

## CONDITION SURVEY OF CONCRETE PAVEMENTS AND ITS EVALUATION

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Concrete pavements in the Tohoku Region of Japan were surveyed. It is indicated that 25 cm slab thickness has been the mainstream after 1970s and 80 percent of them can last the design service lives of 20 years under daily average volume of 700 to 1400 commercial vehicles per lane. In order to investigate cracking patterns of concrete slabs, multivariate analysis was employed. According to the results of the analysis, slab width and volume of commercial vehicles were the factors greatly affecting cracking patterns of concrete slabs. Taking into account the analytical results, the current design method was modified. The results of the survey agree comparatively well with the results of the calculation by the modified method.

Concrete pavements in Japan are designed based on the Manual for Design and Construction of Concrete Pavement (1). The first edition of this Manual was made in 1964, at which time the results of studies by Iwama on the structural design of concrete pavements (2) were incorporated. Subsequently, the Manual has been revised several times, but the basic concepts have not changed. In Japan, the service life of a concrete pavement is considered to be 20 years. It was thus thought to review the condition of concrete pavements which have been in service up to this time.

Concrete pavements in the Tohoku Region of Japan were made the objects of this survey. In this region, there is especially a comparatively large proportion of use of concrete pavements for trunk roads. Firstly, in order to gain a grasp of the present state of concrete pavements distributed through roughly the entire area of the Tohoku Region, an overall survey was made sending out questionnaires by mail. Next, survey sections were picked out based on the results, and investigations were carried out focusing mainly on the condition of crack formation. In fact, there are some cases of failures such as punch-out, spalling and pumping in concrete pavements. However, cracking caused by the fatigue of concrete due to traffic vehicles is considered in several design methods as being the most possible failure of concrete pavements.

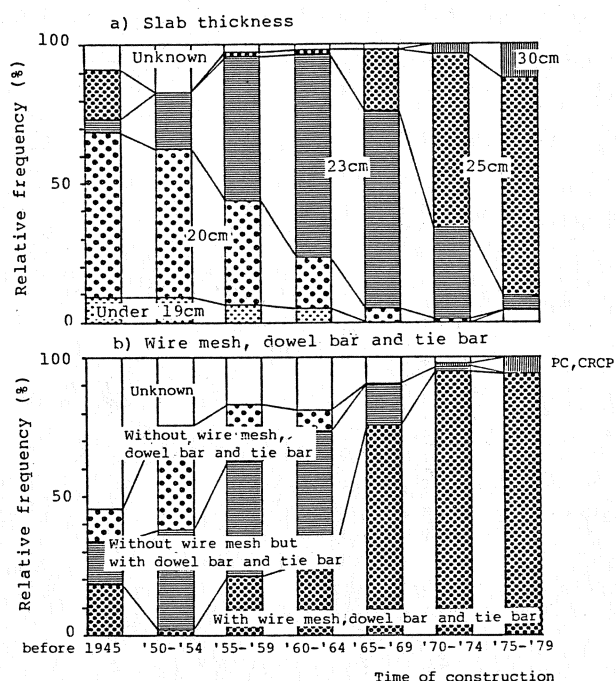
## Survey of Cracking Condition

## Overall Survey

This overall survey was made in 1981 (3) mailing questionnaires to the various road administration offices. The total number of concrete pavements investigated was 2829 for an aggregate length of 1103 km, corresponding to approximately 80 percent of the total length of concrete roads in the Tohoku Region.

Fig. 1 shows the changes in the structures of these concrete pavements. Regarding slab thickness, 23 cm was the mainstream in the latter part of the 1950s, but since the 1970s, 25 cm has become main. In the first edition of the Manual in 1964, it was made the rule to use wire meshes in concrete slabs, and dowel bars and tie bars at joints. Accordingly, concrete slabs with wire meshes have increased rap-

Fig. 1. Changes in the details of concrete slabs.



idly since 1965. Continuously reinforced concrete pavements and prestressed concrete pavements were experimentally constructed in the last decade.

According to the investigation, 49.1 percent, or almost half had been repaired with overlays. The ratios of such rehabilitation made are higher for the slab thicknesses of 20 and 23 cm in earlier construction.

The principal reason for these rehabilitation of concrete pavements is the abrasion of road surfaces by studded tires in winter. According to the investigation, reconstruction of concrete slabs amounted to only 1.3 percent, namely, most of these rehabilitation by overlays did not necessarily indicate that those concrete pavements had come to the ends of their structural lives.

Since cracking was considered as the symptom of the structural failure of concrete pavements, crack formation of concrete slabs of 25 cm in thickness was examined in the present study, 68 sections with well-kept traffic records were picked out and the relations between cumulative volume of commercial vehicles and the following cracking levels were examined.

Level A ... Practically no cracking

Level B ... Cracking produced but degree of cracking less than 30 cm/m<sup>2</sup>

Level C ... Degree of cracking more than 30 cm/m<sup>2</sup>

According to the Manual for Maintenance of Pavement (4), a degree of cracking of 30 cm/m<sup>2</sup> is deemed the reference value for carrying out rehabilitation of concrete pavement.

The relation between cumulative volume of commercial vehicles and cracking level is given in Table 1. The figures in parentheses are the ratios (%) of the various cracking levels with the number of cases in each row as 100. According to this, it can be seen that for cumulative volume of commercial vehicles amounting to 5 to 10 million vehicles per lane, 44 percent has maintained performance of Level A, and 81 percent Level B or higher. It is to be noted that three of the seven cases of Level A included sections of heavy traffic amounting to cumulative commercial vehicle volumes of 10 to 20 million vehicles per lane.

Cumulative volume of 5 to 10 million commercial vehicles per lane can be converted to daily average volume of 700 to 1400 commercial vehicles per lane per day. This indicates that approximately 80 percent of concrete pavements of 25 cm slab thickness can live out their design service lives under traffic of this extent.

Table 1. Relationship between cumulative volume of commercial vehicles and cracking levels for slab thickness of 25 cm.

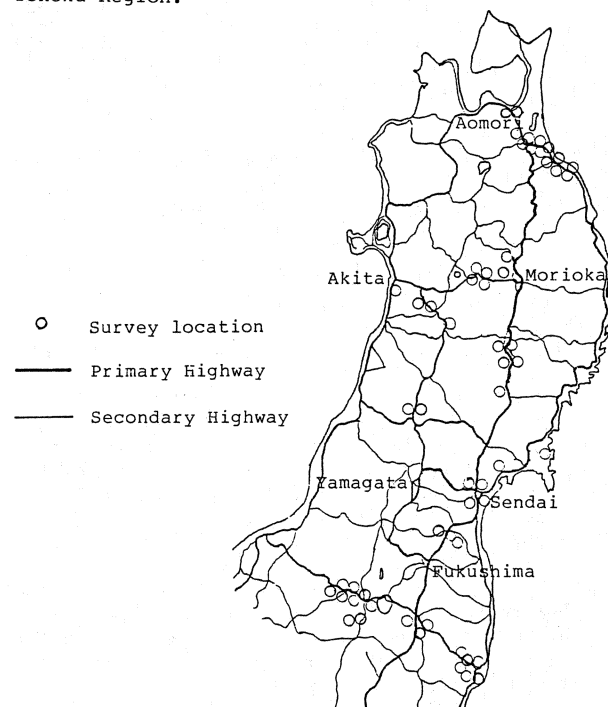
| Cum.vol.of c.v.<br>( $\times 10^4$ v.p.l.) | Cracking Levels |           |           | Total       |
|--------------------------------------------|-----------------|-----------|-----------|-------------|
|                                            | A               | B         | C         |             |
| 1000-500                                   | 7*<br>(44)      | 6<br>(37) | 3<br>(19) | 16<br>(100) |
| 500-100                                    | 22<br>(67)      | 7<br>(21) | 4<br>(12) | 33<br>(100) |
| 100-5                                      | 19<br>(100)     | 0         | 0         | 19<br>(100) |

\* Includes 3 sites of 1000-2000 $\times 10^4$  v.p.l.

#### Detailed Survey

This survey was carried out to investigate the states of crack formation of concrete pavements. The survey locations were those from among the previously mentioned survey sections. These locations of survey are shown in Fig. 2. The total number of the sections was fifty-eight. A single survey section consisted of twenty concrete slabs consecutively constructed.

Fig. 2. Survey locations of concrete slabs in the Tohoku Region.



The cracking conditions were classified according to two kinds of cracking patterns, longitudinal cracks and transverse cracks. In order to analyze the items influencing these two kinds of cracking patterns, Quantification theory II (5), a multivariate analysis technique, was employed.

The number of items is taken as  $P$ , the category numbers of individual items as  $l_1, l_2, \dots, l_p$ , respectively, and the number of groups classified according to the objective of analysis as  $M$ , the number of samples belonging to each group as  $n_1, n_2, \dots, n_M$ , respectively. The data given are converted into the dummy variables below.

$$x_{i(\alpha)}^{r(v)} = \begin{cases} 1: & \text{when sample } v \text{ of group } r \text{ attributes} \\ & \text{to } \alpha\text{-th category of item } i \\ 0: & \text{otherwise} \end{cases}$$

where,  
 $i=1,2,\dots,P$  : item  
 $\alpha=1,2,\dots,l_i$  : category  
 $r=1,2,\dots,M$  : group  
 $v=1,2,\dots,n_r$  : sample

It is assumed that the sample score of each group is given by the following linear equation.

$$y^{r(v)} = \sum_{i=1}^P \sum_{\alpha=1}^{l_i} x_{i(\alpha)}^{r(v)} a_i(\alpha) \quad (1)$$

where, the coefficient  $a_i(\alpha)$  is called category

Table 2. Items, categories and calculated results.

| Item                             | Category No. | Category                | Category weight | Range | No. of Samples |
|----------------------------------|--------------|-------------------------|-----------------|-------|----------------|
| Slab length                      | 1            | 5.0 m                   | 0.00            | 0.03  | 30             |
|                                  | 2            | 5.1-8.0                 | -0.03           |       | 28             |
| Slab width                       | 1            | 2.75-3.00 m             | 0.00            | 0.32  | 8              |
|                                  | 2            | 3.10-3.40               | 0.10            |       | 19             |
|                                  | 3            | 3.50-3.90               | 0.20            |       | 16             |
|                                  | 4            | 4.00-4.30               | 0.32            |       | 15             |
| Slab thickness                   | 1            | 20 cm                   | 0.00            | 0.11  | 15             |
|                                  | 2            | 23                      | 0.01            |       | 34             |
|                                  | 3            | 25                      | -0.10           |       | 9              |
| Commercial vehicles for 12 hours | 1            | 100-2000 vehicles/lane  | 0.00            | 0.22  | 35             |
|                                  | 2            | 2001-3000               | -0.06           |       | 15             |
|                                  | 3            | 3001-4600               | 0.16            |       | 8              |
| Time of construction             | 1            | 1972 and after          | 0.00            | 0.15  | 9              |
|                                  | 2            | Before 1972             | -0.15           |       | 49             |
| Districts of sites               | 1            | Northern part of Tohoku | 0.00            | 0.01  | 29             |
|                                  | 2            | Middle part of Tohoku   | 0.00            |       | 11             |
|                                  | 3            | Southern part of Tohoku | 0.01            |       | 18             |

weight.

The correlation ratio  $\eta^2$  which indicates the degree of the separation between groups may be expressed by the following equation:

$$\eta^2 = \frac{sg^2}{s^2} \quad (2)$$

where,

$s^2$ : variance of sample scores

$sg^2$ : variance of the means of groups

In this analysis, the value of category weight  $a_i(\alpha)$  is determined to make  $\eta^2$  in eq.(2) a maximum.

Employing the category weight  $a_i(\alpha)$  for category  $\alpha$  of item  $i$ , the range  $R_i$  indicating the degree item  $i$  contributes to the sample score is defined as follows:

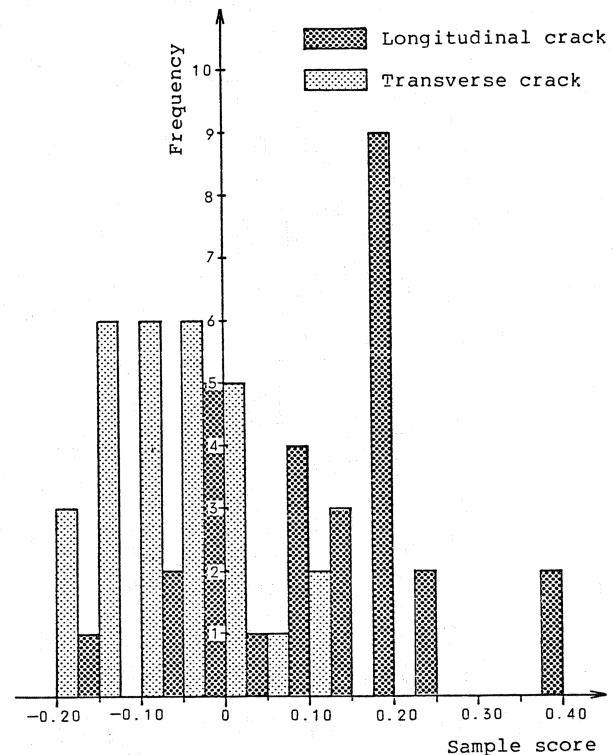
$$R_i = \max a_i(\alpha) - \min a_i(\alpha) \quad (3)$$

In analyses of the results of the survey, the six items given in Table 2 were selected and these items were respectively classified according to the categories shown in the table. The groups classified according to the objectives of analysis in this case are the cracking patterns of concrete slabs, namely, longitudinal cracks and transverse cracks.

The times of construction were divided into "before 1972" and "1972 and after". The Manual was revised in this year and edges of transverse joints came to be reinforced. In Japan, channelization was not common under highway traffic in the 1960s and there was much traffic at center longitudinal joint edges. Later, however, channelized traffic became common and the placement of wheels shifted to become concentrated away from center longitudinal joints.

The results of the analyses are shown in Table 2. According to these results, the items greatly affecting cracking patterns of concrete slabs in order of influence are slab width, volume of commercial vehicles, time of construction, slab thickness, and slab length, while there is practically no

Fig. 3. Distribution of sample scores.



influence of region.

Next, on examination of sample score distributions of the respective data on longitudinal and transverse cracks, the result are as shown in Fig.3. This indicates that when the value of a sample score shifts toward plus there is a tendency for longitudinal cracks to increase. That is, it may be seen that the more the value of category weight of Table 2 shifts toward plus the more tendency there is of longitudinal cracks being produced.

On looking at the various category weights of slab width thought to influence cracking patterns the most, it is seen that longitudinal cracking is more liable to occur the higher the category number that is, the larger the slab width.

With regard to the volume of commercial vehicles having the next largest influence, there are almost no effect with category 1 and category 2, but with category 3, or a road with heavy traffic of commercial vehicles of more than 3000 vehicles per 12 hours per lane, a trend is seen for longitudinal cracks to be formed.

As for time of construction, old concrete slabs placed prior to 1972 show large numbers of transverse cracks, while comparatively new concrete slabs constructed after 1972 show trends of longitudinal cracks being more numerous.

### Evaluation of Survey Results

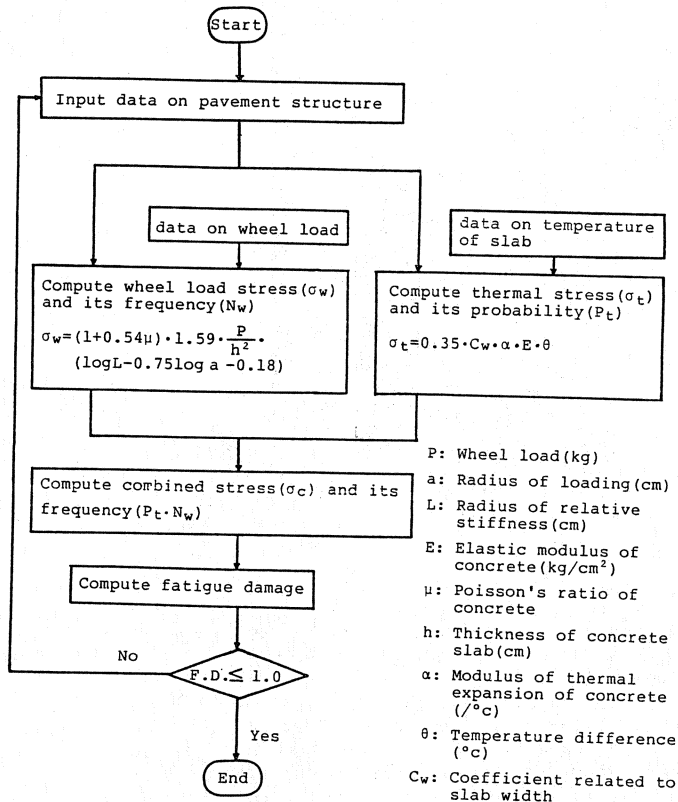
#### Evaluation Method

In this section, the current design method is first examined in evaluating the results of surveys of concrete pavements in the Tohoku Region. Determination of the thickness of a concrete slab in this design method is made according to the sequence of the flowchart shown in Fig. 4.

To elaborate:

- (1) Data on wheel loads such as weight, and cumulative number of loadings are assumed.
- (2) Wheel load stresses and their frequencies are calculated at the longitudinal joint edge.
- (3) Thermal stresses due to warping and their frequency are calculated at the same edge.
- (4) The combined stresses of wheel load stresses and thermal stresses, and their frequency are calculated.

Fig. 4. Flowchart for fatigue analysis of concrete pavement (1), (2).



(5) The flexural fatigue damage is calculated for each combined stress. The sum of the fatigue damage of the individual combined stresses must be smaller than 1.0 for the design service life.

This method was modified for the evaluation of the results of surveys as described below.

(1) The failure mode of a concrete pavement is influenced by the items shown in Table 2. For example, in case of a concrete slab of 25 cm in thickness and 8.0 m in length, sample scores calculated by eq.(1) for slab widths and commercial vehicles are shown in Table 3. Judging from Fig. 3, these sample scores were classified into three cases of longitudinal cracking, transverse cracking and both of them.

Table 3. Classification of cracking patterns.

| Commercial Vehicles for 12 hours | Width of Concrete Slab (m) |           |           |           |
|----------------------------------|----------------------------|-----------|-----------|-----------|
|                                  | 2.75-3.00                  | 3.10-3.40 | 3.50-3.90 | 4.00-4.30 |
| 100 - 2000                       | -0.13                      | -0.03     | 0.07      | 0.19      |
| 2001 - 3000                      | -0.19                      | -0.09     | 0.01      | 0.13      |
| 3001 - 4600                      | 0.03                       | 0.13      | 0.23      | 0.35      |

|||||||: longitudinal cracking

=====: transverse cracking

|||||: both of them

(2) The reliability of the design of a concrete pavement depends greatly on the fatigue curve employed. Recently, therefore, the Committee on Cement Concrete Road of the Cement Association of Japan was carrying out a series of experiments on flexural fatigue of concrete. The fatigue curve obtained in these experiments was adopted in this study (6).

#### Evaluation of Service Life

As a result of the previously-mentioned survey on the condition of concrete pavements, it was found that in case of slab thickness of 25 cm, for daily average volume of commercial vehicles of 700 to 1400 vehicles per lane, the design service life of 20 years can be lived out with a probability of 80 percent. Therefore, in view of the results of fatigue tests, it was decided to use the fatigue curve in case of failure probability of 20 percent. The equation for the fatigue curve is as shown below.

$$\sigma_{\max} / \sigma_b = 1.067 - 0.071 \log N \quad (4)$$

where,

$\sigma_{\max}$ : combined stress

$\sigma_b$ : static flexural strength of concrete

N: cycles of loadings

The structure of a concrete pavement made the object of this study and its mechanical constants of the materials are as follows:

|                                                |                           |
|------------------------------------------------|---------------------------|
| Slab width                                     | 4.0 m                     |
| Slab thickness                                 | 25 cm                     |
| Flexural strength of concrete                  | 45 kg/cm <sup>2</sup>     |
| Elastic modulus of concrete                    | 350000 kg/cm <sup>2</sup> |
| Poisson's ratio of concrete                    | 0.25                      |
| Modulus of thermal expansion of concrete       | 0.00001 /°C               |
| Modulus of subbase reaction (K <sub>75</sub> ) | 10 kg/cm <sup>3</sup>     |

Table 4. Distribution of wheel loads (7).

| Traffic volume level | Mean No. of total vehicles (V/day/direction) | Mean No. of commercial vehicles (V/day/direction) | Number of wheel loads |          |          |          |          |          |          |          |          |           |            |            |
|----------------------|----------------------------------------------|---------------------------------------------------|-----------------------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|------------|------------|
|                      |                                              |                                                   | 0-1<br>t              | 1-2<br>t | 2-3<br>t | 3-4<br>t | 4-5<br>t | 5-6<br>t | 6-7<br>t | 7-8<br>t | 8-9<br>t | 9-10<br>t | 10-12<br>t | 12-14<br>t |
| B                    | 4,986                                        | 749                                               | 8,371                 | 810      | 420      | 229      | 119      | 79       | 45       | 27       | 15       | 6.7       | 4.3        | 0.57       |
| C                    | 8,930                                        | 1,889                                             | 13,934                | 1,855    | 1,210    | 620      | 335      | 208      | 118      | 59       | 30       | 13        | 8.5        | 1.6        |
| D                    | 12,727                                       | 4,696                                             | 16,610                | 3,611    | 3,091    | 1,978    | 1,005    | 623      | 378      | 176      | 86       | 36        | 19         | 1.8        |

The statistical data of wheel loads used were those shown in Table 4. This table shows the traffic wheel loads measured at various locations by the Japanese Ministry of Construction (7). The traffic volume of the concrete pavements surveyed in this study corresponds to either B or C of this table.

With respect to temperature differences and their probabilities of occurrence, those shown in Table 5 were used (1),(2). These are considered as being average probabilities of temperature occurrence in Japan.

The results of calculations made based on these conditions were as shown in Table 6. The fatigue damage was 0.5 for traffic volume level B, and the fatigue damage was 1.1 for level C. That is, it was found that the results of calculations by the modified method agree with the results of the survey of actual performances of concrete pavements.

Table 5. Temperature difference between top and bottom of a concrete slab and its occurrence probability for slab thickness 25 cm (1),(2).

| Temperature difference(θ) | Occurrence probability(Pr) |
|---------------------------|----------------------------|
| 18-19.9 °C                | 0                          |
| 16-17.9                   | 0                          |
| 14-15.9                   | 0.002                      |
| 12-13.9                   | 0.016                      |
| 10-11.9                   | 0.037                      |
| 8- 9.9                    | 0.085                      |
| 6- 7.9                    | 0.110                      |
| 4- 5.9                    | 0.155                      |
| 2- 3.9                    | 0.205                      |
| 0- 1.9                    | 0.390                      |
| 0.1- 2.0                  | 0.600                      |
| 2.1- 4.0                  | 0.335                      |
| 4.1- 6.0                  | 0.063                      |
| 6.1- 8.0                  | 0.002                      |
| 8.1-10.0                  | 0                          |

Table 6. Calculation results of fatigue damage for slab thickness 25 cm.

| Traffic volume level | B    | C    | D    |
|----------------------|------|------|------|
| Fatigue damage       | 0.50 | 1.10 | 1.80 |

### Conclusions

The results obtained in the study are as follows:

(1) As a result of the survey made on the condition of concrete pavements in the Tohoku Region, it is indicated that 80 percent of the concrete pavements of 25 cm slab thickness can last the design service life of 20 years under daily average volume of 700 to 1400 commercial vehicles per lane.

(2) On studying these survey results by multivariate analysis, it was learned that the cracking patterns of concrete slabs are greatly influenced by slab width and volume of commercial vehicles, and that the wider the concrete slab and the larger the volume of commercial vehicles, the more readily do longitudinal cracks occur.

(3) Taking into account the above survey results, and examining concrete slabs of 25 cm slab thickness by the modified method, it was found that the slabs can last out their design service lives of 20 years with a probability of 80 percent. This agrees with the results of the survey.

### References

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(All in Japanese)