MEASUREMENT AND ANALYSIS OF RC DECK DEFORMATION AFTER 27 YEARS OF SERVICE

T. SHIMADA[1*], T. MATSUMOTO[2], T. HAYASHIKAWA[2], and X.HE[2]

[1]*Graduate School of Engineering, Hokkaido University, Japan*
[2]*Faculty of Engineering, Hokkaido University, Japan*

ABSTRACT

Nowadays in Japan, there are a large number of old bridges, and their deck deterioration is a considerable problem. Examples of deck deterioration are concrete cracking, scaling, free lime, punching shear failure and rusty water, combined with fatigue or frost damage. Dealing with these damages appropriately is of capital importance to ensure the bridge security and serviceability. In this study, experimental data obtained from a field loading test of an RC deck viaduct 27 years after its construction, are analyzed and compared with numerical results of a finite element analysis. The obtained results show that the RC deck does not present important defects from the structural point of view, and no large deformations are observed.

Keywords: RC deck deformation, field loading test, static elastic analysis

1. INTRODUCTION

In Japan, many of the currently used bridges were built between 1960s and 1980s. Therefore, the number of viaducts which were built more than 50 years ago will rapidly increase in the following years, representing an important percentage of the total number of bridge structures in Japan. Due to this fact, a remarkable increase of the costs of the maintenance of these infrastructures is expected. However, given the delicate financial condition of Japan, ensuring and lengthen the service life of these structures seems to be the most adequate strategy to follow.

Focusing on the most important RC deck deterioration processes and damages, cracking due to corrosion and free lime, as well as hexagonal pattern crack and punching shear failure due to traffic cycling loads and freeze-thaw cycles, especially in cold regions could be highlighted. It is important to estimate the degree of deterioration and damage of the RC deck, and, according to this, to propose the most adequate strategies for maintenance of the viaduct, increasing the life span of the bridge and also decreasing its life cycle cost.

In this study, the field loading tests are conducted on an RC deck viaduct, which has been through 27 years since its construction. Some remarkable deteriorations such as free lime and mesh crack were observed. Therefore, on one hand, we try to get the deformation by measuring the deformation

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* Corresponding author: Email: field1013@yahoo.co.jp

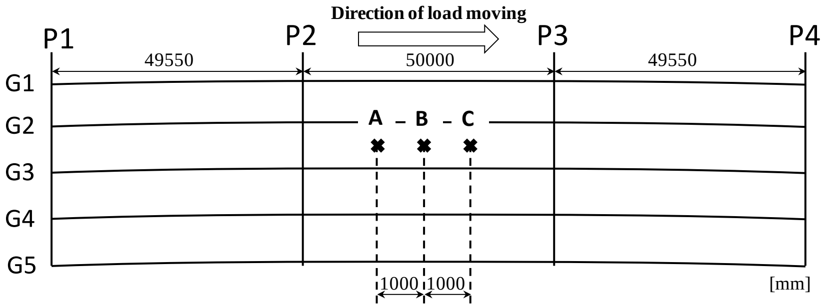


Figure 1: The viaduct ground span

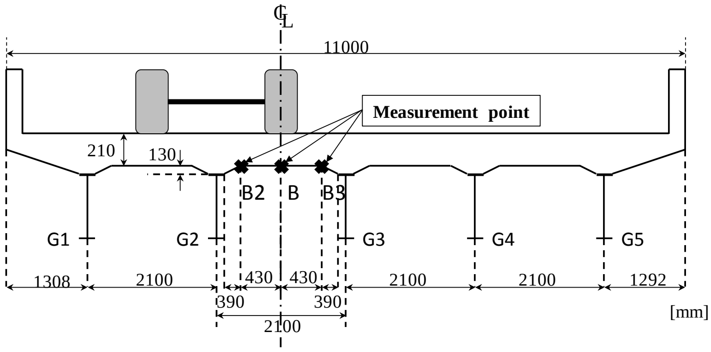


Figure 2: Cross section of the superstructure

of the deck and the width of the crack in longitudinal and transverse direction. On the other hand, we can make a comparison with the data acquired through the tests to the numerical results that are acquired by using an analytical method based on finite element analysis.

2. FIELD LOADING TEST

2.1. Viaduct and deck

The object of this study is a viaduct which was build in 1985, a three-spans continuous curved viaduct with RC deck slab supported by five steel girders. The viaduct ground span is shown in Figure 1. The cross section of the superstructure is shown in Figure 2. The measurement points were set up between P2, P3 and G2, G3. Remarkable crack and free lime was observed in this deck and already spread to the entire bridge deck. It seems that water has already permeated into the internal of the RC deck.

2.2. Measurement installation

The measurement of the deck deformation and crack width should avoid a concrete cast joint as far as possible. The measurement installation is shown Figure 3. A simply supported beam was placed on an intermediate strut, and three displacement gauges were set up on this beam. The measurement points were set up not only in the center of the deck span, but also in the end of the haunch for G2 and G3. The reason for setting up the simply supported beam on the intermediate strut is to reduce the measurement error as much as possible. When traveling load acts on the RC deck, not only the deck, but also the girder and the intermediate strut will be distorted, so that setting up the beam as such makes it possible to reduce the measurement error. Clip gauges were set up in order to measure the crack width. Each one of the cracks happened around the center of the deck in longitudinal and transverse direction was chosen to study. Clip gauges were adopted to measure it.

2.3. Loading and measurement sequence

In order to conduct the loading test, a truck was used. The dimensions of the truck are shown in Figure 4 and the weight of the truck is shown in Table 1. The front axle of the truck with two tires, while the rear axles of the truck with eight tires. Now we call the front axle as F, the rear front axle as RF and the rear rear axle as RR.

Firstly, we put the front axle of the truck in A position which is shown in Figure 1. Then we measured the deck deformation at B, B2, B3 points and measure the crack width at the chosen points. Secondly, we moved the front axle to position B and C, measure the deck deformation and the crack width again. After the measurement of the front axle was finished, the measurement of rear axles should start and the method is the same with the front axle. Only difference is that the load application point of the rear axles is defined as the middle of rear two axles.

2.4. Result

The measurement was conducted three times and values were measured respectively. The measurement result is shown in Table 2. Positive value is corresponds to the directions that the deck deformed and the crack opened.

For deck displacement, it can be confirmed that almost all displacement happened in B point, where the center of deck span, is larger than that in the end of the haunch B2, B3. Moreover, the deck displacement happened in the rear axles case is obviously larger than that in the front axle case. This is because, while the load acts on the center of deck span and the weight of the front axle is relatively smaller than the rear axles. Three points, A, B and C, were set up to observe the value of the loading test. When the load acts on B position which is right above the measuring point, the

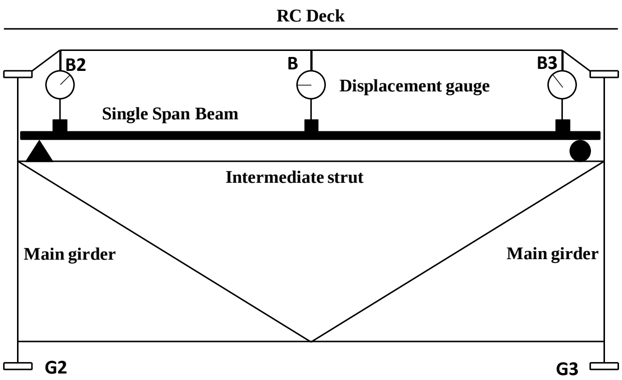


Figure 3: Measurement installation

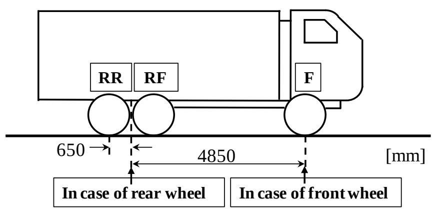


Figure 4: The dimension of the truck

Table 1: Weight of the truck

Total weight	F axle	RF axle	RR axle
211.68[kN]	58.80[kN]	76.44[kN]	76.44[kN]

Table 2: Measurement result

About deck deformation

	Load at A point			Load at B point			Load at C point		
	B2	**B**	**B3**	**B2**	**B**	**B3**	**B2**	**B**	**B3**
When front axle									
1st time	0.005	0.01	0.01	0.02	0.0325	0.01	0.005	0.01	0.01
2nd time	0.05	0.005	-0.0067	0.016	0.028	0	0.024	0.03	0.01
3rd time	-0.002	-0.002	-0.004	-0.006	0.01	-0.006	0	0.016	0.006
When rear axles									
1st time	0.04	0.05	0.026	0.032	0.054	0.03	0.028	0.038	0.0217
2nd time	0.018	0.054	0.016	0.02	0.05	0.018	0.014	0.048	0.016
3rd time	0.014	0.038	0.016	0.016	0.044	0.02	0.01	0.036	0.022

[mm]

About crack width

	Load at A point		Load at B point		Load at C point	
	X	**Y**	**X**	**Y**	**X**	**Y**
When front axle						
3rd time	0.0002	-0.002	0.002	0.0006	0.0008	-0.002
When rear axles						
3rd time	0.0018	0.003	0.0014	0.0016	0.0004	-0.0024

Notice: Replace, bridge axis is X, perpendicular bridge axis is Y [mm]

maximum deck displacement was observed. But when focusing on the rear axles cases, the value of A is similar to B and C. This is probably because that the load application point of the rear axles is defined as in the middle of two axles, RF and RR, so that when the rear axles exist on A or C, the RF or RR tires are closer to B actually. However, since the spindle of a used displacement gauge is hard to reset, so that the tendency of increasing is more reliable than the tendency of decreasing.

When focusing on the crack width, it is obvious that in transverse direction, positive and negative value was observed alternately, while in longitudinal direction, only positive value was observed. On the other hand, a different value changing tendency was observed between the front axle case and the rear axles case. The reason is that, firstly the front axle with only one axle, while the rear axles with two axles and secondly the intervals of the load application point is too large.

3. FINITE ELEMENT ANALYSIS

3.1. Finite element model

The finite element analysis was conducted with MSC.Marc, a non linear structural analysis software. The analytical model is shown in Fig 5. Only the RC deck was taken into consideration, while the

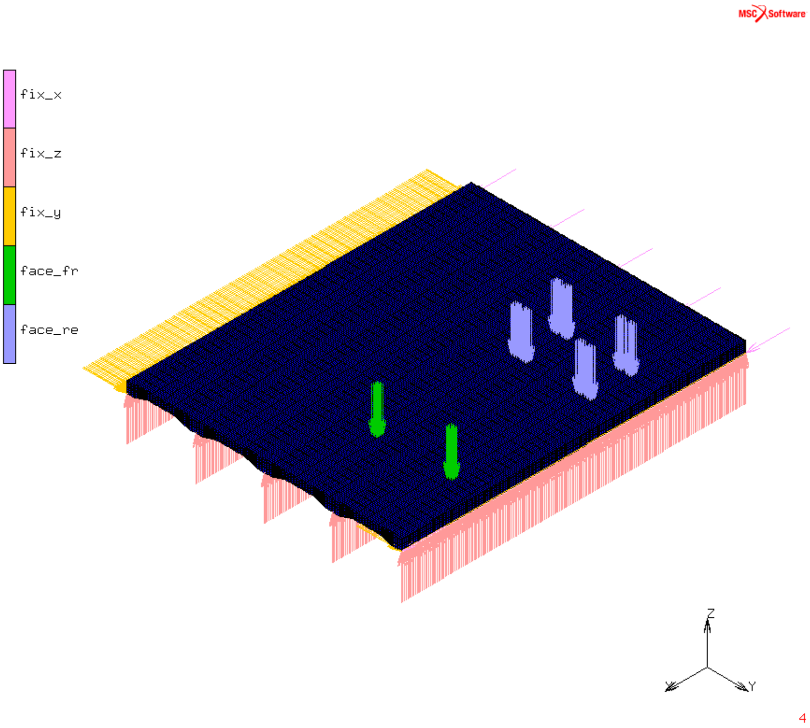


Figure 5: Finite element model

Table 3: Material properties

	Young's modulus	Poison's ratio
Concrete	22.5 [GPa]	0.2
Steel	200 [GPa]	0.3

Table 4: Load condition

	Face load
Front tire	0.6837 [N/mm^2]
Rear tire	0.4444 [N/mm^2]

Table 5: Cross section area of truss elements

	Main reinforcement	Longitudinal reinforcemen
Tensile	286.523*8	397.154*4
Compressive	286.523*4	198.577*4
Haunch	198.577*4	—
	per 1000[mm]	[mm^2]

bracket was omitted. The bridge in longitudinal direction was set up as an infinitely long model which can effectively assume the full vehicular load, and the width of the bridge in transverse direction was decided after omitted the bracket. The dimensions of the analytical model are as follows, the length in longitudinal direction is 10600[mm], the length in transverse direction is 8400[mm], deck thickness is 210[mm], haunch height is 130[mm], deck span is 2100[mm], deck span except bracket is 860[mm]. The interval between the tires is referring to the actual size, which the interval of rear double tire is 86[mm], RF and RR tire is 1250[mm]. As for the boundary condition, in longitudinal direction, the end of the main girder was fixed. In transverse direction, main girder G1 and G5 were fixed. In vertical direction, five main girders were fixed. In the meanwhile, as for the load condition, the vehicular load was uniformly distributed over the area, where the active area is 43000[mm^2] which is approximately 200*200=40000[mm^2]. For the concrete in the RC deck, 6 or 8 node solid element was set up. As for the main reinforcement, reinforcing bars, haunch reinforcement was set up as truss element. Material properties are as follows:, for the concrete elements, Young's modulus is $22.5*10^3$[N/mm^2] and Poison's ratio is 0.2. For the steel elements, Young's modulus is $20*10^4$[N/mm^2] and Poison's ratio is 0.3. Details of the reinforcements are shown in tables 3-5.

3.2. Numerical result

In order to analyze the deformation of the deck, we can focus on the value in B position, where the center of the deck. It is obvious that, the value in B position is larger than that in A position, C position and the value in the end of the haunch position. On the other hand, the graphs of the deflection curve in the end of the haunch for G2 and G3 are always different in spite of the loads from the front tires was acted on the center of deck. We can explain in this way, between G1－G2 or G2－G3 girders, loads was assumed, while between G3－G4 or G4－G5 girders, no load was assumed, which means load condition is not a symmetric condition and directly caused the difference between the graphs of the deflection curve. This section clarifies that even if the vehicle load acts on the center of the deck, the deformation of the bridge deck are always different in transverse direction.

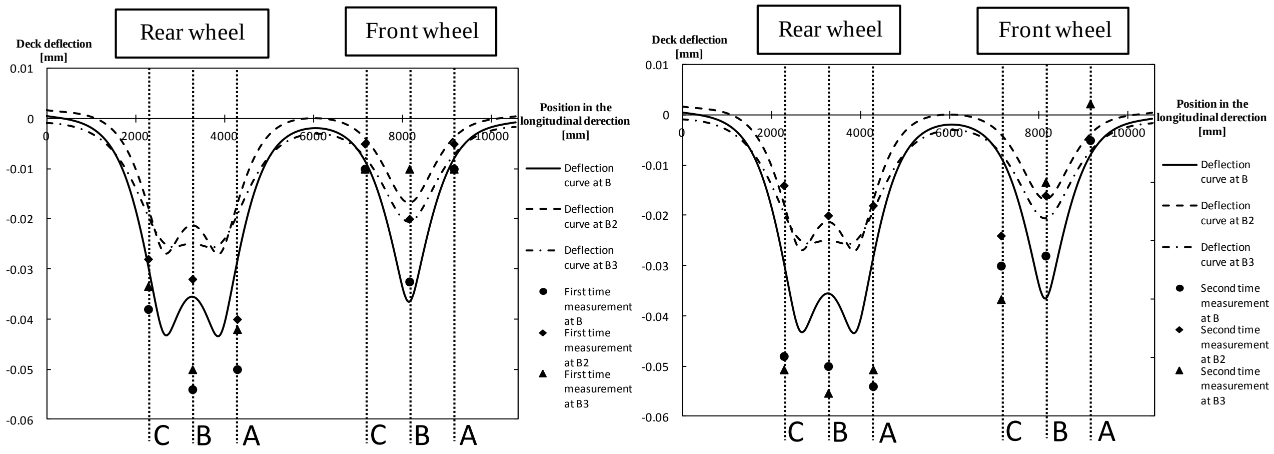
As for the analysis of the strain of deck, firstly we can focus on the value in longitudinal direction. We can see that the value in longitudinal direction is always a positive value. On the other hand, in transverse direction, positive value and negative value are observed alternately during the passing of vehicle load. As for the value of the strain, it was observed that the absolute value of the positive value is larger than that of negative value and, in the meanwhile, it was confirmed that the acting of load makes a larger influence on the bridge in longitudinal direction than that in transverse direction. Moreover, the strain of front axle is always larger than the value of rear axles in spite of the value of deck deformation due to the weight per tire of the front axle is heavier than the rear axles. However the numbers of the front tires and rear tires are different, so that as for the total weight, the value of rear tires is larger instead.

Therefore, the total weight makes a larger influence on the deformation of deck and resulting a larger value in the rear axles, while on the contrary, the weight per tire makes a larger influence on the strain of the deck resulting a larger value in the front axle was confirmed.

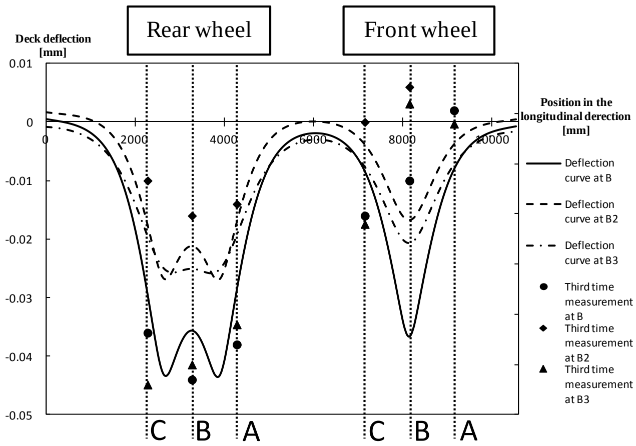
4. COMPARISON

4.1 Deck deformation

Both the measurement and numerical result of deck deformation at the center of deck of between girders G2, G3 and at the end of the haunch for G2 and G3 were shown in Figure 6. To obtain accurate result, the measurement was conducted for three times and the measurement values were plotted in Figure 6 (a)-(c). There are some decrease tendencies of displacement due to the equipment error, while we can regard them as references. Moreover, no significant difference was

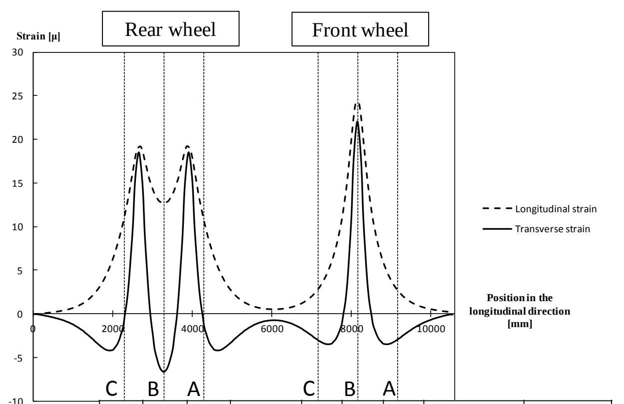


(a) First measurement **(b) Second measurement**



(c) Third measurement

Figure 6: Deck deformation



+	+	+	+	+	+	Analysis	Longitudinal direction
+	+	+	+	+	+	Measurement	
≒0	−	≒0	−	+	−	Analysis	Transverse direction
−	+	+	−	+	−	Measurement	

Figure 7: Strain

observed between the measurement value and the numerical result, meaning that no remarkable decrease of deck stiffness happens. On the other hand, a relatively large difference result was observed among each measuring process which probably due to the vehicle loading position error or the problem of the measuring equipments accuracy.

4.2 Strain

The numerical result of strain and the sign of crack length were shown in the Figure 7. In this paragraph qualitative comparison for strain is made. From comparison, it is found that the sign in longitudinal direction is same with each other. However in transverse direction which is front axle case is same but in rear axles case it is not same. This is probably due to the vehicle loading position error or rear axles are two axles.

5. CONCLUSION

In this study, the field loading tests are conducted on an RC deck viaduct, which has been through 27 years since its construction and with some remarkable deterioration. Deck displacement and crack width were investigated. Moreover, the RC deck overall three-dimensional finite element analysis model was conducted in order to make a comparison with the value acquired through the tests with the numerical results.

The results show that, although some remarkable deteriorations such as free lime and mesh crack were observed, but according to the experimental value, no significant difference with the numerical result was observed on the aspect of the deformation of deck, which means no significant performance penalty happened.

Although there is no safety problem was confirmed, but due to the obvious deterioration such as free lime and mesh crack were observed, there is necessity to set the waterproof layer for the deck and inspect regularly.

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