SURVEYING OF ROAD SURFACE USING 35MM CAMERAS BY PHOTOGRAMMETRIC METHOD

Masanori OHAMA

Pacific Aero Survey Co., Ltd.

2-13-5 Higashiyama, Meguro-ku, Tokyo, Japan

ABSTRACT

Any effective maintenance and management of pavements requires accurate data and information on pavement distress such as cracking and rutting. Road surveying for this purpose, however, is becoming increasingly difficult due to ever growing traffic volume. To overcome this difficulty, two types of vehicle-borne road surface photographing systems have been developed by applying photogrammetric methods using 35mm cameras.

The first type is comprised of a 35mm pulse camera and a hairline projector which are mounted on a remodelled medium size bus. The system is designed to take photographic records of ruts in the road surface at regular intervals as specified. The second type, intended for surveying of cracks, is capable of continuous photographing of road surfaces with a 35mm slit camera and lighting equipment. For photographic data reduction, aerial photogrammetric techniques are applied. While having sufficient accuracy, these systems and methods are scores of times more efficient and several time less costly then conventional methods.

1. Introduction

For the effective planning of maintenance and management of pavement surfaces that extend tens or hundreds of thousands of kilometers, highway administrators must have a good understanding of the existing conditions of road surfaces in quantitative terms as they constantly change.

Formula (1) as shown below is an example of the criteria that Japanese highway administrators use for overall evaluation of asphalt pavement surfaces.

$$PSI = 4.53 - 0.174\overline{RD}^2 - 0.371\sqrt{C} - 0.518 \log \delta \; ..... \; (1)$$

where

PSI: Asphalt pavement serviceability index (overall evaluation

$\overline{RD}$: Average rut depth (cm)

C : Cracking ratio (%)

δ : Standard deviation of longitudinal roughness (mm)

Generally, the road surface surveying as performed by the highway administration on a regular basis refers to the measuring of ruts (lateral roughness), cracks and longitudinal roughness to be applied in Formula (1).

The road surface surveying as such has been performed manually in the past (referred to as "the direct method" hereafter). But this has been made extremely difficult by increasing traffic volume in recent years in terms of safety, efficiency and impact on the traffic. With respect to rutting and cracking in particular, it is practically impossible to measure manually by blocking traffic although longitudinal roughness can be measured by using a profilemeter from a cruising vehicle.

In view of this situation, we have developed the following systems and methods which enable automatic measuring of ruts and cracks by applying photogrammetric techniques.

(a) The system (called RDP-75) that photographs at certain intervals lateral conditions of road surfaces while traveling on the road by using a 35mm pulse camera and a hairline projector, and the method to measure rutting from the photos.

(b) The system (called ROADRECON-70) that takes continuous photographs of raod surface conditions while traveling on the road by using a 35mm slit camera and lighting equipment, and the method to measure cracks from the photos.

This paper describes these systems and methods and their applications.

The rut depth and the cracking ratio applicable to Formula (1) can be defined as follows although they could vary depending on the grades of roads and standards to be applied.

(a) Rut depth: Rutting or ruts as used here refer to the furrows caused in the pavement surface by repeated loads as a result of the passage of wheeled vehicles. D_0 and D_1 in Figure 1 represent 'rut depths'. In the direct method, they are measured by a profilemeter or by setting a straight bar across the road. Measurements are taken at 20 meter intervals. (Figure 2)

Cracking ratio: Cracking refers to cracks in general, linear or mesh-like, or pot holes. The cracking ratio is given by the following formula.

Cracking ratio =

$$\frac{\text{Crack length (m) x 0.3 (m) x Crack area (m}^2\text{)}}{\text{Survey area (m}^2\text{)}} \times 100 \qquad \text{........ (2)}$$

In the direct method, lengths and areas of cracks are measured from sketches drawn by individual surveyors or photographs taken with a hand camera. Therefore, the resulting measurements tend to vary between individual surveyors.

2. Development of a Method for Photographic Measurement of Rutting

2-1 Application of Optical Bar

In the direct method, rut depths are measured in relation to the base line provided by a straight bar set across the road. We have developed a new method that, by replacing the straight bar with an optical bar for the same purpose, photographs the potical bars projected on the road surface. In the course of the development of this application of optical bars, through various experiments a new 'hairline projector' has been successfully developed. (Figure 4) The specifications of this hairline projector are as follows.

(a) Lighting : Stroboscopic flash

(b) Electric discharge capacity : 350 Joule/sec.

(c) Flash time : 0.1 - 0.2μ sec.

(d) Repeat capacity : 2 Hz (2 times/sec.)

(e) Projection lens : f = 9.8mm F = 1.8

2-2 Geometric Relations between the Projection Angle of an Optical Bar and the Camera

In principle, a projection angle of the optical bar relative to the road surface can be chosen arbitrarily. Considering the structure of the vehicle so as to make it easy to mount the projector, we set the projector angle at 26°33' and the camera in a position perpendicular to the road surface. Their geometric relations are as shown in Figure 5.

In Figure 5, the rut depth, RD, can be obtained as follows.

$$RD = \frac{H}{f} \frac{d_1 + d_2}{\cot\theta} \qquad \ldots\ldots\ (3)$$

where

RD : Rut depth

H : Camera height

f : Focal length

d_1, d_2 : Rut depth as observed in photo

θ : Projection angle of optical bar (hairline projector)

Now if the rut depth as observed in the photograph is defined as rd, it is given as $rd = d_1 + d_2$

Then Formula (3) can be expressed as follows.

$$RD = \frac{H}{f} \frac{rd}{\cot\theta} \qquad \text{....... (4)}$$

where the projection angle of optical bar is given as $\theta = 26°33'$ for our system and, therefore,

$$\cot\theta \fallingdotseq 2 \qquad \text{....... (5)}$$

Formula (4) now can be expressed as follows.

$$RD = \frac{H}{f} \times \frac{rd}{2} \qquad \text{....... (6)}$$

In Formula (6) above, the rut depth, RD, is given in terms of rd, i.e., the rut depth as observed in the photo. The rd, in turn, is given in terms of a variance relative to the base line. Therefore, it becomes necessary to provide two control points to be indicated in the photo. Actually, these two control points are provided by the cross points of the lane mark and the optical bar. (Figure 1)

2-3 Structure and Performance of RDP-75

The RDP-75 system is designed primarily for night-time operation. It consists of a 35mm pulse camera (f=15mm), a hairline projector, a power source and a remote control device mounted on a medium size bus.

Based on the results of experiments to determine the optimum geometric relations between the camera and the hairline projector, the hairline projector is installed over the bumper of the vehicle at an angle of 26°33' to the road surface and the camera is mounted at a height of 3 meters from the ground perpendicularly facing the road surface. Figure 6 shows the geometric relations between these two components of the system. As a result, the designed photographing scale is

$$\frac{f}{H} = \frac{15}{3000} = \frac{1}{200}$$

The major performance feature of RDP-75 is the automatic photographing at regular intervals by synchronizing the camera shutter and the flashing of the hairline projector with the traveling speed of the vehicle. Specifically, the camera shutter and the strobe flashing are synchronized to traveled distances as monitored by a trip meter from rotation of the wheels and then relayed by the pulse transmitter. Figure 7 is the system diagram showing this mechanism of

RDP-75. Figure 8 is a photo showing RDP-75 as installed on the vehicle. Figure 9 is a photo taken by RDP-75.

Other performance features of RDP-75:

(a) It is capable of photographing at speeds ranging from 0 km/h to 80 km/h.

(b) The camera is equipped with a data box in which records of photographed locations, distances, etc. are stored.

(c) The film magazine has a loading capacity of 400 feet of film so that in the case of photographing at a regular interval of 20 m, for example, approximately 100 km can be covered by one magazine load of film.

(d) Since the system utilizes optical bars, the photographing work is limited to night-time.

(e) The system is operated usually by a crew of two to three persons (including one driver) and 100 km to 200 km of road surfaces can be covered in one night.

2-4 Development of Method for Photographic Measuring of Rut Depths

The following two systematized methods have been developed for photographic measuring of rut depths by applying photogrammetric techniques.

(a) Method using a stecometer and a computer.

(b) Method that takes measurements from the photos enlarged 10 to 20 times.

In the former method, by determining the coordinates of continually photographed optical bars and feeding them into a computer, variances (d_1 and d_2 in Formula (3)) relative to the base line are obtained. Figure 10 shows an example of the output.

The latter method obtains the variances (rd in Formula (6)) relative to the base line from the projected images of ruts in the enlarged (10 to 20 times) photo. Figure 11 shows the measuring instruments. The latter method is more efficient but less accurate than the former method.

2-5 Review of Measuring Accuracies

Generally, accuracies of measuring instruments or measuring methods are evaluated in terms of variances relative to the true values but here the accuracies are discussed as compared with the directly measured values (referred to as 'the direct measurement values' hereafter).

(a) Theoretical errors

The rut depths applied in our methods are given by Formula (4). If the errors of the height of a camera (H), the rut depth as observed in the photo (rd) and the projection angle of an optical bar (θ) are expressed as ΔH, Δrd and $\Delta\theta$ respectively, the orror of the rut depth, ΔRD, is given as follows.

$$\Delta RD = \frac{H + \Delta H}{f} \cdot \frac{rd + \Delta rd}{\cot(\theta+\Delta\theta)} - \frac{H}{f} \cdot \frac{rd}{\cot\theta} \quad \cdots (7)$$

When the standard deviations of ΔH, Δrd and $\Delta\theta$ are assumed for experimental purposes as 24mm ($\sigma\Delta H$), 0.0093mm ($\sigma\Delta rd$) and 5' ($\sigma\Delta\theta$) respectively, ΔRD values can be computed for each of three different RD's of 5mm, 10mm and 20mm with the results as shown in Table 1 below.

Table 1 Theoretical Errors of RD

RD / Standard deviations of errors (σ)	5mm	10mm	20mm
$\sigma\Delta H$, $\sigma\Delta rd$, $\sigma\Delta\theta$	-0.93~1.01mm	-1.05~1.07mm	-1.17~1.19mm
$2\sigma\Delta H$, $2\sigma\Delta rd$, $\sigma\Delta\theta$	-1.95~2.04	2.07~2.15	2.31~2.38
$3\sigma\Delta H$, $3\sigma\Delta rd$, $\sigma\Delta\theta$	-2.90~3.09	3.07~3.26	3.43~3.60

In Table 1, since ΔH, Δrd and $\Delta\theta$ are computed up to 3σ, it can be reasonably assumed that the resulting values indicate the limit of theoretical errors of RD.

(b) Comparison with Direct Measurement Values

Table 2 shows the photographic measurement values compared with direct measurement values.

Table 2 Comparison with Direct Measurement Values

Measuring location	Photo-graphing method	Number of samples	$\overline{RD}$		$\overline{\Delta RD}$
			Photographic measurement	Direct measurement	
A	Stationary Moving	30 30	4.43mm 4.69	3.49mm	0.94mm 1.20
B	Moving	26	14.37	13.31	1.06
C	Moving	16	20.94	20.25	0.69

In this particular case, the average error relative to the direct measurement values is approximately 1mm. From these results, however, the average errors are known only from a limited number of samples. Therefore, the differences (ΔRD) from the direct measurement values of all samples (N=120) are plotted against the theoretical errors to obtain Figure 12.

As can be seen from Figure 12, the theoretical errors nicely match the errors relative to the direct measurement values. While there is a tendency for the errors to increase as the absolute values of rut depths increase, the errors are generally 2 to 3mm. Therefore, the overall accuracy of our systems can be reasonably assumed as 2 to 3mm. Considering that rut depths as obtained by Formula (1) usually occur on the order of centimeters, this accuracy should be sufficient enough.

3. Development of Method for Photographic Measuring of Cracks

The direct method for measuring cracks relies on sketches drawn by surveyors or photographs taken with a hand camera for determination of lengths and areas of cracks. Therefore, the results tend to vary from one surveyor to another and thus are poor in reliability. Furthermore, there are problems involved in efficiency and safety.

To compensate for these shortcomings of the direct method, we have developed a system (called ROADRECON-70) which accurately photographs the road surface conditions as well as a method to measure cracks from the photos thus taken.

3-1 Structure and Performance of ROADRECON-70

ROADRECON-70 is designed to be operated during night-time. The system consists of a 35mm slit camera (f=14.5mm), lighting equipment, a power source and a remote control devise, installed on a medium size bus.

The camera is installed at a height of 3 meters perpendicularly facing the road surface. The lighting equipment is mounted in a position in geometric relation to the camera as shown in Figure 13. The photographing scale, therefore, is $\frac{f}{H} = \frac{14.5}{2900} = \frac{1}{200}$.

The major performance feature of ROADRECON-70 is its capability to take continuous photos with a constant exposure by synchronizing the film speed and the light intensity (i.e., camera iris) to traveling speeds of the vehicle. Namely, the film speed and the light intensity (camera irises) are synchronized by means of pulse signals generated by the rotation of the wheels. The error in synchronization of film speed has been found to be less than 1%. (Figure 14)

Figure 15 is the system diagram of ROADRECON-70 showing this mechanism. Figure 16 is a photo showing ROADRECON-70 in operation. Figures 17 is a part of the continuous photos taken by ROADRECON-70.

Other performance features of ROADRECON-70:

(a) It is capable of photographing at speeds ranging from 10 km/h to 60 km/h.

(b) Distance counters appear in the photo on the space outside the perforations every 100 meters.

(c) The film magazine has a loading capacity of 1,000 feet of film so that approximately 60 km of road surface can be continuously photographed with one magazine load of film.

(d) Photographing can be performed either during the daytime or during the night. Night-time is preferable, however, to take photos with a more consistent exposure.

(e) The system is operated usually by a crew of two to three persons (including one driver) and approximately

100 km of road surface can be photographied in one night.

3-2 Method for Photographic Measuring of Cracking Ratio

The computation of the cracking ratio with Formula (2) requires measurements of lengths and areas of cracks in the road surface. With respect to linear cracks, their lengths can be easily measured from the photos. But for mesh-like cracks, the sizes of their areas have to be measured, which depend on the manner of how the areas are determined.

To meet this requirement, we have developed a method based on grid cells for measuring sizes of cracked areas.

Figure 18 shows one example of crackes area calculation by this method using grid cells with a cell size of 0.5m x 0.5m.

Figure 19 is a photo of film analyzers for cracked area calculation with increased reliability. Grid cells of a desired cell size can be mounted over the screen of the analyzer. This film analyzer is capable of projecting a photo at a magnification of up to 10 times.

Cracked areas are calculated from the photo in terms of the numbers of grid cells representing such areas and the results are fed into a computer to compute the cracking ratio. This method thus enables the processing of large quantities of data with higher reliability.

3-3 Accuracy of Measurements

The following are factors that affect the accuracies of photographic measurements of cracks.

(a) Factors due to the resolution of the photography.

(b) Errors in synchronization of film speeds and variations in scale due to vibrations of the camera.

(c) Differences in measurements due to individual performances of surveyors.

These factors can be defined as follows in quantitative terms based on experimental values.

(a) Limit of photographic resolution : 2 mm

(b) Areal error resulting from variation in scale: Approx. 2% (0.2% in case the cracking ratio is 10%).

(c) Measuring errors due to individual performances of surveyors : 0.149% in cracking ratio. (Figure 20)

In order to determine the extent that these errors affect the final results of cracking ratios, cracking ratios are obtained from carefully prepared sketches and photos taken by ROADRECON-70 as shown in Table 3.

From the above, it has been found that:

(a) Photographic measurement identifies cracks of 1mm in width, which exceeds the resolution limit of 2mm. (With the lighting angle of ROADRECON-70 being 15° - 25°, the photographed images of cracks could be 2 - 3mm in the photo depending on the shade.)

(b) In the direct method, sketches are not complete no matter how carefully they are drawn.

(c) Considering the accuracy of the grid cell method, errors due to variations in scale are negligible.

Table 3 Cracking Ratios Obtained from Photos and Sketches

Locations	Photographic Measurements	Measurements from Sketches
P-14-12.3m	27.3%	32.3%
P-18-11.7	18.8	18.8
P-28-11.5	24.7	23.3
P-35-30.0	45.5	42.2
P-38- 2.5	9.7	7.8

P-No. denotes Pier Number.

From the above results, it can be said that the grid cell method based on photos is superior to the direct method in reliability. (Figure 20)

4. Efficiency and Cost

Tables 4 and 5 show the comparisons of efficiency and costs between the direct method and our method based on values obtained by experience.

Table 4 Rut Measurement

	Photographic Method	Direct Method	Photographic Method compared with Direct Method
Efficiency	100-200 km/day	2 km/day	Approx. 50 to 100 times
Cost	15,000 yen/km	80,000 yen/km	Approx. 1/5
Crew	2-3 persons	4-5 persons	Approx. 1/2

Remarks
Ar 20 m intervals Covering the process up to output Field work

Table 5 Crack Measurement

	Photographic Method	Direct Method	Photographic Method compared with Direct Method
Efficiency	100 km/day	2 km/day	Approx. 50 times
Cost	20,000 yen/km	40,000 yen/km	Approx. 1/2
Crew	2-3 persons	2-3 persons	Same

Remarks
Continuous photographing Covering the process up to output Field Work

The comparisons as shown in the above tables indicate that our method is 50 to 100 times more efficient and 1/2 to 1/5 less costly than the direct method.

5. Conclusion

The systems and methods described in this paper have been developed with a view to providing road administrators with useful data and information on the existing conditions of pavement surfaces. The most significant accomplishment of these developments is the successful application of photogrammetric techniques to road surveying for accurate, efficient and low cost measuring of ruts and cracks.
It is expected that they will have wide use as a road surveying system to assist road administrators in maintenance management of pavements.

6. Acknowledgment

I appreciate the assistance and encouragement provided by officials of the Ministry of Construction and the Japan Highway Public Corporation in the course of this research and development for the practical application of our systems.
I wish to thank Prof. Taichi Oshima of Hosei University for his helpful consultation and guidance in preparing this paper.

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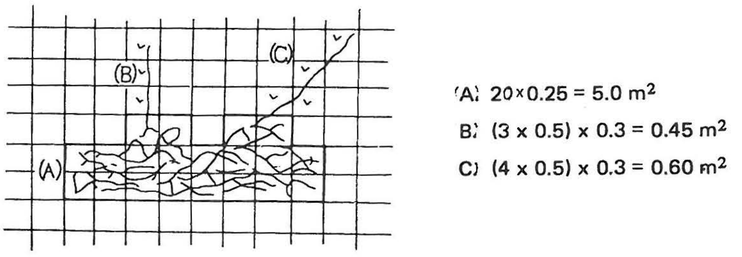


Figure 18 Example of crack area calculation by grid cell method

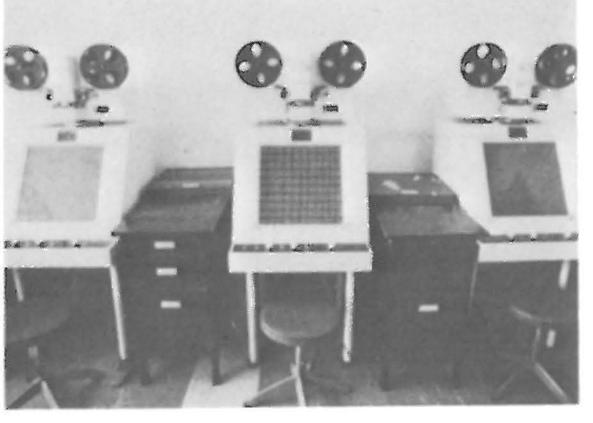


Figure 19 Film analyzers

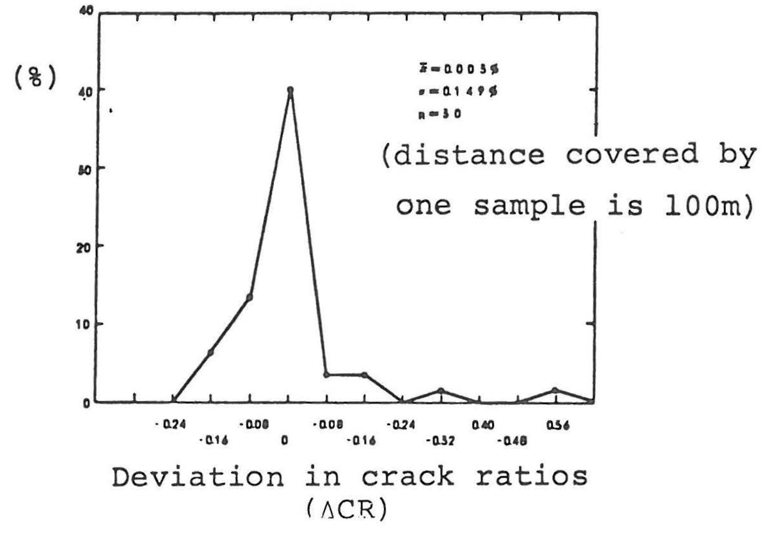
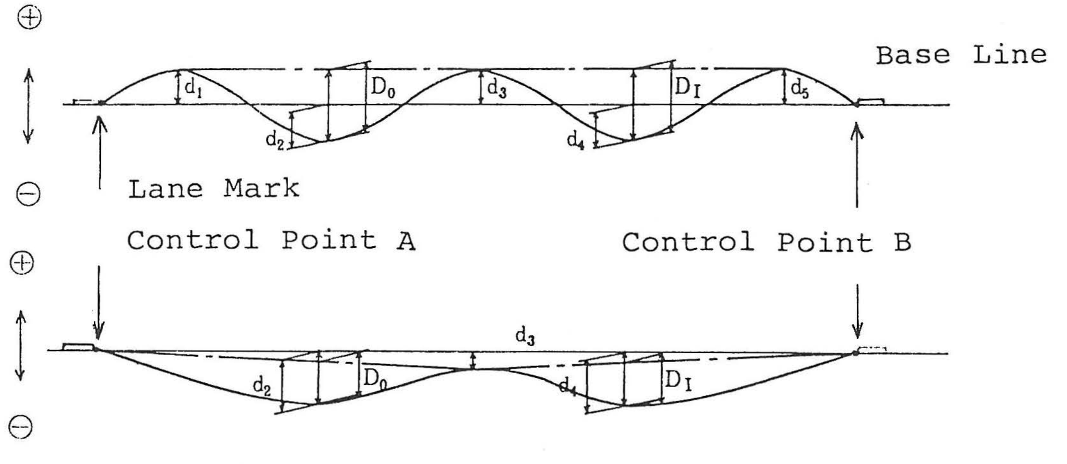


Figure 20 Errors of cracking ratios by grid cell method



$$D_0 = \frac{d_1 + d_3}{2} - d_2 \qquad D_1 = \frac{d_3 + d_5}{2} - d_4$$

Figure 1 Definition of Rut Depth

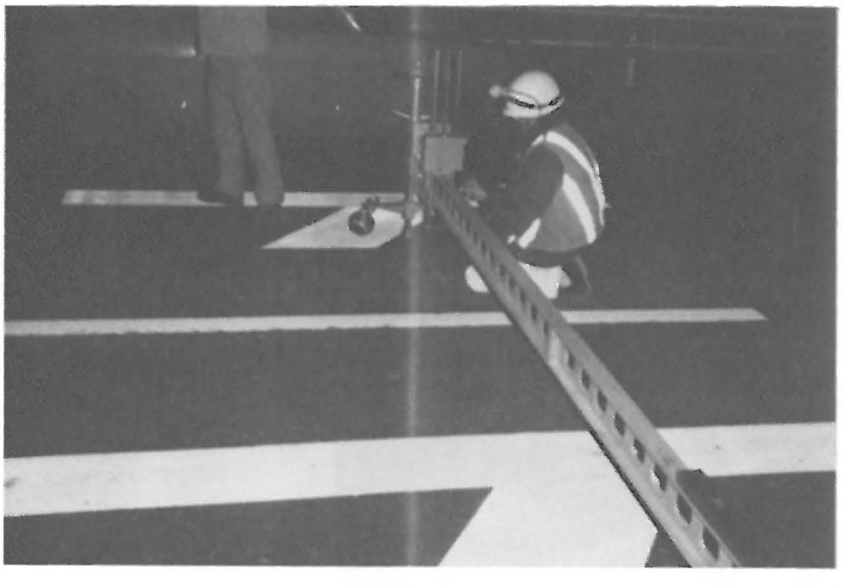


Figure 2 Surveying using a profilemeter

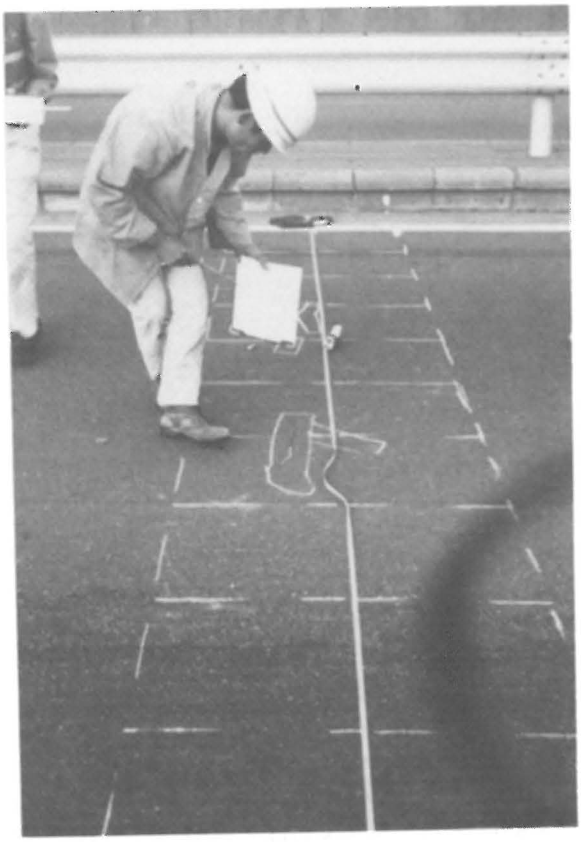
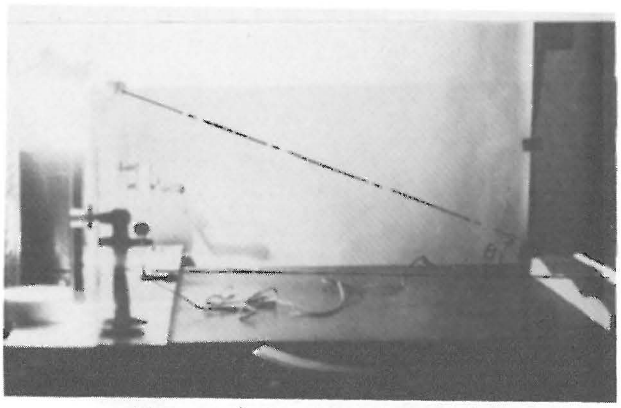
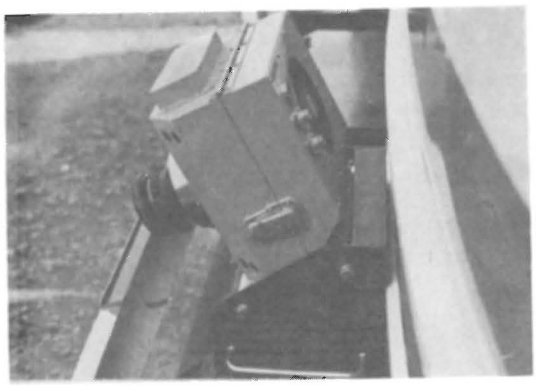


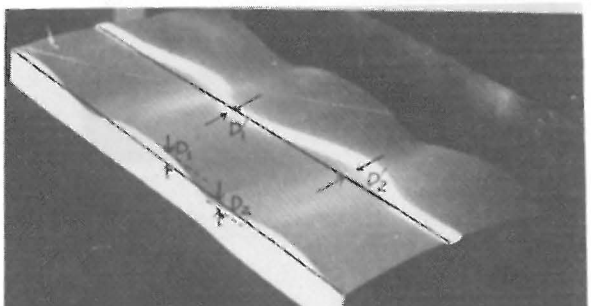
Figure 3 Sketching of cracks at site



a. Experiment on projection of optical bars (θ = 26°33')

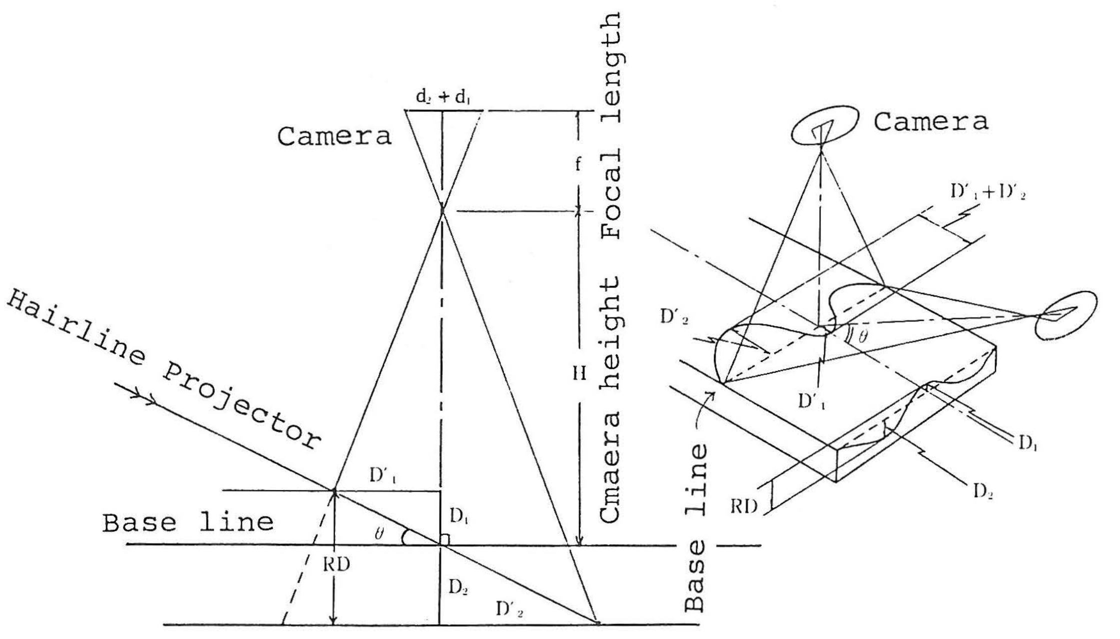


c. Hairline Projector



b. Optical bar projected on a model road surface

Figure 4 Experimental photographing of optical bars and Hairline Projector



RD : Rut depth

$d_1 + d_2$: Rut depth as observed in photo (rd)

θ : Projection angle of hairline projector

Figure 5 Geometric relations between Optical Bar and Camera

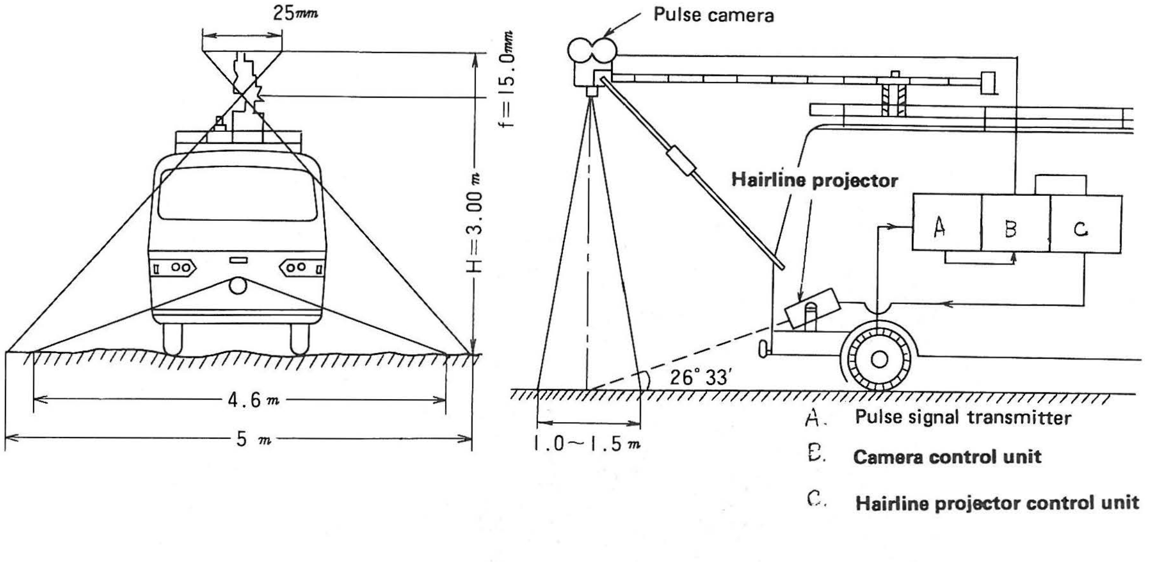


Figure 6 The systems as mounted in vehicle

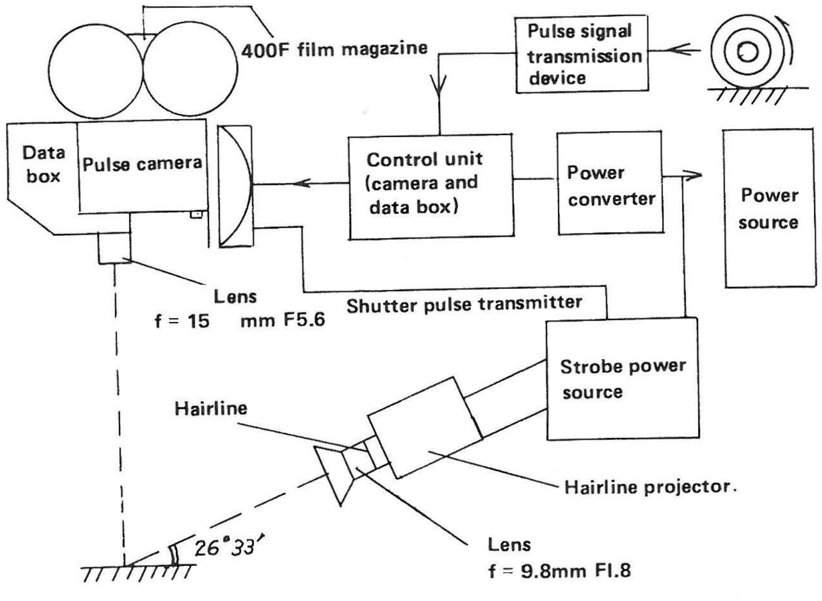


Figure 7 System Diagram of RDP-75

Figure 8 RDP-75

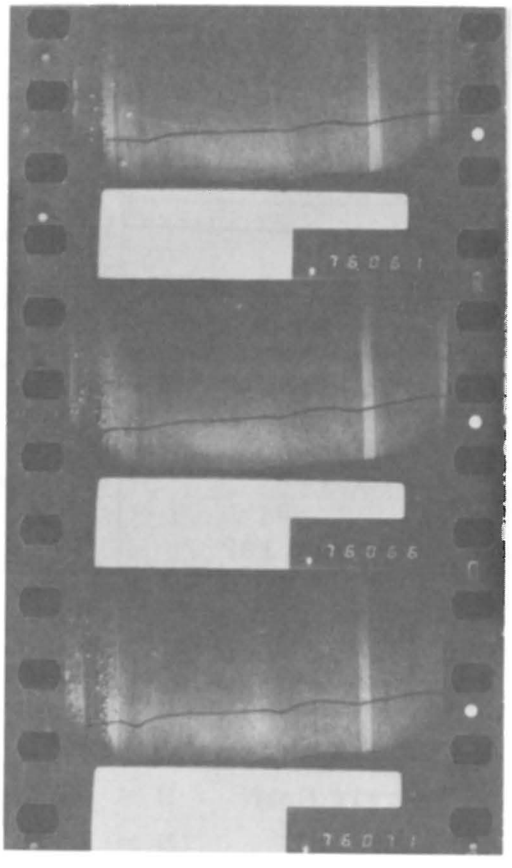
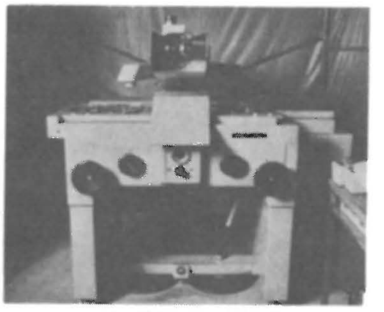
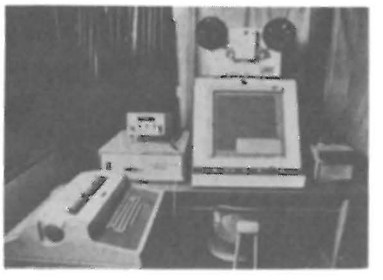


Figure 9 Rutting photographed by RDP-75 (Optical bar appears in black.)



a. Stecometer



b. Film analyzer

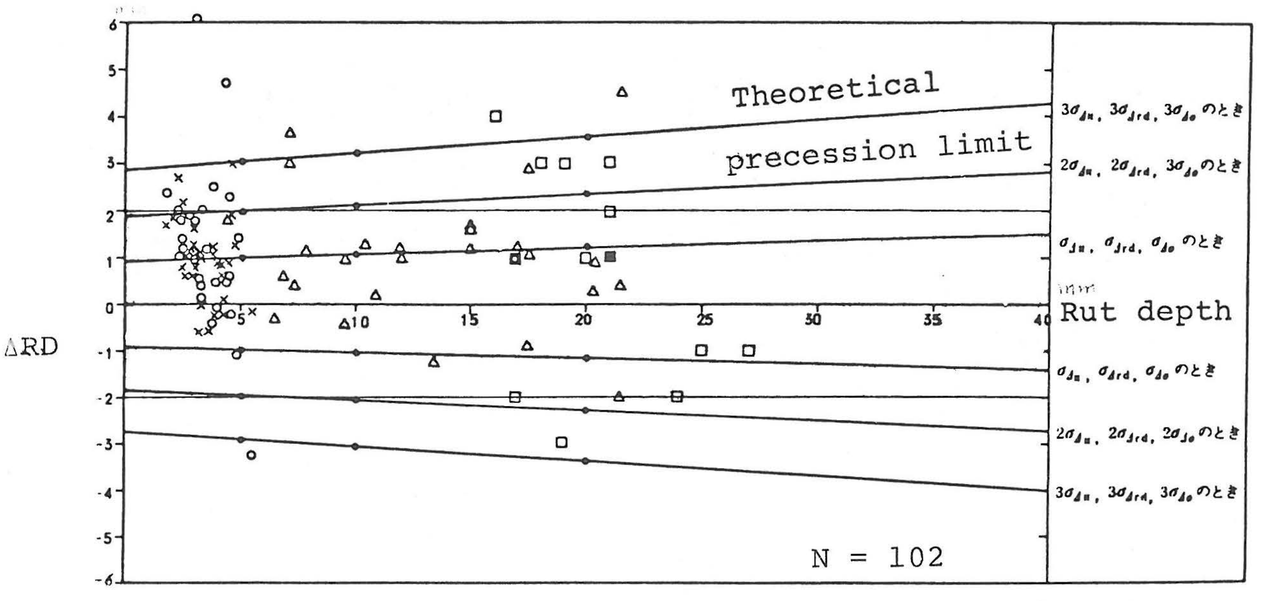
Figure 11 Rut depth measuring instruments

WADACHI BORE KEISANSHO

A-LINE (SOKOU) JIMUSHO MEI ... YOKOHAMA

K-POST		D1	D2	D3	D4	D5	DO	DI	DM	RANK
5+0		1	-10	2	-6	0	11	7	11	C***
5+1		0	-7	1	-6	0	8	7	8	B**
5+2		0	-15	-1	-8	0	14	8	14	C***
5+3		1	-11	2	-8	0	12	9	12	C***
5+4	B	0	-13	-2	-7	0	12	6	12	C***
5+5	B	0	-5	0	-2	0	5	2	5	A*
5+6	B	0	-6	0	-8	1	6	7	7	B**
5+7	B	0	-9	0	-5	0	9	5	9	B**
5+8		0	-12	2	-8	0	13	9	13	C***
5+9		0	-9	1	-7	0	9	7	9	B**

Figure 10 Example of rut depth data output



X	Measuring location A	(Stationary)	N = 30
o	Measuring location A	(Moving)	N = 30
Δ	Measuring location B	(Moving)	N = 26
	Measuring location C	(Moving)	N = 26

Figure 12 Comparisons between theoretical errors and direct measurement values

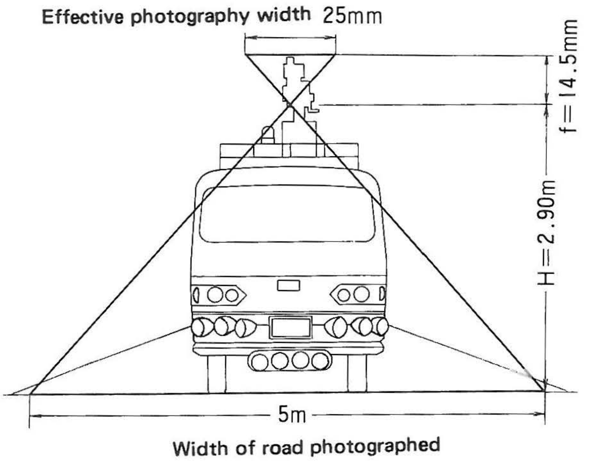


Figure 13 Camera and lighting equipment mounted on vehicle

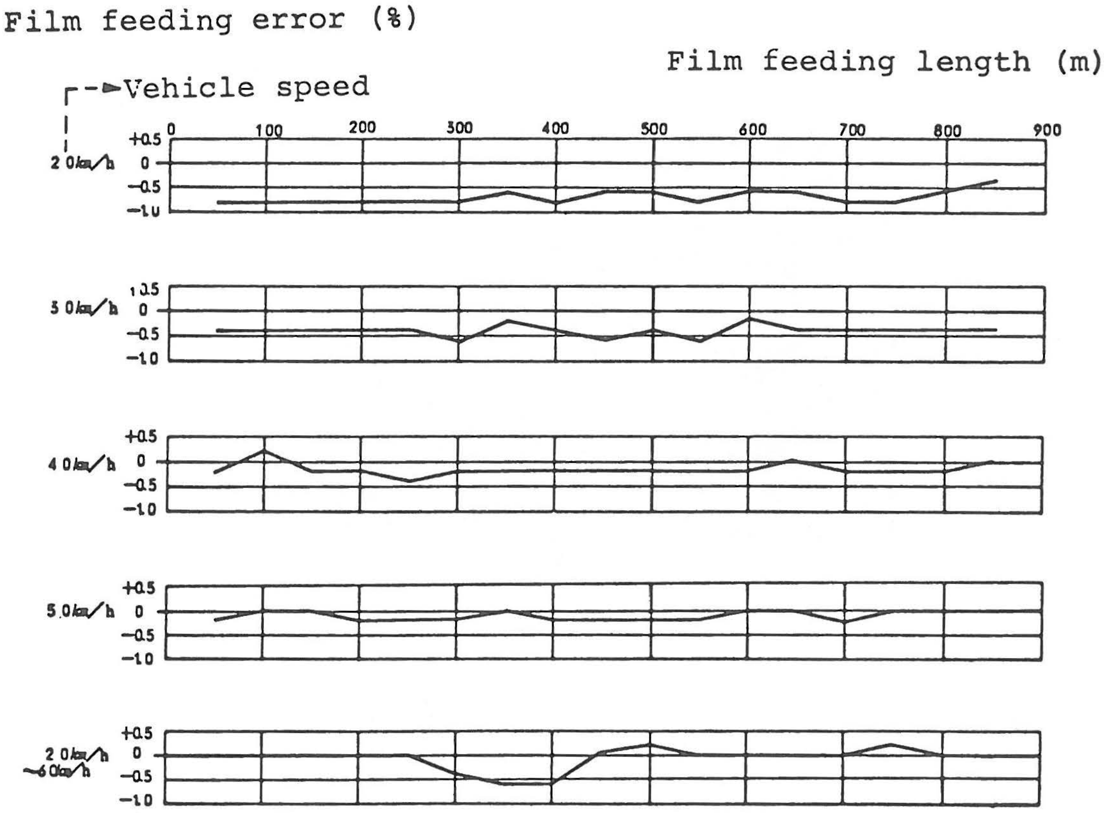


Figure 14 Film feeding errors of ROADRECON-70

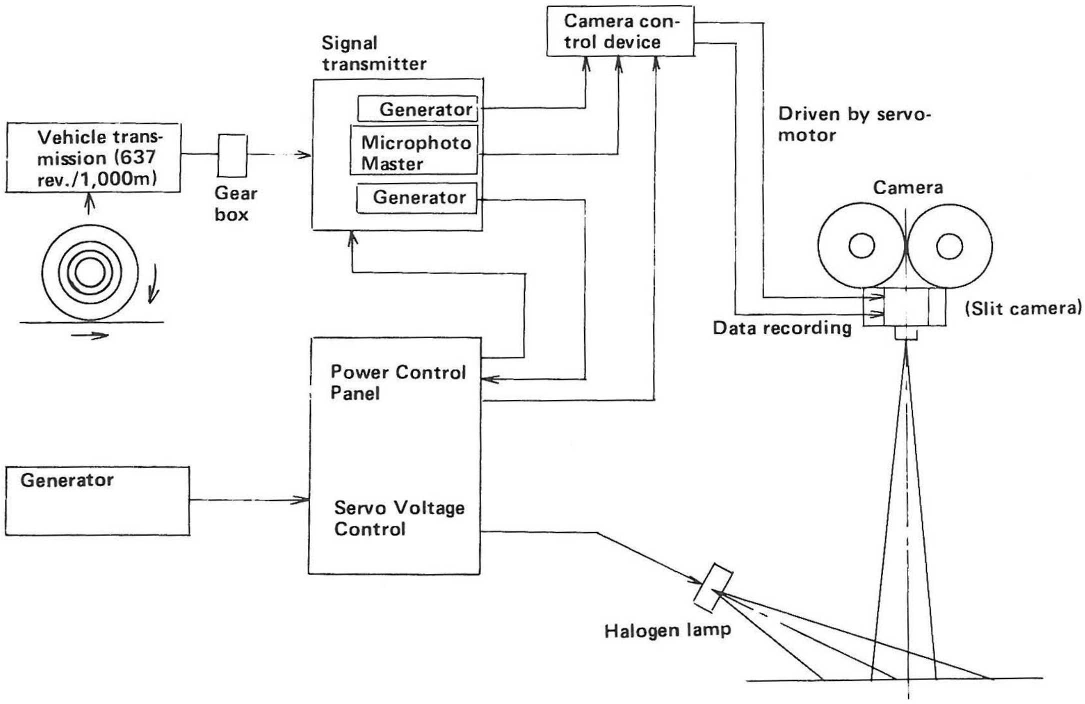


Figure 15 System Diagram of ROADRECON-70

Figure 16 ROADRECON-70 in operation

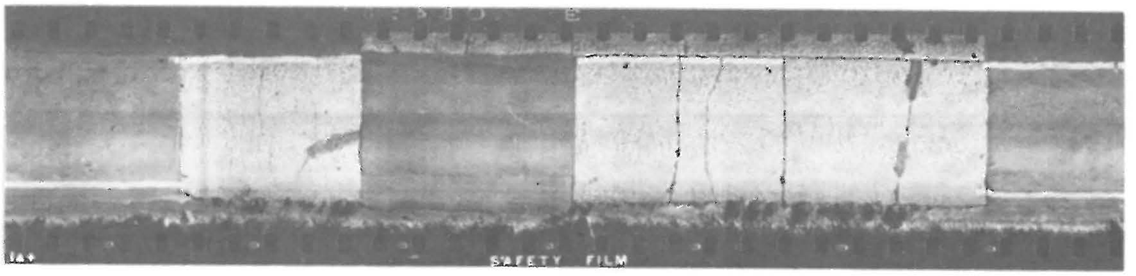


Figure 17 Continuous photograph of road surface taken by ROADRECON-70