ROAD MAINTENANCE STUDY COURSE

EVALUATION OF PAVEMENT CHARACTERISTICS

(Present Pavement Conditions, Evaluation Techniques and Application of Pavement Management Framework for Pavement Maintenance)

by

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1. GENERAL

Modernization of roads in Japan dates back to 1954, when the first 5-year road improvement program was formulated. During the period of 30 years since then, amazing improvements have been made. In 1954, the total length of the national highways and municipal roads was 144,628 km, of which only 5,049 km or 3.5 %, was paved. In 1980, however, the length of those roads has increased to 171,048 km of which the paved roads amounted to 82,924 km, or about 48.5 %. In addition to this, a section of the Meishin Expressway was first opened to traffic in 1963 and extension of in-service expressway has reached to 3,000 km of length in this year. Such drastic improvement of Japanese roadways is considerably ascribed to a) allocation of gasoline tax for the expenditure of road construction and maintenance and b) adoption of toll road system.

The roads in Japan are classified into the following four classes by the law: (a) national expressways, (b) national highways, (c) municipal roads and (d) town and city roads. New construction, operation, maintenance and rehabilitation of the national expressway system have been conducted by the governmental organization of Nihon Doro Kodan (The Japan Highway Public Corporation - J.H.P.C.) and those of roads (b) through (d) above are conducted by the Ministry of Construction or the appropriate local government. Typical pavement cross sections for these highways are shown in Fig. 1.

The scope of this report covers the present pavement conditions, measurement and evaluation techniques of pavement characteristics, and pavement management framework oriented for maintenance which are practised in Japan mainly for the national expressway system and the national highway system at present.

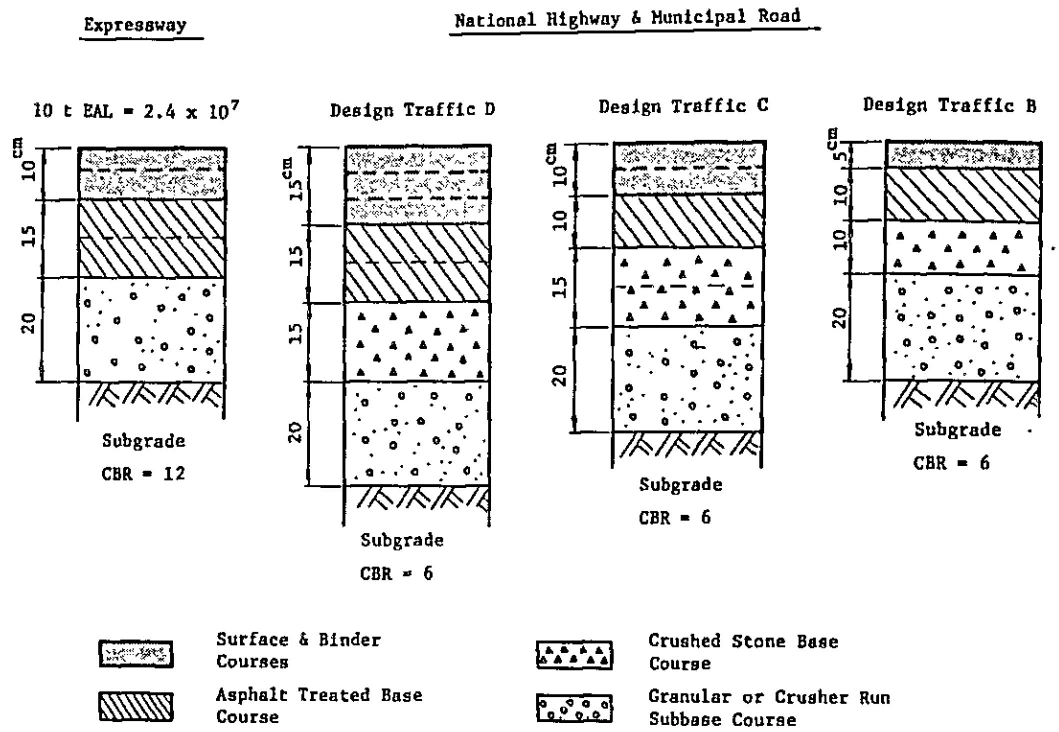


Fig. 1 Typical Asphalt Pavement Cross Sections

2. PRESENT PAVEMENT CONDITIONS IN JAPAN

2-1 National Expressway System

Recently the present status of the pavement condition has been well known through the nation-wide inventory study which can be attainable by the newly developed innovational evaluation equipments.

Based on the inventory study[1] in 1977 through 1979 and related research study, rutting due to the heavy commercial vehicles and abrasion due to the studded tires are the most problemable pavement characteristic for the expressway pavements. Cracking, low skid resistance, pot holes, longitudinal surface roughness and other characteristics are less observed and we can say these are well controlled at present.

Present status of the individual pavement characteristic is explained in the proceeding Sections.

a) Rutting and Abrasion

Rutting, observed along the wheel path, is caused by the densification and/or plastic flow of the bituminous mixture with the passage of heavy wheel load and resultant pavement surface forms the shape similar to sinosoidal wave in the transverse direction.

A typical rutting is shown in Fig. 2. It is interesting to note the depth of deformation observed. Maximum rut depth on the surface is 24 mm and deformation on the top of the asphalt treated base course is only a couple of millimeters, while no deformation can be seen on the top of subbase course. This is comparative to the AASHO Road Test Result which showed the deformation of subgrade was dominant for thinner pavement with excess rutting.

Distribution of rut depth, measured at 100 m intervals, for the representative expressways is shown in Fig. 3. From this figure we notice that 135.6 lane-km, 4.5 % of investigated 3,042 lane-km, might be repaired when we apply the rut depth maintenance level of 20 mm.

Progress of rut depth is also analyzed using the same data and summerized as below:

Rutting --- 1 mm per million passages of heavy commercial vehicles

Abrasion --- 4 mm per million passages of heavy commercial vehicles

When these values are converted to the yearly progress, the following figures are resulted depending on the heavy commercial traffic volume, use of studded tires and other conditions:

Rutting --- 2 mm/year for very heavily travelled expressway
--- 0.5 mm/year for moderate traffic expressway

Abrasion --- 7-10 mm/year for severe cold region
--- 3 mm/year for moderate cold region

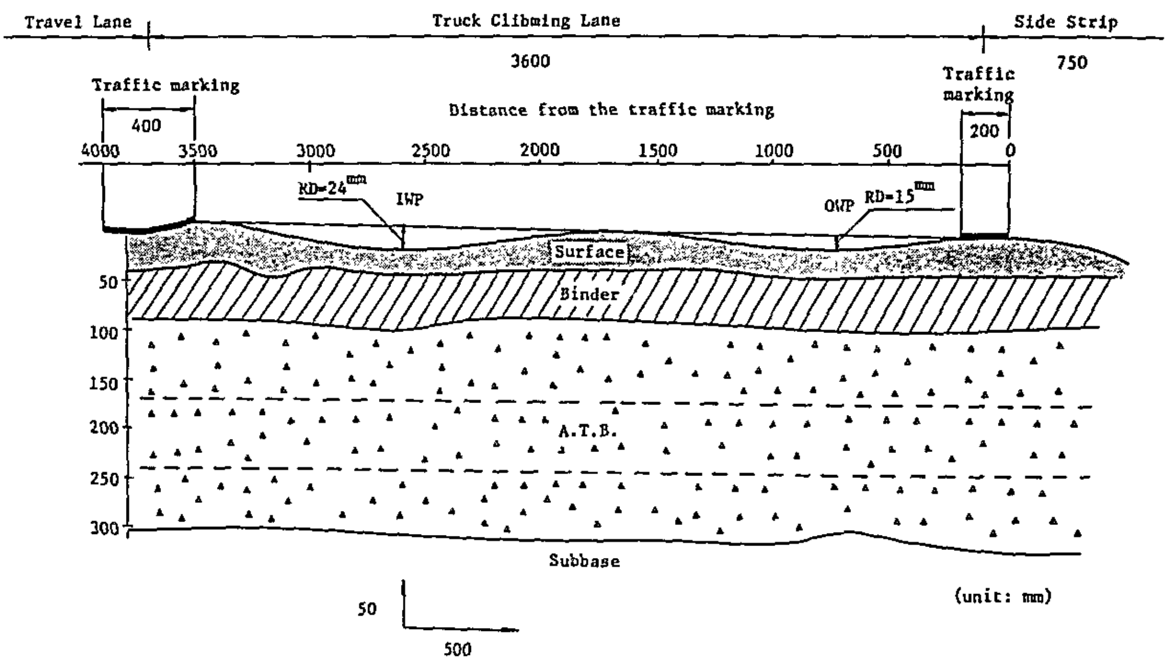


Fig. 2 Cross Section of Rutted Pavement on the Tomei Expressway

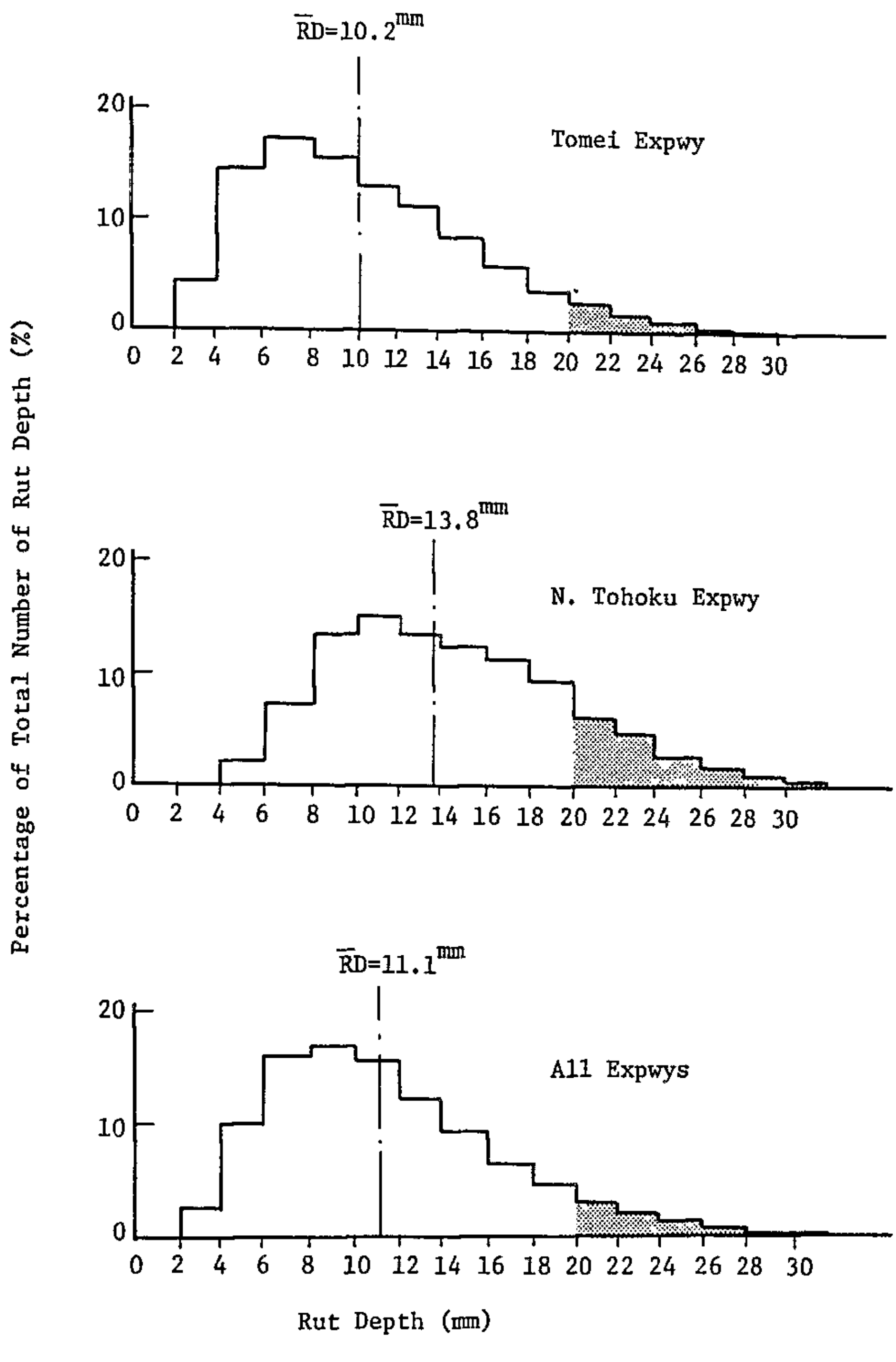


Fig. 3 Distribution of Rut Depth

-- 1974 Inventory Study for Expressway --

b) Cracking

Cracking has been the most interested pavement characteristic by the pavement engineer since it is considered directly to reflect the structural defects, if there exists any. Types of cracking might be classified as longitudinal, transverse, alligator, reflection, shrinkage and slippage crackings.

In our experiences, the initiation of cracking is the longitudinal one at the position of inner or outer wheel path. And all crackings investigated so far start from the top of the surface. This is not explained by the conventional fatigue theory that fatigue cracking initiates from the bottom of the bituminous layer. Longitudinal cracking may progress to the alligator cracking in later stage when the foundation support is not strong enough. Typical longitudinal and alligator crackings are shown in Figs. 4 and 5.

Present status of cracking, expressed by the roadway length of 10 % or more crack ratio, is shown in Fig. 6. Looking at the data for the whole expressway shown in the rightest portion of Fig. 6, only 40 lane-km out of 5,158 lane-km in-service show 10 % or more crack ratio.

As for the progress of cracking, crack ratio of 2 % increases with the passage of million heavy commercial vehicles. This is converted to 4 % and 1 % annual increases for heavy traffic and moderate traffic conditions, respectively.

To be mentioned in Chapter 6, we consider the pavement repair at the stage of 30 % or larger crack ratio, pavement life due to cracking might be 7 to 30 years. Therefore, necessity of pavement repair due to cracking is less than that of rutting or abrasion described above.

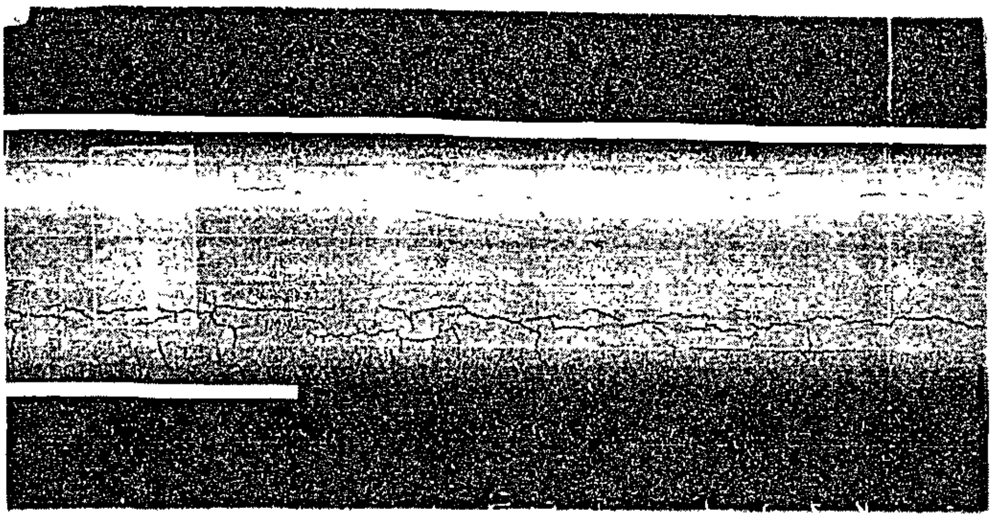


Fig. 4 Typical Cracking Observed on the Tomei Expressway

-- Longitudinal Cracking and Its Progressive Stage to the Alligator Cracking --

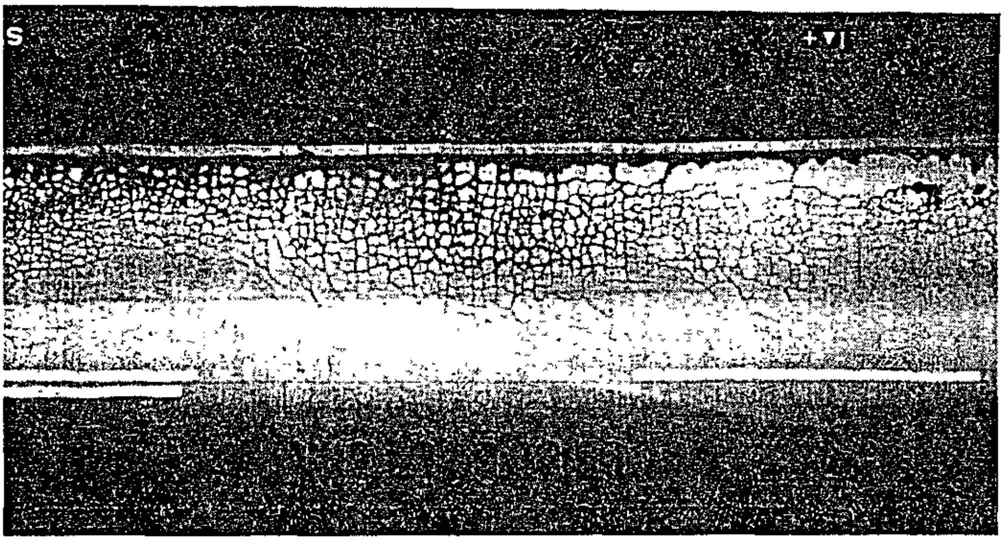


Fig. 5 Typical Alligator Cracking Observed on a National Highway

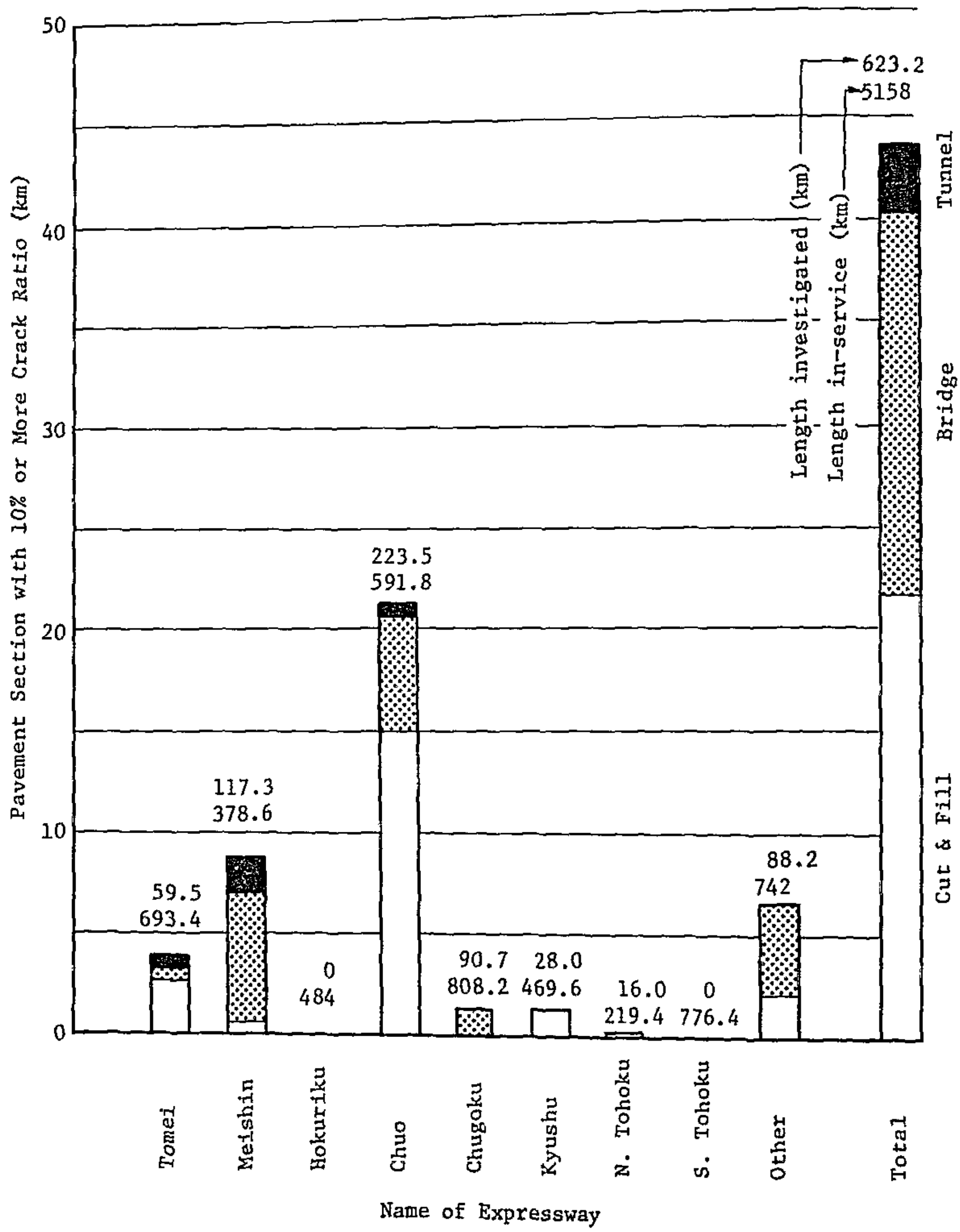


Fig. 6 Pavement Sections with 10% or More Crack Ratio
-- 1974 Inventory Study for Expressway --

c) Skid Resistance

Skid resistance generated at the interface between the pavement and a tire is considered one of the most important characteristics for high-speed driving. Skid resistance characteristics of tires operating in the brake slip mode is defined in Eq. (1) and explained in Fig. 7.

$$SN = 100 \times \mu = 100 \times \frac{F}{W} \quad \text{-------------------------------} \quad (1)$$

where SN = Skid Number

μ = Coefficient of friction defined by physics

F = Friction force generated between tire and pavement contact patch under the brake slip mode (kg)

W = Vertical wheel load (kg)

Basic characteristics of skid resistance and safety driving may be summerized as below.

* Skidding problem is considered only on the wet pavement.

* Required skid resistance for safety driving varies with the corresponding driving maneuver. The higher skid resistance is required at the higher speed driving, more quick cornering and sudden stops.

* Obtainable skid resistance between the pavement and a tire, on the other hand, decreases with the increase of driving speed.

* Obtainable skid resistance is further affected by the numerous factors such as harshness of aggregate, texture of pavement surface, tread pattern of the tire, quality of tire rubber and temperature.

* The construction of the least speed gradient surface is the final goal from the engineering stand of view. This might be attained by the careful selection of harsh aggregates and the proper gradation to obtain enough macro and miro textures of

the surface mixture. Speed gradient of typical expressway pavement and skid resistance trend with time for different aggregates are illustrated in Figs. 8 and 9.

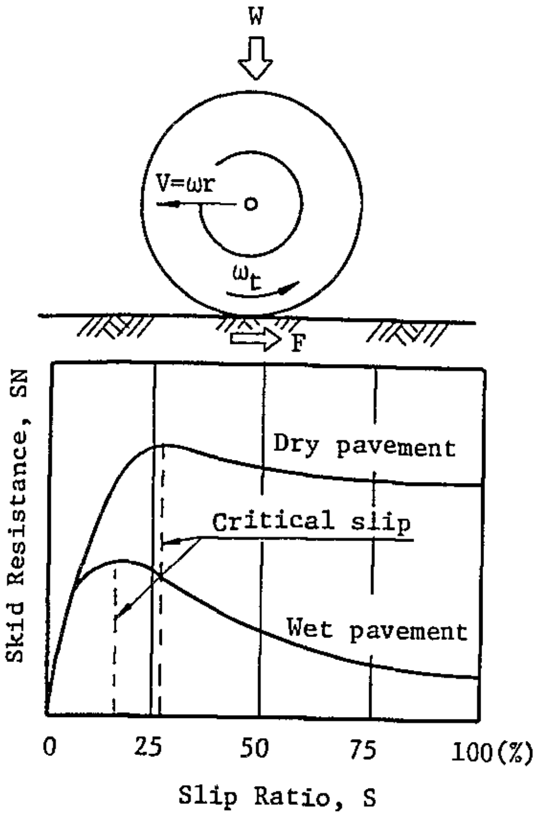
Distribution of skid numbers measured on the representative expressways is shown in Fig. 10. Since the minimum value of skid resistance for safe driving is around 15-25, the present situation is considered to be satisfactory.

d) Longitudinal Surface Roughness and Bump

It is well known that the excess surface roughness makes a driver uncomfortable for high-speed driving. Pavement smoothness in our expressway system is in fairly good condition except bumps at the backfill of the structure and large settlement due to the compression of soft ground. Occurence of the bump, generally speaking, is inevitable even though careful consideration for material selection and compaction of the backfill has been paid. Therefore, routine maintenance are conducted by filling the bituminous mixture at the depressed portion of the pavement, when it is accessary.

e) Pot Holes

Pot holes are indented pavement as shown in Fig. 11. They are not severe problem in our country but can be observed at the unfavorable conditions proceeding to the heavy rainfall or during the spring thaw period. The possible cause is the lower bituminous mixture resistance against the traction force generated by the passage of tires. Lower mixture resistance might be due to improper asphalt property, non-uniform gradation, unsatisfactory compaction and so forth.



$$SN = 100 \times \frac{F}{W}$$

where SN = Skid number
F = Friction force (kg)
W = Wheel load (kg)

$$S = 100 \times \frac{\omega - \omega_t}{\omega}$$

where S = Slip ratio (%)
ω = Angular velocity of the rolling tire corresponding to vehicle speed
ω_t = Angular velocity of the slipping tire

Fig. 7 Skid Resistance Characteristics of Tires Operating in the Brake Slip Mode

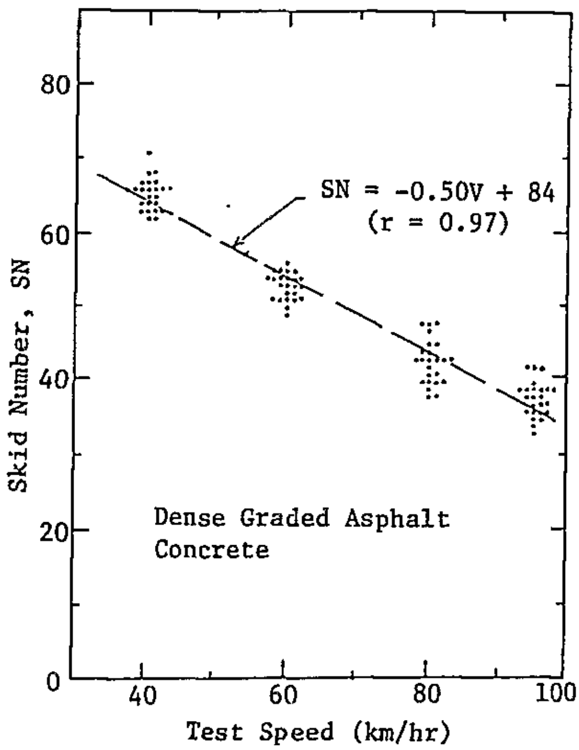


Fig. 8 Speed Gradient of Skid Number

-- Typical Dense Graded Asphalt Concrete for Expressway --

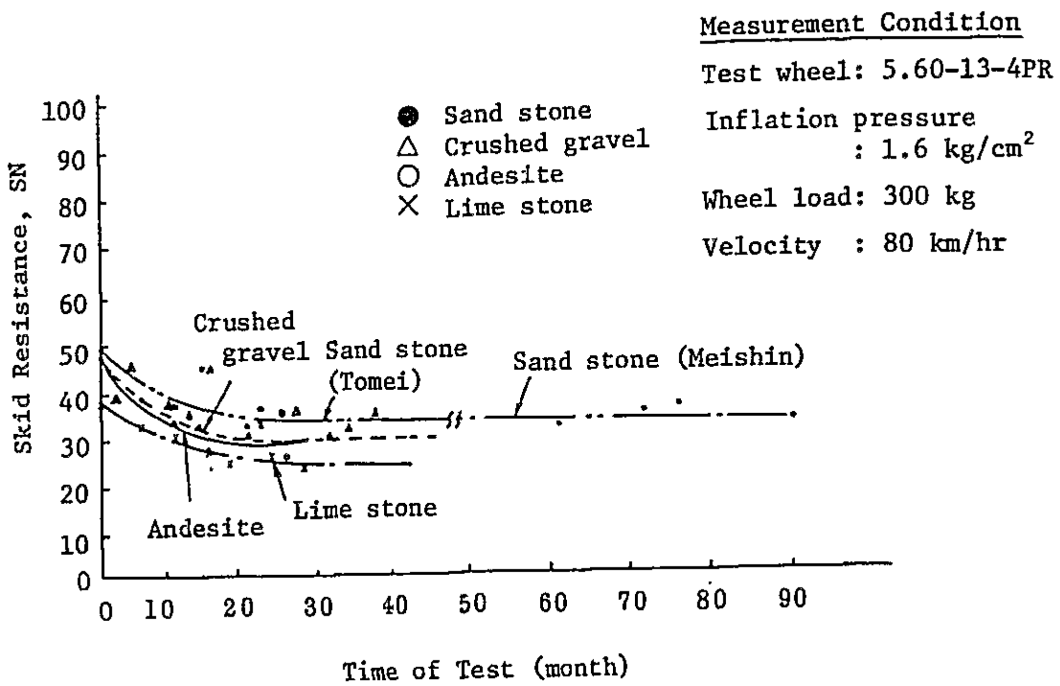


Fig. 9 Decrease of Skid Resistance with Time in Terms of Aggregate Type

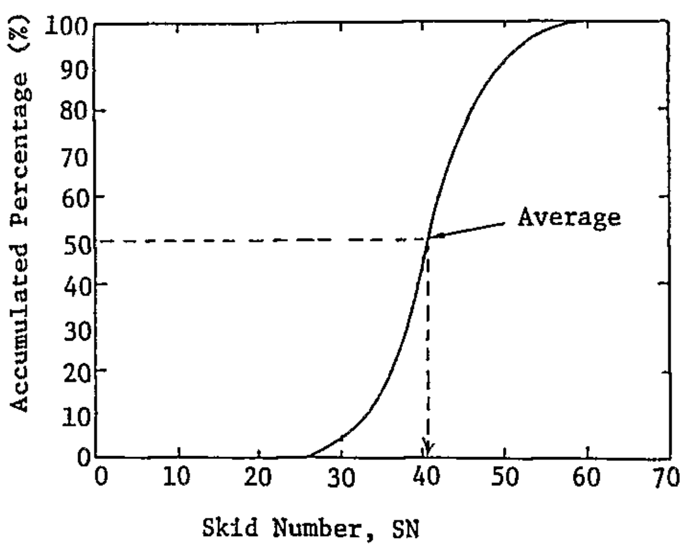


Fig. 10 Distribution of Skid Number
-- 1977 Inventory Study for Expressway --

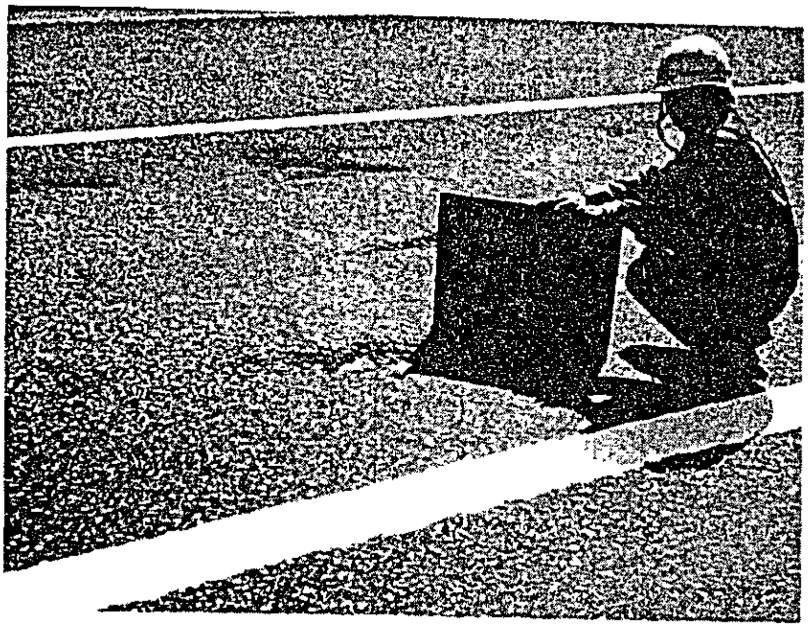


Fig. 11 An Example of Pot Hole Observed in Spring Thaw Period

-- The Tohoku Expressway --

2-2 National Highway System

As in the case of the expressway pavements, rutting and abraision, and cracking are the main pavement characteristics to be discussed for the national highway system.

The Ministry of Construction carried out the inventory study[3)]totaling 1,118 km in length, of which 249.6 km is sampled from the design traffic classification B pavement (light pavement), 599.2 km from C pavement (medium pavement) and 269.2 km from D pavement (heavy pavement).

The overall result is summerized in Table 1. Right and bottom portion separated by the dashed line of this table is considered to be repaired as soon as possible judged from the proposed standard described later in Chapter 6. The length which needs immediate repair is around 120 km or 10 % of investigated length.

Table 1 Summary of Present Pavement Conditions for National Highway

		Rut Depth (mm)														Total length(km)	% of length	Cumulative %
		0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	Over 61			
Crack Ratio (%)	0	0	29	547	876	729	620	524	457	298	145	69	24	9	8	4335	38.8	38.8
	0.1 - 5	0	35	502	933	837	664	504	413	318	164	67	24	11	9	4481	40.1	78.9
	5.1 - 10	0	13	118	160	140	145	98	79	54	24	18	4	2	2	857	7.7	86.5
	10.1 - 15	0	4	57	84	74	58	42	39	28	21	9	5	5	3	429	3.8	90.4
	15.1 - 20	0	4	38	48	49	36	40	38	18	15	4	2	1	2	295	2.6	93.0
	20.1 - 25	0	2	16	23	33	29	26	26	26	12	2	3	1	2	201	1.8	94.8
	25.1 - 30	0	2	25	23	21	21	25	17	16	9	5	0	0	0	164	1.5	96.3
	30.1 - 35	0	0	7	17	14	19	13	12	7	6	7	2	2	1	107	1.0	97.2
	35.1 - 40	0	0	1	9	7	11	17	10	17	6	5	2	0	1	86	0.8	98.0
	40.1 - 45	0	0	3	9	11	4	7	13	6	5	2	0	1	0	61	0.5	98.5
	45.1 - 50	0	1	6	5	1	14	5	8	4	2	2	1	0	1	50	0.4	99.0
	50.1 - 55	0	0	2	1	4	5	5	9	6	1	1	0	0	0	34	0.3	99.3
	55.1 - 60	0	0	1	2	4	2	6	3	4	1	1	0	0	0	24	0.2	99.5
	Over 60.1	0	0	3	4	7	8	7	13	8	3	2	1	0	0	56	0.5	100.0
Total length (km)		0	90	1326	2194	1931	1636	1319	1137	810	414	194	68	32	29	11180	100	
% of length		0	0.8	11.9	19.6	17.3	16.6	11.8	10.2	7.2	3.7	1.7	0.3	0.3	0.3	100		
Cumulative %		0	0.8	12.7	32.3	49.6	64.2	76.0	86.2	93.4	97.1	98.8	99.7	99.7	100			

Note: Right bottom portion separated by the dashed line indicates MCI_0, MCI_1 or MCI_2 is equal to or less than 3.

3. PAVEMENT MANAGEMENT

The needs of pavement maintenance are going to increase from the study described in the previous Chapter. Maintenance budget, on the other hand, is not expected automatically to increase with the needs of maintenance. Such constraint requires more efficient budget allocation based on the reasonable and systematic judgements for the maintenance work.

General flow of the reasonable and systematic maintenance of the pavement, or pavement management, being carried out for the expressway could be expressed in Fig. 12.

In this Figure, we classified the pavement characteristics into two groups; (a) roughness and bump, pot hole, and localized cracking and (b) rutting and abrasion, cracking, and skid resistance.

The former is the pavement characteristics observed in limited areas and needs the minor rehabilitation. Hence, this is usually evaluated, judged and repaired by the individual maintenance office.

The latter, on the other hand, is usually observed on the large scale and needs the major rehabilitation. This is evaluated, judged and planned to repair by the administration bureau which supervises 5-7 maintenance offices. Excution of repair work itself is done by the appropriate maintenance office even in this case.

Pavement management has three important phases: (a) evaluation of pavement condition, (b) establishment of maintenance levels, and (c) excusion of rehabilitation which includes planning, budgeting and repair working.

3-1 Evaluation of Pavement Conditions

Evaluation of pavement conditons is the first phase of pavement management. For the minor rehabilitation characteristics, patroling or visual inspection is the practical method. For the major rehabilitation characteristics, however, innovational techniques suitable for the inventory study are adopted. Several considerations for this evaluation phase are summerized as below.

* Evaluation must be done along the entire length of the expressway administrated. The reason of this requirement comes from the legal responsibilities which are very severe for those administrate expressway system in Japan.

* High-speed measurement without any traffic control on the in-service expressway is requested. This invented several high-speed evaluation vehicles described later in this report.

* Efficient data reduction system is requested to handle a large number of data obtained by the entire length evaluated.

3-2 Establishment of Maintenance Levels

The second phase of pavement management is the establishment of the maintenance levels. Several considerations at this phase are summerized below.

* Quantitative levels are favorable, since they are easy to operate effectively and uniformly.

* Requested levels by the social opinions.

* Practically operative levels from the point of budget allocation.

* Rational levels from the engineering stand of view.

3-3 Excution of Rehabilitation

The final phase of the pavement management is the excution of maintenance work in which, planning, budgeting and examination of repair method are included. In addition to the technical examination for new pavement construction, method of traffic control at the work site on the expressway, constraint of work time, and selection of construction equipments due to restricted work area must be examined in detail.

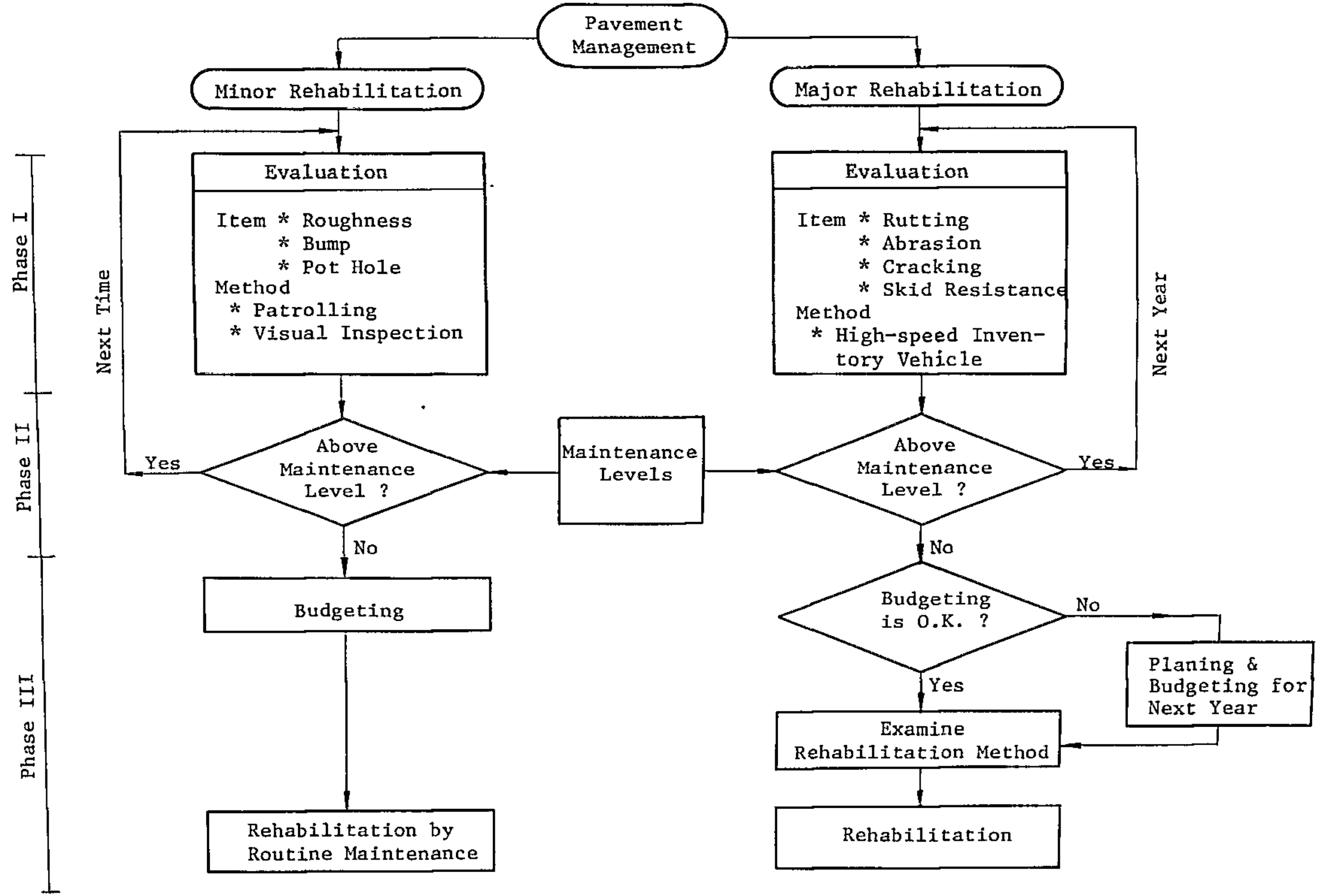


Fig. 12 Flow Diagram of Pavement Management Applied for Expressway System

4. MEASUREMENT OF PAVEMENT CONDITIONS

4-1 Visual Inspection

Visual inspection of the pavement condition is one of the essential activities to maintain the pavement in good condition. This is usually done by the daily patrolling or specially arranged engineers. Daily patrolling, which inspect not only the pavement but also the whole conditions of the highway, is conducted once a day by two engineers from a specially disigned patrol vehicle equipped with some tools.

Patrol men inspect the pavement conditions such as pot holes, excessive bumps and trace of oils, and, if necessary, they make the temporary repairs on the spot.

Inspection by specially arranged pavement engineers may be done to inspect the detailed pavement condition. They walk along the highway and sketch the area, degree and possible causes of pavement distress such as cracks, ruts, roughness and so forth. An example of inspection sheet used by the Ministry of Construction is shown in Table 2.

4-2 Measurement of Pavement Conditions by Conventional Methods

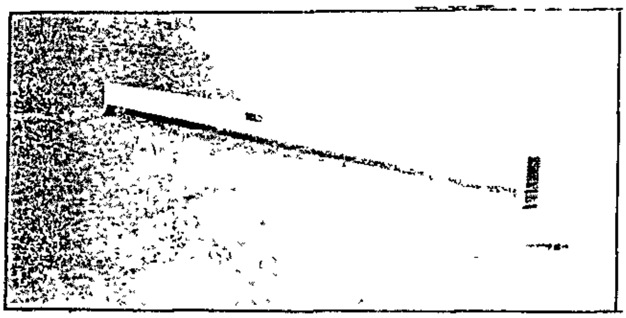
a) Rutting and Abrasion

Rutting and abrasion of the pavement may be conveniently measured by a rut depth meter which is a straight edge specially designed to measure the transversal pavement profile. Two types of rut depth meter are illustrated in Figs. 13 and 14.

For rut depth meter shown in Fig. 13, distance between instrument height and the pavement surface is manually measured by a scale at a constant interval, usually 20 cm increments, in transverse direction. Then transverse profile is constructed by plotting the measured values on the sheet and connecting them. In measurement by the instrument shown in Fig. 14, transverse profile is automatically drawn on the recording sheet when we traverse the measuring wheel from one side to the other.

Table 2 An Example of Visual Inspection Sheet - Ministry of Construction

Pavement Distress	Extent or Amount of Distress
Texture	1 Extremely coarse 2 Coarse 3 Medium 4 Fine
Uniformity of Mixture	1 Uniform 2 Partially non-uniform 3 Non-uniform
Amount of Asphalt	1 Excess and flushed 2 A little excess and partially flushed 3 A little excess but no flushing at present 4 Optimum 5 A little dry side
Skid Resistance	1 Enough Skid resistance 2 Normal skid resistance 3 May slippery
Rut Depth	1 Excess 2 Medium 3 A little
Pot Hole & Ravelling	1 Excess 2 A few 3 None
Abrasion	1 Excess 2 A little 3 None
Longitudinal & Transverse Cracking	1 Excess 2 A little 3 None
Alligator Cracking	1 None 2 Crack Ratio = 0 ∿ 5 % 3 " = 5 ∿ 10 % 4 " = 10 ∿ 20 % 5 " = 20 ∿ 50 % 6 " = 50 ∿ 100 %



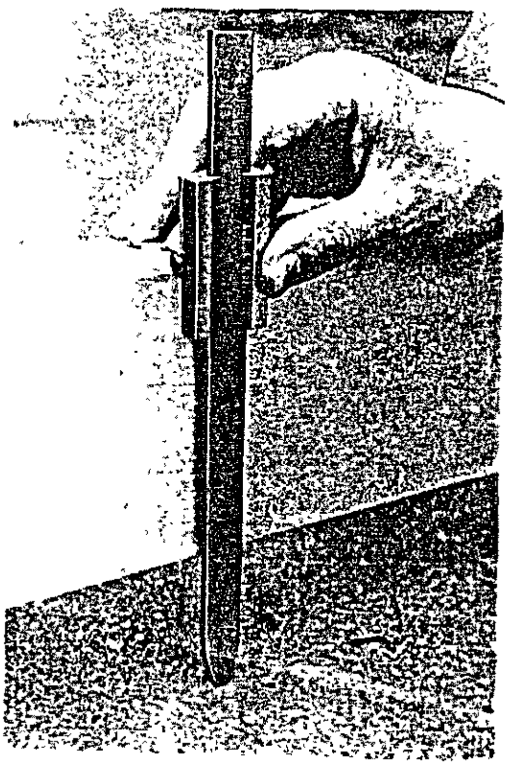
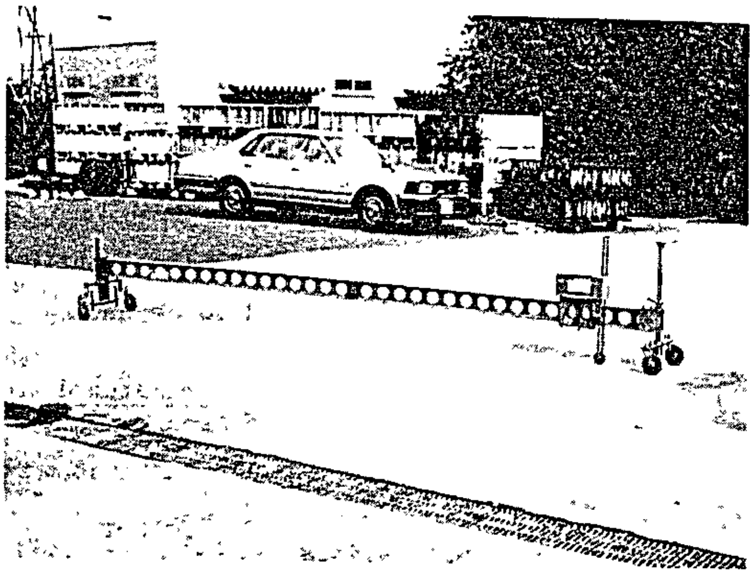


Fig. 13 Rut Depth Meter (Type I)
-- General View and Detail of Measuring Scale --



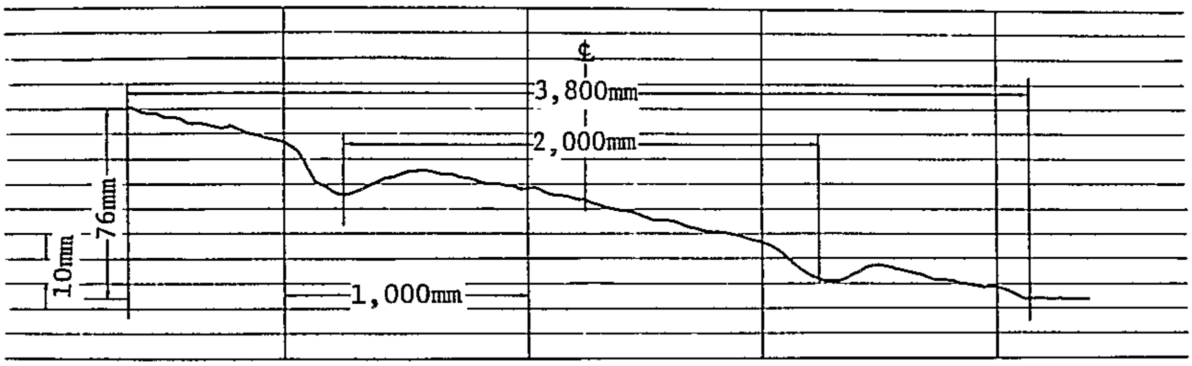


Fig. 14 Rut Depth Meter (Type II)

-- General View and Typical Recording --

b) Cracking

The conventional method for cracked pavement is inspection and sketching by the pavement engineer. Area of cracked pavement, types of cracks, length and opening of cracks, and other related information are investigated and recorded on the sheet. An example of such investigation is shown in Fig. 15.

To express the cracked pavement condition quantitatively, crack ratio defined by Eq. (2) is adopted in Japan.

$$\text{Crack Ratio (\%)} = \frac{\text{Cracked Area } (m^2) + \text{Patched Area } (m^2)}{\text{Investigated Area } (m^2)} \times 100 \qquad (2)$$

Determination of cracked area is as follows.
For the alligator crack, area of squared envelope of cracks is measured, and crack length x 0.3 m is defined as cracked area for longitudinal and transverse cracks as shown in the calculation in Fig. 15.

c) Skid Resistance

The British Pendulum Tester shown in Fig. 16 is used to measure the frictional characteristics of the pavement in the field as well as in the laboratory. It is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The principle of this equipment can be stated that the potential energy, E_1, prior to test minus the potential energy, E_2, after the swing must equal the energy, Ed, dissipated by friction. In equation form,

$$Ed = E_1 - E_2 \qquad (3)$$

Inasmuch as

$$Ed = d \cdot F = d \cdot f \cdot L \qquad (4)$$

where d = Sliding distance of the rubber block

f = Friction coefficient

L = Slider load

The frictional coefficient, f, can be expressed by

$$f = (E_1 - E_2)/ d \cdot L \quad \text{-----------------------------------} \quad (5)$$

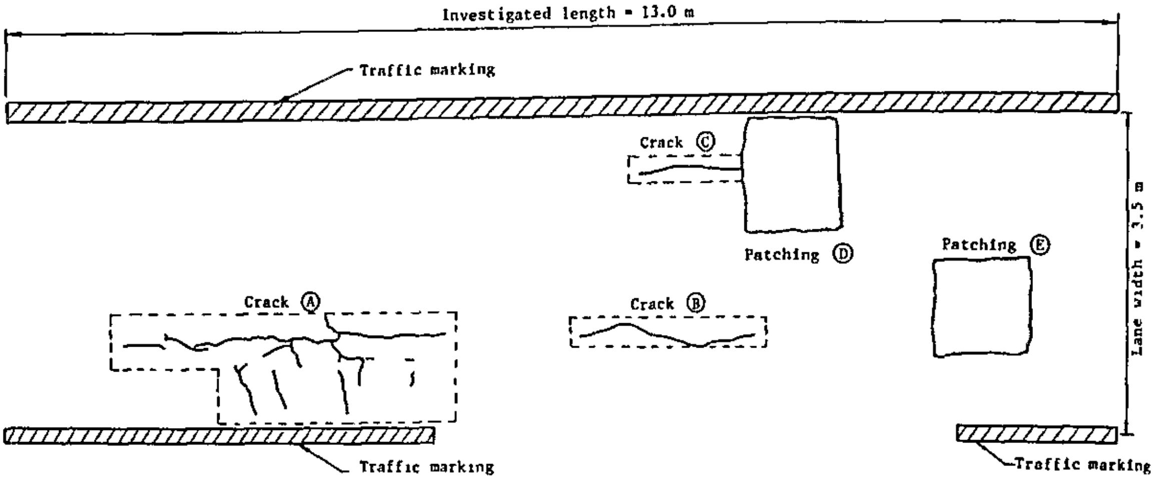
and hence is propotional to the energy difference if the sliding distance and slider load are fixed.

In the actual measurement in accordance with Test Method of KODAN 221, place the pendulum in release position and rotate the drag pointer counter-clockwise until it comes to rest against adjustment screw. Then, release the pendulum to make swing and read the British Pendulum Number, BPN, which is pointed by the drag pointer. Care must be paid for adjustment of slider load, slide length and the quality of slide as well as wetting the pavement throughly prior to each test.

d) Longitudinal Surface Roughness and Bump

The conventional method to measure the surface roughness is a usage of profilometers shown in Figs. 17 and 18. Wheel base length of 8 m, termed as 8 m-profilometer, is used for the new pavement construction of expressways and that of 3 m, termed as 3 m-profilometer is used for maintenance of all highways and new pavement of national highways. For both profilometers, front wheels and rear wheels make the base line and a center wheel measures the pavement roughness relative to the base line described above. Test method is specified in KODAN 220 and the Manual for Design and Construction of Asphalt Pavement, respectively. Measured roughness is quantitatively expressed in Profile Index, PRI, for 8 m-profilometer and Variance, σ, for 3 m-profilometer as shown in Eqs. (6) and (7).

$$PRI = \frac{\Sigma a_i}{L} \quad \text{---} \quad (6)$$



Calculation of Crack Ratio

Ⓐ	Alligator	1.25 x 0.6 + 2.85 x 1.25	= 4.3
Ⓑ	Longitudinal	2.3 x 0.3	= 0.7
Ⓒ	Longitudinal	1.35 x 0.3	= 0.4
Ⓓ	Patching	1.1 x 1.25	= 1.4
Ⓔ	Patching	1.1 x 1.05	= 1.2
		Total	= 8.0 m²

Investigated Area 13.0 x 3.5 = 45.5 m²

$$\text{Crack Ratio} = 100 \times \frac{8.0}{45.5} = 17.6\%$$

Fig. 15 Crack Investigation and Determination of Crack Ratio

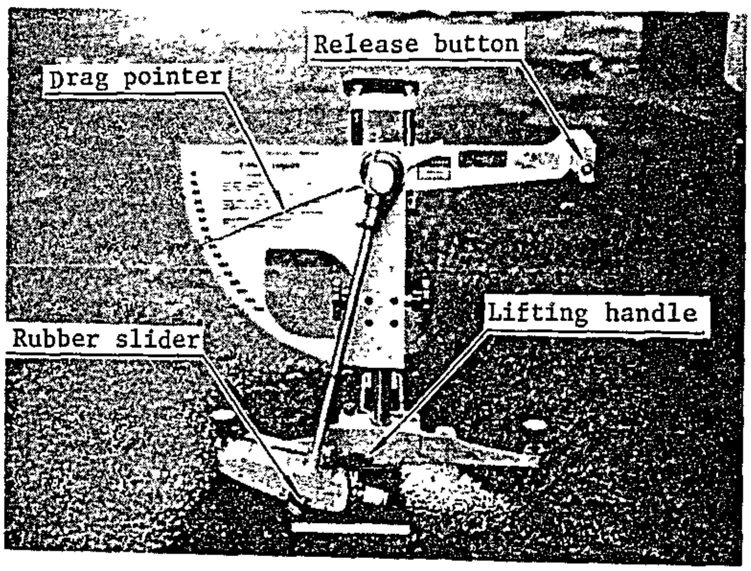


Fig. 16 British Pendulum Tester

where PRI = Profile Index (cm/km)

a_i = Deviation in excess of 6 mm width band (cm)

L = Total length investigated (km)

$$\sigma = \sqrt{\frac{(x_i - \bar{x})^2}{n - 1}} \quad \text{-----------------------------------} \quad (7)$$

where σ = Variance of roughness (cm)

x_i = Individual distance from the base line

$\bar{x}$ = Average of x_i

n = Number of samples

Bump at the backfill of the structure is measured by the string and the rule as shown in Fig. 19.

Longitudinal length of measurement is 15 m from the expansion joint of the abutment. Lateral position of measurement might be outer, inner and between wheel paths.

Depth of the pavement surface from the base line string is measured at 0.5 m intervals for up to 5 m and 1 m intervals between 5 to 15 m.

The profile of backfill settlement is drawn and the maximum depth, D_{max}, is read off from the profile.

Alternative method to evaluate the bump is so called subjective rating by the maintenance engineers. They drive a patrol vehicle and rate the degree of bump which greatly affects the rid-ability travelling through the structure backfill. This is sub-jective evaluation, but, when the evaluator is well trained to compare the rideability and the maximum depth of backfill set-tlement, the rating is practically useful for the maintenance need judgement.

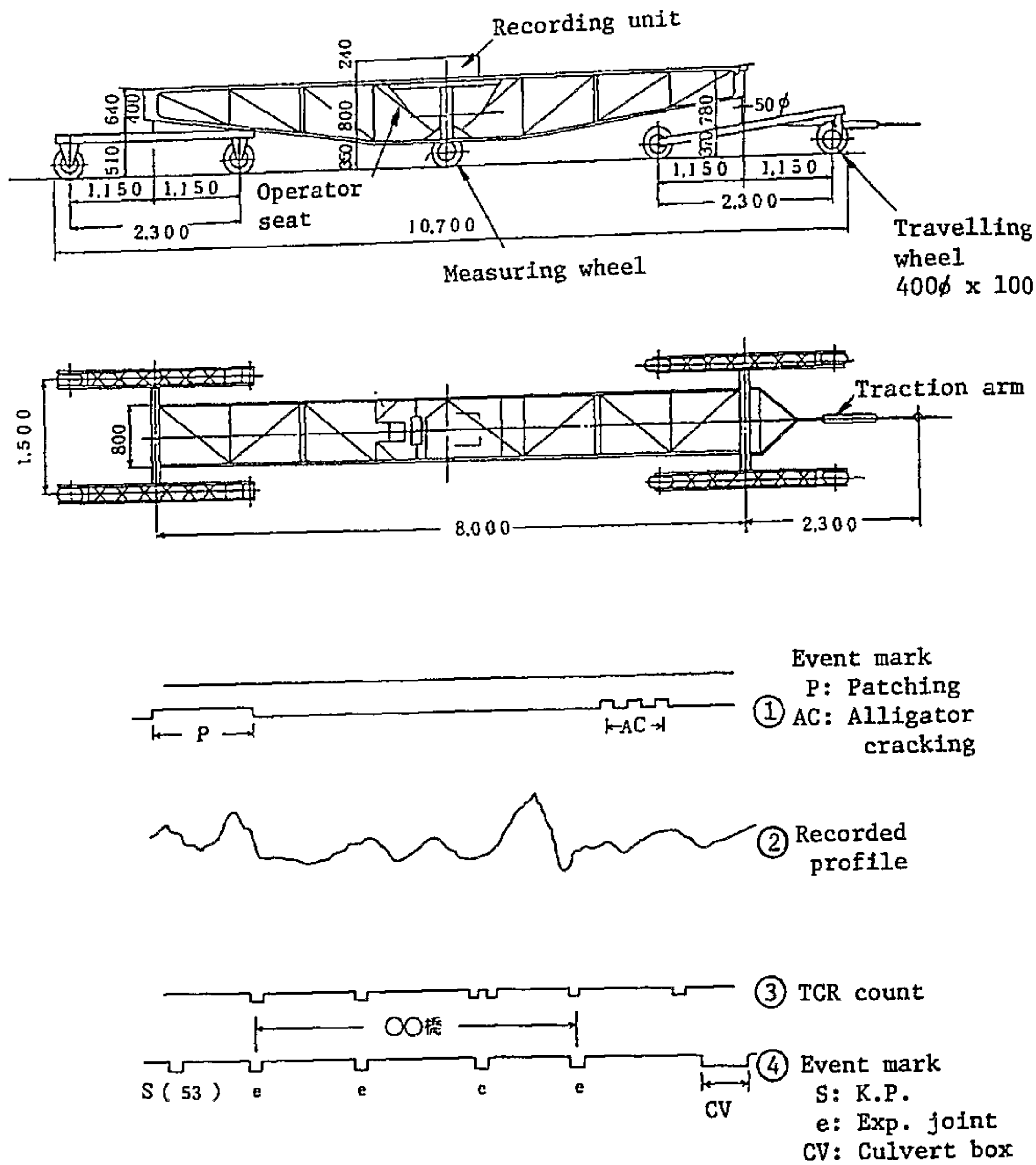
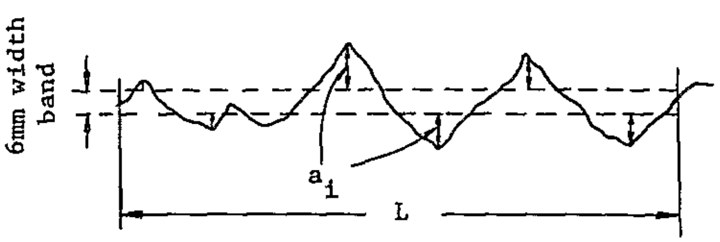


Fig. 17-a General View and Typical Recording of 8m-Profilometer



$$PRI = \frac{\Sigma a_i}{L}$$

where

PRI = Profile index (cm/km)

a_i = Deviation in excess of 6mm band (cm)

L = Total length investigated (km)

Fig. 17-b Determination of Profile Index, PRI, from Recorded Profile

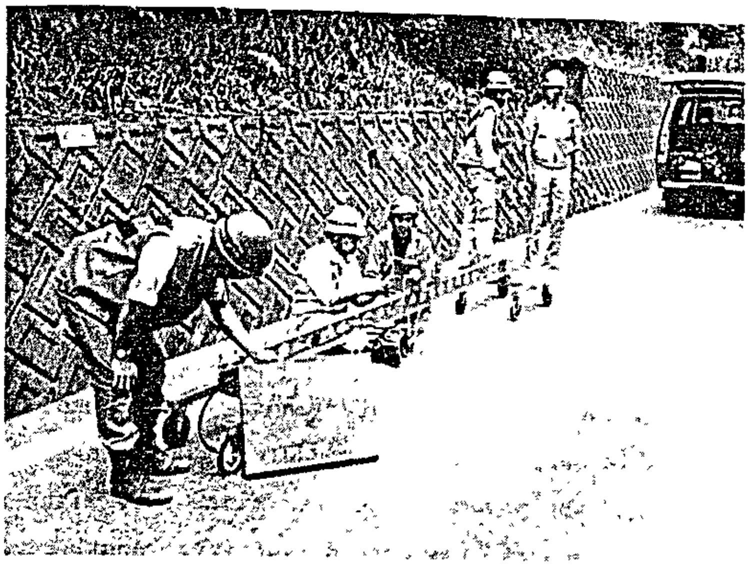


Fig. 18 General View of 3m-Profilometer

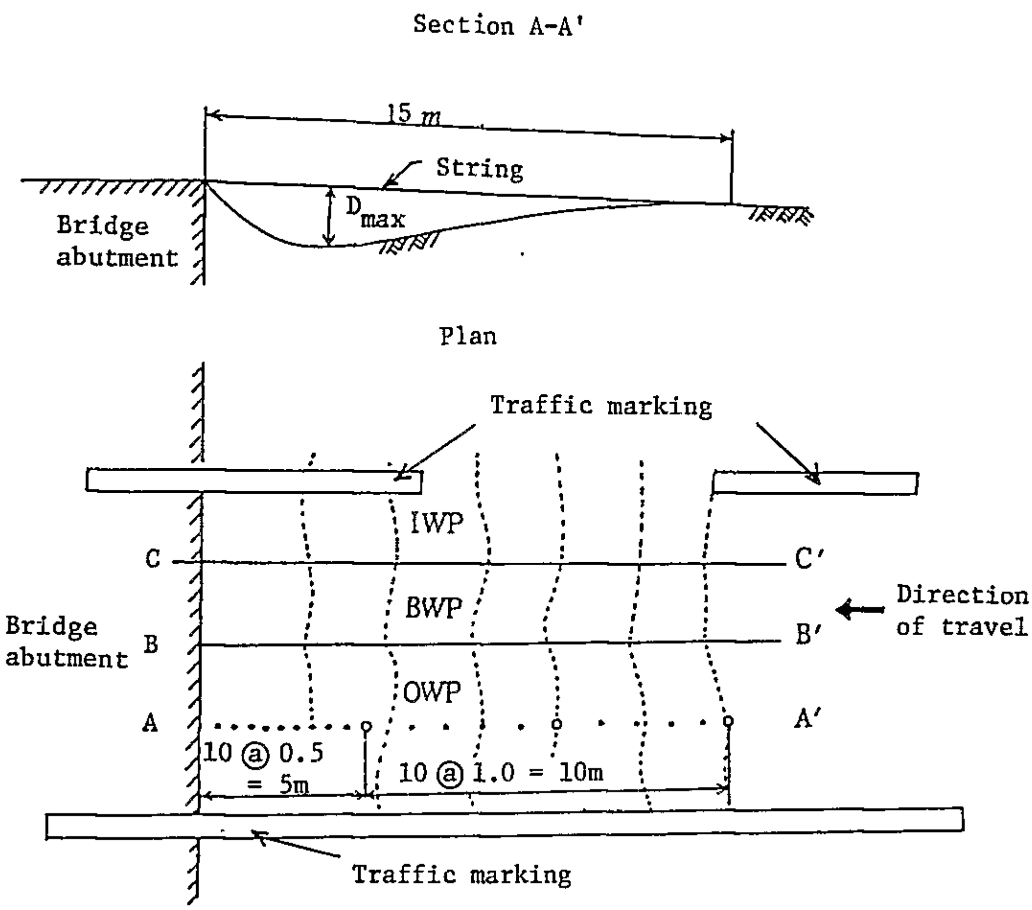


Fig. 19 Measurement of Bump at the Backfill of Abutment

e) Pot Holes

Pot holes are evaluated by inspection and sketching as the case of cracking. Area and size of pot holes, degree of asphalt stripping, uniformity of mixture gradation, possible hardening of asphalt and other related conditions are carefully examined.

f) Deflection

Items a) through e) described above are pavement characteristics observable on the surface, hence, are concerned by both the driver and the pavement engineer since they might affect the ridability and the pavement durability. Another characteristic soly concerned by the pavement personnel is surface deflection which shows the structural adequacy of the pavement.

The most popular measurement method for this purpose might be the Benkelman Beam Deflection as shown in Fig. 20-a.

Benkelman Beam method is widely used in Japan for the construction control of embankment and base course. To evaluate base and subgrade strength on the in-service highway, the Benkelman Beam deflection test is carried out on the surface course with 7 ton wheel load condition in accordance with Test Method of KODAN 102. A typical deflection curve is illustrated in Fig. 20-b with the maximum deflection of 1.37 mm in this case.

Relationship between the Benkelman Beam deflection and cracking has been studied and shown in Fig. 21.
Fig. 21 is constructed from pavement research program carried out on the heavily travelled expressway.[4] At that time, test sections of the expressway were 7 years in service and carried $6 \sim 8 \times 10^6$ applications of 10 t EAL (Equivalent Axle Load). Under such conditions, no cracks were observed for sections whose deflection is less than 0.5 mm. On the other hand, all sections with greater than 0.6 mm deflection showed the longitudinal or alligator cracks in any degree. The test section with the least deflection of 0.2 mm shows good condition with no occurence of cracking after 14 years service and 1.6×10^7 10 ton EAL applications at present.

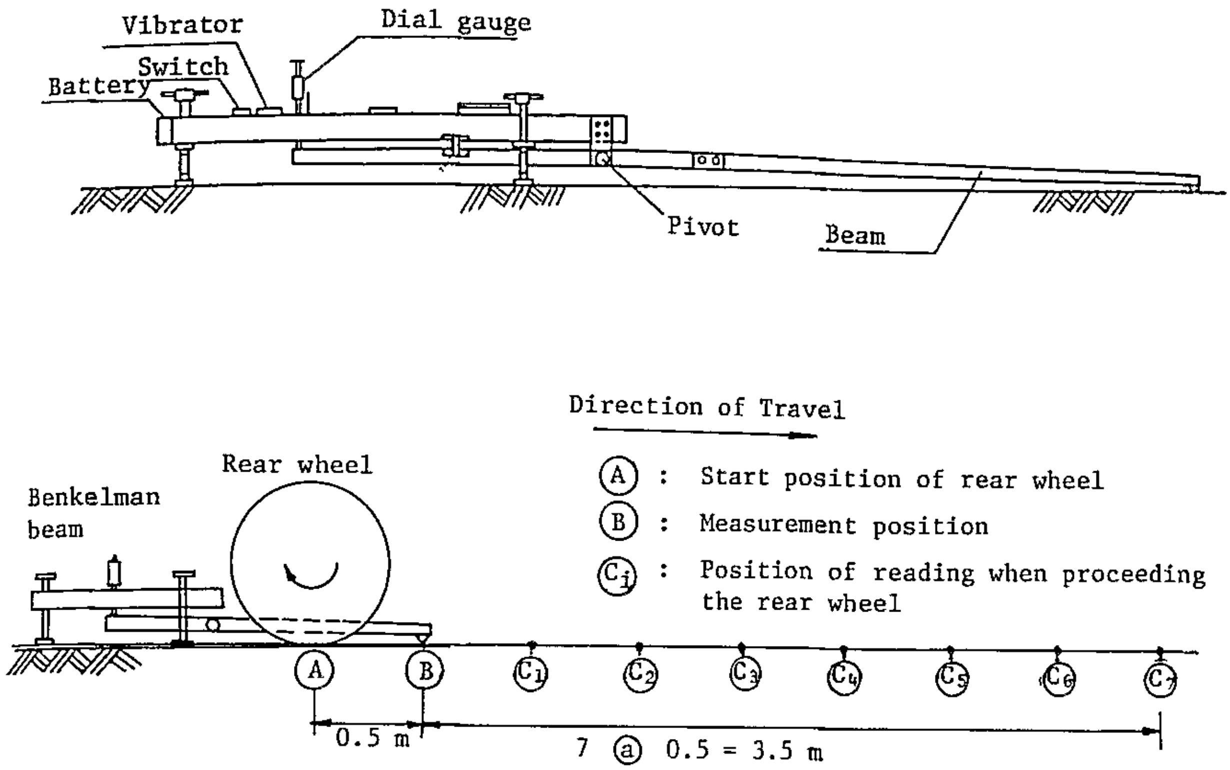


Fig. 20-a Measurement of Surface Deflection by Benkelman Beam

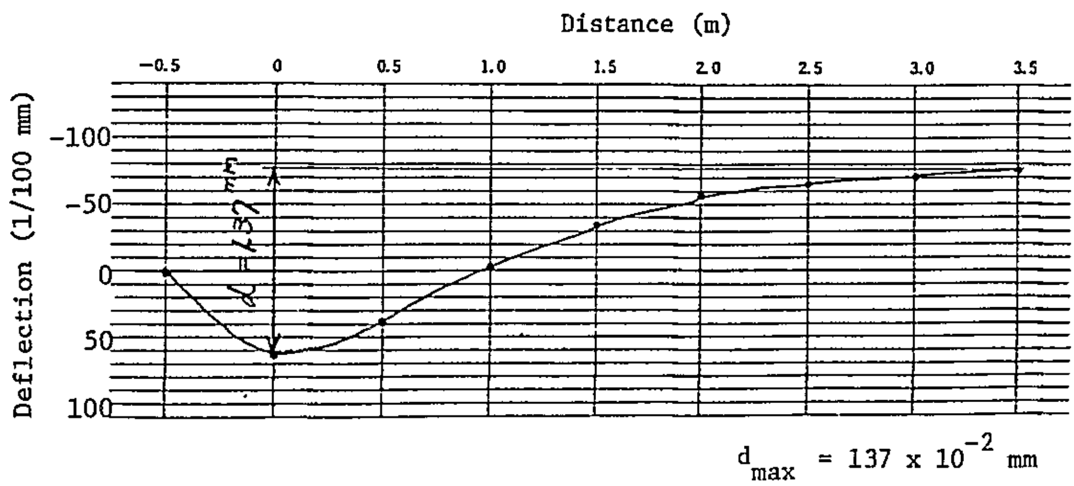


Fig. 20-b Typical Deflection Curve with Maximum Deflection of 1.37 mm

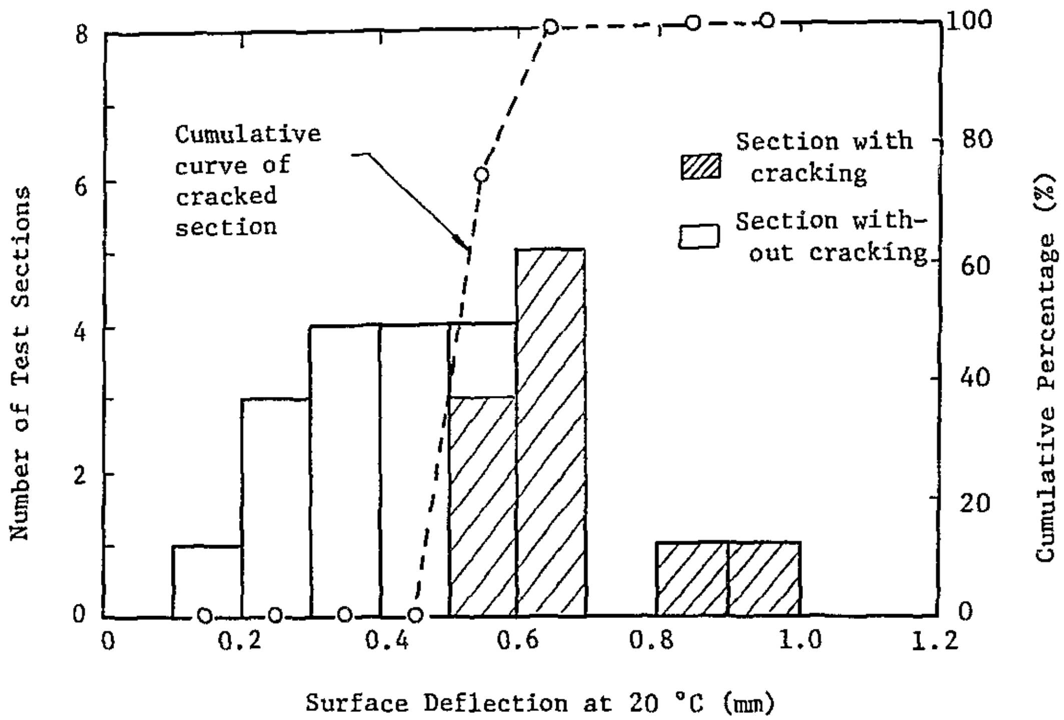


Fig. 21 Observed Relationship Between Benkelman Beam Deflection and Cracking

4-3 Measurement of Pavement Conditions by Innovational Methods

Measurement methods being described in this section are those developed for maintenance purpose especially suitable for inventory study and establishment of maintenance plans.

a) Rutting and Abrasion

Rutting and Abrasion along the entire length of pavement administrated by a specific organization can be measured by the Rut Depth Photographic Recorder, RDP75, developed by a private surveying company in 1975. General view and system diagram of the instrument are shown in Fig. 22. The Rut Depth Photographic Recorder is composed of an illumination unit with hair line projector, camera unit and pulse signal transmitter which actuates the photographical interval. All these units are mounted on the small sized bus (micro-bus). The hairline projector projects the hairline on the rutted pavement. The projected hairline makes the shadow which is similar to but enlarged shape of the actual shape of rutting. The vehicle mounted pulse camera then takes the projected hairline vertically from 3.0 m in height.

Measuring principle is illustrated by Fig. 23. In Fig. 23, given D_2 is the depressed portion of rut depth on the pavement, D_2' is the projected rut depth, d_2 is photographed rut depth on the film, H = 3 m is photographing distance, f = 15 mm is forcal distance, and $\Theta = 26° 33'$ is an angle of hairline projection, the following equations can be constructed:

$$D_2' = D_2 \cot \Theta \quad \text{------------------------} \quad (8)$$

$$d_2 = \frac{f}{H} \cdot D_2' \quad \text{------------------------} \quad (9)$$

Substituting d_2' in Eq. (8) for Eq. (9), Eq. (10) results

$$D_2 = \frac{H}{f} \cdot \frac{d_2}{\cot \Theta} \quad \text{------------------------} \quad (10)$$

If an upheaved portion of D_1 exists, Eq. (11) is also made.

$$D_1 = \frac{H}{f} \cdot \frac{d_1}{\cot \Theta} \quad \text{------------------------} \quad (11)$$

Since Rut Depth, RD, is defined as $D_1 + D_2$,

$$RD = \frac{H}{f} \cdot \frac{d_1 + d_2}{\cot \Theta} = \frac{3000}{15} \times \frac{d_1 + d_2}{2} = 100 \times (d_1 + d_2) \text{--} \quad (12)$$

In other words, RD can be determined by half of the apparent rut depth on the film multiplied by the scale ratio, H/f = 3000/15 = 200.

Some operational features of rut depth measurement are summarized as below.

* Measuring speed : 0 ∿ 80 km/h
* Measuring width : 4.6 m
* Measuring interval : 5, 10, 20, 50 and 100 m
* Measuring accuracy : ±2 mm

Typical photographed rutting is shown in Fig. 24. Rut depth on the film is measured by the cordinate analyzer.

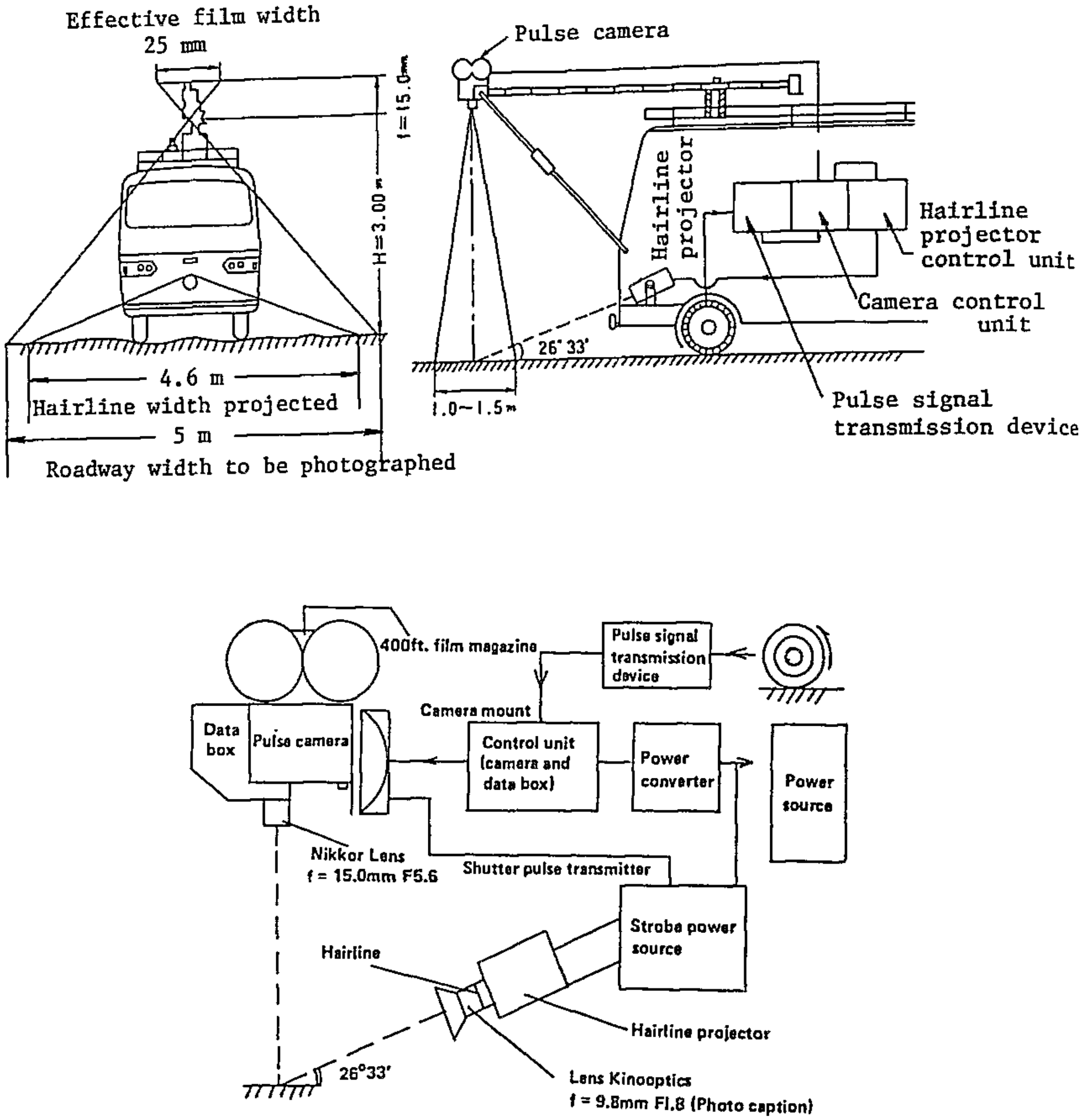


Fig. 22 General View and System Diagram of Rut Depth Photographic Recorder

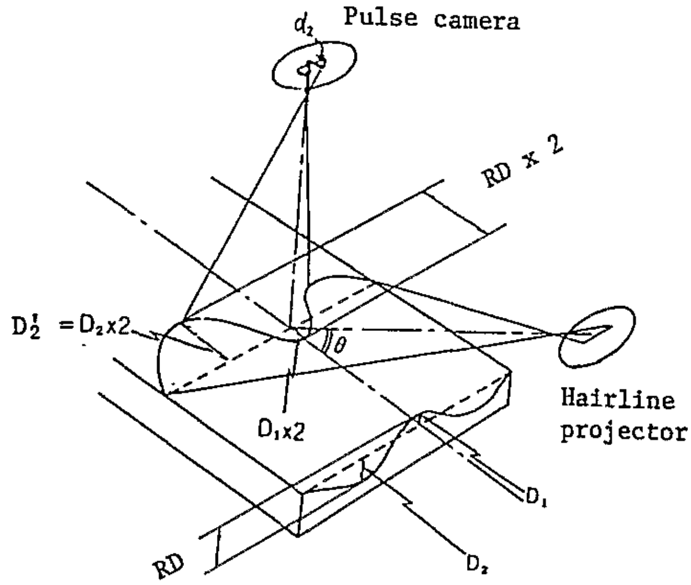


Fig. 23 Measuring Principle of Rut Depth Photographic Recorder

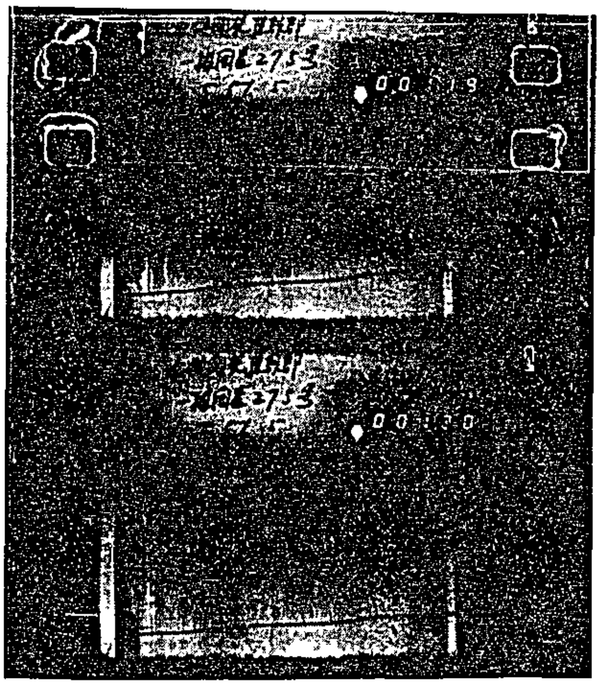


Fig. 24 Typical Rutting Photographed by the Rut Depth Photographic Recorder

b) Cracking

Cracking of the pavement can be continuously recorded by the Road Surface Photographic Recorder, Roadrecon 70, developped by the private surveying company in 1970. It consists of a camera unit, illumination unit, power source unit, and signal transmitter. All these units are mounted on the small sized bus (micro-bus) and photographically records the cracking condition with high travelling speed.
One of the most important mechanism of this system is to syncronize the film feeding speed and illumination intensity with the travelling speed.

General view and system diagram of this equipment are shown in Fig. 25. Some operational features are summerized as below.

* Measuring speed	:	10 ∿ 60 km/h
* Measuring width	:	5.0 m
* Measurable minimum crack opening	:	1.0 mm
* Photographed scale	:	1 : 200
* Maximum measuring length per a film magazine	:	approximately 60 km

A film analyzer incorporating a comparator and a meshed plate are employed to analyze the films. In determination of the cracked and patched areas, 0.5 m x 0.5 m or 1/4 lane width (= 0.875 m) x 1.0 m mesh plate is overlaped on the film as shown in Fig. 26, and the number of the meshes covering cracks and patchings is counted. The area of alligator cracking is determined by the number of meshes counted multiplied by the individual mesh area (0.25 m^2 or 0.875 m^2) and area of longitudinal or transverse cracking is determined by the number of meshes counted multiplied by 0.3 m x 0.5 m = 0.15 m^2 or 0.3 m x 1.0 m = 0.3 m^2. A comparator may be used simultaneously to obtain area or length measurement by means of the coordinate values.

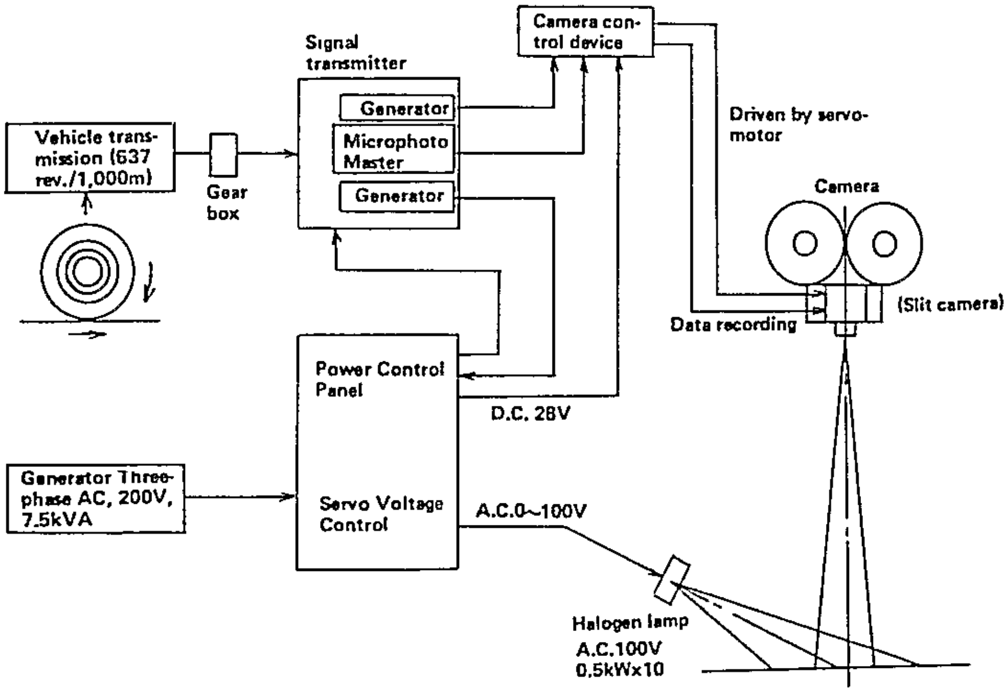


Fig. 25 General View and System Diagram of Continuous Road Surface Photographic Recorder

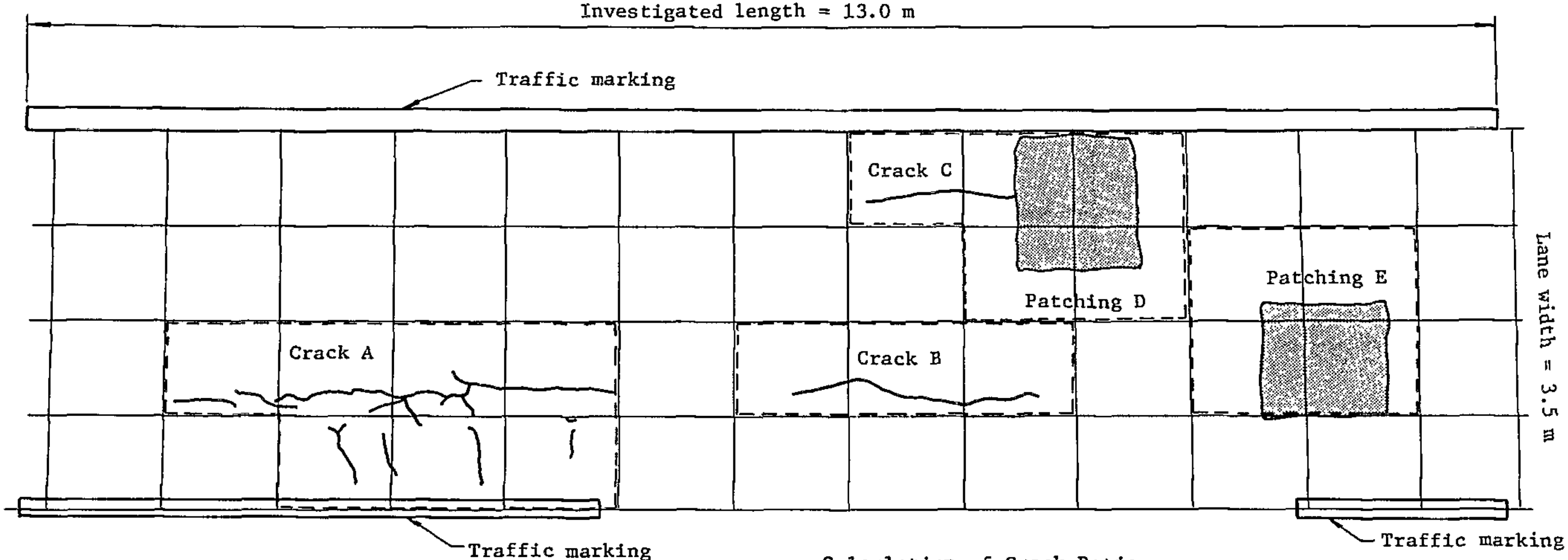


Fig. 26 Determination of Crack Ratio by Means of Mesh Method

-- Example of 1/4 Lane Width x 1 m Mesh --

Calculation of Crack Ratio

Ⓐ	Alligator	7 x 1 x 0.875	= 6.1 m^2
Ⓑ	Longitudinal	3 x 1 x 0.3	= 0.9
Ⓒ	Longitudinal	1 x 1 x 0.3	= 0.3
Ⓓ	Patching	4 x 1 x 0.875	= 3.5
Ⓔ	Patching	4 x 1 x 0.875	= 3.5
		Total	14.3 m^2

Investigated Area 13.0 x 3.5 = 45.5 m^2

$$\text{Crack Ratio} = 100 \times \frac{14.3}{45.5} = 31.4\%$$

c) Skid Resistance

Skid Resistance between the pavement and a tire is measured by a locked wheel skid test vehicle in accordance with the test method of KODAN 222.

The general view of skid test vehicle is shown in Fig. 27-a. A test vehicle travels at a constant speed with rolling the test wheel. When it is desired to measure the skid resistance, the test wheel is completely locked and the generated braking force, F, and the wheel load, P, are simultaneously measured. Then skid number, SN, is determined by Eq. (13).

$$SN = \frac{F}{P} \times 100 \qquad (13)$$

J.H.P.C. now owns two types of skid test vehicle as shown in Fig. 28. The larger sized test vehicle at top is owned by the Laboratory of J.H.P.C. and mainly operated for the research purpose. Skid resistance of various bituminous mixtures, decrease of skid resistance with speed and time in service, and correlation study of skid number and the traffic accidents have been representative research subjects. Routine measurement of skid resistance on the in-service expressway is carried out approximately once a year with the medium sized test vehicle shown at bottom which is stationed at the some administration bureaus. Measurement is made at 200 m intervals with travelling speed of 80 km/h. Two water tank trucks with 10,000 ℓ capacity are employed uniformly to wet the pavement prior to the skid measurement. Wetting of the pavement is very important, since the thickness of water film extremely affects the measured skid resistance. Water film thickness of 0.5 mm to 1.0 mm is successively obtained by two water tank trucks.

A typical recording of skid measurement is also shown in Fig. 27-b. Braking force is determined by the height of trace, H, multiplied by a specific constant. Under the constant wheel load condition, the skid resistance becomes propotionally high to the height of recorded trace.

Other information on the test vehicles described above are summerized in Table 3.

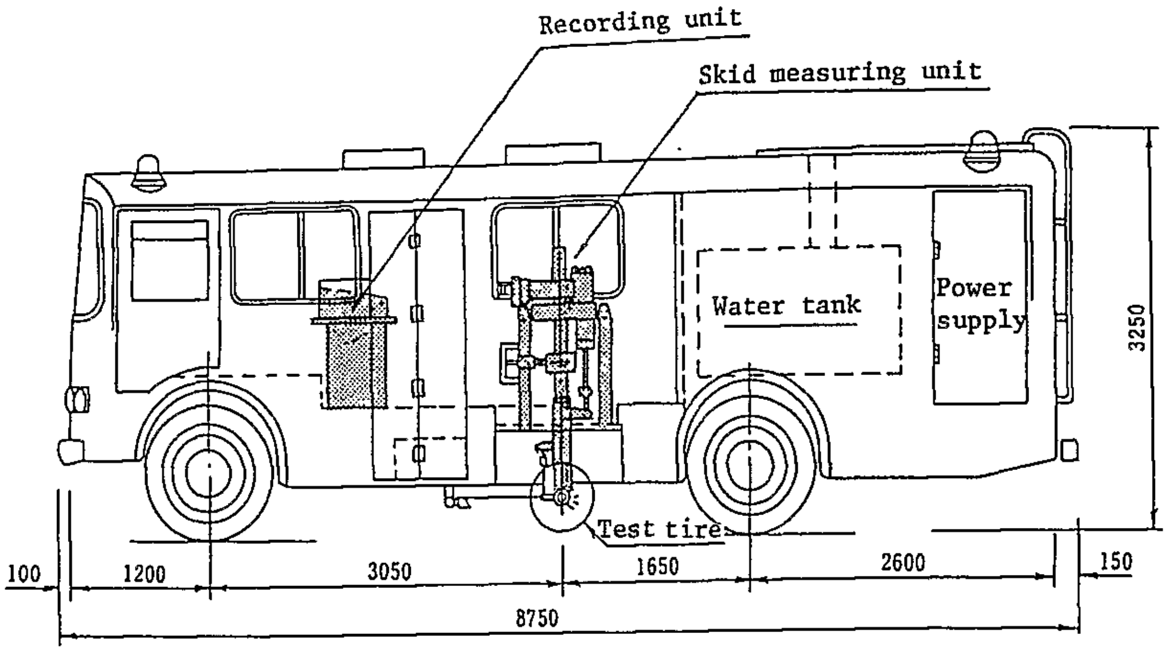


Fig. 27-a General View of Skid Test Vehicle
(The Laboratory of Japan Highway Public Corporation)

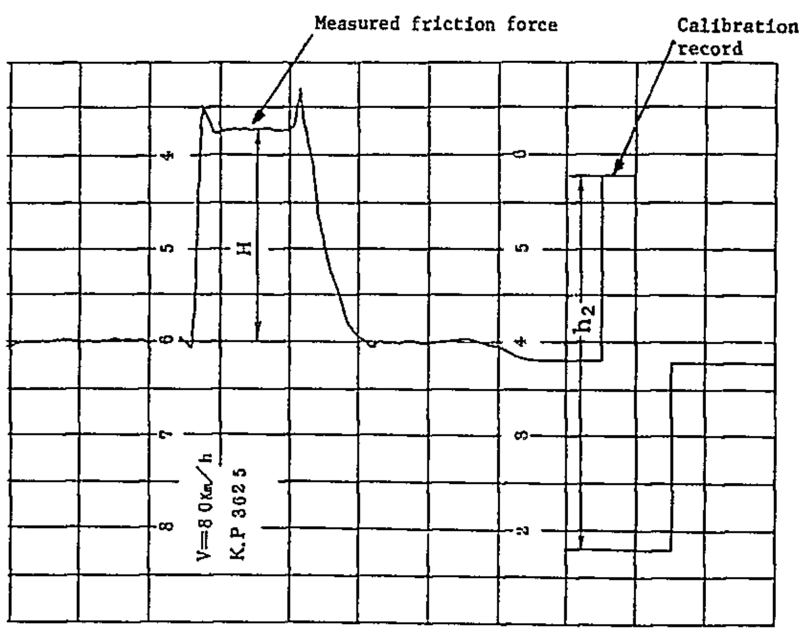


Fig. 27-b Typical Recording of Skid Resistance

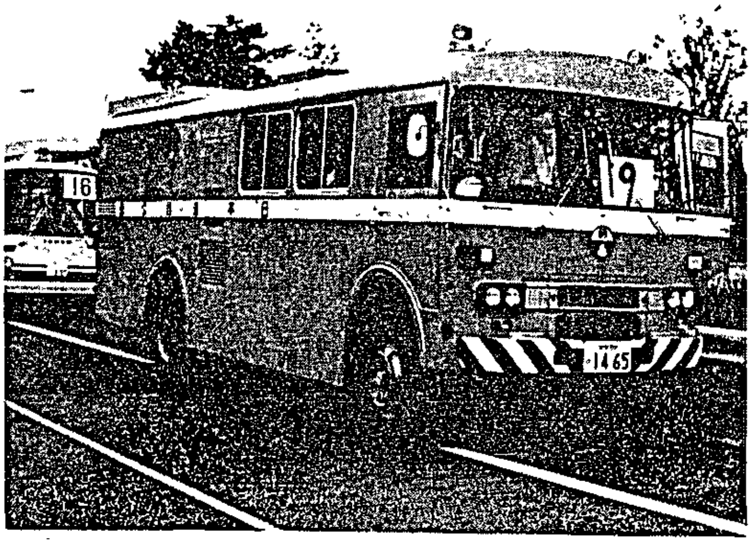


Fig. 28 Skid Test Vehicles Owned by Japan Highway Public Corporation

Table 3 Specification for Skid Test Vehicle
-- The Laboratory of Japan Highway Public Corporation --

Item	Specification
Vehicle	
Maximum Speed	140 km/h
Maximum Grade	$\Theta = 19.5°$
Minimum Radius	8.2 m
Skid Measuring Unit	
Mode of Measurement	100% locked braking mode & cornering mode
Maximum Wheel Load	500 kg
Steering Angle	0 ∿ 45°
Test Tire	5.6 - 13 - 4PR
Recording Unit	
No. of Channels	6
Recorded Items	Braking force Rolling resistance force Side force Cornering force Wheel load Test wheel speed Vehicle speed Pavement temperature

d) Longitudinal Surface Roughness

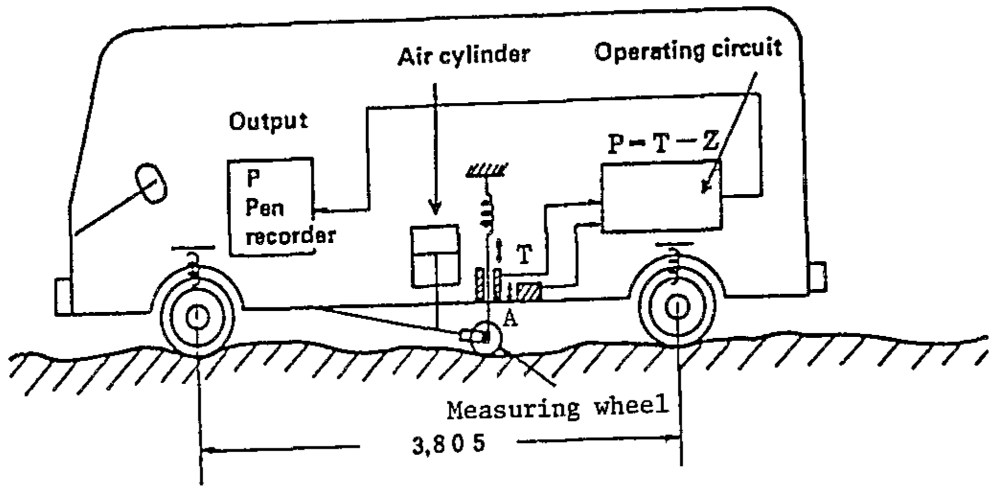
Longitudinal pavement roughness can be measured by the High-speed Profilometer, PHP-77, which was developed by the private surveying company in 1977. The high-speed profilometer, illustrated in Fig. 29-a, consists of a measuring wheel (the fifth wheel), accelerometer, operating circuit and recording unit which are mounted on a small sized bus used for the continuous photographing of the pavement cracking.

When the test vehicle travels along the highway at 40 km/h or less, differential transformer measures the vertical displacement of the measuring wheel, T, and the accelometer simultaneously measures the acceleration, A, of the vehicle itself. Vehicle displacement, Z, can be obtained to integrate the measured acceleration twice. And, finally, the pavement roughness, P, can be computed by T subtracts Z. Measured profiles by the high-speed profilometer and 3m-profilometer described previously are shown in Fig. 29-b. Conversion of the high-speed profilometer count, X_{20} or X_{10}, to σ of the 3m-profilometer is as follows.

$\sigma = 0.563 \sqrt{X_{20}}$ for measuring speed 20 ∿ 40 km/h

$\sigma = 0.0583 \sqrt{X_{10}}$ for measuring speed around 10 km/h

where X_{20} or X_{10} is the count number which is counted by one unit when the deviation is accumulated to 1 cm.

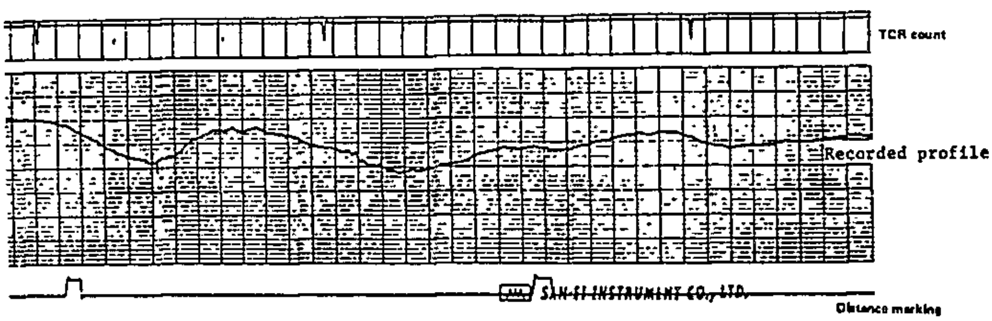


T : Differential transformer

A : Servo accelerometer

P : Longitudinal roughness = $T - \iint A_{(t)}\,dt = T - Z$

Fig. 29-a System Diagram of High-speed Profilometer



Example of Profile Recorded by High-speed Profilemeter at V = 40 km/hr

Example of Profile Recorded by 3 m-Profilemeter at V = 3 ∿ 4 km/hr

Fig. 29-b Comparison of Pavement Profiles Measured by High-speed and 3m-Profilometers

5. EVALUATION OF MEASURED PAVEMENT CONDITION

Measurement and evaluation of the individual pavement characterisitc described so far are quite simple and practically helpful in most cases. But it is obviously difficult to tell the composite performance where different type of distresses with different degree are existent.

Present Serviceability Index, PSI, used in the AASHO Road Test [2] is the famous concept in this field. It has recently been recognized, however, that PSI is not fully express pavement performance from the view point of structural distresses which are the major concern of the maintenance personnel. In other words, decrease of PSI is largely influenced by the loss of longitudinal surface smoothness and it is not significantly influenced by the existence of rutting and cracking. Since rutting and cracking are the main reasons to improve the surface condition in Japan, several organizations have been tried to develop the evaluation method suitable for our pavement conditions. Among those, a couple of evaluation method are briefly discussed in this Chapter.

5-1 Maintenance Index, MI, developed by J.H.P.C.

A new idea of pavement performance evaluation was developed based on a statistical method called pair-wise comparison in 1975 [5]. The basic idea for this method is that the pavement performance superiority of a pair of pavement sections with different distress levels is judged by the selected pavement engineers and these judgements are analyzed by a statistical method to form the numerical ratings. Supposing a pavement section with 2 % of crack ratio and 40 mm rut depth and 15 % of crack ratio and 5 mm rut depth, it was asked which section should be superior in performance or have the priority to improvement. Similar questions were repeated to cover all pairs of pavement sections with different distress levels, which could not be theoretically determined the priority of improvement.

Quantitative evaluation of pavement performance was expressed in terms of a value of 0 to around 10 by analyzing the interview survey results. The smaller the value is, the better performance the pavement shows. Pavement performance thus determined were defined as the Maintenance Index, MI, with an appropriate subscripts as $MI_{(RD)}$, $MI_{(CR)}$ and $MI_{(R,C)}$. Here, RD expresses abbreviation of rut depth; CR, crack ratio; and R,C, combination of rut depth and crack ratio.

Among several cases analyzed, three equations are shown in Eqs. 14 through 16 and in Fig. 30.

$$MI_{(RD)} = 0.24826\ (RD) + 0.00098\ (RD)^2 \quad \text{-----------} \quad (14)$$

$$MI_{(CR)} = 0.47500\ (CR) - 0.01010\ (CR)^2 + 0.00023\ (CR)^3 \quad \text{------} \quad (15)$$

$$\begin{aligned} MI_{(R,C)} &= MI_{(RD)} + MI_{(CR)} \\ &= 0.24826\ (RD) + 0.00098\ (RD)^2 + 0.47500\ (CR) \\ &\quad - 0.01010\ (CR)^2 + 0.00023\ (CR)^3 \quad \text{---------} \quad (16) \end{aligned}$$

It is noted that when maintenance priority examined by rutting or cracking, Eq. (14) or Eq. (15) is applied and when maintenance priority examined by two factors Eq. (16), which is a sum of Eqs. (14) and (15), is applied.

In Fig. 30, dashed lines show the uncorrected (original) relationship while solid lines do the corrected one equating $MI_{(RD)} = MI_{(CR)} = 3.9449$ for RD = 15 mm, CR = 10 % and $MI_{(RD)} = MI_{(CR)} = 6.8205$ for RD = 25 mm, CR = 20 %, respectively. Correction was made under the concept that $MI_{(RD)}$ and $MI_{(CR)}$ should theoretically be identical at Level A and Level B defined in Table 4 in Chapter 6.

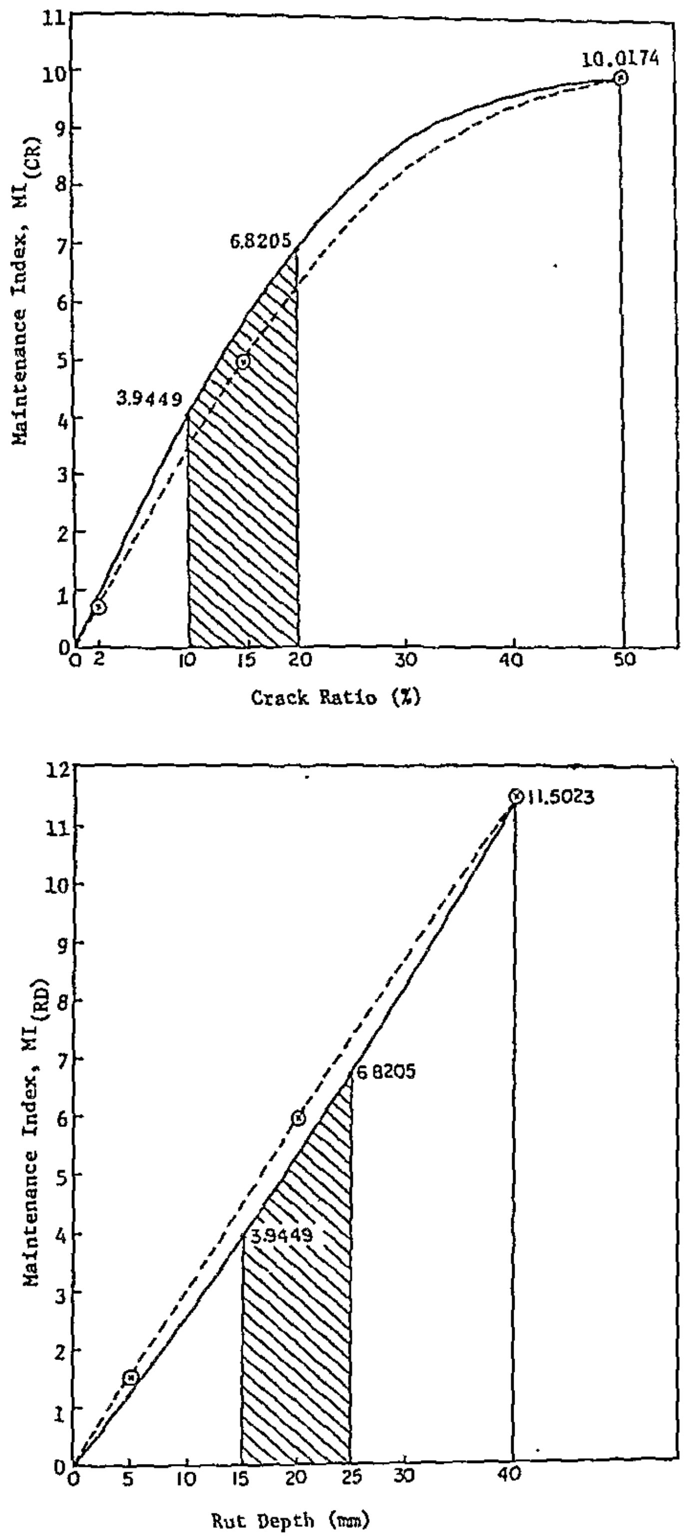


Fig. 30 Graphical Explanation of Maintenance Index and Pavement Condition

5-2 Maintenance Control Index, MCI, Developed by the Ministry of Construction

Ministry of Construction developed, in 1982, the performance evaluation equations oriented for the maintenance need as in the case of MI but utilizing the multiple-regression technique [3]. Those are termed as the Maintenance Control Index, MCI, with an appropriate subscripts as MCI_0, MCI_1 and MCI_2.

Pavement characteristics employed in this analysis are rutting, cracking and surface roughness and established the equations using these three factors. For the practical purpose at present, however, evaluations by rut depth and/or crack ratio are discussed in the proceeding discussion, since the influence of pavement roughness to MCI is relatively smaller than that of rutting or cracking and the number of observed data for roughness is not large enough compared to those of rutting and cracking.

Performance evaluation thus determined are shown in Eqs. (17) through (19), and in Fig. 31.

$$MCI_0 = 10 - 1.51C^{0.3} - 0.3D^{0.7} \quad \text{-------------------------- (17)}$$

$$MCI_1 = 10 - 2.23\,C^{0.3} \quad \text{------------------------------ (18)}$$

$$MCI_2 = 10 - 0.54D^{0.7} \quad \text{------------------------------ (19)}$$

where, MCI_0 = Maintenance Control Index termed by crack ratio and rut depth.

MCI_1 = Maintenance Control Index termed by crack ratio alone.

MCI_2 = Maintenance Control Index termed by rut depth alone.

C = Crack ratio (%)

D = Rut depth (mm)

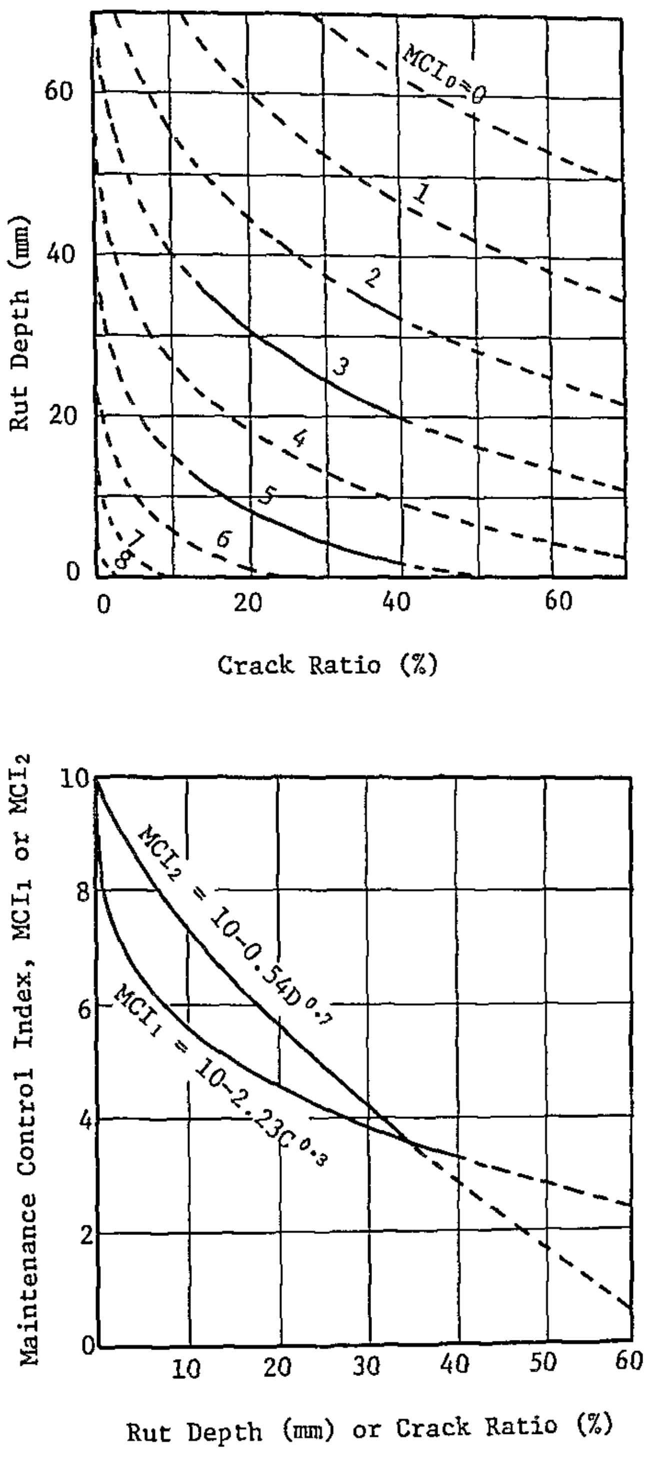


Fig. 31 Graphical Explanation of Maintenance Control Index, MCI, and Pavement Condition

6. PROPOSED MAINTENANCE LEVELS

Based on the considerations discussed in the preceding Chapter, maintenance levels for the national expressway system and the national highway system are proposed. They are shown in Tables 4 and 5.

Among the considerations to set up those maintenance levels, background from the engineering point of view is briefly mentioned in this part.

Rutting and Abrasion

a. Sprash sprayed from the deposited water at rut when a vehicle travels.

b. Safety consideration when changing the lane for passing maneuver.

Cracking

a. Durability of pavement in accordance with types and degree of cracking.

b. Estimation of cracking occurence in the future.

Skid Resistance

a. Analysis of skid resistance and wet accident rate

Roughness and Bump

a. Acceptable rating from comfortability of driving

b. Damaging effects for the bridge deck due to impact load caused by travelling through the bump

c. Traffic noise and vibration effects to the surrounding residents

In addition to the considerations listed above, present pavement conditions, present status of pavement rehabilitation and maintenance levels or related standards proposed by other agencies in the world were throughly examined for all items.

Table 4 Proposed Maintenance Levels for National Expressway and Arterial Toll Highway Systems

Pavement Character-istics	Classification	National Expressway		Toll Highway (Arterial)	
		Level A*1	Level B*2	Level A*1	Level B*2
Rut Depth (mm)	Through Lane	15	25	20	30
	Truck Climbing Lane	20	40	25	45
Crack Ratio (%)	All Site	20	40	20	40
Skid Number	Standard Site	30	25	30	25
	Difficult Site	30	25	30	25
Bump	Backfill of Abutment	-	20	-	30
	Backfill of Culvert Box	-	30	-	30
	Expansion Joint	-	15	-	20

*1 Level A : Pre-maintenance level in which immeadiate rehabilitation does not required but examination of distress causes and planning of rehabilitation should be considered.

*2 Level B : Terminal level, or rehabilitation should be done up to this level

Table 5 Proposed Maintenance Levels for National and Municipal Highway Systems

Pavement Characteristics	Heavy Trafficed Hwy	Light Trafficed Hwy
Rut Depth (mm)	30 ∿ 40	40
Crack Ratio (%)	30 ∿ 40	40 ∿ 50
Skid Number	25	-
Longitudinal Roughness (cm)	4 ∿ 5	-
Bump		
Backfill of Abutment (mm)	30	40
Backfill of Culvert Box (mm)	30	-
Pot Hole (cm)	20	20

7. APPLICATION OF EVALUATED INFORMATION TO THE MAINTENANCE MANAGEMENT

Inventory study by means of the innovational equipments described so far collects useful information in large numbers and in uniform quality. Thus, we are able to use these information effectively to manage the pavement in many ways - especially useful for the long term or short term planning startagy. These examples are illustrated in Figs. 32 through 35.

Summary Information on Inventory Study

The following information can be obtained from the list shown in Fig. 32.

a) Pavement designation --- Section surveyed (KP), section length; bituminous or rigid pavement; tunnel, bridge, viaduct or cut and fill sections; and area classification.

b) Measured pavement condition --- Date of measurement, crack ratio, rut depth (maximum and average), surface roughness and computed MCI.

c) Projected pavement condition in the future --- Date of projection, projected values of crack ratio, rut depth, surface roughness and MCI.

d) Latest Rehabilitation Record --- Date of repair, repair method such as surface treatment, planing, overlay, etc.

Pavement Performance Chart

Measured pavement conditions and computed MCI are schematically plotted against the kilometer post as shown in Fig. 33. Designation of pavement type, designation of highway structure and repair record can also be printed out if necessary. If we draw the maintenance level on the chart, sections need to repair are easily read off as the visual information.

-------- ロメンセイジョウデータ イチランヒョウ --------

9 ナガノ コクドウ
3 マツモト コクドウ
9 ナガノケン
19 コウセン

Maintenance office, Route No. etc.

Year (S56 ネンド)

K.P. (キロポスト)	Section length	Pav't type	Br. or tunnel	Area	Measured: Year	Measured: CR	Measured: RD	Measured: $\overline{RD}$	Measured: Profile	Measured: MCI	Projected: CR	Projected: $\overline{RD}$	Projected: Profile	Projected: MCI	Latest repair: Year	Latest repair: Method
213.200 - 213.300	100	AS		620	S53	0.	16	12	2.25	7.8	0.	18	2.87	7.2	S50	R
213.300 - 213.400	100	AS		620	S53	0.	19	16	1.59	7.5	0.	22	2.05	6.9	S50	R
213.400 - 213.500	100	AS		620	S53	0.	20	18	1.74	7.3	0.	24	2.25	6.8	S50	R
213.500 - 213.600	100	AS		620	S53	0.	20	16	1.74	7.5	0.	22	2.25	6.9	S50	R
213.600 - 213.700	100	AS		628	S53	0.	15	12	1.81	7.8	0.	18	2.32	7.3	S50	R
213.700 - 213.800	100	AS		598	S53	0.	12	10	1.81	8.0	0.	16	2.32	7.4	S50	R
213.800 - 213.900	100	AS		580	S53	0.	13	12	2.13	7.8	0.	18	2.72	7.2	S52	R
213.900 - 214.000	100	AS		580	S53	0.	13	11	1.88	7.9	0.	17	2.42	7.3	S52	R
214.000 - 214.100	100	AS		600	S53	0.	20	12	1.88	7.8	0.	18	2.42	7.2	S52	R
214.100 - 214.200	100	AS		600	S53	0.	21	14	1.81	7.6	0.	20	2.32	7.1	S52	R
214.200 - 214.300	100	AS		600	S53	0.	14	10	1.94	8.0	0.	16	2.48	7.4	S52	R
214.300 - 214.400	100	AS		600	S53	0.	12	11	2.01	7.9	0.	17	2.57	7.3	S52	R
214.400 - 214.500	100	AS		600	S53	0.	13	10	2.07	8.0	0.	16	2.65	7.4	S52	R
214.500 - 214.600	100	AS		618	S53	0.	14	11	2.30	7.9	0.	17	2.93	7.3	S52	R
214.600 - 214.700	100	AS		614	S53	0.	19	15	2.13	7.5	0.	21	2.72	7.0	S51	R
214.700 - 214.800	100	AS		600	S53	0.	16	13	2.13	7.7	0.	19	2.72	7.1	S51	R
214.800 - 214.900	100	AS		600	S53	0.	17	14	2.13	7.6	0.	20	2.72	7.1	S51	R
214.900 - 215.000	100	AS		600	S53	0.	18	15	1.66	7.5	0.	21	2.14	7.0	S51	R
215.000 - 215.100	100	AS	B	590	S53	0.	11	9	2.66	8.1	0.	15	3.37	7.5	S51	R
215.100 - 215.200	100	AS	B	616	S53	0.	13	12	2.46	7.8	0.	18	3.13	7.2	S51	R
215.200 - 215.300	100	AS		620	S53	0.	12	11	1.94	7.9	0.	17	2.48	7.3	S51	R
215.300 - 215.400	100	AS		620	S53	0.	12	10	1.94	8.0	0.	16	2.48	7.4	S51	R
215.400 - 215.500	100	AS		620	S53	0.	12	12	1.88	7.8	0.	18	2.42	7.2	S51	R
215.500 - 215.600	100	AS		620	S53	0.	21	13	1.88	7.7	0.	19	2.42	7.2	S51	R
215.600 - 215.700	100	AS		620	S53	0.	14	13	1.66	7.7	0.	19	2.14	7.2	S51	R
215.700 - 215.800	100	AS		620	S53	0.	15	12	1.66	7.8	0.	18	2.14	7.3	S51	R
215.800 - 215.900	100	AS		620	S53	0.	12	11	2.01	7.9	0.	17	2.57	7.3	S51	R
215.900 - 216.000	100	AS		620	S53	1.0	30	23	1.94	5.4	2.5	29	2.48	4.4	S49	A
216.000 - 216.100	100	AS		660	S53	1.0	21	19	2.19	5.7	2.5	25	2.80	4.7	S49	A
216.100 - 216.200	100	AS		660	S53	2.0	29	20	2.51	5.3	5.1	26	3.19	4.2	S49	A
216.200 - 216.300	100	CO	T	660	S53	0.	11	9	3.33		0.	12	3.94		S49	N
216.300 - 216.400	100	CO	T	660	S53	0.	11	8	3.13		0.	11	3.75		S49	N
216.400 - 216.500	100	CO	T	660	S53	1.0	9	8	3.17		4.2	11	3.79		S49	N
216.500 - 216.600	100	AS	T	660	S53	0.	28	11	2.66	7.9	0.	17	3.37	7.3	S49	N
216.600 - 216.700	100	AS		660	S53	2.0	28	19	2.13	5.4	5.1	25	2.72	4.3	S49	A
216.700 - 216.800	100	AS		610	S53	0.	28	25	1.74	6.7	0.	31	2.48	6.2	S49	A
216.800 - 216.900	100	AS		564	S53	0.	22	13	2.25	7.7	0.	19	2.87	7.1	S52	R
216.900 - 217.000	100	AS		580	S53	0.	16	12	2.35	7.8	0.	18	2.99	7.2	S52	R

KP ← 現地距離標に対してのズレであり、＊で表す

ブランク

Fig. 32 Summary Information on Inventory Study

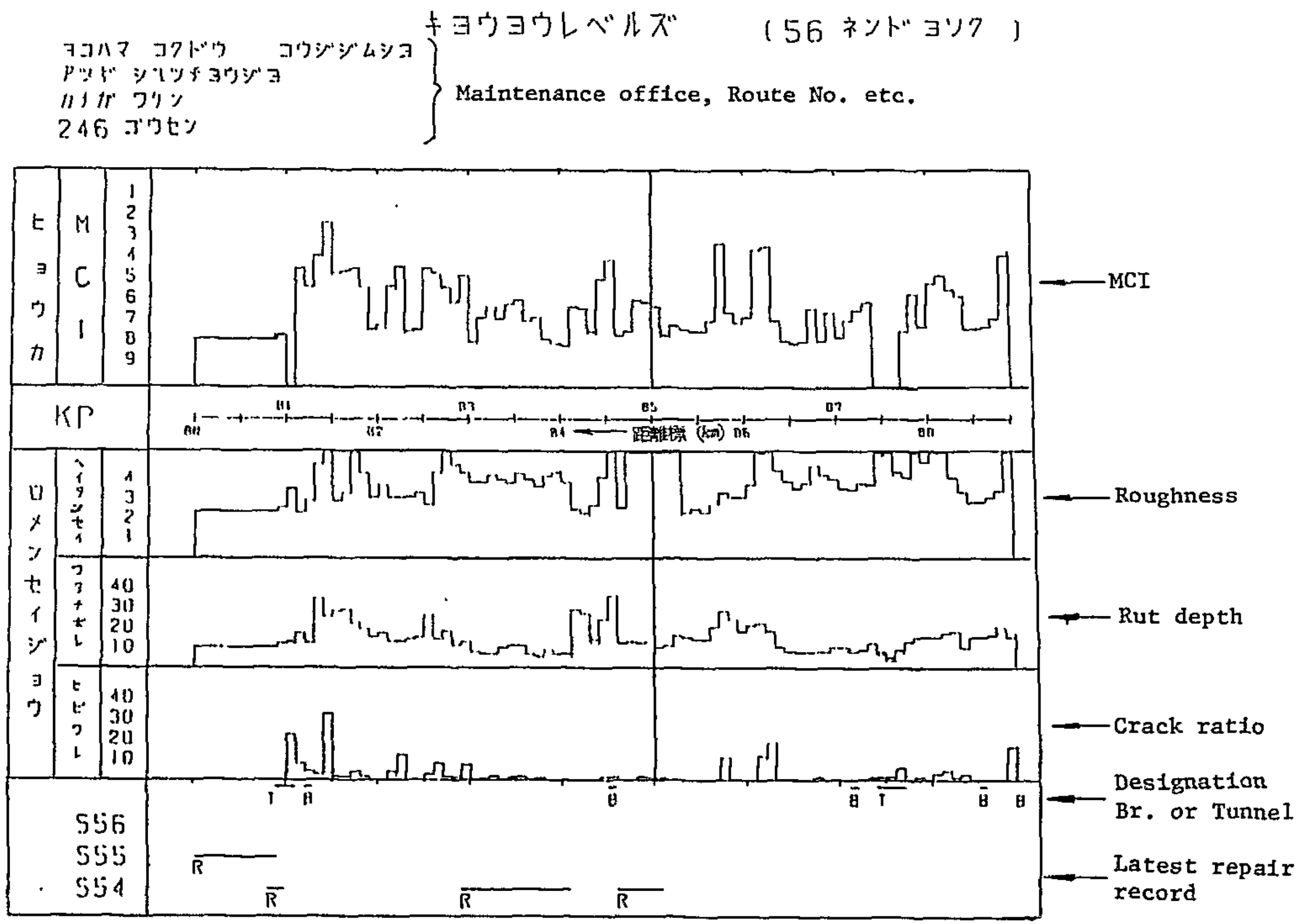


Fig. 33 Pavement Performance Chart

List of Sections to be Repaired

The selected sections can be printed out as the list for rehabilitation as shown in Fig. 34.

Histgram and Accumulated Curve of Measured Conditions

For the planning of rehabilitation program or budget allocation purposes, Fig. 35 might be the useful tool.

If we decide the section below MCI = 4.5 should be repaired in this year, the corresponding area and percent of total area are read off as 1,480 km^2 and 24 %.

On the other hand, available budget constraints to improve only 1,480 km^2, then the section with MCI = 4.5 or less can be selected as the candidate.

Simulation of Future Pavement Condition

Future pavement condition varies with the present status and the rehabilitation to be imposed.

Fig. 36-a simulates the pavement condition in terms of MCI_0 if no rehabilitation is carried out for ten years from now on. It is quite obvious from this figure that pavement will deteriorate quickly.

Fig. 36-b simulates the pavement condition under the assumption that sections with MCI = 4 or less must be repaired in the future. To fulfill this assumption, about 10 % of the total length of highway should be repaired every year with the maximum repair rate of 13 % at 5th and 6th years.

These information might be used for the long range budget proposal for the Government.

維持修繕区間リスト

PAGE= 70

----- ｲｼﾞ ｼｭｳｾﾞﾝｸｶﾝ ﾘｽﾄ ----- (ｶﾞｲﾄﾞﾗｲﾝ MCI = 4.5, L= 300M/ 500M)

ﾛﾒﾝ : ｱｽﾌｧﾙﾄ

W X Y ← Parameters for list up

ｼﾞﾑｼｮ 9 (ﾅｶﾞﾉ ｺｸﾄﾞｳ
ｼｭｯﾁｮｳｼﾞｮ 3 (ﾏﾂﾓﾄ ｺｸﾄﾞｳ
ﾛｾﾝﾊﾞﾝｺﾞｳ 19 (ﾖｿｸ)

} ← Maintenance office, Route No. etc.

KP+-

KP1 ------- KP2 Section	ｴﾝﾁｮｳ(M) Length	ｾﾋﾞﾜﾚ CR	ﾜﾀﾞﾁﾎﾞﾚ RD	ｼﾞｭｳﾀﾞﾝ Profile	ﾋｮｳｶﾁ(MCI) MCI	ﾒﾝｾｷ(M**2) Area
185.200 - 185.700	500	34.6	33	4.03	1.7	3500
183.300 - 183.800	500	31.4	33	3.82	1.9	3556
183.800 - 184.300	500	6.4	37	3.16	3.2	3578
184.700 - 185.200	500	4.0	37	2.73	3.5	3520
185.700 - 186.200	500	2.6	36	3.79	3.9	3596
202.900 - 203.400	500	2.1	35	2.83	4.1	3720
181.800 - 182.300	500	2.3	31	2.78	4.3	3600
202.100 - 202.600	500	1.5	31	2.65	4.6	3644
206.200 - 206.700	500	1.4	29	3.56	4.7	3372
*** ｼｮｳｹｲ ***	4500					32086

Fig. 34 List of Sections to be Repaired

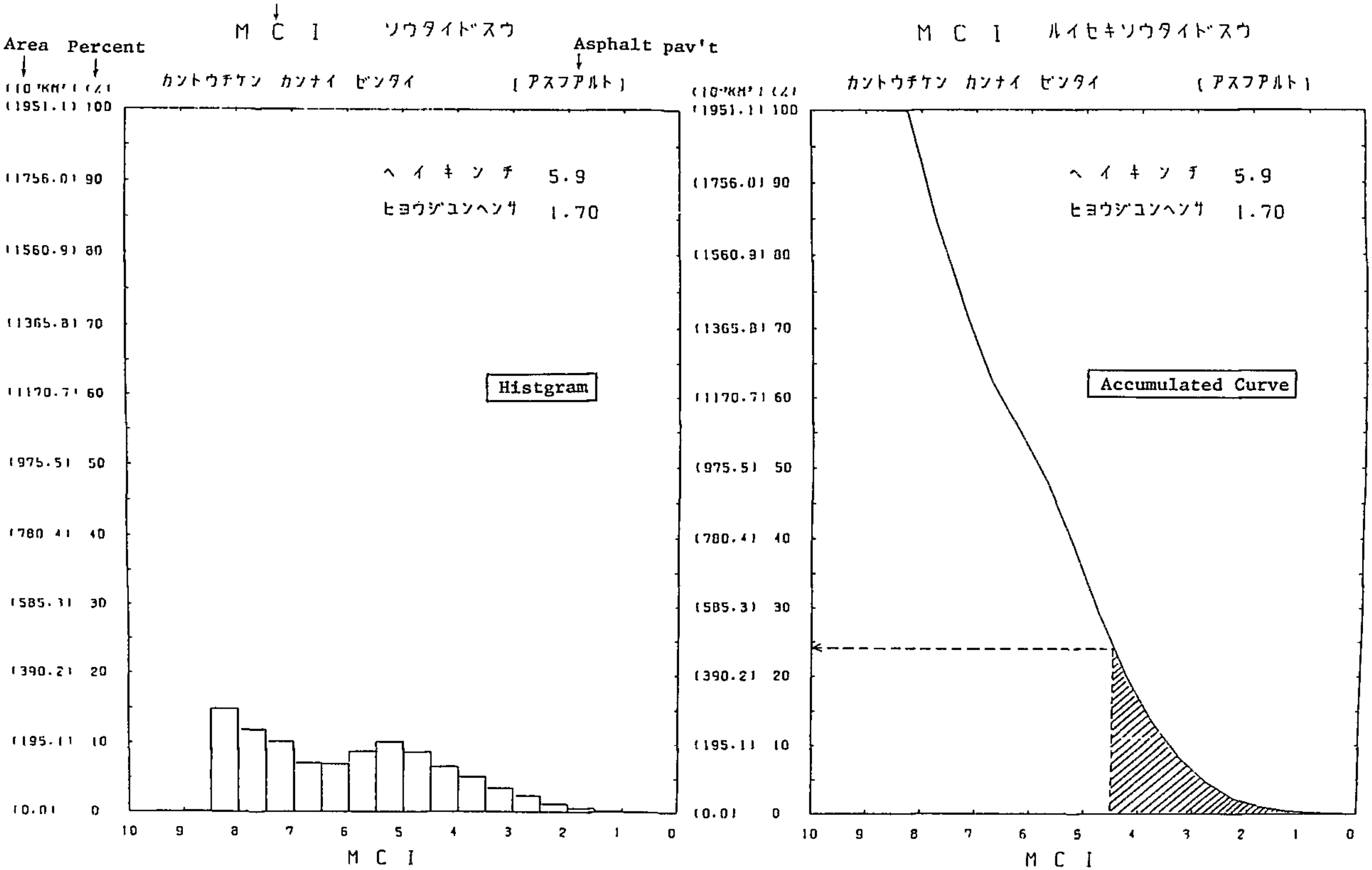


Fig. 35 Histgram and Accumulated Curve of Measured Condition -- An Example of MCI

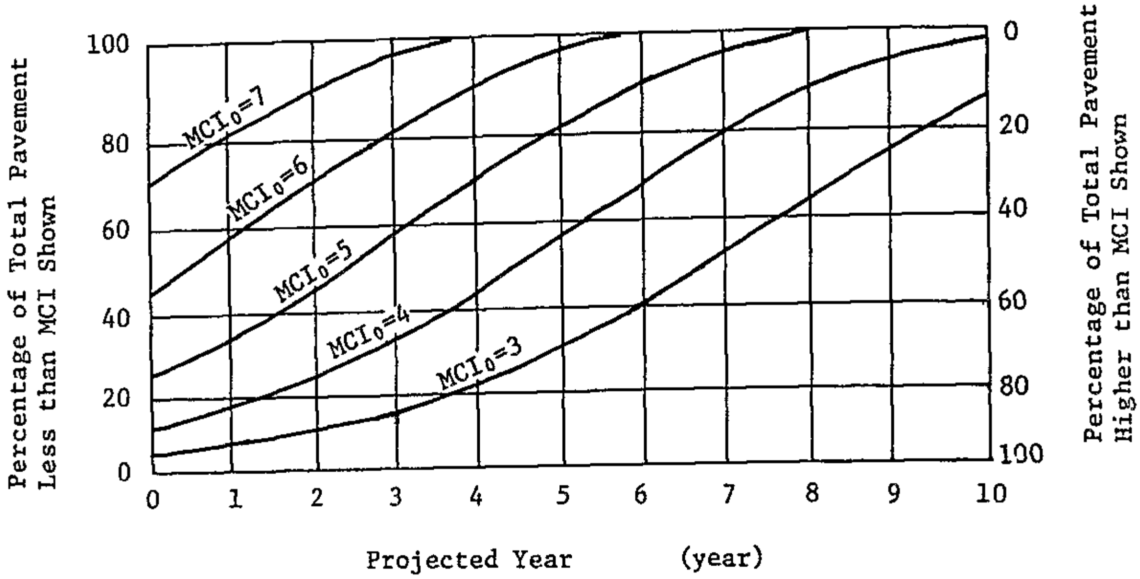


Fig. 36-a Projected Pavement Condition under the Assumption of No Rehabilitation for 10 years

Figures at top show annual repair rate.

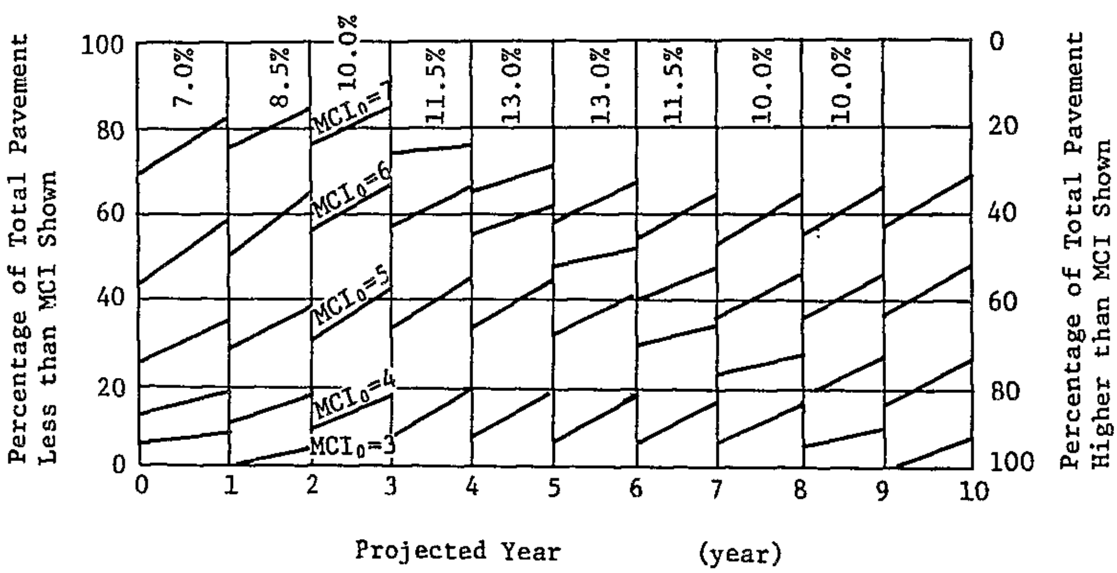


Fig. 36-b Projected Pavement Condition under the Rehabilitation Stratagy to Diminish the Pavement with MCI = 4 or Less

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ROAD MAINTENANCE STUDY COURSE

ASSESSMENT AND PRIORITY OF MAINTENANCE

by

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JAPAN INTERNATIONAL COOPERATION AGENCY

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ASSESSMENT AND MANAGEMENT OF MAINTENANCE

1. Introduction

1-1 Roads in Japan

Roads in Japan are classified into four categories:

- National Expressways
- National Highways
- Prefectural Roads
- Municipal Roads

Construction and maintenance of these roads are carried out, in general, by the central government or by the local governments.

The administrators of these roads are prescribed in "The Road Law" as follows:

- National Expressways .... Minister of Construction
- National Highways
  - Designated Routes or Sections ...... Minister of Construction
  - Non-designated Routes or Sections .. Prefectural Governors
- Prefectural Roads .... Prefectures
- Municipal Roads .... Cities, Towns or villages

In case of tall roads, however, the execution is done by public corporations. For example, the national expressways are all toll roads and the Japan Highway Public Corporation is authorized to exercise a part of the authority of the Minister of Construction in accordance with the rules provided by "the Special Measures Law for Road Improvement" for constructing and maintaining the expressways.

Of the prefectural and municipal roads, those which are especially important and need rapid improvement are designated as the Principal Local Roads.

The present situation of roads in Japan is shown below.

Table 1 Present Situation of Roads in Japan

Classification	Total Length (km)	Paved Section		Number and length of bridges and tunnels			
				Bridges		Tunnels	
		Length (km)	Ratio (%)	Number	Length (km)	Number	Length (km)
National expressways	2,579.1	2,579.1	100.0	2,941	288	97	66
National Highways	40,211.7	33,503.4	83.3	36,306	1,058	1,720	488
Principal Local Roads	43,906.4	23,831.8	54.3	36,113	722	872	159
Prefectural Roads	86,930.0	25,588.3	29.4	65,662	1,278	882	135
Sub-total	173,627.2	85,502.7	49.2	440,058	3,752	1,410	129
Municipal Roads	939,760.3	94,905.0	10.1	578,139	6,809	4,884	911
Total	1,113,387.5	180,407.7	16.2	581,080	7,097	4,981	977

1-2 National Highways

National highways form the trunk transportation network together with national expressways.

National highways consist of 342 routes and their total length amounts to 40,000 km.

Minister of Construction administrates the designated routes (or sections) of national highways and prefectural governors administrate those non-designated.

Formerly, prefectural governments had been responsible for administrating all national highways in their jurisdictions, but since 1958, Minister of Construction has been administrating directly the important routes (or sections) of them.

Generally, designated routes have heavier traffic volume than those non-designated.

The length of designated routes is shown below:

Table 2 Length of National Highways

April, 1980

	Total	Length of designated routes
Mainland	34,515 km	13,632 km (39.5%)
Hokkaido	5,319	5,319 (100%)
Okinawa Islands	378	276 (73.0%)
Total	40,212	19,227 (47.8%)

These designated routes are administrated by the agencies as follows:

Mainland	Regional Construction Bureaus (8) Work Offices (72) Branch Offices (206)
Hokkaido	Hokkaido Development Bureau Development Construction Divisions (10) Branch Offices (49)
Okinawa Islands	Okinawa General Bureau Work Offices (2)

The number of staff and employees, such as engineers, technical workers and clerks, occupied with administration of national highway in mainland is about 6,000.

These staff and employees are occupied not only with maintenance and repair of roads but with the works concerning traffic safety, snow removal, disaster rehabilitation, and legal affairs.

The road maintenance management system and maintenance level vary with the type of road. Of course, the roads are given more careful maintenance the higher the degree of their importance is.

This text centers on the maintenance of the national highways (designated routes).

2. Inventories

A quantitative inventory of road network is an essential pre-requisits to any maintenance operation.

The Ministry of Construction has a data bank concerning the following items for those sections of the national highways which come under the jurisdiction of its work offices.

- the pavement area (length),
- the number, location and type of road signs, road lighting facilities, guard rails, etc.,
- the location and kind of street trees,
- the area of roadside grass to be moved,
- the number, location, length and type of ditches and drainage facilities,
- the location and type of protection facilities for snow, falling stones and collapsing slope,
- the location and type of bridges, tunnels.

The data bank covers the records of maintenance and repair, and these records are cataloged in unified formats recommended for respective types of inventories.

As regards the pavements, the surface detriorative properties, maintenance control index (MCI) and its forecasted index, and history of repair are stored in a computer according to the findings of continuous photographic surveys conducted every three years.

3. Inspections

There are two means of determining road conditions, which complement one another:

- visual assessment,
- quantitative assessment.

3-1 Visual Assessment

Routine Inspections;

Each work office conducts patrol of its jurisdictional national highways once every day. The patrolmen inspect the conditions of carriageways, footways, shoulders, slopes, guardrails, road signs and other road facilities while driving a patrol car or if necessary on foot (see Fig. 1).

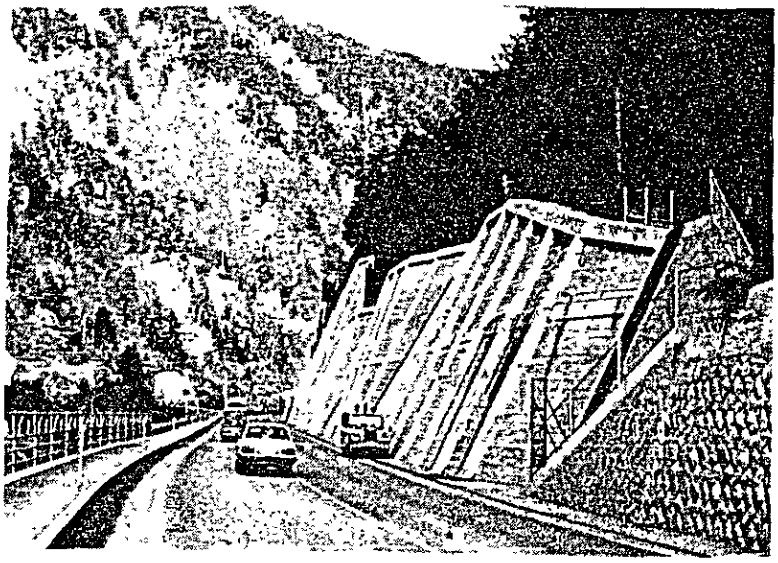

Fig. 1 A patrolman inspecting the stone guard net

Whenever minor defects requiring immediate action are detected, the patrolmen take a stopgap measure or ask the maintenance crew for service.

In addition, night patrol is made once every week (in major cities) or once a month (in other cities) for inspection of the road lighting facilities.

The results of road patrol are recorded in the patrol sheet and reported to superiors. Annex-A is an uniformed format of patrol sheet.

Systematic Inspections:

The inspection of important structures such as bridges, tunnels, retaining walls, slope protection facilities (walls, nets, fences, etc.) is carried out systematically by a team of expert engineers once every two to three years. Fig. 2 shows the special car which is used in bridge inspections.

The findings of the systematic inspections are kept on the inventory cataloque, and at the same time are reflected in the remedial maintenance program and preventive maintenance program as discussed later on.

Fig. 2 The car with bridge inspection equipment

3-2 Quantitative Assessment

Special measures are necessary for the quantitative assessment of important structures such as road pavement and bridges.

In Japan, a system in which the cracks, rutting and longitudinal irregularities of road surfaces are automatically recorded by a continuous photographic recorder carried on a vehicle and are analyzed has been in operation.

In order to measure the skid resistance and deflection of road surfaces, there are used skid test vehicles and dynaflects.

These measuring instruments will be discussed in detail in the session, "PAVEMENT ASSESSMENT TECHNIQUE."

In the event a bridge - one of the most important structures - is found damaged by visual inspection, its load carrying capacity is investigated carefully.

The measured defects, such as cracks in cement concrete slab and corrosion of members, are checked with the design documents of the bridge, and if the load carrying capacity is judged insufficient, the bridge is reinforced with steel plates, additional members, etc.

For those old bridges for which the design documents have not been available, they are subjected to a loading test using a truck as the circumstances require.

4. Maintenance Operations

The road maintenance operations are diversified, and their contents are different from country to country. But, they may be classified into three major categories.

It is difficult to draw a fine line between these categories as they cross into each other.

Routine Maintenance;

- to execute an activity of servicing the roads periodically for the purpose of maintaining the required performance of roads.

It includes the sweeping of roads, cleaning of drainage and other road facilities, watering, weeding, pruning, sealing of cracks and joints in the pavement, remarking of roads, repainting of steel bridges, snow removal, etc.

Remedial Maintenance;

- to remedy dificiencies of pavement, structures and road furniture after the occurrence of damage.

Patching, remedying ditches, drains, concrete stabs, lighting facilities, traffic control devices, etc., are main examples of such maintenance activities.

In the event the damage found by daily road patrol of the road structures and road furnishings is judged highly detrimental to the safety of road users, it is repaired as soon as possible. The damage coming under this category includes potholes (usually 20 cm or more in diameter), destroyed guardrails and faulty street lighting facilities to name a few.

Where the circumstances do not permit immediate repair, the defective parts are jury-rigged (e.g., filling the potholes with sand, stringing a zebraic rope at the defective section of guardrail), and are reinstated later.

In case the slab of a bridge is potholed, it is quite dangerous.

In such a case, the pothole is immediately covered with a steel plate.

Preventive Maintenance;

- to prevent the deterioration of structural characteristics of pavement, bridges, tunnels and other important road facilities.

Its main purpose is to upkeep the initial qualities of structures and to maintain a given level of services. Surface dressing, overlaying, replacing of pavement, strengthening slabs of bridges, disaster protection works (e.g. setting sheds, fences, etc., alongside the road in mountaineous area) fall into the category of preventive maintenance.

5. Maintenance Works Programs

The maintenance work covers a variety of road inventories, and in many cases is conducted on a smaller scale than the construction work. Another feature of the maintenance work is that it is carried out for the roads in service. Accordingly, the maintenance work must be conducted in an efficient manner according to a program in order not to intercept the traffic.

In Japan, the Ministry of Construction's work offices for national highways have annual and monthly maintenance programs of their own.

Annex B shows an example of the annual program. The symbols Ro, Re and Pr appearing in the remarks column of the program denote the routine maintenance, remedial maintenance and preventive maintenance, respectively.

6. Quality Standards and Level of Services

The purpose of quality standards is to define the boundaries at which a certain maintenance activities should be carried out.

Quality standards help to determine:

- when to take action;
- what type of action should be taken.

And they must, as far as possible, be expressed in quantitative terms.

It is, however, impossible or unsuitable to express standards in quantitative terms for all types of road structures and furniture.

As regards most of routine maintenance works, it is practical to specify the number of tasks to be done every day (every week, every month or every year). The frequency of tasks may be a factor representing the level of services rather than the quality standards.

The level of services differs depending on the importance of roads, traffic volume, local climatic conditions, and geographic conditions (urban or rural, in the hilly terrane or on a flat terrane), etc. In Japan, the level of services of national highways is set as follows:

- sealing of pavement joints .... once/year;
- weeding .... twice or three times/year;
- pruning .... twice/year (summer and winter);
- watering .... every day in dry season (July ∿ September)
- road marking .... once or twice/3 years (once/year in snowy districts);
- re-painting of steel bridges .. once/7∿10 years;
- road sweeping .... 3∿5 times/week, urban area (big cities)
  2∿3 times/month, urban area
  5∿10 times/year, rural area;
- cleaning of ditches, drains, outfalls, etc.
  ...... once/year (at the beginning of rainy season).

In Japan, the quality standards are set for the road surfaces. As regards the asphalt pavements, for example, the road surfaces are judged in need of maintenance and repair when their defects have reached the limits specified in the following quantitative terms.

	Rut depth	Bump		Skid Resistance Coefficient	Roughness	Crack ratio	Pot hole diameter
		Abutment	Culvert Box				
Highways with heavy traffic	30∿40 mm	30 mm	40 mm	0.25	3 m profile 4.0∿5.0	30∿40 %	20 cm
Other highways	40	30	-	-	-	40∿50	20

In Japan, the maintenance control index (MCI) expressed as a function of two or three of the terms, rut depth, crack ratio and roughness, is proposed for practical purposes, and has been employed by many maintenance agencies.

One such MCI is shown below:

$$MCI = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$$

where

C: crack ratio (%)

D: rut depth (mm)

σ: roughness (longitudinal) (mm).

An analysis of the volumes of maintenance data about Japan's national highways shows that while the MCI value of a newly paved road surface is 9 to 10, it will be reduced to less than 4.0 in 10 to 12 years. Usually, the overlaying is conducted when the MCI value has lowered below about 4.0. From the viewpoint of trafficability, however, it is desirable to keep the MCI value above 5.0.

MCI will be discussed in detail in the session "PAVEMENT ASSESSMENT TECHNIQUES" of the seminar.

7. Allocating Financial Resources

Financial resources for road maintenance are limited and must, accordingly, be allocated and used to best effectiveness.

The construction of new roads, bridges and tunnels is a costly undertaking. It needs heavy investments, and once completed, these vital public assets require a constant supply of much labor and much money for maintenance.

Nevertheless, most of people are nonchalant about this maintenance phase of the roads, bridges and tunnes.

It is one of the great missions of the road maintenance force to get the following across to the public and the financial authorities:

- The highway is a wasting asset if not effetively maintained, and expenditure deferred now may lead to much greater expenditure later.

7-1 Investment for the Five-Year Program

In Japan, all the road works have been conducted according to the Five-Year Road Improvement Programs.

At present, the Eighth Program (1978-1982) is under way at a total cost of ¥28,500,000 million.

This Five-Year Program, approved by the Cabinet Council in May 1978, is based on the five major policies, each having an investment share as shown in the following table.

Table 3 Investment for the Eighth Five-Year Road Improvement Program (1978 ∿ 1982 fiscal years)

(Billion Yen)

Policy for:	- guarantee of traffic safety,	6,730
	- provision of the base for daily life,	7,470
	- improvement of living environment,	3,550
	- building of the foundations of regional development,	5,620
	- repletion of road maintenance and repair.**	4,430
Reserve		700
Total		28,500*

Note: * The table above shows the total amount of five-year investments planned by the Central Government, local governments and public corporations (Japan Highway Public Corp., Metropolitan Expressway Corp., etc.).

** The investment in the maintenance and repair includes salaries and wages for the government employees engaged in the maintenance of the national highways.

As is clear from the foregoing table, the investment in the maintenance and repair accounts for 15.5% of the total planned outlay, and is the highest ever earmarked in the five-year programs.

7-2 Annual Expenditure for Maintenance and Repair of National Highways

With the increase in the road inventories and improvement in the level of services, the outlay for the maintenance of national highways has been rising steadily year after year.

Table 4 shows the expenditures in the past ten years for the maintenance of designated national highways.

In the past, the maintenance expenditures had seen an annual growth rate of more than 10%. But in these years, the growth rate has been clipped to less than 10% in line with the government policy of not spreading the public investments. In Japan, people have come to realize the importance of road maintenance, and the investment in maintenance has been rising when the investment in construction has been crawling sideways in the past few years.

Table 4 Annual Expenditure for Maintenance and Repair

(National Highways (designated), Mainland)

Fiscal Year (Yi)	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Length (L km)	12,357	12,691	12,706	12,839	12,857	12,877	12,893	12,929	12,958	12,960
Expenditure (E* billion yen)	29.96	33.16	37.85	44.32	55.34	69.73	83.17	90,13	94.08	98.67
Rate (Yi/Yi-1)	1.15	1.11	1.14	1.17	1.25	1.26	1.19	1.08	1.04	1.05
E/L (million yen/km)	2.42	2.61	2.98	3.45	4.30	5.42	6.45	6.97	7.26	7.61

Note: * The expenditures above do not include the following:

- Costs for snow and ice control in the snowy districts,
- Payroll for the government employees engaged in the maintenance of national highways.

Contents of annual expenditure for maintenance and repair of National Highways are shown in Table 5.

Table 5 Contents of Expenditure for Maintenance

(Mainland, 1981 fiscal year)

Million yen

	Expenditure	%
Pavement		
- patching, sealing, surface dressing, etc.	16,640	48.0
- overlaying, re-paving	30,714	
Shoulders and Slopes	3,384	3.4
Structures (bridges, tunnels, etc.)	16,658	16.9
Re-painting of Steel Bridges	3,111	3.2
Electric Power Fee (for road lighting, tunnel ventilation, etc.)	4,121	4.2
Road Furniture (signs, lightings, guard rails, etc.)	4,470	4.5
Disaster Prevention Works	6,221	6.3
Road Sweeping	6,208	6.3
Others	7,138	7.2
Total	98,665	100

It is found from Table 5 above that nearly a half of the maintenance cost was invested in the maintenance and repair of pavements. According to a simulation analysis, however, it is urged to increase the annual investment in the improvement of pavements by 50 to 60% if we are to maintain the quality standared (MCI $\geq$ 4.0).

The greater part of the investment in the structures is used for the maintenance and repair of bridges.

Maintenance and repair of bridges has become one of the most important works lately, because damages of slabs and other members of bridges has been increasing as results of bigger size vehicles and heavier axle loads.

Earthquake-resistant strengthening of existing bridges is also important work in Japan. In an emergency, trunk roads such as national highways should be the most important transportation facilities for relief and restration activities.

ROAD MAINTENANCE STUDY COURSE

ROAD MAINTENANCE EQUIPMENT

by

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JAPAN INTERNATIONAL COOPERATION AGENCY

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ROAD MAINTENANCE EQUIPMENT

1. Introduction

The maintenance is of controlling importance for the purpose of eliciting the maximum service life of the roads. The road administrator is obliged to detect road defects and failures in early stages and make necessary repairs and remove the causes as quickly as possible. The road maintenance tasks are diversified, and most of them are undertaken by machines. The machines used are also various in types and sizes to meet specific needs of the tasks. As the road maintenance and repair is to be conducted without hampering the ordinary traffic, the road maintenance equipment is required to fulfill the following requirements more than the ordinary construction machinery.

(1) Small yet powerful.

(2) Safe to vehicles and pedestrians passing by.

(3) Faster working speed, and higher mobility.

(4) Less noisy and less vibratory to protect the amenities.

The road maintenance and repair tasks are classified as follows.

(1) Cement concrete pavement

Replacement sealing of joints and cracks, grading, patching, repairing of scuffs, overlaying.

(2) Asphalt concrete pavement

Replacement, patching, dressing, grading, surface treatment, resurfacing, anti-skid treatment, overlaying.

(3) Other than pavement work

Weeding and lawn mowing for shoulders, application of fertilizer, cleaning of gutters and sewers, repairing of covers for gutters, stabilization of slopes, weeding for slopes, installation and repairs of protections against falling stone, protection of retaining walls, patching of protections and retaining walls, cleaning of road surfaces, cleaning and repairs of road signs, repainting of road markings, inspection, repair, cleaning and repainting of guardrails, redressing of sidewalks, inspection, cleaning and repainting of bridges, cleaning of tunnels, inspection and repair of tunnel ventilation systems, cleaning of street lighting facilities, bulb replacement, pruning and trimming of roadside trees, watering and application of fertilizer for roadside trees, protection and pest control of roadside trees, snow removal.

These tasks may be largely classified by types of jobs as follows.

(1) Patrol inspection of roads

(2) Maintenance and repair of road surfaces

(3) Cleaning of road facilities

(4) Removal of snow from roads

(5) Other maintenance and repair activities

2. Road inspection equipments

2.1 Patrol car

The road administrator is required to patrol the roads within his beat, check for road abnormalities, monitor traffic conditions and to direct and supervise the road menders. To this end, a patrol car is indispensable.
The patrol car is rigged with a sematic red/yellow revolving light to command the attention of others, and a radio transmitter-receiver to communicate with the base station to inform the road maintenance office or other authorities of the traffic conditions and emergencies. It also carries a portable sign aboard for the purpose of working safety as it is often required to dispose of damaged vehicles and roadblocks.

2.2 Bridge inspector

This is a large truck fitted with three booms for the purpose of giving the road administrator access to the underside of a bridge for inspection. The gondla can be lowered 4.6 m below the bridge, and can also be brought under the bridge for close inspection. The boarding capacity of the gondla is 2 persons. The boom has a maximum outreach of 15 m, enabling the maintenance worker to work at an elevated place.
The gondla can be manipulated either at the operating station on the turntable or within the gondla. The operating station and the gondla are interconnected with an interphone system for close co-ordination between the ground party and gondla party in order to ensure the working safety of gondla party.

2.3 Life car

This car is for use for elevated work, and is available in three types - articulated boom type, telescopic boom type and telescopic ladder type.
In any type, the gondla is lifted to position hydraulically with ease, and is provided with various protections to ensure the working

safety at elevated places.

Just as with the bridge inspector, the gondla can be controlled and operated from either the operating station or within the gondla.

3. Surface maintenance equipments

3.1 Motor grader

This is most efficient for the repair of gravel roads. The size of the motor grader usually is expressed by the length of its blade, and ranges from a tiny 2.2 m class to a mammothized 5.0 m class. (Table 3-1)
The motor graders are classified by ISO as follows. (Fig. 3-1)

Table 3-1 Specification of Motor Grader.

Classification	Blade length, m	Vehicle weight, tons	Blade weight, tons	Lenear blade pressure, tons/m	Rated engine output, ps
Six-wheeled	5.0 4.0 3.7	27.4 15.1 11.2~12.4	12.1 7.1 6.2~7.4	2.4 1.8 1.7~2.0	254 165 118~130
Front-wheel steering	3.1	9.1~9.5	5.1~5.4	1.6~1.7	110~116
Four-wheel drive	2.5 2.2	7.3~7.4 4.0~5.2	4.0~4.4 2.0~2.3	1.6~1.8 0.9~1.0	75~78 41~65

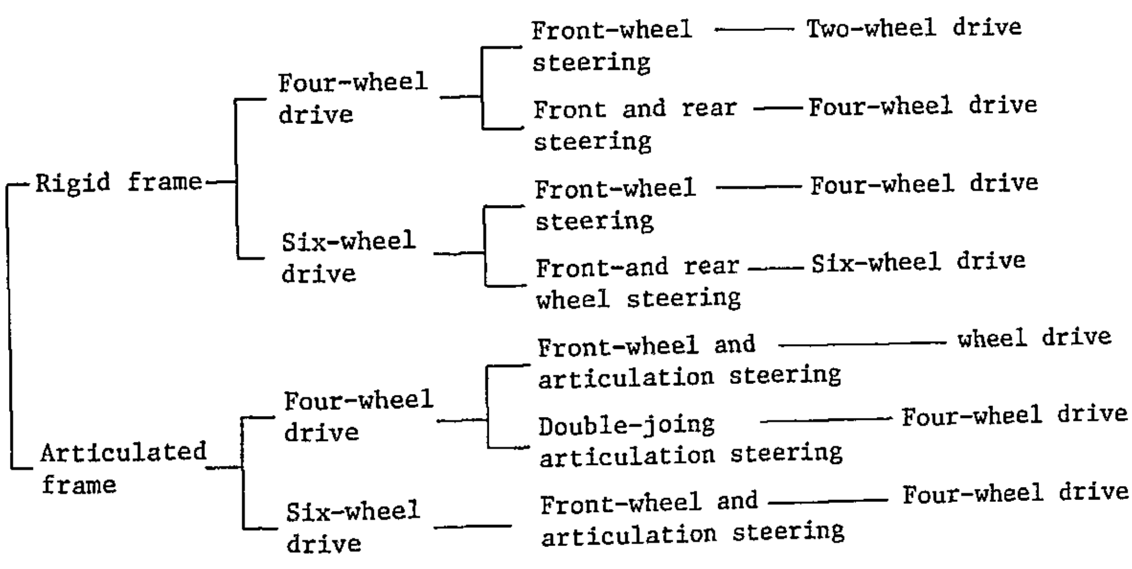


Fig. 3-1 Classificaiton of Motor Grader (ISO)

The motor grade usually has an integrated frame (rigid frame). In recent years, however, the articulated frame type has been on the rise.
The articulated type has its front and rear frames pin-jointed together near the blade. These frames are articulated rightward and leftward hydraulically. The articulated type is characterized in that it has a small turning radius and is able to perform an offset running for special jobs.
The standard working speed of the motor graders used for the maintenance of gravel roads is 4 to 10 km/h.

3.2 Road stabilization machine

A process in which cement, asphalt, lime, etc. are mixed into soil for the purpose of improving the bearing capacity of base course is called the road stabilization process.
This process is classified into two; one in which stabilizing agents are job-mixed, and the other in which they are mixed in an asphalt plant or the like.
The machine used for job-mixing the stabilizing agents is the road stabilization machine.
This machine is composed of a carriage and a working implement, and is often equipped with a ripping device, water tank, emulsion tank and sprayer.
The carriage is available in the wheel type and crawler type.
The working implement is composed of a rotor and a hood, and the rotor, which is operated up and down by means of a hydraulic device, is fitted with tines, which turn to rake up the road surface and mix stabilizing agents into the soil.

3.3 Surface cutting planer

The asphalt pavement will rut and corrugate with time of use.
Uneven surfaces thwart the vehicles running stably and often lead to a major traffic accident. For the purpose of ensuring the traffic safety, the road surfaces must always be kept smooth. There are various processes available for dressing road surfaces. The surface

cutting planer is a machine to cutting off swellings above grade, and is available in the rotary cutter type and blade type. Usually, a road heater is used for heating the pavement prior to cutting for the purpose of reducing the cutting resistance and increasing the cutting speed. A kerosene burner or propane gas burner is used as a road heater.

The surface cutting planer is available in various sizes from a large-capacity one having a cutting width of 1,800 mm and weighing 17,000 kg to a small one having a scraping width of 540 mm and weighing 1,200 kg.

3.4 Road maintenance vehicle

A vehicle piggybacking various implements for make-do patching, sealing and repairs and performing running repair services is called the road maintenance vehicle.

This vehicle is equipped with a combination of the following devices to meet specific jobs involved, system and scale of work, etc.

(1) Equipment necessary for cutting or ripping the pavement.
(2) Machine for cleaning the joints.
(3) Compactor.
(4) Crane
(5) Asphalt kettle and sprayer
(6) Protections for working safety
(7) Others

The road maintenance work calls for at least four to six road menders, and the vehicle must be provided with a cabin for accommodating them.

3.5 Pavement breaker

When a pavement is superannuated or damaged, it must be broken up in an efficient manner for repavement.

The machine used for this purpose is called the pavement breaker.

The pavement breaker is available in drop hammer type, percussion type and crusher type.

The drop hammer type has about 500 kg weight tipped with a chisel, and raises and drops the weight automatically at a rate of about 20 times a minute to break up the pavement.

The drop hammer type is highly efficient, and undertaken the job at a low cost. For this reason, it has won a high popularity in Japan. The only drawback is its heavy noise and vibration to the nuisance of the residents near the work site. In this amenity-conscious society, the employment of the drop hammer type pavement breaker in the urban area has become more and more difficult in recent years.

The percussion type pavement breaker is a modification of a hydraulic shovel excavator; namely, it is fitted with a percussion breaker instead of a bucket.

The percussion breaker is operated hydraulically or pneumatically to give its chisel end a percussive force for breaking up the pavement. This equipment is effective in breaking the pavement, overage houses, concrete structures and rocks.

The crusher type pavement breaker crushes a concrete structure by means of hydraulic cylinders. Its working vibration and noise are low, making the crusher type pavement breaker particular useful in the urban civil engineering work. It is a modification of a hydraulic shovel excavator; namely, it is fitted with a crusher instead of a bucket. The hydraulic pump for the excavator is directly used for the crusher cylinders.

The crusher type pavement breaker is able not only to break up the pavement, but also to cut off steel bars, and is suitable for demolishing reinforced concrete structures. For the purpose of breaking up the concrete pavement, a small-size crusher type pavement breaker with a breaking capacity of 46-ton class will be suitable.

The crusher type breaker of up to 120-ton class in breaking capacity is available for taking down overage buildings. The maximum hydraulic working pressure is 250 kg/cm^2.

3.6 Asphalt distributor

The machines for distributing bituminous material are classified into asphalt engine sprayer and asphalt distributor.
The asphalt engine sprayer is composed of a kettle for melting asphalt and a spray bar. It is operated by a small engine to spray asphalt through a manually guided hose. The asphalt engine sprayer is used for a small-scale surface treatment, and is not suitable where it is necessary to distribute asphalt uniformly over a broad tract.
On the other hand, the asphalt distributor has its sprayer mounted on a truck, and can distribute asphalt uniformly over a lengthly or wide tract. Its working efficiency is high.
When distributing bituminous material by making use of the asphalt distributor, the following precautions must be observed.

(1) The heating temperature varies depending on the bituminous material used.

(2) It is necessary to establish the relationship between the spray dial scale and the actual spray rate with the spray temperature as a parameter.

(3) It is also necessary to make sure that the transverse spray rate is uniform. The transverse spray uniformity must be held within 15% for asphalt emulsifier and within 10% for straight asphalt.
In the longitudinal direction, the uniformity must be held within 10% irrespective of the bituminous material used.

Figs. 3-2 and 3-3 show an example of deviation in the asphalt distributor spray rate measured in the transverse and longitudinal directions.

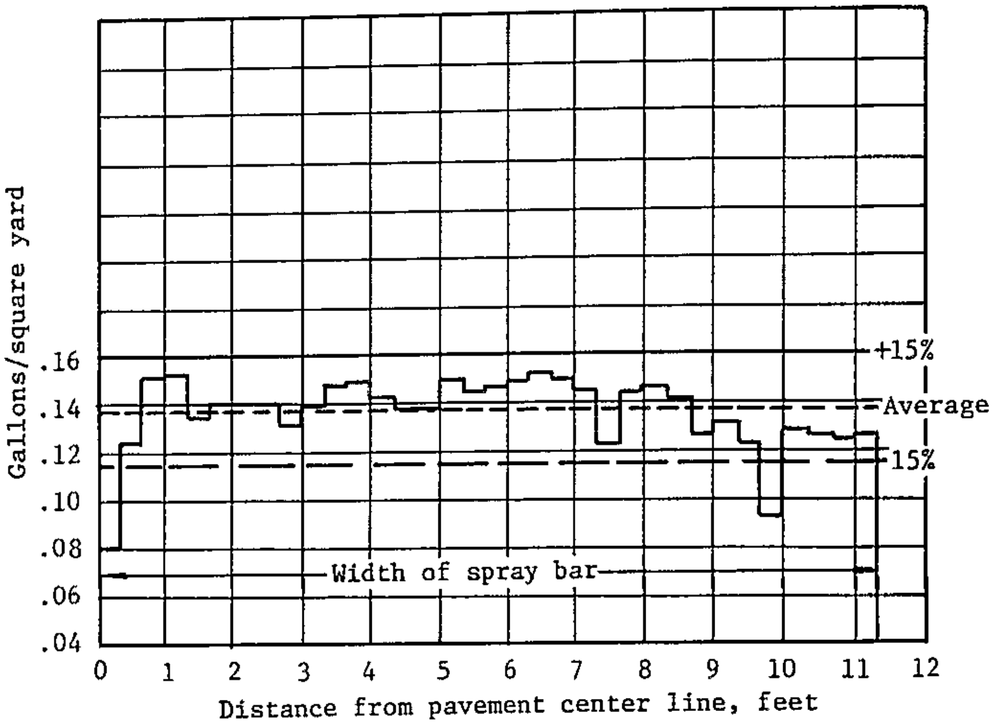


Fig. 3-2 Changes in spray rate in the transverse direction

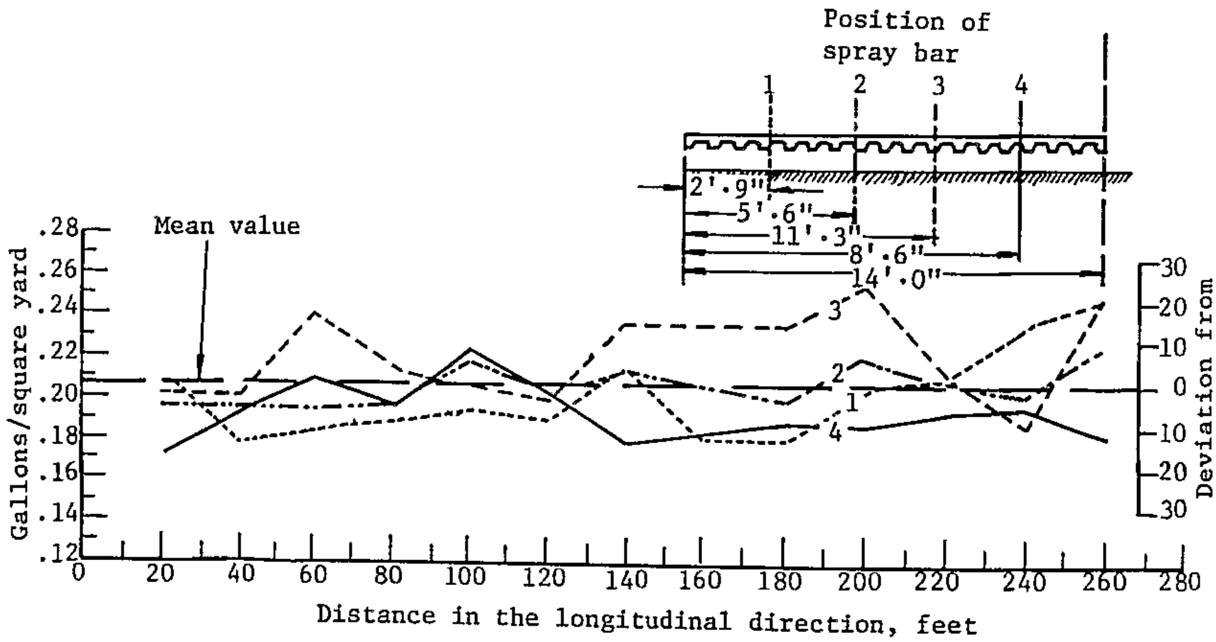


Fig. 3-3 Changes in spray rate in the longitudinal direction

The asphalt distributor is a delicate machine, and its circulatory system, spray bar, valves, nozzles, etc. should be washed and cleaned after work for the purpose of maintaining its performance completely all the time.
The tank is available in various sizes from 1,000 liters to 6,000 liters, and its size should be selected to best meet the scale of the work.

3.7 Concrete cutter

For partial cut of concrete pavement or asphalt pavement, a concrete cutter is used.
The concrete cutter has a thin disk on which industrial diamond blade chips are welded. The disk is run at a high speed for cutting off or grooving cement concrete or asphalt concrete.
The diamond disk is available in various sizes, from 8" in diameter to 30" in diameter. The width of the groove is 2.5 to 3 mm.
If a 30" disk is used, a maximum cutting depth of up to 14" (300 mm) is achievable.

3.8 Portable asphalt plant

There is a portable asphalt plant which undertakes running repairs of asphalt pavements. Usually, the portable asphalt plant is of the towed type, and is hauled by a truck or the like to site.
It prepares an asphalt mixture while running, and the mixture is used to plug the potholes.
The portable asphalt plant is much simplified in structure as compared with the stationary asphalt plant, and the quality of asphalt mixtures it can offer usually is not so good as the stationary plant can offer.
The portable asphalt plant carries out heating and mixing on the road, and is often found to be an obstacle to the traffic. Worse, it generates noise and belching forth stink and sooty smoke to the great annoyance of roadside inhabitants. For this reason, the portable asphalt plant should not be used in heavy-traffic roads or in the urban area.

3.9 Sealing machines

3.9.1 Joint cleaning machine

The joint cleaning machine is a means to remove aged joints of concrete pavement. This machine has a disc studded with steel picks and a brush. The disk and brush are driven to remove old joint filler, stone and other foreign objects from the joints and cracks.

3.9.2 Joint sealing machine

This is a machine to inject joint filler into the joints and cracks, and is equipped with a heating kettle to keep the molten filler at a proper temperature and an injector to feed the filler to a specified place under pressure.

3.10 Mudjack

This machine is used to fill in the cavities between the concrete slab and base course or to thrust up the sunken slab to a normal level.

The filler used for this purpose is cement mortar or asphalt. To charge the cement mortar, a grout pump usually is employed. A machine equipped with an injection pump and a mixer is called the mudjack. Blown asphalt (penetration: 10 to 40) is used where asphalt is to be used. Blown asphalt is heated and molten at temperatures exceeding 210°C, and is injected to affected places at a pressure of 2 to 4 kg/cm^2. For the purpose of injection, an asphalt distributor or the like is used.

4. Cleaning equipments

4.1 Road sweeper

The road cleaning to be conducted as a link of road maintenance and management is indispensable for the assurance of safe and comfortable trafficability, prevention of traffic accidents, maintenance of a desired street-scape, and also for the protection of the amenities of roadside residential quarters.

The dust that can be seen on the roads are diverse, and the road sweeper must be able to collect any such dust other than heavy loads such as sand and soil washed out from roadside slope and the like.

The road sweeper is classified by carriage, sweeping device and ejector system.

4.1.1 Classification by carriage

(a) Three-wheeled type: Equipped with a special chassis specifically designed for road sweeping purposes. This road sweeper is of the front-drive, rear-steering, rear-engine type, and has a small turning radius, so it features a high mobility.

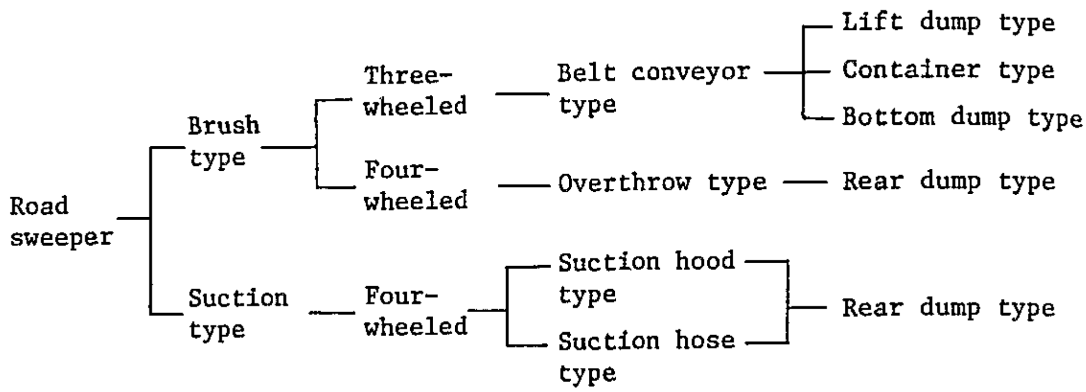
(b) Four-wheeled type: A special modification of an ordinary truck. This road sweeper is high in running speed, and is equipped with an engine for exclusive use for road sweeping implement. Doubles as a road sweeper and a trash carrier.

4.1.2 Classification by sweeping function

The road sweeper is classified into two types; one in which a brush and a belt conveyor (or bar feeder) are used in combination to feed dust into a hopper (brush type), and the other in which dust are sucked into a hopper by a vacuum force (vacuum type).

4.1.3 Classification by ejector

The road sweepers are classified by ejector systems as follows.



4.2 Gutter cleaner

Dredging sand and mud from the gutters in very important as it makes the gutters draw well, prevents the roads from being waterlogged, ensures traffic safety, prevents the road surfaces from damage, and improves the environmental hygiene.

The gutter cleaner is available in the blower type and the vacuum pump type. The blower type is equipped with a blower which draws air into a hopper to suck up dust by a vacuum force through a draft tube.

In the vacuum pump type, the hopper is maintained at a high vacuum pressure to suck dust and sludge in. This type is suitable for cleaning the gutters and catch-basins.

4.3 Drain pipe cleaner (jet cleaner)

Usually, the drain pipe cleaner (jet cleaner) is used for cleaning sewer pipes of up to 600 mm in diameter if the sludge in them is loose.

The drain pipe cleaner is equipped with a high-pressure hose tipped with a special nozzle. The nozzle washes away solids by a high-velocity forward jet of water, and lets the hose snake forward by the high-velocity backward jet of water. Also, the backward jet washes solids down out of the pipe.

The drain pipe cleaner is equipped with a high-pressure pump, water tank, high-pressure hose reel, etc. on a truck.
The high-pressure pump is driven either by an exclusive engine or by the power take-off system of the truck engine.
The drain pipe cleaner is also available in the auger type and bucket type.
The auger type has a flexible shaft tipped with a rotary excavating auger, and is suitable for cleaning a comparatively short drain pipe.
The bucket type is composed of a bucket and a drag wire. The bucket is run through a pipe by being a winch-driven drag-wire to scrape solids out. It is suitable for cleaning large-size sewer pipes.

4.4 Guardrail cleaner

This machine thrusts a revolving brush against the guardrail while spraying water and detergent over it for continuous cleaning of guardrails.
The guardrail cleaner is equipped with a rotary brush, water tank, detergent tank, etc. on a truck chassis.
The working speed is 0.5 to 5 km/h, and the running speed is just the same as the ordinary truck.
The water tank capacity is 1,100 liters, and the detergent tank capacity is 400 liters.
The working height is adjustable from 200 mm to 1,200 mm above grade.
In addition to guardrails, the machine can clean the net type fences.

4.5 Tunnel cleaner

This is a machine to clean the tunnel walls.
Its construction is almost the same as the guardrail cleaner, except that the cleaning brush can be moved in a circle along the tunnel walls.

4.6 Sign plate cleaner

This is a machine to clean the traffic signs. Usually, the signs are washed manually by a worker on the gondla of a lift car. But this method was superseded by this machine because of hazards involved in the heavy traffic roads.

The machine is equipped with a telescopic ladder, rotary brush and a cleanser tank. During work, the machine is stabilized by outriggers. The brush can be moved 600 mm back and forth and 1,500 mm right and left. It can also be twist 120°.

The machine is remote controlled from the gorund, and the cleaning work is quite safe.

5. Other maintenance equipment

5.1 Line marker

The line marker is a machine to draw lane markings, pedestrian crossing markings, etc.
The paints used are available in ordinary paint type applicable at normal temperatures and a heating type which is heated and molten before application.
The line marker is composed of an engine, compressor, air tank, paint tank and sprayer, etc., and is carried on a pickup for delivery to site. It is also equipped with a device for spreading fine glass beads which increase the reflectance of lane markings.
For drawing a broken line, an electronic pulse controlled broken line marking device which turns the sprayer on and off automatically is used.

5.2 Road sprinkler

The road sprinkler is used for cleaning the road surfaces, gutters, etc., for watering roadside trees, and also for spraying anti-freezing solution for the prevention of frosting. Usually, the road sprinkler is equipped with a pump, and can feed water into its tank on its own.
The pump is driven by the power take-off system of the truck engine.
In case of a high-pressure road sprinkler, an exclusive engine is provided. The water tank is coated with an anti-salt paint for corrosion protection.

5.3 Aggregate spreader

This is a machine to spread fine aggregate on thin layer over the road surfaces. It is available in the rotary type and gravitational fall type.
The rotary type has a revolving disk under the hopper, and the revolving disk slings aggregate off by its centrifugal force.
The gravitational fall type allows aggregate to fall gravitationally through a slit below the hopper to spread aggregate uniformly over the entire width of the slit.

Both types are available as a simple modification of a dump truck or as an exclusive machine.

5.4 Mowing machine

The shoulders and slopes rank with weeds are often found a major hazard to the road traffic, and should be removed. Usually, the road shoulders are installed with guardrails, electric poles, traffic signs and other objects that hamper weeding.
The mowing machines for road use are available in various types, including a truck-mounted type, self-propelled type, hand-guided type and shoulder-strapped type.
The cutting head is available in the clipper type, revolving cutter type, propeller type, etc.

5.5 Compactor

The compactors for road maintenance are available in various types. They are required to be small in size, but powerful. Accordingly, most of them use vibratory force or impact. They include the vibration roller, vibroplate, tamper, rammer, etc.

5.6 Construction signs and sign cars

The construction signs are important for the purpose of the working safety of road gang and prevention of traffic accident by calling the attention of the vehicles.
If the road maintenance or construction work runs over a long period, sign stanchions are used. For a running service, such as weeding and sweeping, a sign car is convenient. The work at night involves hazards, and illuminated signs are effective. Other safety contrivances include a jointed figure called "the Safety John" who works well and is employed for highway services throughout Japan.

6. Recycling of asphalt pavement

Ever since the 1973 oil crisis the price for asphalt has been rising at a spiraling rate as the price for crude oil soars. In the past, superannuated or broken pavements were dug up and disposed of at dump site. In recent years, however, every road constructor has been making efforts to recycle waste pavement mainly because the price for fresh asphalt has become prohibitively high and partly because the recycling technology has progressed. In support of this, the research and development for plants to reuse waste pavement for base course or for asphalt mixtures has been actively pursued.

It is expected that a surface recycling process in which a bitterly rutted or corrugated pavement area is stripped off and patched with a mixture of strippings and a small amount of fresh asphalt mixture will be put to practice shortly.

6.1 Recycle asphalt plant

Lumps of waste asphalt pavement are trucked to the plant yard for rejuvenation. They are no longer waste, but are an important source of paving materials.

These lumps are first steamed or immersed into hot water, and then crushed into aggregate. The aggregate is then classified. Since the aggregate is already coated with asphalt, it is only necessary to add a small amount of fresh asphalt for a recycled pavement mixture. For the heating and mixing of the apshalt mixture in the recycle plant, drum mixers usually are employed.

The recycled mixture compares well with the fresh mixture in quality. And the best news of all, its cost is below 70% of the fresh asphalt mixture.

6.2 Surface recycling

The surface recycling method is an in situ process in which those parts of the pavement which are affected with rutting, corrugation or minor cracks are infrared heated and raked up 3 to 4 cm deep, patched with a mixture of rakings and a small amount of asphalt mixture, graded and compacted level with the good pavement.

This process, however, cannot be applied for the remedy of such failures as due to insufficient base course bearing capacity, serious cracks caused by heavy loads, and major ruts. But it is useful for the repair of minor surface irregularities, minor cracks and defacements.

This surface recycling process has been acclaimed for its high energy-saving, resource-saving, low-cost performance. Originated in the United States, this process finds its way in Europe, particularly in West Germany where it has been used extensively.

The major manufactures of the surface recycling systems include Culter, of U.S.A., and Wirtgen, Vögel and Strabag, of W.G.

7. Snow remover

Japan is one of the most snowy countries in the world, and has to spend much money and labor for removal of snow from the roads in Winter. So far, the development of snow-removing machines has been pushed forward in Japan, and Japan now has become the largest owner of snow-removing machines in the world. The snow-removing machines include rotary snow remover, snow-dozer, motor grader, snow truck, snow loader, etc.

ROAD MAINTENANCE STUDY COURSE

CONSTRUCTION EQUIPMENT MANAGEMENT

by

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JAPAN INTERNATIONAL COOPERATION AGENCY

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CONSTRUCTION EQUIPMENT MANAGEMENT

1. Requirements for the operation and management of construction equipment

1.1 Fundamentals of operation and management

Mechanization is one of the instrumentalities for construction work. What type of mechanization should be used is to be determined depending on the type and nature of work involved.

Mechanization in the field of consturction work has made giant strides forward in every respect, and today the construction equipment of various types, mechanisms and functions are available to meet specific requirements of various tasks. But the machines will cramp their style unless operated and managed properly. To have a thorough knowledge of the construction machine and the skill in its use is significant not only for the workmanship of engineering, but also for the operation and management of the machine itself.

The methods of operation and management of mechanized work should be predicated upon the requirements of the works to be constructed, (1) improvement in construction speed, (2) reduction in construction cost and (3) improvement in quality.

In order to achieve these three objectives, the planning of work, maintenance and operation of construction machinery, and planning of machine procurement, etc. should be conducted carefully from the engineering and managerial viewpoint.

It is the most important for the machine operator to follow the manufacturer's instructions strictly, accurately and faithfully. Cutting corners to save yourself a chore or even a slight negligence may lead to a major trouble. If you stint on a penny for what it is worth, you may lose pounds.

1.2 Statistics on achievements

In the construction work, you can never get away with scamping or once-over-lightly.

To do your jobs scientifically, it is very important to keep yourself well informed of what your construction machinery really is. And, the operation logs and maintenance reports serve as a statistical basis upon which to keep your business rolling. Accordingly, you should never save yourself the trouble of filling out these logs and reports. These records are then statistically processed and analyzed in order to formulate measures for improved working efficiency, reduction of unit costs and for breakthrough of problems. Without statistical data, you will just find yourself doing business at the sacrifice of efficiency and paying much for what will be saved otherwise.

However diligent the person in charge of equipment may be in keeping records, his efforts will be ineffective if the records are laid up by his boss who does not know how to use them.

1.3 Measures for reducing the construction cost

The unit costs for construction are governed largely by whether the construction has been planned and executed in a well-knit manner. When a number of equipments are used in combination or when equipments and labor force are combined, the overall working efficiency will be controlled by what is the lowest in working efficiency.

If the work processes follow a continuous or are conducted in tandem, the entire work will be forced to stop if any one of the processes gets out of order. Namely, only a single equipment failure can let all other equipments run idle, and you will find yourself on a treadmill only to run up the bills.

Then, how should be reduce the construction unit costs: Now let us study what the unit cost is. The unit cost may be expressed by the following formula.

Unit cost (U) = Total construction cost (E)/Work done (W)

$W = Q \times A \times B$

$E = D + O + R + T + S$

Where, Q: work volume per hour

A: number of working hours per day

B: number of working days

D: depreciation cost or rental

O: operating expenses

R: repair costs

T: transportation charges

S: administration costs, etc.

As the formula above suggest, it is necessary to arrange the terms in a manner to maximize the denominator and minimize the numerator. In order to increase the work volume per hour (Q), it will be necessary to use a machine of a large capacity or of a high working efficiency or to employ a method ensuring a high working efficiency. If you employ a large-capacity machine to increase Q, then you should give your attention to the fact that you are increasing the terms D, O, R and T. In such a case, therefore, you should study various viable cases from which to choose the best that will minimize the total construction cost.

In order to increase the number of working hours per day (A), it is necessary to minimize the down time, servicing time, and breaks. To this end, the plans for works must be worked out to ensure a streamlined flow of activities, and the machines should be kept in good working order to get the programs going without hitch.

In order to increase the number of working days (b), the works should be scheduled for such a period or season of the year when the weather or site conditions are favorable, and also the down time due to machine troubles should be minimized. In other words, the daily maintenance should be conducted without omission, and the inventory control of spare parts should be improved for quick servicing.

When it comes to the minimization of operating costs (C), one is often tempted to consider that cheap fuel, oil and materials and cheap labor be used, but the difference in cost between cheap and qualities is not so significant.

It is therefore wise to use fuel and lubricants of proven quality and skilled machine operators.

Repair costs (R) can be minimized only if the equipments are maintained and serviced punctually according to operation manual or shop manual. In this respect, it is of great importance to establish a well-knit inspection system and push forward preventive maintenance actively according to it.

It is also desirable to minimize the machines running idle and to combine the machines in a manner that will elicit the maximum from every one of them. The necessity of standby machines, spare parts and the service shop is dependent on the scale and conditions of construction works, and its effect on the total construction cost is not so small.

The education and training of operators and daily and periodic inspection of equipments are particularly important among the site duties and responsibilities that are conducive to the reduction of equipment expenses.

A skilled worker means one who can operate his machine at the lowest possible cost and at the highest possible efficiency.

1.4 Keeping of construction equipment

So that we can push forward the construction works as scheduled, we are required to keep every machine in good condition at all times. This calls upon every operator and every site overseer to be conversant with the preliminary maintenance and field services.

1.4.1 Storage of equipment

At site, the equipments at rest should be kept in a shed or covered with a sheet so that they can be protected from storm, wind, dust, the heat of summer and the cold of winter, and other various elements.

The equipments should also be applied with rust inhibitor wherever required. Even the stationary equipment should be provided with the same protective measures as above.

1.4.2 Oil service

Lubrication is one of the most important maintenance activities, because statistics show that most of machine troubles are caused by shortage of oil and grease or by the use of nonstandard lubricants.

Improper lubrication affects the machine limitlessly, and often leads to a major trouble.

Thus, the machine operator is obliged to lubricate his machines with care, and the site overseer is also required to supervise whether the machines have been lubricated well.

The machine parts and components must be lubricated with the oils and greases and at the cycles diligently as specified in relevant machine operating instructions or lubrication tables.

Spent lubricants must be replaced completely with fresh ones.

1.4.3 Periodic inspection

Every machine must be inspected and maintained before and after use every day. This daily inspection and maintenance is undertaken by the machine operator himself.

In addition, the machines must be inspected and maintained after a definite number of working hours. For example, they are subjected to weekly inspection and monthly inspection by authorized machine inspectors who check up those parts or components which are hard to inspect daily or which are vital to the machine performance.

These inspections should be conducted in a planned manner, and if defectives are found, they should be fixed up immediately in a proper manner.

1.5 Maintenance and repair of construction equipment, and parts

1.5.1 Maintenance and repair

The maintenance and repair is classified into two type; one in which maintenance and repair is conducted at site (field service), and the other in which maintenance and repair is conducted at a specialty shop or motor pool (shop service).

The scope of field service should be determined with account taken of the types of machines used, geographical conditions of site, scale and period of works, etc.
Usually, the field service should cover the running trouble-shooting, parts replacement and other services that can be accomplished by making use of simple field service kits. Namely, the field service kits should include a machine tool capable of making small parts and a welding machine. It is very convenient to use a service car which carries a machine tool, tools and jigs, welder, etc. Those replacement parts which are used at site should be kept at site.
The shop service includes overhauls to be conducted once a year or after completion of the works.
The overhauls should be planned in advance in coordination with the programs of works.
The replacement parts which will be required should be prepared in good time in order to shorten the lead time for repair.
Replacing parts in assemblies and repairing the assemblies at a service shop are a good way to the reduction of repair time.

1.5.2 Spare parts

It is ideal to prepare the spare parts according to past records. But this is very difficult.
Consider a case where three units of the same machine are used and another case where ten units of the same machine are used, and what do you think the spare parts requirements are? It should be noted that the ratio of the quantity of spare parts required for the former case to that for the latter is not 3 to 10. Usually, the latter requires less spare parts per unit.
Operating the machines of the same model at site is therefore beneficial from the viewpoint of spare parts economy.
When you formulate a logistic plan for spare parts supply to a specific project according to the experience in a past project of different nature, you should carefully examine the expected machine operating conditions, availability of service shops and the skill of operators, etc. in addition to the number of machines required.

2. Work records

2.1 Importance of work records

Work record and an account of expenses for equipments provide a basis of future engineering or of the estimate of future projects. More often than not, owners of construction equipment feel that past records fall far short of the actual needs; so they often try to find a better way of keeping records of equipment expenses. But there are many who slight or grudge keeping the records. On the other hand, there are many cases where the records, though followed another example, are not turned to good account.
Precious data in the records are liable to be left forlorn unless they are taken purposefully. Unless the data on record are analyzed closely, it will be almost impossible to find out an effective way of cutting down on the costs and expenses for equipment or to identify the causes of abnormally high expenses.

2.2 Kinds and forms of work records

If new equipments or new methods are introduced in mechanized construction work, their operating characteristics usually are required to be taken stock of in various manners.
When a construction project is carried out by making use of machines, at least the following records should be kept.

- o Work journal (operating journal)
- o Maintenance and repair report
- o Overhaul report

By enumerating and marshaling these records, we can obtain data useful for various purposes. The data on the work journal are enumerated and summarized into a monthly report. The repair report offers a basic reference for each specific machine.

(1) Work journal

The work journal is to be kept by the machine operator for each specific machine he operates. It should contain daily operating conditions such as hours run, volume of work done, maintenance and repair services rendered, and consumables used.

(2) Maintenance and repair report

The maintenance and repair report covers the affairs relating to inspection and maintenance services rendered on the occasions other than daily inspection and maintenance, and states the troubles found, their causes, measures taken, and the expenses required for repairs, etc.
According to this report, the parts and man-hours required for maintenance and repair, the costs for repair per operating hour, the causes of troubles, etc. are identified.

(3) Overhaul report

The overhaul report is a statement of overhaul, and shows data about the various parts and components used for repairs in a concise schedule.
This report should be accompanied by a table of measurements of wearing parts for the purpose of facilitating the determination of what measures be taken at the time of servicing.

2.3 Information from the work records

The planning and engineering of the construction projects, machine operation and management should always be predicated upon the data on the work records. Otherwise, neither improvement nor advancement in mechanized construction work can not be expected. Unless data are available, we are denied any measure for assessing the efficiency and economic standings of the mechanized works, and will be unable to manage the machines for highly advanced mechanized works.
On the other hand, if work records are kept properly, enumerated, marshaled and analyzed, we can have an important clue to improvement of our daily activites.
The information that can be derived from the work records is as follows.

(1) From work journal: -

(a) Basic data necessary for the estimate of running costs

The consumption per hour of fuel, lubricants, tires, and other consumables, and the number of man-hours for a specific type of work, can be determined.

(b) Troubleshooting data

By comparing the costs actually required with the estimate, we can find the causes of excess costs, and can formulate measures for cost reduction.

(c) Data for operation factor and working efficiency

It is possible to determine the volume of work done per hour, per day or per month and thus to determine the cost per unit volume of work. It is also possible to check whether the work is carried out at a specified rate of energy input.

(d) Data for the estimate of construction period, equipment needs, etc.

From the work records, it is possible to estimate the construction period, the number of machines and manhours required and to determine how to manage the machines and labor.

(e) Data for maintenance schedule

It is also possible to work out a maintenance and repair schedule necessary for keeping the machines in working order all the time.

(2) From maintenance and repair report: -

(a) Basic data necessary for the estimate of costs for maintaining and repairing the machines

It is possible to estimate the costs for the maintenance and repair of each specific machine and to know the difference in maintenance and repair costs between the new and old machines.

(b) Data for assessing the quality of field services

The costs for maintenance and repair provide a basis upon which it is possible to judge whether the field maintenance, servicing and management of the equipments are undertaken properly.

(c) Data for preventive maintenance

The maintenance and repair report offers data about which troubles are responsible most for the push-up of construction costs. Namely, by identifying the troubles and their causes, we can formulate the measures to reduce the frequancy of troubles.

(d) Troubleshooting data

By identifying the troubles and their causes, we can formulate proper measures for fighting away the troubles.

(e) Data which tell of the weak spots of the equipments or warn the operators about equipment handling

By analyzing the data on the maintenance and reports, we can identify the weak points of each specific equipment, the points to be observed in handling the equipment, and the points that need improvement.

(f) Data for maintenance schedule

By analyzing the data on the maintenance and repair report, it is possible to determine when and what machine parts or components be maintained and serviced.

(g) Data for procurement planning

Statistics on the consumption of wires, cutting edges, teeth, etc. and on the frequency of parts failures will provide a basis for the procurement planning of parts and consumables.

(h) Data for break-even point

By determining the running hours vs. costs relationship of a equipment, we can determine the economic useful life of the equipment and thus when to replace it.

(3) From overhaul report: -

(a) Histry of equipment

The overhaul report offers data for intensive analysis of each specific type of machine with respect to technical and economic factors in relation to the environment in which it has been used, and offers guidelines for improvement in the operation and management of the equipment.

(b) Data for overhaul planning

The overhaul report helps formulate the time and way of the next overhaul.

(c) Troubleshooting data

When a machine gets out of order, we can refer to the overhaul report to check for the defective parts and the dates they were installed, to clear up the causes and provide proper measures.

3. Field maintenance

3.1 Essentials of field maintenance

Whether the equipment can display its performance to the fullest extent at site hinges on whether it is operated and serviced properly.

3.1.1 Thorough lubrication

Although everyone knows the importance of lubrication, but as well he is apt to neglect the lubrication.
There are many cases of engine failures due to negligence in lubrication.
Lubricating the machine as required by the manufacturer's manual will prove in the long run to extend its service life, though the lubricating cycles and the amount of lubricant brands specified may seem too good for the machine. There are many such operators who used oils of poor quality to stint on money only to find their engines and transmissions seized up.
In recent years, the service of life of diesel engine has been extended amazingly. This is partly because the lubricants have been improved and partly because the lubricating requirements have been tightened.
The bearings which are running under heavy loads should be lubricated with special high-quality grease for prevention of seizure.

3.1.2 Protection of engine from dust

(1) Air filter

If dust is admitted into the engine through its intake system, the cylinders and valve guides, etc. will be worn excessively. For this reason, the air filter should always be kept clean, and should be replaced whenever required.

(2) Fuel filter

A fuel filter is necessary to clean fuel of impurities, to prevent the injection pump from seizing up and wearing down and also to free the nozzle from failures. By carefully and periodically maintaining and servicing the fuel filter, we can keep the engine operating in good condition.

(3) Oil filter

The purpose of oil filter is to remove solids suspended in the oil flow. Namely, it prevents the oil pipe from being fouled up and at the same time ensures smooth lubrication of bearings.

(4) Cooling system is important

The cooling system should always be filled up with fresh-water. Regrettably, there are many troubles due to the failure of cooling system. Particular attention should be paid to the cooling system at the turning of the seasons or when it is frigid. In order to provide against freezing trouble, anti-freezer should be used. At site, river water or mineral-rich water may be used which will form scale in the cooling system to constrict the water passage and hence to cause local overheat or reduce output.

3.1.3 Importance of appearance inspection

The operator should keep his machine clean all the time. If the machine is clean, it is easy to check the oiling points and oil level and to adjust the machine and at the same time we can check hidden causes of trouble in advance. In the construction machine mounted with an engine, bolts and nuts and other components are liable to get loosened owing to engine vibration, and loosened components will take undue stress and fail prematurely, leading to a major machine failure. The loosened bolts, nuts, connections and other components should be tightened up firm whenever detected.

3.1.4 Importance of preventive maintenance

The major reason of site troubles or failures include erroneous operation, improper maintenance, careless adjustment and negligence of routine inspection. It should be noted statistics show that the erroneous operation is responsible, among others, for major accidents.

However well-trained the operator may be, his overconfidence or maturity in experience often throw him off his guard. Therefore, the machine operator should always attend his machine with all diligence and attentiveness.

The inspection designed for prevention of troubles should be conducted once a week for small machines and once a month for large machines or plants.

3.2 Servicing facilities at site

The servicing facilities required at site are different with the geographical conditions of site, the types and quantity of the machines operated at site, etc.

3.2.1 Site near motor pool

If there is a motor pool or equivalent near the site, the site facilities for repairing services will be simplified largely.

The machine operator should always inform the motor pool of inspection findings, and ask the motor pool for services whenever the troubles beyond his control happen.

The motor pool should also get ready to offer prompt, powerful technical supports. It is advisable to dispatch well-conditioned care-free machines to a distant site and to operate the moot machines near the motor pool.

3.2.2 Site distant from the motor pool

(1) Small-scale construction site

At a small-scale site distant from the motor pool, the machine operator is obliged to do everything from the operation of machine, maintenance to inventory control of spare parts and even to the repair services.
When it is required to repair his machine, the operator may have to go and forge, weld, machine or repair the machine components at a nearby shop if available.
Accordingly, the equipments to be dispatched to a distant site should be comparatively new and least prone to trouble, and the machine operators should have enough experience, skill and sound judgment, and should also be quick-witted and aggressive.
The mechanical engineers should also be dispatched to site as often as possible for inspection and maintenance of the machines.

(2) Large-scale construction site

At a large-scale long-term project site, it is necessary to employ a well-knit site management system for the equipments. Namely, a chief engineer (foreman) should be assigned to manage the equipments and their operation for the purpose of improving the overall working efficiency of the equipments. The servicing facilities should be more fully equipped the far the site is from the motor pool.
Namely, the servicing facilities should be designed by taking into account the transportation costs and the lead time. It may be justified to install an overhaul facility.

4. Spare parts

4.1 Importance of spare parts

However excellent the equipment may be, it can fail. Without spare parts, the machine will not work an inch when deadline for the project is near at hand.

A machine which is inferior a little in efficiency, but which is reliable from the viewpoint of spare parts availability, is more eligible than a higher-efficiency machine the spare parts of which are hard to come by.

When you want to buy a machine, you should first investigate the machine manufacturer or dealer about the availability of spare parts and necessary skills.

When you are going to buy a machine of foreign origin, you should be particularly careful about the selection of its type. Namely, the fleet of your machines should be standardized as much as possible. On the contrary, if your machines are diversified in types and sizes, you may have to prepare as many spare parts and to take as much trouble in management. This in turn will lead to a reduction in overall working efficiency.

4.2 Inventory control of spare parts

4.2.1 Requirements

Making a spare parts procurement plan in anticipation of replacement is quite difficult technically.

If the procurement plan goes amiss, you will find yourself pressed for some parts when other parts are laid up galore.

An inventory plan for the spare parts to be kept at site or motor pool should be worked out in consideration of the following.

(1) Scheduled period of machine operation

According to the period during which the machines are required to be available or run at site, the procurement of spare parts should be planned. If the period is long, the procurement should be made in steps. The types and quantities of spare parts should also be figured out according to the total number of running hours estimated.

(2) Working conditions at site

The singularities of working conditions, particularly those affecting the machine wear, should be investigated. For example, excavation and transportation of rocks will wear out the undercarriage of bulldozer, dipper teeth of power shovel, etc. soon. If the work is to be undertaken in a dusty place, the filter element for the engine may have to be replaced frequently.

(3) Availability of maintenance facilities and skills at site

What facilities are available at site for the purpose of maintenance? Is it possible to fabricate parts at site? And, to what degree? What testing instruments are available at site? Is it possible to perform welding?
All these points should be considered in formulating the spare parts inventory plan.

(4) Skill of operator

The frequency of machine troubles varies with the skill of the machine operator. It is therefore necessary to anticipate the troubles due to difference in skill or personal equation of individuals.

(5) Geographical conditions

It is also required to investigate whether there is a telecommunications or traffic convenience between the logistic base (manufacturer's workshop or local distribution depot) and the work site, whether there is a machine shop, forging shop or foundry near the work site.

(6) Number of machines used

The number of the machines of the same model used in team is also a factor of determining the quantity of spare parts

to be kept on hand.
An inventory plan of the spare parts for those machines with which the machine operator is familiar will be easy to make up according to past data. But, the machines new to the machine operator will defy the inventory planning. As regards the unfamiliar machines, the spare parts inventory planning should be carried out through stocktaking survey of replacement services another site.

4.3 Procurement of spare parts

Discussed below are the major issued of parts procurement.

4.3.1 Genuine parts and imitations

Whether the machine is manufactured home or abroad, it is quite safe to use genuine parts for it. But, the parts manufactured by non-original equipment manufacturer are available on the market and used conveniently.
There are many non-original parts the manufacturers of which are known and which have proved effective and reliable. In no case, however, you should use any imitations the manufacturers of which are not known to you and which are considered moot in quality, durability and reliability.

4.3.2 Avoiding the purchase of parts which are likely to remain on the shelf

Inventory is a buffer against uncertainty in supply and demand. Without proper inventory control, however, you may simply accumulate too much of wrong kinds of inventory because their demand has been less than expected.
But the dead stock will freeze up the otherwise realizable capital, and may invite financial difficulty.
Use of imported machines often is accompanied by too much inventory of dead stock.
On the other hand, if domestic machines are employed, their

spare parts will be available from the domestic manufacturers in good time. Even after a machine failure, parts may be available without hampering the work. Thus, the inventory carrying cost or risk will be less.

4.3.3 Time to procure spare parts

Some parts may have to be kept on hand as soon as the machine is commissioned. Such parts should therefore be delivered to site at the same time with the machine for which they are used. If a new machine is to be used, such parts should also be procured together with it.

4.4 Inventory control

4.4.1 Parts warehouse

For the purpose of keeping spare parts for construction machinery, it is necessary to install an exclusive warehouse equipped with lockers, cribs and shelves are prepared to keep spare parts in a well-sorted manner according to their types, quantity, shapes and sizes.

The warehouse should also be equipped with an uncrating yard, an index card filing room, and a marshaling system. A space for keeping tires, wires and large articles should also be provided. The floor space and shelf space should be determined according to the types and quantities of spare parts to be kept.

4.4.2 Preparation of a card catalog of spare parts

There are many ways of cataloging the incoming and outgoing parts. An example of cataloging is shown in Table 4.1.

Table 4.1 Stock record card

Date	Remark	Voucher No.	Unit Cost	Received		Issued		Balance	
				Quantity	Amount	Quantity	Amount	Quantity	Amount

Equipment	Parts Number	Description	Remarks:

5. Keeping the construction equipment in a shed

5.1 Shedding principles

The construction equipment needs utmost protective care when kept in a shed for a long period.
When an engine is left unused for a long period or when it is demounted from the vehicle and kept for a long period, it will get rusty or corroded, and its fuel system may get blocked up. For this reason, the engine and transmission should be carefully protected internally and externally. Rust and corrosion set in as soon as the construction equipment is laid up. Thus, protective measures should be provided as soon as possible.
Never leave the construction equipment to take care of itself.
Before shedding the construction equipment, remove rust and scale completely, and then apply rust inhibitor.

5.2 Measures for engine before shedding

For the purpose of corrosion protection, follow the steps below.

(1) Remove oil from the crankcase while it is warm.

(2) Charge fresh oil of specified brand up to the "FULL" mark.

(3) Top up the fuel tank with specified fuel, and run the engine for about 2 min. under no load.

(4) Check the oil level of the air cleaner, and charge fresh make-up oil as required.

(5) When it is expected that the ambient temperature falls below zero during storage, charge anti-freezer into the cooling water as specified.

(6) Totally close all the openings in the engine. To close the openings, use paper or tape sufficient in strength and waterproofness.

5.3 Measures for the body before shedding

(1) Inspection and repair

Carefully inspect and test each part of the body, and make repairs and adjustments so that the machine is ready for use anytime.

(2) Oiling and greasing

Apply oils and greases of specified brands as required.

(3) Parking

Carefully clean each part of the body, and park at a damp-free, level, hard ground. Take care not to soil the tires with oil or grease.
Apply the parking brake.

(4) Battery

When the ambient temperature is unlikely to change violently during storage, the battery may be left on the vehicle.
But, the battery terminals should be disconnected. If the vehicle will not be used for more than a month, it is recommended to remove the battery and keep it at the service shop.

(5) Corrosion protection

Check each part of the body for rust. Remove ruse completely, and apply paint.

(6) Air tank

Open the drain cock at the bottom of the air tank.

(7) Fuel tank and hydraulic tank

Charge the fuel and hydraulic oil into the fuel tank and hydraulic tank to the full in order to purge air out of the tanks. If air remains in the tank, moisture in the air will condense when cooled.

(8) Tires

Inflate the tires to a specified pressure. During storage, check the tire pressure once every other week.

6. Lubricant control

6.1 Importance of lubricant control

Today, everyone knows that the lubricant control for the construction machinery is one of the most important measures for preventive maintenance.
The workmanship in the lubricant control governs the service life of the construction machinery, and therefore is directly concerned with the interest of the enterprise.
The following discusses the precautions on the replacement of lubricants.

6.2 Oil replacement, and check-up of machine

The first objective of the lubricant control relates to the management for oil replacement, and the second objective to the internal diagnosis of the machine at the time of oil replacement. These two are closely interrelated.

(1) Control of oil replacement cycle

The oil replacement is carried out according to various procedures, and the oil replacement procedures are different from shop to shop. Anyway, it is of primary importance to follow the manufacturer's recommended replacement cycle strictly. We service every machine according to its service meter. Accordingly, it is imperative to read the service meter accurately at regular intervals, and to service the machine whenever the service hours have reached.
Servicing should be conducted according to the service meter readings, and not weekly or monthly by rote. This is because the number of days before the servicing is due varies depending on the number of hours run every day.

(2) Method of oil replacement, and machine diagnosis

What is meant by the oil replacement is not simply the replacement of spent oil and filter element. The spent oil and filter element offer an important clue by which to judge the internal conditions of the machine. When oil is drained through a cloth, foreign objects will be caught on the cloth if the machine inside is subjected to abnormal wear. Namely, we can diagnose the machine as follows.

(a) If the drained oil is blackened bitterly with carbon, the following must be checked.

  (1) Has the oil replacement cycle been observed strictly as instructed?

  (2) Aren't the piston and piston rings worn excessively to increase the blow-by gas excessively?

  (3) Aren't there any abnormalities inside?

(b) If the drained oil shows too low a value of viscosity, the following must be checked.

  (1) Is the fuel running from the nozzle, injector or fuel line?

  (2) Aren't the piston or piston rings defective to cause a deficiency in compression? Isn't the unfired fuel running down into the oil in the oil pan?

(c) If the drained oil is milky or reddish brown, it is suspected that the oil is mixed with water; namely, that the cooling water is leaking into the oil.
Check for defective cylinder liner seal, cracks in the cylinder head, slackened prechamber, internal leakage of aftercooler, etc. The water leakage can be detected as condensate is formed in the breather during operation or as the stick gage is wetted with water.

(d) When greasing with a grease gun, if you can operate the grease gun lever at a smaller effort than usual, it is suspected that the shaft, seal, etc. connected to the greasing port are damaged. Check them immediately.

(3) Engine check-up when replacing the oil filter element

When replacing the filter element, be sure to open the filter element, and check for metal dust (iron, aluminum, copper alloy, etc.) lodged in the filter element.
If the filter element is of the metal-clad cartridge type, be sure to tear it down with a cutter for inspection.
Never incinerate or dispose of the oil filter element without inspection immediately after removal from the machine.

(4) The person in charge of oil replacement should preferably be one who can also troubleshoot the engine.

(5) Oil replacement for other parts of the machine

The oil replacement procedure referred to above applies not only to the engine, but to all the other parts of the machine as well.

7. Construction costs

7.1 Breakdown of construction costs

The construction costs are classified according to various methods. Of the construction costs, those concerning the construction equipment usually are classified into the rental (or ownership cost), operating cost, repair cost, management cost, and overhead.
It is said that these costs are hard to estimate accurately. This is because the costs and working efficiency are largely dependent on the working conditions, length of work period, workmanship of management and control of the machines at site, operators' skill, attitude and attentiveness, etc. Fig. 7.1 shows the breakdown of the construction costs.

OWNERSHIP COSTS		REPAIR COSTS		OPERATING COSTS			SUPERVISION AND OVERHEAD COSTS
		Repairs Costs					
Depreciation	Interest Insurance Taxes	Overhauls	Repairs and Maintenance	Operator's Wages	Fuel and Lubrication	Blades, Cable and Tires	Supervision and Overhead Costs

Fig. 7.1 Breakdown of construction costs

7.2 Rental (ownership cost)

In Japan, the rental or ownership cost refers to the sum of the depreciation cost, overhaul charges, interest rate, insurance premium and taxes.
In some case, overhaul charges are included in the repair costs. If a contractor owns a machine, he will have to pay depreciation cost, interest, insurance premium and taxes. But if he borrows it, he has to pay a rent for it.
The amount inversted in the purchase of a machine should be paid off by the works done during the service life of the machine. Namely, the machine should be depreciated according to the hours run. The depreciation in annual instalments is irrational because the hours run vary from year to year and hence because the degree of

damage of the machine does not agree with the degree of its depreciation.

7.3 Operating costs

The operating costs include the wages for operators, fuel cost, lubricant cost, and costs for consumables such as blades, cables and tires.

The estimate of these costs should be predicated upon as much past data as possible. However, these costs vary depending on the types of equipments and geographical conditions, and are subject to commodity price changes.

Accordingly, they are required to be estimated to meet the circumstances. As the costly equipment is left to the care of an operator, it should be borne in mind that the contractor should employ a well-educated, skilled operator rather than an unskilled operator. For the well-educated, skilled operator does more than his wages to reduce the construction cost as a whole.

The fuel consumption of a machine varies depending on the work load. It is therefore necessary to estimate the fuel consumption per hour according to past data on the standard operating condition, heavy load condition, and light load condition.

7.4 Repair costs

The repair costs include the costs for parts and service for trouble-shooting, adjustment, parts replacement and periodic overhaul.

There are various methods of estimating the repair costs. One method uses a factor representing the ratio of the total repair cost during the machine service life to the purchase value. Namely, the repair cost per unit hour is calculated by dividing the product of the factor and the purchase value by the service life in hours.

According to this method, however, the repair cost is estimated too high when the equipment is in its early stages of use. It increases with time of use.

With the exception of proven equipments, it is difficult to estimate the repair cost accurately.

The repair cost varies widely depending on the operating conditons and the workmanship of operation and maintenance.

7.5 Costs for consumables such as tires

The service life of the blades, tires, cables and other consumables changes largely depending on the working conditions. Their costs do not follow a simple proportional relationship with the running hours, and should not be included in the repair cost account. These consumables should be cost-accounted separately.
Table 7.2 shows an example of the estimate of the costs for tires.

Table 7.2 Expected service life of tires

Equipment	Capacity	Operating conditions		
		Good	Normal	Heavy
Dump truck	2t ∿ 11t	1,500h	1,000h	500h
	15t ∿ 45t	1,700	1,400	1,100
Tractor shovel (wheel type)	$0.5m^3$ ∿ $5.0m^3$	3,500	2,500	1,500
Motor scraper		2,500	2,000	1,500

8. Determination of economic service life

In order to estimate the cost per hour of the construction equipment, it is necessary to know the economic service life in hours of the construction equipment beforehand. The following shows a method of determining the economic service life of the construction equipment. Usually, the equipment is subjected to wear and tear occasioned by use. In order to keep the equipment in good shape, it should be maintained and repaired regularly. There is a tendency that the costs for maintenance and repair rise with time of use.

The machine is an assembly of components which are different in durability from each other. In order to maintain the performance of the machine, such components must be replaced at intervals. This kind of maintenance usually is called the overhaul.

The relationship between the running hours and the cumulative repair cost follows the dotted line in Fig. 8.1

As illustrated, the repair costs increase with increase in the running hours.

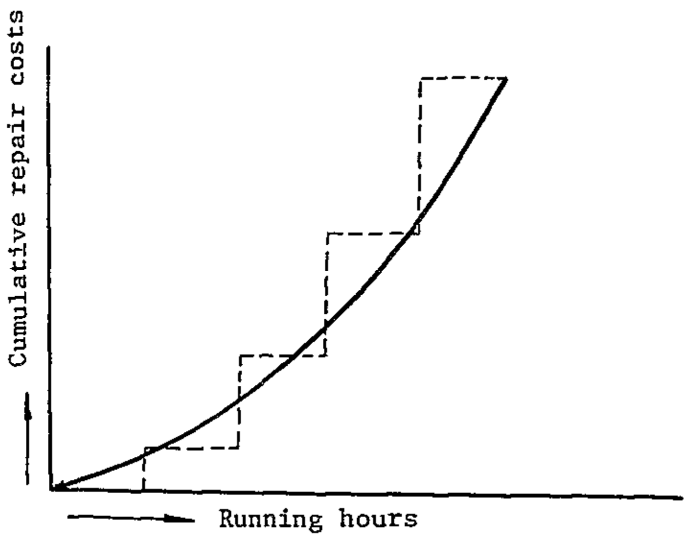


Fig. 8.1 Running hours vs. cumulative repair costs

In order to calculate the repair costs, depreciation cost and ownership costs theoretically, it is desirable to normalize the running hours vs. cumulative repair costs relationship into a solid line as shown in Fig. 8.1

Since the equipment always necessitates maintenance and repair so far as it is to serve as required, its cost required up to a given time, x, is calculated as the sum of the purchase value, P, and the cumulative repair costs, R. By dividing the sum by x, we can determine the cost per hour (C) as expressed by the following formula.

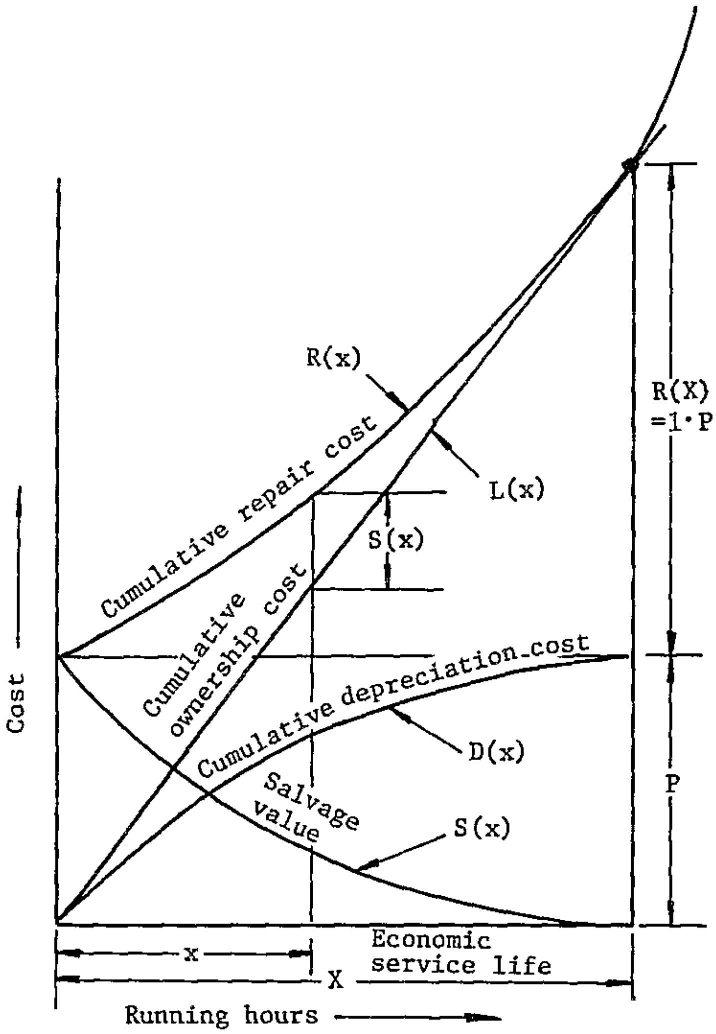
$$C = (P + R)/x$$

If the cumulative repair costs increase in linear to the running hours, the hourly cost of the equipment will decrease with increase in the number of running hours. In actuality, however, the cumulative repair costs increase at an accelerated pace with increase in the running hours. This means that there should be the number of running hours at which the hourly cost becomes a minimum, and which is termed the economic service life. This is represented in Fig. 8.2.

Referring to Fig. 8.2, P is the purchase value, R(x) the cumulative repair cost curve, and x an optionally selected point of time. Draw a straight line tangent to R(x), and read the running hours corresponding to the point of tangency. The reading (X) is the economic service life. Assume that the cumulative repair cost, R(x), at the economic service life (X) is expressed by $f \cdot P$ where f is the repair cost coefficient. Then, the cumulative equipment operating cost is expressed by $(1 + f) \cdot P$.

Assuming that the salvage value is zero, the hourly running cost (C) is given by $(1 + f) \cdot P/X$.

The hourly running cost at a given point of time is expressed by $(P + R(x))/x$. It is extremely high in the early stages of use as shown in Fig. 8.2, and declines with increase in x. At a point where the curve R(x) comes in contact with the straight line, the hourly running cost reaches the minimum. When the value x passes beyond that point, the hourly running cost starts rising again. It is therefore found that the equipment is worth using at repair costs until the time X, but that beyond the time X, the equipment will not pay.



P: Purchase value

R(x): Cumulative repair cost up to time x

X: Economic service life

Fig. 8.2 A diagram for evaluating the cost of construction equipment

For your reference, the following gives a formula for determining the curve R(x).

$$R(x) = mx^n \cdot P \quad \cdots\cdots \quad (1)$$

$$\text{or } R(X) = f \cdot P \quad \cdots\cdots \quad (2)$$

Where, P: purchase value

m,n: constants particular to each specific machine

f: repair cost coefficient

The slope of the straight line which passes through the origin and which is tangent to the curve R(x) is given by the following formula.

$$\left|\frac{dR(x)}{dx}\right|_{x=X} = m \cdot nX^{n-1} \cdot P = (1 + f)P/X \quad \ldots\ldots\ldots \quad (3)$$

From Eqs. (1) and (2), $mX^n \cdot P = f.P$

From Eq. (3), $m \cdot nX^{n-1}P = (P + mX^nP)/X$

$$\therefore\ n = 1 + (1/f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

By substituting $mX^n = f$ into Eq. (4), we obtain the following.

$$m = f/(x^{1 + 1/f}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

By making use of Eqs. (4) and (5), Eq. (1) can be rewritten as follows.

$$R(x) = f(\frac{x}{X})^{1 + \frac{1}{f}} \cdot P$$

The method above was proposed by Mr. Adolph Ackerman, an American civil engineer engaged in a project designed for the overall development of the Tennessee Valley in the 1930s, and is called the Ackerman system.

9. Estimate of ownership cost

The ownership cost is one of the important factors for the operation and management of construction equipment. It is usually expressed in terms of the hourly value which is calculated by dividing the sum of depreciation cost, repair cost and adminitration cost by the number of running hours. In principle, this hourly value is calculated to be constant within the economic service life irrespective of whether the machine is new or old.

Introduced below is the manual published by the Associated General Contractors of America (AGC). (abbreviation)

In Japan, the hourly running costs of about 2,800 standard construction equipments are determined refer to this mannual.

For reference, part of the data taken from American (Table 9-1) and Japanese (Table 9-2) data contained in the tables entitled "an estimation table of the construction equipment ownership cost" is shown below.

Table 9-1 An estimation table of the construction equipment ownership cost (USA)

EQUIPMENT		Average Economic Life In Hours	Average Use Hours Per Year	Average Annual Ownership Expense in % of New Acquisition Cost					Average Hourly Ownership Expense in % of New Acquisition Cost	Average Hourly Repair & Maintenance Expense in % of New Acquisition Cost	Combined Average Hourly Ownership and Repair & Maintenance Expenses in % of New Acquisition Cost	Contractor's Application of A.G.C. Schedules
				Depreciation	Replacement Cost Escalation	Interest on Investment	Taxes, Insurance and Storage	Total Ownership Expense				
Tractors												
Crawler, diesel engine, direct drive Flywheel HP												
From	To											
20	59	4800	1200	22.5	7.0	7.5	4.5	41.5	0.0346	0.0216	0.0562	
60	70	6000	1200	18.0	7.0	7.0	4.5	36.5	0.0304	0.0206	0.0510	
80	109	7000	1400	18.0	7.0	7.0	4.5	36.5	0.0261	0.0183	0.0444	
110	159	7000	1400	18.0	7.0	7.0	4.5	36.5	0.0261	0.0159	0.0420	
160	229	8400	1400	15.0	7.0	7.0	4.5	33.5	0.0239	0.0163	0.0402	
230	300	9800	1400	12.9	7.0	4.5	4.5	31.4	0.0224	0.0174	0.0398	

Table 9-2 An estimation table of the construction equipment ownership cost (Japan)

Classification Code No.	Specification			Original Purchasing Price (thousand yen)	Economic Life (year)	Average Annual			Repair & Maintenance Cost Rate (%)	Annual Administration Cost Rate (%)	Equipment Ownership Cost				Reference	
											per operating hour		per use day		Conversion per operating hour	
	Capacity (t) * indicates the type widely used in Japan	Rated Output (p.s.) (PS)	Weight (t) (t)			Operating Hours	Operating Days	Use Days	(%)	(%)	Cost Rate/hr (x10⁻⁶) (×10⁻⁶)	Cost/hr (yen)	Cost Rate/diem (x10⁻⁶)	Cost/diem (yen)	Conversion per Operating Hour Cost Rate/hr (x10⁻⁶)	Conversion per Operating Hour Cost /hour (yen)
01 Bulldozer & Scraper																
0101 Bulldozer																
11 [Standard]																
010-1	1t	8	0.9	1,090	5	800	120	165	80	7.0	313	341	970	1,060	513	559
030-1	3	39	3.6	4,120	"	"	"	"	"	"	"	1,290	"	4,000	"	2,110
060-1	6	64	6.3	6,020	"	1,000	150	210	95	"	280	1,690	762	4,590	440	2,650
080-1	8	76	8.7	8,260	"	"	"	"	"	"	"	2,310	"	6,290	"	3,630
110-1	11	108	11.9	10,900	6	1,100	165	230	100	"	220	2,400	630	6,870	352	3,840
150-1	15	141	14.6	14,400	"	"	"	"	"	"	"	3,170	"	9,070	"	5,070
210-1	21	211	22.1	22,000	"	"	"	"	"	"	"	4,840	"	13,900	"	7,740
320-1	32	319	33.5	33,500	"	1,200	180	250	105	"	208	6,970	580	19,400	329	11,000
440-1	44	410	44.1	53,600	"	"	"	"	"	"	"	11,100	"	31,100	"	17,600

JICA