ANALYSIS OF DAMAGE OCCURING IN STEEL PLATE GIRDER BRIDGES ON NATIONAL ROADS IN JAPAN

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Abstract

Data on damage found in steel bridges on national roads in Japan as a result of inspections over a recent approximately ten-year period were collated and analyzed. The subjects of this research were non-composite and composite steel plate girder bridges, which were selected because they are the most common types of bridges in the country. Three types of damage were studied: corrosion, cracks in steel and cracks in concrete decks. The corrosion was remarkable at the ends of girders; cracks in steel were often found at the end of stiffeners in connecting parts of main girders and cross beams, and cracks in concrete decks were most likely to have occurred at the end of main girders and at points one-fourth of the way across on spans.

Introduction

Japan's roads include highways, national roads, prefectural roads and city and town roads. The total number of bridges on all these roads is as high as 670,000. Research was done on steel bridges on national roads in three of the four main islands of Honshu, Shikoku, Kyushu and some other smaller islands administratively linked to those islands. Bridges on Hokkaido were not covered by this study. The 8,230 bridges inspected during the approximately ten years from 1994 to 2003 on national roads account for 87.5% of all bridges on national roads, and 4,304 of that total, are steel bridges — 52.3% of the national road bridges inspected.

Data were collected on damage found on non-composite and composite steel plate girder bridges, which are the most common types of bridges. The research included a study of the data on corrosion, steel cracks and concrete deck cracks that significantly influence the superstructure. The analysis, which took into account the location of damage, occurrence frequency, bridge construction year and other factors, will be used as basic material to make bridge inspections more useful.

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2. Study of damage

2.1 Classification of damage found on bridge members

The damage to bridge members found in the inspections was classified into five stages from “serious damage” to “no damage.” Class II, which is defined as “heavy damage” is further classified into seven additional stages (see Tables 2.1, 2.2). This report covers the analysis of Class II damage. Although Class I damage is a stage in which damage has progressed further than Class II damage, Class I wasn’t included in this research because it is very few in number and, once identified, Class I damage is repaired quickly.

TABLE 2.1: CLASSIFICATION OF DAMAGE

Damage classification	Condition
I	Damage serious, could become hazard to traffic safety
II	Damage remarkable; detailed examination needed to determine if repair is necessary
III	Damage found, trace research necessary
IV	Damage found, necessary to record level of damage
O.K.	No damage found as a result of inspection

TABLE 2.2: DETAIL FOR CLASSIFICATION II

Priority	High ↑	II-1	Immediate repair necessary after immediate detailed study
		II-2	Immediate repair advised
		II-3	Early detailed study advised; repair as needed
		II-4	Repair as needed
		II-5	Consider need for repair, after a detailed examination
	↓	II-6	Repair as part of normal maintenance work
	Low	II-7	Trace study needed (re-inspect within three years)

2.2 Numbers of bridges studied

Table 2.3 provides a breakdown of Class II damage found in non-composite and composite steel plate girder bridges, including the numbers with main girder corrosion, steel cracks, and cracked decks.

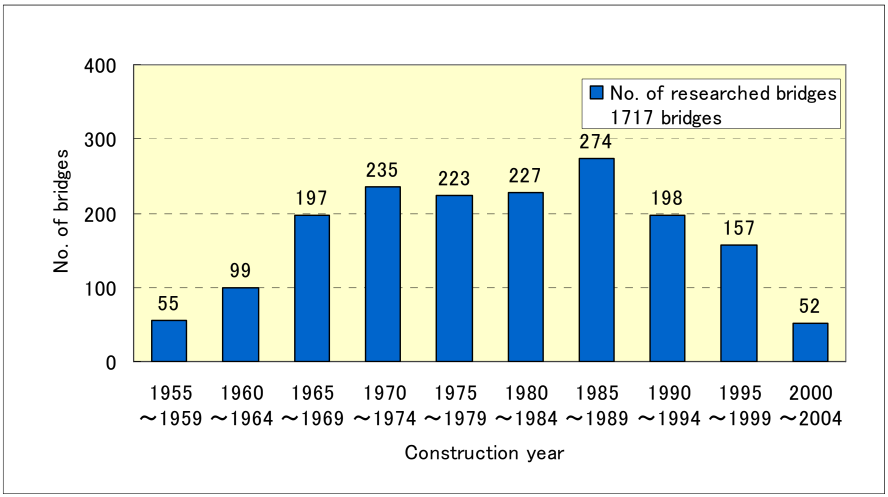
TABLE 2.3: RESEARCHED STEEL BRIDGES

Type of steel plate girder bridge	No. of bridges *1	Damage	Classification	No. of bridges *2
Non-composite	1,726	Corrosion of main girder	II-1,2 and 3	38
Composite	1,351			43
Non-composite	1,726	Crack in main girder	II-1,2,3,4,5,6 and 7	34
Composite	1,351			24
Non-composite	1,726	Crack in concrete deck	II-1,2 and 3	32
Composite	1,351			41

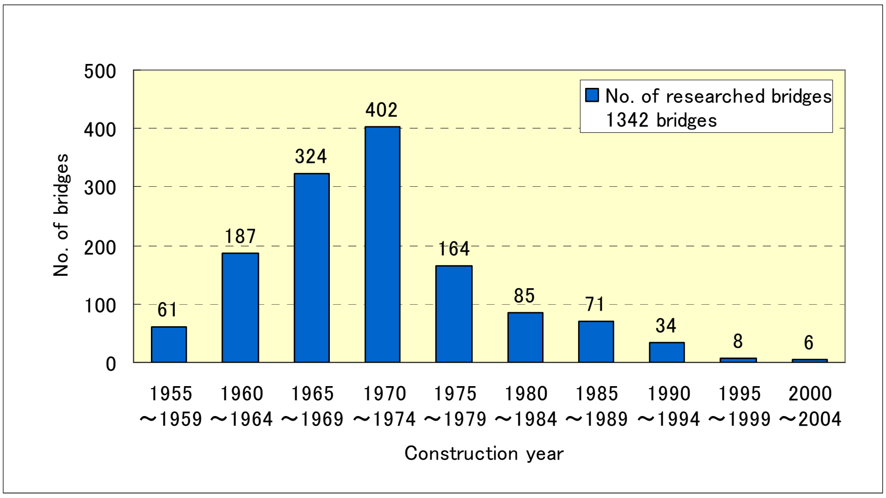
*1 : inspected bridges in 4,304 bridges *2 : bridge No. of the Classification

3. Arrangement and analysis of damaged bridges

The two graphs for Figure 3.1 show the relationship between the construction year and the numbers of non-composite and composite plate girder bridges that were inspected.



a. Non-composite steel plate girder bridges (1,717 bridges) (data from 1,726 bridges)



b. Composite steel plate girder bridges (1,342 bridges) (data from 1,351 bridges)

Fig.3-1: NOS. OF BRIDGES BY CONSTRUCTION YEAR (EVERY FIVE YEARS)

The number of non-composite type bridges increased gradually until about 1974. Subsequently, about 200 were constructed every five years until about 1994. The number of these bridges inspected also gradually decreased after 1995, because of new bridges. More bridges of the composite type were constructed from about 1960 to 1974. The highest number was 402 from 1970 to 1974. This was about 1.7 times more than the non-composite type during the same period. However, their number decreased sharply after 1975.

3.1 Corrosion of steel plate girder bridges

A breakdown of bridges found with Class II-1, 2 and 3 corrosion damage shows 38 non-composite bridges and 43 composite bridges. The results below are collated according to construction year, location of corrosion and concurrent damage.

(1) Damage situation by construction year

Fig 3.2 shows the relationship between construction year and number of non-composite and composite steel plate girder bridges with corrosion. Many bridges with Class II-1, 2 and 3 damage were of non-composite type and built between 1960 and 1984. In the case of the composite type, many were built in the 1960-1974 period. This rate for the composite type is generally proportionate to all numbers of constructed bridges (see Fig 3.1b). In the case of the non-composite type, however, this wasn't the case (see Fig.3.1a).

(2) Damage location and cause

The location of corrosion on non-composite and composite steel plate girder bridges was studied by dividing bridge divisions longitudinally, from the end of girders (included middle support point of continuous girders), one-fourth of span and center of girder as shown in Fig. 3.3. The number of bridges with corrosion on each of these parts is shown in Fig.3.4.

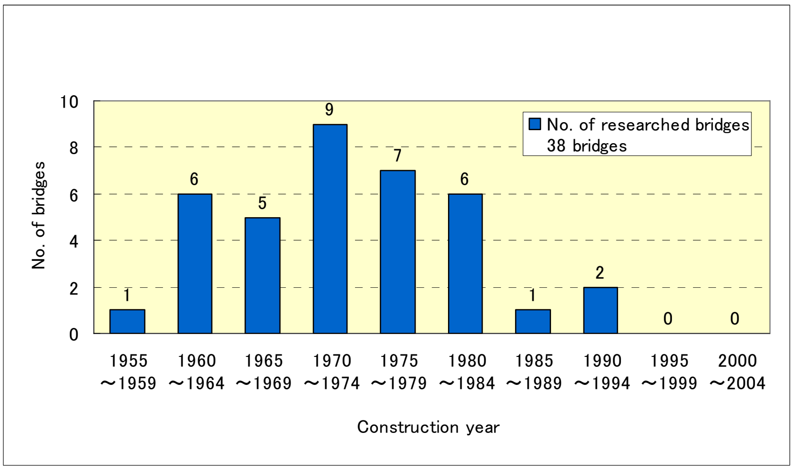
(a) Corrosion at end of girder

Among the non-composite type, 35 bridges were corroded at the end of a girder. The rate was 92.1 % of all corroded bridges. Among the composite type, 38 bridges, 88.4 %, were the same. Corrosion cases are shown in Fig 3.5 a.

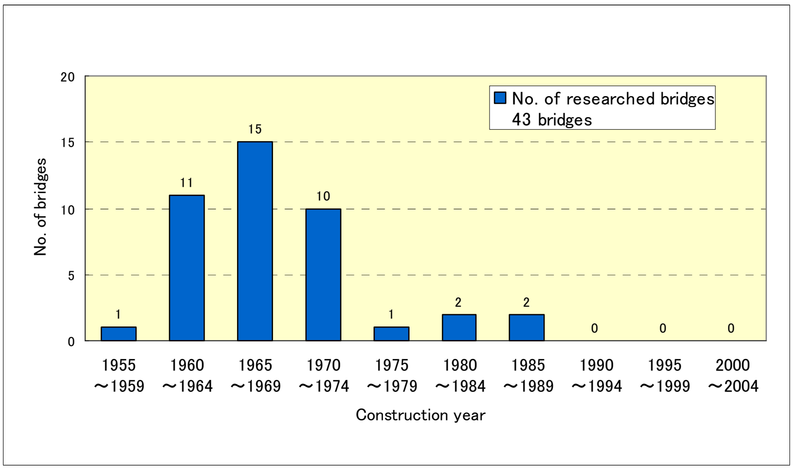
Comparatively older bridges tended to corrode as a whole on the span. Water leaks from expansion joint and drainage, besides water pool and moisture around bearings made girder ends corrode rapidly in many cases.

(b) Corrosion other than at end of girder

There were bridges corroded in the middle part of inner girders, the cross part of flanges on outer girders and webs, and splice plates. These were examples of corrosion other than that at the end of girders that had progressed. An example of corroded splice plates is shown in Fig. 3.5 b. There are also cross beams or stringers corroded progressively with cracks. Even among the comparatively recently built bridges, particularly those built using corrosion-resistant steel and to which freeze-resistant coatings were applied had local corrosion. Some bridges held water on its members and the corrosion progressed because of damage of drainage or irrelevant drain hole. Water had leaked through cracks in the deck, and corrosion at upper flanges in main girders was found. However, only two bridges (5.6%) were cases of corrosion being found not at the end of girders, but only at other points.



a. Non-composite steel plate girder bridge (Corrosion, II-1,2,3)



b. Composite steel girder bridge(Corrosion, II-1,2,3)

Fig. 3.2: BRIDGE NUMBERS BY CONSTRUCTION YEAR (EVERY FIVE YEARS)

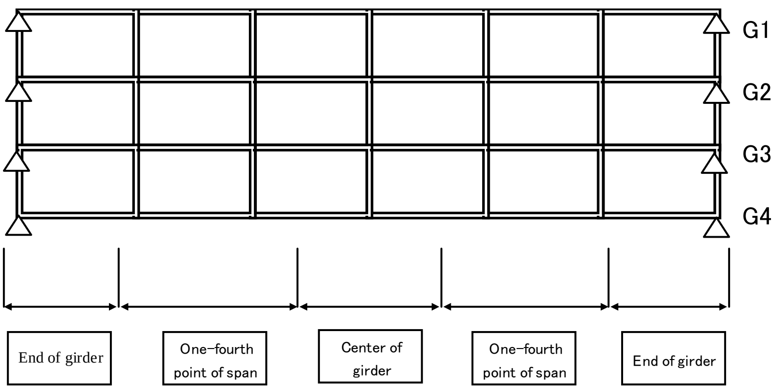
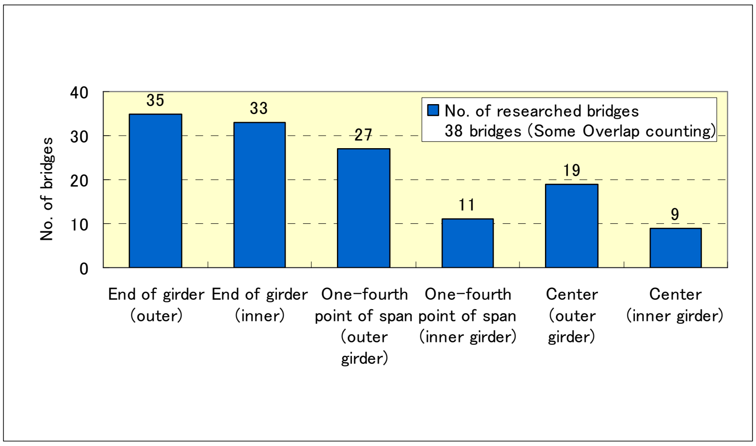
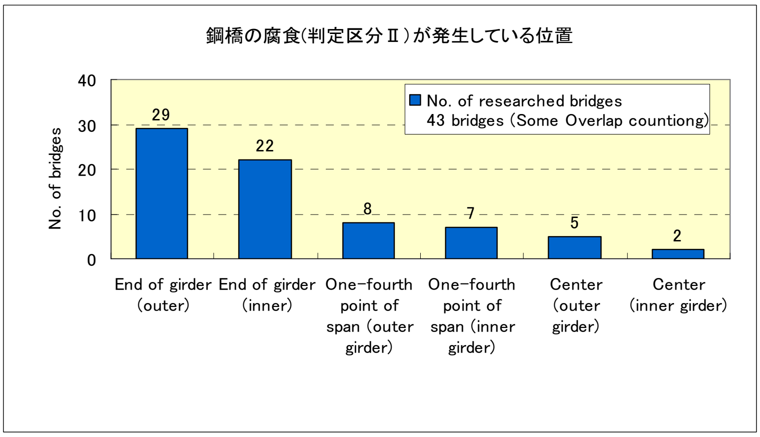


Fig. 3.3 CATEGORIZATION OF MAIN GIRDERS (IN CASE OF FOUR GIRDERS)



a. Non-composite steel plate girder bridge



b. Composite steel plate girder bridge

Fig.3.4: LOCATION OF CORROSION (II-1,2,3)

a. End of girder b. Splice plate

Fig. 3.5: EXAMPLE OF CORROSION (NON-COMPOSITE STEEL PLATE GIRDER BRIDGE)

Among the composite type, a somewhat higher number, 11.6 % of all the bridges, were corroded only in locations other than at the end of girders.

(c) Corrosion of exterior and interior girders

Among the non-composite type, many bridges were corroded at both the exterior and interior girders. The rate was 86.8% of the bridges studied, and only a few cases were found of corrosion being overwhelmingly at only the exterior or interior girders.

The other hand, among the composite type, many cases of corrosion were found on exterior girders, 76.8 % of all those studied. The rate for corrosion of interior girders was 55.9 %.

(d) Corrosion inside sections of girders

Much corrosion in sections of girder in composite-type bridges appeared at lower flanges than on web or upper flanges; the rate was 65.1 % of the bridges studied.

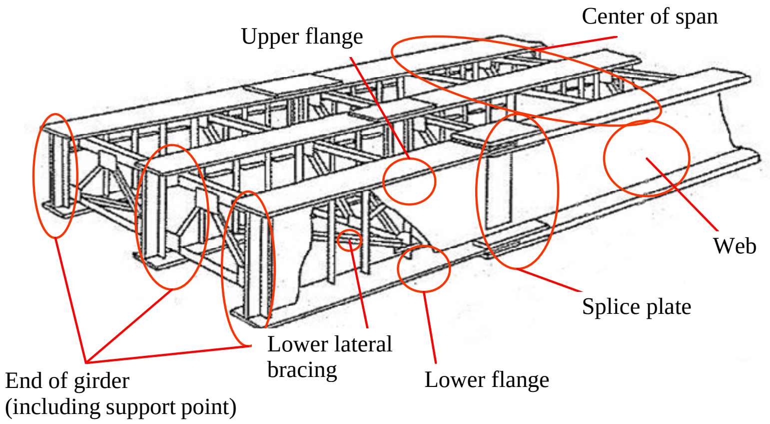


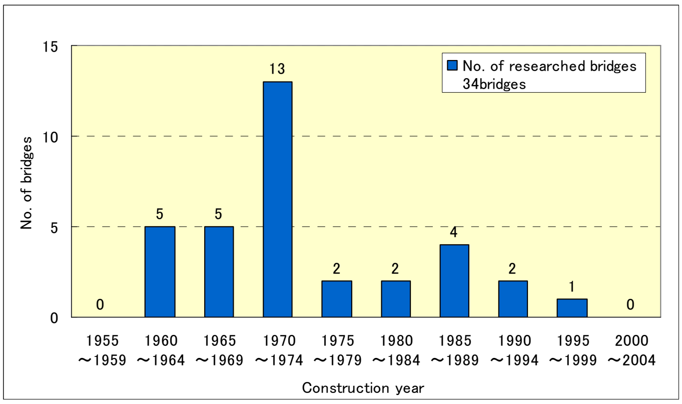
Fig. 3.6: LOCATIONS WHERE CORROSION HAD OCCURRED

3.2 Categorization and analysis of occurrence of locations with steel cracks

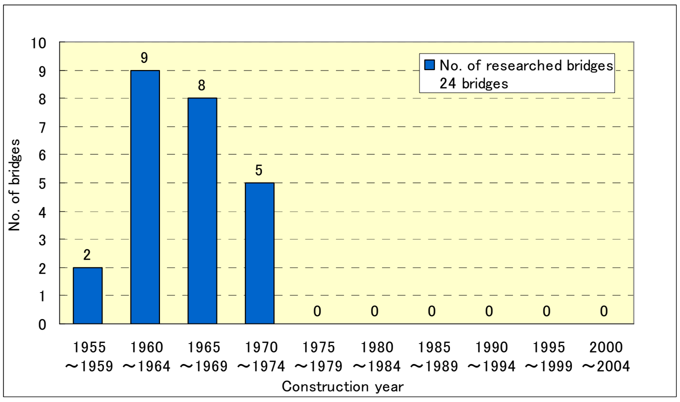
Among the non-composite type, 34 bridges had Class II steel cracks, as did 24 among the composite type. These were categorized and analyzed according to construction year, location of the cracks and concurrent damage. The results are outlined below.

(1) Condition of damage by construction year

Fig. 3.7 shows the relationship between construction year and number constructed for both non-composite and composite steel plate girder bridges. Many non-composite type bridges constructed in the 1960-1974 period had cracks — 23 of the 34 bridges which had steel cracks bridges, or 67.6 % of that total. Most noteworthy was the fact that bridges constructed between 1970 and 1974 show a high occurrence rate. Composite type built in the 1960-1974 period had a similar occurrence rate.



a. Non-composite steel plate girder bridges



b. Composite steel plate girder bridges

Fig. 3.7: NUMBER OF BRIDGES WITH STEEL CRACKS (II-1-7)AND CONSTRUCTION YEAR

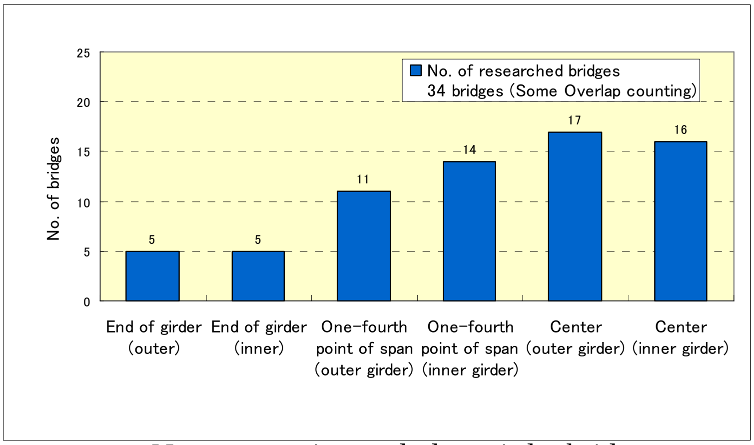
(2) Locations of damage

Locations where steel cracks were found on girders were researched based on the classifications shown in Figure 3.3. The numbers of bridges in each classification with cracks are shown in Figure 3.8., which includes cracks from the end of a girder that continue to the steel girder middle bearing point.

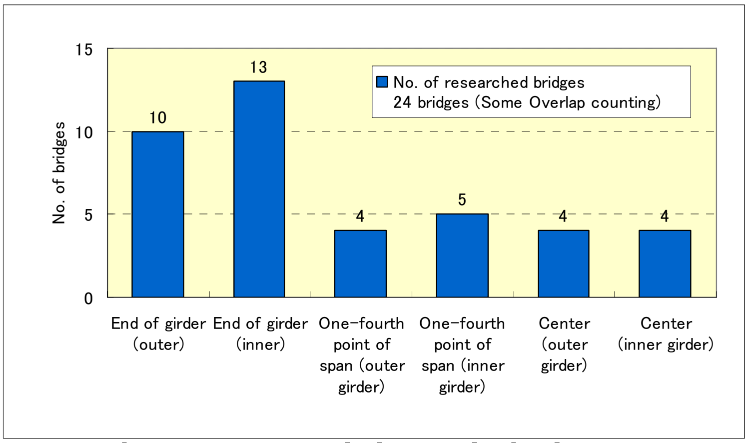
(a) Cracks occurring at girder ends

Among non-composite type bridges, there were five bridges of cracks occurring at ends of exterior girders and also five bridges of cracks occurring at ends of interior girders. This number is less than the number of cases in which cracks had occurred at the center or the one-fourth point of a span. Locations of the cracks included cracks at fillet welding of main girder lower flange and at end parts of vertical stiffeners, and this type of damage was often found on skew bridges.

Among composite types, the number of bridges on which cracks occurred at the ends of girders included 10 on exterior girders and 13 on interior girders. These numbers were greater than those for cracks at the center or one-fourth point. The locations of cracks were the same as for the non-composite type: 9 bridges had cracks at fillet welding of main girder lower flange and vertical stiffener, 8 bridges at fillet welding of a web and lower flange, next at sole plate, and at the welding of gussets of lateral members. The numbers for these cracks were greater for skew bridges than right bridges.



a. Non-composite steel plate girder bridges



b. Composite steel plate girder bridges

Fig. 3.8: LOCATIONS OF STEEL CRACKS (II-1-7)

(b) Crack at point one-fourth of the span distance

Among non-composite types, the number of bridges on which cracks occurred at the one-fourth point was 11 for exterior girder cracks, and 14 for interior girder cracks. These slightly exceeded those found at the end of girders. There was little difference between exterior and interior. Most of the cracks occurred in fillet welding between main girder upper flanges and stiffeners at connecting parts of main girders and cross beams, or at main girders and cross frames. Cracks occurred in 9 right bridges and 6 skewed bridges (Fig, 3.9).

Similar to the non-composite type, 4 composite-type bridges had cracks in exterior girders and 5 had cracks in interior girders. This number of the bridges was less than the number of bridges with cracks occurring at girder ends. The locations of cracks included those on the fillet welding between main girder upper flanges and stiffeners at the main girder and cross beam connections. Similar to the non-composite type, we found cracks on six skewed bridges and one right bridge.

Fig. 3.9: OCCURRENCE OF A CRACK ON A COMPOSITE STEEL GIRDER BRIDGE

(c) Crack at center of span

The number of non-composite-type bridges with cracks at the center of a girder was 17 with exterior girder cracks and 16 with interior girder cracks. These numbers exceed the numbers for other locations. There was not much difference between the numbers for exterior and interior girders. Many cracks were found on the fillet welding of main girder upper flanges and stiffeners of connecting parts of main girder and cross beams. This figure included 9 right bridges and 7 skewed bridges. Only one bridge had a crack at the welding part of a gusset connecting the main girder and lateral bracing in a right bridge.

Among the composite type, four bridges had cracks at the center of a girder, a number less than that of bridges with cracks at the end of a girder. Many of these cases were of cracks at the fillet welding between a main girder upper flange and a stiffener at the connection with a cross beam like on non-composite types. Skewed bridges had more cracks than right bridges.

(3) Traffic Volume

The 12-hour traffic volume on non-composite plate girder bridges on which Class II cracks occurred was from a minimum of 4,269 cars to a maximum of 60,965 cars. Only 3 of 34 bridges had a volume of less than 10,000 cars. The 12-hour traffic volume for composite bridges was from 3,308 cars (min.) to 52,932 cars (max.), with only 4 of 20 with a volume of less than 10,000 cars. These facts point to the effect of heavy traffic volume as a factor in the occurrence of cracks. The ratio of large vehicles such as buses or trucks ranged from 11 to 41% on non-composite-type bridges and from 10 to 52% on composite-type bridges.

(4) Distribution of cracks and concurrent damage

Many cracks on non-composite plate girder bridges were distributed near the center of the span in a longitudinal direction. These accounted for 73.5% of cracks on all researched bridges. The rate at which Class II cracks occurred was low at the end of girders, and tended to grow gradually higher nearer the centers of spans. Among cracks in a transverse direction, the percentage appearing on interior girders is rather high, however there is not such a large difference between exterior and interior girders. The percentages of Class II cracks appearing concurrently with concrete deck cracks and corrosion in general were 79.4% and 82.4 %, respectively, for all researched bridges.

Many longitudinal cracks on composite-type bridges were distributed near the ends of girders, accounting for 75.0% of these types of cracks on all bridges studied. No special feature was observed for cracks in a transverse direction. Corrosion in general accounted for 54.2% of damage occurring concurrently with cracks found on all researched bridges.

3.3 Categorization and analysis of occurrence of concrete deck cracks

The locations of concrete deck cracks (longitudinal and transverse directions) in concrete decks were categorized and analyzed according to construction year, traffic condition, arrangement of main girder.

(1) Damage condition by service life

The relationship between the construction year of non-composite and composite steel plate girder bridges that had concrete deck cracks (Class II-1, 2 and 3) and the number of these bridges. Concrete deck cracks were found in 81.3 % of the 26 bridges built in 1965-1979. Noteworthy is the fact that many of the occurrences were on bridges built in the 1970-1974 period. The number is 12 bridges, or 37.5 %.

On the other hand, many composite bridges were built in 1965-1974, and deck cracks in these bridges are also found. The number is 37 bridges, and the rate is 90.2 %. Looking at the relationship between the construction year of the bridges found with deck cracks and the number of bridges shows a high number of cases among bridges built in the 1970-1974 period among both the non-composite and composite type. This pattern of distribution clearly differs from the trend for bridge construction years (See Fig. 3.1). This trend clearly appears in Figure 3.1. We can surmise that the load carrying capacity and durability of the concrete decks declined remarkably after about 30 years of service life.

(2) Effect of traffic volume

The traffic volumes and ratios of large vehicles were as follows: The traffic volume on non-composite steel plate girder bridges (32 bridges) was 3,000-77,800 cars in every 12 hours of daytime, and the large-vehicles ratio ranged from 9.5 to 43.9 %. The volume for composite types (41 bridges) was 2,300-45,800 cars for every 12 hours, and the large-vehicle ratio was 9.4-48.0 %. As for the relationship between traffic volume and the occurrence of deck cracks, bridges on which the traffic volume exceeded roughly 30,000 cars showed a trend in which damage (Class II-1, 2 and 3) occurs on all bridge decks.

(3) Relationship between main girder arrangement and concrete deck cracks

Approximately half of the non-composite bridges studied, 15 bridges, were of the type with four girders. The space between each main girder was about three meters. Many bridges had two lanes. On the composite type also, about half of the bridges studied, 20 bridges, had four girders. The arrangement of the main girder was the same as the non-composite type. Next to the four-girder type, is three-girder type, and after that the five girder type.

(4) Location of damage

The locations of damage are shown in Figure 3.11. This illustration divides the area of the deck of span into the areas at the ends of girders, the area one-fourth across and the central part in the longitudinal direction. The locations are divided according to outer and inner parts in the transverse direction.

a) Deck cracks on non-composite steel plate girder bridges

The bridges studied included 32 of the non-composite type. The arrangement of locations according to a numbers of crack occurrences is the one-fourth point, the ends of girders, the center of the span and the areas around the middle bearing point. Twenty-one bridges had cracks at the one-fourth point; 18 of the bridges had cracks at the ends of girders; and 14 bridges had cracks at the center of the span. There was little difference between the numbers of transverse cracks on exterior and interior girders.

b) Deck cracks on composite steel plate girder bridges

Forty-one composite plate girder bridges were investigated. In order of numbers of cases, the locations where deck cracks occurred were at girder ends, points 1/4 across the deck, the center of the span, and intermediate support points.

Cracks at girder ends were generated on 28 bridges; 26 had cracks at the 1/4 points; and 25 had cracks in the central part of the deck span. There was no significant difference between the exterior and interior sides of the deck in the distribution of transverse cracks.

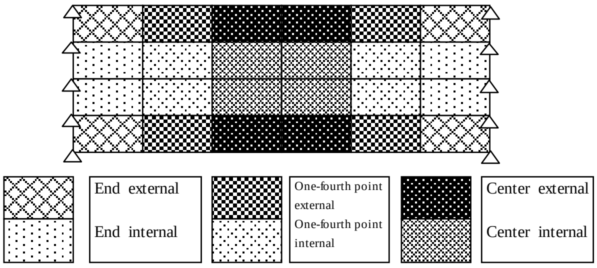


Fig. 3.11: DECK AREAS

Fig. 3.12: CRACKS IN CONCRETE DECK

4. Summary

Non-composite steel plate girder bridges and composite steel plate girder bridges with important damage such as corrosion, cracks, and deck cracks (Class II damage) were extracted, sorted and analyzed according to construction year, damage location and damage level. The results obtained are summarized below.

(1) Corrosion

A great deal of corrosion was found at the ends of girders. Corrosion (Class II-1, 2, 3) at the girder ends was seen in 90% of the corroded bridges analyzed in this study. It can be surmised that the corrosion advanced due to leakage of water from drainage appliances or expansion joints, collected water or moisture near bearings. Instances of corrosion other than at girder ends included corrosion at the center of spans and on splice plates. It is assumed that the causes of that corrosion included the spreading of antifreeze agents, damage to drainage facilities, and water leaking from deck cracks.

(2) Cracks

Many cracks generated at the center of spans (girders) or at points 1/4 of the way across the spans occurred in the welds of ends of vertical stiffeners that connect main girders to cross beams or cross frames. It is thought that many cracks occurred in those portions because many non-composite plate girder bridges are continuous. On the other hand, such cracks did not often occur in composite plate girder bridges compared with non-composite plate girder bridges because a high percentage of composite plate girders are simple girders.

Cracks in girder ends or near the bearing supports are seen on the welds of stiffener ends or between webs and flanges. There was a relatively higher number of cracks in skew bridges among both composite and non-composite type bridges.

These cracks accompany corrosion in many cases, but the relationship between cracks and corrosion has not been confirmed.

(3) Concrete deck cracks

Deck cracks (Class Ⅱ-1, 2, 3 damage) were found in 26 out of 32 non-composite plate girder bridges, and 37 out of 41 composite plate girder bridges. In order of numbers found, the locations of deck cracks in non-composite plate girder bridges were at points 1/4 across the spans, at girder ends, at central parts of spans and at the intermediate support points. There were also no large differences in exterior and interior distribution of transverse cracks on the sides of the decks, which was similar to the case for composite plate girder bridges.

The most numerous location of deck cracks on composite plate girder bridges was at the ends of girders; next was at points 1/4 of spans, followed by central parts of spans, and then at intermediate support points. As for the distribution of transverse cracks, as was the case with non-composite plate girder bridges, there was only a slight difference between numbers of exterior and interior crack locations.

Many bridges with deck cracks were constructed from 1965 to 1979. The amount of distribution bars for RC deck slab was increased along with revisions of design standards from the late 1960’s through the late 1970’s. Therefore, bridges constructed in the 1960's were possibly subjected to deck cracks due to a lack of distribution bars in RC deck slab. However, it is surmised that bridges constructed after the late 1970’s were subject to deck cracks due to increasing traffic volumes, declining durability and load-carrying capacity, and natural deterioration due to aging.

(4) Comparison of composite and non-composite steel plate girders

Although no clear difference was found in corrosion or deck cracks between non-composite plate girder bridges and composite plate girder bridges, non-composite plate bridges seemed to have slightly greater tendency to crack than composite plate girder bridges. It is assumed that local stress acting on composite steel girders is less than that in non-composite girders because RC deck slab resists live loads together with steel girders

The recent tendency in Japan is not to build bridges with composite girders. Complex work procedures are needed to temporarily remove RC deck slab in composite girder bridges, because of the need to fully secure the stability of the entire girder even in the case of partial removal. This is one of the reasons why the number of composite girder bridges has decreased.

References

1) Bridge Inspection Manual (draft), *Civil Engineering Technology*, No.2651, 1988. July (in Japanese)