STUDY REPORT
ON
THE IMPROVEMENT
OF
THE STATE RAILWAY OF THAILAND
TRACK MAINTENANCE SYSTEM

NOVEMBER 1980

THE INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the Government of Kingdom of Thailand, the Government of Japan decided to take up a study on the rapid rail wear and frequent derailments. The Japan International Cooperation Agency (JICA) conducted the study by dispatching one short-term expert, Mr. Yasuo Sato of the Japan National Railways, to Thailand from October 2 to December 1, 1979.

The expert conducted a survey on wearing conditions of rails and the property of railcars in collaboration with the staff of the Royal State Railways of Thailand (RSR). After further studies conducted in Japan, the expert has compiled the present report on the improvement of RSR track maintenance system.

I sincerely hope that this report will contribute to the modernization of railway transportation in Thailand and to the enhancement of friendly relations between Japan and Thailand.

I would like to take this opportunity to express my deep appreciation to the authorities and people concerned in Thailand for their close cooperation extended to the expert.

November 1980

Keisuke Arita
President
Japan International Cooperation Agency

SUMMARY

1. Since 1975 when ALSTHOM locomotives were introduced, the State Railway of Thailand (hereinafter referred to as RSR) has sent up the rail replacement ratio at the sharp curves of the North Main Line running in the mountainous terrains because of serious wear of rails.

2. The rails were sampled from these sections, and their properties were examined only to find no abnormalities. It is evident that the serious wear is due to interaction between the wheels and rails.

3. A material having a fine pearlite structure is recommendable for rails because it is resistant to abrasion. Alloy rails coming under this kind have already been installed with success. However, there is a specially heat-treated rail which is advantageous over the alloy rails from the economic viewpoint and which the RSR is recommended to install for trial.

4. Our investigations suggest the following for the purpose of retarding the rail wear.

   (1) The RSR has not established standard train operation diagram, and the trains have been run at various speeds so far as the maximum allowable speed and the running time permit. We saw some trains running squeaking in serious cant deficiencies. Thus, it is recommended to study out a standard operating diagram in which like trains can run with no substantial difference in running speeds.

   (2) On presupposition that the trains are operated in an orderly way according to the standard operating diagram, the following formula should be applied to the calculation of the cant.

   $$e = 8.338Vo^2/R$$
   $$Vo = \sqrt{\Sigma Vi^2 / N}$$

   (3) It will take you much time to study out a standard operating diagram.

   For the purpose of checking the wear of the high rails due to shortage of cant, the cant as calculated from the following formula should preferably be applied to the sharp curves in the mountainous site.

   $$e = 2/3 \{8.338 (V + 10)^2/R\}$$

   But the formula above is likely to increase the cant excessively with increase in the train speed, and its application should be limited to the sections where the maximum speed is 45 km/h.

   (4) The maximum cant must be determined in consideration of the wind load which acts to turn over the cars. It is found that lightweight cars are liable to be capsized when subjected to the maximum wind velocity on record by the Thai Meteorological Agency.

For the purpose of preventing the turnover of the cars, it is recommended to install an anemometer on every gale-prone bridge and to establish a system in which the train is stopped whenever the wind velocity exceeds 30 m/sec.

It will take much time to complete this system, and it cannot be helped for some time now that the maximum cant is increased up to about 95 mm in order to reduce the rail wear.

5. A proper gage clearance can be determined according to Porter's method in which the relationship between the lateral pressure on the locomotive and the gage clearance is established. In order to apply this method, it is necessary to know the modulus of elasticity of the side bearer of ALSTHOM locomotive. In a test conducted by the RSR, the modulus could not be determined with an enough accuracy. Thus, the calculation according to Porter's method is put over until the accurate value of the modulus is available from the manufacturer.

6. The results of the investigation of the wheel wear suggest taking the following maintenance services for the cars.

   (1) The wheels should be dressed in good time before they assume a serious state of wear as shown in Fig. 4.5.4 or Fig. 4.5.6.

   (2) The truck should be aligned and corrected so that a pair of wheels on the axle will not show a large difference in wear.

   Judging from the typical patterns of wheel wear, the rail which has a large radius of curvature in the head as in the UIC type or Japan's N type will be less subject to wear.

7. Some sections disclosed partial side wear.

   It is inferred that the track may have been misaligned to have a locally reduced radius of curvature. In order to obviate the partial side wear, it is necessary to correct the alignment of curved sections. To this end, there should be provided a curve lining calculator.

   Of late, there is available a handy microcomputer-aided calculator on the market.

8. The lateral pressure of ALSTHOM locomotive as calculated from the measurement of lateral displacement of the track is found 1.5 times as much as that of GE locomotive. This large lateral pressure will be the major causes of serious rail wear, and is considered to be attributable to the design of the side bearer incorporated in the ALSTHOM locomotive.

   Thus, it is recommended to improve the side bearer of ALSTHOM locomotive.

9. In order to reduce the wearing rate of the rail, it is necessary to grease the rail.

What is important in this case is that the greasing must be carried out effectively and economically while reducing the slippage. It is therefore desirable to provide a flange greaser to the car.

10. The derailment cases were investigated, and the following are our recommendations.

(1) The derailments due to the negligence of the workers are predominant, and the following measures should be taken.

1) Education and training of the workers to strictly observe the regulations.

2) To study out a train operation diagram, and to educate and train the driver to follow the diagram for the purpose of running the trains on schedule.

3) The regulations concerning the track blocking work and motor trolley use should be established and observed strictly in keeping with the upgraded punctuality of train operation.

4) The duties and responsibilities for the operation of signals and the switches should be made clear for the purpose of putting the operation of signals and switches under tight control.

5) A proper qualification system should be established in order to screen train drivers, signal operators, switch operators, motor trolley drivers and field work supervisors, etc.

(2) For the purpose of preventing the derailment accidents defective cars or defective tracks, the following measures should be taken.

1) To study and practice the standards for replacement of track material and car parts.

2) The civil engineers and mechanical engineers should cooperate to measure the lateral pressure on the car and derailment coefficient aboard the train and to study and practice the lateral pressure reduction measures and derailment preventive measures.

11. Recent cases of derailment were investigated, and it was found that the train often derailed when the ALSTHOM locomotive restarted after a pause on the transition curve. Namely, it is inferred that the outside wheel on the leading axle experiences a large turning lateral force, especially ALSTHOM loco., when its load becomes small. Thus, the following measures are recommended.

(1) Avoid stopping and starting the train within the transition curve or curved sections if at all possible. If such start-up and stop is unavoidable, the starting shock should be minimized.

(2) Realign the transition curves and curved sections and minimize the level errors.

(3) Replace defective rails and sleepers in the transition curves and curved sections and secure the rail fastenings tight.

(4) Study the introduction of heavy track repairing machines and track measuring cars and promote it for the purpose of tooling up and rationalizing the realignment work of curves and transition curves.

12. The current system of accident reporting needs some improvement from the viewpoint of accident analysis and its feedback to the formulation of preventive measures.

It is therefore recommended to establish a format covering the entries specified in Table 6.3.2.

13. The track improvement programs to be undertaken by the RSR are enumerated in Chapter 7, and should be put to in-depth study and implemented under the guidance of experts.

STUDY REPORT ON THE IMPROVEMENT OF STATE RAILWAY OF THAILAND TRACK MAINTENANCE SYSTEM

1. Introduction

The States Railway of Thailand (RSR) is operating the lines having an aggregate length of 4,452 km.

These lines are mainly composed of the rails weighing 50 lbs., 60 lbs., 70 lbs., and 80 lbs.

Before WW II, the 50 lbs. rails were used. But after WW II, they have been gradually replaced by 60 lbs., 70 lbs. and 80 lbs. rails for the purpose of increasing the transport capacity and bearing up against increased axle load.

As the replacement work has been going on briskly under post-war rehabilitation plant and modernization plant, the 50 lbs. rails have already been cleared away from the main lines.

Flash butt welders have been introduced in keeping with the progress of the use of heavier rails, and more than 60% of the aggregate length of the lines has come to be accounted for by welded rails. There are installed many long rails which measure more than 1 km in length.

The long rails are not used for the bridges with a span of more than 20 m and along the sections whose radius of curvature is less than 800 m. Since the more than 87% of the lines are straight as shown on Table 1.1, the ratio of long rails will increase further for the economy of rolling stock maintenance cost and for the improvement of riding comfort.

Table 1.1 Ratio of Track Length by Radius of Curvature

Radius of curvature	Ratio of track length (%)
Straight	87.25
1,000 m and up	5.47
1,000 to 500 m	3.98
500 to 300 m	1.77
300 to 180 m	1.53
up to 180 m	0

The sharp curve sections account for a small fraction of the lines, but are localized in the mountainous regions. They are also steep sections, and constitute a deterrence from increasing the transport capacity or speed. It is most effective for the betterment of transportation in the mountainous regions to improve the profile and alignment of the track. But this calls for vast sums of money. If the transport capacity and speed can be increased with the existing lines intact, the investment costs will be reduced, but the following problems must be solved.

(1) Use of cars capable of running on steep slopes and sharp curve sections.

(2) Reinforcement of track in sharp curve sections.

(3) Protection of rails in the sharp curve sections from wear.

Namely, the protection of rail wear in the sharp curve sections is one of the most crucial problems to be solved for the purpose of transport improvement in the mountainous regions in Thailand.

For the purpose of replacing overage steam locos, the RSR has introduced ALSTHOM locos from France since 1975, but the rails in the sharp curve sections in the mountainous regions have had to be replaced at a prohibitively high rate because of accelerated rail wear.

As the cars and tracks have grown old, the derailment cases have come to be reported at a higher frequency. Some derailment accidents reported were due to ALSTHOM locomotives.

The protection of rail wear and prevention of derailment are vital to the growth of the RSR and of the economy of Thailand, and have been investigated and studied, accordingly. In the past, the rail wear problems were surveyed. As regards the most serious sections, the ESCAP experts undertook a survey and submitted recommendations to the RSR.

According to the ESCAP survey, it was pointed out that the anomalous rail wear came primarily from the method of operating the trains over the steep sections and from the way to apply braking forces. Certainly, the method of train operation over steep sections can be a cause of rail wear, but the rail wear is governed essentially by the following factors.

(1) Development of large lateral force.

(2) Friction between the rail and wheel flange.

(3) Rail material and heat treatment.

In view of these basic matters, we have conducted a comprehensive survey covering the structures of cars and track.

2. State of Use of Rails in the RSR

2.1 Classification of Rails by Lines and Their Replacement

As we have discussed in the introductory section, the RSR employs 50 lbs., 60 lbs., 70 lbs. and 80 lbs. rails. Their lengths by lines are as shown in Table 2.1.1. The three arterial lines -- the South Line, the Northeast Line and the North Line -- use 70 lbs. and 80 lbs. rails which were laid according to post-war rehabilitation plan and modernization plan.

Table 2.1.1 Aggregate Length by Type of Rail (km)

Line	Aggregate length (km)	Aggregate length by type of rail (km)			
		50 lbs.	60 lbs.	70 lbs.	Heavier than 70 lbs.
North	879	36	--	839	4
East	271	102	100	69	--
Northeast	1,102	7	--	993	102
South	1,573	94	118	703	658
Mae Klong	65	34	31	--	--
Total	3,890	273	249	2,604	764

As shown in Table 2.1.2, the replacement volume of these rails has increased since 1975.

The replacement has been due primarily to the side wear of high rails in the sharp curve sections in the mountainous regions.

The RSR has so far tried various measures including the use of spares and transposition of inside and outside rails only to find their efforts far short of the replacement needs.

Table 2.1.2

FY	Rail replacement volume (m)				
	North Line	East Line	Northeast Line	South Line	Total
1975	930	--	--	6,177	7,107
1976	6,899	--	795	1,220	8,915
1977	14,037	--	3,631	2,273	19,941
1978	24,172	--	6,182	4,813	35,167
1979	12,845	--	940	5,811	19,596
Total	58,883	--	11,548	20,295	90,726

The transposition of inside and outside rails is effective in extending rail life though it is a temporary measure. What should be considered in transposition is the deviation of joint positions; in the case of parallel joints, the rails must be cut in order to correct the jointing positions. The rails may be modified into the staggered joint type, but this is accompanied by the following problems.

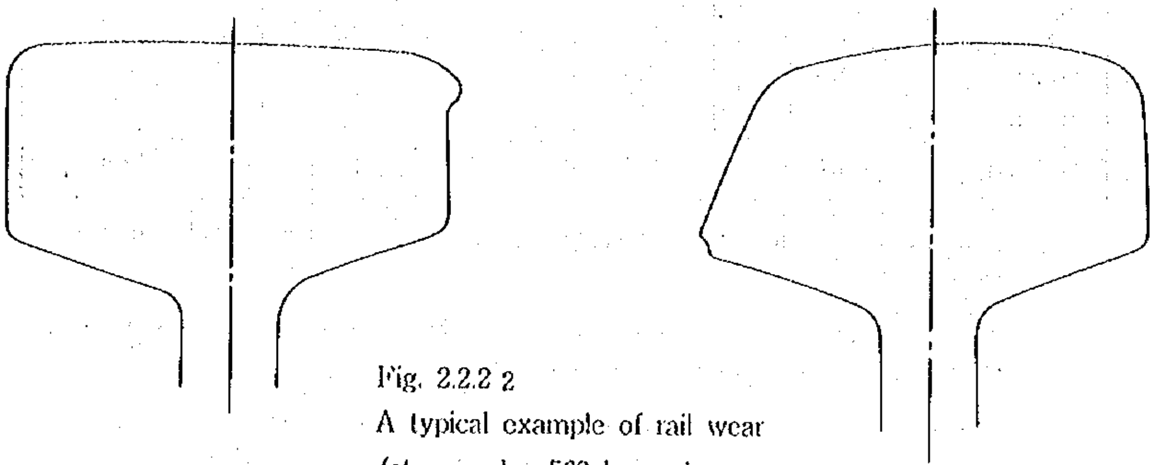

Fig. 2.2.2 2
A typical example of rail wear (at around a 569 km point on the North Main Line)

(1) High liability to cause the trains to roll.

(2) Potential hazards that the depression at joint could cause irregularity in cross level.

(3) Increase in the number of those sleepers at joints which defy tamping.

Thus, our experience dictates that the parallel joint system should be maintained.

2.2 Analysis of Rail Wear

The survey this time focused on the rail wear in the mountainous sections of the North Line and Northeast Line.

The RSR, to their credit, has employed a highly effective, advanced method in which the rail wear along the curved sections is measured once a year and the measured data are marshaled in a computer for determination of the sections requiring rail renewal.

The rail wear data for the section between Hang Chat St. and The Chompu St. on the North Line are as shown in Table 2.2.1. The section is among the black spots full of steeps and curves.

Its alignment and profile are as shown in Fig. 2.2.1. A typical example of rail wear measured in this section is shown in Fig. 2.2.2, and is characterized by the following points.

(1) The outer rail along the curve shows serious side wear.

(2) The inside rail shows horizontal wear to a slight degree.

(3) The degree of wear seems to have a significant relationship with the train speed; the higher the speed, the larger the side wear. On the curves where the speed is comparatively low, the side wear is less though horizontal wear is seen.

(4) There is no significant relationship between the slope and wear.

The principal causes of serious side wear on the high rails will be as follows.

(1) Strong lateral force acting between the flanges and rail.

(2) Slip between the flanges and rail.

(3) Insufficient lubrication between flanges and rail.

(4) Lack of anti-abrasiveness on the head of rail.

In addition, the following are conceivable as factors to promote the side wear.

(1) Acceleration and deceleration of train.

(2) Sanding at a slope.

(3) Lateral rigidity of track.

(4) Elasticity of roadbed.

(5) Track irregularity.

(6) Maintenance condition of cars, particularly the wheel wear.

(7) Motion characteristics of car.

The following are the factors that tend to aggravate the horizontal wear of the inside rails.

(1) Wheel load on the rail.

(2) Slip or creep between the rail and wheel tread.

(3) Rail deficient in anti-abrasive property.

Those promoting the horizontal wear are just the same as with the side wear of the outer rails. In the chapters to follow, we will see all these factors in detail and discuss the measures against rail wear.

Table 2.2.1

No.	Location		Length	Radius of curvature	Service life in years	
	Start	End			Inside rail	Outside rail
1	km 666.337	km 666.649	312	1000	49.4	14.1
2	660.038	660.299	262	400	42.5	4.6
3	660.925	661.051	126	400	32.5	9.6
4	661.172	661.369	197	200	35.0	5.3
5	661.384	661.498	114	400	41.8	5.2
6	661.528	661.779	251	200	29.1	2.8
7	661.779	661.923	144	250	36.0	4.9
8	661.923	662.046	123	300	37.4	2.5
9	662.046	662.177	132	250	38.2	4.8
10	662.177	662.381	203	180	29.1	1.9
11	662.439	662.848	409	180	28.2	1.8
12	662.860	663.006	147	200	30.7	1.8
13	663.139	663.282	144	300	39.0	3.4
14	663.306	663.725	418	200	34.9	6.3
15	664.122	664.368	246	400	40.4	11.1
16	664.854	665.035	181	400	43.4	4.2
17	666.113	666.442	329	300	36.1	2.4

Table 2.2.1

No.	Location		Length	Radius of curvature	Service life in years	
	Start	End			Inside rail	Outside rail
	km	km				
18	665.442	665.849	407	300	41.7	2.5
19	666.007	666.545	538	200	37.1	3.8
20	666.617	666.889	273	300	38.8	3.7
21	666.889	667.105	216	400	40.7	9.2
22	667.135	667.279	144	200	34.4	2.9
23	667.303	667.494	192	300	36.8	5.6
24	667.530	667.722	192	400	39.8	9.9
25	667.740	667.998	257	200	34.4	0.6
26	667.998	668.144	146	250	34.0	2.9
27	668.288	668.515	227	180	28.6	3.3
28	668.515	668.886	371	300	34.2	4.9
29	668.976	669.158	182	300	37.5	3.8
30	669.188	669.350	161	200	29.0	4.9
31	669.375	669.560	185	400	41.3	3.5
32	669.590	669.775	188	400	40.2	8.1
33	669.998	670.250	253	300	38.7	9.7
34	670.590	670.832	252	800	49.5	12.4
35	670.868	671.037	169	200	34.1	3.7
36	671.561	671.753	191	180	26.1	5.2
37	671.777	672.077	301	180	28.5	4.6
38	672.210	672.417	207	180	26.0	0.5
39	672.440	672.662	222	180	25.9	2.3
40	672.679	672.848	169	200	32.2	1.9
41	673.069	673.219	150	200	26.7	0.3
42	673.219	673.547	328	800	51.2	13.9
43	673.577	673.912	335	300	37.4	4.0
44	674.154	674.346	191	180	24.3	3.2
45	674.370	674.525	156	180	27.7	2.6
46	674.657	674.867	210	600	46.3	10.9
47	674.891	675.178	287	180	27.2	1.6
48	675.208	675.459	251	180	25.9	1.5
49	675.477	675.722	245	180	23.8	4.4
40	675.746	676.004	258	180	28.2	0.8
51	676.022	676.207	185	180	24.3	4.4
52	676.261	676.321	60	300	36.3	3.2

Table 2.2.1

No.	Location		Length	Radius of curvature	Service life in years	
	Start	End			Inside rail	Outside rail
53	km 676.051	km 676.483	132	300	38.6	4.3
54	676.525	676.681	156	300	40.9	3.4
55	676.891	677.096	205	400	36.8	4.6
56	677.108	677.223	115	300	38.9	4.8
57	677.292	677.400	108	300	37.0	4.1
58	677.448	677.544	96	300	38.0	4.0
59	677.580	677.688	108	300	35.8	3.4
60	678.000				55.2	54.7
61	678.068	678.126	108	300	36.1	4.3
62	678.144	678.275	132	250	31.1	0.5
63	678.447	678.663	216	180	22.5	1.3
64	678.705	678.890	186	180	20.1	5.1
65	678.908	679.033	124	300	34.6	4.6
66	679.191	679.352	162	180	25.5	4.5
67	679.370	679.496	126	180	21.5	4.7
68	679.514	679.813	299	180	24.1	4.9
69	679.831	680.035	204	180	22.6	1.5
70	680.065	680.149	84	300	33.2	4.1
71	680.173	680.263	90	300	38.7	3.8
72	680.287	680.425	138	200	26.3	2.1
73	680.448	680.628	179	180	25.9	6.5
74	680.659	680.844	185	600	46.9	10.5
75	680.898	681.032	135	180	27.2	2.2
76	681.152	681.352	198	180	27.2	2.0
77	681.368	681.529	162	200	31.0	2.5
78	682.904	683.028	124	450	35.6	7.5
79	683.035	683.148	113	300	32.0	5.2
80	683.215	683.303	89	300	40.6	6.3
81	683.309	683.423	114	300	34.8	5.1
82	683.532	683.699	168	180	26.6	2.2
83	683.796	683.897	101	800	48.2	15.6
84	683.907	684.126	219	200	32.2	2.1
85	684.210	684.443	233	180	23.3	1.9
86	684.479	684.785	306	600	40.5	9.4
87	684.803	685.070	267	180	28.1	1.9

Table 2.2.1

No.	Location		Length	Radius of curvature	Service life in years	
	Start	End			Inside rail	Outside rail
88	km 685.081	km 685.377	296	200	32.9	2.6
89	685.379	685.746	368	180	27.9	4.9
90	685.902	686.057	156	180	30.8	5.2
91	686.089	686.283	193	180	26.3	2.3
92	686.360	686.625	266	180	24.1	2.8
93	686.668	686.918	249	180	27.5	5.0
94	686.975	687.058	82	180	31.3	4.7
95	687.089	687.331	242	180	28.1	5.0
96	687.500	687.589	89	180	28.3	4.9
97	687.614	687.984	370	180	28.6	5.0
98	687.997	688.177	180	180	25.0	2.2
99	688.236	688.405	169	180	25.6	5.0
100	688.355	688.630	275	300	41.4	5.2
101	688.912	689.037	125	250	38.7	4.2
102	689.049	689.167	117	250	35.3	6.9
103	689.195	689.399	204	180	27.7	1.8
104	689.417	689.723	306	180	30.3	5.5
105	689.883	690.273	390	200	36.9	2.4
106	690.413	690.614	201	200	32.7	2.3
107	691.221	691.462	241	300	41.4	5.7
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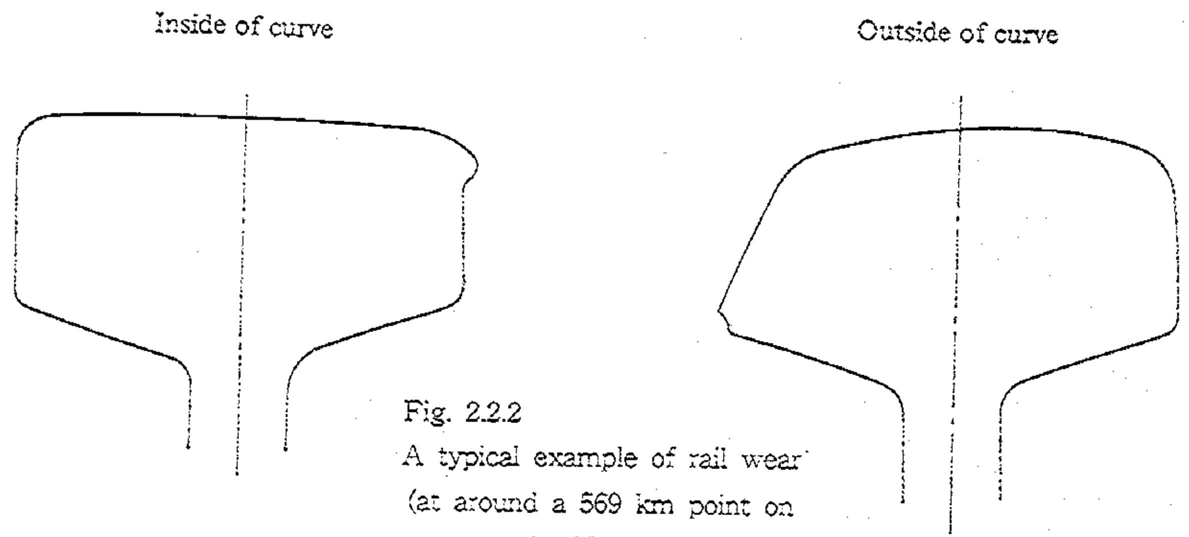
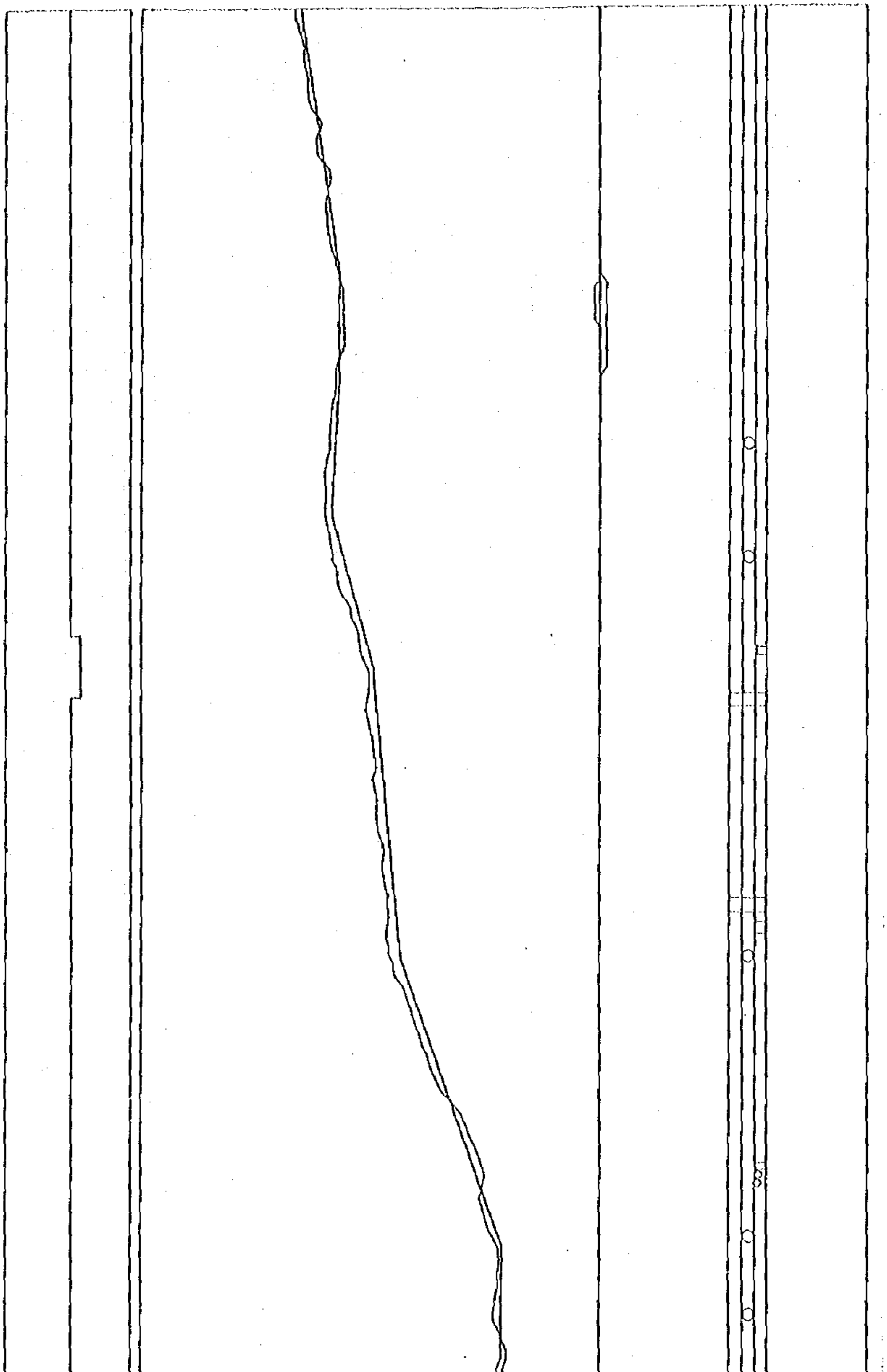


Fig. 2.2.2
A typical example of rail wear
(at around a 569 km point on
the North Main Line)



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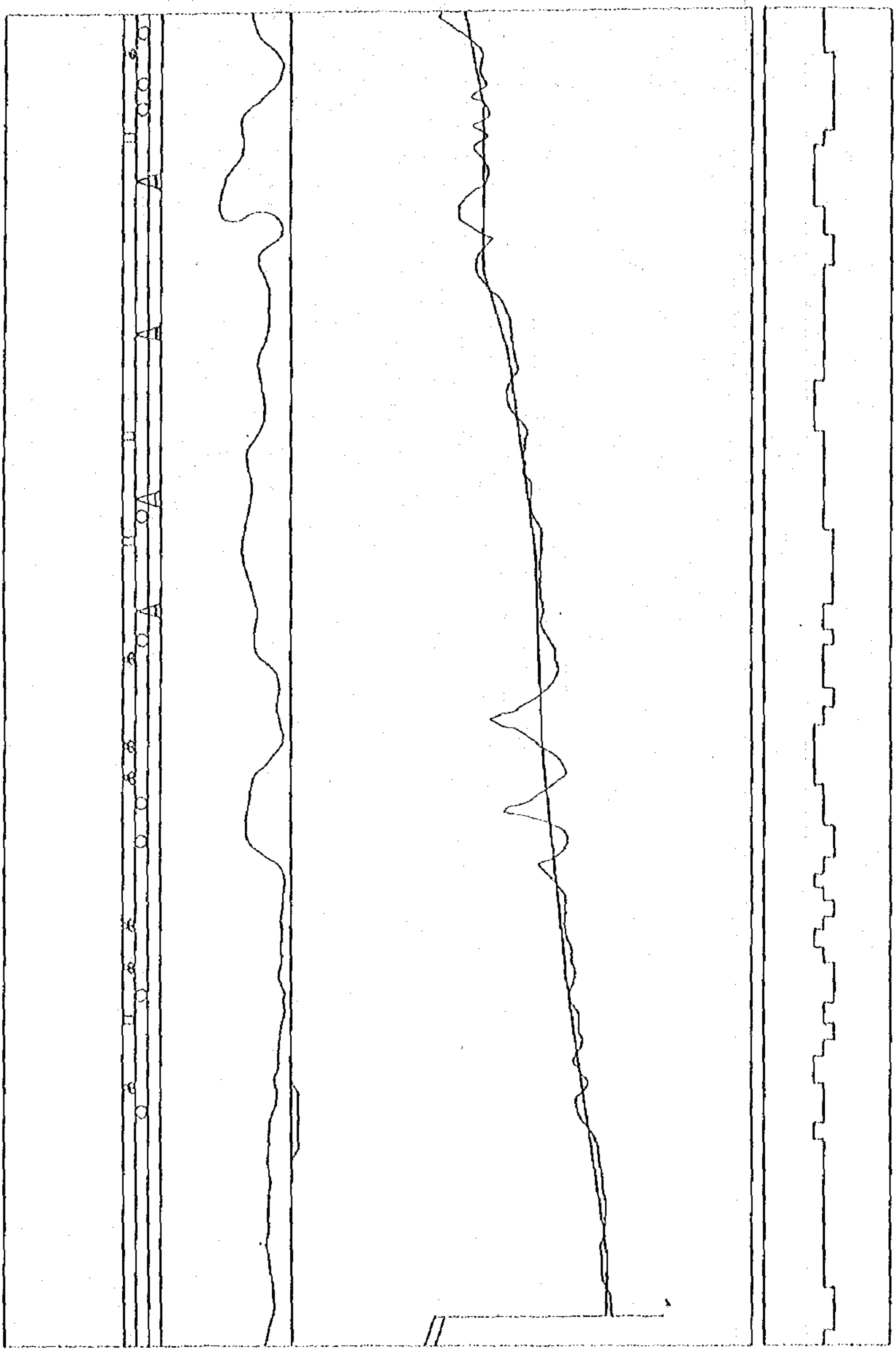
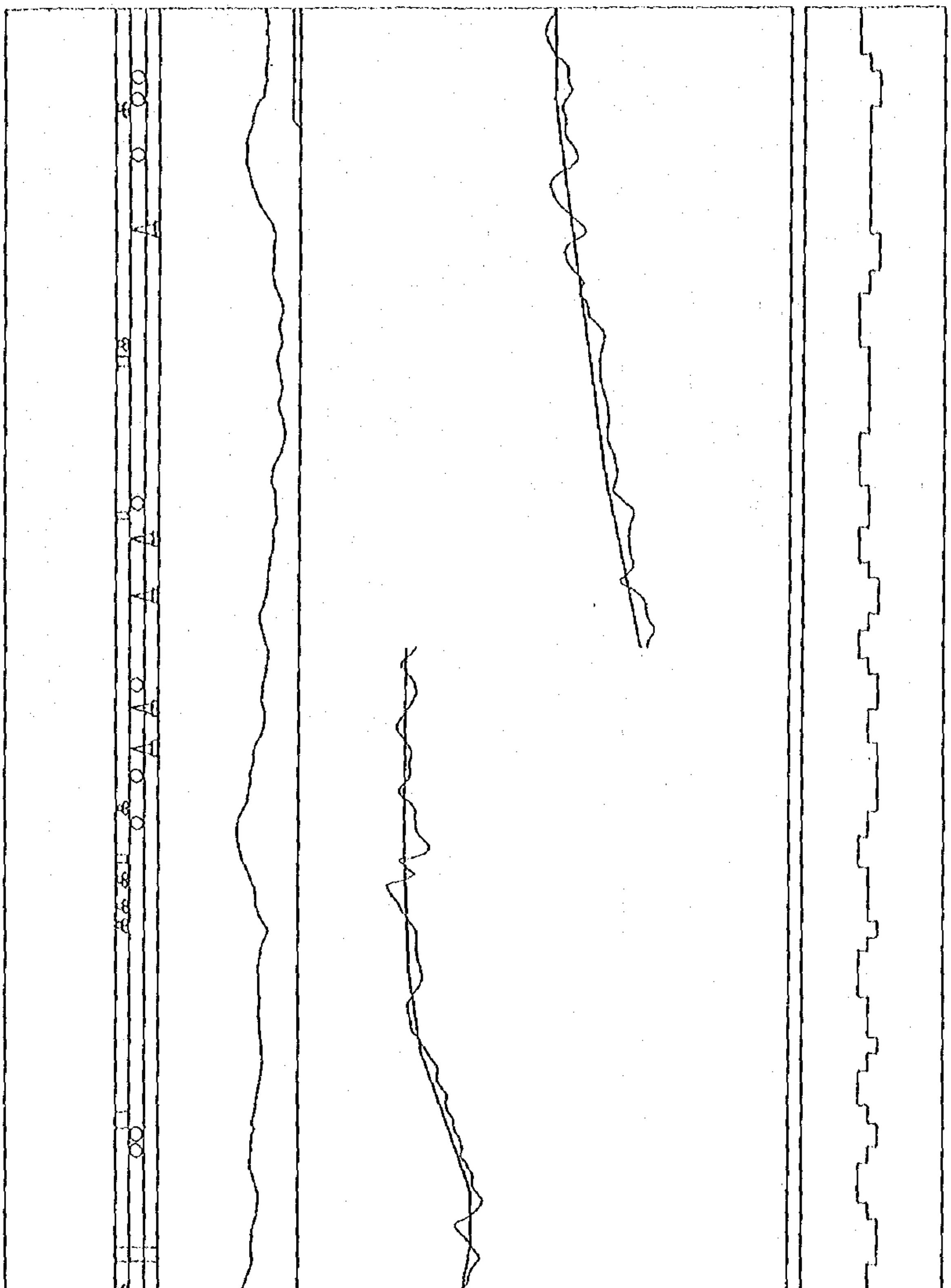
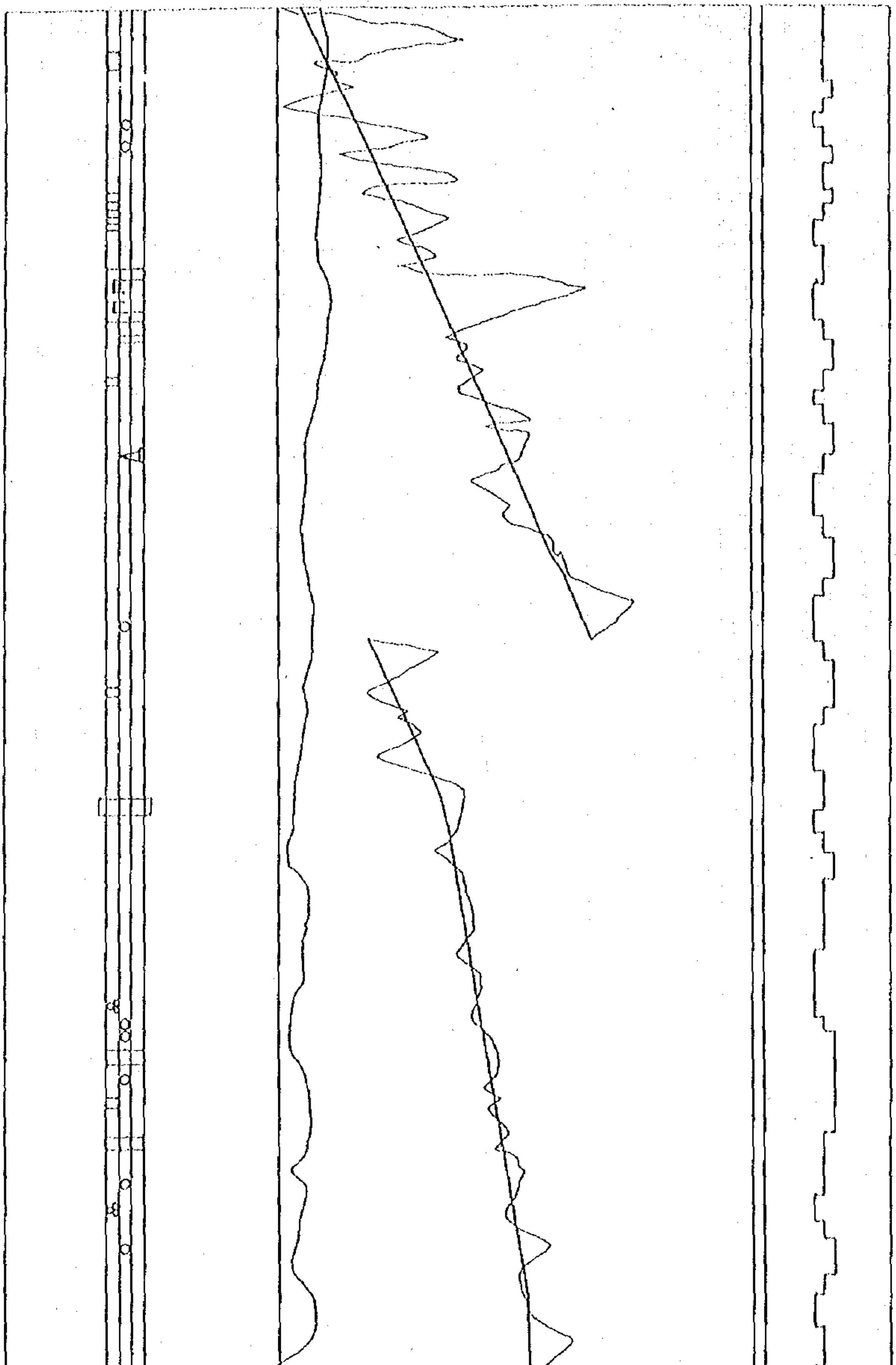
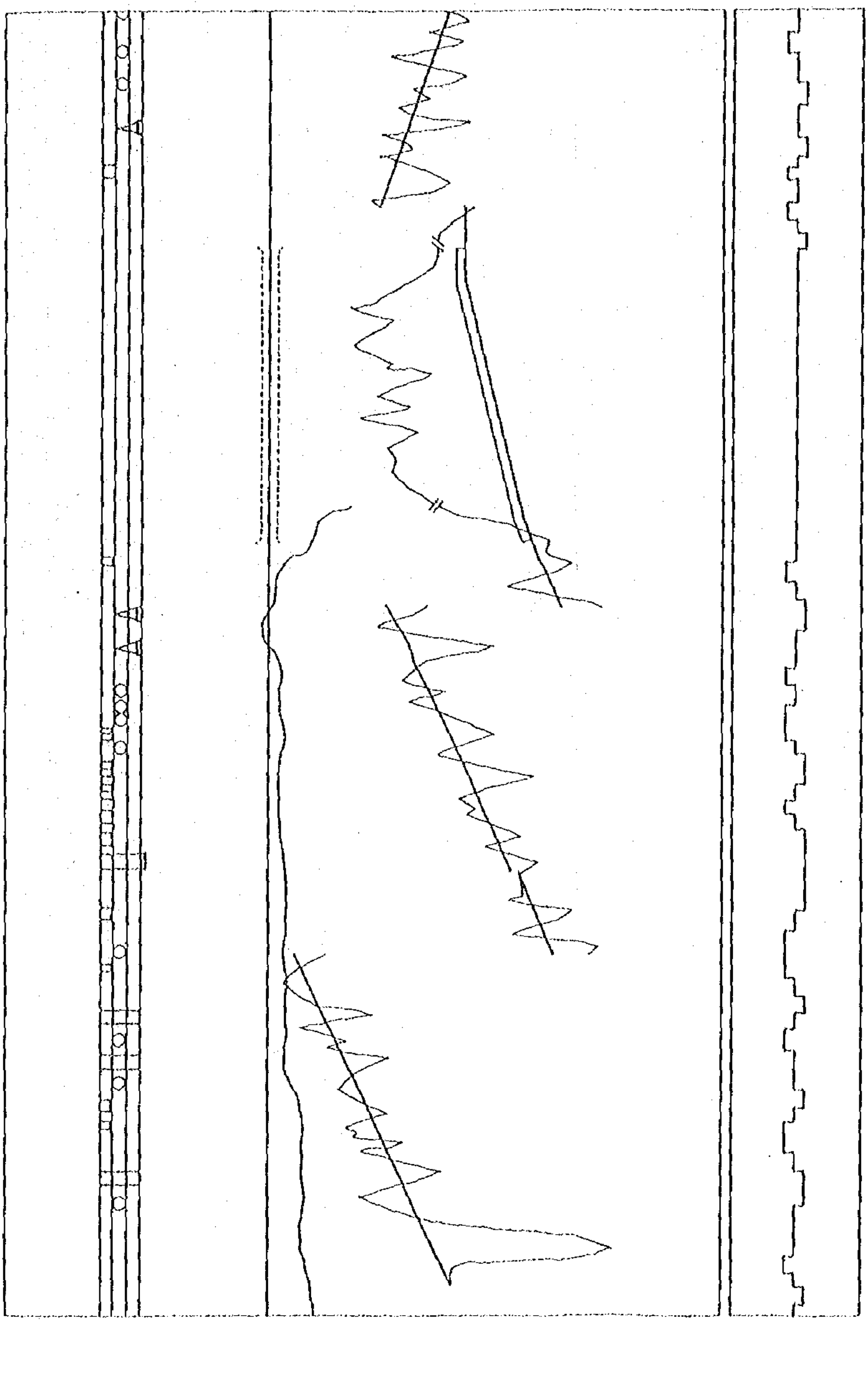
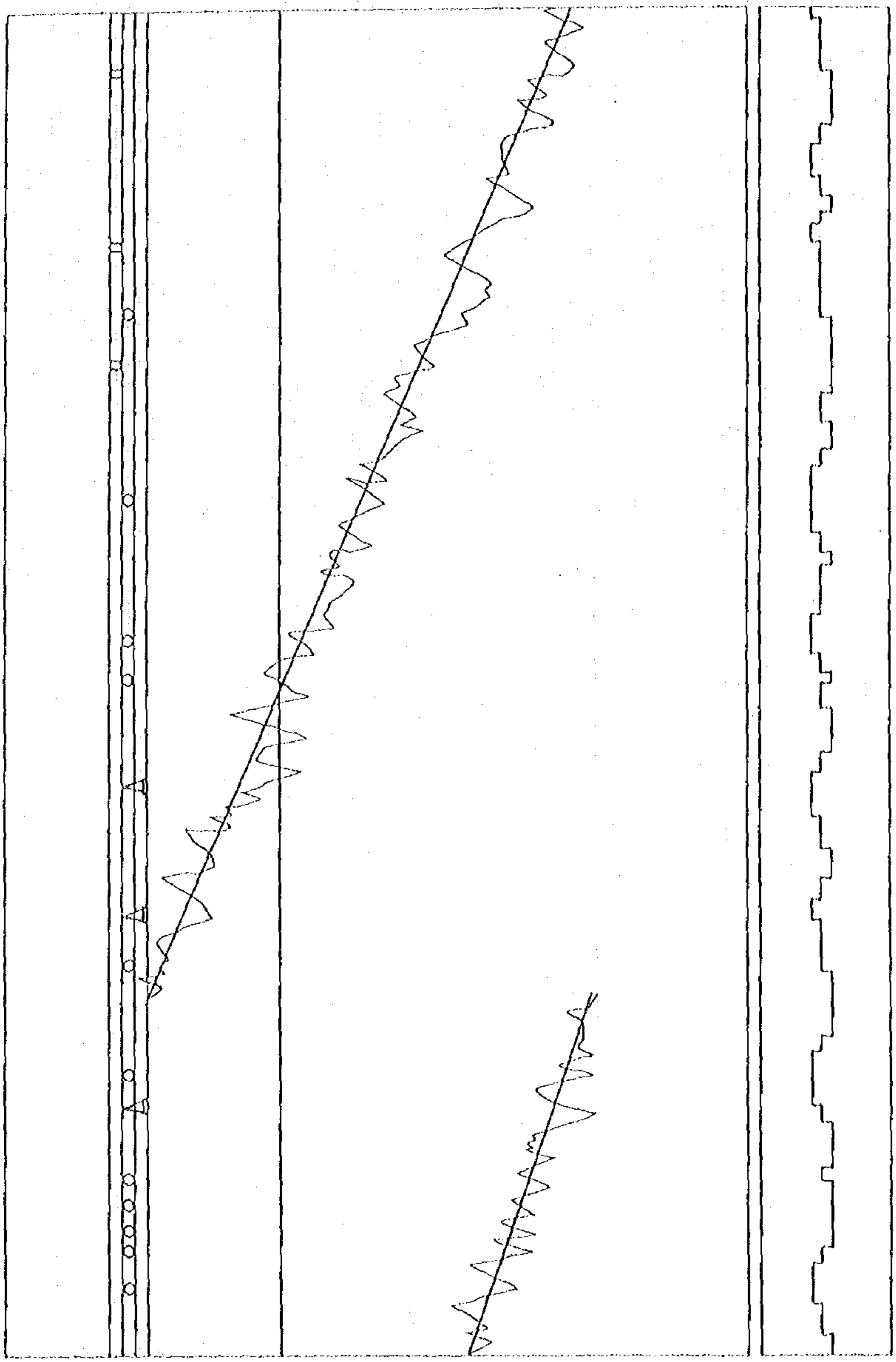
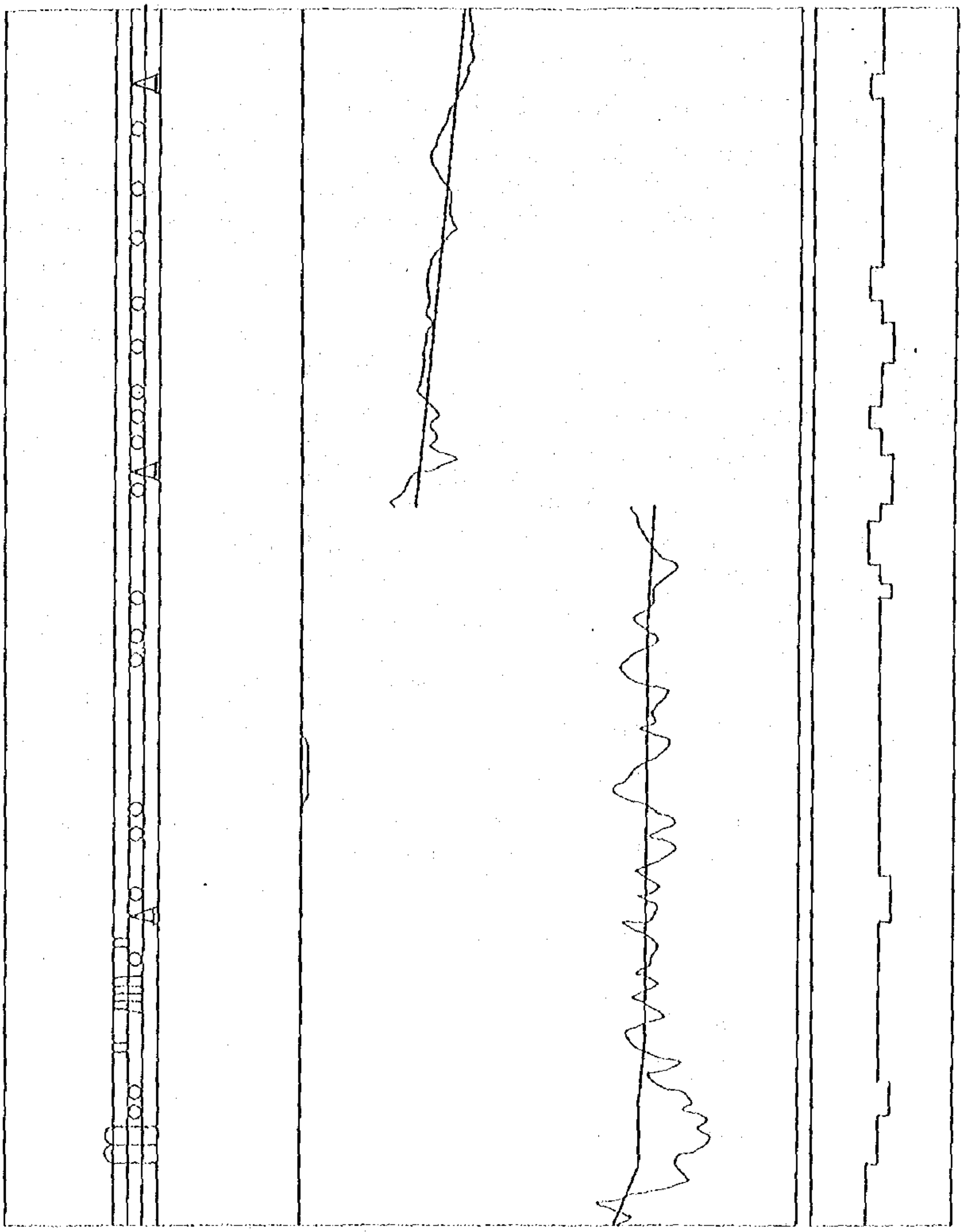












3. Results of Materials Testing on Worn-out Rails

3.1 Samples from the Outer Rails in the Curved Sections

The materials of the heavily worn outer rails were tested. The results are as shown below. The samples used are listed in Table 3.1.1; they included three types of ordinary rails, two types of head-hardened rails and wheel tire.

Table 3.1.1

Samples	No.
Ordinary rail (Denchai CPI)	2302
Ordinary rail (Lanpang CPI)	2305
Ordinary rail (Lanphun CPI)	2303
Head-hardened rail (Fuji Iron & Steel's Kamaishi)	2301
Head-hardened rail (Yawata)	2304
Wheel tire	2300

3.2 Properties of Ordinary Rails

3.2.1 Purposes and types of tests

The worn-out rails were put to the following tests for the purpose of examining their properties in relation to the rail wear.

Tests

1. Pattern of wear
2. Chemical analysis
3. Sulfur print
4. Macro etching
5. Micrography
6. Hardness distribution

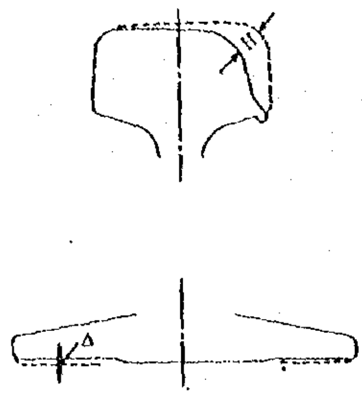
3.2.2 Pattern of wear

The cross section of each sliced piece of samples was polished and its profile was recorded. The profiles thus obtained are shown in Figs. 3.2.1 through 3.2.6. The rails from which samples were taken were installed as outer rails in curved sections, and their inner edges were worn out seriously. Some of them had their bottoms given stepped wear which may have been developed due to repeated contact with the rail fastenings.

Table 3.2.1 summarizes the results of a survey of rail wear.

Table 3.2.1 Degree of Wear

Sample No.	H (mm)	V (mm) (max.)
2301	10.5	1.0
2302	19.5	--
2303	8.5	--
2304	12.0	1.2
2305	22.5	1.4



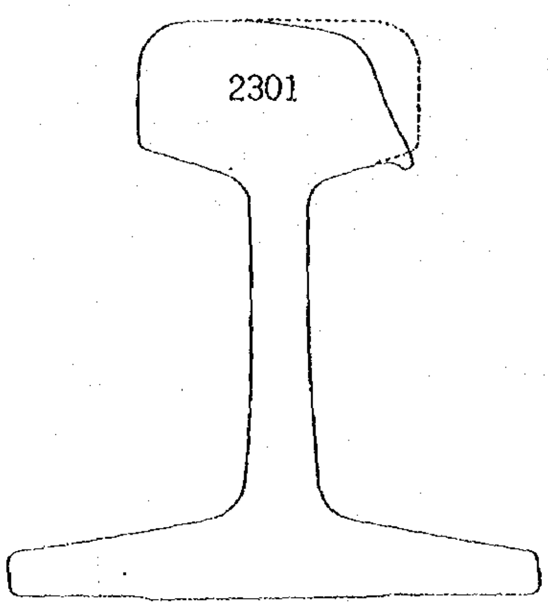


Fig. 3.2.1

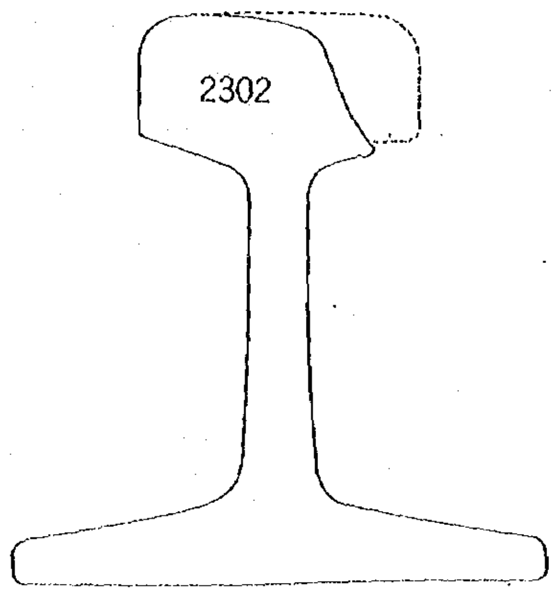


Fig. 3.2.2

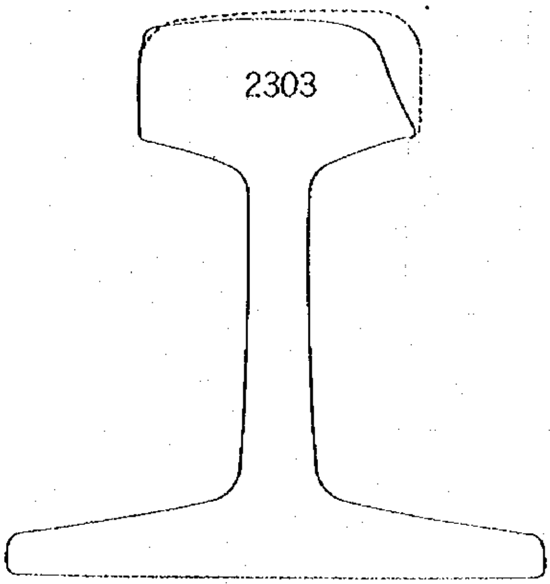


Fig. 323

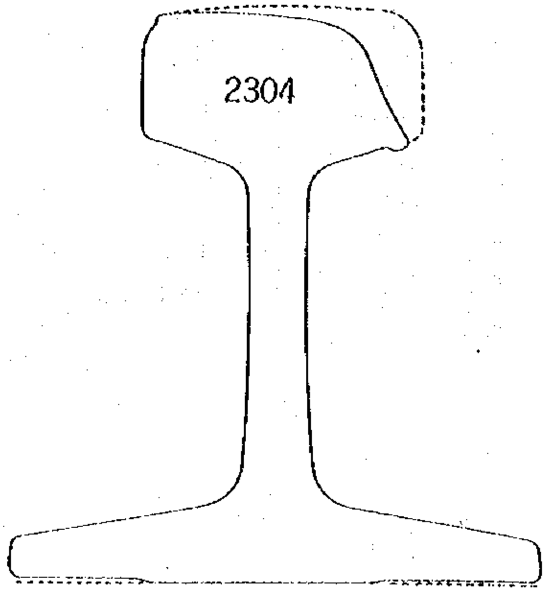


Fig. 324

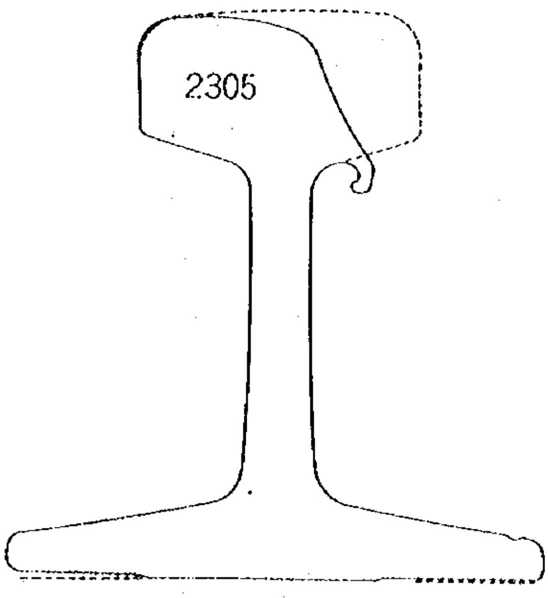


Fig. 325

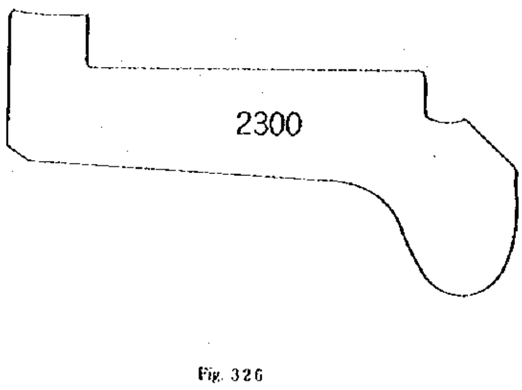


Fig. 326

3.2.3 Chemical analysis

Specimens obtained from the position illustrated in Fig. 3.2.7 were subjected to chemical analysis using reagents and also to emission spectrochemical analysis.

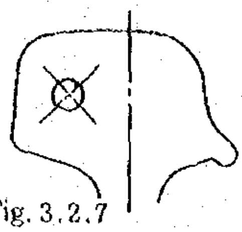


Fig. 3.2.7
Sampling position

The test results are as shown in Tables 3.2.2 and 3.2.3. There was noticed a slight difference in the results between the reagent method and spectrographic method, but the steel types of respective rails could be identified.

Table 3.2.3 shows the steel types and steel-making processes deduced from the test results.

Table 3.2.4 Steel Types and Steel-making Processes Deduced from the Test Results

Sample No.	Steel type	Steel-making process
2301	80 kg/mm^2 high-carbon steel	Basic open hearth process
2302	70 kg/mm^2 medium-carbon manganese steel	Basic open hearth process or Thomas converter process
2303	80 kg/mm^2 high-carbon steel	Basic open hearth process
2304	80 kg/mm^2 high-carbon steel	Basic open hearth process
2305	70 kg/mm^2 medium-carbon manganese steel	Basic open hearth process
2300 (reference)	80 kg/mm^2 high-carbon steel	Basic open hearth process

Table 3.2.2 Chemical Analysis

Sample No. \ Composition, %	C	Si	Mn	P	S
2300	0.71	0.31	0.64	0.026	0.026
2301	0.61	0.15	0.68	0.012	0.026
2302	0.48	0.15	1.10	0.027	0.035
2303	0.61	0.13	0.84	0.022	0.028
2304	0.64	0.13	0.86	0.017	0.033
2305	0.44	0.20	1.08	0.016	0.026

Table 3.2.3 QV Analysis

Sample No. \ Composition, %	C	Si	Mn	P	S
2300	0.68	0.29	0.67	0.022	0.023
2301	0.60	0.15	0.68	0.011	0.023
2302	0.46	0.15	1.13	0.024	0.029
2303	0.58	0.13	0.85	0.020	0.024
2304	0.61	0.14	0.87	0.015	0.024
2305	0.43	0.19	1.09	0.014	0.023

3.2.4 Sulfur print test

The results of sulfur print tests on the samples are as shown in Photo 3.1. Neither sample rails and tire showed detrimental segregation of sulfides. They all were found warrantable.

3.2.5 Macro etching test

The results of macro etching tests on samples are shown in Photo 2. The results were different from sample to sample. Table 3.2.5 summarizes the test results.

Table 3.2.5 Results of Macro Etching Test

Sample No.	Macrostructure	Segregation
2301	Heat-treated for head hardening	No problem
2302	As-rolled	do.
2303	As-rolled	do.
2304	Heat-treated for head hardening	do.
2305	As-rolled, but pad-welded on the top	do.
2300 (reference)	As-rolled (flange alone heat-treated)	do.

3.2.6 Microstructure

The microstructures at various parts of samples are shown in Photos 3.3 through 3.8.

The observations of these microstructures are summarized below.

1) 2301

The part right under the top center of the rail shows a martensite structure suggestive of proper tempering in the head-hardening heat treatment. The worn edge of the rail head is removed of martensitic layer, disclosing a plastic flow of fine pearlitic layer due to wheel contact.

At the center of the rail head is a coarse structure having ferrite and pearlite. At the center of the rail bottom is a fine structure of ferrite and pearlite. This difference in grain size may have been developed owing to the difference in cooling velocity after the end of rolling.

2) 2302

A plastic flow due to wheel contact is noticed in the form of deformation of the ferrite + pearlite structure. It is more serious at the place nearer to the gage corner than at the central surface of the rail head. The grain size in the inner layer of the rail head is large, but the thin-walled bottom has a fine grain size and has a decarburized layer in the surface.

3) 2303

The rail head shows a coarse structure both in the top layer and inner layer. The top layer shows a plastic deformation. The bottom shows a fine structure, and presents the most serious decarburized layer among the samples.

4) 2304

The central surface layer of the rail head shows a deformation of a structure consisting of tempered martensite and fine pearlite, suggesting that the hardening is insufficient. The decarburized layer of the rail bottom is not so conspicuous.

5) 2305

The rail head has a pad-repaired layer and a thermally affected inner layer adjoining it. The coalescent layer presents a bainite-like cast structure of low-carbon alloy steel. That part of the thermally affected layer which is near the weld metal shows a fine structure of ferrite and pearlite.

At the end, the structure is coarser than the parent material. The worn-out top layer of the rail head is galled of weld-repaired part to develop a plastic flow of the parent metal. The wear and deformation are the most serious of all the samples.

The rail bottom shows a fine grain size, and has an extensive decarburized layer.

6) 2300 (reference)

A normal structure typical of rolled tire, showing a pearlitic structure almost free from proeutectoid ferrite. The flange shows a structure of ferrite and pearlite which may have been developed natural cooling after reheating, and its inner layer leaves a trace of thermal influence.

Photo 3.1 Sulfur Print Test

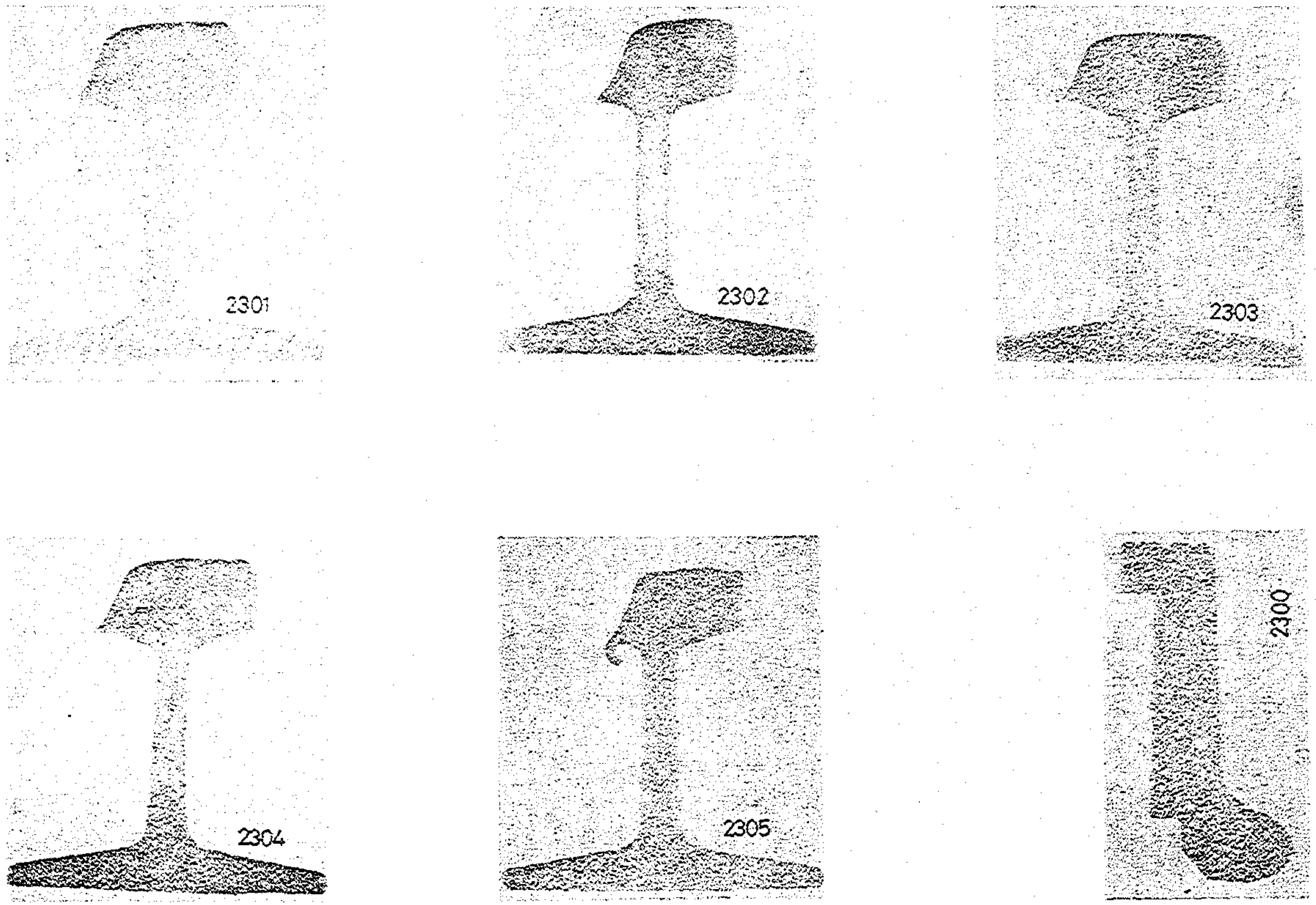


Photo 3.2 Macro Etching Test

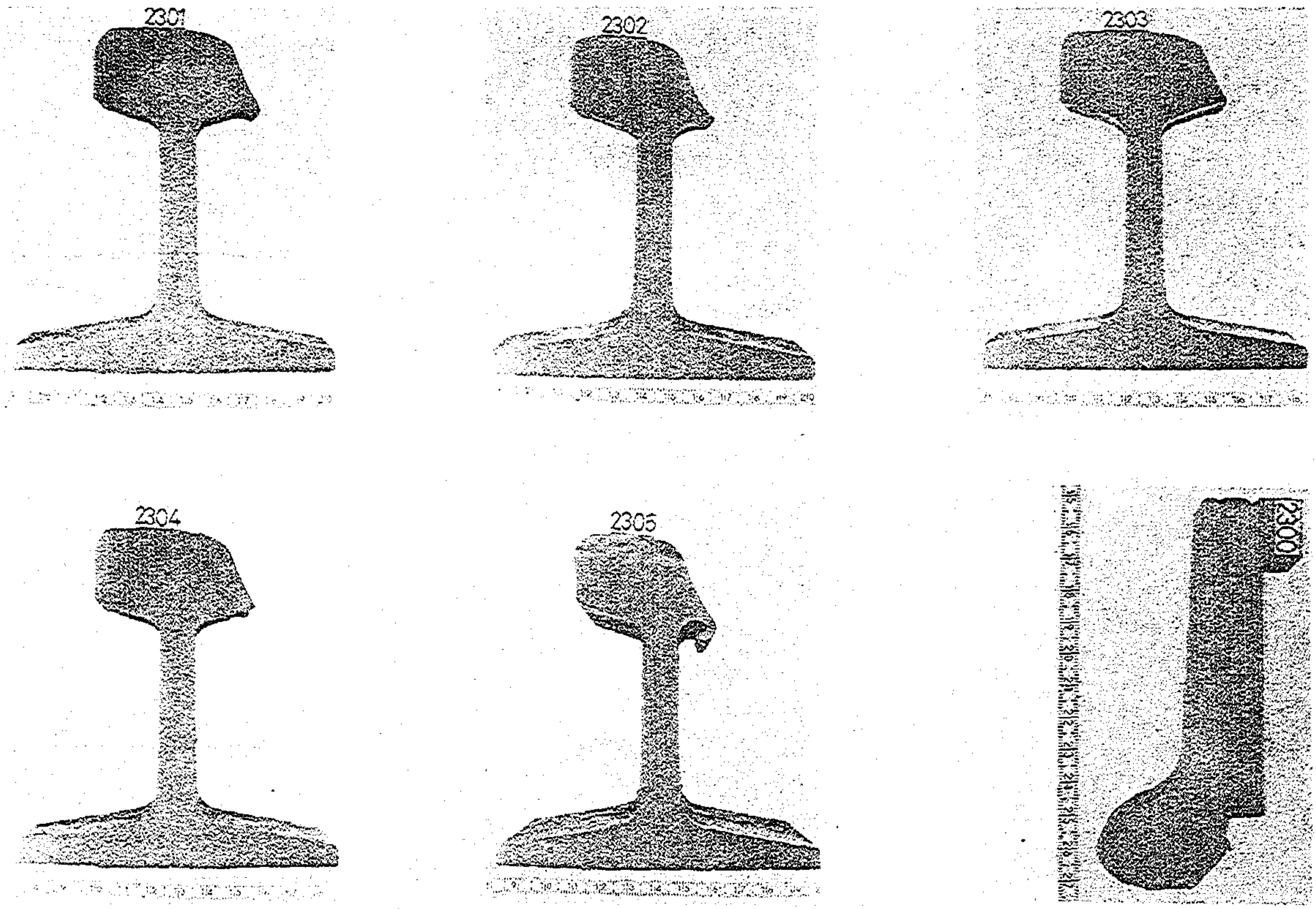
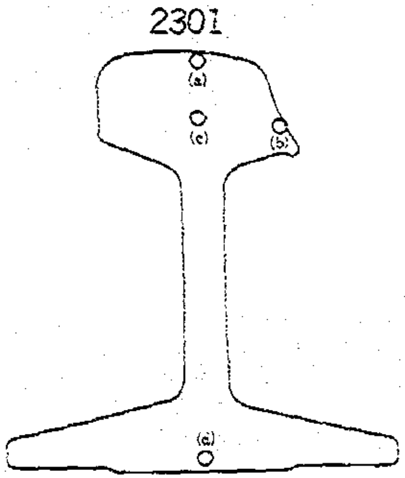


Photo 3.3 Microstructure



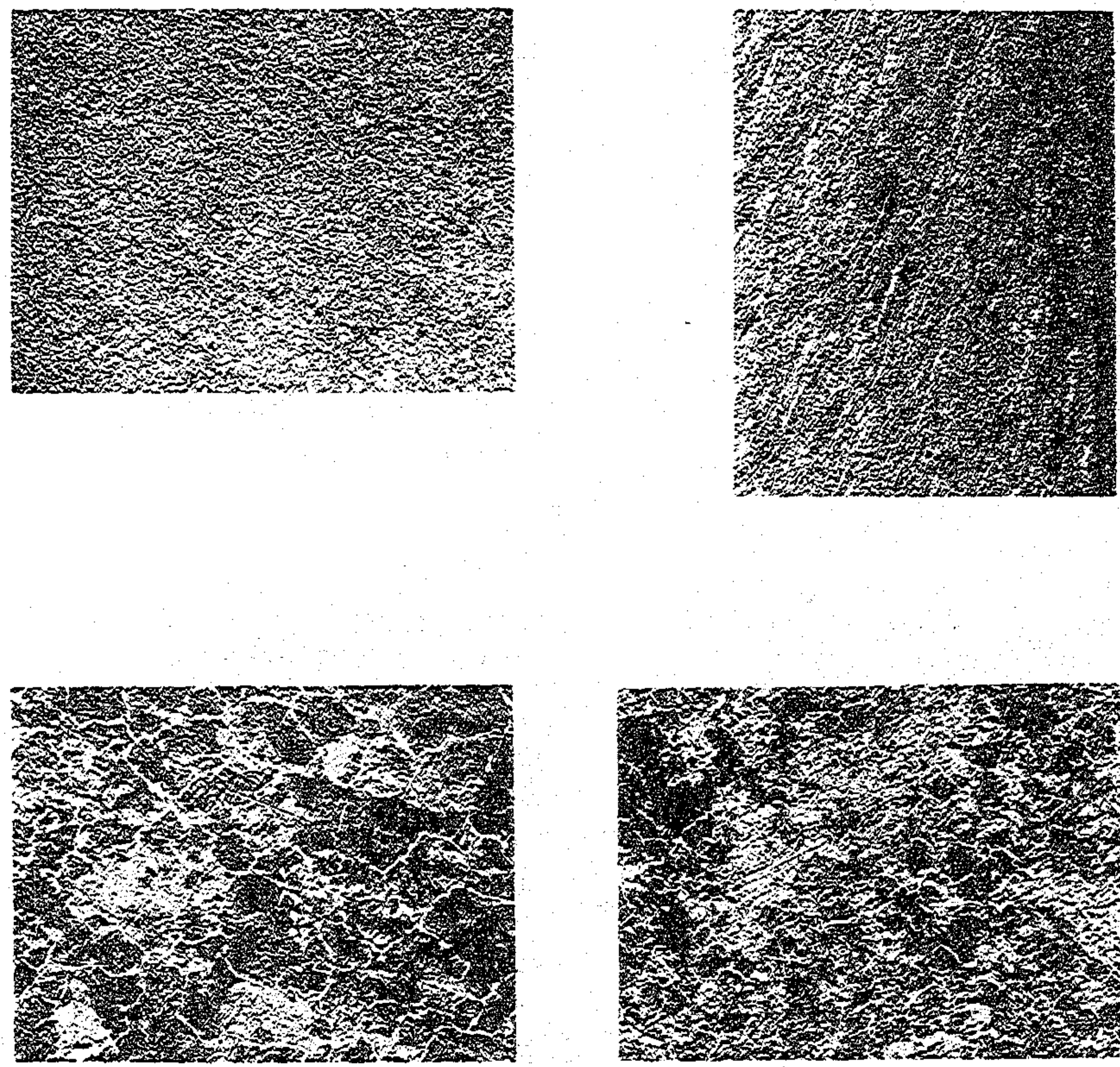


Photo 3.4 Microstructure

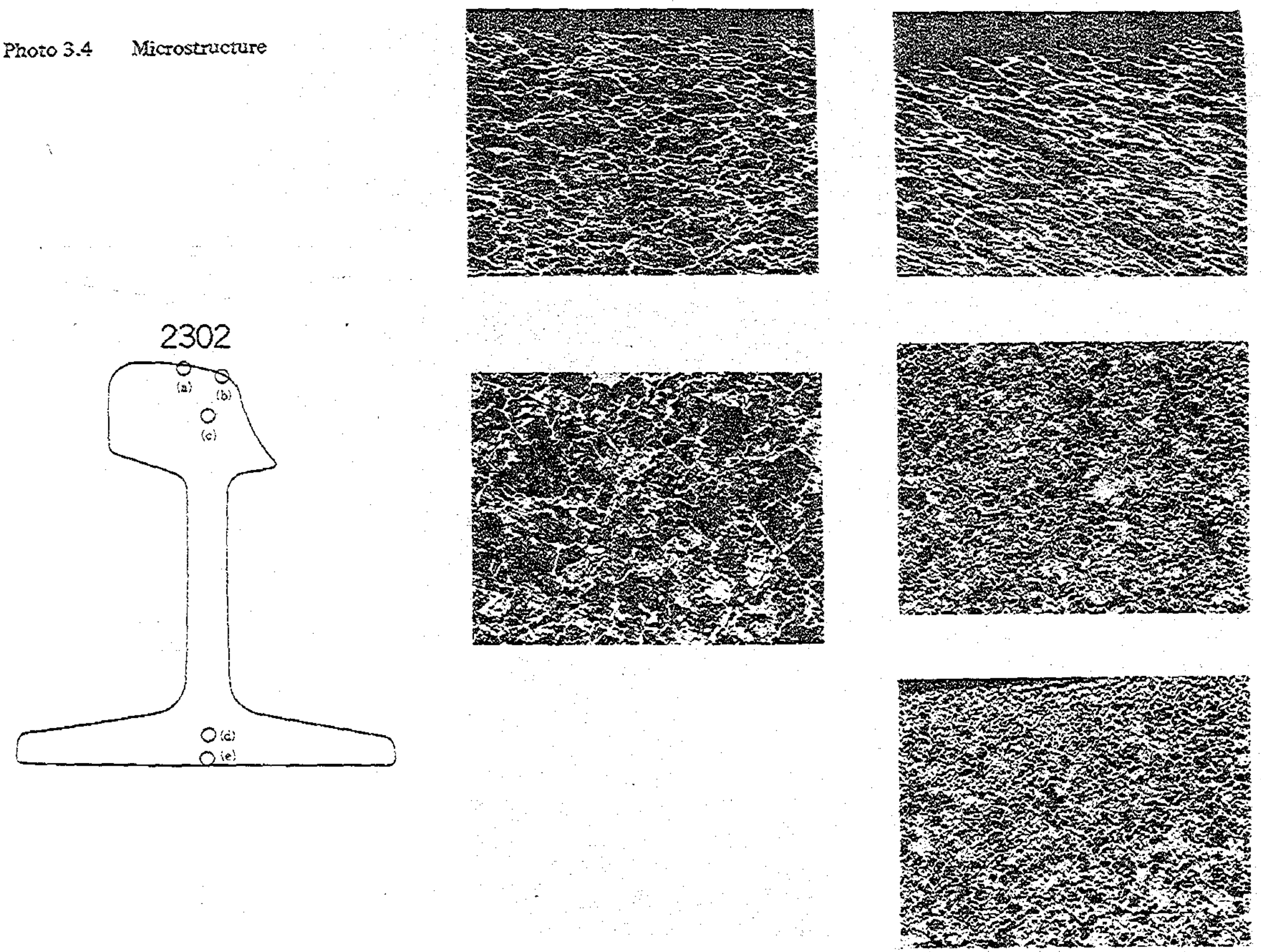


Photo 3.5 Microstructure

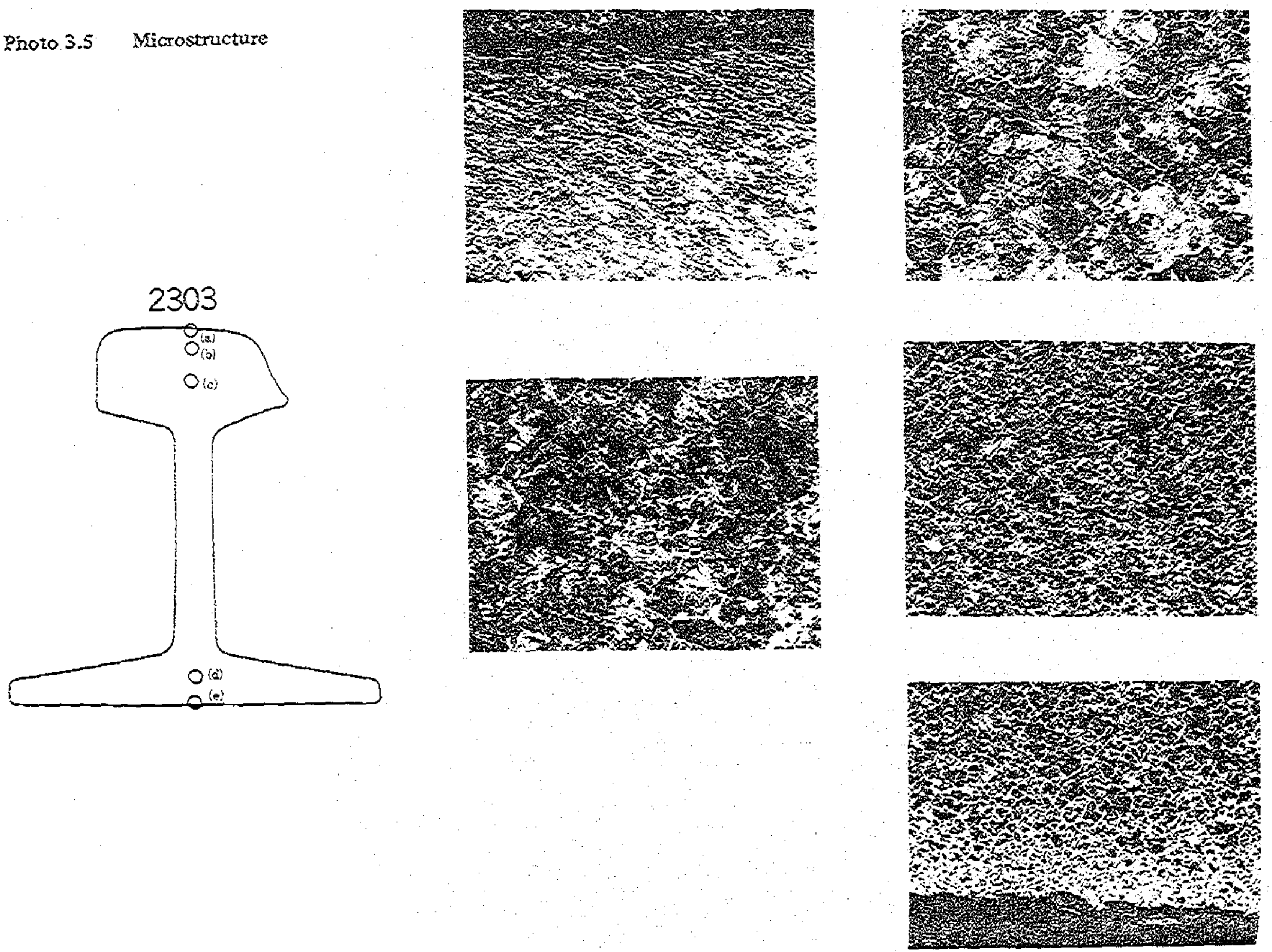
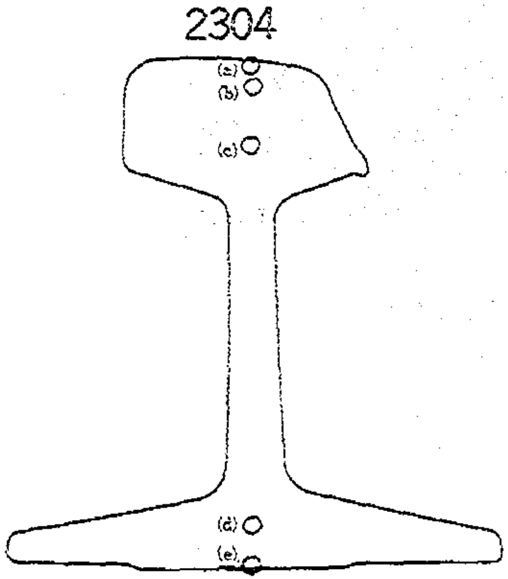


Photo 3.6 Microstructure



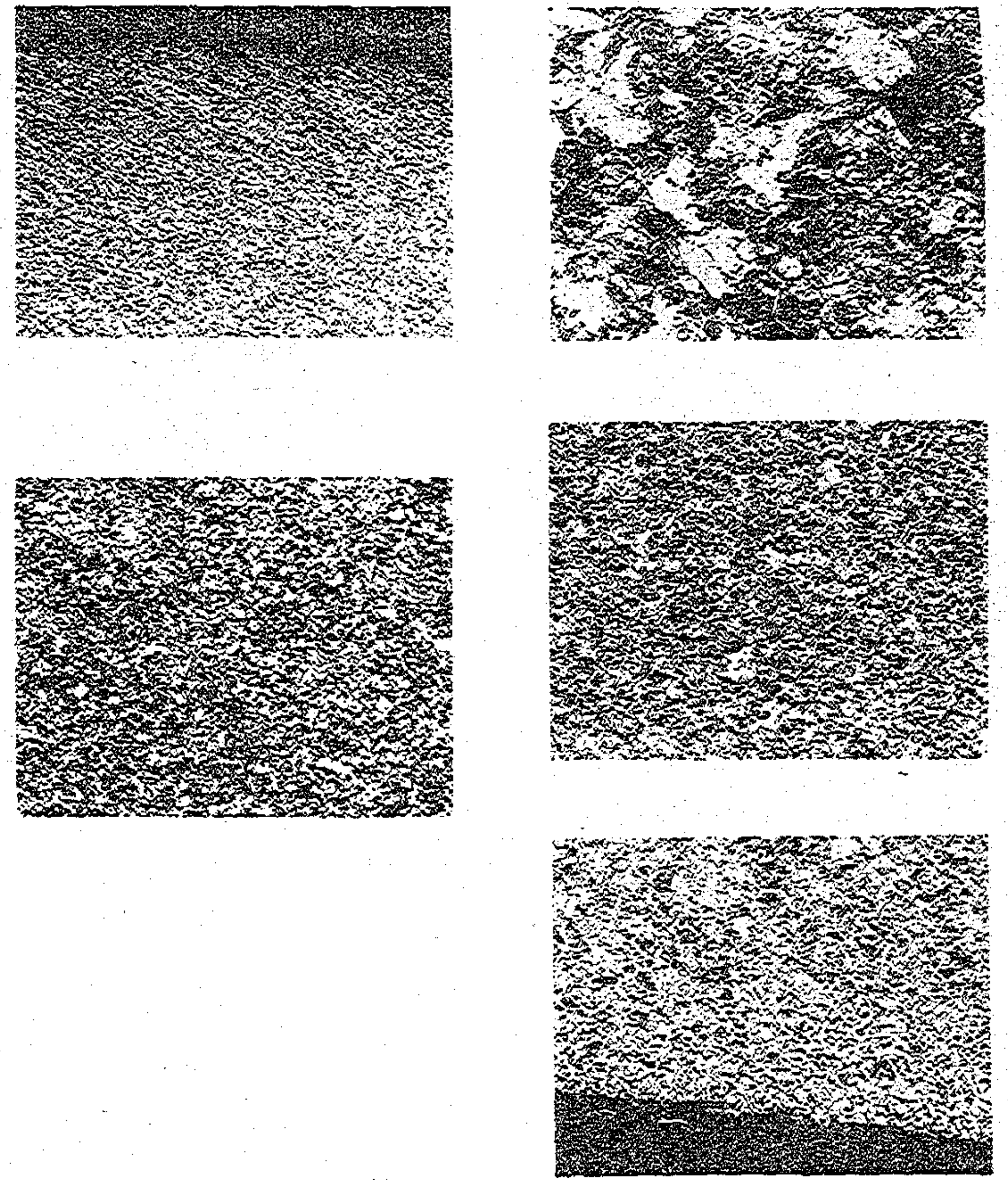
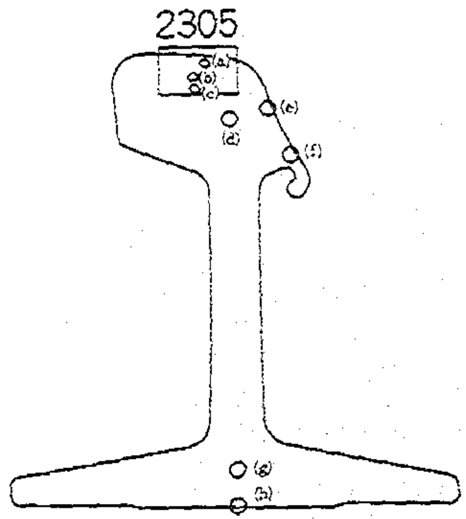
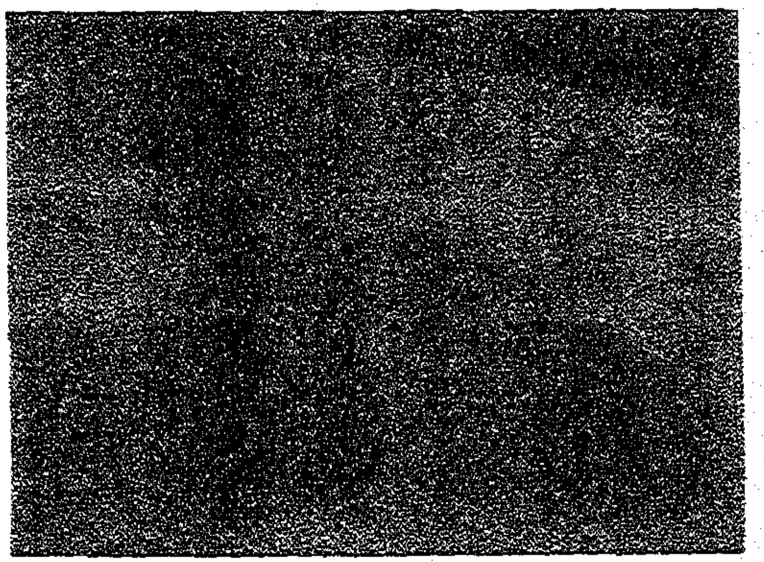
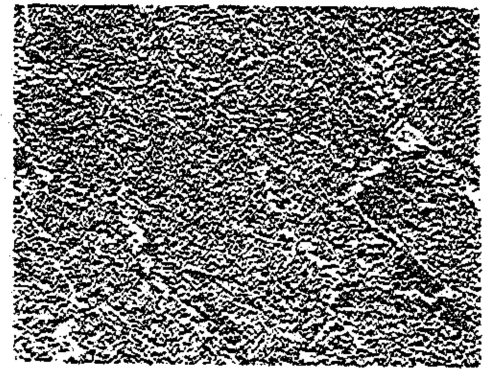
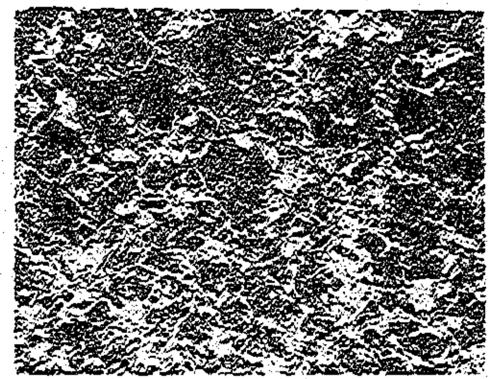


Photo 3.7.1 Microstructure









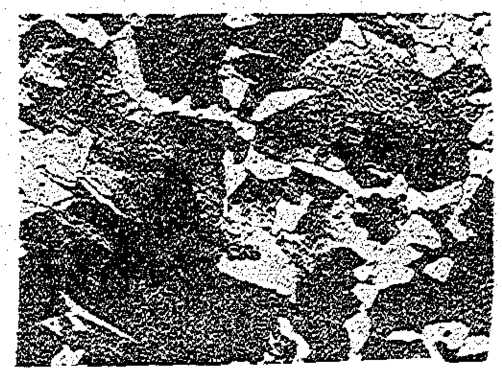


Photo 3.7.2 Microstructure

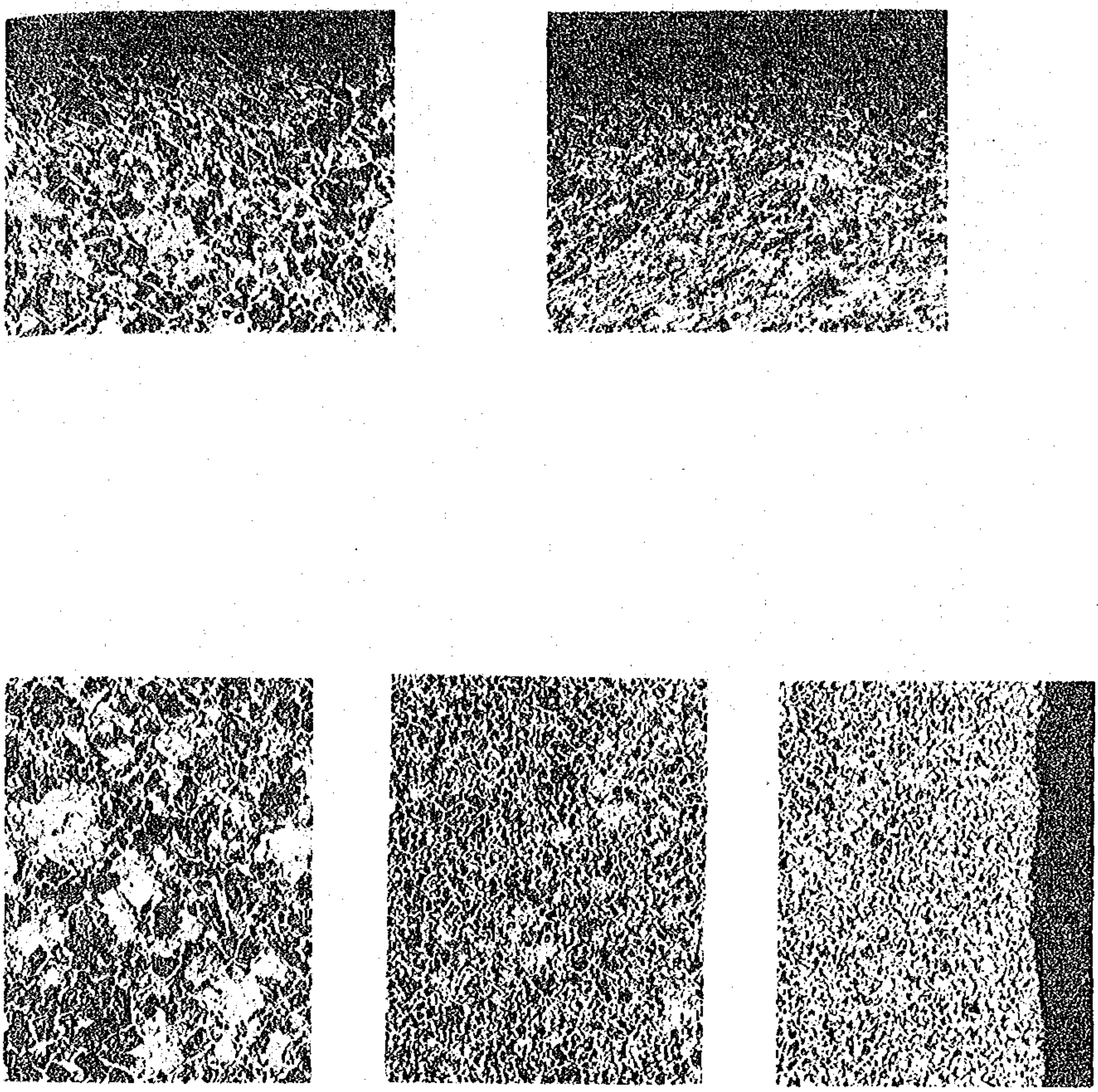
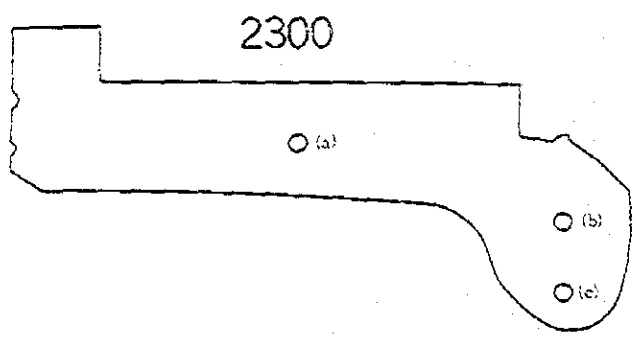
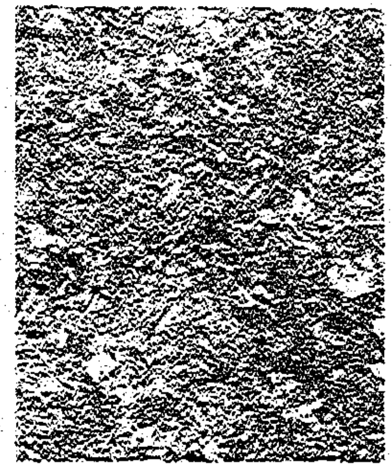
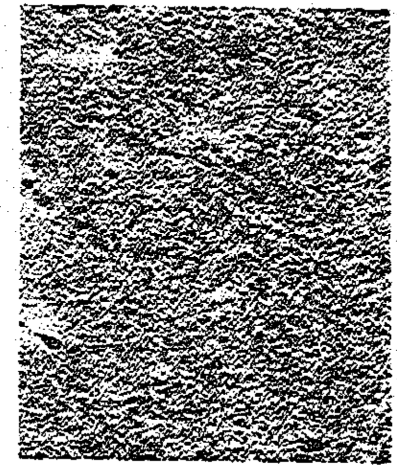
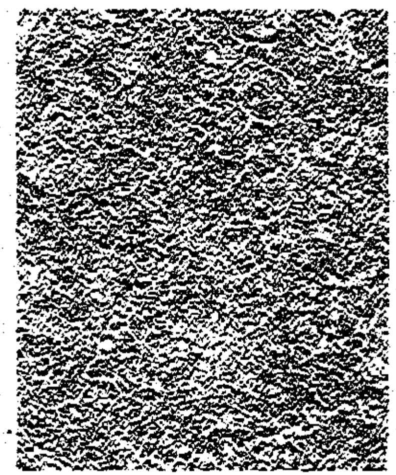


Photo 3.8 Microstructure









3.2.7 Hardness distribution test

The rail heads of the samples were subjected to Vickers hardness test. The hardness distribution is as shown in Figs. 3.2.2 through 3.2.12. The reference material (tire) was put to Brinell hardness test, and the results are as shown in Fig. 3.2.13.

1) 2301

As regards the hardened layer, the hardness vs. depth diagram is normal in the main, except for the jaw of the rail head which shows a hardness a little above a specification value. 2301 shows the highest hardness of all the samples. The hardness of the parent metal is HV 220.

2) 2302

The parent material shows HV 235, and there is no substantial difference between the surface layer and inner layer. The wear due to wheel contact is not aggravated so much. The central part of the rail head and the surface layer opposite of the gage corner show an increase in the hardness due to cold working; the maximum hardness is HV 330, and its depth is about 8 mm.

3) 2303

A slight difference in hardness between the surface and inner layers of the rail material; the surface layer is a little harder, and is followed by a work-hardened layer whose hardness is HV 320 over a depth of about 4 mm.

4) 2304

The hardness is at the lower margin of the specification values, and is a little lower for the heat-treated layer. Because of the combined effect of heat treatment and work hardening, the maximum hardness is HV 400, and its depth is 2 mm. The hardness of the parent metal is HV 230.

5) 2305

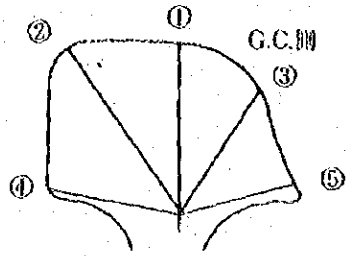
The parent metal shows a hardness of HV 210, the lowest of all the samples. The pad-repaired coalescent layer, which has been subjected to work hardening, shows HV 310. The surface layer where side wear is noticeable is hardened to HV 300.

6) 2300 (reference)

The tire hardness is HB 220, a little shorter for its carbon content. The thermally affected zone shows a further lower value of HB 210.

Fig. 3.2.8.

Vickers Hardness
No.2301
(Load 10kg)



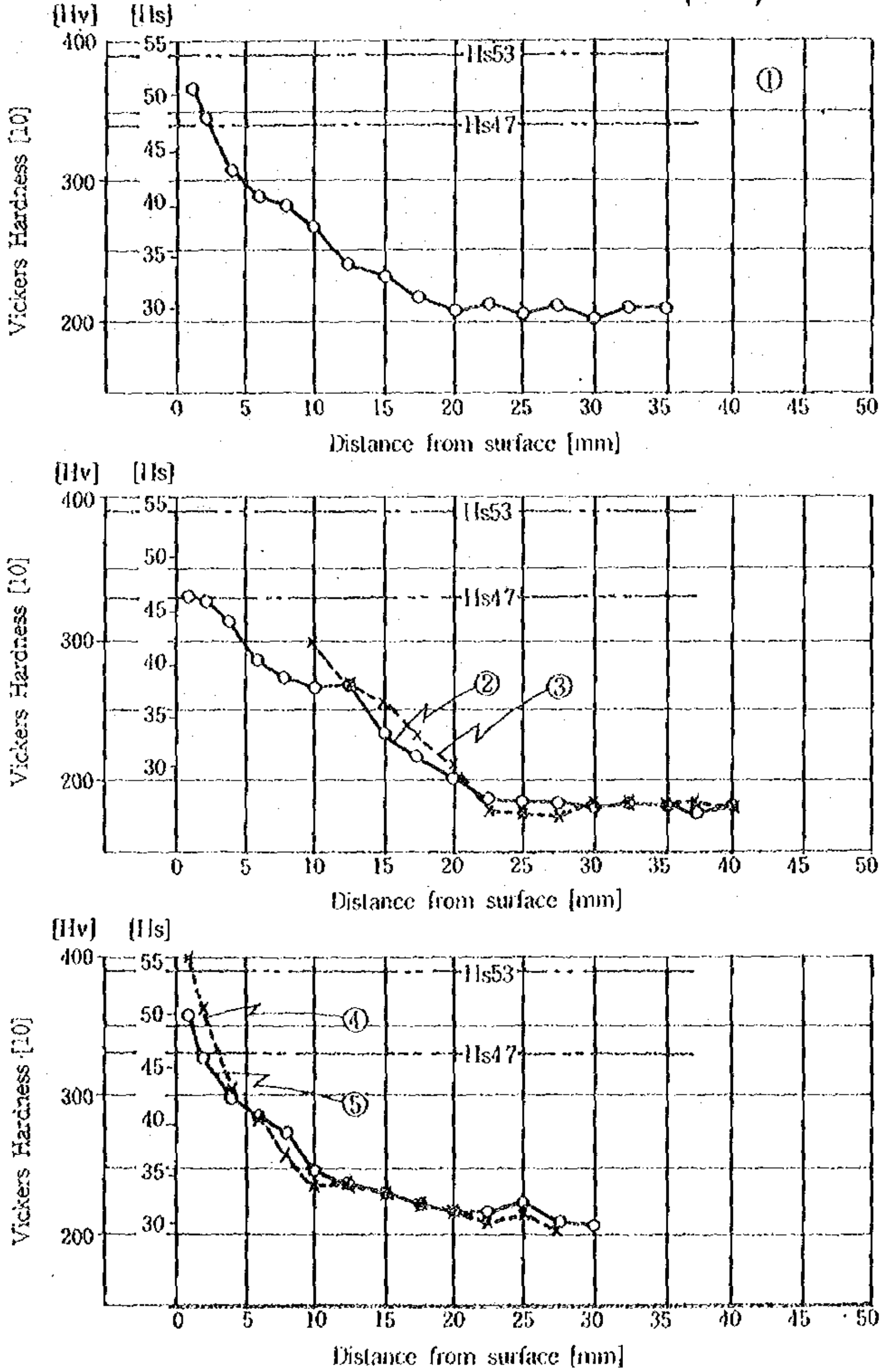


Fig. 3.2.9

·Vickers Hardness
No.2302
(Load 10kg)

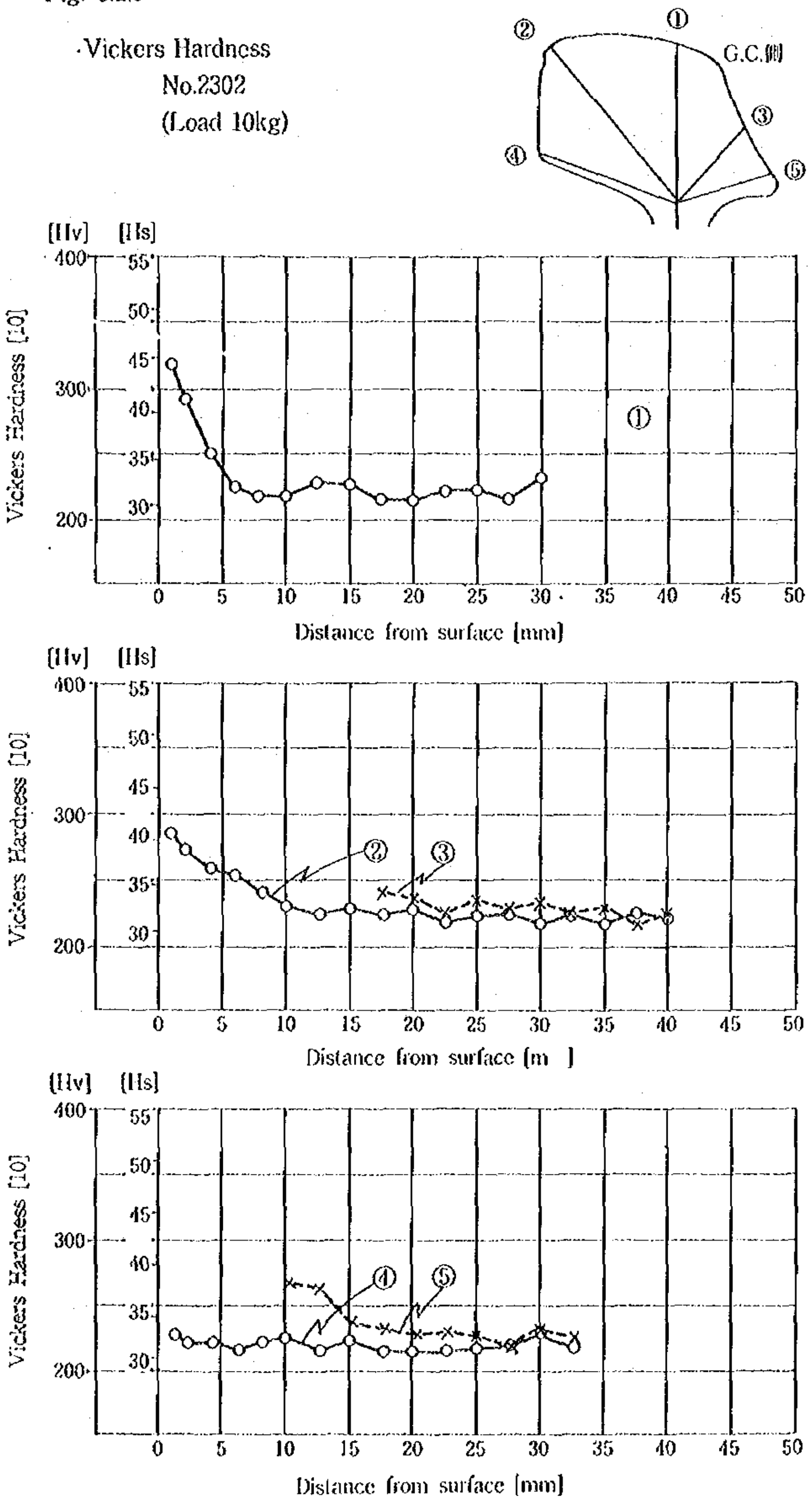


Fig. 3.2.10

Vickers Hardness ②
No.2303
(Load 10kg)

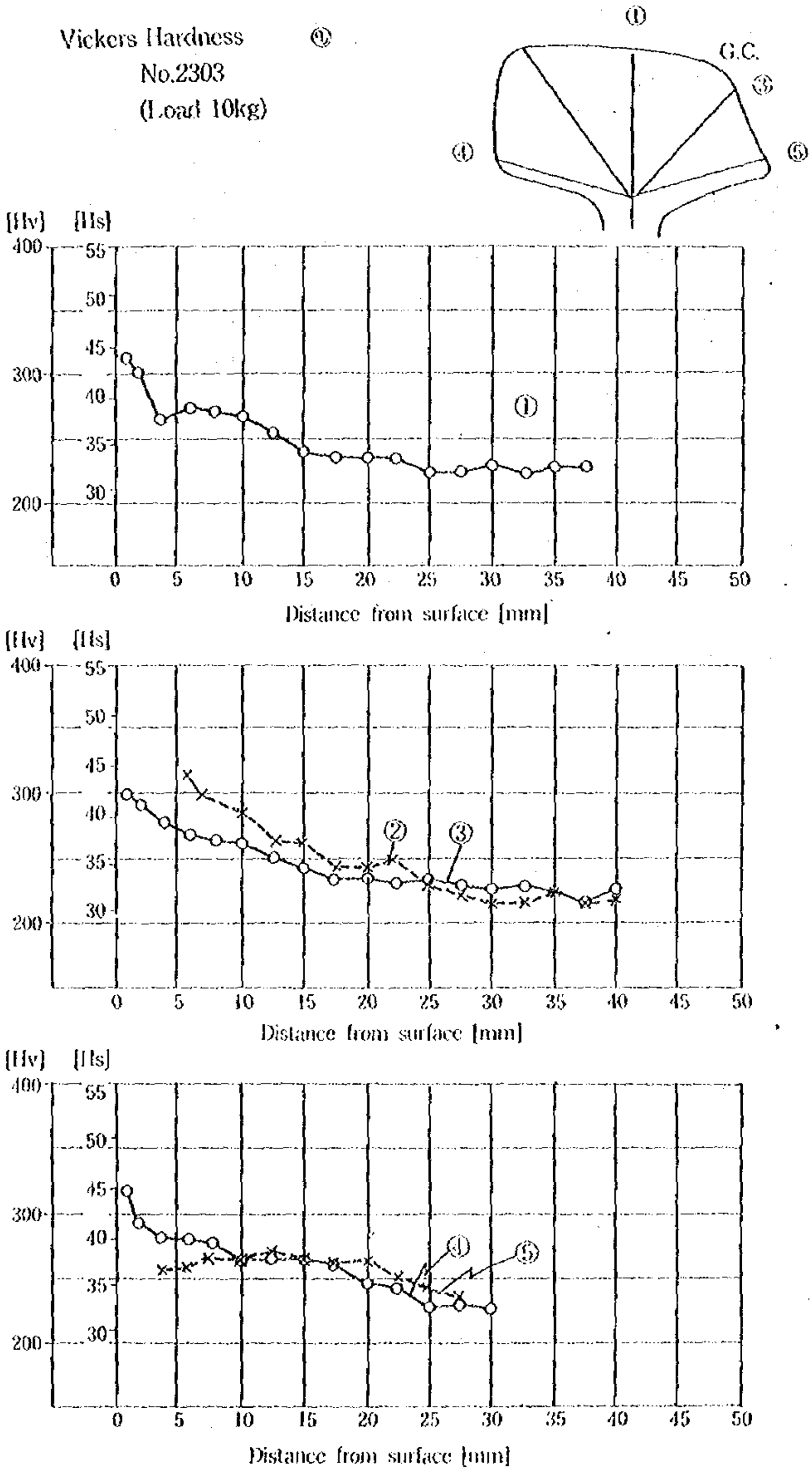
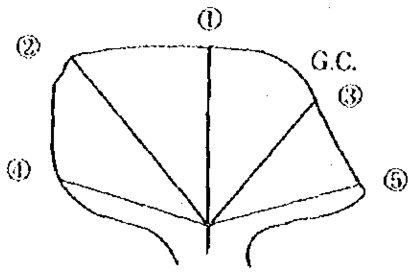


Fig. 3.2.11

Vickers Hardness
No.2304
(Load 10kg)



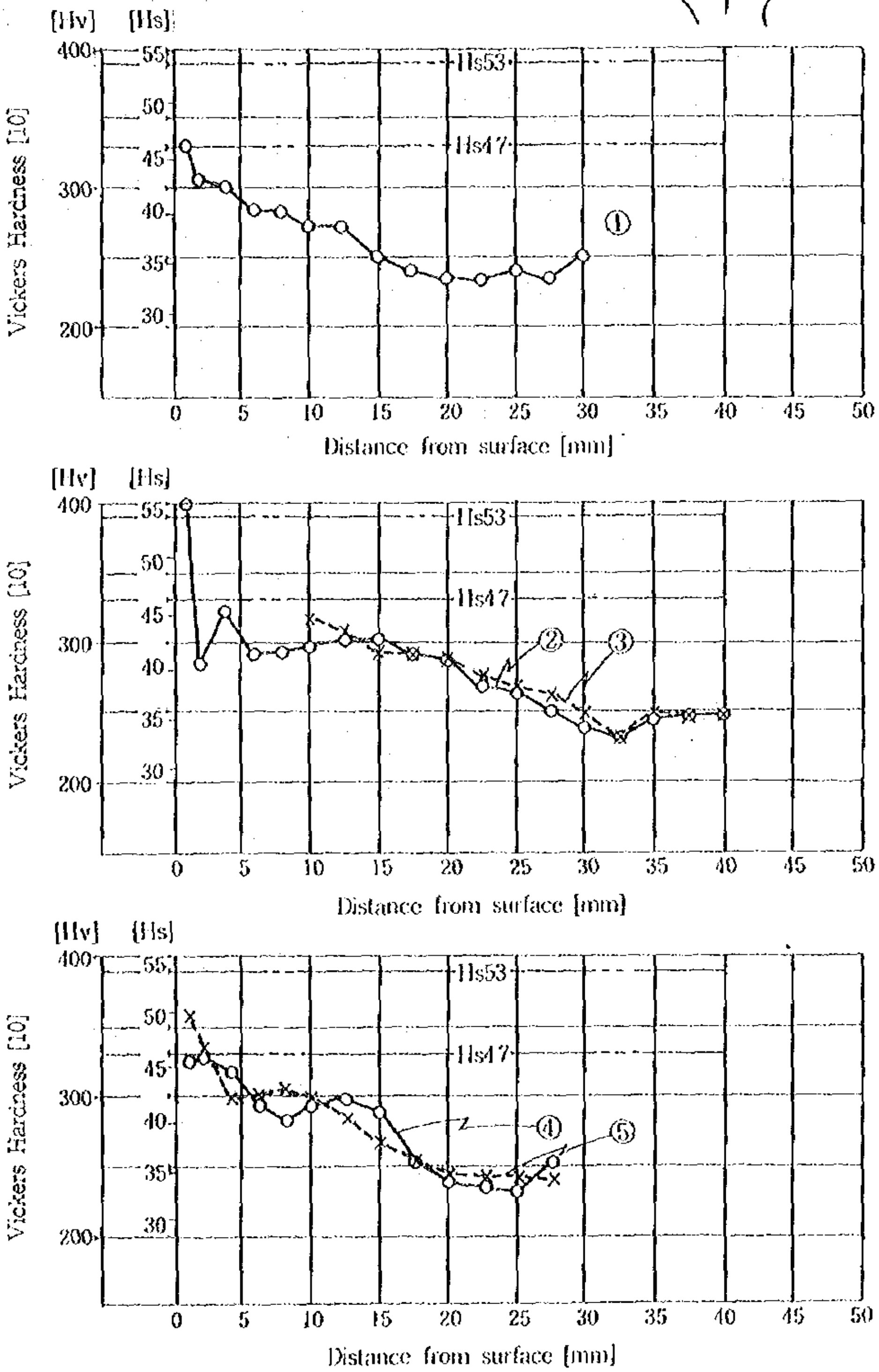
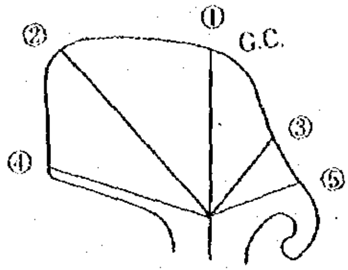
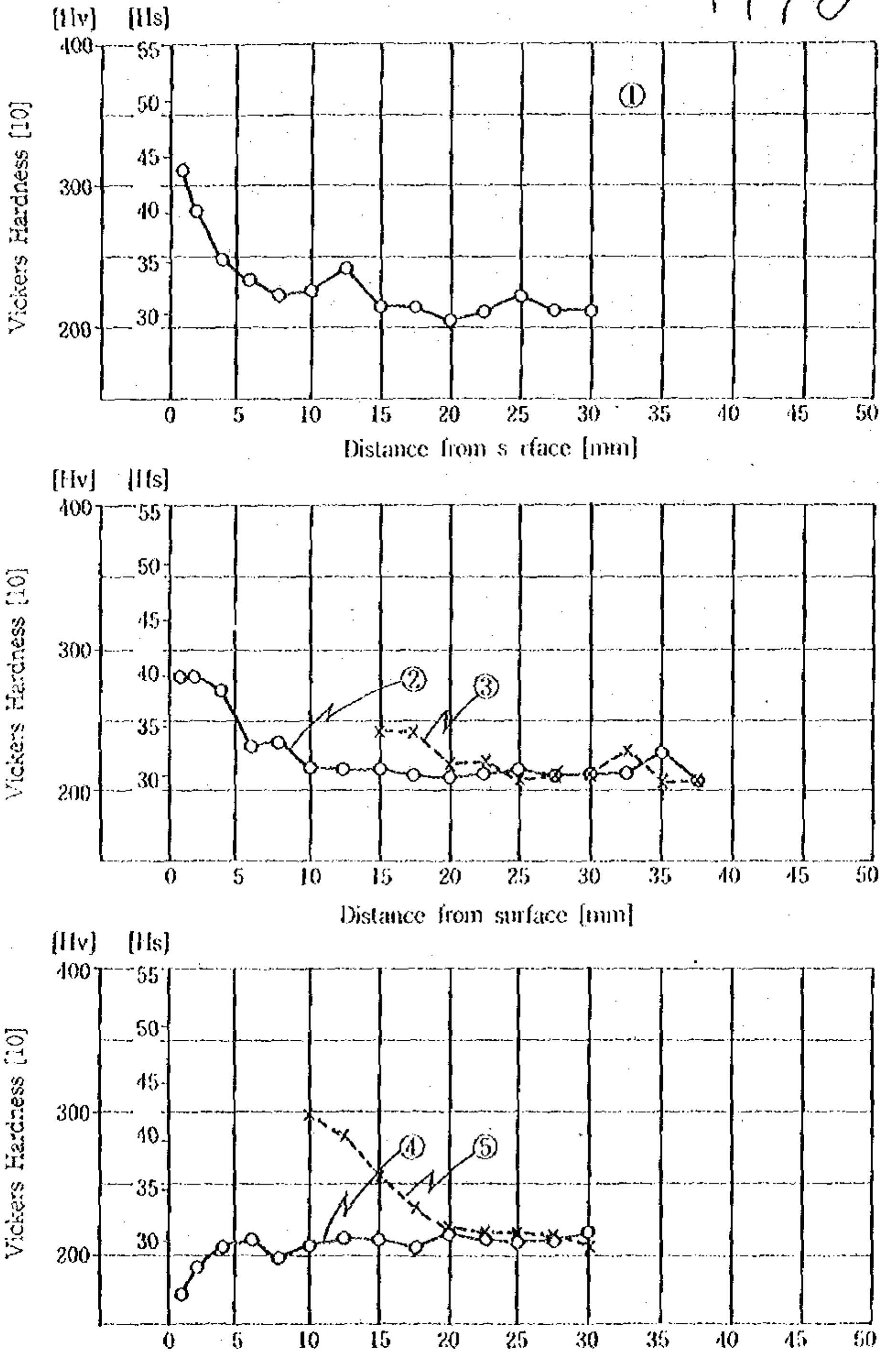


Fig. 3.2.12

Vickers Hardness
No.2305
(Load 10kg)





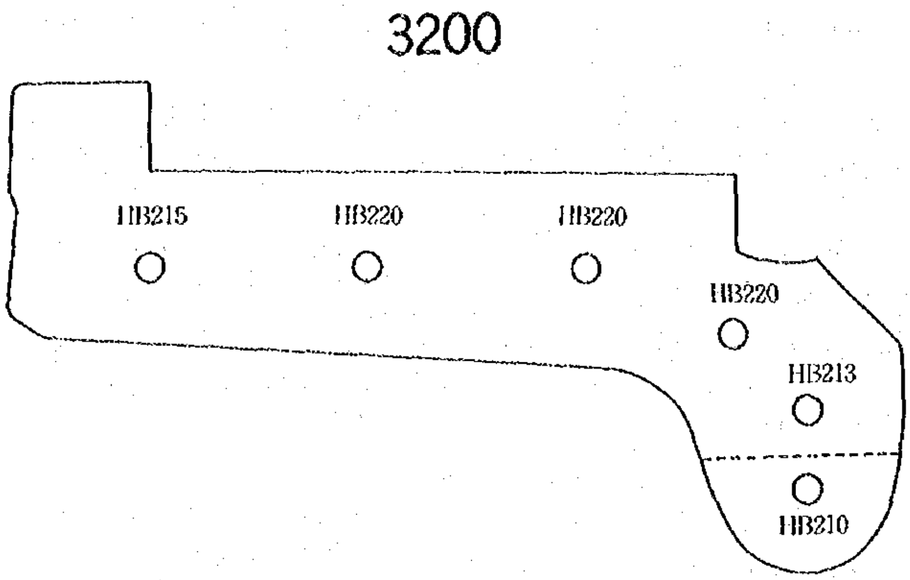
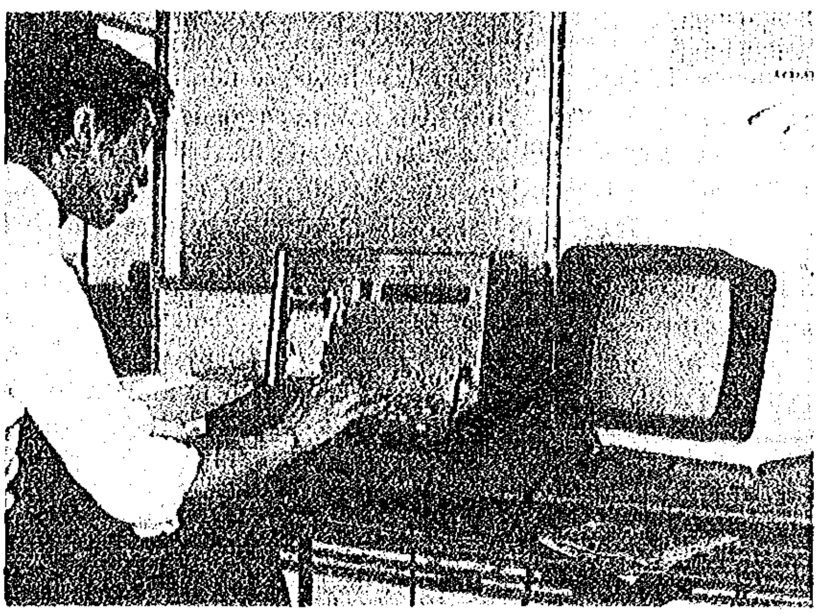


Fig. 3.2.13 Tir hardness distribution



3.3 Test Results

So far as the test results show, there are no samples which are condemned. It is therefore judged that the rail wear is not ascribable to defectiveness of material.

The rails from which samples are obtained are neither equal in, nor known clearly about, the period of use and service conditions, and are hard to compare with each other.

Of the rails tested, 2305, which is 70 kg/mm^2 medium-carbon manganese steel, has showed the most serious wear.

Taken altogether, it is considered that the rails to be laid in the wear-prone sections in the mountainous regions should be of a high-carbon steel of a fine pearlite structure.

The rails filling the bill are available as follows.

(1) High-carbon wear-resistance alloy steel rail

Krupp (West Germany), ATH

(2) Head-hardened rail

US Steel, Curb Master

Nippon Steel Corp. & Nippon Kokan, NHH rail

W.G. alloy rails have already been installed in the Northeast Line with a substantive result in the reduction of wear. But the alloy rails are disadvantageous in that they are expensive because they use precious alloying elements such as chromium. The rails which are hardened by heat treatment to have a fine pearlite structure are more economical than the alloy rails. By way of reference, rails of this kind used in the Japanese National Railways (hereinafter referred to as JNR) are outlined in the appendix.

It should be noted however that the wear-prone sections are as small in radius of curvature as 200 m, and that the head-hardened rails used in the JNR may, or may not, do themselves justice. The measurements in the North Line show that there is no significant difference in the degree of wear between the ordinary rail and head-hardened rail.

4. Structural Design of Car and Track, and Rail Wear

4.1 Structural Factors of Car and Track That Govern Rail Wear

The factors that cause rail wear have been discussed in para. 2.2. Of them, the development of lateral force between the wheel flange and rail and the development of slip between the wheel flange and rail are concerned with the structural design of the car and track and the shapes of the structural members thereof.

As regards the track structure and the shapes of track structural members, the following are considered most significant to rail wear.

(1) Cant

(2) The slack of track

(3) Rail shape

As regards the car structure and the shapes of car structural members, the following are considered most significant to rail wear.

(1) Arrangement of axles

(2) Turning performance of bogie

(3) Axle load

(4) Shape of wheel, and dimensions of wheel axle

4.2 Deficiency in Cant, and Lateral Force

The track is provided with a cant at a curved section so that the resultant force of the centrifugal force and gravitational force to be developed on a train passing through the curved section will fall normal to the center of the track.

It should be noted however that the train does not always run at a speed that goes well with the preset cant; namely, any train passing through a curved section will more or less experience what is left uncounterbalanced of the centrifugal acceleration or gravitational acceleration.

This unbalance develops when the cant is too much or too short as against the train speed. If the cant is deficient, the train will experience an acceleration tending outward of the center of curvature. If the cant is excessive, the train will experience an accelerating tending inward toward the center of curvature.

The resultant unbalanced force will act on the bogie by way of the connection between the car body and bogie, developing a lateral force on the rails. Let us assume a simple example in which vibration is neglected and in which the center of friction of the bogie lies near the rear axle. Then, the lateral force, Q, is approximated by the following formula.

$$Q \doteqdot \frac{W}{2} \mu [1 - \frac{h_G*}{a}(\frac{v^2}{gR} - \alpha)] + 2(\frac{v^2}{gR} - o) \quad \ldots (4.1)$$

Where, W: axle load

μ : friction coefficient between rail and wheel

a: ½ of gage

h_G*: height of gravitational center

R: Radius of curvature

v: velocity

α: cant

g: gravitational acceleration

In Eq. (4.1), the term, $(\frac{v^2}{gR} - o)$, is a centrifugal acceleration due to shortage of cant. If this is taken as C, Eq. (4.1) is rewritten as follows.

$$Q \doteqdot \frac{W}{2} [\mu (1 - \frac{hG^*}{a} C) + 2C] = \frac{W}{2} [\mu + (2 - \frac{\mu hG^*}{a})C]$$

For ordinary cars, $\mu \doteqdot 0.3$ and $h_G^* /a \doteqdot 1.5$ to 2.0, and the increase in C, that is, increase in the cant leads to an increase in the lateral force. In the RSR, the cant, e, is determined according to the following formula.

$$e = \frac{2}{3} [\frac{8.338}{R} (V + 5)^2] \text{ (mm)}$$

Where, V: maximum speed at the curved section (km/h)

R: radius of curvature (m)

This corresponds to two-thirds of the equilibrium cant as shown in Table 4.2.1.

In the RSR, the maximum cant is set at 90 mm, and the allowable cant shortage at 50 mm.

The maximum speed is given by the following formula.

$V_{max} = / (e + to) R/8.338$ in which (e + 50) is less than 90 mm.

In the RSR, the maximum speed of the train is determined by taking into account the conditions relating to track structure as shown in Table 4.2.2.

In the RSR, the locomotives are equipped with a speed recorder for recording the running speeds. In November 1979, eight trains were investigated about the speeds passing through 105 curved sections between Hang Chat St. and The Chompu St. on the North Line. As shown in Fig. 2.2.1, the Hang Chat St. to The Chompu St. section runs on a hilly terrain, and the maximum speed is limited to 45 km/h.

The survey results are as shown in Tables 4.2.3.1 through 4.2.3.3. If the speed recorder had been accurate enough, there were sections where the trains were run at a speed far above the maximum value. Fig. 4.2.1 shows the relative frequencies of curves for trains with respect to speed. The train speeds exceeded the maximum limit at about 30% of curves.

The equilibrium cants were calculated according to the record, and the cant deficiencies were calculated in Tables 4.2.3.4 through 4.2.3.6 and Fig. 4.2.2 with reference to the cants specified in Table 4.2.1. From these tables and figure, the following are found.

(1) Cases in which the train ran at a cant deficiency of more than 10 mm were more than 30%.

(2) Cases in which the train ran at a cant deficiency of more than 30 mm were more than 10%.

(3) There were cases in which express trains and passenger trains cleared the curves at a high speed in spite of a serious cant deficiency.

Turning along the curves at a high speed to develop a shortage in cant is a cause of developing a serious lateral force, and the situation must be improved. Namely, the cants must be set to meet the train speeds. In the JNR, the cant is calculated according to the following formula.

$$C = 8.4 \frac{Vo^2}{R}$$

Where, C: set cant (actual cant)

Vo: average speed

R: radius of curvature

There are many formulas proposed for the calculation of the average speed appearing in the formula above. Usually, however, the following formula is applied.

$$Vo = \sqrt{\Sigma V_i^2 / N}$$

Where, V_i: speed at which the train clears the curve

N: number of trains

Assuming that almost every train runs at a limit speed of 45 km/h at the sharp curves of R = 180 m, the deficiency of cant according to the formula employed by the RSR will be as follows.

$$E - c = 8.338V^2 / R - \frac{2}{3} [8.338 (V + 5)^2 / R]$$

$$= 8.338 (45) - \frac{2}{3} [8.338 (50)^2 / 180] = 16.6$$

Namely, this deficiency happens to all the trains. Although a method in which the actual cant is set at, say, two-thirds of the equilibrium cant is practical when the curve-clearing train speeds are varied, but it is not reasonable if the train speed settings are quite limited.

It is inferred that the RSR is forced to use two-thirds of the equilibrium cant because the train operation diagram (speed curve) necessary for scheduled running of trains has not yet been established.

The speed curve is a diagram drawn based on the tractive force of the loco and train resistance in order to show the speed vs. time relationship of a train. It can be determined theoretically according to actual train running data.

The speed curve brings about the following benefits.

(1) The train service time is made clear, making it possible to offer punctual train services.

(2) The speed curve can be used for the projection of power consumption by train.

(3) The speed curve can be used as a measure to assess the speed increase due to improvement in alignment, profile and route change.

(4) The speed curve can be used as a measure to assess the reduction in the running time due to increase in the train speed.

(5) The speed curve can be used for the planning of line structure, e.g., cant and length of transition curve.

The speed curve can be drawn up according to the following procedure. An example of the speed curve is shown in Fig. 4.2.3.

(1) Draw a diagram showing the relationship between the tractive force and speed of the tractive unit.

(2) Draw a train resistance curve according to calculation.

(3) Calculate the acceleration of the train according to (1) and (2) above.

(4) Delineate the speed vs. distance curve by applying the result of (3) above to the following formula.

$$S = \frac{a(V_2^2 - V_1^2)}{f_m}$$

Where, S: distance

a: constant (4.1 to 4.3 in Japan)

fm: mean accelerating force

V: speed

$$S = V^2 / 7.2D$$

Where, D: deceleration due to braking

(5) Draw the speed curve according to (4) above.

The speed curve thus drawn should be compared with the actual running conditions of the train, and should be corrected by taking into account the factors relating to season and weather conditions.

For the purpose of minimizing the cant deficiency, it is recommended to determine the curve-clearing speeds of up and down trains on a single track according to the speed curve and calculate the average speed according to the following formula.

$$Vo = / \Sigma V_i^2 / N$$

The speed curve have many advantages, and should preferably be prepared in cooperation with train operators for the purpose of facilitating the planning of track facilities. For pressing needs, there is a method using an actual train operation diagram.

In this method, the data of the speed recorders mounted on the locomotives are marshaled to obtain a standard operation diagram, which is then used to determine the cant. This method, however, is inferior to the planned train operation diagram (speed curve) method explained in the foregoing in the following points.

(1) Since the actual achievements are taken as a basis, the actual train operation diagram is weak in compelling power. According to the planned train operation diagram, if the train is operated as instructed on it, the train will be run at a planned speed and to a planned time schedule.

With the actual train operation diagram, which is obtained by averaging actual achievements, however, the train operations cannot always be set the same.

(2) The train operating methods shown on the actual train operation diagram are not always the best, and may involve losses in the running time and energy consumption.

Anyway, the reduction of the cant deficiency at the sharp curves will go a long way toward the reduction of rail wear, and the following measures are recommended, accordingly.

(1) To statistically marshal the train operation data obtained by the speed recorders mounted on the locomotives for the purpose of determining the average curve-clearing speeds.

(2) To set the cants in a manner not to cause a serious deficiency in cant as against the average curve-clearing speeds determined.

To this end, it is recommended to statistically analyze the data of at least 200 trains.

The data obtained about the eight trains this time are too short for the calculation of the cants.

The methods explained above are all acceptable logically. If it is permitted to sacrifice the logicality to a slight degree, the following method is also available. If there are trains running at a speed which develops a cant shortage of as much as 70 mm as shown in Fig. 4.2.3, it is necessary to increase the cants on the average.

Namely, the speed at which the set cant is calculated should be increased.

Currently, the speed at which the cant is calculated is (V + 5) km/h. If this is replaced by (V + 10) km/h, the cant for V = 45 km/h is calculated as shown in Table 4.2.4 below.

Table 4.2.4

Radius of curvature	Equilibrium cant at V = 45 km/h	Current cant	Revised cant
200 m	84.4	69.5	84.1
400 m	42.2	34.7	42.0
600 m	28.1	23.2	28.0
800 m	21.1	17.3	21.0
1,000 m	16.9	13.9	16.8

This across-the-board increase in cant will reduce the rail wear.

In this method, however, the sections where the maximum speed is high will have an excessive cant. Thus, this method should be limited to the sections where the maximum speed is low.

In this method, the cant is given by the following formula.

$$e = \frac{2}{3}\left[\frac{8.338\,(V + 10)^2}{R}\right]$$

If R = 180 m, the cant is calculated as follows.

$$e = \frac{2}{3}\left[\frac{8.338\,(45 + 10)^2}{180}\right] = 93.4 \text{ mm}$$

Namely, it is desired to set the maximum cant at 95 mm.

Table 4.2.1 Actual Cant in mm

Speed km/hr / Radius m.	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Spead km/hr / Radius m.
160	5	10	15	20	30	45	55	70	85										160
165	5	10	15	20	30	45	55	70	85										165
180	5	5	10	20	30	40	50	65	75										180
200		5	10	10	25	35	45	55	70	85									200
225		5	10	10	20	30	40	50	60	75	90								225
250		5	10	10	20	25	35	45	55	65	80								250
300		5	5	10	15	25	30	40	45	55	65	80	90						300
325		5	5	10	15	20	25	35	45	60	60	70	85						325
350		5	5	10	15	20	25	30	40	50	55	65	80	90					325
375		5	5	10	15	20	25	30	35	45	55	65	75	85					350
400		5	5	10	15	15	20	30	35	40	50	60	70	80	90				400
420		5	5	10	10	15	20	25	35	40	50	55	65	75	85				420
450			5	10	10	15	20	25	30	35	45	50	60	70	80	90			450
470			5	5	10	15	20	25	30	35	45	50	60	65	75	85			470
500			5	5	10	15	20	25	30	35	40	45	55	65	70	80	90		500
550			5	5	10	15	15	20	25	30	35	45	50	55	65	75	80	90	550
575			5	5	10	10	15	20	25	30	35	40	45	55	60	70	80	85	575
600			5	5	10	10	15	20	25	30	35	40	45	50	60	65	75	85	600
650			5	5	5	10	15	15	20	25	30	35	40	50	55	60	70	75	650
700			5	5	5	10	15	15	20	25	30	35	40	45	50	55	65	70	700
750				5	5	10	10	15	20	25	25	30	35	40	45	55	60	65	750
800				5	5	10	10	15	15	20	25	30	35	40	45	50	55	65	800
880				5	5	10	10	15	15	20	25	25	30	35	40	45	50	55	880
900				5	5	10	10	15	15	20	20	25	30	35	40	45	50	55	900
985				5	5	5	10	10	15	15	20	25	30	30	35	40	45	50	985
1000				5	5	5	10	10	15	15	20	25	30	30	35	40	45	50	1000
1100				5	5	5	10	10	15	15	20	20	25	30	35	35	40	45	1100
1165				5	5	5	10	10	10	15	10	20	25	25	30	35	40	45	1165
1200					5	5	5	10	10	15	10	20	25	25	30	35	40	40	1200
1230					5	5	5	10	10	15	10	20	20	25	30	35	35	40	1230
1250					5	5	5	10	10	15	10	20	20	25	30	30	35	40	1250
1300					5	5	5	10	10	15	10	20	20	25	25	30	35	40	1300
1400					5	5	5	10	10	10	10	15	20	25	25	30	30	35	1400
1500					5	5	5	10	10	10	10	15	20	20	25	25	30	35	1500
1600					5	5	5	5	10	10	10	15	15	20	20	25	30	30	1600
1700						5	5	5	10	10	10	15	15	20	20	25	25	30	1700
1750						5	5	5	10	10	10	15	15	20	20	25	25	30	1750
1800						5	5	5	10	10	10	15	15	15	20	25	25	30	1800
2000						5	5	5	5	10	10	10	15	15	20	20	25	25	2000
2500							5	5	5	5	10	10	10	15	15	15	20	20	2500
3000								5	5	5	5	10	10	10	10	15	15	15	3000
4000									5	5	5	5	5	10	10	10	10	15	4000
5000										5	5	5	5	5	5	10	10	10	5000
7000												5	5	5	5	5	5	5	7000

Table 4.2.2 Data on Train Speed

Track Characteristics	Max. allowable train speed (Kph.)	Track condition
Tangent	100	-80 - lb long welded rails with elastic rail fastenings; wood or concrete sleepers at 65 - cm. spacing; 20 - cm. ballast cushion.
	90	-70/80-lb rails(or reconditioned 80 - lb long weldod rails) with either elastic rail fastenings, or a combination of dog spikes and elastic rail fastenings; wood or concrete sleepers at 65 - 67 - cm spacing; 20 - cm ballast cushion.
	70	-60 - 80 - lb rails either standard rail length or short welded with either dog spikes, or a combination of dog spikes and elastic rail fastenings; 2nd grade wood sleepers, or reconditioned ones at 70 - cm spacing; 15 - cm ballast cushion.
Curve	45	-R < 400 m, and G > 15 ‰
	55	-R < 400 m, and 10 ‰ < G < 15 ‰
	Same as tangent	-R > 400 m, and G < 10 ‰
Turnout	80/30	-80 lb, No. 12
	60/15	-70 lb, No. 10
Siding	30	-Turnouts of No. 12 only.
	15	-When turnouts of less than No. 12 are concerned.

Fig. 4.2.1

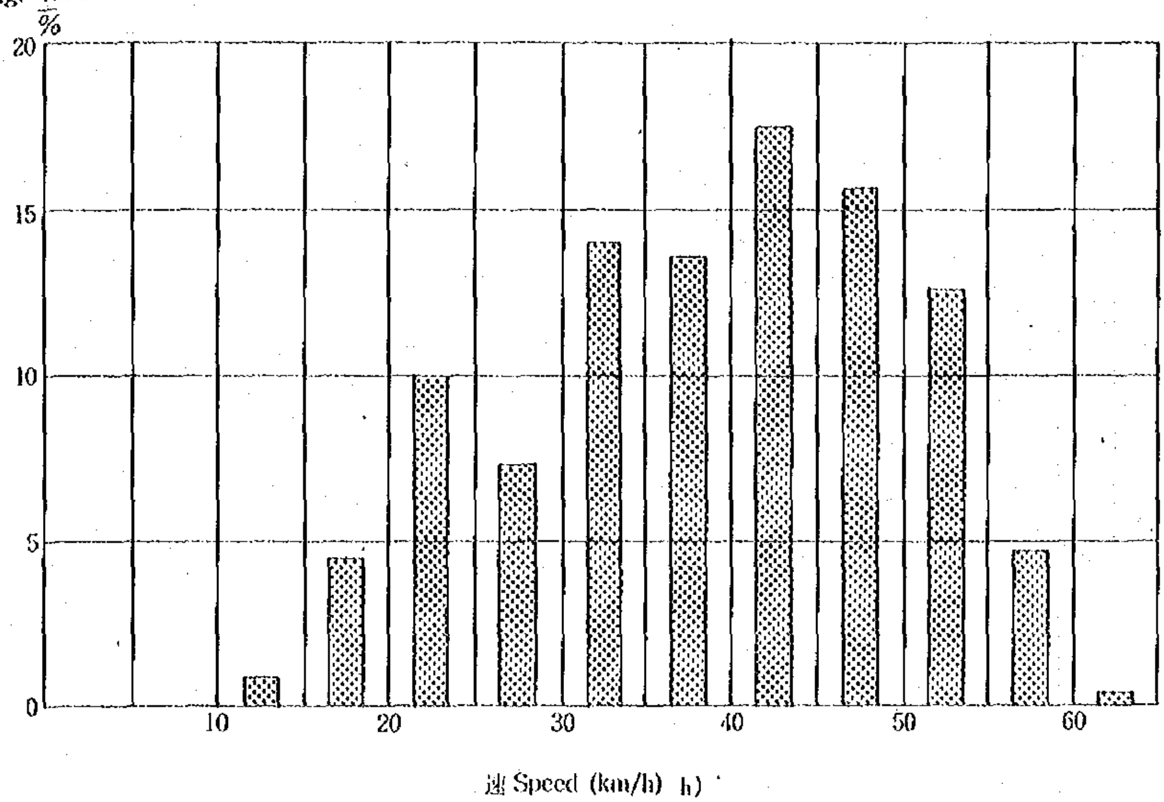


Fig. 4.2.2

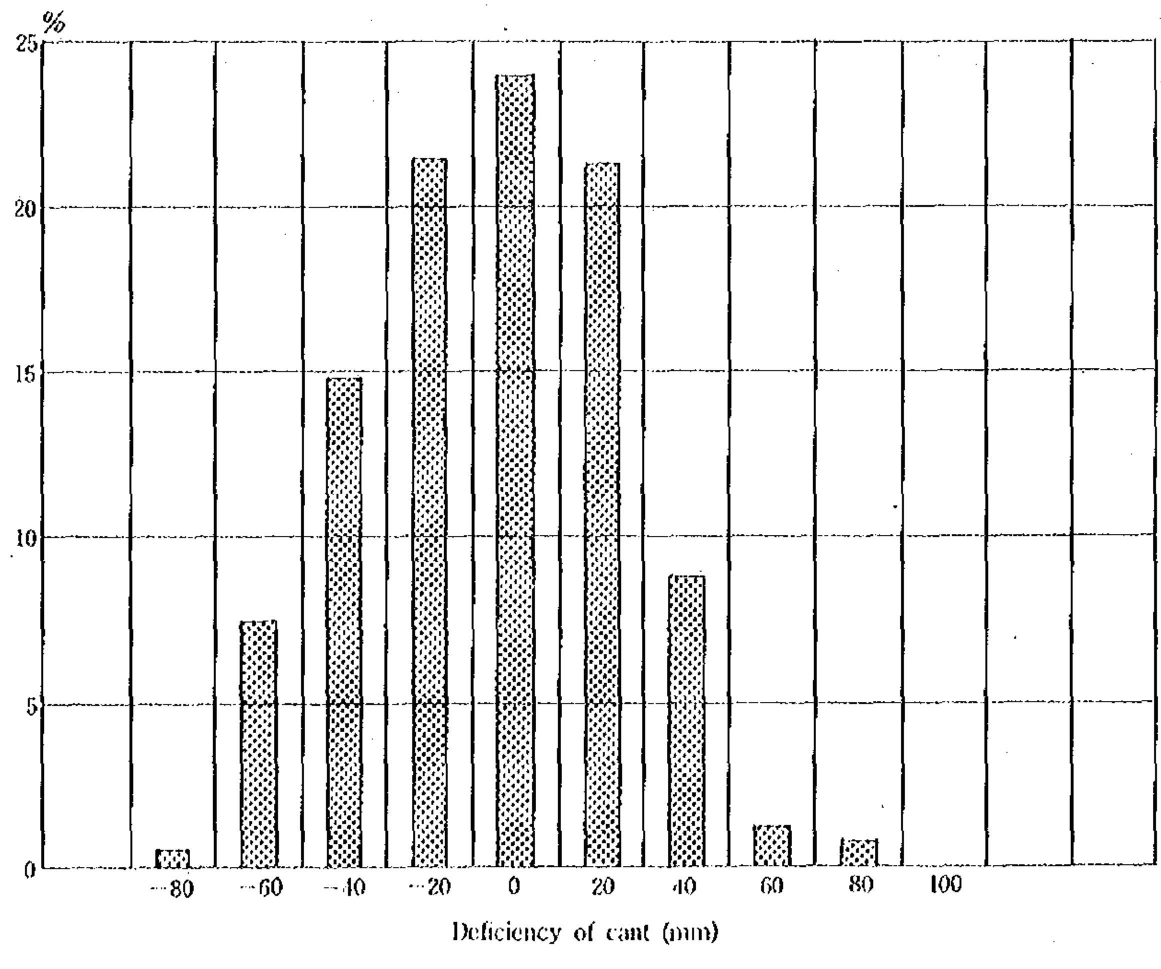


Table 4.2.3.1

Nov., 1979

Location		Radius of curvature	Train speed (km/h)							
B C	E C		643	602	643	636	7	8	38	37
		m								
660.038	660.299	400	46	50	50	37	50	50	60	48
925	661.051	400	37	37	45	47	37	40	10	52
661.172	369	200	33	37	43	47	40	40	50	50
384	498	400	33	37	43	47	45	37	55	48
528	779	200	33	37	40	47	46	35	55	50
779	923	250	35	37	40	49	49	25	53	50
923	662.046	300	35	37	40	50	50	30	52	50
662.046	177	250	40	37	42	50	50	50	52	50
177	381	180	40	37	44	50	50	55	51	50
439	848	180	43	37	45	50	50	55	51	50
860	663.006	200	43	40	42	50	52	57	52	50
663.139	282	300	45	40	42	50	52	59	52	50
306	725	200	45	42	42	52	50	59	52	50
664.122	664.368	400	45	45	50	50	51	59	57	51
854	665.035	400	35	40	42	50	55	50	50	58
665.113	442	300	37	40	40	45	55	50	42	58
442	849	300	45	46	45	42	50	51	45	52
666.007	666.545	200	43	48	50	52	45	40	48	51
617	889	300	45	40	42	50	50	35	40	52
889	667.105	400	50	48	50	45	45	59	50	48
667.135	279	200	45	50	52	45	40	59	54	47
303	494	300	40	45	50	47	40	55	55	49
530	722	400	32	45	50	45	40	55	50	50
740	998	200	32	40	40	45	42	45	40	55
998	668.144	250	32	45	32	47	50	45	40	56
668.288	515	180	40	45	35	47	50	40	37	52
515	886	300	35	42	40	45	52	35	35	52
976	669.158	300	50	42	48	45	50	40	35	50
669.188	350	200	50	45	48	45	47	50	35	49
375	560	400	45	47	49	50	42	55	35	49
590	775	400	40	47	47	50	40	55	40	50
998	670.250	300	32	47	40	50	40	55	35	51
670.580	832	800	37	49	35	49	50	50	40	50
868	671.037	200	30	49	39	42	46	47	40	45
671.561	735	180	20	40	38	48	45	47	35	55
777	672.077	180	25	35	40	40	50	35	42	50

Table 4.2.3.2

Location		Radius of curvature	Train speed (km/h)					(km/h)		
B. C	E. C		643	602	643	636	7	8	38	37
km	km	m								
672.210	672.417	180	30	35	42	45	50	35	45	49
440	662	180	33	37	44	45	50	37	45	48
679	848	200	33	41	45	40	46	40	47	47
673.069	673.219	200	35	45	40	45	46	45	52	50
219	547	800	37	42	40	45	50	42	52	50
577	912	300	40	42	41	45	50	42	51	50
674.154	674.346	180	43	40	42	45	45	47	48	49
370	525	180	43	37	45	45	40	47	45	45
657	867	600	35	40	47	45	40	62	42	40
891	675.178	180	28	38	42	37	27	45	41	35
675.208	459	180	27	48	40	37	27	45	42	35
477	722	180	25	38	35	35	25	45	40	33
746	676.004	180	25	38	25	35	20	47	41	31
676.022	207	180	25	38	20	35	25	46	41	31
261	321	300	25	38	20	30	17	47	41	31
351	483	300	25	38	25	30	15	47	41	31
525	681	300	25	35	25	30	15	50	40	31
891	677.096	400	25	30	22	27	17	40	40	31
676.108	223	300	25	20	20	25	17	40	30	31
292	400	300	25	20	21	20	20	40	47	31
448	544	300	25	15	22	20	20	37	40	31
580	688	300	25	25	20	20	20	40	37	31
677.018	678.126	300	25	30	18	20	20	40	32	31
144	275	250	25	27	20	22	20	45	30	31
447	663	180	25	28	18	20	22	45	37	31
705	890	180	25	32	15	20	22	42	49	31
908	679.033	300	25	32	18	20	22	43	40	31
678.191	352	180	25	30	18	22	22	45	40	31
370	496	180	25	30	18	22	22	45	40	31
514	813	180	25	27	15	25	22	45	40	31
831	680.035	180	25	22	20	22	20	40	42	31
679.065	149	300	25	15	20	20	20	41	41	31
173	263	300	25	15	18	20	20	40	40	31
287	425	200	25	15	18	20	20	40	40	31
448	628	180	25	25	15	20	21	40	40	31
659	844	600	25	25	15	22	21	40	41	31

Table 4.2.3.3

Location		Radius of curvature	Train speed (km/h)							
B. C	E. C		643	602	643	636	7	8	38	37
km	km	m								
680.898	681.032	180	25	26	15	22	21	45	41	31
681.152	350	180	25	25	15	20	21	50	40	31
368	529	200	20	27	17	25	22	40	40	31
682.904	683.028	450	10	20	15	30	30	20	10	30
683.035	145	300	10	15	10	20	30	20	20	20
215	303	300	20	20	15	30	30	20	30	30
309	423	300	20	25	17	30	40	35	35	40
532	699	180	20	35	15	32	52	30	37	45
795	897	800	20	40	15	35	50	36	36	40
907	684.126	200	20	40	15	35	35	36	35	40
684.210	443	180	18	38	17	35	37	36	33	42
479	785	500	22	38	20	37	40	35	32	41
803	685.075	180	20	37	15	35	50	35	34	40
685.081	377	200	18	37	15	35	45	32	34	38
379	746	180	18	35	17	32	47	30	35	42
902	686.057	180	22	32	10	32	37	30	37	40
686.089	283	180	22	32	20	32	45	30	37	41
360	625	180	22	30	22	32	55	30	35	40
668	918	180	22	28	20	32	55	30	35	42
975	687.058	180	22	25	20	32	52	30	35	45
687.089	331	180	10	25	22	32	52	30	35	42
500	589	180	20	25	25	32	55	30	34	42
514	984	180	22	25	30	32	47	30	31	41
997	688.177	180	20	27	32	32	50	30	30	45
688.236	405	180	22	30	33	32	55	30	31	45
355	630	300	22	30	35	32	55	30	32	42
912	689.037	250	25	38	40	32	50	30	33	45
689.049	167	250	27	42	42	32	55	30	32	45
195	399	180	27	45	43	32	57	32	33	45
417	723	180	26	40	43	35	52	35	35	45
883	690.273	200	42	37	46	35	50	45	42	45
690.413	614	200	35	38	50	45	40	50	49	45
691.221	691.462	300	35	40	48	45	50	51	53	50

Table 4.2.3.4

Location		Radius of curvature	Cant (mm)	Rail wear (mm^2)		Trains and their cant deficiencies (mm)							
B. C	E. C			Inner rail	Outer rail	643	602	643	636	7	8	38	37
km	km	m											
660.038	660.299	400	35	1.857	1.660	9.1	11.1	17.1	-6.5	17.1	17.1	40.0	13.0
925	661.051	400	35	1.772	1.840	-6.5	-6.5	7.2	11.0	-6.5	-1.0	-32.9	21.3
661.172	369	200	70	1.852	1.842	-24.6	-12.9	7.1	22.0	-3.3	-3.3	34.2	34.2
384	498	400	35	1.851	1.683	-12.3	-6.5	3.5	11.0	7.2	-6.5	28.1	13.0
528	779	200	70	1.795	1.680	-24.6	-12.9	-3.3	22.0	18.2	-18.9	56.1	34.2
779	923	250	55	1.824	1.760	-14.1	-9.3	-1.6	25.0	25.0	-34.2	38.6	28.4
923	662.046	300	45	1.830	1.610	-10.9	-6.9	-0.5	24.5	24.5	-19.9	30.1	24.5
662.046	177	250	55	1.855	1.755	-1.6	-9.3	3.8	28.4	28.4	28.4	35.1	28.4
177	381	180	75	1.821	1.630	-0.9	-11.6	14.7	40.8	40.8	65.1	45.5	40.8
439	848	180	75	1.811	1.624	10.6	-11.6	18.8	40.8	40.8	65.1	45.5	40.8
860	663.006	200	70	1.812	1.611	7.1	-3.3	3.5	34.2	42.7	65.5	42.7	34.2
663.139	282	300	45	1.845	1.652	11.3	-0.5	4.0	24.5	30.1	51.7	30.1	24.5
306	725	200	70	1.855	1.905	14.4	3.5	3.5	42.7	34.2	75.1	42.7	34.2
664.122	664.368	400	35	1.839	1.895	7.2	7.2	17.1	17.1	19.2	37.5	32.7	19.2
854	665.035	400	35	1.865	1.647	-9.5	-1.6	1.8	17.1	28.1	17.1	17.1	35.1
665.113	442	300	45	1.819	1.607	-6.9	-0.5	-0.5	11.3	39.0	24.5	4.0	48.5
442	849	300	45	1.869	1.610	11.3	13.8	11.3	4.0	24.5	27.3	11.3	30.1
666.007	666.545	200	70	1.877	1.741	7.1	26.0	34.2	42.7	14.4	-3.3	26.0	38.4
617	889	300	45	1.843	1.663	11.3	-0.5	4.0	24.5	24.5	-10.9	-0.5	30.1
889	667.105	400	35	1.842	1.827	17.1	13.0	17.1	7.2	7.2	37.5	17.1	13.0
667.135	279	200	70	1.850	1.685	14.4	34.2	42.7	14.4	-3.3	75.1	51.6	22.0
303	494	300	45	1.825	1.750	-0.5	11.3	24.5	16.4	-0.5	39.0	39.0	21.7
530	722	400	35	1.834	1.852	-13.7	7.2	17.1	7.2	-1.6	28.1	17.1	17.1
740	998	200	70	1.850	1.535	-27.3	-3.3	-3.3	14.4	3.5	14.4	-3.3	56.1
998	668.144	250	55	1.815	1.653	-20.8	12.5	-20.8	1 .7	28.4	12.5	-1.6	49.6
668.288	515	180	75	1.815	1.732	-0.9	18.8	-18.3	27.3	40.8	-0.9	-11.6	50.3
515	886	300	45	1.802	1.718	-10.9	4.0	-0.5	11.3	30.1	-10.9	-10.9	30.1
976	669.158	300	45	1.831	1.669	24.5	4.0	19.0	11.3	24.5	-0.5	-10.9	24.5
669.188	350	200	70	1.794	1.815	34.2	14.4	26.0	14.4	22.0	34.2	-15.9	30.1
375	560	400	35	1.847	1.622	7.2	11.0	15.0	17.1	1.8	28.1	- 9.5	15.0
590	775	400	35	1.837	1.788	-1.6	11.0	11.0	17.1	-1.6	28.1	- 1.6	17.1
998	670.250	300	45	1.842	1.938	-16.5	16.4	-0.5	24.5	-0.5	39.0	-10.9	27.3
670.580	832	800	15	1.850	1.760	-0.7	10.0	-2.2	10.0	11.0	11.0	1.7	11.0
868	671.037	200	70	1.847	1.736	-32.4	30.1	-6.6	3.5	18.2	22.0	-3.3	14.4
671.561	753	180	75	1.787	1.870	-56.5	-0.9	-8.1	31.7	18.8	27.3	-18.3	65.1
777	672.077	180	75	1.814	1.827	-46.0	-18.3	-0.9	-0.9	40.8	-18.3	-6.7	40.8

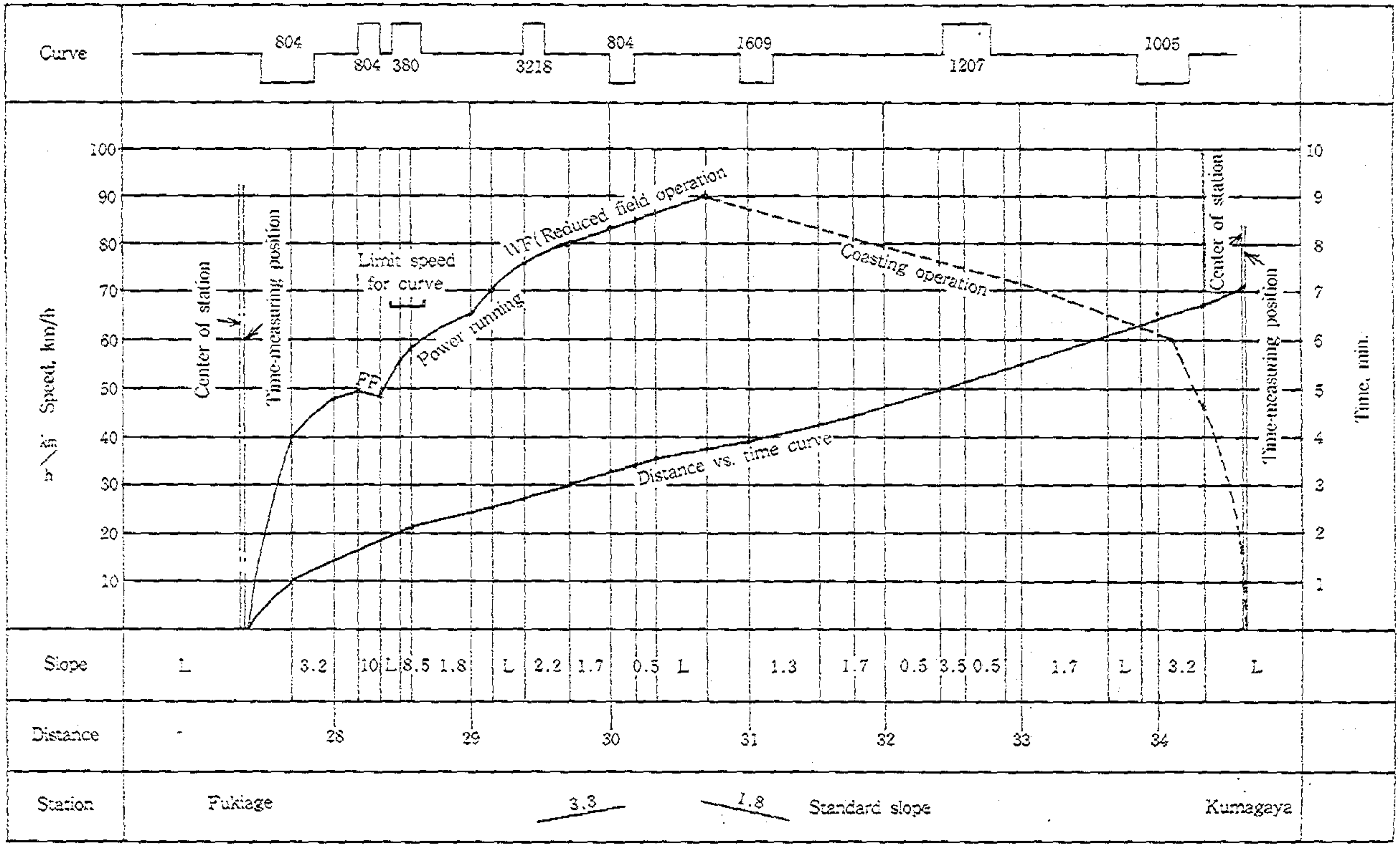
Table 4.2.3.5

Location		Radius of curvature	Radius of curvature	Rail wear (mm^2)		Trains and their cant deficiencies (mm)							
B. C	E. C			Inner rail	Outer rail	643	602	643	636	7	8	38	37
km	km	m											
672.210	672.417	180	75	1.786	1.530	-33.4	-18.3	6.7	18.8	40.8	-18.3	18.8	36.2
440	662	180	75	1.785	1.657	-24.6	-11.6	14.7	18.8	40.8	-11.6	18.8	31.7
679	848	200	70	1.827	1.622	-24.6	0.1	14.4	-3.3	18.2	-3.3	22.0	22.0
673.069	673.219	200	70	1.770	1.512	-18.9	14.4	-3.3	14.4	18.2	14.6	42.7	34.0
219	547	800	15	1.857	1.792	-0.7	3.4	1.7	6.1	11.0	3.4	13.1	11.0
577	912	300	45	1.816	1.680	-0.5	4.0	1.7	11.3	24.5	4.0	27.3	24.5
674.154	674.346	180	75	1.767	1.725	10.6	-0.9	6.7	18.8	18.8	27.3	31.7	36.2
370	525	180	75	1.805	1.680	10.6	-11.6	18.8	18.8	-0.9	27.3	18.8	18.8
657	867	600	25	1.848	1.782	-8.0	-2.8	5.7	3.1	-2.8	28.4	-0.5	-2.8
891	675.178	180	75	1.800	1.610	-38.6	-8.1	6.7	-11.6	-41.2	18.8	2.9	-18.3
675.208	459	180	75	1.785	1.602	-41.2	-8.1	-0.9	-11.6	-41.2	18.8	6.7	-18.3
477	722	180	75	1.762	1.810	-46.0	-8.1	-18.3	-18.3	-46.0	18.8	-0.9	-24.6
746	676.004	180	75	1.811	1.550	-46.0	-8.1	-46.0	-18.3	-56.5	27.3	2.9	-30.5
676.022	207	180	75	1.767	1.810	-46.0	-8.1	-56.5	-18.3	-46.0	23.0	2.9	-30.5
261	321	300	45	1.820	1.643	-27.6	-4.9	-33.9	-19.9	-37.0	16.4	1.7	-18.3
351	483	300	45	1.841	1.690	-27.6	-4.9	-27.6	-19.9	-38.7	16.4	1.7	-18.3
525	681	300	45	1.862	1.650	-27.6	-10.9	-27.6	-19.9	-28.7	24.5	-0.5	-18.3
891	677.096	400	35	1.800	1.660	-21.9	-16.2	-24.9	-19.8	-38.9	-1.6	-1.6	-14.9
677.108	223	300	45	1.844	1.715	-27.6	-33.9	-33.9	-27.6	-37.0	-0.5	-0.5	-18.3
292	400	300	45	1.827	1.684	-27.6	-33.9	-32.7	-33.9	-33.9	-0.5	-6.9	-18.3
448	544	300	45	1.836	1.677	-27.6	-38.7	-31.5	-33.9	-33.9	-6.9	-0.5	-18.3
580	688	300	45	1.825	1.651	-27.6	-27.6	-33.9	-33.9	-33.9	-0.5	6.4	-18.3
678.018	678.126	300	45	1.810	1.691	-27.6	-19.9	-36.0	-33.9	-33.9	-0.5	-6.5	-18.3
144	275	250	55	1.788	1.520	-43.9	-39.6	-53.3	-49.8	-53.3	12.5	-4.9	-22.9
447	663	180	75	1.747	1.590	-46.0	-38.6	-60.0	-56.5	-52.6	18.8	-1.6	-30.5
705	890	180	75	1.720	1.861	-46.0	-27.6	-64.5	-56.5	-52.6	6.7	-4.5	-30.5
908	679.033	300	45	1.805	1.706	-27.6	-16.5	-36.0	-33.9	-31.5	6.4	-0.5	-18.3
679.191	352	180	75	1.781	1.821	-46.0	-33.4	-50.0	-52.6	-52.6	18.8	-0.9	-30.5
370	496	180	75	1.736	1.833	-46.0	-33.4	-50.0	-52.6	-52.6	18.8	-0.9	-30.5
514	813	180	75	1.755	1.844	-46.0	-41.2	-54.6	-46.0	-52.6	18.8	-0.9	-30.5
831	680.035	180	75	1.748	1.601	-46.0	-52.6	-56.5	-52.6	-56.5	-0.9	6.7	-30.5
680.065	149	300	45	1.793	1.684	-27.6	-38.7	-33.9	-33.9	-33.9	1.7	1.7	-18.3
173	263	300	45	1.842	1.669	-27.6	-38.7	-36.0	-33.9	-33.9	-0.5	-0.5	-18.3
287	425	200	70	1.766	1.632	-43.9	-60.6	-56.5	-53.3	-53.3	-3.3	-3.3	-29.9
448	628	180	75	1.785	1.962	-46.0	-46.0	-64.6	-56.5	-54.6	-0.9	-0.9	-30.5
659	844	600	25	1.852	1.770	-16.3	-16.3	-21.9	-18.2	-18.9	-2.8	-1.6	-11.6

Table 4.2.3.6

Location		Radius of curvature	Cant	Rail wear (mm^2)		Trains and their cant deficiencies (mm)							
B. C	E. C			Inner rail	Outer rail	643	602	643	636	7	S	38	37
km	km	m											
680.898	681.032	180	75	1.800	1.650	-46.0	-43.7	-64.6	-52.6	-54.6	18.8	2.9	-30.5
681.152	350	180	75	1.800	1.640	-46.0	-46.0	-64.6	-56.5	-54.6	40.8	0.9	-30.5
368	529	200	70	1.815	1.659	-53.3	-39.6	-57.9	-43.9	-49.8	-3.3	-3.3	-29.9
682.904	683.028	450	30	1.790	1.742	-28.1	-22.5	-25.8	-13.3	-13.3	-22.5	-28.1	-13.3
683.035	148	300	45	1.782	1.735	-42.2	-38.7	-42.2	-33.9	-19.9	-33.9	-33.9	-33.9
6 215	303	300	45	1.857	1.785	-33.9	-33.9	-38.7	-19.9	-19.9	-33.9	-19.9	-19.9
309	423	300	45	1.807	1.727	-33.9	-27.6	-37.0	-19.9	-0.5	-10.9	-10.9	-0.5
532	699	180	75	1.793	1.655	-56.5	-18.3	-64.6	-27.6	50.3	-33.4	-11.6	18.8
795	897	800	15	1.841	1.828	-10.8	1.7	-12.7	-2.2	11.0	--1.5	-1.5	1.7
907	684.126	200	70	1.827	1.633	-53.3	-3.3	-60.6	-18.9	-18.9	-16.0	-18.9	-3.3
684.210	443	180	75	1.756	1.635	-60.0	-8.1	-61.6	-18.3	-11.6	-15.0	-24.6	6.7
479	785	500	30	1.822	1.780	-21.9	-5.9	-23.3	-7.2	-3.3	--9.5	-12.9	-2.0
803	685.070	180	75	1.810	1.633	-56.5	-11.6	-64.6	-18.3	40.8	-18.3	-21.5	-0.9
685.081	377	200	70	1.820	1.660	-56.5	-12.9	-60.6	-18.9	14.4	-27.3	-21.8	-9.8
379	746	180	75	1.808	1.846	-60.0	-18.3	-61.6	-27.6	27.3	-33.4	-18.3	6.7
902	686.057	180	75	1.740	1.867	-52.6	-27.6	-70.4	-27.6	-11.6	-33.4	-11.6	-0.9
686.089	283	180	75	1.768	1.660	-52.6	-27.6	-56.5	-27.6	18.8	-33.4	-11.6	2.9
360	625	180	75	1.715	1.693	-52.6	-33.4	-52.6	-27.6	65.1	-33.4	-18.3	-0.9
668	918	180	75	1.770	1.852	-52.6	-38.6	-56.5	-27.6	65.1	-33.4	-18.3	6.7
975	687.058	180	75	1.822	1.830	-52.6	-46.0	-56.5	-27.6	50.3	-33.4	-18.3	18.8
687.089	331	180	75	1.773	1.857	-70.4	-46.0	-52.6	-27.6	50.3	-33.4	-18.3	6.7
500	589	180	75	1.772	1.845	-56.5	-46.0	-46.0	-27.6	65.1	-33.4	-21.5	6.7
614	984	180	75	1.800	1.856	-54.6	-46.0	-33.4	-27.6	27.3	-33.4	-30.5	2.9
997	688.177	180	75	1.775	1.650	-56.5	-41.2	-27.6	-27.6	40.8	-33.4	-33.4	18.8
688.236	405	180	75	1.744	1.857	-52.6	-33.4	-24.6	-27.6	65.1	-33.4	-30.5	18.8
355	630	300	45	1.850	1.735	-31.5	-19.9	-10.9	-16.5	39.0	-19.9	-16.5	4.0
912	689.037	250	55	1.837	1.718	-34.2	-6.8	-1.6	-20.8	28.4	-24.9	-18.6	12.5
689.049	167	250	55	1.827	1.865	-30.7	3.8	3.8	-20.8	45.9	-24.9	-20.8	12.5
195	399	180	75	1.787	1.627	-41.2	18.8	10.6	-27.6	75.5	-27.6	-24.6	18.8
417	723	180	75	1.835	1.890	-43.7	-0.9	10.6	-18.3	50.3	-18.3	-18.3	18.8
883	690.273	200	70	1.789	1.655	3.5	-12.9	18.2	-18.9	34.2	14.4	3.5	14.4
690.413	614	200	70	1.765	1.642	-18.9	-9.8	34.2	14.4	-3.3	34.2	30.1	14.4
691.221	691.462	300	45	1.866	1.755	-10.9	-0.5	19.0	11.3	24.5	27.3	33.0	24.5

Fig. 4.2.3



Curve
804
804 380
3218
804
1609
1207
1005
Speed, km/h
100
90
80
70
60
50
40
30
20
10
Time, min.
10
9
8
7
6
5
4
3
2
1
Center of station
Time-measuring position
Limit speed for curve
FF
Power running
WF (Reduced field operation
Coasting operation
Distance vs. time curve
Center of station
Time-measuring position
Slope
L
3.2
10
L
8.5
1.8
L
2.2
1.7
0.5
L
1.3
1.7
0.5
3.5
0.5
1.7
L
3.2
L
Distance
28
29
30
31
32
33
34
Station
Fukiage
3.3
1.8
Standard slope
Kumagaya

4.3 Maximum Cant

As explained in the foregoing, the maximum cant employed by the RSR is 90 mm.

This value is a little shorter compared with the maximum cant employed by the JNR even though the gage used in Thailand is 1,000 mm. If the maximum cant is small, it could develop a cant deficiency at sharp curves. Let us study the increase in the maximum cant here.

The maximum cant is determined according to whether the train is safe against turnover inward toward the center of curvature when it is at a standstill or running at a dead slow speed.

Referring to Fig. 4.3.1, let us calculate the safety factor against inward turnover hazards according to the following simplified formula.

$$\frac{C}{G} H = \frac{1}{S} \frac{G}{2}$$

$$S = \frac{G}{C} \cdot \frac{G}{2H} = \frac{G^2}{2HC}$$

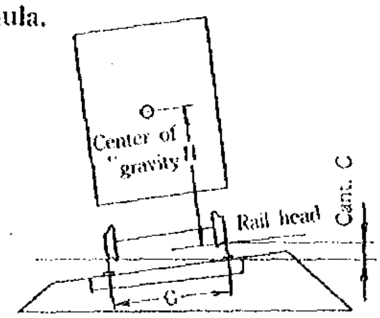


Fig. 4.3.1

Where, C: cant

G: gage

H: height of the center of gravity

S: safety factor

Now let us make comparison between the Japan National Railways and the Thai National Railway.

JNR

G = 1,067 mm

H = 1,700 mm

C = 105 mm

$$S = \frac{1,067^2}{2 \times 1,700 \times 105} = 3.19$$

RSR

G = 1,000 mm

H = 1,700 mm (assumed to be the same as in JNR)

C = 90 mm

$$S = \frac{1,000^2}{2 \times 1,700 \times 90} = 3.26$$

If the same safety factor as in the JNR is taken, the maximum cant against G = 1,000 mm is calculated as follows.

$$C = 90 \times \frac{3.26}{3.19} = 92 \text{ mm}$$

There is no significant difference developed in the maximum cant between the two safety factors.

The safety factor calculated above refers to the case where no wind is blowing. In case a train is standing on a superelevated curve, the critical wind pressure at which the outer wheel of a car will come afloat is given by the following formula.

$$Uc = Uco / \sqrt{1 - C/G - 2h_G/G}$$

Where, Uco is a critical wind pressure for a cant of 0 mm, and is given by the following formula.

$$Uco = \sqrt{WG/Cy.\varphi.S.h'_{BC}}$$

Where, $h'_{BC} = h_{BC} + (Cy + Cy.\varphi.e)\, W_B$

W: ½ of car weight (kg)

G: gage (m)

C: cant (m)

h_G: effective height of the center of gravity (m)

Cy: coefficient of displacement of bogie spring due to lateral force (m/kg)

ρ: air density (kg.sec./m^4)

S: ½ of the area of lateral projection of car body (m^2)

h_{BC}: height of the center of wind pressure on the car body above the rail head (m)

e: distance between the center of gravity of car body and the center of lateral wind pressure (m)

$Cy\varphi$: coefficient of angular displacement of bogie spring device against moment (1/kg)

W_B: ½ of car body weight (kg)

The Uco for the cars of the JNR is calculated in Table 4.3.1.

Table 4.3.1

(m/sec.)

Type of car	NAHA 10	SUHA 43	KIHA 17
Uco	37.0	42.6	50.1

With these values as a basis, the turnover critical wind velocity, Uc, is calculated for various cants with respect to a gage of 1,000 mm. See Tables 4.3.2.1 and 4.3.2.2. The results are plotted in Fig. 4.3.2. If a car is running along a curve, the turnover critical wind velocity, U, is given by the following formula.

$$U = U_{co}/l - 2h_{G'}\sqrt{G\,[\,(1 - \frac{\mu}{1+\mu}\cdot h_{GT}/h_{G'})\,\alpha_H \pm (\frac{v^2}{Rg} - C/G)]}$$

Where, h_{GT}: height of the center of gravity of bogie above rail head (m)

v: running speed (m/sec.)

g: gravitational acceleration (9.8 m/sec.^{2})

W_T: bogie weight

μ: W/W_B

αH: $\alpha H = 0.00125V$ ($V = 80$ km/h)

$\alpha H = 0.1V$ ($V = 80$ km/h)

The turnover critical wind velocity, Uc, of a car running along a curve with a cant deficiency of 60 mm is calculated according to this formula as shown in Table 4.3.2.2 below.

Table 4.3.2.2

(m/sec.)

Type of car	HAHA 10	SUHA 43	KIHA 17
Uc	28.4	35.6	37.9

On the other hand, the maximum wind velocity on record in Thailand is, according to the Thai Meteorological Agency, as shown in Table 4.3.3.

Table 4.3.3

Region	Place of observation	Wind velocity	
		km/h	m/sec.
North	Lampang	129.50	35.9
Northeast	Ubon Rachathani	125.80	34.9
Central	Don Muang	157.50	43.7
East	Sattahip	135.05	37.5
South	Songkhla	140.60	39.1

In the JNR, it is stipulated in Article 491 of the Train Operations Standards that the train operation be discontinued when the wind velocity exceeds 30 m/sec.

In the RSR, this kind of rule does not exist.

Table 4.3.2.3 Uco at G = 1,000 mm

Type of car	NAHA 10	SUHA 43	KIHA 17
Uco	36.0	41.4	48.7

Table 4.3.2.4 Inward Turnover Critical Wind Velocity at Maximum Cant

Type of car Max. cant	NAHA 10	SUHA 43	KIHA 17
90 mm	31.0	35.3	42.5
95 mm	30.7	35.0	42.1
100 mm	30.4	34.6	41.8
105 mm	30.1	34.2	41.4
110 mm	29.7	33.8	41.0

In the JNR, anemometers are installed at the bridges and measured at the stations and maintenance-of-way depots to see if the wind velocity exceeds 30 m/sec.

In order to increase the maximum cant above the current value of 90 mm, it is recommended to provide measures which interrupt the train operation when a gale is blowing or is expected.

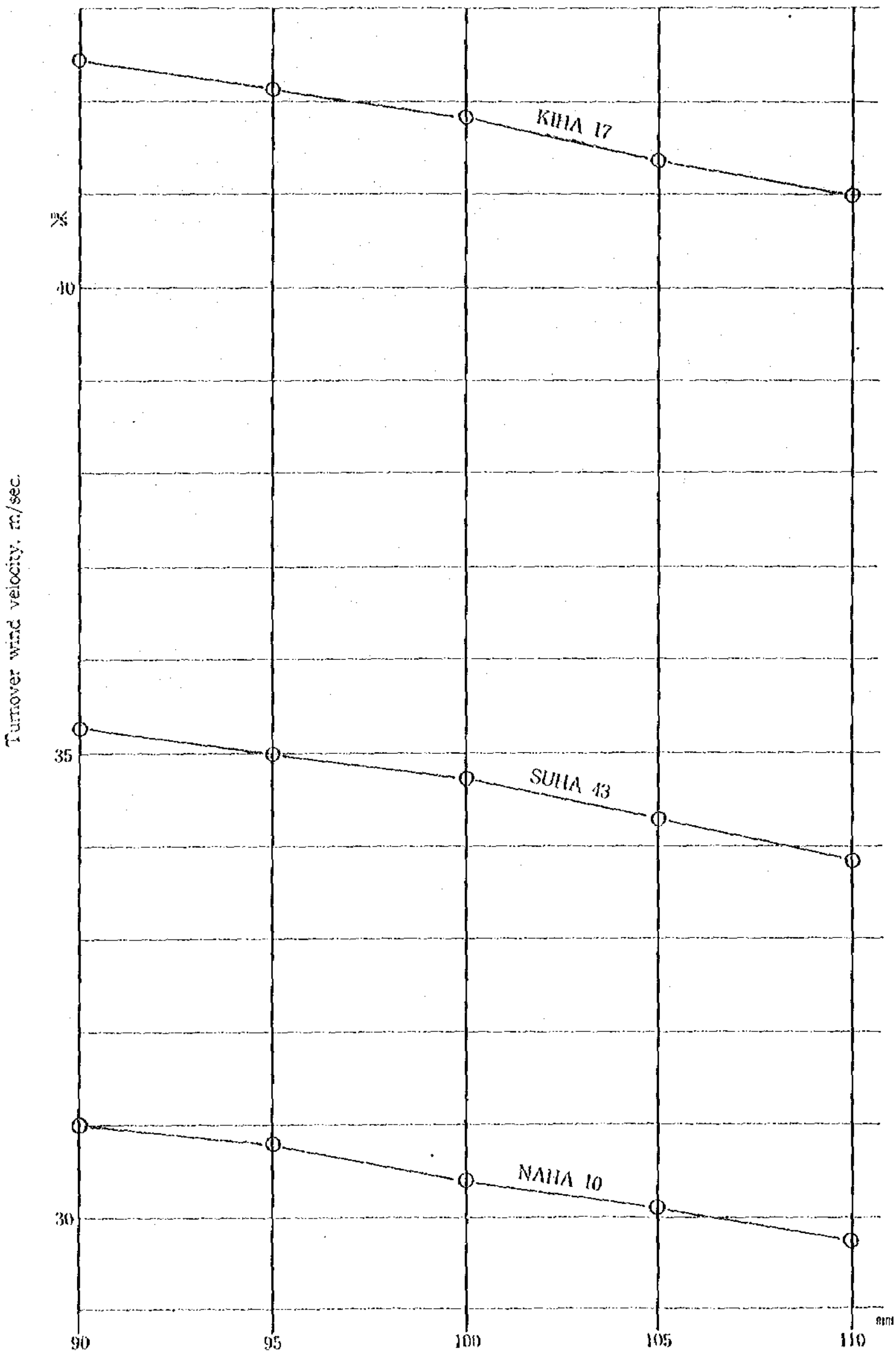
However, the risk of turnover due to gale may be omitted, because

(1) in Thailand, the probability of appearance of gales is far below compared with Japan;

(2) it is rarely the case that the train stops on a sharp curve when a gale is blowing;

(3) it is rarely the case that a strong wind blows normal to the superelevated side of the standing train.

In addition, the probability of concurrence of evil conditions above is very low. Thus, it is quite logical and practical to increase the maximum cant from the existing 90 mm to 95 mm.



Turnover wind velocity, m/sec.
KIHA 17
SUHA 43
NAHA 10
40
35
30
90
95
100
105
110
mm
Maximum cant

Fig. 4.3.2

4.4 Slack of Track

In the JNR, the following theoretical formula is applied for the purpose of determining the slack necessary for the car to clear a curve.

With reference to Fig. 4.4.1, our empirical formula dictates that a slack be provided at the position which lies three quarters of the fixed wheel base back from the front axle and in the direction in which a line drawn parallel to the wheel axle runs toward the center of the curvature.

So that the rear axle can clear said position without experiencing resistance, the slack must be as follows.

$$S_1 = L^2/8R = (1.5B)^2/8R$$

The maximum value of the fixed wheel base is 4.6 m, and S_1 is rewritten as follows.

$$S_1 = 6/R \text{ (m)}$$

In the JNR, the maximum distance across outer flats of the wheel flanges is 1,054 mm, the minimum clearance with the gage is 9 mm, and the difference with a given gage is 13 mm.

From the above conditions, the turning allowance is set at 10 mm. The difference obtained by subtracting half the turning allowance (5 mm) from S_1 is considered a satisfactory slack.

$$S_1 = \frac{6,000}{R} - 5 \text{ (mm)}$$

The slack to be incorporated in the track so that the car turns a curve successfully is calculated theoretically as follows.

With reference to Fig. 4.4.2, the condition under which the car clears a curve with the flange of the rear inside wheel in contact with the inside rail is given by the following formula.

$$S_1 = (3/4.B)^2/2R \qquad S_2 = (1/4.B)^2/2R$$

$$S = S_1 - S_2 = B^2/4R$$

By substituting the maximum fixed wheel base (4.6 m) into the formula right above, S is rewritten as follows.

$$S = (4.6)^2/4R = 5.3/R \quad \text{(m)}$$

$$= 5,300/R \text{ (mm)}$$

By subtracting the turning allowance (10 mm) from S, we obtain the slack (see below) necessary for the car to clear a curve.

$$\frac{5,300}{R} - 10 \text{ (mm)}$$

These two slacks are plotted on Fig. 4.4.3.

In the past, the JNR took it for granted that the required slack would lie between these two slacks as determined in Table 4.4.1. In recent years, the speed of a freight train consisting of two-axle freight cars has been increased. In keeping with this, the maximum cant has been set at 25 mm for the purpose of preventing the derailment of freight cars due to snaking motion, and the slack has been set as shown in Table 4.4.2.

In Fig. 4.4.4, a comparison is made between the JNR and the RSR with respect to slack.

It is evident from the discussions above that the slack does not always assume the value that will minimize the lateral force on the locomotive.

The following introduces Porter's method of calculating the effect of slack on the lateral force developed on a locomotive rounding a curve.

To apply Porter's method of ALSTHOM locomotive, the conditions for calculation are as follows.

(1) The loco delivers a tractive effort of 500 tons.

(2) The radius of curvature is 180 m.

(3) The cornering speed is 48 km/h.

(4) The cant of the curve is 75 mm.

(5) The slope has an upgrade of 20/1,000.

Under these conditions, it is possible to calculate the outer rail lateral force with respect to various slacks according to Porter's method and the find out an optimum slack.

For the purpose of calculating the lateral force according to Porter's method, there are necessary some known or half known external forces on the loco.

(1) Known external forces

1) Running resistance of freight train

There are many formulas proposed for the calculation of the running resistance of a freight car. In the JNR, the following formula is established.

$$R_W = r_W \cdot W_W$$

$$r_W = 2.07 + 0.000653\ V^2$$

Where, R_W: train resistance (kg) of freight car

r_W: running resistance (kg/t) of freight car

W_W: weight of freight car (t) = 500 tons

V: running speed (km/h) = 45 km/h

Hence, $R_W = (2.07 + 0.000653 \times 48^2) \times 500$ (kg) = 1,787

The running resistance of the loco is given by the following formula.

$$R_e = r_e \cdot W_e$$

$$r_e = 2^2 + 0.015\ V$$

Where, R_e: running resistance of loco

W_e: weight of loco (t) = 82.5 tons

Hence, $R_e = (2.2 + 0.015 \times 48) \times 82.5 = 241$ kg

The air resistance of the train is given by the following formula.

$$Ra = 0.6f\,(v/10)^2$$

Where, Ra: air resistance

f: projected area of front (m^2) = 9 m^2

Hence, $Ra = 0.6 \times 9 \times (48/10)^2 = 124$ kg

From above, the running resistance of the freight train is calculated as follows.

$$Rf = R_W + R_e + R_a = 1{,}787 + 241 + 124 = 2{,}152 \text{ kg}$$

2) Curve resistance

In the JNR, the curve resistance, r_r, is calculated according to the following formula.

$$r_r = 600/R \text{ (kg/t)}$$

Where, R: radius of curvature = 180 m

Thus, the curve resistance of a freight car is calculated as follows.

$$R_{rW} = (600/180) \times 500 \text{ kg} = 1{,}667 \text{ kg}$$

The curve resistance of a loco is calculated as follows.

$$R_{re} = (600/180) \times 82.5 = 275 \text{ kg}$$

3) Slope resistance

The slope resistance, R_G, is given by the following formula.

$$R_G = W.G_d \ (kg)$$

Where, G_d: gradient (o/oo)

Thus, the slope resistance of a freight car, R_{GW}, is calculated as follows.

$$R_{GW} = 500 \times 20 = 10{,}000 \text{ kg}$$

The slope resistance of a loco is calculated as follows.

$$R_{Gc} = 82.5 \times 20 = 1{,}650 \text{ kg}$$

4) Centrigugal force

The centrifugal force acting on the center of gravity of the loco is given by the following formula.

$$P = (\frac{v^2}{gR} - \frac{C}{G}) \cdot W$$

Where, v: speed (m/sec.) = 4.8/3.6 = 13.33 m/sec.

g: gravitational acceleration = 9.8 m/sec.^{2}

C: cant = 75 mm

G: gage = 1,060 mm (for cant calculation)

Thus, $P = (\frac{13.33^2}{9.8 \times 180} - \frac{75}{1{,}000}) \times 82{,}500 \text{ kg} = 2{,}127 \text{ kg}$

The external forces acting on the ALSTHOM loco are summarized in Table 4.4.3.

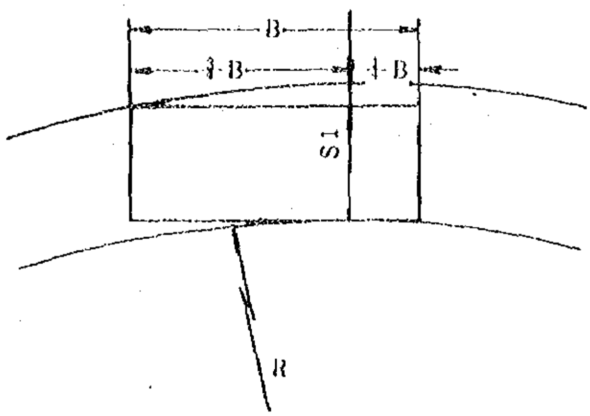
Table 4.4.1 Slack According to the Old Rule of the JNR

Radius of curvature	Slack
up to 170 m	30 mm
170 to 200 m	25 mm
200 to 240 m	20 mm
240 to 320 m	15 mm
320 to 440 m	10 mm
440 to 600 m	5 mm

Table 4.4.2 Slack According to the New Rule of the JNR

Radius of curvature	Slack
up to 200 m	25 mm
200 to 240 m	20 mm
240 to 320 m	15 mm
320 to 440 m	10 mm
440 to 600 m	5 mm

Fig. 4.4.1



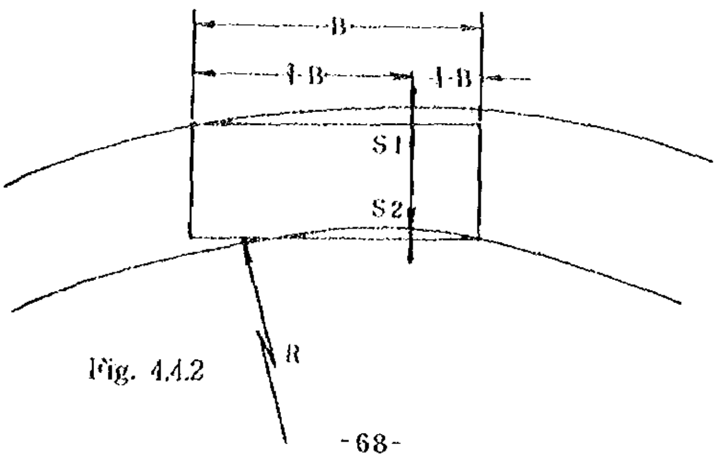


Fig. 4.4.2

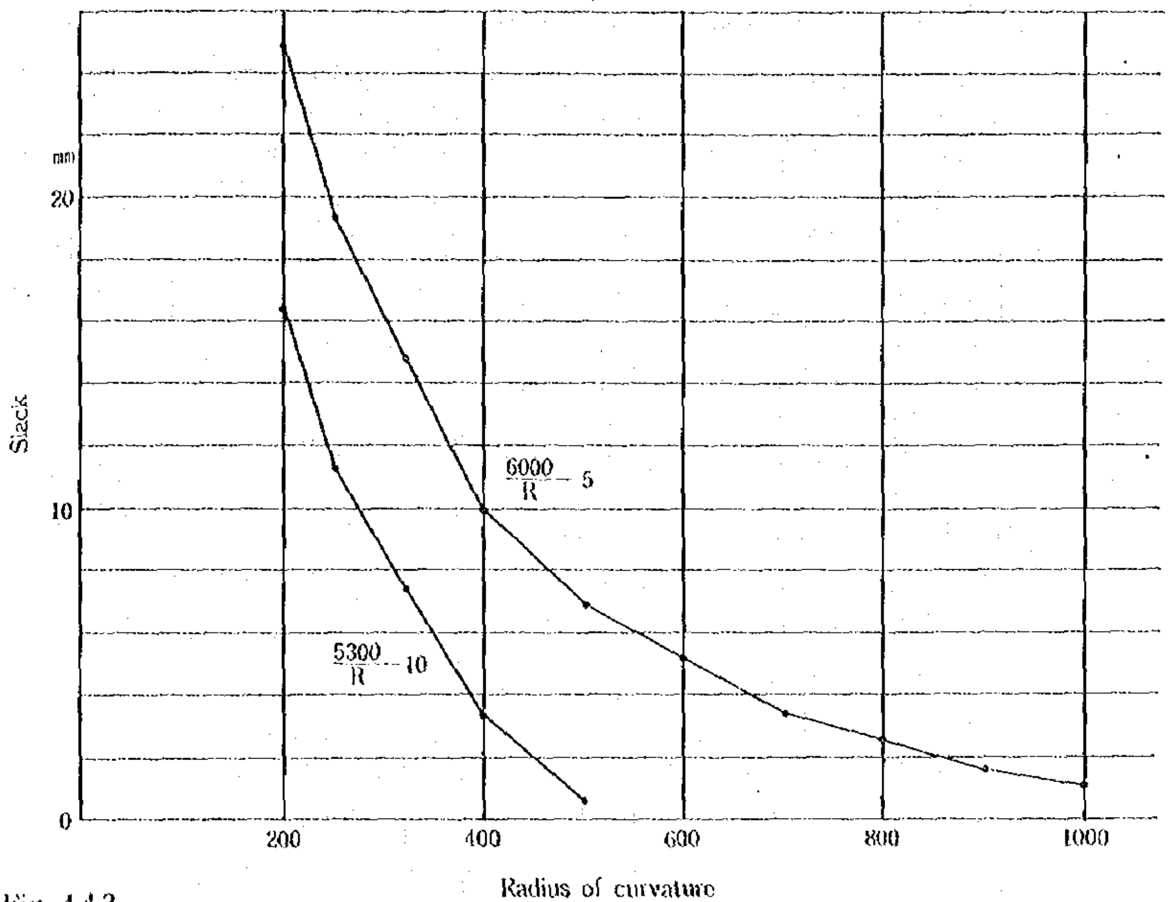


Fig. 4.4.3

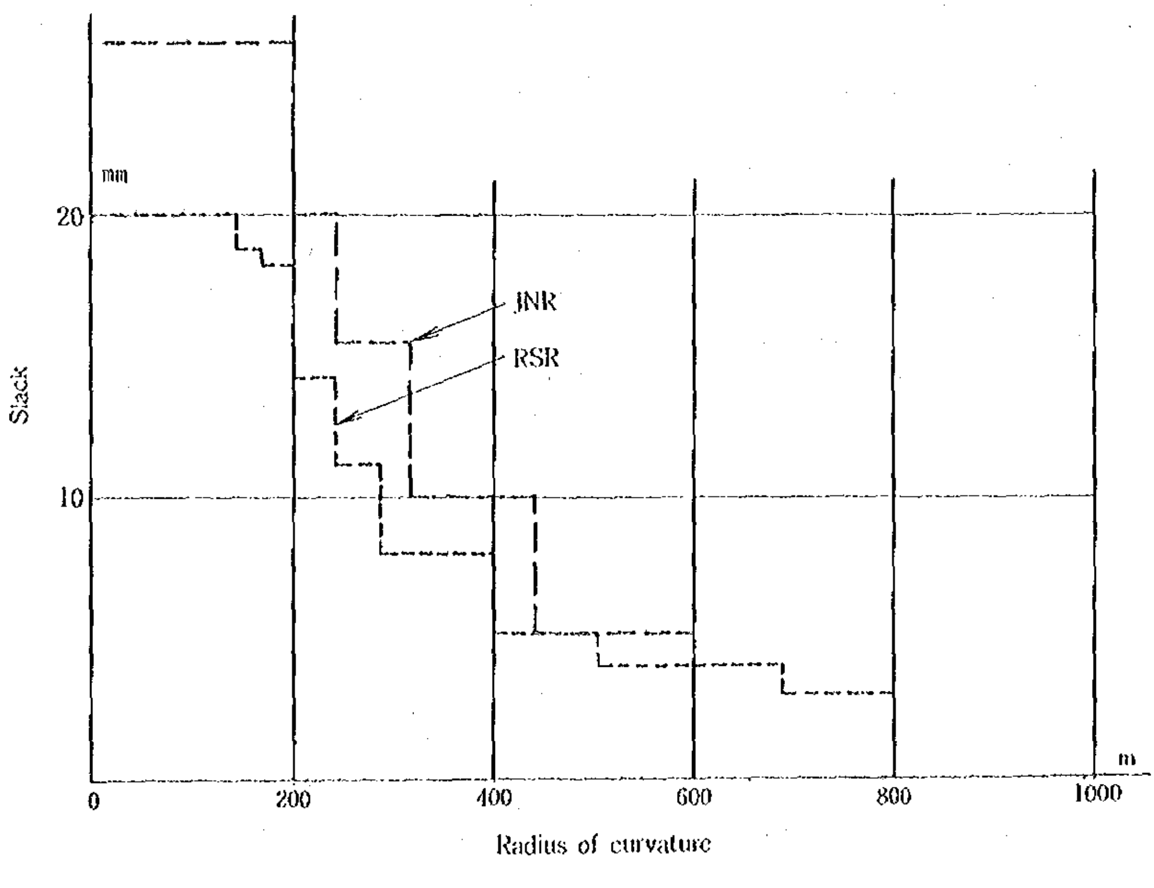


Fig. 4.4.4

(2) Variation of wheel load due to external force

The position of the center of the gravity of the ALSTHOM loco (H_G) is not known. But it is estimated from Japan's locomotives to be 1.675 m. The variation of the wheel load due to external forces is calculated as follows.

Table 4.4.3

External Force	Locomotive	Freight car
Running resistance	241	1,787
Air resistance	124	--
Curve resistance	275	1,667
Slope resistance	1,650	10,000
Centrifugal force	2,127	---

The variation of the inside and outside wheel loads due to centrifugal force is given by the following formula.

$$\sigma W = W_e \cdot (H_G/G) \left(\frac{v^2}{R_g} - \frac{C}{G}\right)$$

Where, H_G: height of the center of gravity of loco ≑ 1.5 m

Thus, $\sigma W = 82{,}500 \times (1.675/1.06) \left(\frac{13.32^2}{180 \times 9.8} - \frac{75}{1{,}000}\right) = 3{,}360$ kg

Hence, the wheel loads on the inner and outer rails are calculated as follows.

Outer rail: $82{,}500 \div 12 + 3{,}360 \div 6 = 7{,}435$ kg

Inner rail: $82{,}500 \div 12 - 3{,}360 \div 6 = 6{,}315$ kg

(3) Half-known external forces

The ALSTHOM loco has a rubber side bearer; when a bogie turns in a curve, the side bearer exerts a force of restitution on the bogie according to the turning angle.

The relationship between the force of restitution and the turning angle of bogie is not clear, but would be estimated from the relationship between the position of side bearer and turning angle and the actual relationship between the side bearer displacement and force.

Table 4.4.4

No.	ℓ	Turning angle vs. displacement (mm)					
		0.5°	1.0°	1.5°	2.0°	2.5°	3.0°
(1)	1,569	13.69	27.39	41.09	54.79	68.50	82.23
(2)	952	8.31	16.62	24.93	33.25	41.57	49.89
(3)	952	8.31	16.62	24.93	33.25	41.57	49.89
(4)	1,569	13.69	27.39	41.09	54.79	68.50	82.23

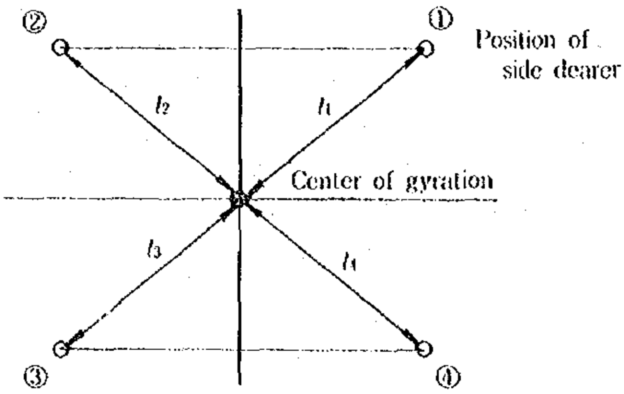


Fig. 4.4.4

The moment of restitution of the side bearers used in the ALSTHOM loco against the turning angle is determined if the modulus of elasticity of the side bearers in the lateral direction is known.

In the test conducted by the RSR, the slide plate used showed a larger friction resistance than was expected originally, and the modulus of elasticity in the lateral direction could not be determined directly.

In this report, therefore, there is shown a method of calculation which will be of help to the RSR in calculating the moment of restitution when the performance of side bearer in question is disclosed by the manufacturer.

The moment of restitution by the side bearers is dependent on the turning angle of bogie as against the car body. Unless the center of friction of the bogie is determined, the accurate moment of restitution cannot be calculated. Porter demonstrated in his treatise that the moment of restitution can be roughly estimated by making use of Roy's diagram, etc. The accuracy of the estimate can be judged if the center of friction is given.

The external forces necessary for the calculation of the lateral force on the loco according to Porter's method are summarized in Fig. 4.4.5 below.

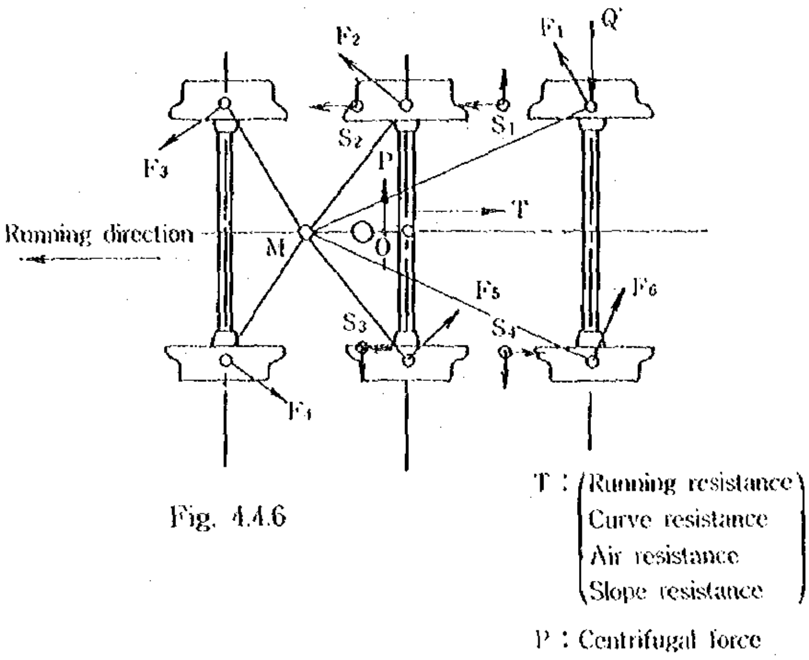


Fig. 4.4.6

It is now possible to calculate point M and the relationship between the lateral force Q and slack.

The calculation is possible when the performance of side bearer asked the manufacturer by the RSR is disclosed, and it is possible to determine roughly the slack for the purpose of reducing the lateral force Q.

It should be noted however that the results of calculation are static ones, and that they should be corroborated by tests on a test section before application to the lines.

In the premises of *Uttaradit* St., there was a siding with varied slacks, and measurements were conducted there. As there were not available the constants substantiating the theoretical computation, the method of analysis of measurements is now under study, and will be submitted independent of this report.

The slack is a factor to be discussed not only from the matter of lateral force, but also from other considerations. One such consideration is related to the gage adjustment of the fastening devices for concrete ties for curve use.

The fastening devices for concrete ties for curve use are required to be adjusted with respect to change in slack. But inexpensive, high-performance tie fastening devices are hard to come by. Thus, for the purpose of employing concrete ties for curve use, it is advantageous to minimize the slack.

If the slack is large, it will cause a two-axle freight car with a short fixed wheel base to develop a snaking motion that leads to derailment.

4.5 Patterns of Wear of Wheels and Rails

The rail wear is governed by the shape of wheel, but little is known about what degree the shape of wheel contributes the wear of rail.

In the JNR, the rail design is based on the concept that the rail wear will be minimized if the rail is designed patterned closely after the contour of actual wear of rail or wheel.

In our survey this time, the wear of the wheels and rails was investigated. The results are as summarized below.

(1) Wear pattern of wheels

A total 225 wheels of locomotives, coaches, and freight cars were investigated about wear.

The wear was measured at the positions illustrated in Fig. 4.5.1. The results were as summarized in Table 4.5.1.

According to this table, the average pattern of wheel wear is determined in Fig. 4.5.2.

Of the wheels measured, there were such seriously worn-out ones as shown in Fig. 4.5.3. These wheels come in contact with the worn-out rail in a state shown in Fig. 4.5.4. As is clear from Fig. 4.5.4, the rolling speed at the rail tread point (A) and flange contact point (B) is different with the difference in diameter; namely, a slip is developed at the flange contact point to accelerate the rail wear.

(Fig. 4.5.5 refers to a typical pattern of rail wear.)

Of the wheels measured, there were a pair of such wheels stuck on the same axle that disclosed wear patterns quite different from each other as illustrated in Fig. 4.5.6. It is inferred that the wheels may have run at angles against the rails because of axle distorsion. The car having a bogie with such a limping running characteristic as above will shorten its span of life because of unstable running.

(2) Wear patterns of rails

The patterns of rails wear at the curves of the North Line investigated by us are as discussed in Chap. 3.

There were not noticeable partial side wear on the rails at the curved sections.

But, part of the Northeast Line which has a radius of curvature of 400 m showed a wavy pattern of partial side wear. This was particularly the case with the sections where the circularity of the curvature was poor because of defective alignment.

Now let us examine the misalignment with reference to the measurements obtained at a 671 km 18 point on the North Line. A versine graph is shown in Fig. 4.5.7. In Fig. 4.5.7, the versine at point (A) is 83 mm, while that at point (B) is 57 mm.

The radius of curvature between these two points are roughly estimated as follows.

$$R = \ell^2/8C$$

Where, R: radius of curvature

ℓ: length of chord = 10 m

C: versine

Namely, at point (A), R = 10 x 10/(8 x 0.083) = 151 m, and at point (B), R = 10 x 10/(8 x 0.057) = 219 m. The difference is 68 m.

Where there are sections in succession which show extreme differences in radius of curvature like the example above, the rails which have smaller radii of curvature will be subject to wear and eventually develop partial side wear.

Table 4.5.1

No.	1	2	3	4	5	6	7	8	9	10
1	0.6	1.5	2.5	1.2	1.6	1.2	1.1	0.9	0.3	0
2	0.4	1.9	3.0	1.4	1.8	2.0	2.1	2.1	2.0	1.2
3	1.0	2.0	4.4	2.0	2.0	1.9	1.2	1.0	0.4	0
4	0.6	1.0	2.0	1.2	2.0	2.0	1.7	1.2	1.0	0
5	1.5	1.5	4.0	10.0	11.0	0.0	10.0	8.5	7.0	4.0
6	1.5	1.1	1.5	5.0	7.5	7.5	8.0	7.0	7.0	2.5
7	1.1	0.5	1.0	6.5	8.5	8.5	6.5	7.0	4.5	3.0
8	1.0	1.5	4.0	9.5	9.5	9.0	8.0	6.5	4.5	2.0
9	1.2	1.0	2.0	2.0	3.0	3.8	3.5	3.0	2.2	0
10	0.5	0.8	2.5	5.0	5.0	5.0	4.5	3.5	2.0	0.5
11	0.5	1.0	3.0	8.0	8.0	8.5	7.5	6.7	4.0	2.0
12	0.8	0.5	0.5	2.9	5.2	5.9	5.2	4.8	3.5	1.0
13	0	0	0	4.0	7.0	7.0	6.5	6.1	5.0	2.5
14	0	0	1.0	7.0	7.1	6.2	5.5	4.5	3.0	0.5
15	0.5	0.0	2.0	1.0	0.7	1.0	1.0	0.5	0	0
16	2.0	2.8	2.8	2.0	1.5	1.0	1.1	1.1	0.5	0

№	1	2	3	4	5	6	7	8	9	10
17	0.5	2.0	4.5	2.5	2.0	1.5	1.0	1.0	0.5	0
18	0	0	0.5	1.0	1.0	1.0	1.1	1.0	0.5	0
19	0.5	0	1.0	2.0	1.7	1.7	1.1	1.0	0.5	0
20	0	0	1.0	1.5	1.1	1.0	0.9	0.5	0.2	0
21	0	0	1.0	1.1	1.5	1.2	1.0	0.5	0.2	0
22	0	0	1.0	0.5	1.0	1.0	0.5	0.2	0	0
23	1.0	1.0	2.0	1.0	1.2	1.0	1.0	0.5	0.2	0
24	0	0	0	0	0.7	0.9	0.3	0	0	0
25	0	0	0	0.2	1.0	1.1	1.0	0.8	0	0
26	0	0	2.5	1.1	1.5	1.1	1.0	0.5	0	0
27	0	0	1.5	1.0	1.1	1.0	1.0	0.3	0	0
28	0	0	0.5	1.0	1.9	2.0	1.1	0.5	0	0
29	0	0	1.5	5.0	5.0	5.0	4.0	4.0	3.0	2.0
20	1.0	0.5	1.0	2.8	4.2	5.0	4.2	4.0	3.0	2.5
31	0.5	0	4.0	5.0	5.0	4.5	3.8	3.0	2.5	1.5
32	0	0	0	0.5	2.5	3.5	3.1	3.0	2.5	2.5
33	0	0	3.0	4.5	5.0	4.5	4.0	3.0	2.2	1.5
34	1.0	0	0	1.1	2.5	3.0	2.5	2.0	1.5	1.0
35	0	0	0	3.5	4.0	4.0	3.0	2.5	2.0	0.5
36	0.5	0	0.5	1.5	3.0	3.2	3.0	2.1	2.5	0.8
37	0	1.0	5.0	4.5	3.2	3.0	2.0	1.5	1.0	0
38	0	0	0.5	1.5	1.2	1.5	1.5	1.5	0.5	0
39	0	1.0	2.0	2.0	3.0	3.0	2.5	2.5	2.0	1.5
40	0.5	1.0	5.5	5.0	5.0	4.5	4.0	3.0	2.0	1.0
41	0.5	2.0	4.0	2.0	2.0	1.5	1.0	1.0	0.5	0
42	0	0	1.0	0.5	1.0	1.5	1.5	1.5	1.1	0.3
43	1.0	3.0	5.0	2.5	2.0	2.0	1.5	1.0	0	0
44	0.5	0	1.0	1.5	1.0	1.0	1.5	1.5	1.0	0
45	2.0	3.5	4.0	2.0	2.0	1.5	1.0	1.0	0.5	0
46	1.0	2.0	2.2	1.0	1.7	2.0	2.0	1.5	1.0	0.2
47	1.0	1.5	2.0	2.0	1.2	1.0	1.0	1.0	0.2	0
48	0.5	1.1	2.0	2.1	3.0	3.0	2.5	2.2	1.1	0
49	1.0	2.0	3.0	1.5	1.5	2.0	2.0	2.0	1.0	0.5
50	1.0	1.2	3.5	4.0	4.2	4.1	3.8	3.0	2.0	1.0
51	0.5	1.5	2.2	1.0	1.2	1.2	1.5	1.5	1.0	0
52	0.5	1.8	5.0	3.5	3.5	3.5	2.5	2.2	2.0	0

No.	1	2	3	4	5	6	7	8	9	10
53	0	0.2	1.5	1.0	1.5	2.0	2.0	1.5	1.0	0
54	0	1.0	2.0	1.1	2.0	2.0	1.8	1.1	0.5	0
55	0.5	1.5	2.0	1.5	2.0	2.0	1.5	1.0	0.5	0
56	0.5	1.0	2.0	1.0	1.5	1.5	1.0	1.0	0.5	0
57	0	1.0	1.5	1.0	1.0	1.0	1.0	0.5	0	0
58	0	0.5	1.5	1.0	1.0	1.2	1.0	0.5	0	0
59	0	1.0	2.0	1.1	1.5	1.5	1.5	1.0	0.5	0
60	0.5	1.0	2.0	1.1	2.0	1.5	1.6	1.1	0.5	0
61	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0
64	0	0	1.0	0.5	0.5	0.2	0	0	0	0
65	0	0	0.5	0	0	0	0	0	0	0
66	0	0	0.5	0	0	0	0	0	0	0
67	0	0	0.5	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0
73	0	0.5	2.0	0.5	1.0	1.0	1.0	0.5	0.2	0
74	0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0
75	0.5	0	2.0	1.0	1.1	1.0	1.0	0.5	0.2	0
76	0	0	2.0	1.0	1.0	1.0	1.0	0.5	0	0
77	0	1.0	1.0	0.5	0.5	1.0	0.5	0.5	0	0
78	0	0.5	2.0	1.0	1.0	1.0	1.0	0.5	0.2	0
79	1.0	2.0	4.5	4.0	4.0	4.0	3.5	3.0	2.0	1.0
80	1.0	0.5	2.0	2.5	3.0	4.0	3.5	3.2	2.0	1.0
81	0.5	1.0	1.5	1.5	2.0	2.5	2.0	2.0	1.0	0.5
82	0	0	1.0	1.0	1.5	2.0	2.0	2.0	2.0	1.0
83	0.2	1.5	3.5	3.0	3.0	2.5	2.0	1.5	0.2	0
84	0.2	1.5	2.5	1.0	1.5	2.2	2.2	2.0	1.5	0
85	0	0.5	2.0	2.0	2.5	3.0	2.5	2.0	1.5	0
86	0	0	2.0	2.1	3.0	3.0	2.5	2.0	1.0	0
87	0	0.5	1.0	1.1	1.5	2.0	2.0	2.0	1.0	0
88	1.0	1.0	1.5	1.0	1.2	2.0	2.0	2.0	1.5	0

No.	1	2	3	4	5	6	7	8	9	10
89	0	1.0	2.0	1.5	2.0	2.5	2.1	2.0	1.5	1.0
90	0	1.0	3.0	3.0	3.5	3.5	3.0	2.5	1.1	0
91	0	0	2.0	1.5	2.0	2.0	1.0	1.0	1.0	0
92	0	0	0	1.0	0.5	1.0	1.0	1.0	0.5	0
93	0	0	0.5	1.0	1.0	1.0	1.2	1.0	0.5	0
94	0	0	2.0	2.0	2.0	1.8	1.0	0.5	0.2	0
95	0	0	0	1.0	1.0	1.0	1.0	1.0	0.2	0
96	0	0	2.0	1.2	1.5	1.5	1.0	1.0	0.7	0
97	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
98	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
99	0	0	1.0	1.0	1.0	1.0	0.5	0.2	0	0
100	0	0.8	2.0	1.0	1.1	1.0	1.0	0.2	0	0
101	0	0	1.1	1.1	1.6	1.5	1.1	1.0	0.2	0
102	0	0	1.8	1.2	1.5	1.2	1.0	0.5	0	0
103	0	0	1.1	1.0	1.1	1.2	1.0	1.0	0.5	0
104	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
105	0	0.6	2.0	2.0	2.1	2.0	2.0	1.5	0.6	0
106	0	1.0	2.5	2.0	2.1	2.1	2.0	1.5	1.0	0
107	0	0.5	2.0	2.0	2.1	2.2	2.0	2.0	1.1	0.5
108	0	0	1.1	1.0	1.2	1.5	1.1	1.0	0.2	0
109	0	1.0	1.8	1.5	1.7	1.7	1.1	1.0	0.3	0
110	0	1.0	2.0	1.5	1.8	1.8	1.5	1.2	1.0	0
111	0	1.5	2.5	1.8	1.8	2.0	1.8	1.5	1.0	0
112	1.0	2.0	2.5	1.5	1.5	1.6	1.3	1.0	0.5	0
113	0.5	1.1	3.0	3.0	3.0	2.5	2.0	2.0	1.5	0.5
114	0	0	1.0	1.0	1.0	1.0	1.0	1.0	0.3	0
115	0	1.0	2.5	2.0	2.0	2.0	1.5	1.0	1.0	0
116	0.2	1.0	2.5	2.0	2.0	2.0	1.2	1.0	0.5	0
117	0	0.5	2.5	3.0	3.0	3.0	2.5	2.0	1.0	0
118	0	0	1.5	2.0	3.0	3.0	2.5	2.0	1.1	0
119	0	0	1.8	2.0	2.5	2.5	2.0	1.5	1.0	0
120	0	0	2.0	2.5	3.0	3.0	2.5	2.0	1.0	0
121	0	0.5	2.0	2.5	3.0	2.5	2.0	1.5	1.0	0
122	0	0	2.0	2.0	2.2	2.5	2.0	1.8	1.0	0
123	0	0	2.0	3.0	3.2	3.0	2.5	2.0	1.1	0
124	0	0	1.5	1.0	1.0	1.0	1.0	0.5	0.5	0

No	1	2	3	4	5	6	7	8	9	10
125	0	0	1.5	1.0	1.0	1.0	1.0	0.5	0.5	0
126	0	0	1.0	1.0	1.0	1.0	0.5	0.5	0	0
127	0	0	1.0	0.5	1.0	1.0	0.5	0.5	0	0
128	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0
129	0	0	1.0	1.0	1.0	0.8	0.5	0.5	0	0
130	0	0	2.0	1.0	1.0	1.0	1.0	0.5	0.5	0
131	1.0	2.0	1.5	1.0	0.5	0.5	0.5	0	0	0
132	0	0	1.0	0.5	0.5	0.5	0.5	0	0	0
133	0	0	1.0	1.0	1.0	1.0	0.5	0	0	0
134	0	0	1.5	1.0	1.0	1.0	1.0	0.2	0	0
135	0	0	0.5	0.5	1.0	1.0	1.0	0	0	0
136	0	0	1.0	1.0	1.1	1.0	1.0	0.5	0	0
137	0	0	1.0	0.8	1.0	1.0	0.5	0.2	0	0
138	0	0	2.0	1.0	1.1	1.0	0.5	0	0	0
139	0	0	0	0.5	1.0	1.0	1.0	0.5	0	0
140	0	0	1.0	0.3	1.0	1.0	1.0	1.0	0.3	0
141	0	0	1.2	0.5	1.1	1.1	1.1	1.0	0.2	0
142	0	0.5	0	0	1.0	1.0	1.2	1.5	1.0	0
143	0	0	0	0.2	1.0	1.0	0.8	0.3	0	0
144	0	1.0	1.5	1.0	1.1	1.2	1.1	1.0	0.3	0
145	0	1.5	2.0	0	1.0	1.2	1.2	1.2	0.3	0
146	0	0.5	2.0	1.0	1.2	1.5	1.2	1.0	0.2	0
147	0	0	1.5	1.0	1.8	2.0	1.5	1.2	0.5	0
148	0	1.0	0.3	0.3	1.0	1.3	1.2	1.0	0.5	0
149	0	1.0	1.0	0.5	1.0	0.8	0.8	0.5	0.3	0
150	0	0	1.1	1.0	1.0	1.0	1.0	0.5	0.2	0
151	0	0	1.0	1.0	0.5	0.5	0.3	0	0	0
152	0	0	1.0	1.0	0.8	0.5	0	0	0	0
153	0	1.0	1.0	1.0	0.5	0.3	0.2	0	0	0
154	0	0	1.0	1.0	1.0	0.5	0.5	0	0	0
155	0	0	1.0	1.0	0.5	0.3	0	0	0	0
156	0	0	1.0	1.0	0.5	0.5	0.3	0	0	0
157	0	1.0	1.0	1.0	0.3	0	0	0	0	0
158	0	0	2.0	1.1	1.8	2.0	1.5	1.1	0.5	0
159	0	0	2.0	1.5	2.0	1.8	1.1	1.8	0	0
160	0	0.5	0.5	1.0	1.0	1.1	1.5	1.5	1.1	0

No	1	2	3	4	5	6	7	8	9	10
161	0	0	1.0	1.0	1.0	1.0	0.7	0.5	0	0
162	0	1.0	2.0	1.5	1.5	2.0	2.0	1.5	1.0	0
163	0	0	1.0	1.0	1.7	2.0	1.5	1.0	1.5	0
164	0	0	0	1.0	1.2	1.0	0.5	0.5	0	0
165	0	0	0	0.5	0.5	0	0	0	0	0
166	0	0	0.5	0.5	1.0	1.0	1.0	0.5	0	0
167	0	0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0
168	0	0	1.1	0.5	1.0	1.0	1.0	0.5	0	0
169	0	0	1.0	0.5	1.0	1.0	1.0	1.0	0.5	0
170	0	0	1.0	0.5	1.0	1.0	1.0	0.5	0	0
171	0	1.0	2.5	1.5	1.5	1.2	1.0	1.0	0.6	0
172	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
173	0	1.0	2.0	1.0	1.0	1.0	1.0	0.9	0.5	0
174	0	0	1.1	2.0	2.0	2.0	2.0	1.5	1.0	0
175	0	1.1	6.0	5.0	5.0	4.5	4.0	3.0	2.0	0.5
176	0	0	0.5	1.5	2.0	2.0	2.0	2.0	1.5	0
177	0	0	1.0	1.0	1.0	1.0	1.0	0.8	0.5	0
178	0	0	1.0	1.5	3.0	3.0	2.5	2.2	1.8	0
179	0	0	1.0	1.5	2.0	3.0	3.0	3.0	2.5	0.5
180	0	1.0	5.0	5.0	5.0	4.5	4.0	3.0	2.0	0
181	0	0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	0.5
182	0	0	0	0	0	0	0	0	0	0
183	0	0	0	0.5	0.5	0	0	0	0	0
184	0	0	0.5	0.5	0.5	0	0	0	0	0
185	0	0	0	0.5	0.5	0	0	0	0	0
186	0	0	0.5	0.5	0	0	0	0	0	0
187	0	0	0.5	1.0	0.5	0	0	0	0	0
188	0	0	0	0	0	0	0	0	0	0
189	0	0	0	0.5	0	0	0	0	0	0
190	0	1.5	2.0	1.0	1.0	1.0	1.0	1.0	0.5	0
191	0	0	1.5	1.0	1.0	1.2	1.0	1.0	0.5	0
192	1.0	1.5	3.0	2.0	2.0	2.0	1.0	0.5	0	0
193	0	1.0	2.5	1.5	1.5	1.2	1.0	0.5	0	0
194	0.5	2.0	4.0	2.0	2.0	2.0	1.5	1.0	0.3	0
195	1.0	2.0	4.0	2.0	2.0	1.5	1.0	1.0	0	0
196	1.0	1.5	2.0	1.0	1.0	1.1	1.0	1.0	0.5	0

№	1	2	3	4	5	6	7	8	9	10
197	0	0	1.0	0.5	1.0	1.0	1.0	0.5	0	0
198	0.5	1.0	1.5	2.0	3.0	3.0	3.0	2.5	2.0	0
199	0	0	1.0	1.0	2.0	2.0	2.0	1.5	1.0	0
200	0	1.0	2.0	1.0	1.0	1.0	0.5	0.3	0	0
201	0	0	1.0	1.0	1.0	1.0	1.2	1.0	0.5	0
202	0	0	2.0	4.0	4.2	4.2	4.0	1.5	2.0	0
203	0	0	1.0	1.0	1.5	2.0	1.5	1.5	1.0	1.0
204	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
205	0	0	2.5	1.5	1.2	1.0	0.8	0.3	0	0
206	0	0	1.5	1.0	1.0	1.0	0.5	0.5	0	0
207	0	0	0	1.0	1.0	1.0	1.0	0.5	0.3	0
208	0	0	0	1.0	0.5	1.0	1.0	0.5	0.2	0
209	0	0	1.0	1.0	1.0	1.0	0.5	0.5	0.2	0
210	0	0	1.0	1.5	2.0	1.5	1.2	1.0	0.5	0
211	0	0	1.0	1.0	1.2	1.0	1.0	1.0	0.5	0
212	0	0	1.0	1.5	2.0	2.5	2.5	2.0	1.5	0
213	0	0	1.5	2.0	2.0	2.0	1.5	1.0	1.0	0
214	0	0	1.0	1.0	1.5	1.5	1.0	1.0	0	0
215	0	0	1.0	1.0	1.5	1.5	1.5	1.0	0.5	0
216	0	0	1.0	1.2	1.5	1.5	1.5	1.0	0.5	0
217	0	0	1.0	1.0	1.5	1.5	1.5	1.0	0.5	0
218	0	0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0
219	0	0	1.5	2.0	2.0	2.0	2.0	1.5	1.5	0.5
220	0	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0
221	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0
222	0	0	1.0	1.0	1.0	1.0	0.3	0.3	0	0
223	0	0	1.0	1.0	1.0	1.0	1.0	0.5	0	0
224	0	0	2.0	1.5	1.5	1.0	1.0	0.3	0	0
225	0	0	2.0	1.0	1.5	1.5	1.0	1.0	0.5	0

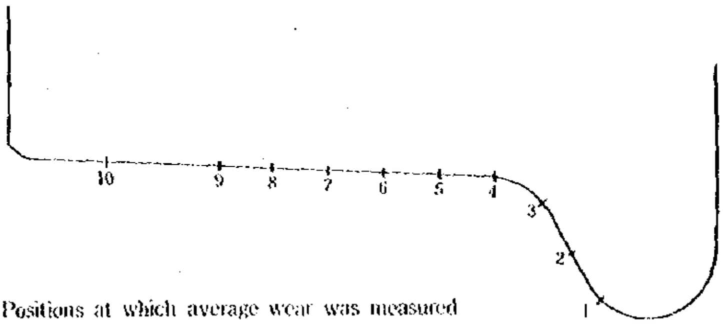


Fig. 4.5.1 Positions at which average wear was measured

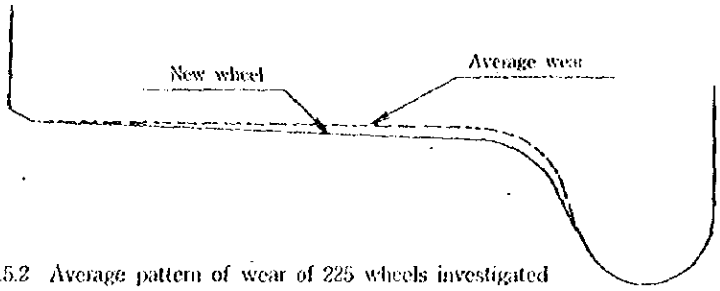


Fig. 4.5.2 Average pattern of wear of 225 wheels investigated

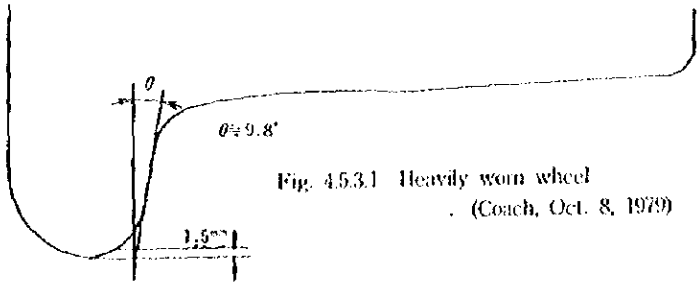


Fig. 4.5.3.1 Heavily worn wheel
(Coach, Oct. 8, 1979)

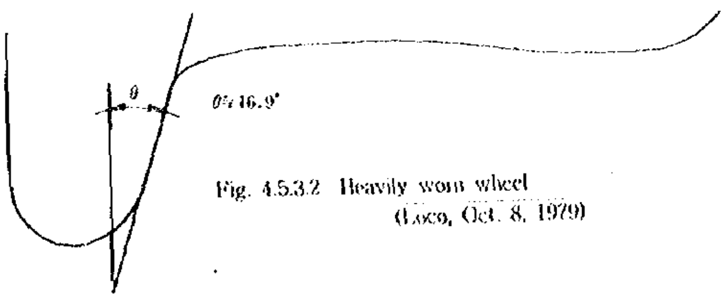


Fig. 4.5.3.2 Heavily worn wheel
(Loco, Oct. 8, 1979)

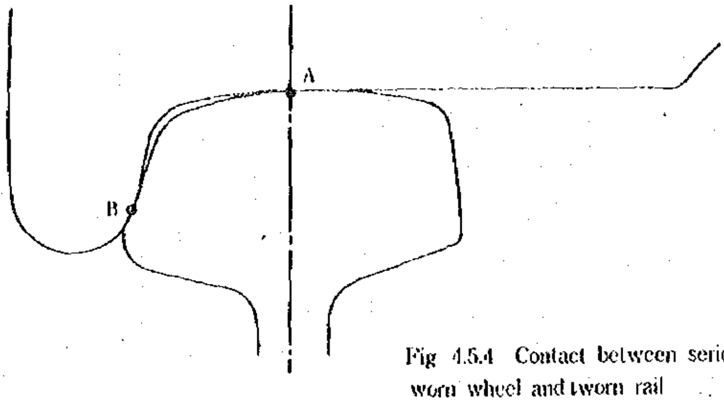


Fig 4.5.4 Contact between seriously worn wheel and worn rail

Wheel : Coach, BSC, Oct. 25 , 1979;
Rail : at around 678 km point)

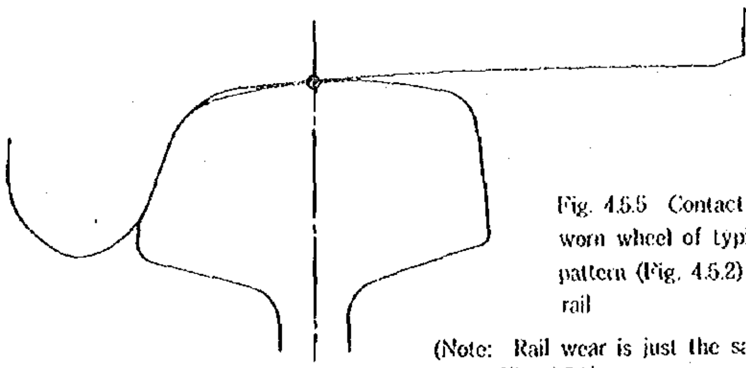


Fig. 4.5.5 Contact between worn wheel of typical wear pattern (Fig. 4.5.2) and worn rail

(Note: Rail wear is just the same as in Fig. 4.5.5)

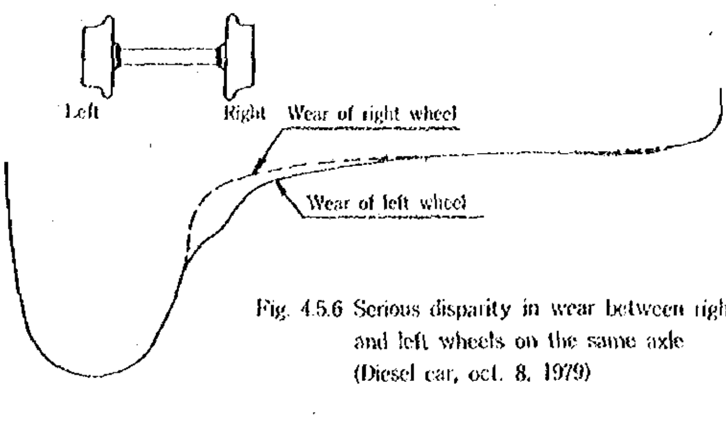


Fig. 4.5.6 Serious disparity in wear between right and left wheels on the same axle
(Diesel car, oct. 8, 1979)

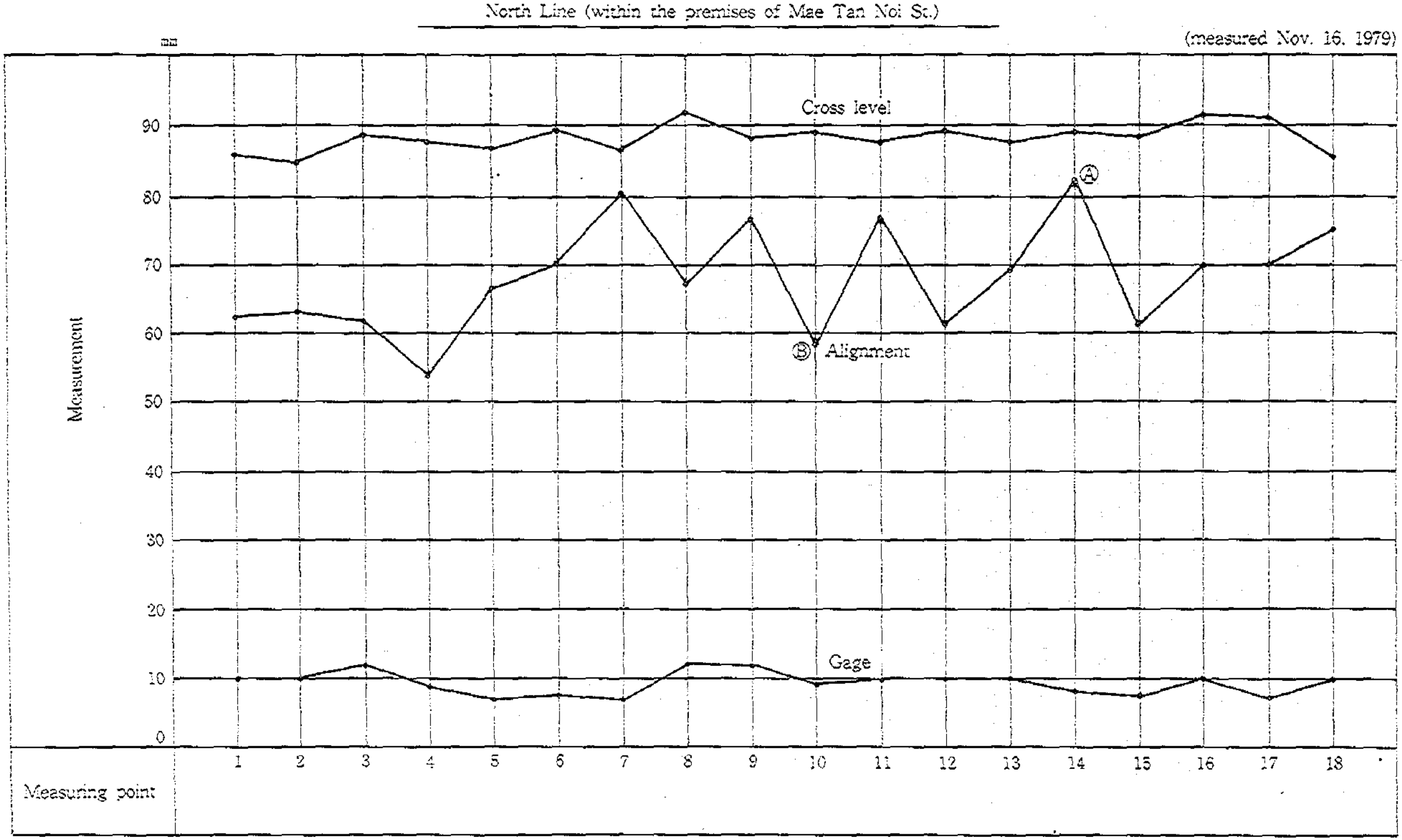

North Line (within the premises of Mae Tan Noi St.)
(measured Nov. 16, 1979)
mm
Measurement
90
80
70
60
50
40
30
20
10
0
Cross level
Ⓐ
Ⓑ Alignment
Gage
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Measuring point

Fig. 4.5.7

Namely, it is required to carry out the correction of curves by the chord-to-rail measurement.

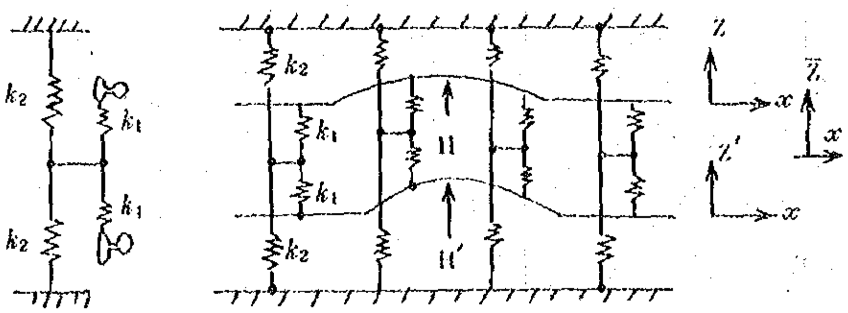
To this end, it is requisite to prepare a cufve lining calculator. Recently, an inexpensive curve lining calculator with a built-in micro-computer is available for efficient computation work.

Any method will do so far as it can correct the misalignment. Anyway, the curve lining should be conducted in a planned manner for the purpose of extending the rail service life and preventing derailment, though the misalignment in the curved section is difficult to inspect and repair compared with straight section.

4.6 Comparison of Lateral Forces by Types of Locos

In order to study what difference exists in lateral force depending on the type of loco, the survey team measured the lateral displacement of rails along the main track of the North Line. The lateral displacement of a rail is expressed by the following set of formulas based on the model illustrated in Fig. 4.6.1.

Fig. 4.6.1



$$EIy \frac{d^4 z}{dx^4} + k_1 (z - z) = 0$$

$$EIy \frac{d^4 z'}{dx^4} + k_1 (z' - z)$$

$$k_1 \ (z - z) + k_1 \ (z' - z) = 2k_2 z$$

The boundary conditions are as follows.

(1) at $x = 0$

$$\frac{dz}{dx} = \frac{dz'}{dx} = 0$$

$$2EIy \frac{d^3 z}{dx^3} = H$$

$$2EIy \frac{d^3 z'}{dx^3} = H'$$

(2) at $x = \infty$

$x' = 0$

$\beta_1 = 4\sqrt{k_1/4EIy}$ $\qquad \beta_2 = 4\sqrt{k_1 k_2/4(k_1 + k_2) EIy}$

Thus, the following are obtained.

$$z = (1/16EIy) [(H + H') \cdot \varphi_1(\beta_2 x)/\beta_2^3 + (H - H') \cdot \varphi_1(\beta_1 x)/\beta_1^3]$$

$$z' = (1/16EIy) [(H + H') \cdot \varphi_1(\beta_2 x)/\beta_2^3 - (H - H') \cdot \varphi_1(\beta_1 x)/\beta_1^3]$$

Where, $\varphi_1(x) = e^{-x}$ $(\cos x + \sin x)$

$\varphi_1(x)$ assumes the maximum at $x = 0$.

Namely, $\varphi_1(0) = 1$

The maximum value of lateral rail displacement develops at the point of action of lateral force, and is given by the following set of formulas.

$$z = (1/16EIy) [(H + H')/\beta_2^3 + (H - H')/\beta_1^3]$$

$$z' = (1/16EIy) [(H + H')/\beta_2^3 - (H - H')/\beta_1^3]$$

The values, β_1 and β_2, vary depending on the tie and fastening device and also on the maintenance conditions. Thus, they could not be determined at the surveyed section. But, it may be safe to consider that the values remain the same at the same point on the same day.

Namely, β_1 and β_2 may have been constant for the trains measured.

The following values are an example in the Japan National Railways.

$\beta_1 = 3.94 \times 10^{-2}$ cm^{-1}

$\beta_2 = 1.62 \times 10^{-2}$ cm^{-1}

In the example above, β_1 is larger than β_2.

The actual measurements of lateral rail displacement within the premises of Mae Tan Noi St. are as listed in Table 4.6.1. It is found that both inner and outer rails are forced outwards. This means that z and z' are opposite to each other in direction. With JNR's β_1 and β_2 as a reference, let us compare the lateral force between ALSTHOM and GE locos.

$z = (1/16EIy)\ \{ (H + H')/(1.62 \times 10^{-2})^3 + (H - H')/(3.94 \times 10^{-2})^3 \}$

$z' = (1/16EIy)\ \{ (H + H')/(1.62 \times 10^{-2})^3 - (H - H')/(3.94 \times 10^{-2})^3 \}$

By substituting the mean values of z and z' (see Table 4.6.1), we obtain the following.

Table 4.6.1

Loco	ALSTHOM	GE
z	3.1	1.7
z'	−1.7	−1.6

R_A = HA/HG = ALSTHOM's H/GE's H

R_A' = HA'/HG' = ALSTHOM's H'/GE's H'

Namely, $R_A \doteqdot 1.5$, $R_A' \doteqdot 1.4$

The values above show that, as compared with GE loco, ALSTHOM loco is suspected to develop a lateral force 1.5 times as much in the outer rail and 1.4 times as much in the inner rail.

Table 4.6.1 ured Nov. 16, 1979

LOCOMOTIVE		ALSTHOM				GE			
TRAIN		98	97	38	Average	468	617	602	Average
Lateral displace-ment, outer rail	①	5.6	5.2	1.9	4.2	3.2	2.3	1.0	2.2
	②	2.8	4.6	1.9	3.1	2.0	1.0	0.9	1.3
	③	2.3	3.1	1.6	2.3	2.1	0.5	1.3	1.3
	④	3.0	3.0	1.7	2.6	2.8	0.6	1.8	1.7
	⑤	3.4	3.6	2.2	3.1	2.8	1.4	1.3	1.8
	Average	3.4	3.9	1.9	3.0	2.6	1.2	1.3	1.7
Lateral displace-ment, inner rail	①	3.0	2.8	1.2	2.3	2.8	1.6	1.1	1.8
	②	2.0	2.4	1.6	2.0	2.3	1.6	1.5	1.8
	③	1.2	2.1	0.8	1.4	1.6	1.3	1.0	1.3
	④	1.6	1.4	1.1	1.4	2.6	1.6	1.0	1.7
	⑤	2.0	1.0	0.6	1.2	2.9	1.1	0.6	1.5
	Average	1.9	1.9	1.1	1.7	2.4	1.4	1.0	1.6
Vertical displace-ment, outer rail	①	4.6	3.8	3.8	4.1	3.8	3.8	3.8	3.8
	②	3.8	3.8	2.7	3.4	3.8	2.3	3.5	3.2
	③	3.5	3.1	3.1	3.2	3.1	2.7	3.1	3.0
	④	3.1	2.3	1.9	2.4	2.3	1.9	2.3	2.2
	⑤	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
	Average	4.1	3.8	3.3	3.7	3.7	3.2	3.6	3.5
Vertical displace-ment, inner rail	①	6.2	5.4	5.4	5.7	5.4	6.2	4.6	5.4
	②	6.2	6.2	5.4	5.8	6.2	6.2	5.4	5.9
	③	7.7	7.7	6.9	7.4	7.7	7.7	5.4	6.9
	④	3.1	3.8	3.8	3.5	3.1	3.8	3.5	3.5
	⑤	3.5	3.8	3.5	3.6	3.8	4.6	3.5	4.0
	Average	5.3	5.4	5.0	5.2	5.2	5.7	4.5	5.1

4.7 Lubrication of Rail Edge and Flange Face

The degree of lubrication between the rail and wheel is one of the important factors governing the rail wear.

The wear of metal is dependent largely on the degree of lubrication of sliding or rolling surfaces. In view of this, it is practiced the lubricate the contact surfaces between the rails and wheels. In the RSR, the rails and wheel flanges have been lubricated with track lubricators manufactured by P & M.

The track lubricators used in the sections surveyed this time were found delivering lubricant in good order. At the curves where track lubricators were installed, rail edges were lubricated in comparatively good order.

A method in which track lubricators are provided for rails for rail lubrication is handy and widely practiced, accordingly. But, for the purpose of lubricating a long span of curve, quantities of lubricant must be applied every time when a train passes. The rail head near the track lubricator gets smeared with lubricant to cause a slip between the tire and rail.

We spotted the track lubricators removed in order to avoid this trouble.

But without the track lubricator, the wear of both rail and wheel flange will be accelerated because of increased friction.

Slip of wheels often takes place in the mountainous regions where the track is steep in slope and sharp in curvature. So far as track lubricator is used, it will be difficult to obviate the slip since the control of delivery rate of lubricant is considerably difficult.

The slip is caused because lubricant spread over the rail head reduces the friction coefficient between the rail and wheel tread.

The friction coefficient is usually called the coefficient of adhesion.

The slip is developed under the conditions given by the following formula.

$$T = \mu . We$$

Where, T: tractive effort of locomotive

μ: coefficient of adhesion

We: weight of locomotive

So that the train can move, the tractive effort of its locomotive must be large enough to overcome the resistance on the train. Then, in order to prevent the slipping, the coefficient of adhesion must be large.

Now let us try calculating the coefficient of adhesion by making use of the train resistance used in the calculation of freight train in Sec. 4.4. From Table 4.4.3, the running resistance of the freight train is given by the following formula with the slope resistance as a variable.

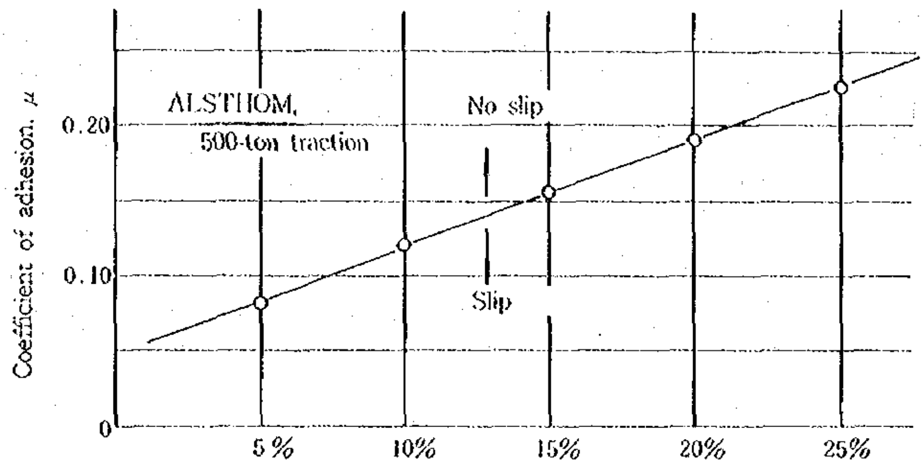
$Rt = 4,094 + 582.5Gd$

In order to overcome this resistance without developing a slip, the coefficient of adhesion must satisfy the following condition.

$$\mu > Rt/Wc = (1/82,500)(4,094 + 582.5Gd)$$

This is graphically represented in Fig. 4.7.1 below.

Fig. 4.7.1



It is generally accepted that the upper limit of the coefficient of adhesion is about 0.2, and it is found that the train will fail to climb up a slope in the mountainous region if the rail head in the curved section is smeared with lubricant.

For the purpose of preventing the slipping while lubricating the rail and wheel for reduction of wear, we cannot choose but reduce the number of cars or load corresponding to the tractive effort which will not cause slip or increase the number of locos in order to reduce the tractive effort per car. Another method is to lubricate the rail from aboard the car. This method is advantageous in that:

(1) the consumption of lubricant can be reduced compared with the track lubricator fixed on the track and the slip can be minimized, because it is possible to apply lubricant sparingly on the needy surfaces of the wheel flanges over the entire length of curve; and,

(2) the maintenance is easy and economical because the number of lubricators required aboard the cars can be reduced compared with that on the track.

Some of the track lubricators installed along the lines in Thailand need to be topped up twice or more every month. Considering the maintenance load necessary for effective anti-abrasion of the rails, the installation of flange lubrications aboard the cars is recommended.

5. Management of Rails by EDPS

In the RSR, a computer is employed to marshal the rail wear data for the purpose of obtaining something of a basis upon which to replace defective rails.

The purposes of track management by making use of EDPS are:

(1) to save labor,

(2) to modernize the operations,

(3) to build up operational information.

Namely, EDPS offers a scientific approach to these for the purpose of upgrading the maintenance level. The subjects of track management for which information processing by EDPS is recommended in order to achieve the purposes stated above include not only rail, but also maintenance work, track materials, equipment, buildings, construction work structures. The control items to be covered by EDPS spread over a wide spectrum, including budgetary affairs, financial statement, logistic services, manning, right-of-ways, special statistical data.

In the JNR, the EDP management system for husbandry of facilities is as shown in Fig. 5.11. The data are exchanged between the head office, regional departments and local shops in order to obtain management data necessary in each stage of operations.

The rail management system coming under this system is outlined as follows.

(1) An outline of rail management system

In the rail management system, the following basic data are checked with the rail replacement standards established by the head office for each railway division for the purpose of preparing rail replacement programs.

1) Data on installed rails

2) Data on the wear conditions of rails in the curved sections

3) Data on periodic replacement of rails in the tunnels

All these data are processed in a computer according to the following sequence.

1) Updating at each local shop of the ledgers kept in the preceding year.

2) Preparation at the head office of local rail replacement schedule to meet budgets and policies with the rail replacement standards as a basis.

3) Modification at the regional departments of the local rail replacement schedules in consideration of special manning requirements and regional conditions.

4) Preparation at the head office of the rail replacement programs according to the modification in (3) above.

5) Renewal of rails according to the rail replacement programs.

(2) **Input schedule and output schedule**

In the JNR, the aggregate rail length is about 80,000 km. Currently, the rails are replaced once every twenty-five years. The input data and output data of the rail management system are shown in Tables 5.1.1 and 5.1.2. The schedules listed in Tables 5.1.1 and 5.1.2 are prepared at the head office, regional departments and local shops and are used after EDP. What should be taken into account before preparation of the facility management system is as follows.

1) Establishment of overall deep-future framework for realizing a well-knit interlinking structure of associated systems.

2) Designing of the types, structures, accuracy and collecting methods of input data for effective use in every system.

3) Identification of purposes and objectives of management systems for husbandry of human resources and materials in a manner to keep and develop the systems.

4) Establishment of organization and clear distribution of duties and responsibilities for the purpose of preparing and updating the programs.

The facility management system is vital to the facility management functions in future, and its planning must be carried out under the guidance of experts in this field.

Fig. 5.1.1

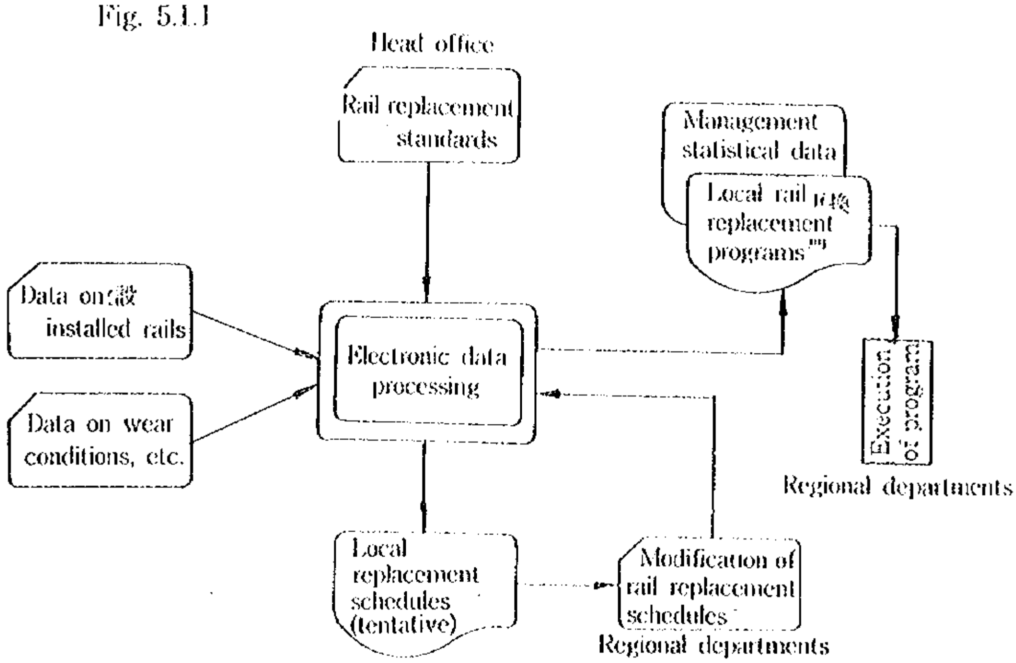


Table 5.1.1 Input Data

No.	Name of data	Prepared by:	Remarks
1	Schedule of battery limits of the maintenance of way branch depots	Regional departments	
2.	Rail identification mark schedule	Maintenance of way branch depots	
3	Rail wear survey schedule	do.	
4	Tunnel schedule	Regional departments	
5	Construction schedule	do.	
6	Long rail installation schedule	do.	
7	Local rail replacement schedule	Maintenance of way branch depots	
8	Modified replacement schedule	do.	
9	Schedule of spare rails, etc.	Regional departments	
10	Schedule of siding rail identification marks	Maintenance of way branch depots	

Table 5.1.2 Output Data

No.	Name of data	Applied to:	Remarks
1	Route map	Head office	
2	Schedule of aggregate length of rails by weight	do.	
3	Schedule of aggregate length of rails by years of use	do.	
4	Schedule of aggregate length of rails by cumulative rail loadings	do.	
5	Schedule of long rails	do.	
6	Replacement schedule of rails by cost	do.	
7	Replacement schedule of main line rails by location	Regional department	(tentative)
8	do.	do.	(final)
9	Replacement schedule of aggregate length of main line rails	Head office	(tentative)
10	do.	do.	(final)
11	Schedule of rail expenditures	do.	
12	Schedule of replacement quantities by standard	do.	
13	Schedule of aggregate length of waste rails	do.	
14	Schedule of aggregate length of siding rails by weight	do.	
15	Actual record of replaced siding rails	do.	

6. Prevention of Derailment

6.1 Status Quo and Features of Derailment Accidents in RSR

According to RSR's statistics, it is reported that the annual average accident rate over the past ten years from 1968 has been 437, and that 60% of the accidents have been accounted for by derailment.

The incidence per 100 km of route length and track length is as shown in Table 6.1.1.

Table 6.1.1 Number of Accidents (length as of the end of 1977)

	Aggregate length, km	Incidence, annual average over ten years per 100 km		Incidence in FY 1977, per 100 km	
		Train accidents	Derailment	Train accidents	Derailment
Route	3,765	11.6	7.1	15.9	10.5
Track	4,452	9.8	6.0	13.5	8.8

The incidence shown in Table 6.1.1 is anomalously high, and the prevention of train accidents and derailment is a matter of urgency for the improvement of RSR's business standing.

The statistics of derailment developed in the RSR over the ten years from 1968 to 1977 are shown in Table 6.1.2, and are plotted in Fig. 6.1.1.

The features of derailment accidents in RSR may be summarized from Fig. 6.1.1 as follows.

(1) In 1969, the total number of derailment cases dropped sharply, but since 1971, the incidence had started rise. In 1976, the incidence rose to the level marked in 1968.

(2) In recent years, the number of derailment accidents due to misoperation has been increasing, sending up the rate of serious accidents.

(3) The number of derailments due to damaged rolling stock and rails has been hovering high since 1974 when it snapped up.

In view of the analysis above, the following measures will be suggested for effective reduction of derailment accidents in Thailand.

(1) Stepped-up efforts to educate and train the railway employees, and formation of habits of observing rules strictly.

(2) Establishment of planned train operation diagrams which all the train operators must abide by in order to run the trains on schedule.

(3) Rigid control of station workers about the handling and operation of signals and switches.

Train accidents

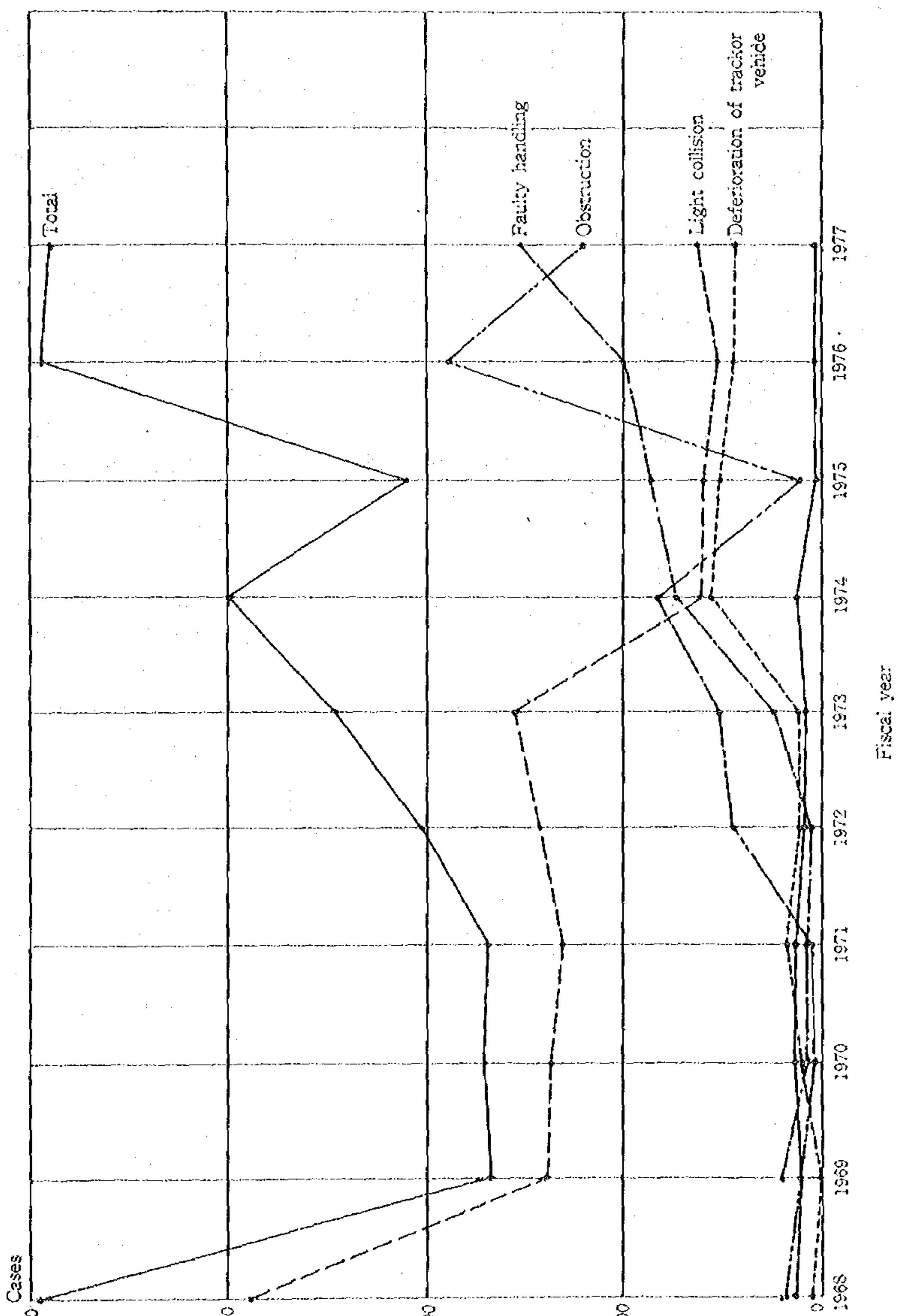


Fig. 6.1.1

(4) Establishment and observance of rules concerning line blocking work and trolley use, and of the system of liaison services related thereto.

(5) Modernization and improvement of track and rolling stock, and establishment of track material maintenance and replacement standards for the purpose of minimizing derailment accidents due to superannuated or damaged line facilities and rolling stock.

(6) Establishment and enforcement of qualification system for engine drivers, trackmen, station train operators, signalmen, etc., and overall review of payroll system and education and training system.

(7) Prevention of train obstruction in cooperation with local governments and educational institutions.

These measures against train accidents should be pushed forward immediately by the joint efforts of departments, divisions, and sections responsible for the management of train operations, rolling stock and line facilities.

6.2 Example of Derailment of Locomotives in Thailand

The general tendency of rolling stock derailment in the RSR has been discussed in the foregoing section. The following are a few examples of spontaneous derailment of locomotives in recent years.

(1) Derailment of GE 4020 locomotive at around 578.845 km on the North Line, June 32, 1965

This accident happened just after the GE 4020 locomotive linked to a train of 33 freight cars departed Phakan St. The train speed was low, and the defects of rolling stock and rails were unknown.

The alignment at the spot of accident was investigated on roadway plan. The roadway map was judged practically accurate, though it was not perfect agreement with the site conditions. According to the survey, the following were found about the alignment.

(a) The spot was a combination of transition curve and vertical easement curve.

(b) The accident happened just after start.

(c) Inner and outer wheel marks on the sleepers did not agree to each other, and expansion of gage suspected to be. But no definite things could not be said. (See Fig. 6.2.1)

(2) Derailment of ALSTHOM 4146 locomotive within the premises of Mae Tan Noi St. at 671.808 km point on the North Line, September 7, 1976

This accident happened just after ALSTHOM 4146 locomotive tracting 6 coaches departed Mae Tan Noi St.

The train speed was low, and no definite defects of rolling stock or track which were condemned for derailment were reported.

A similar survey as in (1) was conducted, and the following features are found.

(a) The accident happened in a curve.

(b) The accident happened just after start. The wheel climing points and the starting points of wheel marks on the sleepers were deviated from each other, but no definite thing can be said about the expansion of gage.

(3) **Derailment of ALSTHOM 4119 locomotive at 574.522 km point on the North Line, Mar. 1, 1977**

This accident happened when ALSTHOM 4119 locomotive just started after stopped in collision with a track-cycle. The features of this accident are as follows.

(a) The accident seems to have taken place at a section where transition curve and vertical easement curve coexisted.

(b) The accident took place just after start.

(4) **Derailment of ALSTHOM 4128 locomotive at 568.450 point on the North Line, Mar. 11, 1977**

This accident happened when ALSTHOM 4128 locomotive hauling 9 freight cars came to the spot.

The features of the accident are as follows.

(a) The spot lies in a transition curve so far as the route plan shows.

(b) The rail wear was serious.

The following are common to all the cases cited above.

(a) The accidents happened in a curve or transition curve.

(b) The accidents happened immediately after the trains started or when they were running at a low speed.

(5) **Derailment in a transition curve or a curve**

It is said that the wheels climb the rails when Nadal's formula given below is satisfied.

$$\frac{Q}{P} > (\tan\Theta - \mu)/(1 + \mu\tan\Theta)$$

Where, Q: lateral force

P: wheel load

The new wheels used by the RSR have $\Theta \doteqdot 60°$, hence the climbing of wheels up the rails will take place under the following conditions.

$$\frac{Q}{P} \doteqdot 1.0$$

Q/P is usually called the derailment coefficient.

It is evident from the above that the climbing is liable to happen if Q becomes larger while P becomes small. In a sharp curve, a turning lateral force acts on the wheels; namely, Q is large. In a transition curve, leaving a curve, the leading wheels tend to come afloat as illustrated in Fig. 6.2.5 because the superelevation decreases gradually to detracting from the wheel load.

In actuality, the wheel load decrease does not take place in the leading axle alone, but can develop a state vulnerable to derailment.

As shown in Fig. 6.2.6, the transition curves surveyed this time were found to have major irregularities in alignment and cross level. These irregularities develop a large lateral force and at the same time reduce the wheel load, aggravating the derailing situation. In the RSR, the emergency limit of the change in cross level for 1st and 2nd class of track is set at 15 mm within 5 m chord. But the change in cross level should be controlled in terms of the value less the twist due to the gradual decrease in superelevation. Large irregularities in cross level in the transition curve lead to large irregularities in flatness, and should be controlled strictly.

Since ALSTHOM locomotive is liable to be derailed, before improvement of such locos, the track irregularities, especially along sharp curves should be strictly be controlled.
To this end, the track irregularities should be measured by making use of a high speed track measuring car. When a train runs on a superelevated curve at a low speed, the superelevation becomes excessive as against the speed, and tends to reduce the outer wheel load and increase the inner wheel load.

The change in the wheel load is given by the following formula.

$$\Delta W = [\,(W \cdot H/G)\,(\frac{V^2}{127g} - \frac{C}{G})\,]$$

If V = 5 km/h, ΔW = 10.95 tons.

Assuming that the change in the wheel load is proportional to the static wheel load, the change per wheel (Wi) is given by the following.

$$\Delta Wi = \frac{10.95}{6} \text{ tons} = 1.82 \text{ tons}$$

P gets reduced by this, and Q/P gets increased.

A train resistance is acting on the locomotive. During power running, a tractive force develops a moment as illustrated in Fig. 6.2.7, reducing the wheel load of the leading axle.

Namely, $M = Th = \Delta P \ell$

$\Delta P = Th/\ell = 2.2$ tons

If this acts on each wheel in proportion to the static wheel load, the wheel load will be reduced by the amount calculated as follows.

$\Delta Pi = \Delta P/6 = 0.4$ tons

Since the following happens, the locomotive becomes liable to be derailed during power running on a curve or a transition curve at a low speed.

(a) Reduction in wheel load due to gradual decrease in superelevation.

(b) Reduction in wheel load due to excessive superelevation.

(c) Reduction in wheel load due to tractive effort.

It is therefore inferred that ALSTHOM locomotives, which are liable to develop a large lateral force, may have caused the accidents cited in the foregoing for the reasons given above.

In order to prevent this kind of train accidents, it is desirable to measure the running stability of ALSTHOM locomotives, that is, lateral force (Q) and wheel load (P), by making use of a wire strain gauge applied to the wheel, in order to formulate proper measures. At present, the instrumentation for this purpose is under way by the hands of the engineers of the RSR's Mechanical department, and the Civil Engineering department should cooperate to prompt the measurement of ALSTHOM locomotives. The measurement will take much labor and time before satisfactory results are obtained.

Enumerated in the following are the items which may as well be put to practice immediately for the purpose of preventing derailment, before improvement of ALSTHOM.

(1) Replacement of defective sleepers in the sharp curves through which ALSTHOM locomotives run, insertion of tie plates, and increase of dog spikes.

(2) Use of chocks against irregular inclination of rail because the shape of RSR's rail clip is not effective against the irregular inclination of rail.

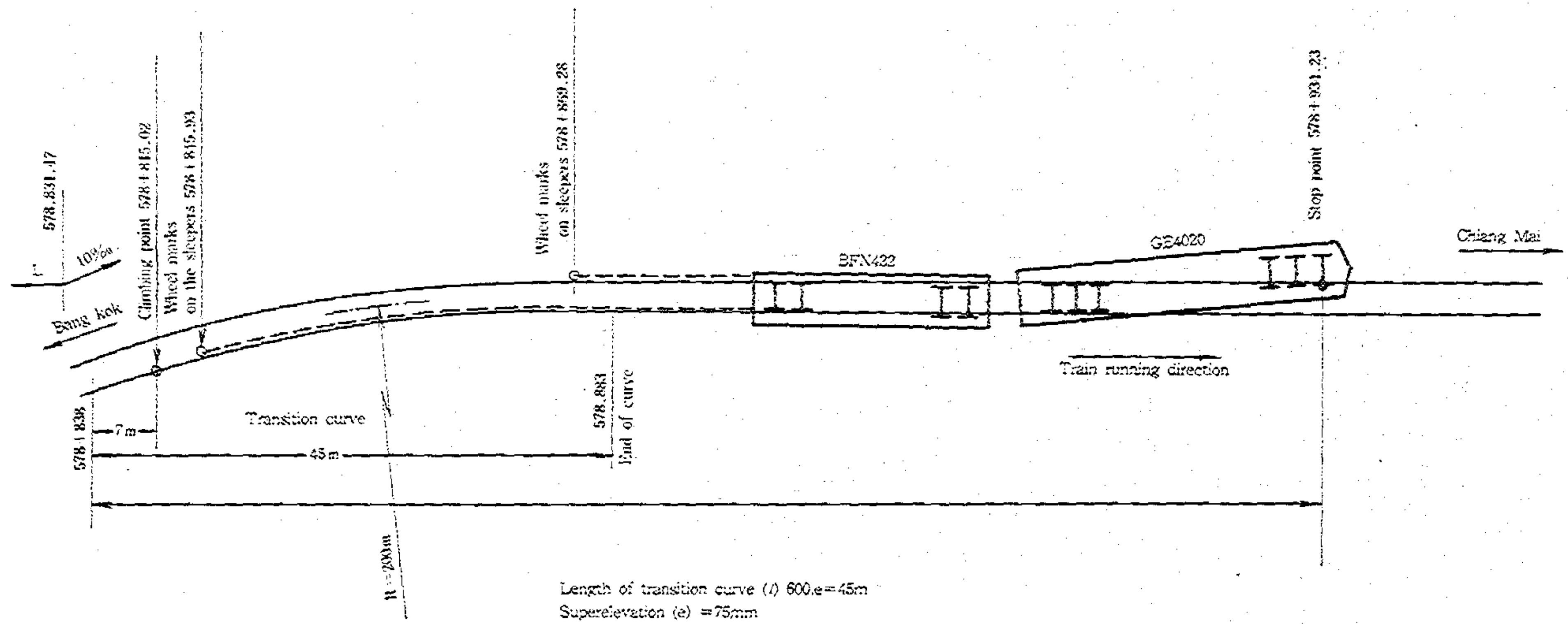
(3) Accurate arrangement of transition curve and gradual decrease in superelevation of the sharp curve through which ALSTHOM locomotive runs.

(4) Avoidance of jerk when ALSTHOM locomotive starts on a curve, particularly within the transition curve at the outlet of the curve. A high risk of derailment exists in case of upgrade. Thus, the starting should preferably be carried out in a straight section cleared of the transition curve.

Anyway, it is recommended to measure lateral force and wheel load of ALSTHOM locomotive by applying a wire strain gauge to the wheel. The measurement should be carried out under the guidance of experts.

Fig. 6.2.1

Derailment of GE 4020 locomotive at 578.845 km point on the North Line. June 22, 1975



Length of transition curve (l) 600.e=45m
Superelevation (e) =75mm

Fig. 6.2.2

Derailment of ALSTHOM 4146 locomotive within the premises of Mae Tan Noi St. at 671.910 point on the North Line. September 7. 1976

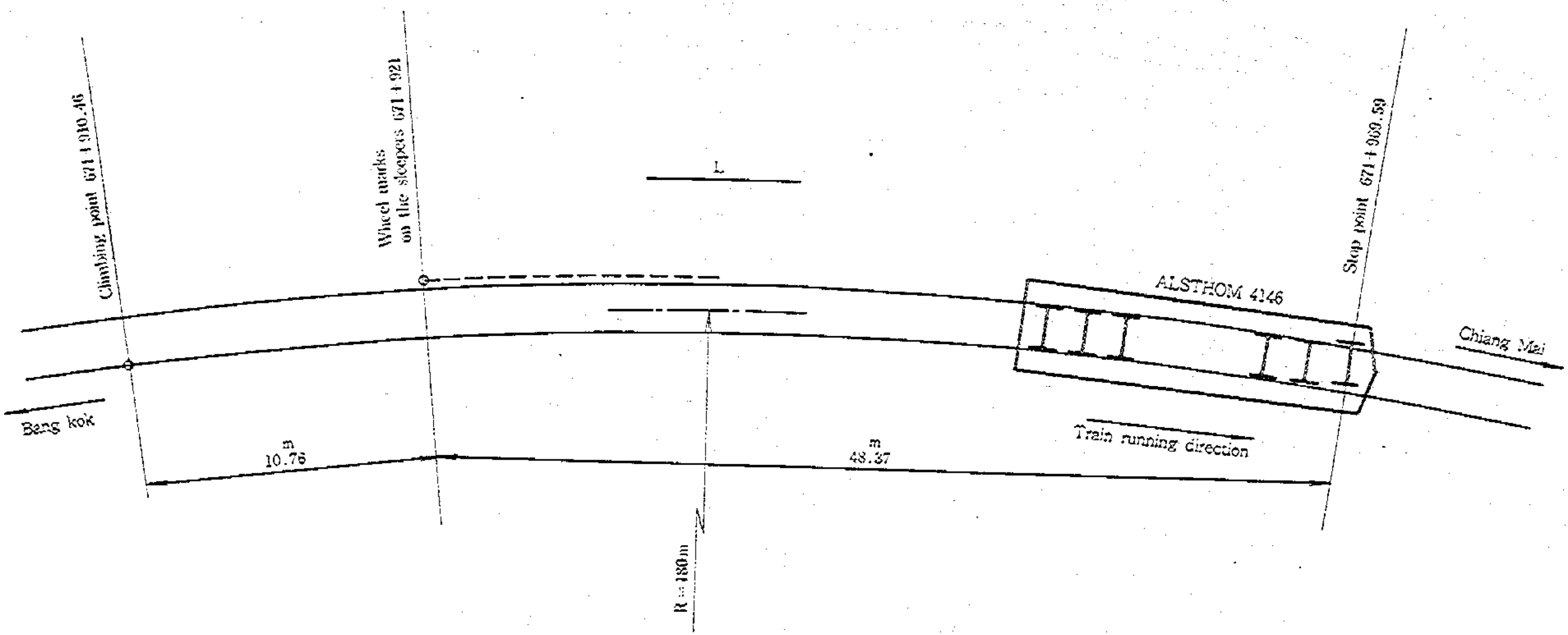


Fig. 6.2.3

Derailment of ALSTHOM 4119 locomotive at 574.520 km point, March 1, 1977

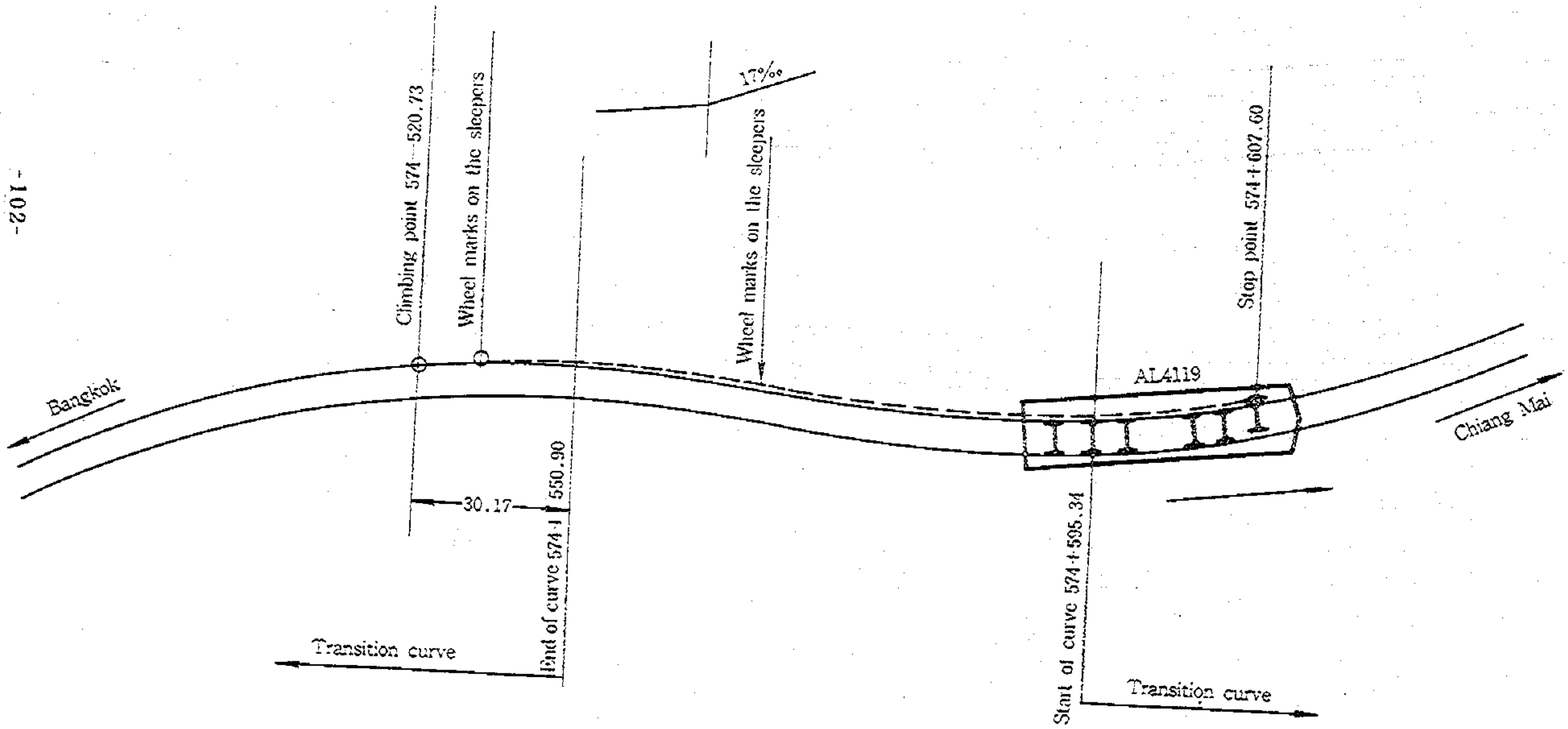
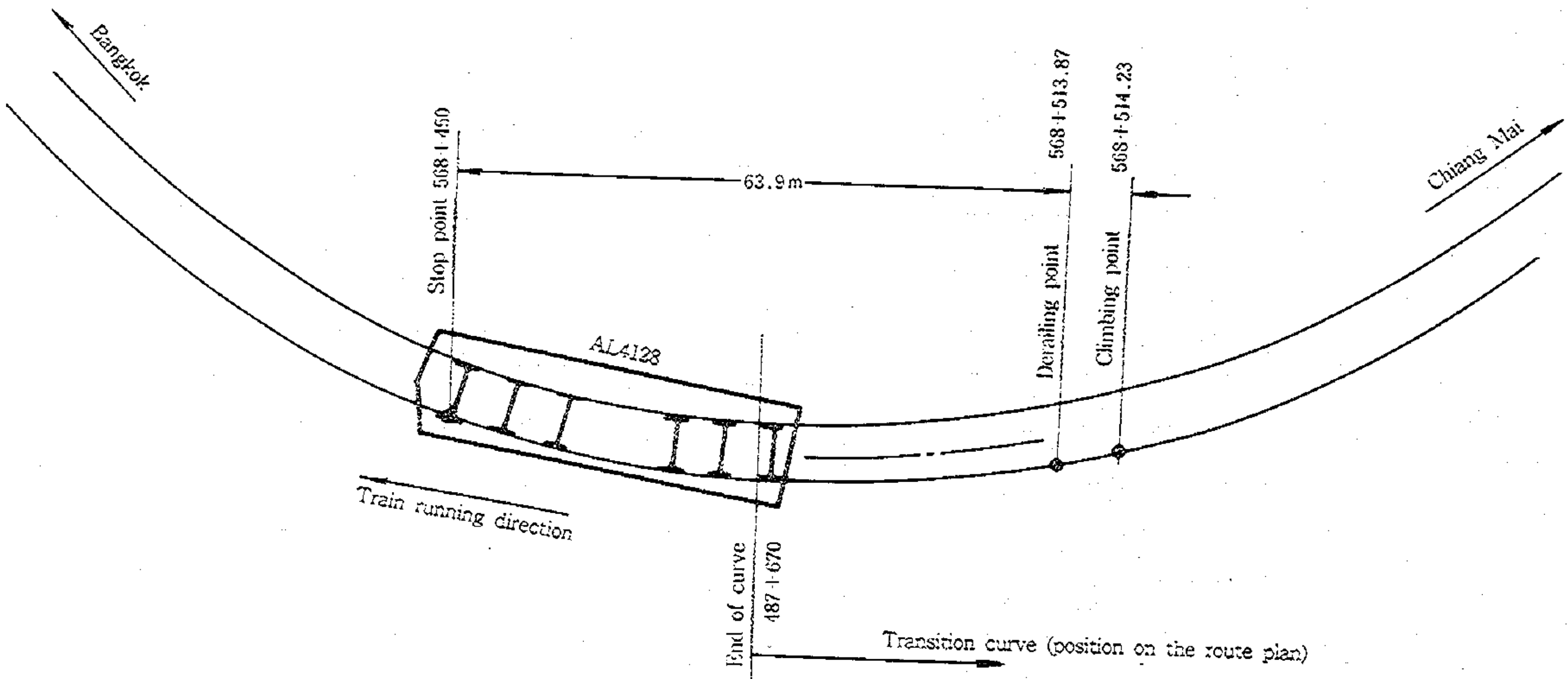


Fig. 6.2.4 Derailment of ALSTHOM 4128 locomotive at 568.513 km point on the North Line, March 11, 1977



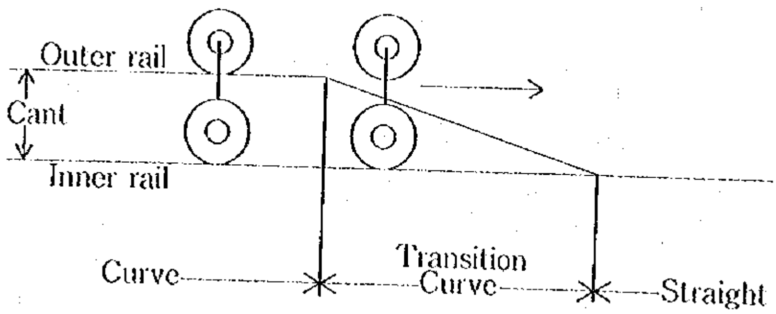


Fig6.2.5

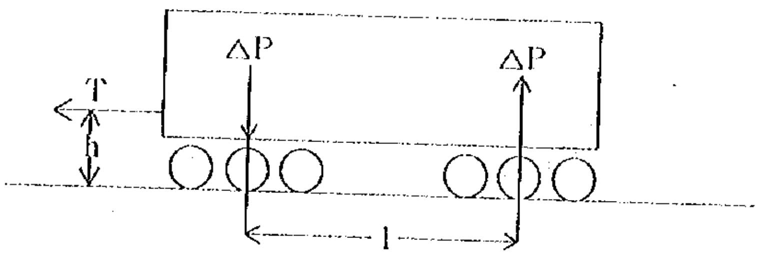
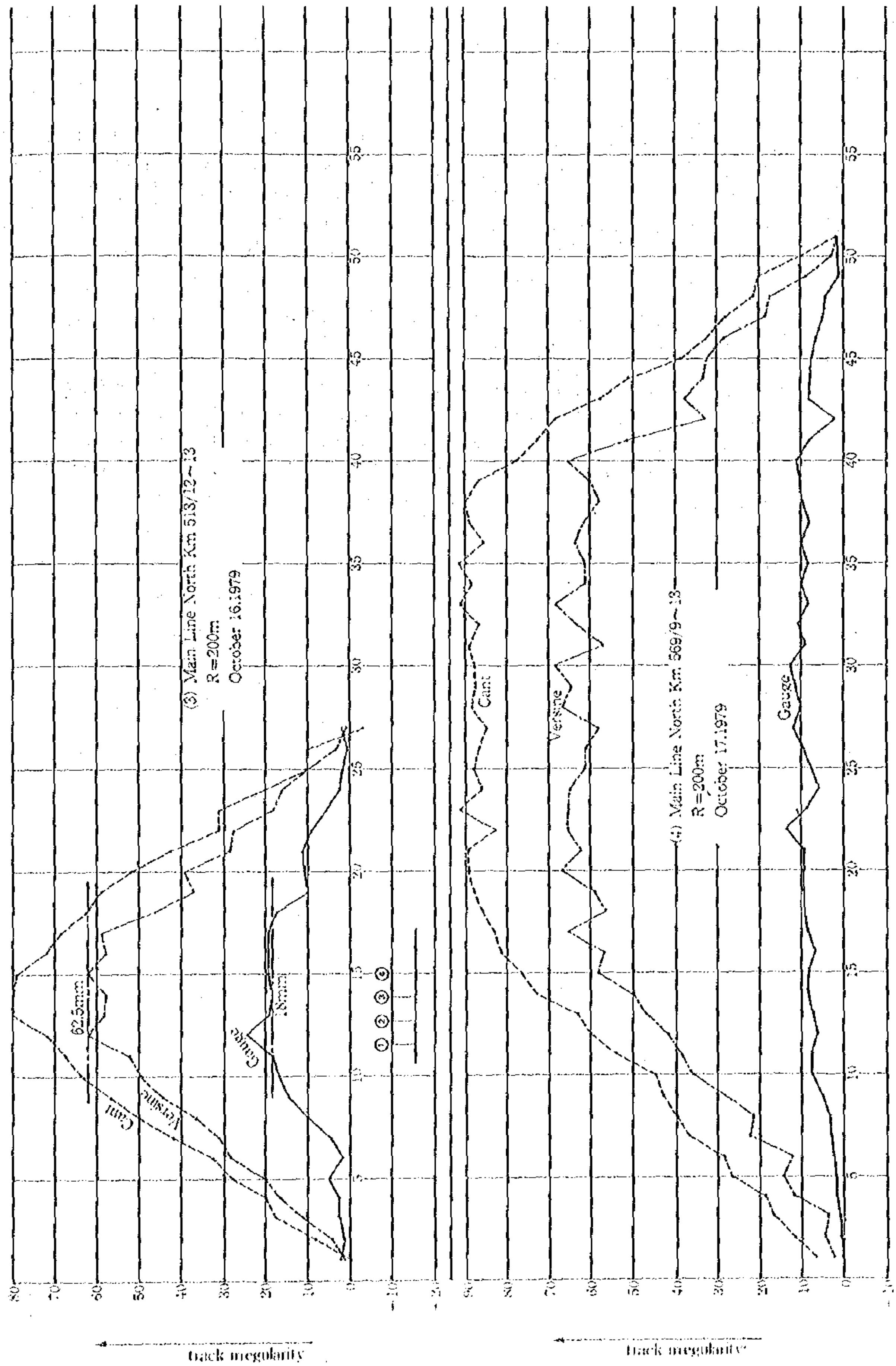


Fig6.2.7


(3) Main Line North Km 513/12~13
R =200m
October 16.1979
Cant
Versine
Gauge
62.5mm
18mm
(4) Main Line North Km 569/9~13
R =200m
October 17.1979
Cant
Versine
Gauge
track irregularity
track irregularity

6.3 Investigation of Derailments

The investigation and recording of derailments in the RSR follow the procedures appearing in Table 6.3.1 for the purpose of clearing up the causes and preventing the relapse. However, we have an impression that the investigation procedures, coverage of investigating items, and recording method needed improvement. The accident investigation and reporting should be conducted in more detail for the purpose of substantiating the accident analysis and formulation of accident preventive measures.

Fig. 6.3.2 shows excerpts of JNR's accident investigation items and reporting format for your reference.

The methods of filling out the accident report and investigation report, analysis of train accidents, and methods of formulating measures should be established based on interdisciplinary knowledge covering Mechanical and Civil Engineering departments. It is recommended for the RSR to establish and practice the train accident handling procedures under the guidance of experts.

RSR PROCEDURE
FOR
INVESTIGATION OF DERAILMENT

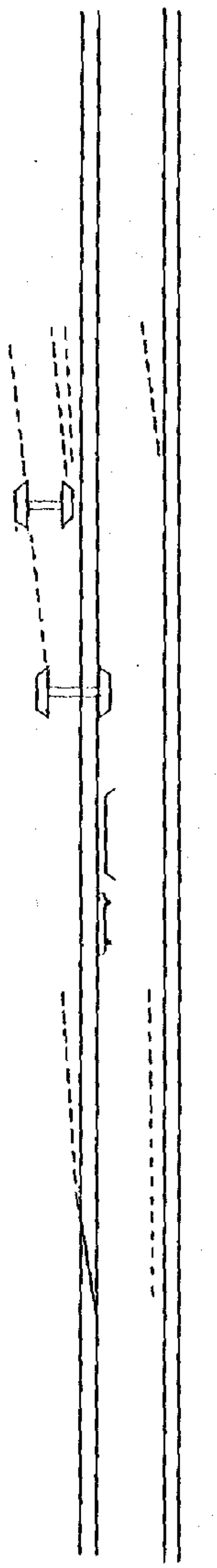
When derailment occurs, local officers from Civil Engineering Department, Mechanical Engineering Department and Traffic Department shall go to the place of derailment as soon as possible. They, then, check together on the following:

1) Signalling equipment.
2) Block working instrument.
3) Time record concerning the block working system.
4) Record on abolition of the token.
5) Wear on flange and tread of all the derailed wheels.
6) Loose -- fitting treads or axles.
7) Scars on wheel tread as a result of faulty braking system.
8) Wear on journal box or bearing block.
9) Condition of bogie suspension.
10) Loading condition.
11) Condition of cars next to the derailed one, both infront and behind.
12) Point of wheel climbing, point of derailment, curve radius, distance from point of derailment to beginning point of circular curve (when derailed on transition curve), clearance between guard rail and running rail (when derailed within turnout switch), distance from point of derailment to point of train stop after derailment.
13) Condition of track about 40 m. prior to the point of wheel climbing or point of derailment; viz., amount of ballast, condition of sleepers, wear and kink of rails, condition of rail fastenings, track irregularity (every 5 m.), longitudinal level, availability of low joints and loose sleepers.
14) Condition of switches and crossings.
15) Any remarkable evidences.
16) Train speed at time of derailment.
17) Any sudden train movement near the place of derailment.
18) Result of taking the derailed vehicle passing the derailment site before repairing the track.

All the above items have to be jointly checked and signed by Traffic Inspector, Locomotive Inspector, Chief Permanent Way Inspector and Signalling Inspector. A sketch showing the condition of derailment is also required. In case any controversy occurs, additional remarks shall be included.

****

6.3.2



Investigation item	(No.)	Track	Rolling stock	Data
	11	Wheel marks on sleepers until stop point		
	10	Running-down of track shoulders	Damage on rolling stock	
	9	Rail rupture		
	8	Damage on structures	Damage on rolling stock	
	7	Change in the number of derailed axles	⊖ ⊗ ⊗	
	6	Run-over		
	5	Bruise on rails	Automatic coumer marks Mark on tire Slipping of parts	
	4	Rail fittings, railroad crossing guardrail	Depression on flange tread	
	3	Wheel marks on sleepers	Mark on wheel tread	
	2	Climbing-down (Thud mark)	Mark on outside edge, mark on flange	
	1	Climbing-up	Flange rim	
	12	State right before accident point		

August, 1971

Train Derailment Investigation Report — Safety engineering section, Train Operation Department

Item	Classification
I. General	1. Summary 2. Outline of the investigation 3. State of derailment, and state of track
II. Train operation	1. Handling, operation and action by the persons concerned 2. Train operation diagram 3. Enlarged view of speed recording chart 4. State of train just before accident
III. Rolling stock	1. Train make-up, and inspection record 2. Derailment and damage state of cars 3. Slipping of car fittings 4. Diagram of car types 5. Measurements of rolling stock 6. Inspection record 7. Wheel shapes 8. Damage on wheel, automatic coupler, etc. 9. Measurement of wheel load 10. Spring constant, spring friction coefficient, load-deflection diagram 11. Yawing resistance of automatic coupler 12. Lateral resistance of link
IV. Track	1. Marks or damage on the track members, derailing position 2. Measurement of track state 3. Measured diagram of track state 4. Measurement of track sinkage 5. Data from high speed track recording car 6. Wear pattern of rail head 7. State of track work 8. Weather conditions
V. Loading	1. Loading condition 2. Sketch of loading on derailed freight car
VI. Restoration work	1. State of restoration work
VII. Causes of accident	1. Discussion of causes

Spontaneous train derailment investigation report

to:__________

I .General (1) Summary

Type of accident		Number of cars derailed					
		Casualties	Classification	Number of passengers	Number of non-passengers	Number of rail workers	Total
Location of accident			Death				
			Injury				
	Railway Operating Division.	Line:	St. to	St. (	km	m)	
Train	Train No.	cars (number of cars in terms of 10-ton load:		cars).			
	Standard number of cars:	; Locomotive No.	: Engine depot:	witnesses			
Brief description of accident							

	Affiliated section	Title	Name	Age	Number of years in present post
Invesigators &					
Others					

Train diagram Remarks

Annex (Attach a photo showing the general view)

I –2 (Summary of investigation)

Investigation subject	Investigation data
Type of accident	Date and time of accident: Weather: rainfall [ ]; snowfall [ ]; snow depth [ ]; ambient temperature.
Location of accident	Railway Operating Division [ ] Line [ ] St. to [ ] St. [ ] km [ ] m; No. [ ] train [ ] cars ([ ] cars in terms of 10-ton load), standard number of cars: [ ]; Type of locomotive: [ ] [ ] Engine Depot
State of derailment	Direction of derailment: Right or Left as viewed toward the running direction: Inside or Outside of the curvature: Wheel climbing-up mark on the switch: [ ] m: Trailing turnout or Facing turnout
	Number of derailed cars: [ ] (from [ ] to [ ])
Operating conditions	Time of departure or passing-by of the preceding station: [ ] • [ ] ([ ] earlier or later than scheduled time); speed: [ ] km/h: during power running or coasting; during brake application at a reduced pressure of [ ] kg/cm²
	during brake release at holding or operating position: standard running speed: [ ] km/h; speed recorder: provided or not provided: Recorded speed: [ ] km/h
Career of the person involved in the accident	Affiliated section: [ ]; Title: [ ]; Age: [ ]; Date employed: [ ]; Date assigned to present post [ ] Period in the present post: [ ] yrs. [ ] mos. [ ] ds.
Track conditions	Class of track: [ ]; Curvature in the running direction, R= [ ] m; Righthand or lefthand superelevation, [ ]; Equilibrium speed: [ ] km/h; Slack: [ ]; BTC: [ ] km [ ] m; ECC: [ ] km [ ] m; ETC: [ ] km [ ] m
	Grade in the running direction: Upgrade [ ] or Downgrade [ ] or level: transition point of grades before and after the spot of accident or grades before and after the spot of accident: [ ] (diagram)
	Type of track: [ ]; Thickness: [ ] mm; Type of sleepers: [ ]; Number of sleepers: [ ] pcs./ [ ] m of rail
	Rail: [ ] kg. [ ] type, [ ] m; Rail joint: Opposite or alternate type
	Rail fastening device: Type [ ]; anti-creeper, [ ]; tie plate. [ ]
Others	Anomalous vibration or shock felt on and before the day of accident [ ]
	Casualties: Death, [ ] persons; injury, [ ] persons
	Real or expected tim of restoration: Date, [ ]; time, [ ] • [ ] '
	Formation of special task force: [ ]; tim of formation: [ ] • [ ] ' Time of disbandment: Date, [ ]; time, [ ] • [ ] '

I-3 State of Derailment, and State of Track

Name of investigator: ____________________

(1) Distance of derailed cars from the rails

to:

(2) Location of cars

(3) State of track

State of track	Curvature	BTC km BCC km R= C= S= EOC km ETC km
	Grad	
Rails		
Sleepers		
Roadbed		
Tie plates		

7. Improvement Plans to be Pushed Forward by the RSR in the Future

The improvement plans which it is found by the survey this time should be promoted by the RSR are summarized below with emphasis on the track maintenance.

(1) Study and preparation of standard planned train operation diagram, and establishment of standard train operating procedures according to it in order to attain the following objectives.

(a) Punctuality of train services.

(b) Prevention of accidents through precise time schedule of train interval and strict control of track blocking work and trolley use.

(c) Study of conformance between track structure (superelevation, transition curve) and rolling stock in order to improve the riding comfort and extend the service life of rolling stock and track materials.

(d) Preparation of data on which to assess the measures for speed-up of trains in the mountainous region of the North Line and on the South Line.

(2) Purchase of heavy track maintenance machines and reinforcement of track materials for the purpose of upgrading the track maintenance level in order to speed up the trains. To this end, particular emphasis should be placed on the following.

(a) Purchase and operation of high speed track measuring car in order to strictly control the track irregularities.

(b) Study and implementation of comprehensive measures against mud-pumping action of ties, including the improvement of roadbed.

(c) Study and implementation of measures for the improvement of fastening devices for wooden sleepers and concrete sleepers.

(d) Improvement of rail specifications for the sections where rail wear is violent, and promotion of on-board wheel flange lubrication.

(e) Purchase of effective curve lining calculator for the purpose of improved curve adjusting.

(f) Study of heavy track maintenance machine work plans for building up cyclic maintenance and repairing systems.

(3) Promotion of research and study through measurement and recording by joint efforts of mechanical engineers of the wheel loads, lateral forces, derailment coefficients and train motions for the purpose of speed up the trains, and formulation of plans for improvement of track structure and materials.

(4) Introduction and promotion of comprehensive EDP system for the modernization of track management.

(1) Study of rail system data input and output schedules.

(2) Study of management standards. For the purpose of studying rail wear standards, it is recommended to purchase a high-precision instruments (planimeter).

(3) Collection, analysis and appraisal of data for rail management.

(4) Study of comprehensive measures for prevention of derailment. From the viewpoint of track and structure management, the following should be undertaken.

(1) Study and implementation of systems for prevention of accidents due to rainfall and strong wind.

(2) Study and implementation of comprehensive disaster prevention programs for superannuated facilities and dangerous spots.

In order to make these effective, it will be important to enlist the advice of experts.

8. Postscript

The RSR's line condition is judged good in the main. But the level of services that the RSR offers should be improved more and more in keeping with the socio-economic growth of Thailand.

The track facilities are voluminous, and their improvement calls for continued efforts on a long-term basis since unlike the rolling stock, the track facilities must be improved step by step while in use.

The improvement of track facilities is not a casual business. The track management engineers should enter upon the modernization of track facilities with energy and determination and with the intention of persevering in it without losing the forward-looking attitude.

In view of this, there are many technological problems standing in the way of RSR's track maintenance and management undertakings. The RSR is called upon to make continued efforts for improvements while facing the challenge of all these problems.

1. FEATURES

In recent years, rail provided with high anti-abraision property is being increasingly in demand not only by ordinary railroads for passengers and freight, but particularly by the mining industry for applications in relation to railroads in the mining districts where it must stand repeated heavy loads and run through quite a series of sharp curves.

To cope with such requirements, Nippon Steel Corporation has devoted itself to developing rail and their efforts have now culminated in the establishment of a new heat-treatment process for the manufacture of New Head-Hardened Rail provided with new chemical compositions.

Some of the outstanding features of New Head-Hardened Rail are as follows:

1) The rail has extremely fine pearlitic structure which is superior to any other microstructures in anti-abraision.

2) The rail is provided with a surface hardness of HB 341~388, and shows a very gradual decrease in hardness inwards.

3) Stable quality is assured through whole length of every rail owing to the entirely continuous heat treatment and roller straightening process.

2. MANUFACTURING PROCESS OF NEW HEAD-HARDENED RAILS

2-1 Flow of Process

New Head-Hardened Rails are manufactured in accordance with the sequence shown in Fig. 1.

1. Receiving as-rolled rail
2. Re-inspection of rail surface
3. Rail end protection and rail connection
4. Induction heating
5. Air cooling
6. Sampling for quality check

   For each 500m of rail treated on each heat-treatment line, a specimen is heat-treated under the same conditions as the product rails and then checked for hardness, hardened area and other mechanical properties.

7. Rail disconnection
8. Press straightening
9. Inspection of hardness and conditions of rail ends and surface
10. Inspection of straightness
11. Marking and binding
12. Storage at ware house
13. Shipment

Fig. 1 Heat Treatment Procedure of New Head-Hardened Rail

2-2 Layout of Heat Treatment Equipments

Fig. 2 shows an overall plan of the heat treatment equipments.

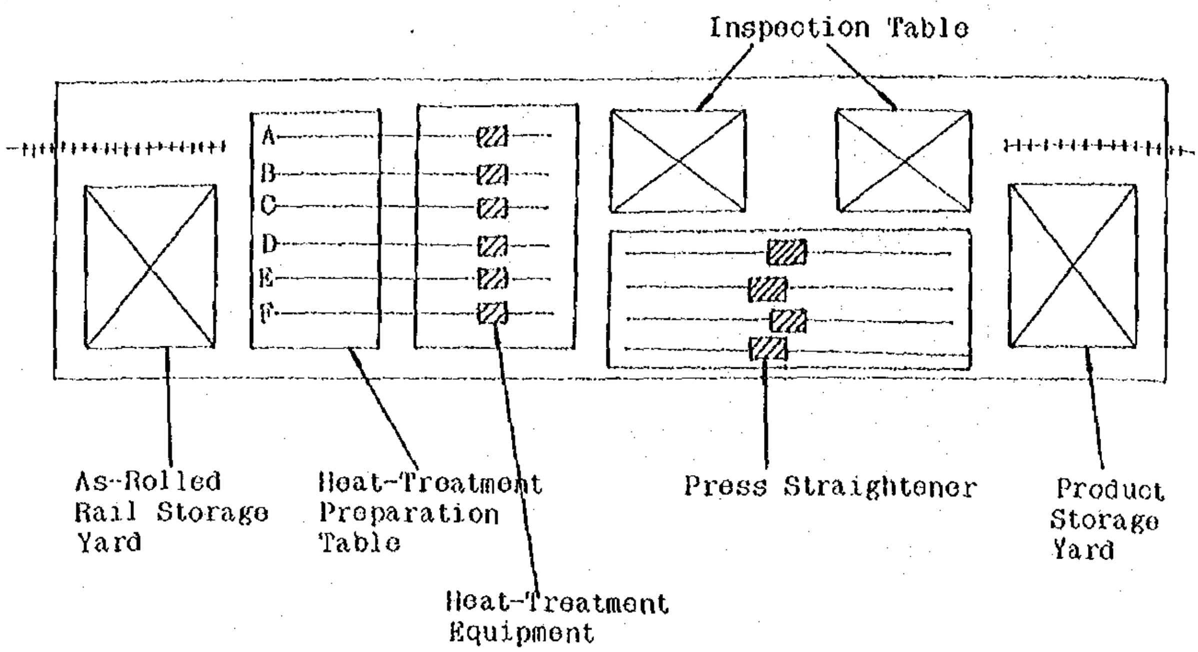


Fig. 2 Overall Plan of Heat-Treatment Equipments

2-3 Test and Inspection

The following tests and inspections are made during the manufacturing process of the rail:

(1) Re-Inspection of Surface of Rails before Heat Treatment

As-rolled rails delivered onto the heat treatment line have already undergone inspection for surface defects at the end of the rolling mill. But visual inspection of the surface of the rail head is conducted again on the preparation table. Also, magnetic particle test, utilizing A.C. magnetic poles is conducted on some selected portions of each rail to detect shrinkage pipe.

(2) Hardness Test

Hardness of all heat treated rails is tested on the rail head on the inspection table, using Shore Hardness Testers

(3) Inspection of Rail Surface

Surface of all heat treated rails is visually inspected on the inspection table.

(4) Inspection of Rail Ends

Both ends of all heat treated rails are checked by the magnetic particle test to detect cracks.

(5) Inspection of Straightness

After correcting deformation due to heat treatment by the press straightener, each rail is inspected mainly with respect to straightness of its ends.

3. SPECIFICATIONS

The below-listed rails are supplied in accordance with our following specifications:

AREA	136^{lb}, 115^{lb}
JIS	60^{kg}, 50^{kgN}, 50^{kg}

The other types of rails also will be replied to the customer's requirement, considering the min. quantity needed.

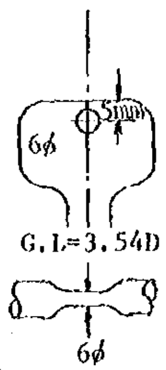
3-1 Chemical Composition

C.	0.70 ~ 0.82%
Mn	0.70 ~ 1.00%
Si	0.10 ~ 0.35%
P	0.030% Max
S	0.030% Max

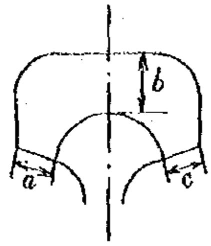
3-2 Mechanical Properties (after heat treatment)

Tensile strength	$120Kgf/mm^2$	min
Elongation	14%	min
Hardness (surface of rail head)	HB 341 ~ 388	

Note : Position of Tensile Test-piece



3-3 Profile of Hardened Zone and Others

Depth of Hardened Zone	Heat treated depth: Center of head top...b:15mm or over. Heat treated part under the jaw...a,c:10mm or over. 
Cross-sectional Hardness	There shall be no part exceeding Vickers-hardness (Hv) 410.
Disribution of Hardness in Section	Shall be sloped gradually toward the inside, with no sharp drop or discontinuity.

Note: "Hardened Zone" refers to the part austenitized at heating of heat treatment.

4. PRODUCTION RESULTS OF 136RE NEW HEAD-HARDENED RAILS

4-1. Properties of As-rolled Rails (before heat treatment)

(1) Chemical Composition

Table 1. Chemical Composition (%)

(Radiation Spectral Analysis)

Heat No.		C	Si	Mn	P	S	Cu	Al
A50189	Ladle	0.76	0.22	0.93	0.020	0.020	–	–
	Check	0.77	0.22	0.95	0.019	0.021	0.015	0.008

(2) Drop Weight Test and Internal Conditions (Nick & Break Test)

Heat No. A50189
Head upwards

Drop weight 907kg

Height 6.7m

* Deflection Ingot No.3 25 mm No break
" No.6 25 mm "
" No.10 25 mm "

Evaluation Good

* Internal conditions

Good (all ingots)

(3) Mechanical Properties

Table 2. Mechanical Properties

(by JIS No. 4 Test piece)

Heat No.	Proof Stress (P.S.) (Kg/mm^2)	Tensile Strength (T.S.) (Kg/mm^2)	Elongation (El) (%)	Reduction of Area (R.A.) (%)	Hardness (Hv)
A50189	58.6	97.7	14.0	20.2	270

4-2 Properties of Rails after Heat-treatment

(1) Macrostructure of heat treated rail

Photo 1. shows the macrostructure of a rail head cross section after heat treatment. The macrostructure exhibits a clear pattern divisible into three layers.

Layer (I), or the black peripheral area, represents the zone which is forcedly quench-hardened after heating to temperature above transformation temperature (730°C or more).

Layer (II), or the white area adjacent to layer (I), represents the heat affected zone where cooling is comparatively slow after heating.

Layer (III), represents the portion of the base metal which is unaffected by heat treatment.

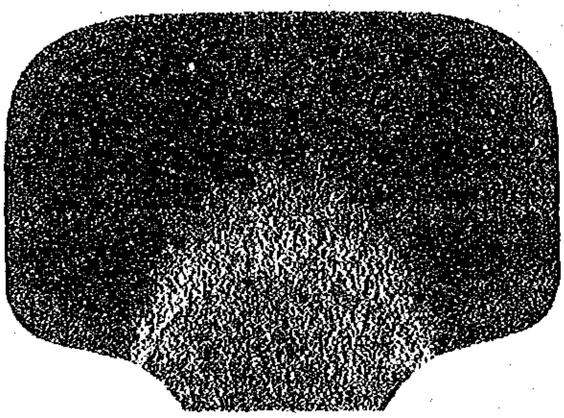


Photo 1. Macrostructure after Heat-treatment

(2) Heat-treatment profile and hardness distribution

Fig. 3. indicates the depths of heat treated zones in the rail shown in Phot 1. The hardened zone, or layer (I), is 18 mm deep.

Its hardness distributions are shown in Figs. 4 and 5. The distribution of hardness is sloped toward the inside. No sharp drop or discontinuity in this hardness distribution is recognized.

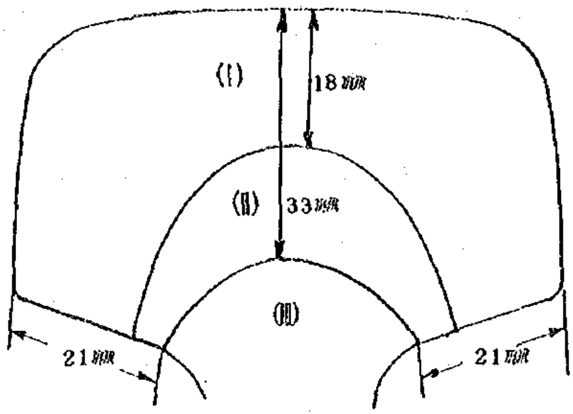


Fig. 3. Depths of Heat treated Zones in the Rail Head

Hardness Distribution

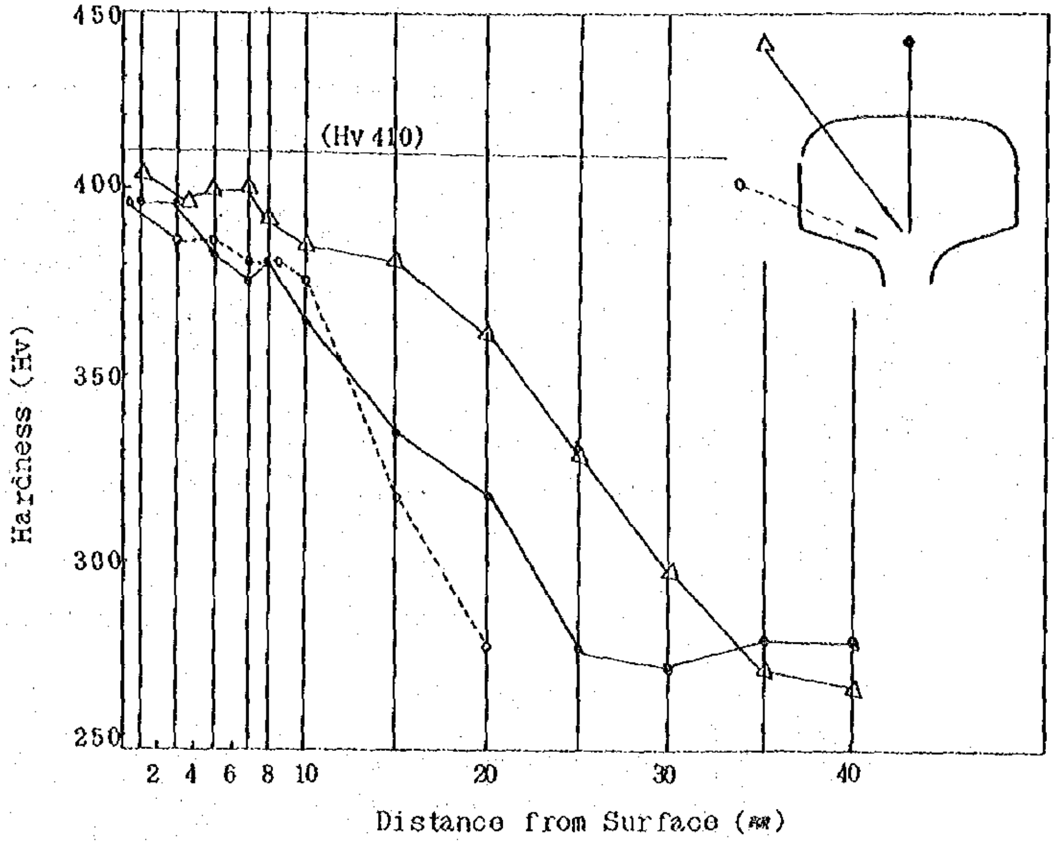


Fig. 4 Hardness Distribution in Hardened Layer

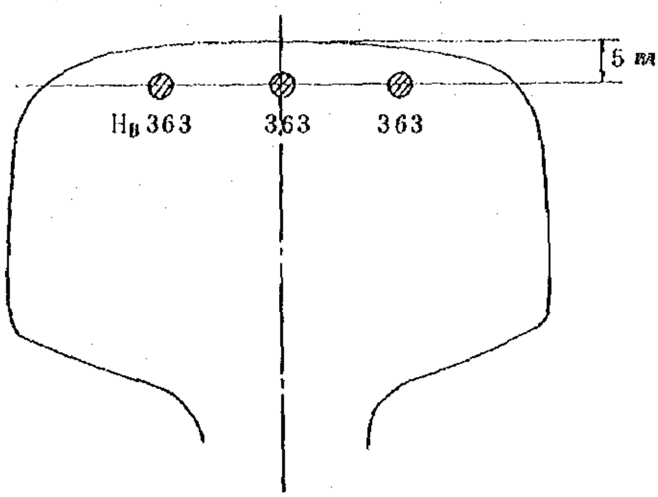


Fig. 5 Hardness in Hardened Layer (HB)

(3) Microstructure

i) Optical microscopic observations

Photo 2 shows the heat treated structure as observed under an optical microscope (x 400).

Microstructure of layer (I) (points 2, 6. 10, and 15 mm) where is forcedly quench-hardened after heating to temperature is invariably troostic fine pearlite above transformation temperature.

Microstructure of layer (II) (point 25 mm) where cooling is comparatively slow after heating is sorbitic fine pearlite.

Microstructure of layer (III) (point 40 mm) is as pearlitic as the microstructure of as-rolled high carbon steel rail.

ii) Electron microscopic observations

Photos 3 and 4 show fine pearlite structures of layer (I) (hardened zone) as magnified x 5,000 and x 10,000 under electron microscope.

The pearlite lamellar spacing is are 0.1μ wide or so.

As-rolled carbon steel rail has approximately 0.5μ wide pearlite lamellar spacing.

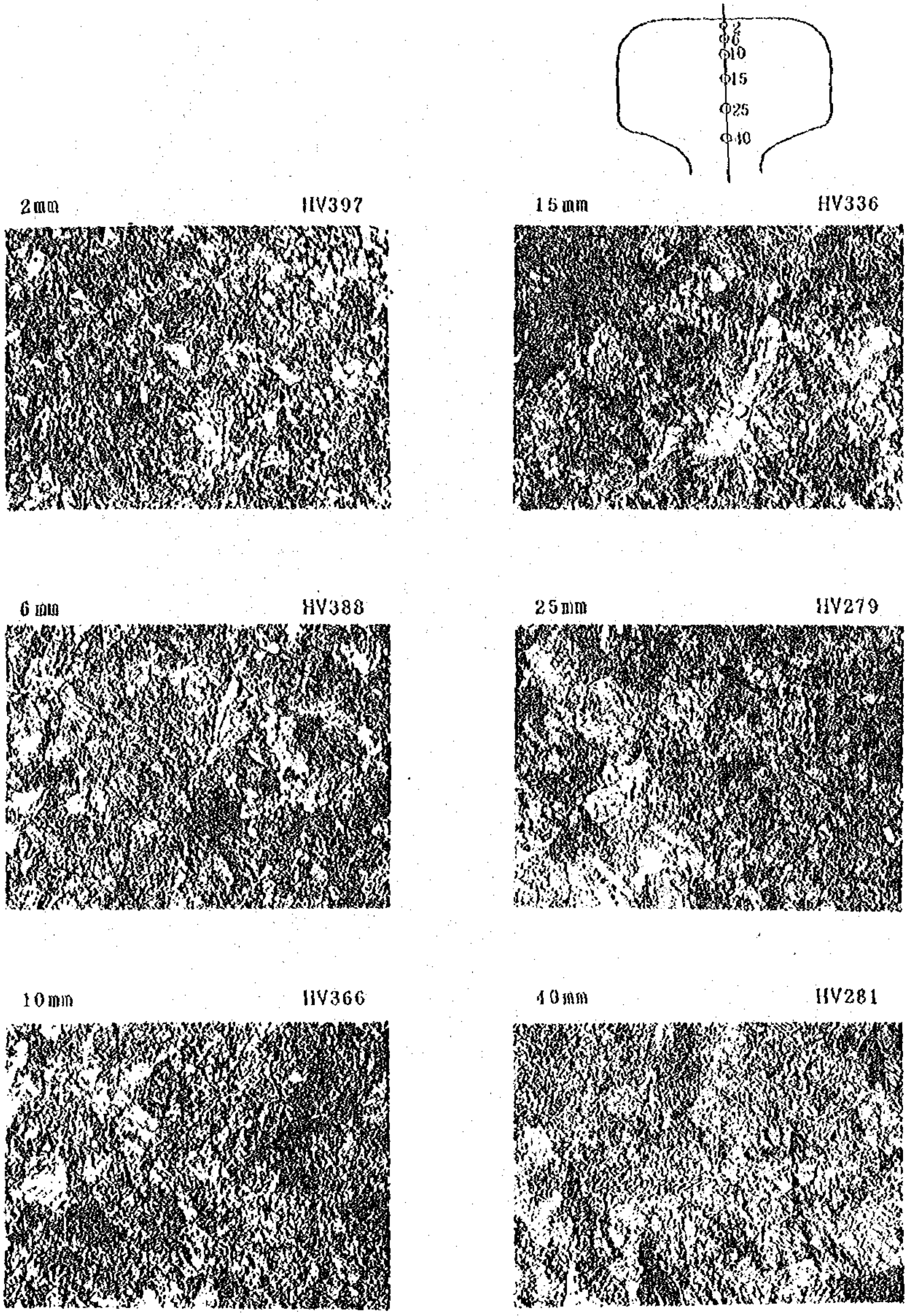


Photo 2. Microstructure (x400)

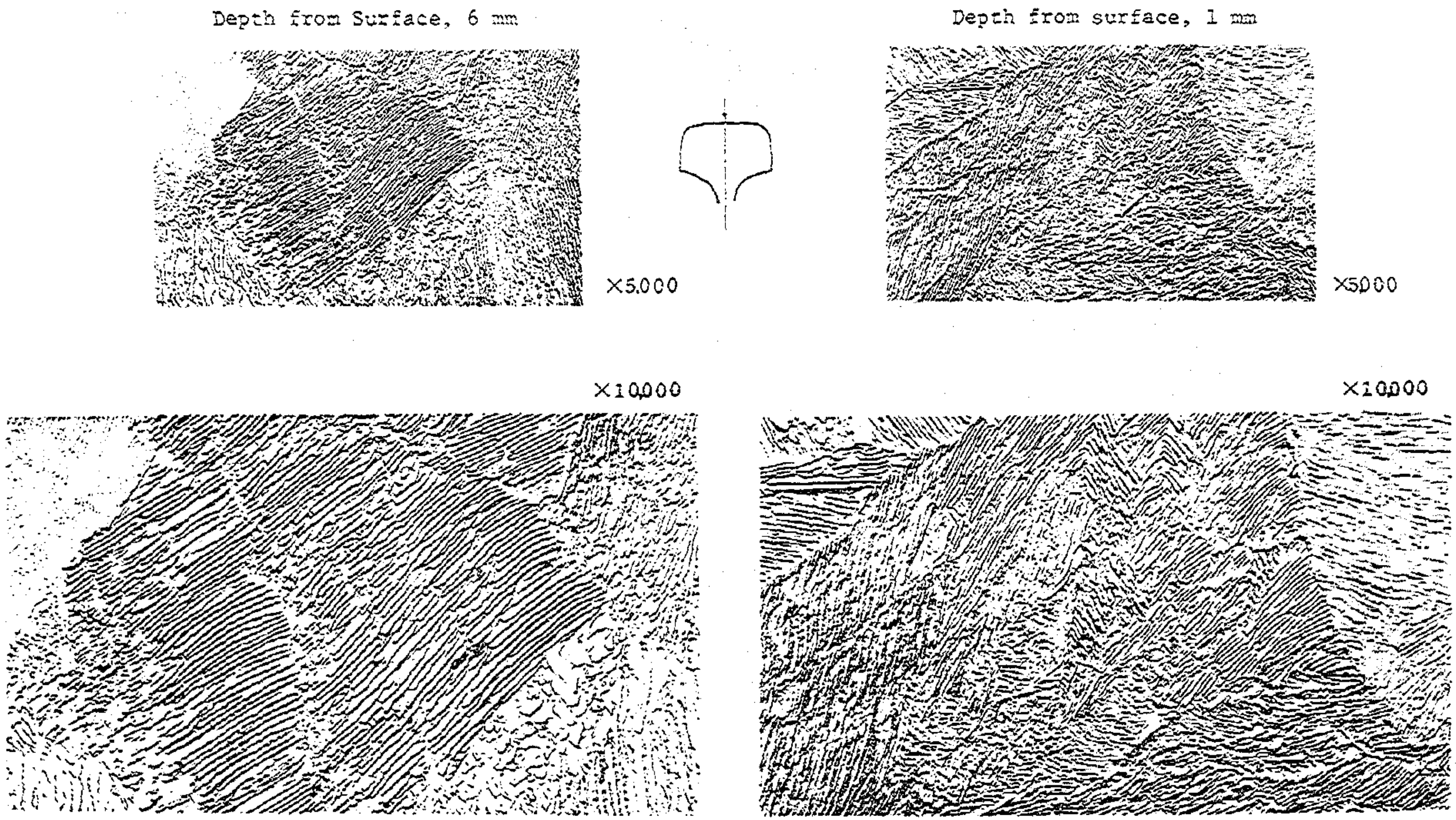
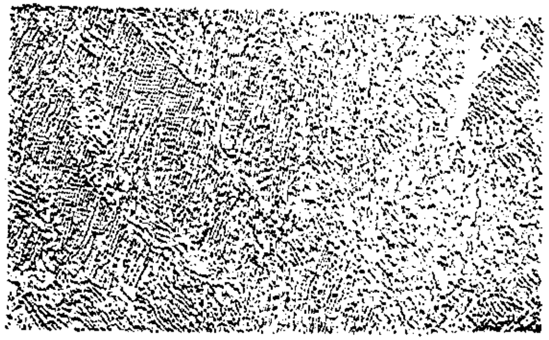
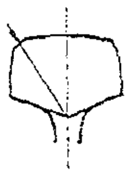


Photo 3. Microstructure

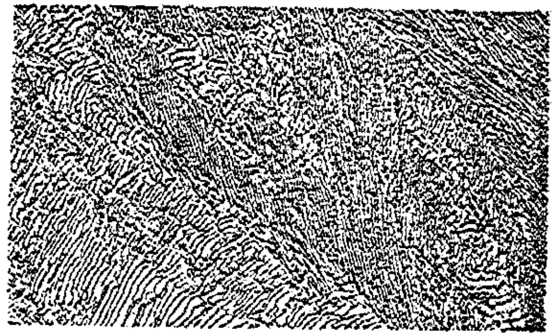
Depth from Surface, 1 mm



×5,000

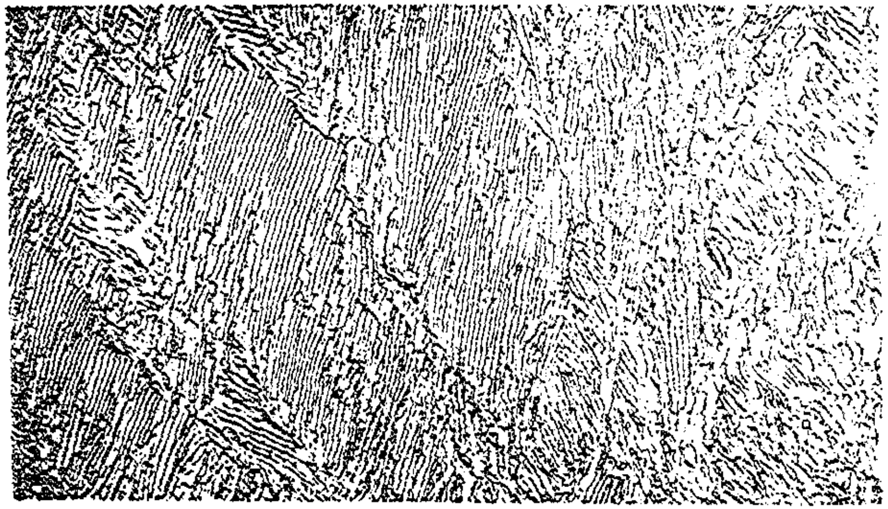


Depth from Surface, 6 mm



×5,000

×10,000



×10,000

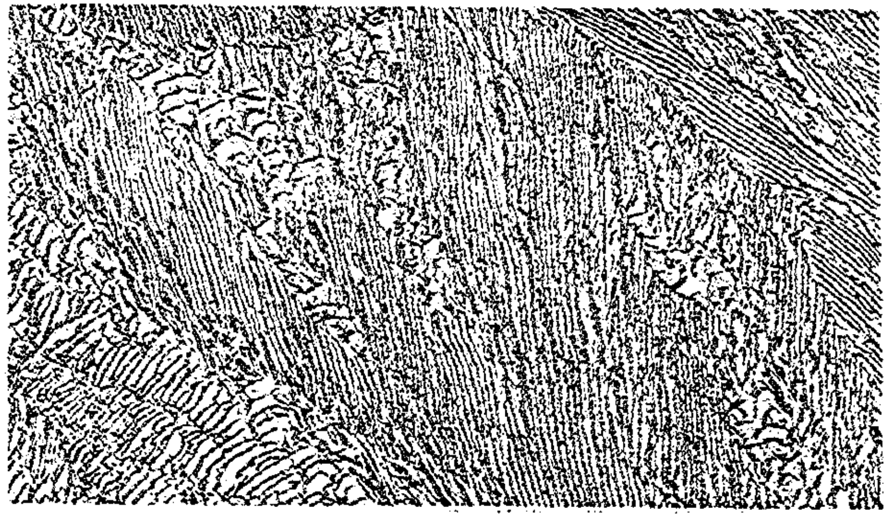


Photo 4. Microstructure

(4) Mechanical Properties of Rail after Heat treatment

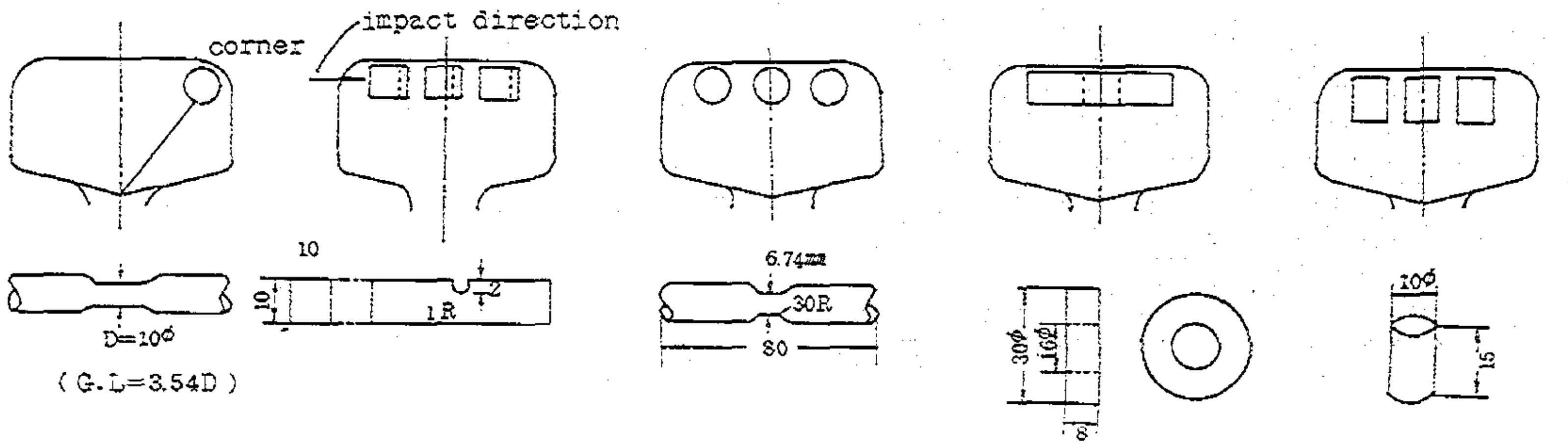
4 — 1 Mechanical Properties

Table 3 Mechanical Properties

Tensile Properties (T.P: JIS No.4) Corner(Dia:10φ)				Impact Properties (2uE)			Hardness	Compressive Limit	Amount of Wear at 500x10³ cycles	Fatigue Limit
P.S (Kg/mm²)	T.S (Kg/mm²)	E.L (%)	R.A (%)	+20℃ (Kg-m/cm²)	0℃ (Kg-m/cm²)	-20℃ (Kg-m/cm²)	(HB)	(%)	(gr)	(Kg/mm²)
92.4	130.5	18.6	30.2	2.1 ~ 2.9	1.6 ~ 2.1	1.4 ~ 1.7	363	55	0.182 ~ 0.193	57

Specimen:

Tensile Impact Fatigue Wear Compression



(G.L=3.54D)

Results of Compression Test:

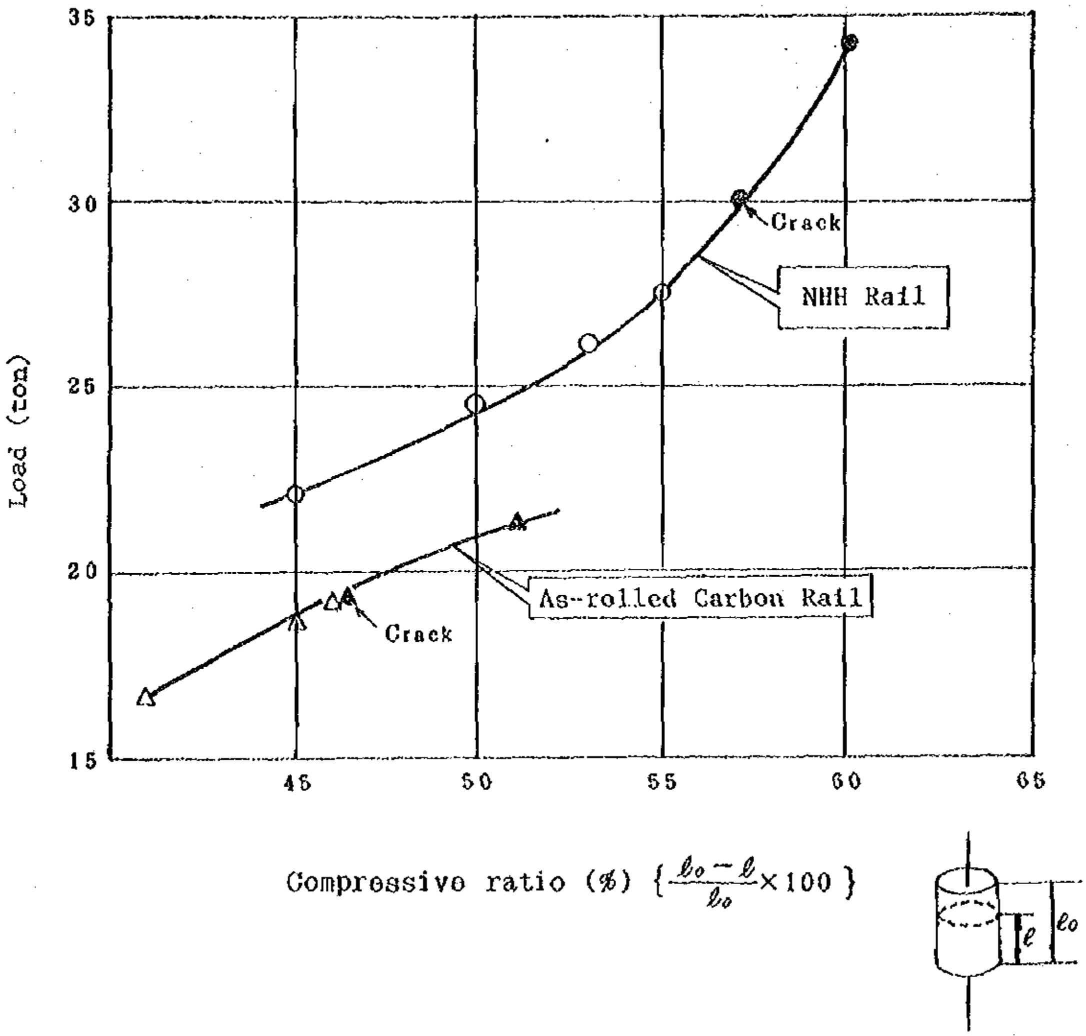


Fig. 6. Results of Compression Test

Results of Wear Test -(1):

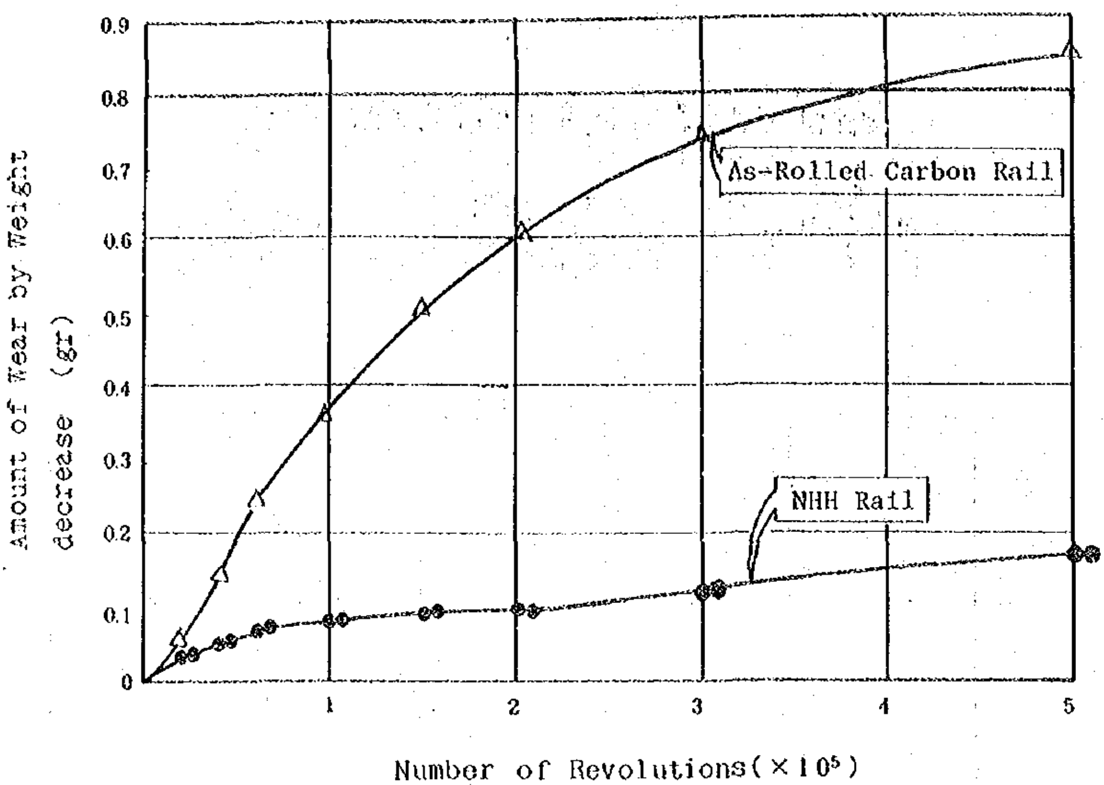
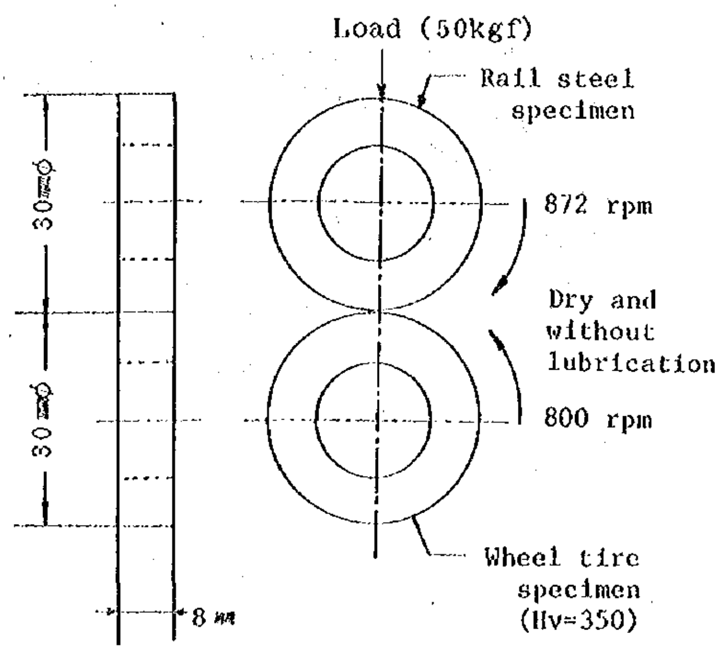


Fig. 7. Results of Wear Test

Wear Test Method

Two disc-like specimens rotate reversely, as shown right, rotating under slip 9% and 50kg load applied normally to rotation axis.

The weight loss of rail steel specimen is measured after designated cycles.



Results of Wear Test -(2):

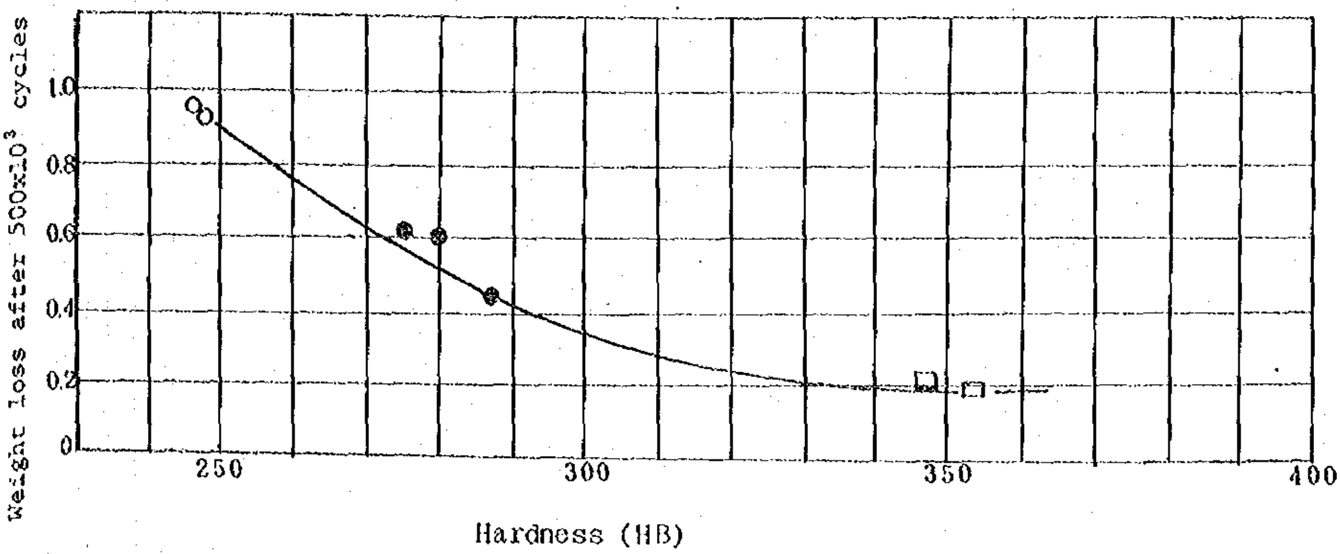


Fig. 8 Effects of Hardness of Pearlitic steels on Weight Loss by Wear Test

Load: 50kgf
Slip: 9%
No lubrication

Marks:

- O : As-rolled carbon rail with pearlite. (0.7C-0.2Si-0.9Mn)
- ⊗ : As-rolled high silicon rail with fine pearlite. (0.7C-0.9Si-1.4Mn)
- □ : NHH rail with very fine pearlite. (0.75C-0.2Si-0.9Mn)

Results of Fatigue Test:

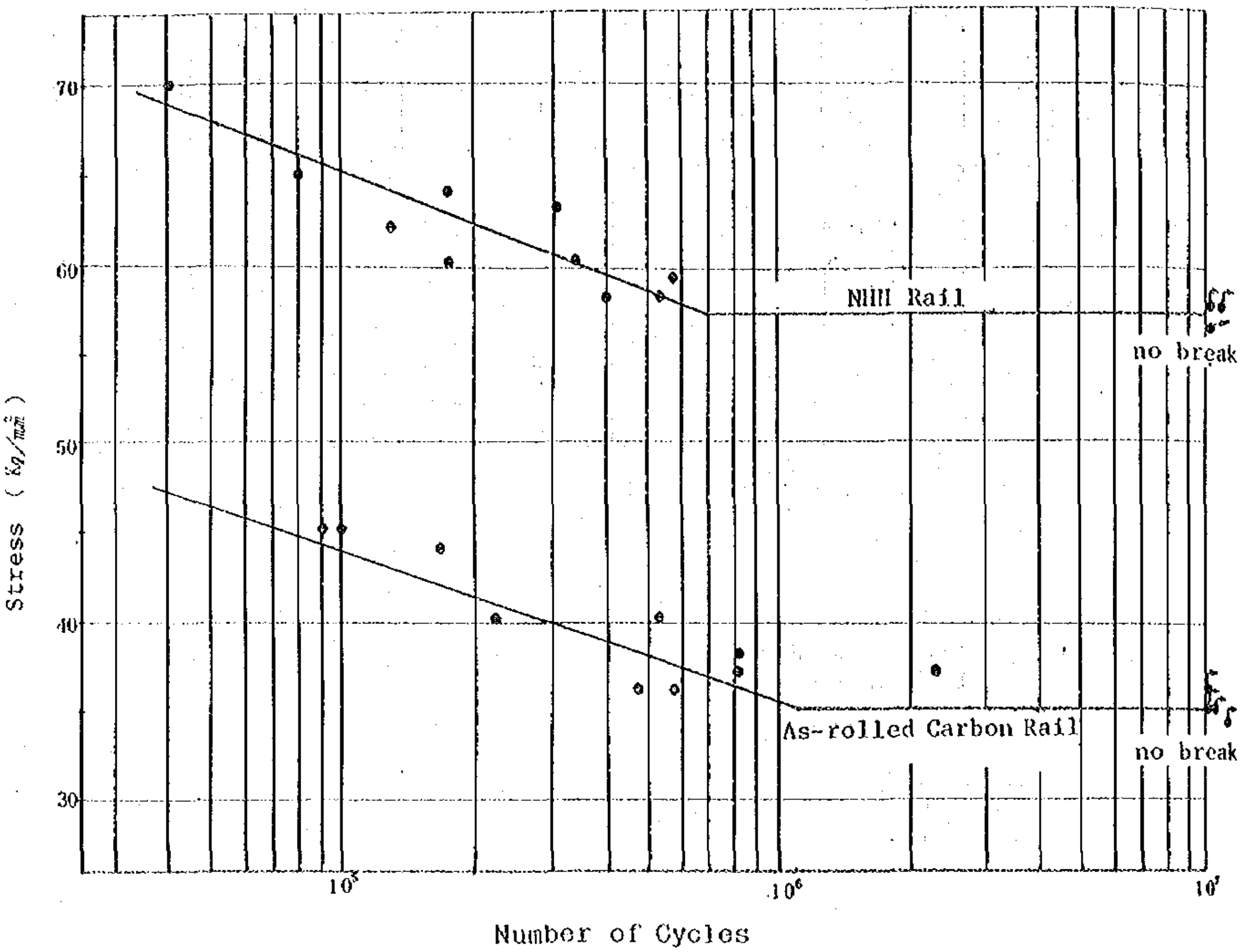


Fig 9. Fatigue Strength by Small Rotating Bending Tester

Method

1) Rotating bending fatigue test

2) RPM = 6000 rpm