- Technical Paper -

WHEEL LOAD RUNNING TESTS TO INVESTIGATE EFFECT OF EXPANSIVE AGENTS ON FATIGUE DURABILITY OF RC DECKS

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ABSTRACT

Effect of expansive agents on fatigue durability of RC slabs is investigated under two different support conditions. Results of fatigue tests for RC slabs under simple support conditions have been reported by the authors. These results are compared with results of expansive and normal RC slabs with composite girders tested under fixed support conditions using the wheel load running machine.

Keywords: expansive agents, fatigue durability, support condition, wheel running machine

1. INTRODUCTION

The service life of RC bridge slabs is seriously compromised by crack occurrence. Shrinkage during early setting is the primary reason for initial crack formation in concrete. Due to the larger surface area when compared with other types of structural members, reduction of shrinkage cracks in concrete slabs is crucial to ensure longer service life. The deterioration damage due to early age cracking is more prominent in the case of RC bridge decks, where crack occurrence is a prerequisite to initiate failure under fatigue loading.

The addition of expansive agents to concrete has been found to provide a volumetric expansion during early setting thus compensating for plastic and drying shrinkage. Early research on the usage of expansive concrete on bridge slabs has shown reduction in crack occurrence and slab deflection [1]. Although extensively used in mitigating early age crack occurrence, the effect of expansive concrete on the fatigue durability of RC bridge decks has not been clearly studied.

The failure mechanism of RC bridge decks under wheel loads has been well documented by fatigue tests using the wheel load running machine [2]. Results of fatigue tests for both expansive concrete and normal RC slabs under simple support conditions using the wheel load running machine have been reported by the authors [3]. The results of the tests on the simply supported slabs confirmed that the use of expansive agents can increase the fatigue durability of RC bridge slabs. Since actual bridge deck slabs are rarely simply supported, additional tests were carried out on bridge slabs under fixed support conditions.

In this report, the results of the former tests are compared with the present results of wheel load running tests for both expansive and normal RC slabs with composite girders under fixed support conditions.

2. EXPERIMENTAL PROCEDURE

The specimens used for the fatigue tests were models of real bridge decks. The reinforcement details as well as slab dimensions are identical for both slab types while the support conditions are different as shown in Fig.1. A general concrete mix design adhering to manufacture specifications was used and is given in Table 1. According to JSCE guidelines, depending on the amount expansive strain generated expansive concrete is broadly classified as shrinkage compensating concrete and chemical prestressing concrete [4]. The concrete mix utilized was of the shrinkage compensating type and the expansive agent was added in place of equal cement content.

All four slabs were cast and cured for 10 days. The sides of the slabs were waterproofed during the curing period to prevent evaporation. Strain gauges were attached at predetermined

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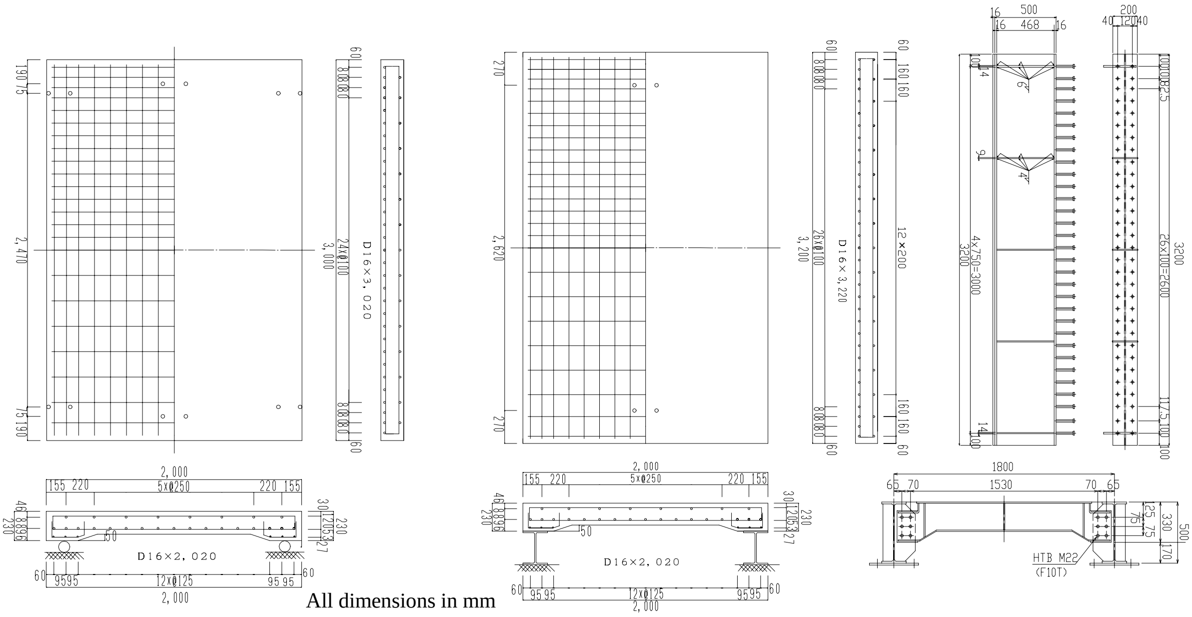
Table 1 Characteristics of concrete mix

Concrete Type	W/(C+E) (%)	s/a (%)	Weight per unit volume (kg/m^3)						Slump (cm)	Air (%)
			Water	Cement	Gravel	Sand	Water reducer	Expansive agent		
Normal	55	44.5	165	300	1019	803	3	-	16.5	4.5
Expansive	55	44.5	165	280	1019	803	3	20	18.3	5.2



(a) Simple support slab

(b) Fixed support slab and details of composite girder

Fig. 1 Slab details

locations on the main and distribution bars before casting. All four specimens were tested using the wheel load running machine under the two different support conditions.

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

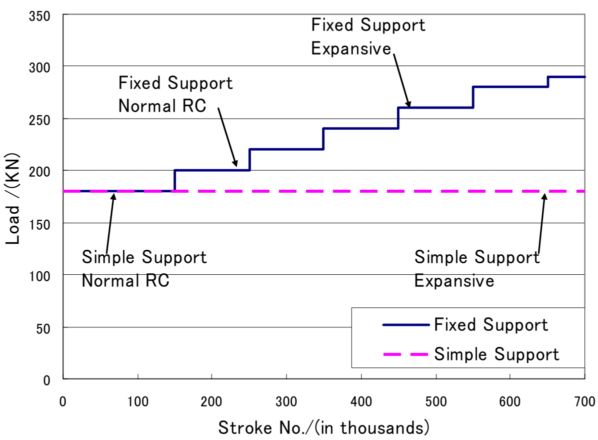


Fig. 2 Loading program

cycles. Due to the reduction of bending moment expected by fixed supports a higher durability was anticipated, and thus, a step loading program was utilized in the fatigue testing of the composite girder slabs tested under fixed support conditions. The initial load was set at 180kN and the load was increased by 20kN every 200,000 cycles after the initial 300,000 cycles. The loading program is shown in Fig. 2 with the ultimate failure position of each slab.

At regular intervals the wheel was stopped at the slab center and two other predetermined locations along the running direction and displacement along the transverse and longitudinal slab axis were recorded under static loading using dial gauges set under the slab surface. Strain readings on the top concrete surface as well as the embedded main and distribution reinforcements were also obtained. Crack occurrence on all surfaces was documented with the corresponding load cycle number. Following the wheel load running tests all the slabs were cut along the transverse and longitudinal center lines in order to evaluate the mode of failure.

Table 2 Material properties

Concrete type	Support condition	Cast date	Fatigue test date	Compressive strength /(MPa) 28 days (cast site)	Compressive strength /(MPa) During fatigue test (Osaka University)	Young's modulus /(GPa)	Poisson's ratio
Normal	Simple	29.03.2004	15.09.2004	36.3	35.3	26.3	0.15
	Fixed		19.07.2005		35.7	23.5	0.20
Expansive	Simple	08.06.2004	28.09.2004	32.6	35.4	26.7	0.20
	Fixed		02.08.2005		35.3	27.9	0.20

3. RESULTS

3.1 Material Tests

Cylinder tests for compressive strength of concrete were carried out 28 days after casting and before the start of the wheel load running test. As seen from the results given in Table 2, there was no significant difference in compressive strength although the fixed support slabs were tested nearly one year after the testing of the simple support slab, while both slabs of each concrete type were cast on the same day. The Young's modulus as well as the Poisson's ratio was found to be very similar for both concrete types. The material tests for the D16 steel showed average yield strength of 337MPa and Young's modulus of 192GPa.

3.2 Fatigue Durability

The wheel load running tests carried out on the simple supported concrete slabs showed that fatigue life can be extended substantially by the addition of expansive agents [3].The normal RC slab under simple support conditions failed in punching shear at 59,000 cycles, less than the expected 200,000 cycles. The normal RC slab under fixed support conditions had a fatigue life of 921,000 cycles in equivalent 180kN load cycles. The increase in fatigue durability is thought to be due to the reduction in maximum bending moment due to the fixed support condition. The same effect is seen in the expansive concrete slabs. The simple support expansive slab failed at 2,189,000 cycles in equivalent 180kN load cycles, whereas the fixed support slab failed at 16,004,000 cycles. It is interesting to note that the simple support expansive slab was more durable than the normal RC slab with fixed supports. From the results it is also seen that the effect of adding expansive agents provides better fatigue durability than changing the support condition of a RC slab. The variation of the center deflection with increasing load cycle number is plotted in Fig. 3. From the graph it is seen that the fixed support expansive concrete slab degradation under fatigue load or loss of deck stiffness is minimal when compared with the other slabs. The simple support expansive concrete slab and the normal RC fixed support slab had similar deflection curves under fatigue loading, but the normal RC slab displayed sudden failure upon reaching a maximum live load deflection of 1.54mm. Fig. 4 shows the S-N comparison for the tested slabs. The equation indicates the S-N relation for normal RC slabs under fatigue loading [2]. From the figures it is clear that irrespective of the support condition the expansive concrete slabs are more than 17 times durable than the normal RC slabs.

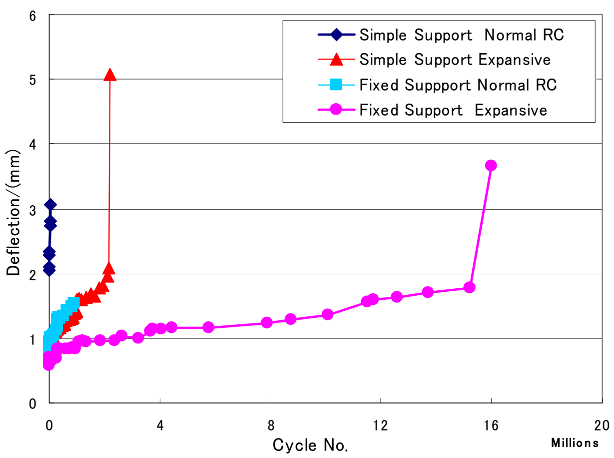


Fig. 3 Live load deflection at center

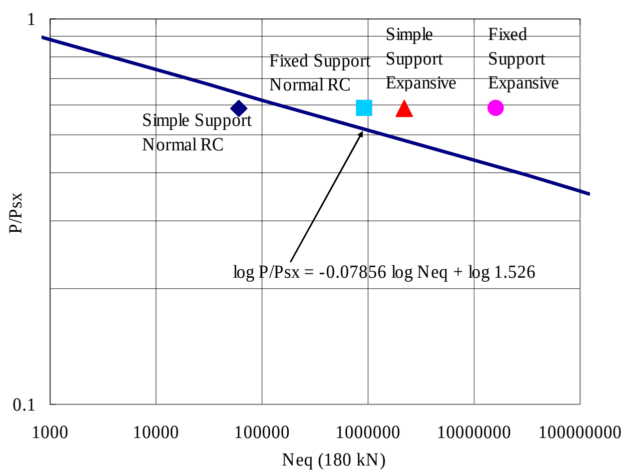
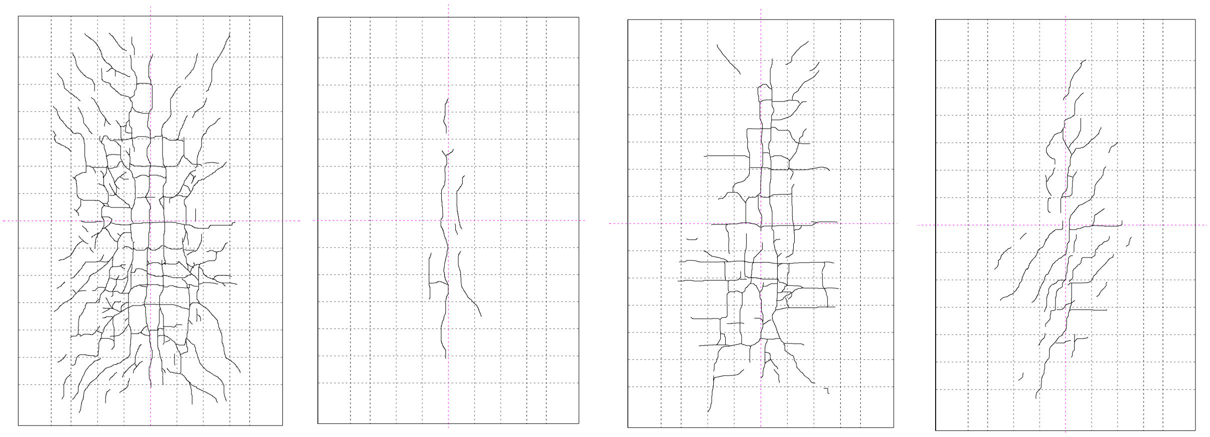


Fig. 4 S-N Relation



(a) Simple support Normal RC　(b) Simple support Expansive　(c) Fixed support Normal RC　(d) Fixed support Expansive

Fig. 5 Crack pattern on bottom surface at 20,000 cycles

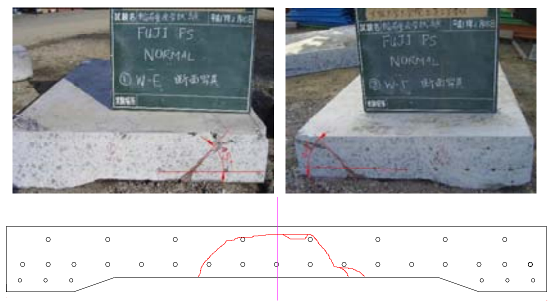
3.3 Crack Occurrence

The initial observation of all fixed support slabs before fatigue tests revealed that the expansive concrete slab had no initial cracking of any kind. In the normal RC slab cracks which are believed to be due to drying shrinkage having smaller crack width when compared with cracks occurring later due to fatigue loading were observed. Most of the early cracking had initiated at the top longitudinal edges of the slab and spread down to the side and also towards the slab center. All cracks were seen to be less than 10cm in length.

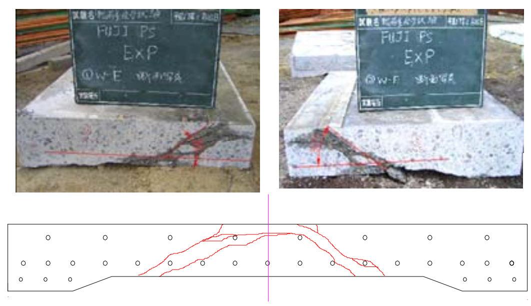
When observing the crack development while under cyclic loading, especially on the bottom surface of the slabs, it was seen that crack growth and propagation in the expansive concrete slabs were considerably small. Fig. 5 shows the crack development at 20,000 cycles on the bottom surface of the different types of slabs. Most of the cracks on the simple support normal RC slab appeared by 20,000 cycles. The initial crack development in the simple support expansive slab was less than the fixed support slab, but this was only up to approximately 100,000 cycles, after which the fixed support slab showed less crack propagation. Significantly less number of cracks was observed on the top surfaces and sides of both expansive concrete slabs. It was noted that diagonal cracks developed in the fixed support expansive slab during the initial 20,000 cycles. This is a deviation from the common grid like pattern and further testing of expansive fixed support slabs are being carried out to study this effect. The crack occurrence in the expansive concrete slabs were more linear when compared with the normal RC slabs which displayed sudden cracking during the initial loading period with relatively less crack formation at the latter stages.

3.4 Punching Shear Angle

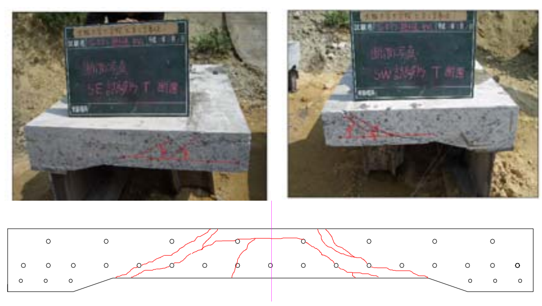
Cutting the slab along the longitudinal and transverse axis revealed that the slabs had clearly failed by punching shear. Previous research has shown that the punching shear angle decreases due to prestressing [6]. The measured punching shear



(a) Simple support Normal RC: Shear angle: 45°



(b) Simple support Expansive: Shear angle: 35°-40°



(c) Fixed support Expansive: Shear angle: 30°-35°

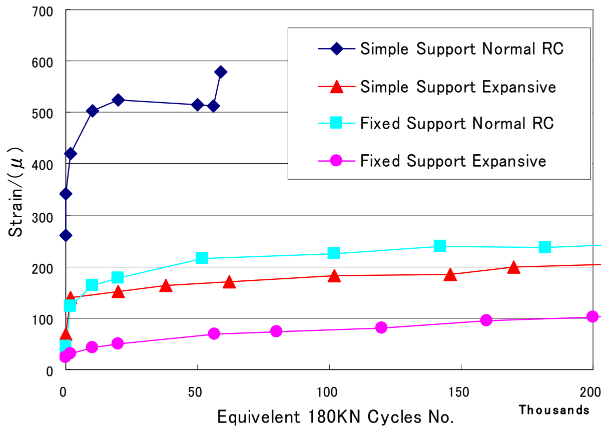
Fig. 6 Punching shear angles

angles of the expansive concrete slabs verified this fact, and the reduction in angle is contributed to the extended durability. As seen in Fig.6, the simple support normal RC slab had a shear angle of approximately 45º, while the expansive concrete slab of the same support condition had a shear angle between 35º and 40º. On the other hand, the expansive concrete fixed support slab had a shear angle between 30º to 35º. Both expansive concrete slabs had more than one crack visible on the shear surface. In the expansive fixed support slab the shear cracks were seen to extend almost up to the edge of the slab haunch. The splitting tensile failure zone was also observed to be greater than twice the cover depth. The reduction in the shear angle of the simple support expansive concrete slab is thought to be due to the prestress exerted on the slab by the reinforcement. In the case of the fixed support expansive concrete slab the additional reduction is thought to be due to the effect of composite girders with fixed supports.

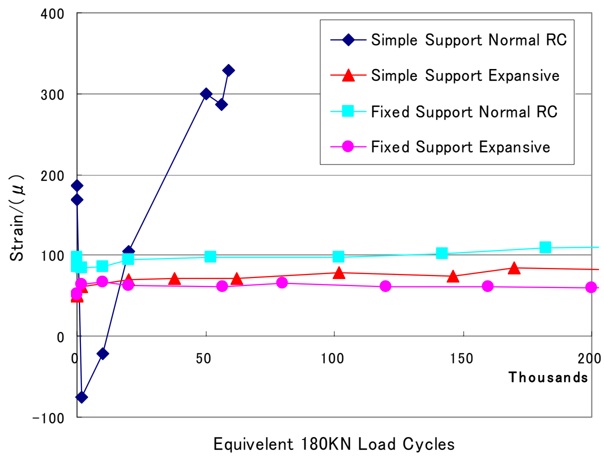
4. DISCUSSION

The material tests revealed that the mechanical material properties of expansive concrete are relatively similar to normal concrete. All slabs were seen to fail under punching shear when tested with the wheel load running machine. Although the failure mode and the crack patterns at failure on the bottom surface were very similar, both expansive concrete slabs were at least 17 times more durable than the corresponding normal RC slab under fatigue wheel loading. Cracking on the top surface and sides of the expansive concrete slabs were minimal, with just one significant crack occurring on the top of the fixed support slab.

The reduction of punching shear angle in the simple support expansive concrete slab confirmed the presence of a chemical prestress. This prestress is thought to offset the tensile stress developed during drying shrinkage. The theory can be validated by observing the strain occurrence in the reinforcing bars within the slab. Fig. 7 shows the change of reinforcement strain in a main bar and a distribution bar near the slab center. From the strain variation it is seen that the expansive concrete slabs have less tensile stress occurrence than the normal RC slabs. It is interesting to note that the reinforcement in the simple support expansive slab has less tensile stress occurrence than the normal RC fixed support slab. Thus it proves that the crack resistance of concrete under fatigue loading increases by the addition of expansive agents. It is also found that by reducing tensile stress occurrence through the use of composite girders with fixed supports can also increase the durability of RC slabs.



(a) 312.5mm from the center of bottom main rebar at the slab center



(b) 50mm from the center of bottom distribution bar 375mm from the slab center

Fig. 7 Reinforcement strain under live load

The deflection due to fatigue loading was checked to evaluate slab stiffness [7]. The deflection characteristics of the simple support expansive slab and the normal RC fixed support slab were found to be relatively similar except for the deflection at ultimate failure. Other than the simple support normal RC slab, all the other slabs displayed a linear increase in deflection with the increase of load cycle number. The rate of increase in deflection was smallest in the fixed support expansive concrete slab, which results in an extended service life. The increase in stiffness of the expansive concrete slabs are attributed to the chemical prestress induced by the prestrained reinforcement. Although it is seen that by the use of fixed support conditions the service life can be extended, it should be noted that the ultimate live load deflection for both the fixed support slabs were smaller than those of the simply support slabs.

5. CONCLUSIONS

The following conclusions were drawn from the results of the fatigue durability tests for expansive and normal RC slabs under simple support and fixed support conditions.

1. The durability of RC with expansive agents added was found to be more than 17 times the durability of normal RC, irrespective of support condition, when tested with the wheel load running machine.
2. The usage of composite girders with fixed supports increased the fatigue durability by more than 7 times. The increase for normal concrete being more than expansive concrete.
3. The addition of expansive agents in amounts to compensate shrinkage reduces the punching shear angle of reinforced concrete slabs by 5º-10º.
4. The combined use of expansive agents and composite girders with fixed supports reduced the punching shear angle by 10º-15º, thus increasing the durability by more than 100 times than that of a typical simply supported normal RC slab.
5. The addition of expansive agents reduces the occurrence and propagation of fatigue cracks in concrete.
6. 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.

As expansive concrete usage is becoming very common in bridge slab construction, in the future it will be necessary to develop a modified punching shear equation which can incorporate the chemical prestress effect and thus can accurately predict the service life of the slab. It is also recommended that further fatigue tests be carried out on expansive concrete slabs, especially simple supported slabs, in order to gather data to develop a reliable S-N relation for RC slabs with expansive agents added. The effect on the fatigue life as well as crack occurrence in the slab due to amount of chemical prestress also needs to be evaluated by changing the amount of expansive admixture.

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