent evaporation. Strain gauges were placed at predetermined locations on main and distribution bars before casting. All specimens were tested using the wheel load running machine under simple support conditions more than 28 days after casting.

The loading program was designed using the punching shear load equation for RC slabs [5]. The running load was calculated to be 180kN for the normal RC slab to fail at the predetermined 200,000 loading cycles. The

Table 1 Characteristics of concrete mix

Concrete Type	w/c (%)	s/a (%)	Weight per unit volume (kg/m^3)							Slump (cm)	Air (%)
			Water	Cement	Gravel	Sand	Water reducer	Expansive agent	PVA		
Normal	55	45.9	179	326	979	803	3.26	-	-	16.5	4.5
Expansive	55	45.9	179	306	979	803	3.26	20	-	18.3	5.2
PVA	55	45.9	162.7	326	979	803	3.26	-	16.3	17.5	4.8

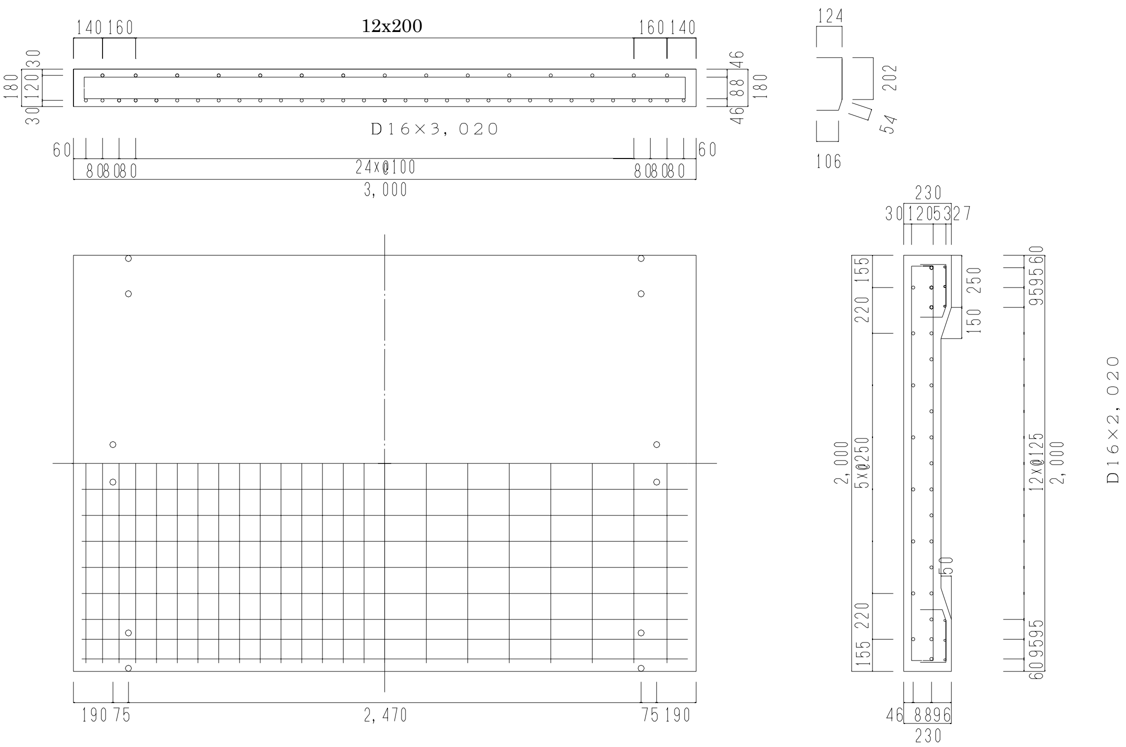


Fig. 2 Slab details

wheel was stopped at the slab center and two other predetermined locations along the longitudinal direction and displacement readings along the longitudinal and transverse sections across the slab center recorded under static loading at regular intervals. Strain readings on the top concrete surface as well as of the embedded reinforcement bars were also obtained. Crack occurrences on all surfaces were documented with the corresponding load cycle number.

3. RESULTS

3.1 Material Tests

Material test results for D16 steel reinforcement bars showed an average yield strength of 337 MPa and Young's modulus of 192 GPa. Cylinder tests for compression of concrete were carried out 28 days after casting and before the start of the wheel load running test. The results are shown in Table 2. The material properties of both expansive and PVA concrete were found to be relatively similar to normal concrete.

Table 2 Material properties

Concrete Type	Compressive Strength /(MPa)	E /(GPa)	Poison Ratio
Normal	35.3	26.3	0.15
PVA	31.9	23.7	0.18
Expansive	35.4	26.7	0.20

3.2 Fatigue Durability

The normal RC slab failed under punching shear at 59,000 cycles. Although the failure was earlier than the expected 200,000 cycles, the crack development and failure pattern was found to be similar to other normal RC slabs.

PVA when added to concrete has been found to reduce tensile stress occurrence. Tested under running wheel loads, it was

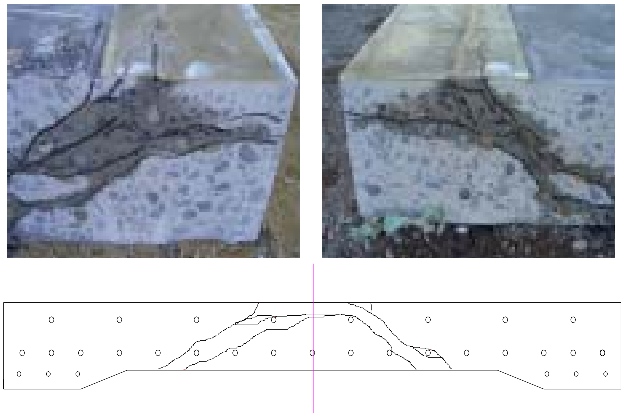


Fig. 3 Punching shear damage in expansive concrete slab section

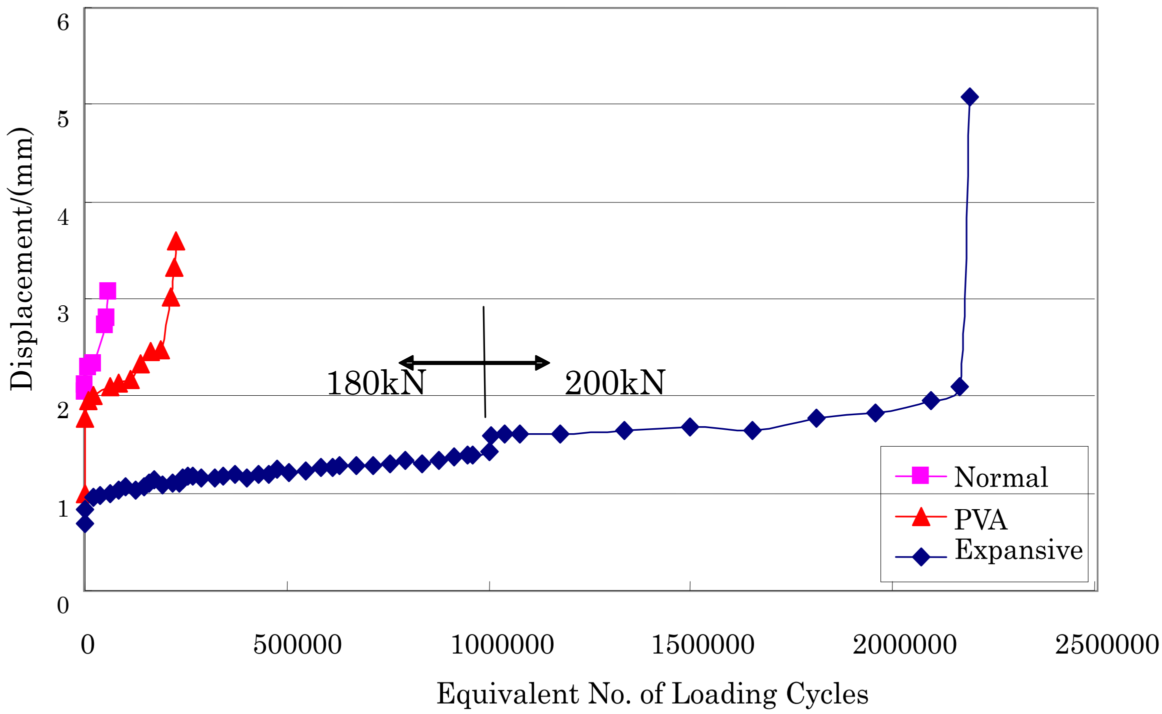


Fig. 4 Live load deflection at center

found that PVA addition had no significant impact on the fatigue durability. The PVA slab failed at 226,000 cycles under 180kN load, only slightly better than the expected failure level of a normal RC slab.

The expansive concrete slab under the same loading reached 1 million cycles without any tendency to fail, at which point the running load was increased up to 200kN. Under the increased load the slab subsequently failed at 1,310,000 loading cycles. Fig. 3 shows the mid section of the expansive concrete slab after failure. The center displacement of each slab is compared with increasing load cycle number in Fig. 4. The data of the expansive slab are converted to 180kN equivalent load cycles after 1 million cycles. The expansive concrete does not seem to deform excessively before failure in comparison to the other two slabs. Degradation under fatigue load or loss of deck stiffness is less, with the maximum deflection at failure being only 2.09mm. All three slabs appeared to fail under punching shear.

From Fig. 4 and the S-N comparison in Fig. 5 it is clear that the total loading cycles until failure of expansive concrete is more than 10 times greater than normal RC. The

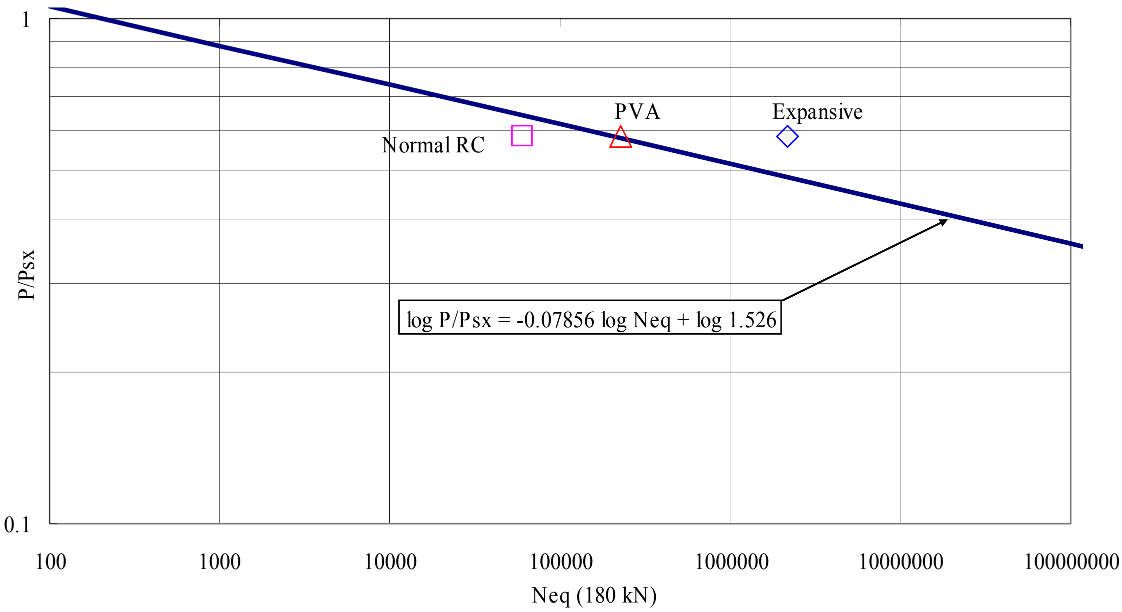


Fig. 5 S-N Relation

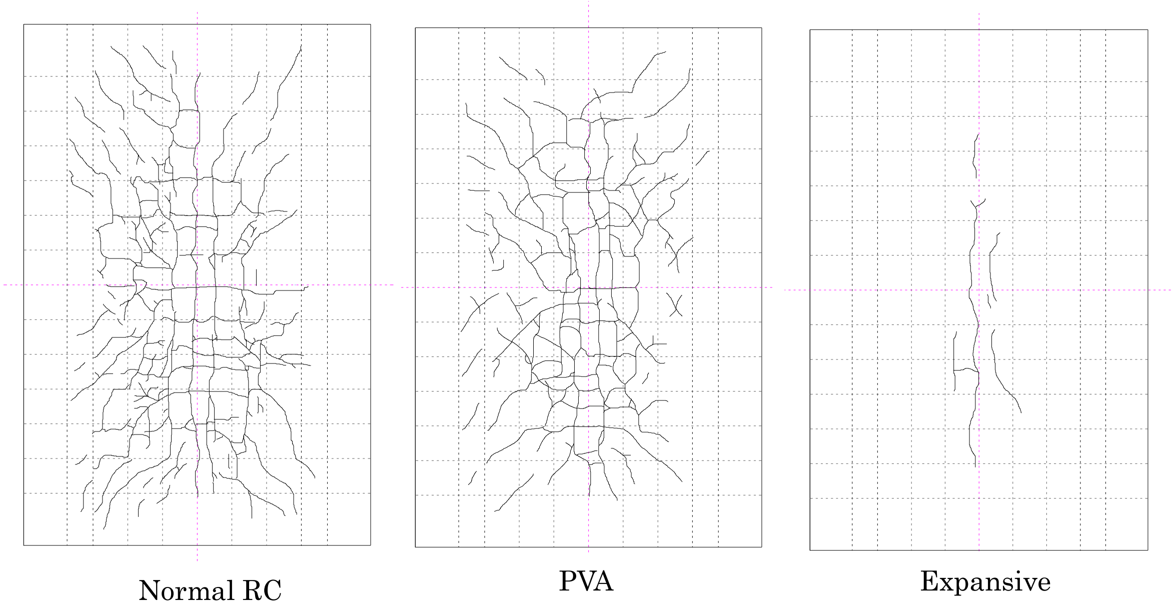


Fig. 6 Crack pattern on bottom surface at 20,000 cycles

equation in Fig. 5 indicates the S-N relation for normal RC slabs under fatigue loading developed by Matsui [1].

3.3 Crack Occurrence

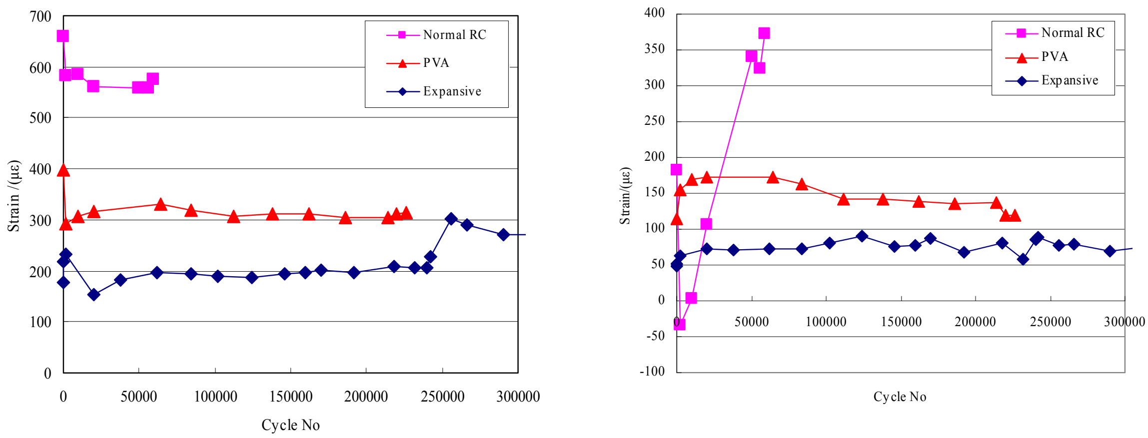
The reason for the durability of expansive concrete is visible by examining the crack occurrence on the bottom surface of each slab with increasing load cycles. Prior research have found that nearly half of the cracks that occur in RC slabs under wheel loads appear within the first 5% of cycles from the total number of cycles for failure [6]. Propagation of surface cracks cease after a finite number of repetitions of wheel loads. The crack patterns at 20,000 cycles are illustrated in Fig. 6. In comparison to the other two slabs, the expansive concrete slab showed very few cracks on the bottom surface. Even after failure of the slab, the top surface was found to be relatively free of cracks. Most of the cracks on the normal RC slab appeared by 20,000 cycles, while the PVA concrete had a similar crack pattern, but less cracks.

The final crack pattern at failure under punching shear is grid like [1, 2, 6] and seems similar in all three types of concrete. It was clear that very few cracks occurred in the normal RC slab and the PVA slab after 20,000 cycles. In the expansive concrete slab crack occurrence was found to be more linear with approximately 80% of the cracks being visible only by 1 million cycles, after which very few new cracks appeared.

4. DISCUSSION

The mechanical material properties show that PVA and expansive concrete are relatively similar to normal concrete and all slabs were seen to fail under the same failure mode when tested with the wheel load running machine. The S-N relation show that durability of expansive concrete under fatigue loading is over 10 times greater than the durability of normal RC.

Due to the initial expansion of the expansive concrete a chemical prestrain is introduced on to the reinforcement bars which in turn provide a chemical prestress to the surrounding concrete. This compressive stress offsets the tensile stresses developed during drying shrinkage. This phenomenon is thought to mitigate crack occurrence, especially during early setting period. This is clear by observing the strain occurrence in the reinforcement bars of each slab. The readings obtained from strain gauges attached to reinforcing bars near the slab center are shown in Fig. 7. From these readings it is seen that the tensile stress occurrence in the reinforcing bars of expansive concrete is relatively small when compared with the other two types of concrete. Previous research has shown that the cracking resistance of expansive concrete under flexure is significantly better than normal RC with smaller crack widths and larger crack spacing [7]. This study proves that expansive agents when added to concrete can also increase the



62.5mm from center of bottom main rebar at slab center

50mm from center of bottom Distribution bar 300mm from slab center

Fig. 7 Strain under live load in reinforcement near slab center crack resistance of concrete under fatigue loading.

The deflection of a slab is considered as a good indication of its stiffness [6]. The deflection of the expansive concrete slab is found to increase linearly while being smaller than both the normal RC and PVA slabs. The increase in stiffness of the concrete slab can be attributed to the chemical prestress induced by the prestained reinforcement.

5. CONCLUSIONS

The following conclusions were drawn from the results of the fatigue durability tests for expansive and PVA concrete slabs.

1. The durability of RC with expansive agents added was found to be more than 10 times the durability of normal RC when tested with the wheel load running machine.
2. Addition of PVA had little impact on the fatigue life of concrete deck slabs
3. Expansive agents reduce the occurrence and propagation of fatigue cracks in concrete.
4. The stiffness of a concrete deck slab is increased by the use of expansive agents resulting in smaller deflections than normal RC under fatigue loading.

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