Fatigue Tests of Open Grid Steel Decks under Running Wheel Loads

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ABSTRACT

To ensure aerodynamic stability for super-long-span suspension bridges, a two-box girder type with open grid steel deck has been proposed based on the wind tunnel tests. In Japan, however, there have never been actual cases of application of open grid steel decks to traffic lanes which is exposed to traffic load. Fatigue tests of full-scale models of open grid decks with different structural details were conducted using Wheel Running Machine in order to investigate the fatigue behavior and the fatigue resistance. Using the test results, estimation of the fatigue life under traffic load was carried out by applying the cumulative damage rule.

1. INTRODUCTION

One of the most important subjects in designing long-span bridges is to ensure aerodynamic stability. The deck with open gratings is advantageous in terms of aerodynamic stability and cost reduction of such long-span bridges. The application of open grid steel decks to super-long span bridges with span length of more than 2,000m has been studied for the purposes of reducing the weight of superstructures and ensuring aerodynamic stability. Based on the results of the wind tunnel studies and analytical studies, it is found that a two-box girder type with open gratings (see Figure 1) is one of the possible stiffening girders for super-long -span brdiges. In another advantageous aspect of open gratings, they are also expected to be useful for ordinary bridges from the viewpoint of reducing snow-removal work in snowy areas.

In Japan, however, there have been few cases of application of open grid steel decks to traffic lanes of bridges, though they have been partially applied to truss-stiffened suspension bridges as aerodynamic countermeasure; i.e. to the shoulders and the center strip where no vehicles run. Several tests regarding the safety of driving vehicles and the fatigue durability were conducted. This paper describes the results of the fatigue tests for open grid steel decks tested using Wheel Running Machine.

2. FATIGUE TEST PROGRAM

2.1 Test Specimens

Figure 2 shows open grid steel deck investigated in this study, which is a two-layer

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structure consisting of surface members (main bar and cross bar) and their supporting stringers. The surface members are connected with stringers by HS-bolts. It enables easy replacement of the surface members directly exposed to traffic load. Figure 3 shows the structural details of a full-scale specimen (Model AR). The surface members are supported by 17 stringers (130mm spacing) which were designed to be grid structure supported by three cross girders. These stringers are penetrated by two I-shape cross beams at the span center and connected by fillet welding.

Table 1 shows the structural details of surface members of test specimens. Model A has a 75mm square grid structure consisting of main bars and cross bars. Model B has a structure using 6mm x 6mm square screw bars which is connected by pressure welding. This Model has been widely used as the members of the drain covers of roadside. Model C has a grid structure of about 50mm x 100mm consisting of the flat bars diagonally placed in longitudinal direction considering high stability of driving vehicles and motor cycles at high speed. Model AR is a modified version of Model A, which increases the rigidity of the main bars. Except Model B, it was confirmed that Model A, C and AR satisfy the fricition requirements between wheels and deck surface at high speed driving based on the results of driving tests. These main and cross bars of surface members were designed as continuous beams supported at the grid points.

2.2 Test Method

Wheel running machine (WRM) of the PWRI shown in Figure 4 and Photo.1 was used for the fatigue tests. Load was applied by moving a 500mm-wide steel wheel back and forth for a distance of ± 1.5m on a track made of loading blocks (500mm x 200mm) placed continuously in a line on the specimens. The frequency of cyclic loading is about 0.8 Hz (the rotation speed of the flywheel is about 25 rotation/min). A steel plate (thickness 12mm x width 560mm x length 4,500mm) is placed on the surface of a piece of plywood (thickness 6mm) laid on the loading blocks for cushioning. The steel wheel runs on the steel plate. A 3.2mm-thick steel plate and a 20mm-thick rubber sheet were also placed under the loading blocks. The combination of two steel plates, a rubber sheets, and plywood give the effect of distributing the contact pressure of the loading blocks as equally as possible.

Step-up loading pattern in which the wheel load increases with a constant number of cycles was applied to each specimen. Loading started with wheel load of 100kN, which was smaller than the design live load of 140kN(including an impact coefficient of 0.4), and increased by 20kN for every 40,000cycles, suspending the wheel load running for each 20,000 cycles to measure static responses of the deck.

3. TEST RESULTS

3.1 Cycles to cracking

Figure 5 shows the numbers of cycles to cracking occurred at specimens. The solid lines indicates loading step(wheel load vs. number of cycles). The tests finished when cracks propagated to some extent. In all the models except Model B, cracks occurred in the surface members at a small number of cycles(the surface members of Model B did not have cracks). At 250,000 to 300,000 cycles, in all the models except Model A(the test finished at about 240,000 cycles), cracks occurred at stringers. Figure 6 shows the displacement for each Model at the center span of the center stringer. The broken line shows the displacement calculated by grid analysis without taking the rigidity of the surface members into account. Though measured displacement become a little larger than calculated value, there is not so much difference until the end of the test, which indicates the deck systems keep load carrying capacities.

3.2 Damage Condition

(1) Surface Members

Figure 7 shows the crack distribution on the half panel of each Model observed after the test. The solid symbols in the figure correspond to the damage conditions that the main bars and/or the cross bars were fractured, and the open symbols indicate that they are cracked although cracks did not reach the stages of fracturing. Figure 8 shows relation between the number of cracks (at 1/4 loading area) at the surface members and the number of cycles. Evaluating the fatigue resistance of each model based on the occurrence frequencies of the crack, it can be listed in descending order as follows: Model B > Model C > Model AR> Model A.

The cracks of Model A and Model AR were roughly distributed in a line in the direction perpendicular to the bridge axis. The locations of the damages closely matched those of the boundaries of the loading blocks with a size of 500mm x 200mm, presumably because the wheel loading via the loading blocks caused relatively high concentrated load around the boundaries. Regarding Model B, no crack was observed in the surface members until the end of the tests (about 360,000cycles at wheel load 280kN). The major reasons are considered as follows: (1)The pressure-welding of the grid point resulted in the high fatigue resistance compared with the fillet welding of the other models. (2)The main bar spacing is small compared with that of the other models so the local stress is smal. In Model C, the number of the cracks of the surface members at the end of the tests was small next to Model B. The main and cross bars of the diagonal grids are connected at an angle of 45° in the londitudinal direction of the bridge axis, and the flexural rigidity in this direction is higher than those of the other models for the tire pressure, resulting in a high wheel load distribution effect.

(2) Stringers

Figure 9 shows an example of the crack occurred at stringers. All the cracks occurred at the welded connections between stringers and cross beams. All the cracks were produced in the upper or lower portions on the stringer sides. The damages are concentrated in the areas directly under the wheel load.

4. ESTIMATION OF FATIGUE LIFE

Rough estimation of fatigue life under traffic load was carried out for Model AR by applying the cumulative damage rule to the fatigue test results. Using axle-weight distribution data (see Figure 10) of large vehicles measured on National Highway Route

357 (Ariake, Tokyo in 1984), the equivalent wheel load P_{eq} (root-mean-cube value) was 33kN. The average number of axles was 2.6axles/vehicle. Figure 11 shows relationship between fatigue life and daily traffic volume of large vehicles calculated from P_{eq} and the average number of axles per vehicle. As described before, about 300,000cycles at the test corresponds to the time when cracks occurred at about 5 grid points of the surface members and that when the first crack initiated at the connection of the stringer. The cycle at the end of the test has no specific meaning, but as shown in Figure 6, at least at that time the deck had its sufficient load carrying capacity. In the range of 2,000 to 3,000 (vehicles/day/lane), the number of years at the time of reaching 300,000cycles was about 20years and 40-60years at the completion of the test. Since the surface members are replaceable structures, they can be maintained by replacing them. On the other hand, the supporting stringers, which is difficult to be replaced, need to be improved for fatigue resistance. This estimation was made under conservative assumptions. Further accurate calculation need to be carried out.

In this study we investigated application of the open gratings to the passing lanes of super-long-span bridges(see Figure 1), therefore nearside lanes are made of orthotropic steel decks. Under heavy traffic conditions, One of practical measures is considered to limit the driving of truck traffic on the open grid steel decks as is sometimes done on suspension bridges abroad.

5. SUMMARY

Wheel running tests of full-scale models of open grid decks with different structural details were carried out to investigate the fatigue durability. Regarding surface members, Models C and Model AR had relatively high fatigue durability among the models which were confirmed to satisfy the requirements for the safety of traveling vehicles by driving tests. Regarding the supporting stringers, the cracks occurred at the welded connections between the stringers and the cross beams. The connection detail needs to be investigated from the point of view of fatigue resistance for practical use. And based on the test results, the fatigue life under traffic load was estimated for Model AR.

ACKNOWLEDGEMENTS

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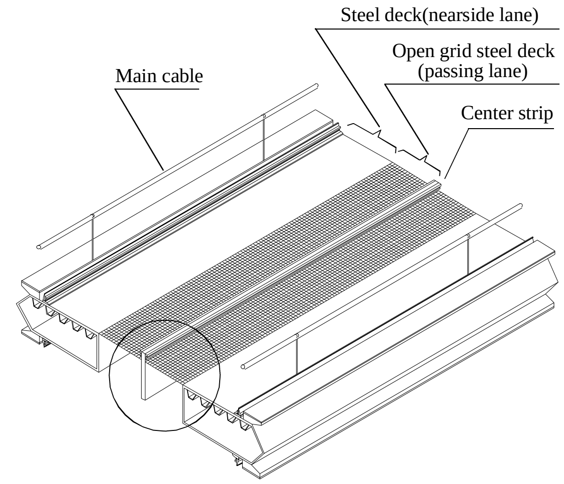


Figure 1 Two-box girder with open grid steel deck

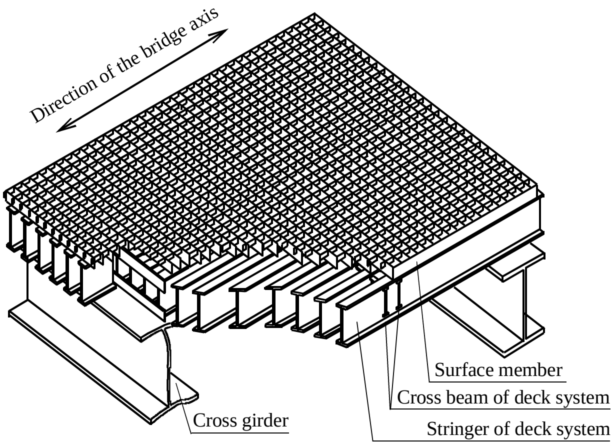


Figure 2 Structure of open grid steel deck investigated

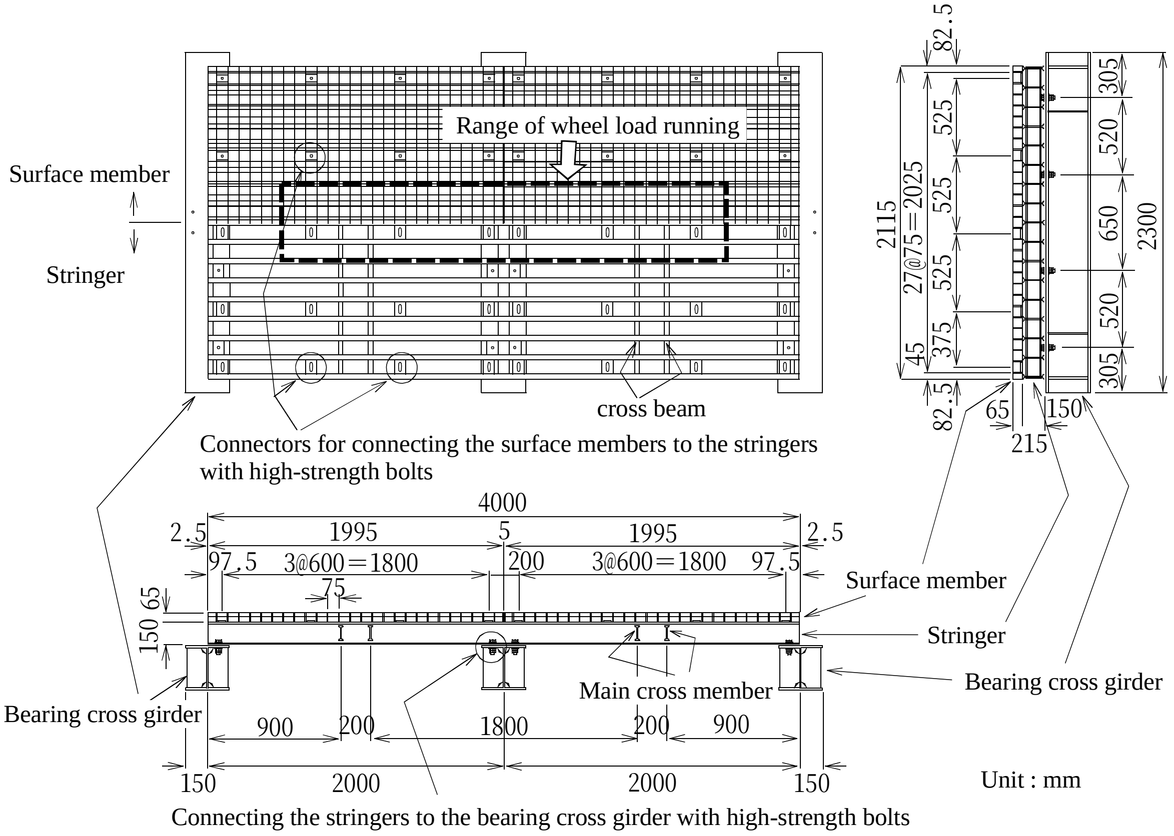
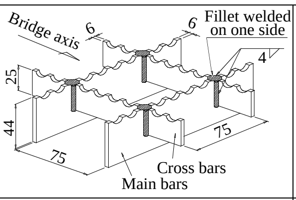
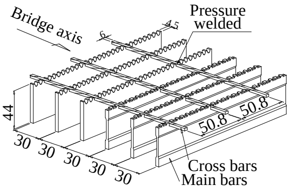
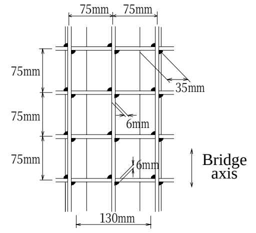
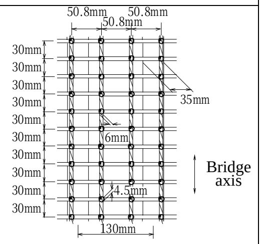
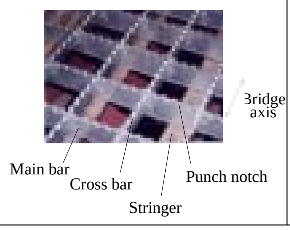
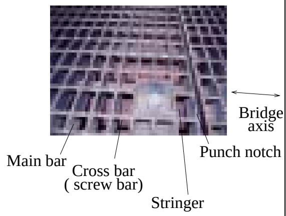
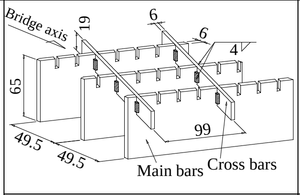
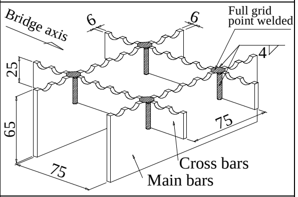
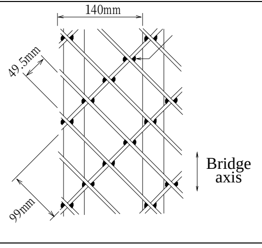
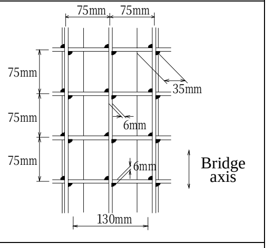
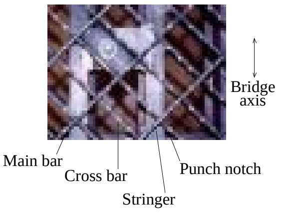
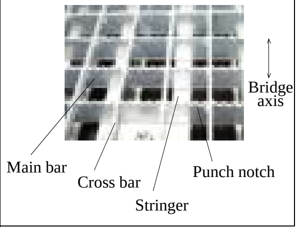


Figure 3 Dimensions of the test specimen

Table 1 Structural details of surface members

Model Name		Model A	Model B
Characteristics	Surface member	Main bar :FB44×6 Cross bar:FB25×6	Main bar :FB44×4.5 Cross bar:SB6×6
		Main bars are cut out at the grid points and fillet welded with cross bars on one side.	The grid points of flat bars are pressure-welded with screw bars.
	Structural girders	Stringer :I-150×35×35×4.8 Cross beam:I-105×30×35×4	
Structural drawing			
			
Photograph			

Model Name		Model C	Model AR
Characteristics	Surface member	Main bar :FB65×6 Cross bar:FB19×6	Main bar :FB65×6 Cross bar:FB25×6
		Main bars are cut out at the grid points and fillet welded with cross bars on one side.	Main bars are cut out at the grid points and fillet welded with cross bars on one side.
	Structural girders	Stringer :I-150×35×50×5 Cross beam:I-105×30×35×4	Stringer :I-150×35×35×4.8 Cross beam:I-105×30×35×4
Structural drawing			
			
Photograph			

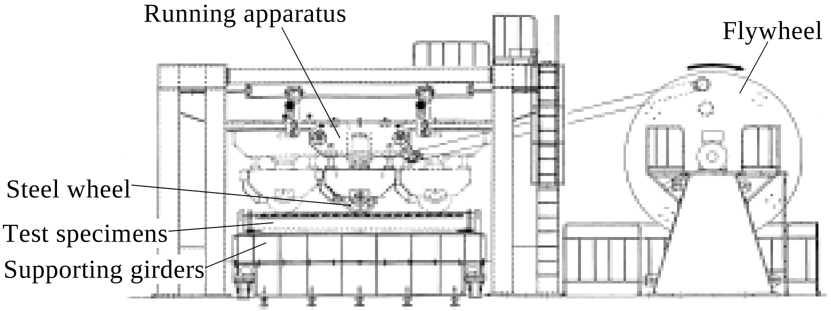


Figure 4 Outline of the wheel load running machine(WRM)

Photo. 1 Test setup

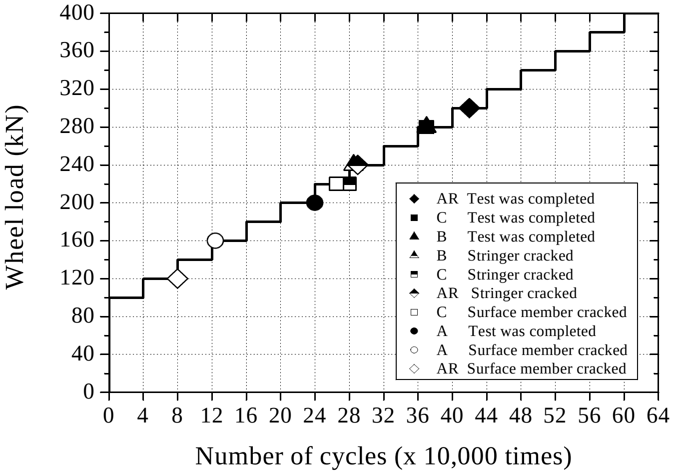


Figure 5 Results of the wheel load running tests of Models A, B, C and AR

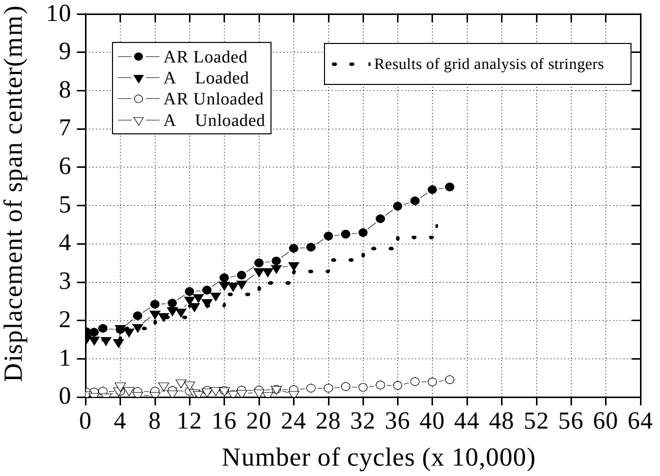
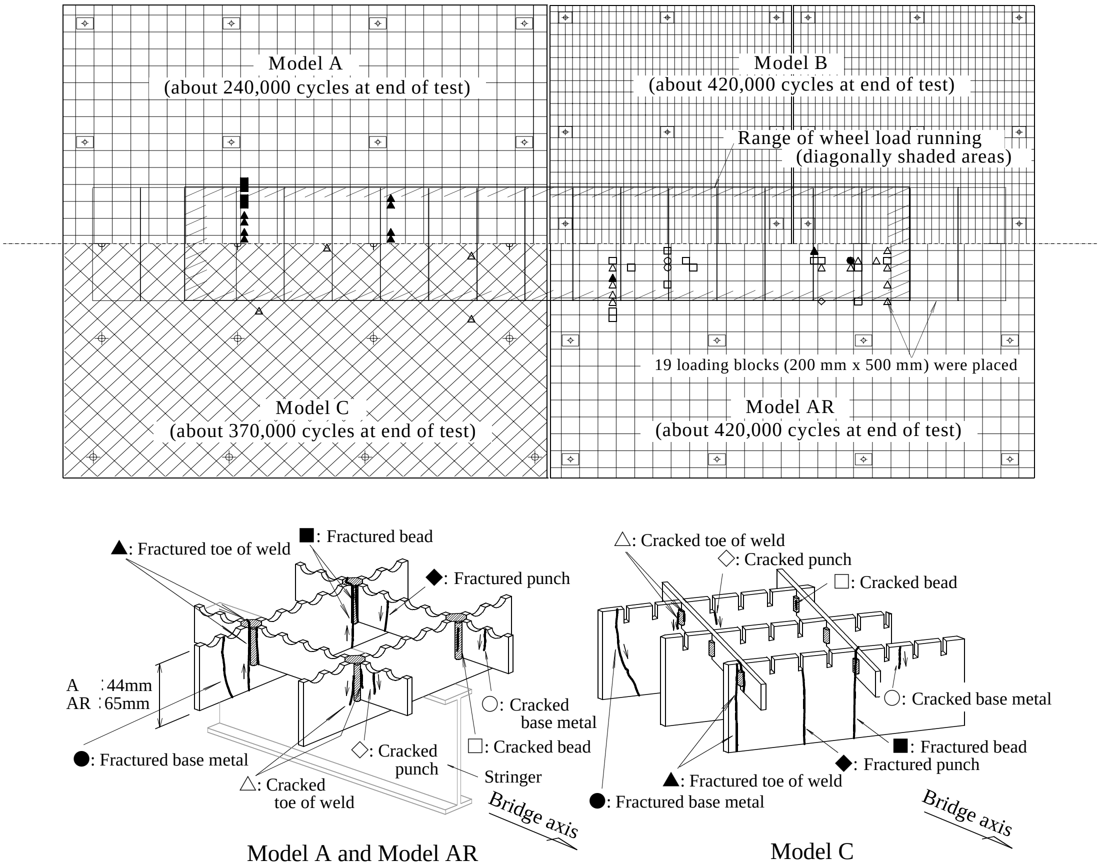


Figure 6 Displacement of the center stringer at span center



Model A and Model AR

Model C

Figure 7 Crack distribution of the surface members (at end of tests)

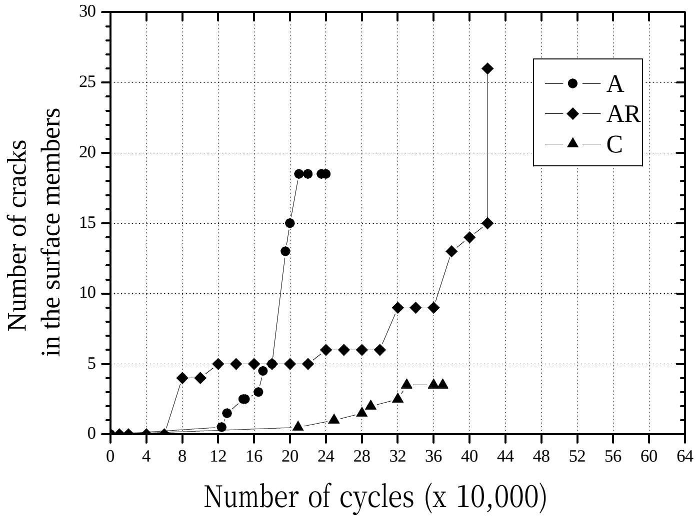


Figure 8 Relationship between the number of cracks in the surface members and the number of cycles

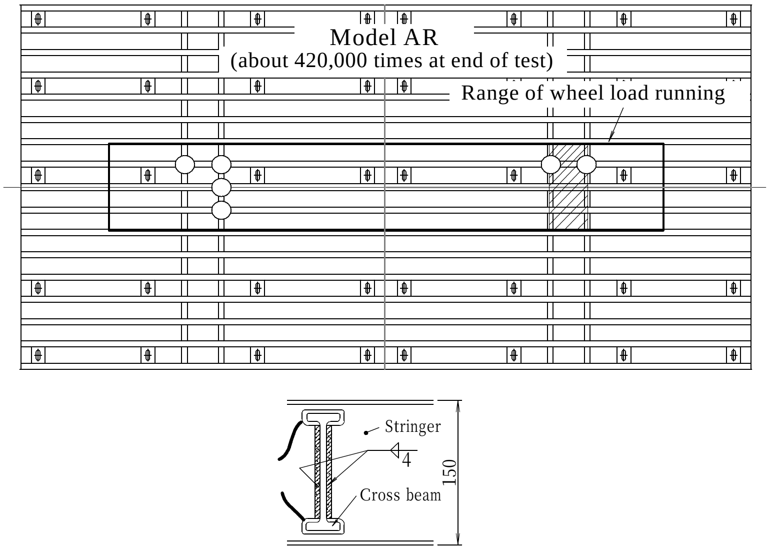


Figure 9 Crack distribution the stringer of Model AR (At end of test)

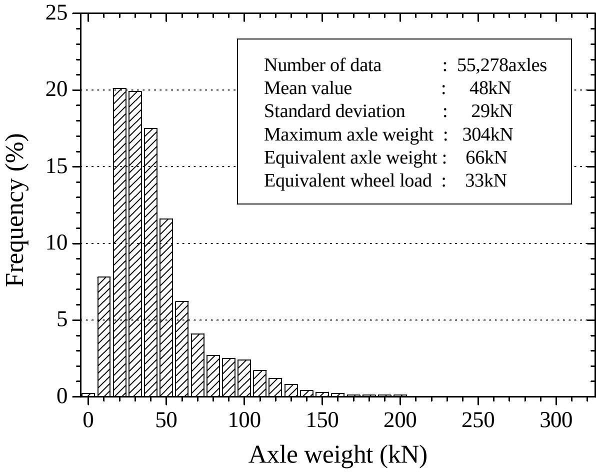


Figure 10 Axle weight distribution of large vehicles

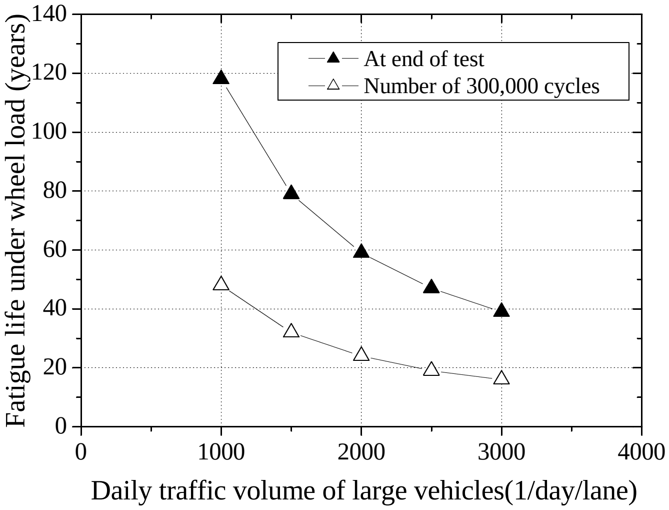


Figure 11 Converted number of years with respect to equivalent converted axle weight