3-14 Multi-step Controlled Brake and Continuous Controlled Brake

Shinkansen EMU brakes are separated by the type of rolling stock into two types: the step control type (Fig. 1) whose steps conforms with those of the automatic train control (ATC) and the continuous control type (Fig. 2) dependent on the adhesion characteristics. As shown in Fig. 2, the continuous control type is more advantageous as it provides the maximum deceleration within adhesion characteristics.

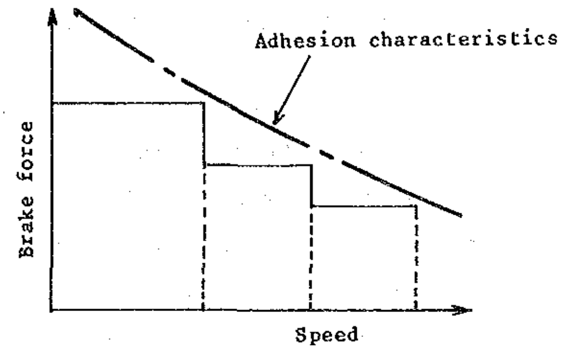


Fig. 1 Step Control Type

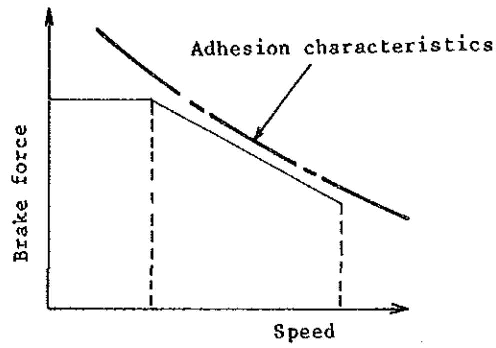


Fig. 2 Continuous Control Type

The brake system in the 100-series Shinkansen EMU is described below as an example of continuous-controlled brake system.

This system provides a continuous control in accordance with speed-adhesion characteristics by means of seven command lines for full service brake control and one command line for emergency brake control which are installed along the all rolling stock.

For service brake, notch information from the handle of brake controller or from ATC is fed to the brake pattern generation device via seven command lines. The brake pattern generation device generates a required brake force in dependence on the notch command and speed signal from the speed generator. While a rheostatic brake is applied at 25 km/h or more as illustrated in Fig. 3, an air brake is applied at the speed lower than 25 km/h because rheostatic brake power is insufficient.

Fig. 3 shows the speed and brake force characteristics when using a service brake.

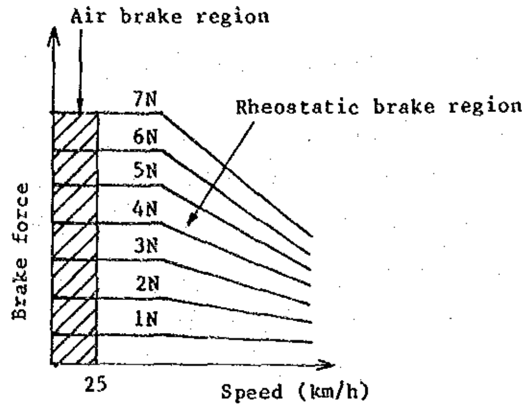


Fig. 3 Speed and Brake Force Characteristics (For Service Brake)

For applying the emergency brake, an emergency brake command is fed to the brake pattern generating device from the brake controller or the ATC. In addition to the rheostatic brake which is as large as that of the maximum service brake (7 notches), the air brake with 40% of the maximum force is applied. The air brake with 140% of the maximum service brake force is applied at the speed lower than 25 kg/h. If the rheostatic brake should not work due to failure either for service or for emergency, the air brake is automatically applied.

Fig. 4 shows the speed and brake force characteristics when applying an emergency brake.

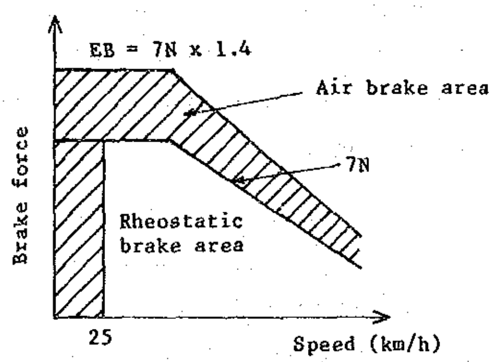


Fig. 4 Speed and Brake Force Characteristics (For Emergency Brake)

The urgency brake is operated when the pressure of air brakes is insufficient due to separation of the train. The urgency brake is applied for the individual car in question to prevent wheel skid and abrasion of brake disc and lining, while the emergency brake is applied for other cars.

The brake force of the urgency brake accounts for 110% of the maximum service brake force.

Fig. 5 shows the speed and brake force characteristics of the urgency brake.

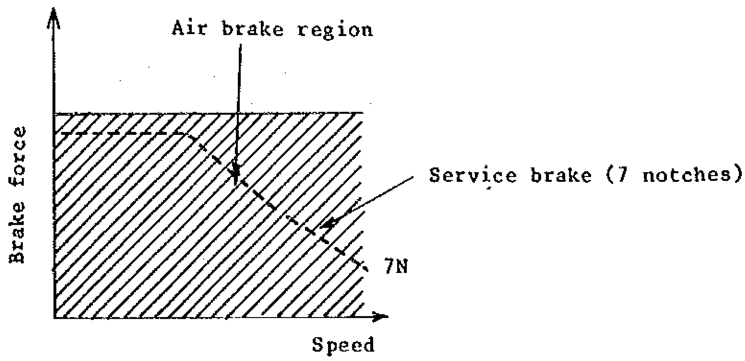


Fig. 5 Speed and Brake Force Characteristics (For Urgency Brake)

Fig. 6 shows the block diagram of the continuous controlled brake system.

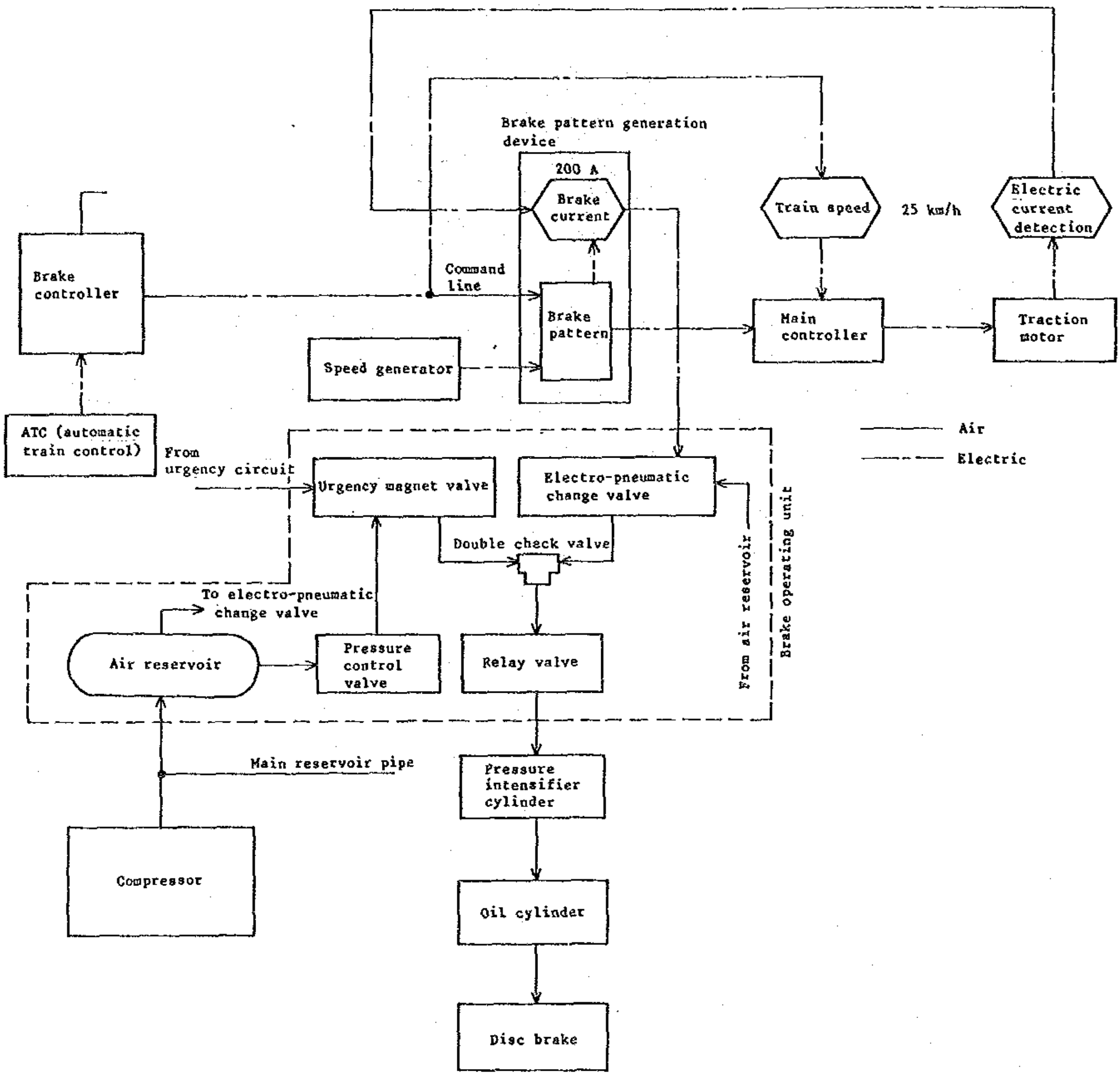


Fig. 6 Block Diagram of the Continuous Controlled Brake System

3-15 Light Alloy Body

The light weight of rolling stock contributes to the reduction of resistance forward motion and track load, and a light-weight body has advantages in various fields as shown in Fig. 1. Comparing with the iron, aluminum alloy has better anti-corrosiveness and the outside plate need not be painted, thus reducing the maintenance cost.

The light alloy rolling stocks, called the light rolling stock are making their debut backed up by the development of extruded aluminum, welding technique and composite materials.

The material cost of aluminum alloy, on the other hand, is several times of that of iron, and welding of aluminum alloy coach is more difficult than the same of steel coach.

Therefore, the cost of aluminum alloy body structure is higher. The specific gravity of aluminum is 34 percent of that of iron and the Young's modulus is one third of that of iron, which makes the deflection large. To obtain the equal equivalent bending rigidity and body bending characteristic frequency of the iron body, the thicker plate has to be used. Therefore, the weight of aluminum body is not so light as considered from the small specific gravity.

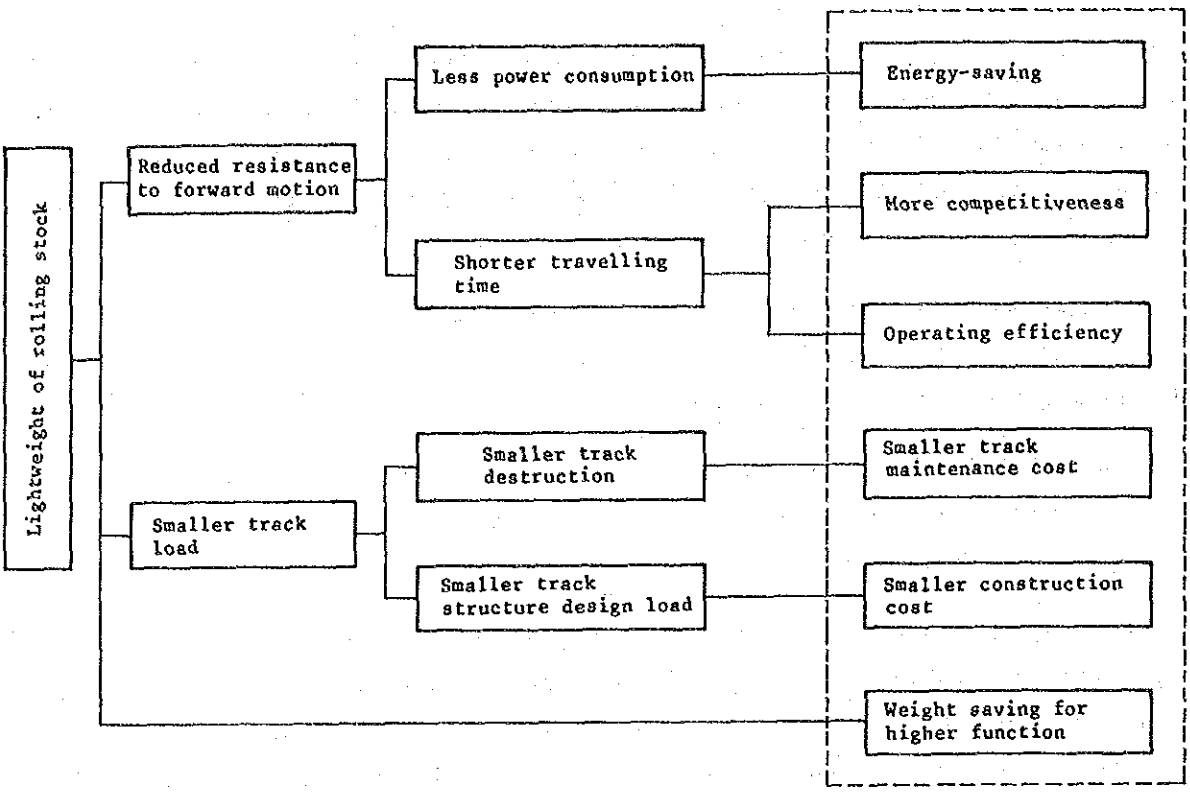


Fig. 1 Advantages of Lightweight Rolling Stock

However, cost increases can be minimized by utilizing a monocoque construction of hollow extruded aluminum, reducing weld lines and employing an easily extrudable material with required strength (see Figs. 4 and 5).

Fig. 2 shows the comparison in body structure weight between steel coach, stainless coach and aluminum coach.

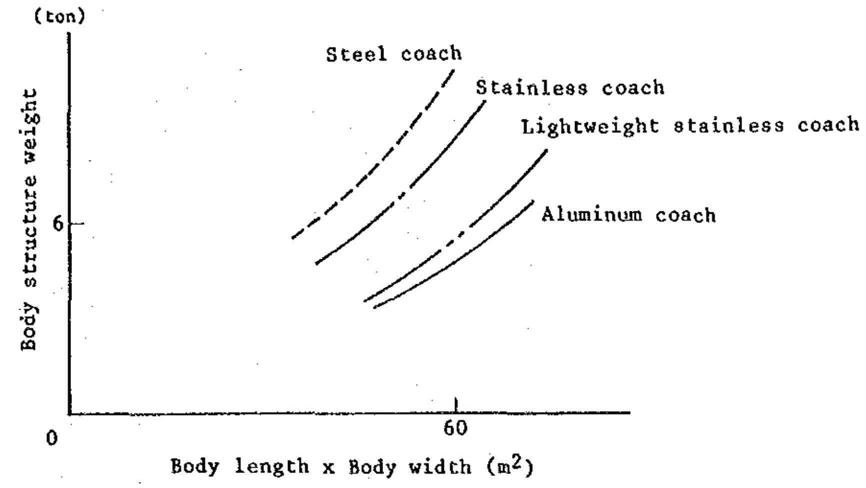


Fig. 2 Comparison in Body Structure Weight

Fig. 3 shows the rolling stock performance improved due to reduction in weight.

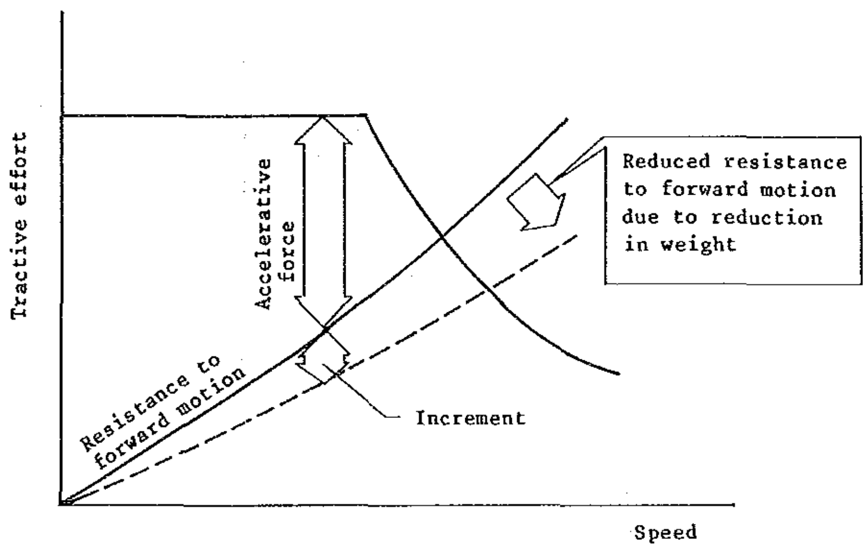


Fig. 3 Rolling Stock Performance Improved due to Reduction in Weight

Fig. 4 shows the sectional view of a lightweight, low-cost aluminum body.

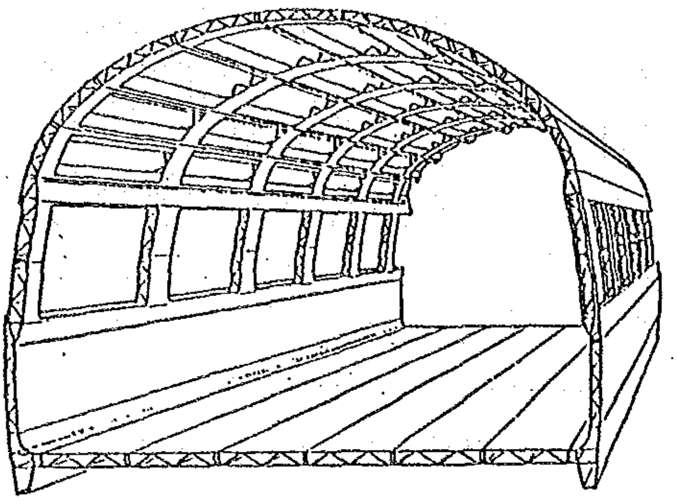


Fig. 4 Sectional View of an Aluminum Body

This body structure is built by welding hollow extruded aluminum as described above, consisting of 6 sections as shown in Fig. 5.

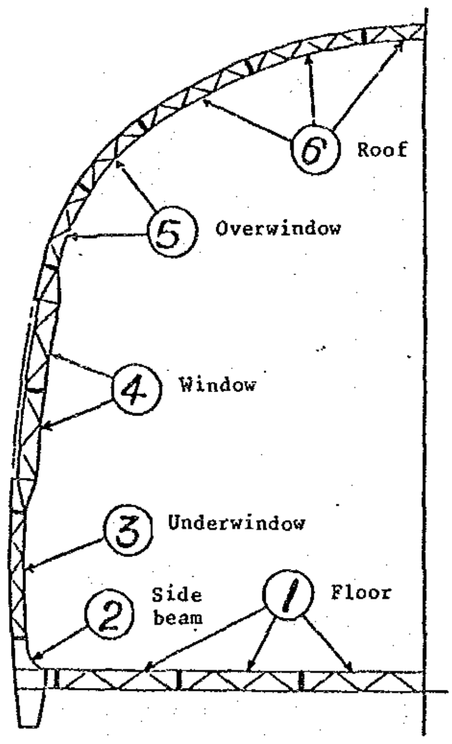


Fig. 5 Basic Section of a Body Structure

3-16 Information System

The information system is composed of a central monitor unit of microcomputers, color monitor displays, monitor terminal units, and information transmission circuits. It serves two purposes, one being monitoring the operating condition of cars and working condition of main apparatus and displaying these information to the driver's cab, in order to help drivers to make appropriate judgment and action in emergency, and the other being passenger service through radio, music and train guide/ indication. Described below is an example of its application to the 100-series Shinkansen EMU.

(1) For drivers

1) An example of emergency measures at failure

When a failure occurs, the failure indicator in the driver's cab warns the driver of the failed equipment. The driver then detaches the failed apparatus by the operating console and checks it with the monitor display. (Fig. 1 shows an example of display of operating conditions of apparatus.)

The driver then calls up a display of operating conditions of apparatus on the monitor display to check if the train is operated properly.

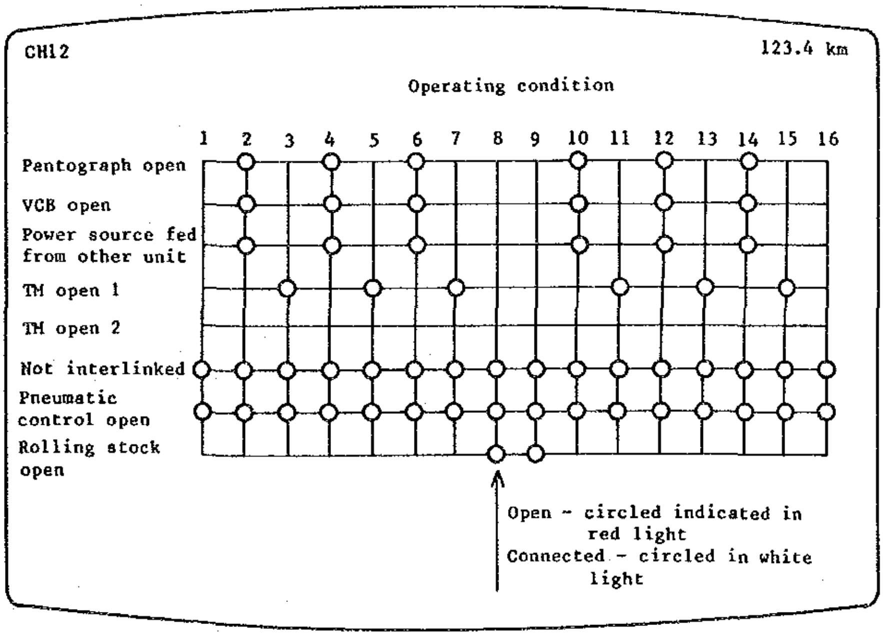


Fig. 1 Display of Operating Conditions

2) The monitor display indicates the following information other than the above.

a) Operating conditions (time, speed, ATC signal, distance)
b) ATC operating condition (Condition of each part of ATC equipment)
c) Analog value of voltage, current, etc. (graphs)
d) Operating condition of the switchboard
e) Others

Fig. 2 shows the arrangement of monitor equipment.

(2) For passenger service

Fig. 3 shows the configuration of a passenger guidance and information system in a train.

The information from the central unit installed in the conductor's room is sent to the passenger guidance and information system within each car through a dedicated transmission line. This system supply passengers with train information (stations where it will stop, time, current location, etc.), information on accidents and disasters and other service information.

Also, radio and music programs are available as part of in-train information service.

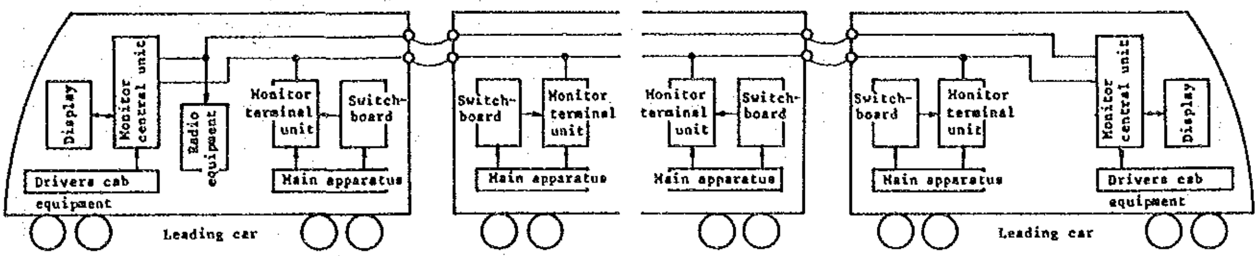


Fig. 2 Arrangement of Monitor Equipment

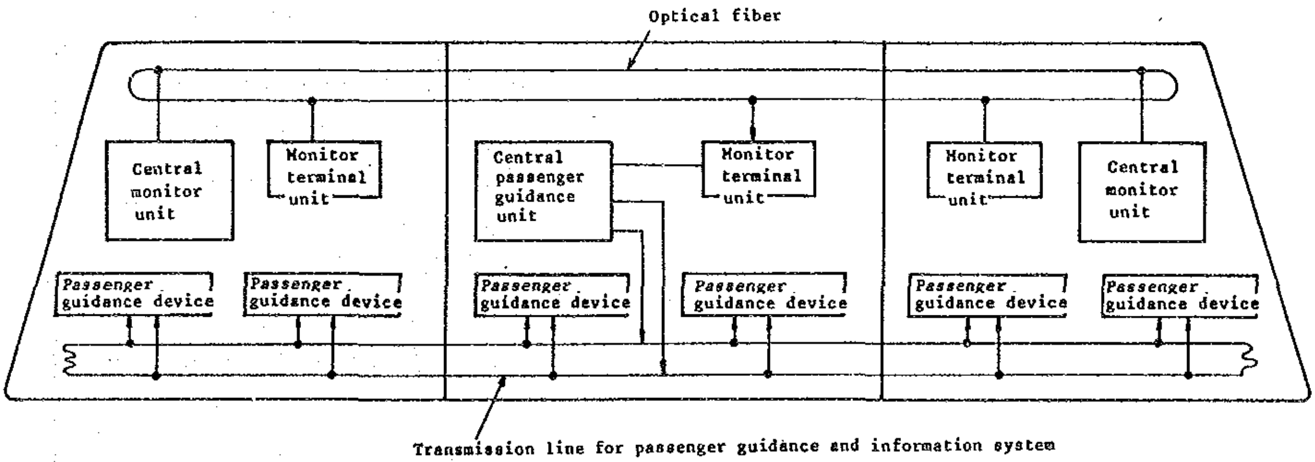


Fig. 3 Configuration of a Passenger Guidance and Information System in Train

3-17 Outline of Light Coach

A comparison of steel structure and light weight structure coaches each with a length of 23,000 mm, width of 3,245 mm and height of 4,039 mm is shown in the following table.

(Unit: kg)

Item	Steel structure	Lightweight structure	Remarks
Body structure (including underframe)	11,000	8,000	Lightweight structure of stainless steel
Interior and assembling	6,000	5,100	Simplification
Seat	1,800	1,500	Weight reduction of foot rests
Air conditioner, ventilator, etc.	3,900	3,100	Dispension-type (The fixed temperature for the thermostat will be altered to remain at 14 degrees lower than the exterior temperature).
Lavatory and toilet	600	300	Change into unit forms through employment of fiberglass reinforced plastics
Outside facilities	700	700	
Bogie	15,800	14,300	Adoption of bolster-less structure, abolition of end beams, etc.
Total	39,800	33,000	

3-18 Inspection Cycle for Coaches and Electric Locomotives of IR

- Passenger coaches

Types of inspection	Period	
Trip	One trip	
Quarterly Roller Bearing	3 months	
T.O.H. (or Lifting)	6 months	for Exp. coaches
P.O.H.	1 year	for Exp. coaches
	1.5 years	for Ordy. coaches

- Electric locomotives

Types of inspection	Period
Trip	One trip
7 days	7 days
15 days	15 days
IA	1 month
IB	2 months
IC	4 months
A.O.H.	1 year
I.O.H	3 years/300,000 km
P.O.H.	6 years/600,000 km

3-19 Cycle and Content of Inspection for Coaches and Electric Locomotives of JR

(1) Inspection cycle

Table 1 Inspection Cycle of Coach and Electric Locomotive in JR

- Coaches

Types of inspection	Period
Daily inspection	One trip
Intermediate inspection	Within three months or 30,000 km
Intermediate inspection (specified replacement)	Within two years or 300,000 km
Periodical inspection	Within four years or 600,000 km

- Electric locomotives

Types of inspection	Period
Daily inspection	One trip
Intermediate inspection	Within three months or 25,000 km
Bogie inspection (A)	Within 1.5 years or 200,000 km
Bogie inspection (B)	Within three years or 400,000 km
Periodical inspection	Within six years or 800,000 km

(2) Content of inspection

1) Coach

a) Daily inspection

Replacement and replenishment of used parts and periodical survey on running devices, brake devices, electrical equipment.

b) Intermediate inspection

Periodical survey of work condition, function and performance of running devices, brake devices, electrical equipment, electric generator and body as well as insulation resistance of electrical parts.

c) Intermediate inspection (specified replacement)

Periodical survey and replacement of the major parts of the specified important equipment such as running devices, brake devices, and meters.

d) Periodical inspection

Overhaul inspection of the major parts by removing them.

e) Operation inspection

On-board inspection, as required, to examine dynamic conditions such as vibration and sway.

f) Non-scheduled inspection

Inspection in the event of failure or accident of coach.

2) Electric locomotive

a) Daily inspection

Replacement and replenishment of used parts and periodical survey of current collector, running device, brake device, electric device and body.

b) Intermediate inspection

Periodical survey of existing conditions, operation, and function of current collector, running devices, brake devices, electric devices, and body as well as insulation resistance of electrical parts.

c) Bogie inspection (A)

Periodical inspection of the major parts such as running devices and brake devices.

d) Bogie inspection (B)

Periodical survey of the major parts of important equipment such as the running devices, brake devices, and power generator.

e) Periodical inspection

Periodical overhaul inspection by removing the major parts.

f) Operational inspection

On-board inspections, as required, to examine dynamic conditions such as acceleration, deceleration, vibration, and sway during its operation.

g) Non-scheduled inspection

Non-scheduled inspection in the event of failure or accident of EL.

3-20 Example of Coach Repair Equipment in JR

Use	Repair equipment
Disassembly	Movable under-floor dust collecting device
Disassembly and assembly	Ceiling crane or lifting jack
Bogie	Bogie frame flusher
	Axle box flusher
	Roller bearing flusher
	Coil spring flusher
	Foundation brake flusher
	Shot blast for coil spring
	Shot blast for foundation brake
	Coil spring magnetic flaw device
	Magnetic flaw device for foundation brake
	Axle ultrasonic flaw detector
	Testing machine for coil spring
	Loading machine for in-house transportation
	Part scavenging device
	Part painting device

3-21 Example of Inspection Equipment for 160 km/h EL and PC

	Testing machine	Content
EL	Asynchronous motor	Performance test of 3-phase motor
	Converter	Performance test
	Inverter	Performance test
EL PC	Electromagnetic air brake	Test of brake operating unit
EL + PC	General circuit testing device	Test of operating conditions of major apparatus and brakes

3-22 Air Hose Assembly of JR's Rolling Stock

In Japan, air hoses of various sizes are used for through-pipes and compressor delivery pipes for passage of air, brake operating units, etc., for railway rolling stock.

As an material of air hoses, cloth-inserted chloroprene rubber is used, and its replacement cycle is set at 4 years, considering the rolling stock inspection cycle.

To prevent bursting, rubber hose is attached without twisting. For hose at the rolling stock end in particular, care is taken so the diameter ratio during running can be kept under 10%. To secure an air hose with a hose band, design is made so that the hose band edge does not hurt the hose. The tightening torque of the hose band is determined with careful consideration of the rubber compression rate of the air hose.

At the joint of a hose and a nipple, the hose with a right-angle end cut is inserted till it touches the nipple base, and should then be secured with a hose band.

The size of the nipple is designed exclusively for each individual hose size, and its diameter is large enough to not allow a hose to be detached easily. The nipple tip is also rounded into a form which will not cut into the hose when the rolling stock shakes.

Fig. 1 shows the air hose, nipple, and hose band and currently used for the rolling stock.

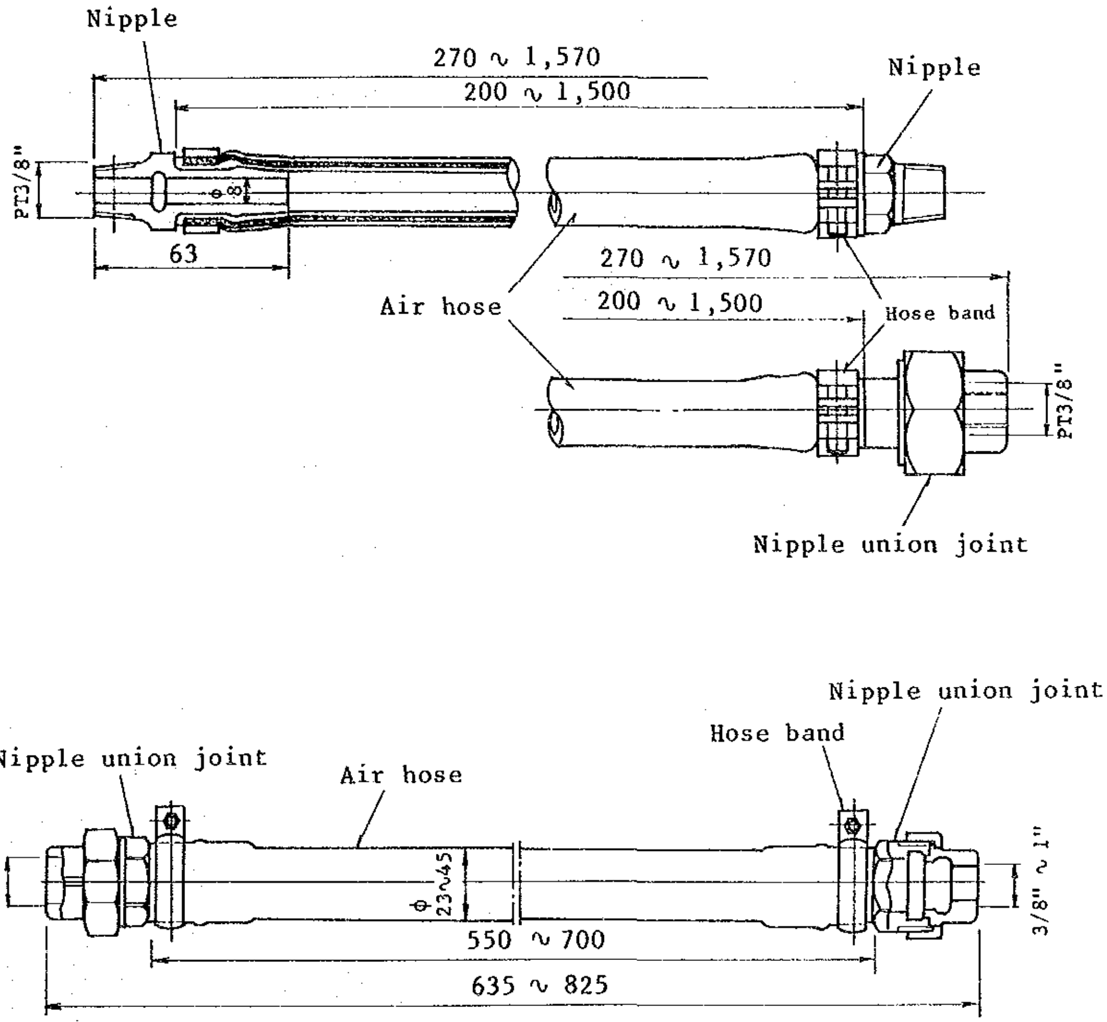


Fig. 1 Air Hose Assembly

3-23 Rolled Screw Air Pipe Exclusively Prepared for JR's Rolling Stock

Carbon steel pipe (tensile strength: 30 kgf/mm^2, chemical element: 0.04% or less phosphor, and 0.04% or less sulfur) is abundantly used for its low cost for rolling stock air piping in Japan.

Since a threaded section of an air pipe is of a low strength, pipes used especially at a shaking part (rolling stock end, bogie, etc.) or a vibrating part (compressor, etc.) and small pipes are subjected to tensile stress, bending stress, or repeated fatigue which will cause cracks.

It is important to prevent cracks at hidden parts (rising pipe, under-floor piping, etc.) where a failure is difficult to find and repair. A thicker threaded section to prevent cracking may increase the rolling stock weight and push up the cost.

To increase the strength at the threaded section using the same material, therefore, rolled screw is employed.

Rolled screw, compared with cut screw, are high in resistance to fatigue and wear, and the tensile strength, bending strength, and fatigue strength are 1.5 ∿ 2 times greater, which allow thinner threaded sections reducing weight by 500 ∿ 1,000 kg for a 16 vehicle train set.

Rolled screw is so effective in sealing that air leaks can be prevented without sealing material or tape, and even complex piping can be constructed without joints.

Outline of cut screw and rolled screw is given below.

(1) Cut Screw (Fig. 1)

Since threads are cut on a pipe, the pipe thickness of the thread root is thin. Notches are also made by a cutting tool. A flaw may develop from a notch and grow into a failure.

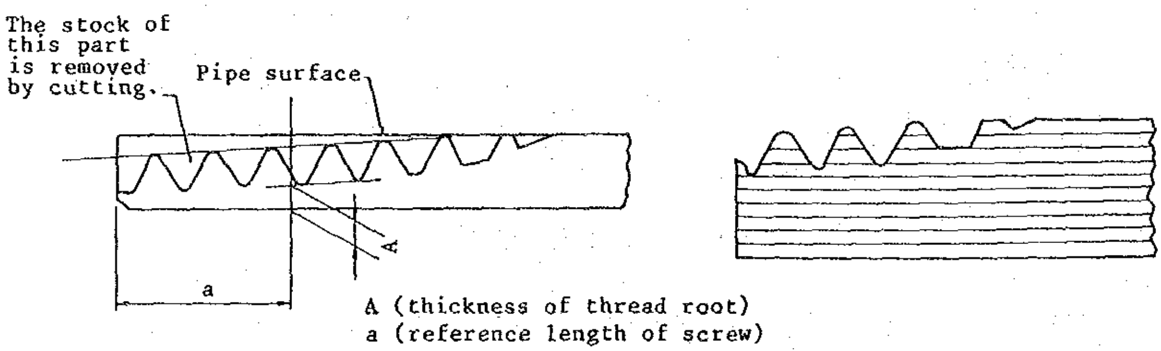


Fig. 1 Cut Screw

(2) Rolled Screw (Fig. 2)

A pipe end is squeezed into a taper in advance. Threads are then rolled on it with thread rolling dies. Since the pipe thickness of threaded root is enough, rolled screw is extremely high in strength.

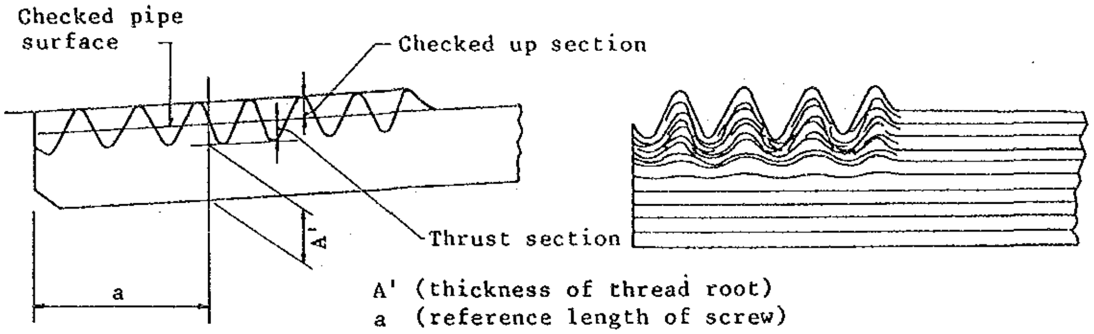


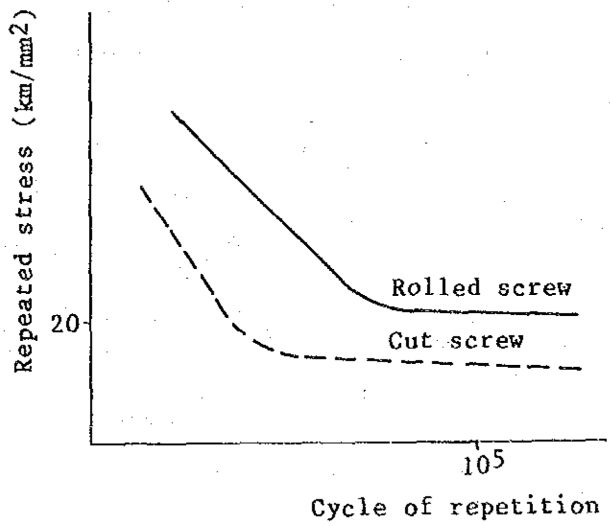
Fig. 2 Rolled Screw

(3) Comparison of cut screw and rolled screw

1) Strength

Kind / Type	Load test	Cut Screw	Rolled screw	Description
10	Tensile strength	100	150	Outer diameter 17.3 mm Thickness 2.3 mm
	Bending	100	162	
	Fatigue	100	167	
20	Tensile strength	100	193	Outer diameter 27.2 mm Thickness 2.8 mm
	Bending	100	186	
	Fatigue	100	175	

2) Stress - repetition cycle curve (with outer diameter of 27.2 mm)



As mentioned above, the strength of a rolled screw is 1.5 ∿ 2 times of that of a cut screw in every test.

3-24 Welding of Rolling Stock Material

Cracking starts at the end beam and the side beam of the bogie frame when a stress or vibration acceleration exceeds the design value.

Cracking on the base material may often start from inferior material or insufficient strength.

When repairing cracks on a bogie frame, the proper method should be chosen individually for each plate thickness and material. The bead should carefully be checked to ensure that the welded section is perfect. Reinforcement near a crack should carefully be provided with adequate form and mounting position of the reinforcement material so no growth of existing cracking nor new cracking occurs.

In welding of rolling stock structural components such as body, bogie, and body fittings, sizing of materials should be made adequately depending on the form and type of components and care should be taken so that the bead penetrates far enough into the base material to assure sufficient strength.

It is desirable to use as many bent plates and sections for members of the bogie frame to minimize welding lines.

It is recommended to standardize the welding method in such a manner that a welder welds a component in go-down-work to assure a satisfactory finish.

3-25 Air Spring

The air spring is mounted on the bogie frame or on the bolster. Therefore, the structure of the swing bolster device can be simplified. In addition, the bogie and the body can easily be cut off, so that vibrations from body oscillation and track can be reduced to improve the riding quality.

The air spring can roughly be classified into the 3-ridge bellows type as per Fig. 1 and the diaphragm type as per Fig. 2. The 3-ridge bellows type, whose strength of stability relies on the elasticity of the bellows itself, may change its characteristics in the course of temperature change and period of use. The diaphragm type air spring, on the other hand, will smoothly change the contact position of the inside/outside cylinder metal fittings and the diaphragm at a lateral displacement, and the internal pressure will work to generate the strength of stability. Extremely stable characteristics, therefore, are maintained.

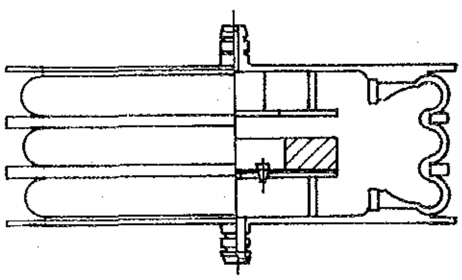


Fig. 1 Bellows Type Air Spring

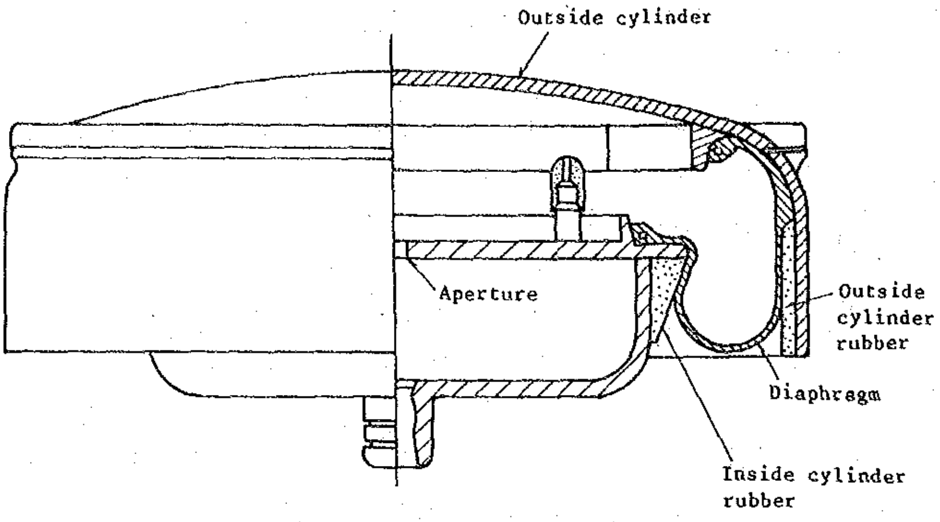


Fig. 2 Diaphragm Type Air Spring

The automatic level controller shown in Fig. 3 will automatically control the pressure in the air spring to keep the body height constant.

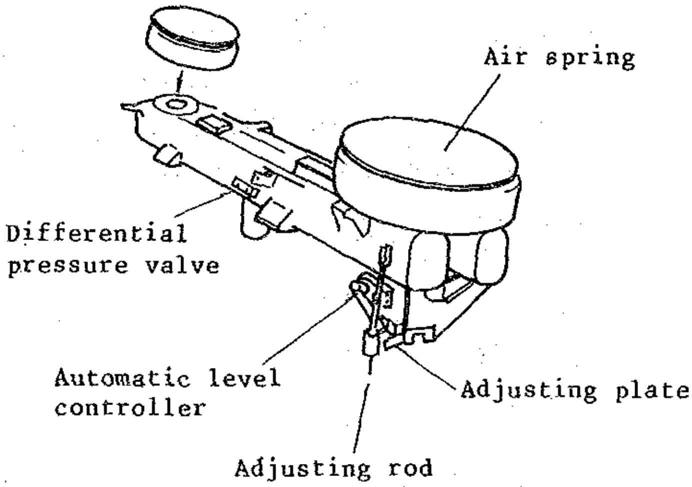


Fig. 3 Bolster Device

For easy check of the correct level of the air spring, and the correct lateral position of the body with reference to the bogie, an adjusting plate is provided under the adjusting rod and the bolster.

If a pressure differential greater than the specified value is generated between the right air spring and the left one, compressed air in one spring is released to the other to prevent an abnormal inclination of the body to assure safe operation of the car. For such an adjustment, a differential pressure valve shown in Fig. 3 is mounted.

3-26 Inspection and Repair Facilities of Shinkansen

An example of the inspection and repair facilities for the Shinkansen in Japan include approximately 1,500 machines and equipment components where 1,000 vehicles are inspected and repaired each year. Below is an example of a layout of inspection and repair facilities for the most important components of high-speed rolling stock such as a disassembly and assembly facility or a bogie and wheel set inspection and repair facility.

(1) Disassembly and assembly facility

The body disassembly shop is where inspection of rolling stock from the bogie replacement shop and dismounting of equipment components are performed. Every workshop has exclusive inspection and repair machines and devices and a work flow system is employed to facilitate labor saving.

In the reverse sequence of disassembly, assembling work is conducted to mount equipment on the body, followed by inspection.

On line is divided into 5 stations based on the work time calculation; 1.5 hours/station for disassembly, and 2 hours/station for assembly.

Fig. 1 shows the details of the work procedures and an example of the layout of disassembling and assembling facilities.

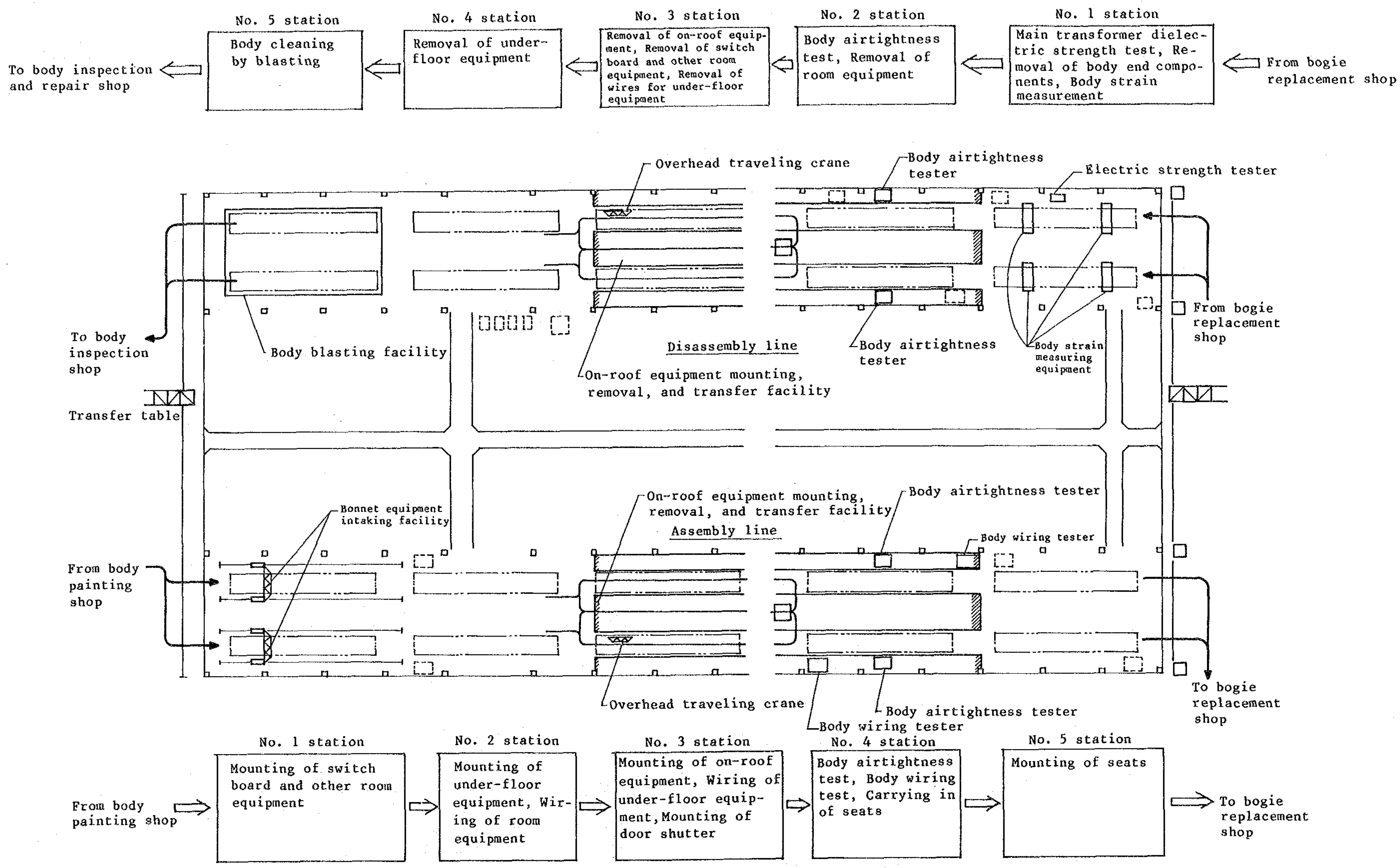


Fig. 1 Layout of Disassembling and Assembling Facilities

(2) Bogie and wheel set inspection and repair facility

Since both the periodical inspection and the bogie inspection are executed at a common workshop, bogie inspection and repair has the greatest share in work volume. For work efficiency improvement, leveling of work volume is devised with utilization of spare parts for bogie frame, wheel set, and traction motor, and adoption of work flow system by use of conveyers.

Fig. 2 shows the layout of a bogie inspection and repair facility, and Fig. 3 and Fig. 4 shows an example of a wheel set inspection and repair facility.

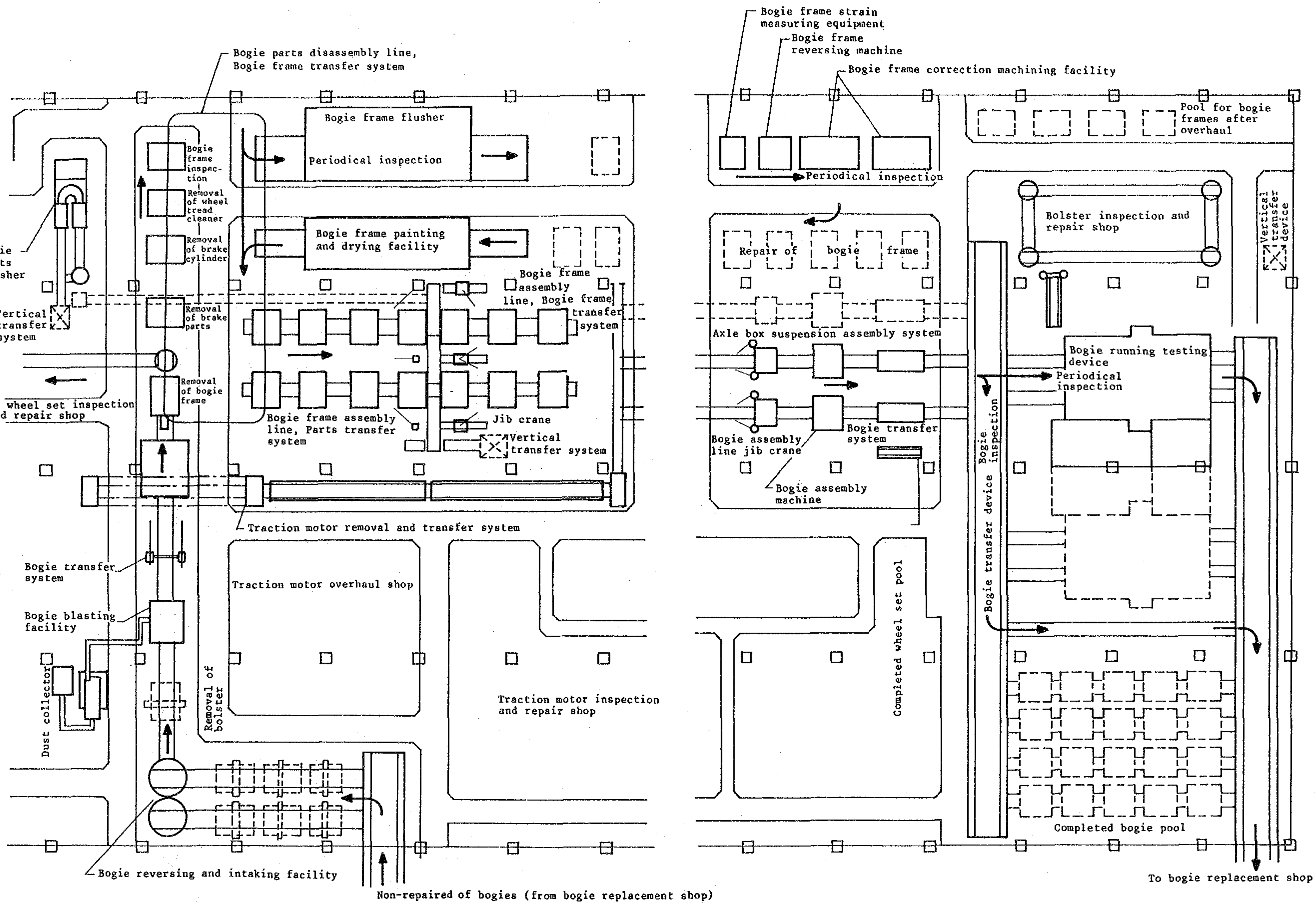


Fig. 2 Layout of Bogie Inspection and Repair Facility

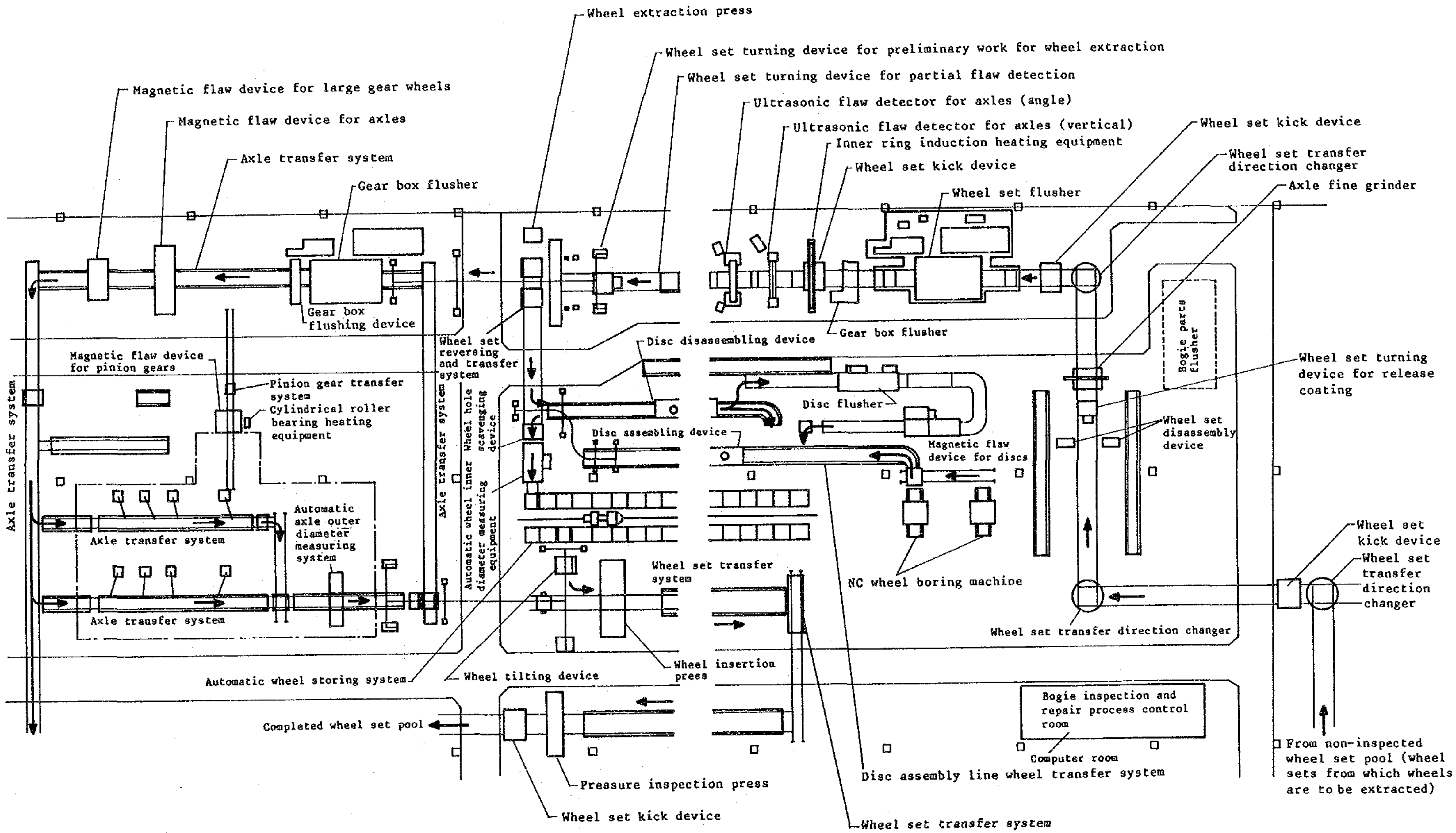


Fig. 3 Layout 1 for Wheel Set Inspection and Repair Facilities

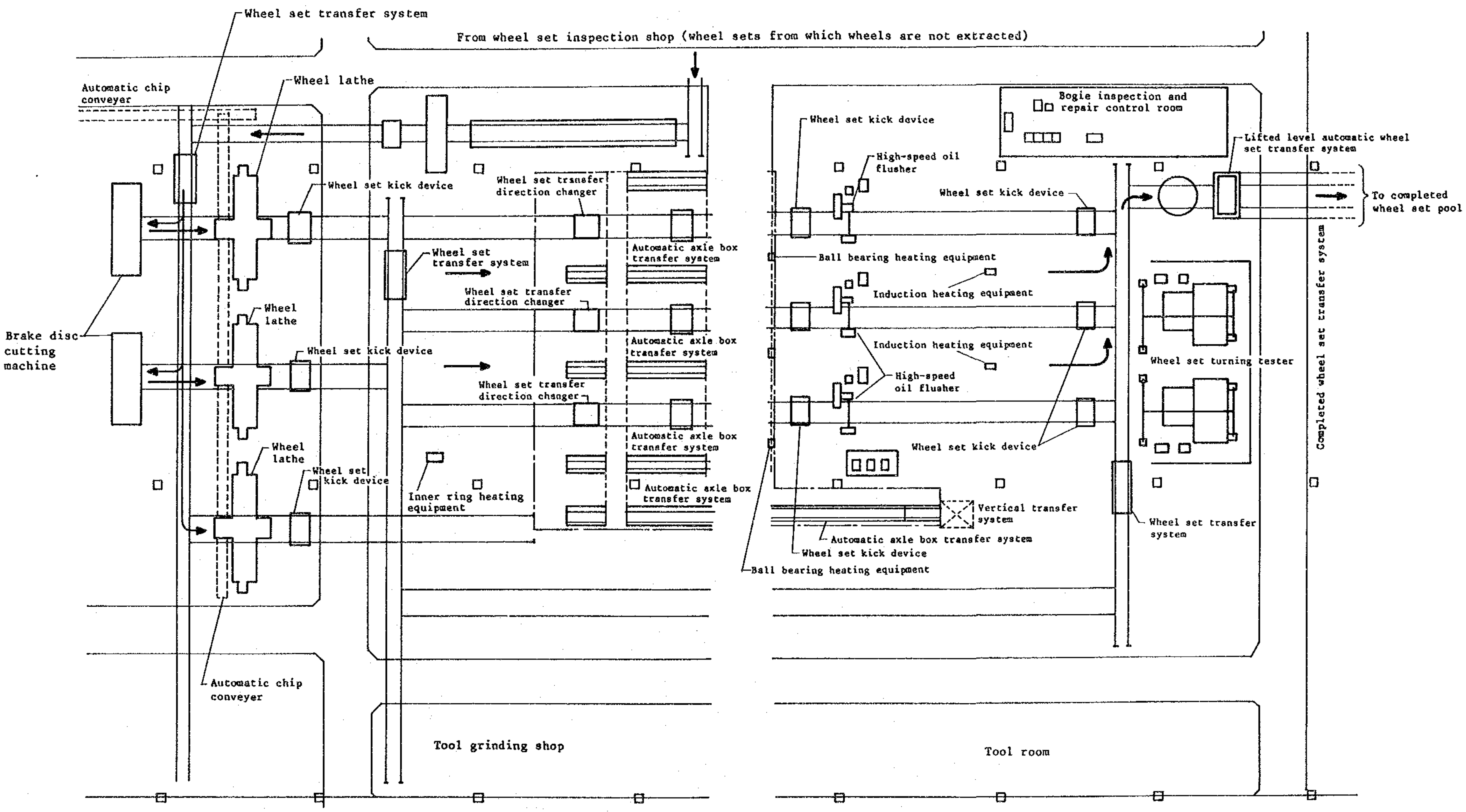


Fig. 4 Layout 2 for Wheel Set Inspection and Repair Facilities

3-27 Bogie Running Test Device

Before attaching a bogie to a body, this testing device gives the bogie a high-speed, heavy load to the same degree as in a case of actual operation to check for abnormal temperature rise in the axle and gearbox, oil leakage, abnormal vibration on the bogie, and other items to find any remaining fault after the bogie inspection and repair.

The testing system is designed to test two bogies simultaneously. The conditions are set so that the body weight is loaded on air springs. Then, various parts are inspected while an operation is executed at a preprogrammed running speed for a prescribed time. The front wheels and rear wheels should be controlled to rotate in the opposite direction to prevent overrun.

The testing device is composed of mechanical components such as track wheels and a loading device, instrumentation equipment such as electrical instruments, thermometers, vibration meters, and control panels, as well as related facilities like a soundproof chamber

Fig. 1 shows a top view and front view of the bogie running test device.

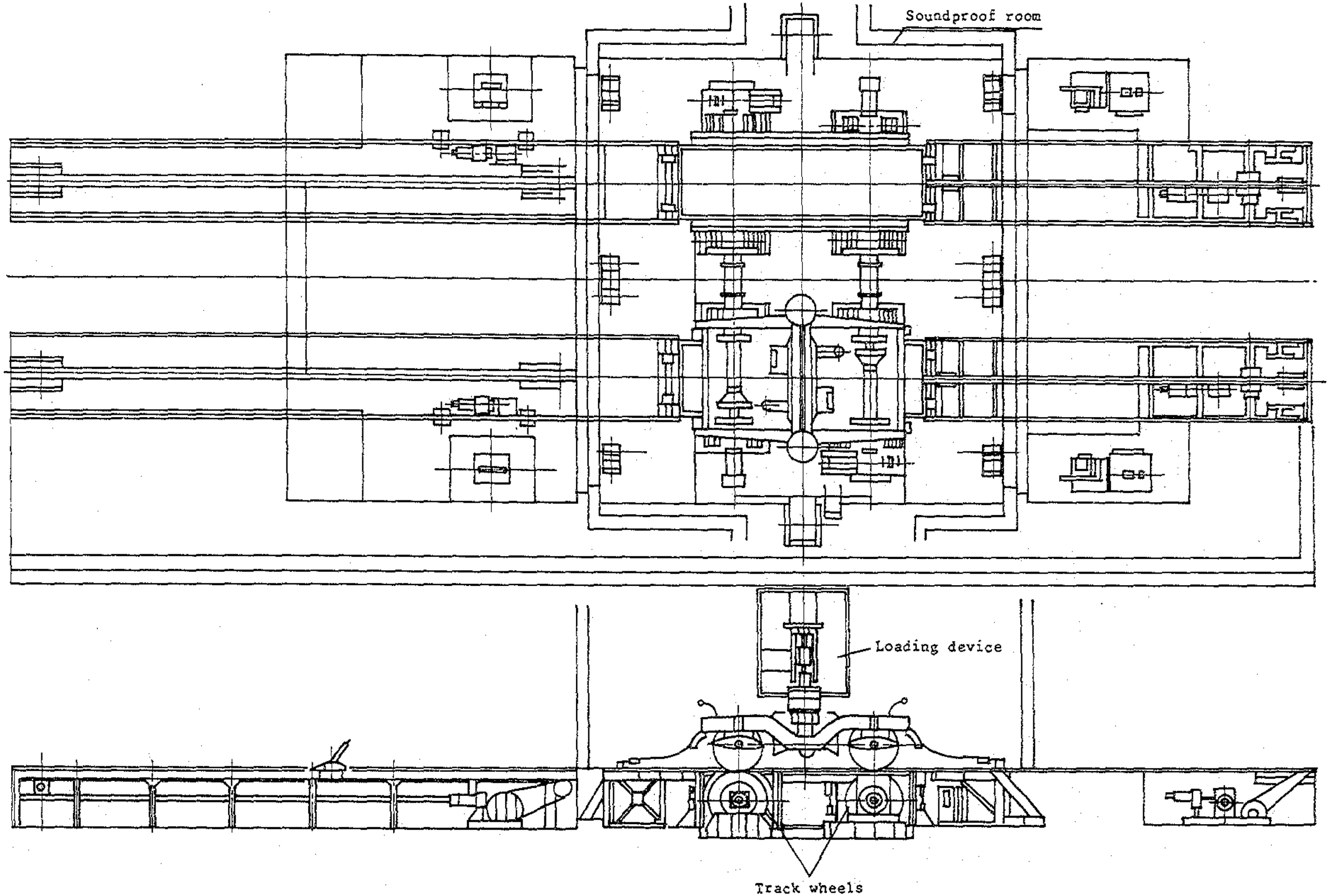


Fig. 1 Bogie Running Test Device

4-1 Standards of Cant in Foreign Countries

Table 1 Maximum Cant and Maximum Deficiency of Cant for Railways in Foreign Countries

Railway of country	Maximum cant Ca	Maximum Deficiency Permissible Cd
England (B.R)	150 mm	. Continuous welded rail Section 110 mm . Other 90 mm
France (SNCF) High speed line	160 mm 180 mm	150 mm in exceptional cases 160 mm 90 mm
Germany (DB)	160 mm	100 mm
Japan (JR) NG (1067 gauge) Shinkansen	105 mm 180 mm	E.C Line 60 mm Other 50 mm 60 mm

Table 2 Radius of Curve and Maximum Permissible Speed

Railway of country	Formula of calculation
BR	C: Cant mm $V = \sqrt{(7.5 + 0.064C)R}$
SNCF	$V = 5.3\sqrt{R} - 5$: Theoretically $V = 4.9\sqrt{R} - 5$: Actually
DB	$V = 4.33\sqrt{R}$
JR NG Shinkansen	 $V = 4.30 \sim 4.43\sqrt{R}$ * $V = 4.5\sqrt{R}$ *

* Calculated on the basis of the maximum cant and the maximum cant deficiency

4-2 Standards of Transition Curve in Foreign Countries

Table 1 Establishment Standards of Transition Curve

Railway of country	Maximum rate of change of cant deficiency (mm/second)	Maximum rate of change of cant (mm/second)
B.R	57	57
SNCF	50 Empirically 60 (Rail car) 70	(Train) 60 (Rail car) 70
D.B	-	35
Japan (JR)	(1,435 mm) Shinkansen 37 Conventional line (1,067 mm) Maximum rate of change of super centrifugal force 0.03 g/sec or less	(1,435 mm) Shinkansen 45 Conventional line (1,067 mm) 1st ∿ 2nd class line 29 3rd class line (1,067 mm) 35 4th class line 40

In Japan, calculation is made through the following formula based on the above standards.

Shinkansen (1,435 mm)
(i) L_1 = 1.0 Ca
(ii) L_2 = 0.0097 CaVm
(iii) L_3 = 0.0117 CdVm

Conventional line (1st class line) (1,067 mm)
(i) L_1 = 1.0 Ca
(ii) L_2 = 0.01 CaVm
(iii) L_3 = 0.009 CdVm

4-3 Reverse Curve

In the case of the Indian Railway, the length of the transition curve jointly owned by reverse curves and the distance of the straight line to be laid between the curves are as follows:

(i) $L = 0.008 \times (C_{a1} + C_{a2}) \times Vm$

or

(ii) $L = 0.008 \times (C_{d1} + C_{d2}) \times Vm$ whichever is greater where C_{a1} and C_{d1} are cant and cant deficiency of curve 1 in mm

C_{a2} and C_{d2} are cant and cant deficiency of curve 2, in mm.

L = is the length of transition curve in metres.

Vm = maximum permissible speed km/h.

It has been stipulated that for high speeds, in Group A & B routes, a straight with a minimum length of 50 m shall be kept between two transitions of reverse curves. On groups A and B routes, straights less than 50 metres between reverse curves should be eliminated by suitably extending the transition lengths. In doing so it should be ensured that the rate of change of cant and versine along the two transitions so extended is kept the same. Whenever such straights between reverse curves can neither be eliminated nor the straight length increased to over 50 metres, speed in excess of 130 km/h should not be permitted.

In the case of Japanese "Shinkansen", the minimum length of the straight line between the curves is set at 100 m. If this length cannot be secured, a transition curve is laid by suitably extending the transition lengths as in the case of the Indian Railway.

Thus straight line is required to prevent an increase in shaking of vehicles occurring at the entrance/exit of the transition curve. According to experiments, the cycle (T) of the lateral shaking of rolling stock is about 1.5 seconds, and the shaking that occurs on the first curve usually causes the largest shaking on the other side after a half cycle, and attenuates in one cycle. From this, the minimum length of the straight line and the curve is set.

$$L = \frac{V}{3.6} \cdot T$$

Shinkansen V = 250 km ..... L = 100 m

In the case of 160 km/h, $L = \frac{160}{3.6} \cdot 1.5 \fallingdotseq 70$ m

Therefore, straight line distance of about 70 m is required between the curves.

4-4 Vertical Curve

As the train runs at higher speeds, the floating of rolling stock occurs at points of grade change owing to centrifugal force. To prevent this, vertical curve are required at such points.

Acceleration of vertical motion applied to the rolling stock passing through a vertical curve can be indicated with the following formula.

$$\alpha = \frac{1}{\Upsilon g}\left(\frac{V}{3.6}\right)^2$$

Υ: Radius of vertical curve

V: Train speed

g: Acceleration of gravity (9.8 m/sec^2)

α: Acceleration of vertical motion

From the view point of preventing the floating of the vehicle, it is sufficient if α is 0.1 or less. Accordingly, the radius vertical curve necessary for the train when its V is 160 km/h, is 2,016 m.

In the present Indian Railway, the radius of vertical curve for A' Group tracks is set at more than 4,000 m, so no improvement is required in this regard.

4-5 Train Speed and Impact Load

In designing steel railway bridges in Japan, impact coefficient is calculated on the basis of the following formula:

$$i = \frac{KaV}{7.2\ Ne\ell} + \frac{10}{65 + \ell}$$

Ka: Parameter Empirically, in the case of Shinkansen Ka = 1.0
Conventional lines Ka = 2.0

Ne: Basic natural vibration of beam at the loaded (Hz)
From actual measuring, $Ne = 70\ \ell^{-0.8}$

V: Train speed

ℓ: Span of the bridge

Impact coefficients at train speed of 130 km/h and 160 km/h on a bridge with a span of 20 m are, i130 = 0.26 and i160 = 0.29, and impact load increase will be 1 + i130 = 1.26 and 1 + i160 = 1.29.

Therefore, no adverse effect is expected.

4-6 Investigation of the Track Structure Associated with the Operation of High-speed Train at 160 km/h

The bearing power of the track structure which is now being updated has been examined with respect to the operation of the 160 km/h high-speed train using the calculation method which formed a basis for the Track Bearing Standard of JR.

(1) Theory of the Track Bearing Standard

The bearing power of the track is calculated according the model shown below.

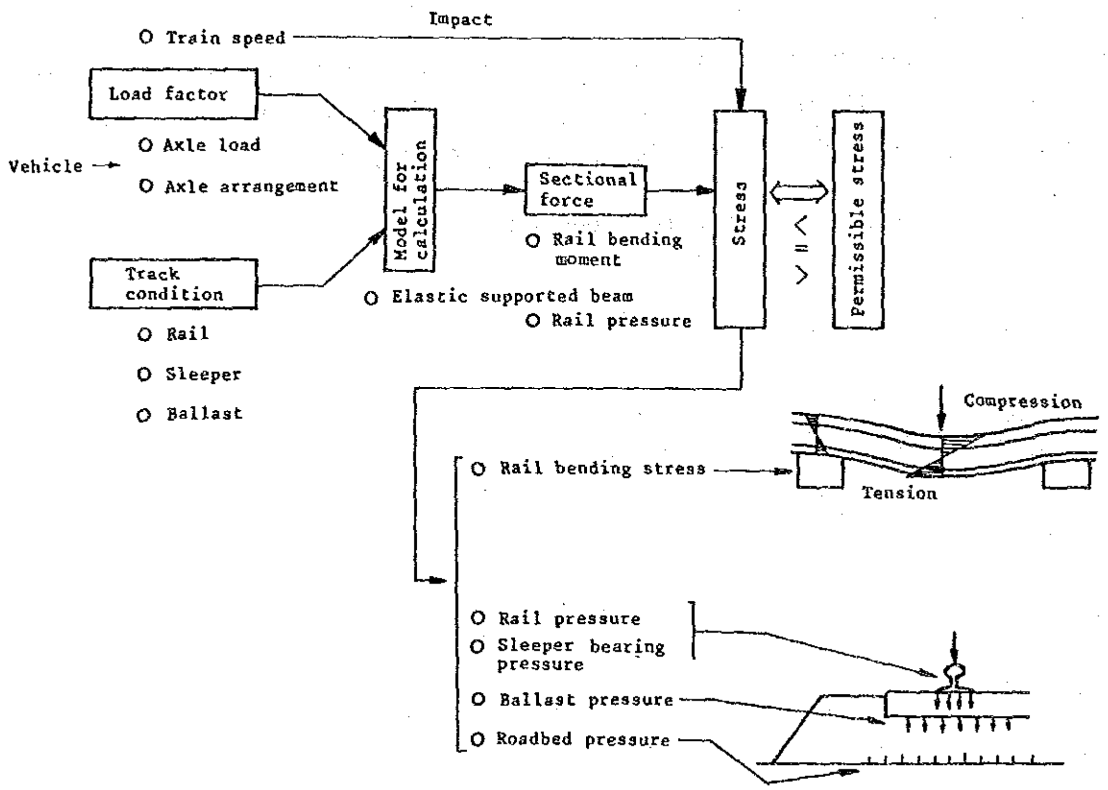


Fig. 1 Calculating Model of Track Stress

1) Calculation of bearing power of track

The bearing power of track is calculated according to the model shown in Fig. 2.

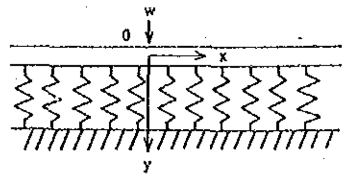


Fig. 2 Beam Model on an Infinitive Elastic Bed

A bending moment M, and a rail pressure P working at a point of distance x against a wheel load W are calculated as follows.

$$EI\frac{d^4y}{dx^4} = -ky \ (k>0)$$

$$M = \frac{W}{4\beta} e^{-\beta x} (\cos\beta x - \sin\beta x)$$

$$P = \frac{W}{2}\{ e^{-\beta(x-\frac{a}{2})}\cos\beta(x-\frac{a}{2}) - e^{-\beta(x+\frac{a}{2})}\cos\beta(x+\frac{a}{2})\}$$

EI: Rail bending rigidity

k : Spring coefficient for bearing

β : $\sqrt[4]{k/4EI}$

a : Sleeper spaces

The rail pressure P working directly below a wheel load is:

$P = W(1 - e^{-\beta \cdot a/2} \cos\beta \cdot a/2)$

2) Modulus of foundation support (Ki)

For calculating permissible bearing stress of ordinary road-bed, through experiments and result of measurement at roads, Table 1 is used.

Table 1 Permissible Bearing Stress of Road-bed

Road-bed condition	Permissible stress (kgf/mm^2)	Remarks
Good	3.0	Sufficiently compacted sandy soil
Ordinaly	2.4	Sufficiently compacted cohesive soil
Bad	1.5	A little soft soil

From this permissible bearing stress the modulus of foundation support (Ki) is calculated in the following formulas.

$$S = \frac{P \cdot P_f}{K_i(P_f - P)} = \frac{P \cdot P_f / P}{K_i(P_f/P - P/P)} = \frac{P_f}{K_i(F_s - 1)}$$

$$K_i = \frac{P_f/F_s}{(1-1/F_s)S} = \frac{P_a}{(1-1/F_s)S}$$

S : Sinking value for loading pressure P

P : Loading pressure

Pf: Ultimate bearing stress

Pa: Permissible bearing stress

Ki: Initial modulus of foundation support

Fs: Safety factor for P

Fs = Pf/P

3) Ballast coefficient

Assuming the ballast is rigidity, considering such a ballast distribution as shown in Fig. 3, and taking the ballast pressure working on the road-bed surfase as the road-bed pressure ballast coefficient C is calculated.

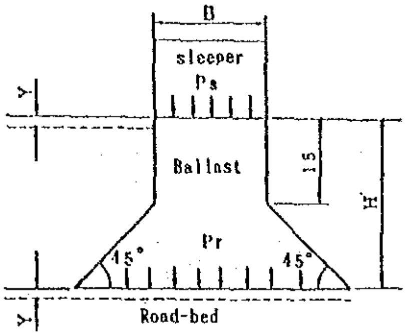


Fig. 3 Sinking of Road-bed and Load Distribution

$$P_s = 2P/(L \cdot B)$$

$$P_r = \frac{2P}{\{L+2(H-15)\} \cdot \{B+2(H-15)\}}$$

Ps: Sleeper pressure

P : Rail pressure

Pr: Road-bed pressure

L : Sleeper length

B : Sleeper width

H : Ballast thickness (cm)

Next, from the modulus of foundation support Ki, the sinking of road-bed Y is calculated.

$$Y = \frac{P_r}{K_i} = \frac{2P}{K_i \cdot \{L+2(H-15)\}\{B+2(H-15)\}}$$

$$C = \frac{P_s}{Y} = \frac{K_i\{L+2(H-15)\} \cdot \{B+2(H-15)\}}{B \cdot L}$$

4) Spring coefficient for bearing rail k

The spring coefficient for bearing rail k is calculated from the formula k=D/a, where the sinking coefficient at rail support D is obtained from the model as per Fig. 4. (in case for PRC)

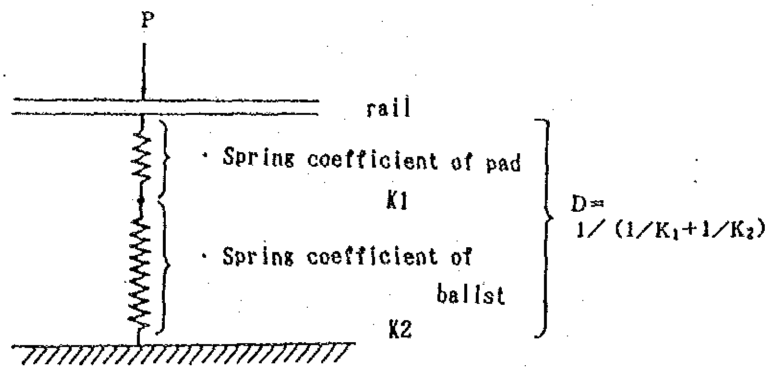


Fig. 4 Sinking Coefficient at Rail Support for PRC

100 tf/m is taken for the spring coefficient of rail rubber pad Ki.

$$K2 = C \times \beta \times \frac{L}{2}$$

5) Road-bed coefficient

Road-bed coefficient Po is calculated in the following empirical formula.

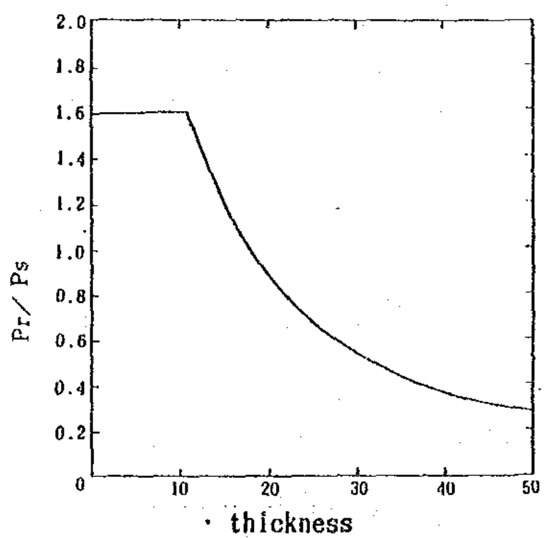


Fig. 5 Ballast Thickness and Ratio of Pr/Ps

$$P_{rmax} = P_s \cdot \frac{58}{10 + H^{1.35}}$$

Prmax: Maximum road-bed pressure (kgf/cm^2)

Ps : Average pressure of sleeper base (kgf/cm^2)

H : Ballast thickness (cm)

P : Rail pressure (kgf)

The maximum value of Pr max/Ps is 1.6. This is shown in Fig. 5.

The road-bed coefficient Po is calculated from the rail pressure.

$$P_s = 2P/(B \cdot L)$$

$$P_{rmax} = 2P/(B \cdot L) \cdot 58/(10 + H^{1.35})$$

$$P_o = \frac{P_{rmax}}{P} = 2/(B \cdot L) \cdot 58/(10 + H^{1.35})$$

$$P_o = 1000 \cdot 2/(B \cdot L) \cdot 58/(10 + H^{1.35})$$

6) *Permissile rail stress*

The permissible rail stress is obtained from the dynamic repeat strength expressed in the S-N diagram of rail steel.

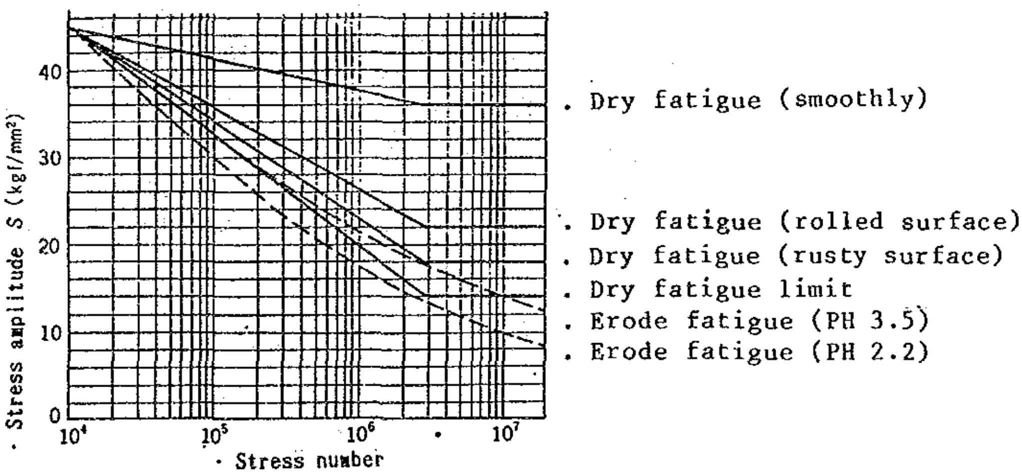


Fig. 6 S-N Diagram

In Germany, the rail fatigue limit is 20 kgf/mm^2 for tensile strength (UTS) 70 kgf/mm^2 and 22 kgf/mm^2 for UTS of 90 kgf/mm^2, while in Japan, the rail fatigue limit is 20 kgf/mm^2 for UTS 80 kgf/mm^2.

The S-N diagram shown in Fig. 6 is the result of calculation of a double sided amplitude of a mean stress of 0 kgf/mm^2 as shown in Fig. 7, but the stress actually generated on a rail is not 0. That is, it is necessary to convert a double sided amplitude stress value to that which appears when the mean stress is not 0. This relation is shown in Fig. 8.

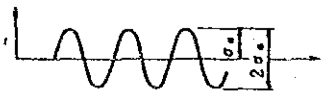


Fig. 7

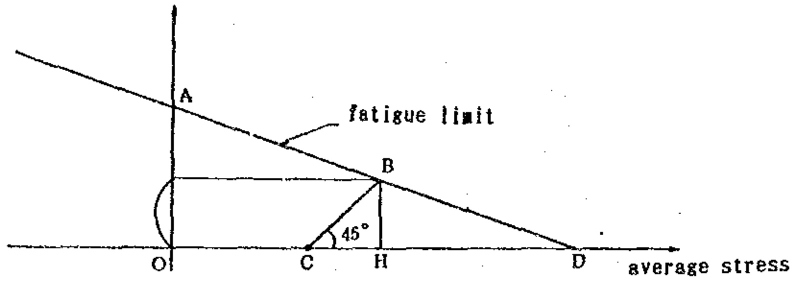


Fig. 8 Diagram of Endurance Strength for Tensil and Compressive

D : Breaking stress

OA: Endurance strength for one side stress amplitude

OC: Maximum static stress by rail residual stress and temperature stress of CWR

The permissible rail stress of the IR's 52 kg rail is calculated as follows.

Minimum ultimate tensile strength: 72 kgf/mm^2

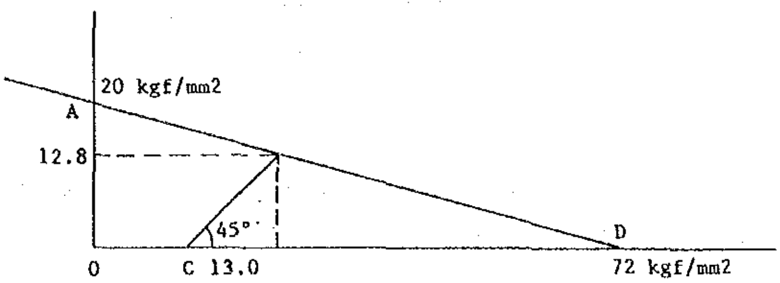
Rail endurance strength : 20 kgf/mm^2

Rail residual stress : 4 kgf/mm^2

Temperature stress (at temperature gaps 35°C)

$\delta = \beta \cdot \Delta t \cdot E = 1.14 \times 10^{-5} \times 35 \times 2.1 \times 10^6 \fallingdotseq 9$ kgf/mm^2

$\overline{OC} = 4 + 9 = 13.0$ kgf/mm^2



$\delta a = 12.8 \text{ kgf/mm}^2$

$2\delta a = 25.6 \text{ kgf/mm}^2$

Lateral rail stress : 6 kgf/mm^2

Safety factor : 80%

Permissible rail stress: $(25.8 - 6) \times 0.8 = 15.7 \text{ kgf/mm}^2$

7) Permissible bearing stress of road-bed

From Terzaghi's supporting strength theory, the result of plate load test on conventional lines, and the target value of the supporting strength on a road, the permissible bearing stress of road-bed is determined for 3 typical road-beds as shown in Table 1.

These permissible bearing stress are calculated assuming a case of breakdown of a road-bed with a sliding surface. When examining a sliding surface, the mean pressure on the road-bed surface (Pb mean) is to be studied. A permissible bearing stress should be corrected to maximum permissible road-bed surface pressure with the formula below, and it should be compared with the maximum road-bed surface presure (Pb max) calculated from the actual load.

The following relationship exists among the mean sleeper bottom surface pressure (Pt), the maximum road-bed surface pressure (Pb max), and the mean road-bed surface pressure (Pb mean).

$$\frac{Pbmax}{Pt} = \frac{58}{10 + H^{1.35}} \qquad H > 11.3 \text{ cm}$$

$$\frac{Pbmean}{Pt} = \frac{B \cdot L}{\{B+2(H - 15)\}\{L + 2(H - 15)\}}$$

$$\frac{Pbmax}{Pbmean} = \frac{58}{10 + H^{1.35}} \cdot \frac{\{B + 2(H - 15)\}\{L + 2(H - 15)\}}{BL}$$

8) Speed impact factor

For speed impact factor, the following formulas made up with recent empirical data are employed.

$i = 1 + 0.5 \cdot V/100$ (with joint)

$i = 1 + 0.3 \cdot V/100$ (CWR)

'i' should not exceed 1.8.

(2) IR's track strength calculation

1) Conditions for track structure

a) Rail

Weight	:	52 kg/m
Bending rigidity	:	453.2×10^7 kgf.cm^2
E x Ix	:	E: Modulus of elasticity
		Ix: Moment of inertia
Section modulus	:	Z = 285.5 cm^3
Permissible rail stress	:	1,570 kgf/cm^2

Calculation is made as per (1)-5).

b) Sleeper

PRC length: 275 cm, Width: 25 cm

Designed rail pressure	:	15,000 kgf
Number of sleepers	:	Case-1 1,540 /km
		Case-2 1,660 /km

c) Ballast thickness : Case-1 25 cm

Case-2 30 cm

d) Road-bed

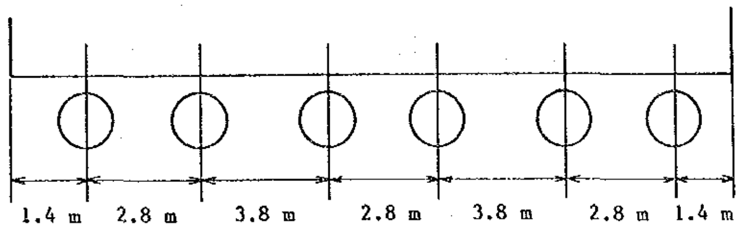
Road-bed condition	:	"Ordinary"
Permissible stress	:	2.4 kgf/cm^2

e) Speed impact factor : For safety's sake, the impact rate for jointed track is used.

2) Type of rolling stock

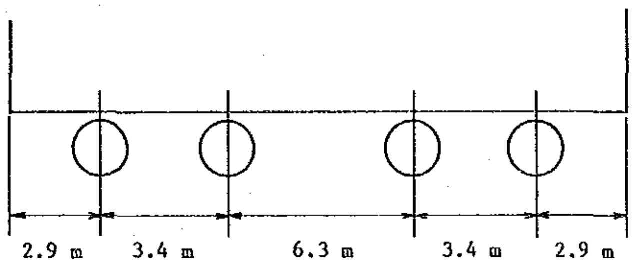
Type of rolling stock (I) Bo-Bo-Bo

From the 1st to 6th axles: 20.5 tf



Type of rolling stock (II) Bo-Bo

From the 1st to 4th axles: 19.5 tf



3) Result of calculation

a) Various track coefficients

Item	Case - 1 Sleeper 1,540 Ballast thickness 25 cm	Case - 2 Sleeper 1,660 Ballast thickness 30 cm
Modulus of foundation support Ki	7.2 kgf/cm^2	7.2 kgf/cm^2
Ballast coefficient C	13.9 kgf/cm^3	17.57 kgf/cm^3
Sinking coefficient at rail support D	32,336 kgf/cm	37,652 kg/cm
Road-bed coefficient Po	0.19365 $kgf/cm^2/tf$	0.15529 $kgf/cm^2/tf$
$\beta = \sqrt[4]{k/4EI}$	0.01287 cm^{-1}	0.013625 cm^{-1}

b) Maximum rail bending moment and maximum rail pressure

Loc. case \ Item \ Track case		Case - 1 Sleeper 1,540 Ballast thickness 25 cm	Case - 2 Sleeper 1,660 Ballast thickness 30 cm
Loc. (I) Bo-Bo-Bo	Max. rail bending moment	198,326 kgfm	188,819 kgfm
	Max. rail pressure	3,938.6 kgf	3,894.3 kgf
Loc. (II) Bo-Bo	Max. rail bending moment	190,828 kgfm	180,502 kgfm
	Max. rail pressure	3,821.3 kgf	3,778.6 kgf

c) Maximum permissible speed from various stresses

Loc. case \ Item \ Track case		Case - 1	Case - 2
Loc. (I) Bo-Bo-Bo	By rail bending moment	252 km/H	274 km/H
	By ballast pressure for road-bed	555 km/H	752 km/H
	By rail pressure for sleeper	561 km/H	570 km/H
Loc. (II) Bo-Bo	By rail bending moment	269 km/H	296 km/H
	By ballast pressure for road-bed	578 km/H	781 km/H
	By rail pressure for sleeper	585 km/H	593 km/H

d) Permissible axle load corresponding to speed

Loc. case \ Item \ Track case		Case - 1		Case - 2	
		Maximum speed		Maximum speed	
		160 km/h	120 km/h	160 km/h	120 km/h
Loc. (I) Bo-Bo-Bo	By rail bending moment	tf 25.7	28.9	27.0	30.4
	By ballast pressure	43.0	48.4	54.2	61.0
	By rail pressure	43.4	48.8	43.9	49.3
Loc. (II) Bo-Bo	By rail bending moment	25.4	28.6	26.9	30.2
	By ballast pressure	42.1	47.4	53.1	59.8
	By rail bending	42.5	47.8	43.0	48.3

4) Conclusion

The application of calculation of JR's Track Bearing Standard to IR's track structure assures sufficient strength in every case. In raising the speed, however, investigations on the track alignment, track irregularity control target values, and strength of structures taking account of impact are necessary. Since a sharp increase in traffic volume is expected in the future, employment of 60 kg/m rail and 1,660 sleepers per kilometer is desirable from the viewpoint of decreasing maintenance work and expanding of the rail replacement cycle.

4-7 Standards for Rail Replacement Cycle in Foreign Countries

Table 1

Railway of country	Accumulated passing tonnage for rail replacement
SNCF UIC 60 Rail	5 ∿ 6 hundred million tons
D.B. S49 (UTS 70 kg) S54 (UTS 90 kg) UIC 60 (UTS 90 kg)	 1.5 ∿ 2.0 hundred million tons 2.5 ∿ 3.5 hundred million tons 4.5 hundred million tons
JR 50N 60 kg	 4 hundred million tons 6 hundred million tons

4-8 Rail Welding Technique in Japan

1. Welding process

The following processes are used for rail welding in Japan.

Rail welding method
- Pressure welding
  - Gas pressure welding
  - Flash butt welding
- Fusion welding
  - Enclosed arc welding
  - Thermit welding

(1) Gas pressure welding

Gas pressure welding is a process by which the rail ends of the two rails are brought into pressure contact with each other and the contact area is heated by oxyacetylene flame. This process is mostly used for continuous welded rail of the Shinkansen and conventional lines, because it assures reliable strength with a relatively low installation cost and allows on-site welding.

The gas pressure welding machines available are of floor-mount type and portable type, the latter being used more than the former not only in on-site welding but also in base welding. Table 1 shows the performance with this welding machine.

Table 1 Performance Specifications of a Gas Pressure Welding Machine (Portable) for Rails

Performance items				Performance
Welding time (minutes)			60 k Rail	Approx. 6
			50 k N Rail	Approx. 5
Standard pressure (t)			60 k Rail	19
			50 k N Rail	17
Pressure-welded length (mm)			60 k Rail	20 + 3
			50 k N Rail	20 + 3
Clamp pressure x stroke			(ton x mm)	Max. 23 x 70
Pressure x stroke			(ton x mm)	Max. 33 x 330
Hydraulic system	Motor		(kW x V)	2.2 x 200
	Hydraulic pump	Max. operating pressure	(Kg/cm^2)	700
		Discharge	(ℓ/min)	1.25 ∿ 12
Dimensions (L x W x H)			(mm)	1,420 x 930 x 390
Weight			(kg)	Approx. 400

Welding work is performed following the procedures below.

Cleaning and grinding rail ends

↓

Setting the welding machine

↓

Welding

↓

Raised metal flash trimming by shearing

↓

Straightening of rail

↓

Grinding

[Advantages and disadvantages]

- Greater joint strength
- The welded part is almost free from a decarburization layer which would be found with flash welding.
- Machine welding allows minimum irregularity in quality due to difference in individual welders' skills.
- Shorter welding time.
- The pressure welding machine is light in weight, requires no electric power supply and offers good mobility.
- Some trouble is involved in treatment of the rail ends to be worked.

(2) Flash butt welding

The flash butt welding process is widely used for plant welding in the Indian Railway. Flash butt welding machines of floor-mount type have been used for a long time in Japan as well. Site welding has been done using portable welding machines in construction works of the Sanyo Shinkansen.

[Advantages and disadvantages]

- Greater welding strength and reliability
- Shorter welding time (2 to 4 minutes)
- Greater installation cost and significant electric power
- Requires skilled workers for maintenance and control of equipment

(3) Enclosed arc welding

This process is arc welding specifically directed to site welding.

The procedures are as follows: set the distance between the rail ends to 17 ± 3 mm, adjust the uneven level of rail surface, preheat the rail bottom to about 500°C, start welding from the bottom and go on to the web and the head removing slag, while enclosing the welding part with a water-cooled copper covering, and finally postheat the welded part and add grind-finishing. The total process take 150 to 180 minutes.

[Advantages and disadvantages]

- Allows welding the rails placed on the track
- Greater mobility
- Takes longer welding time
- Requires welding skills
- Requires electric power

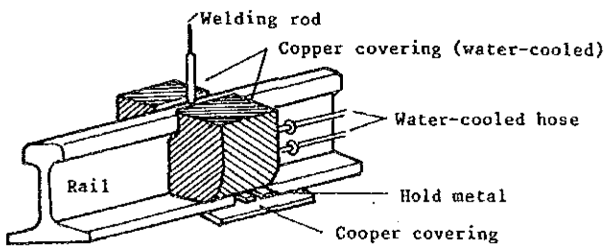


Fig. 1 Enclosed Arc Welding

(4) Thermit welding

The conventional thermit welding had been used widely in Japan for site welding as well as enclosed arc welding.

However, since this method could not necessarily provide sufficient durability, the thermit-welded parts of the Tokaido Shinkansen had to be re-welded using another welding process by the year of 1976.

Since 1980, an improved thermit welding process as shown below is being introduced in lieu of the conventional thermit welding.

Table 2 Comparison of Thermit Weldings

	New type thermit	Thermit welding
Mould	Iron oxide coarse-grained sand, CO_2 formula Heated to 180°C and dried In-plant intensive production system	Caking sand with bentonite Greensand mold dried in air On-site flask molding or in plant
Gap of rail end	24 ∿ 26 mm	12 ∿ 16 mm
Solvent	High carbon steel similar to rails 50N Rail 11 kg	Alloy steel of chrome and vanadium containing 0.3% of carbon 7 kg
Preheating	1.5 ∿ 2 minutes Temperature approx. 600°C	15 ∿ 18 minutes Approx. 900°C
Reaction and inject Reaction time Tapping method Type of inject into mould	 16 ∿ 30 seconds Aut-tapping Top pouring from top side	 30 ∿ 50 seconds Manual tapping Bottom pouring from side pouring gate to top the surface of the bottom
Postheating	Not necessary	Heated to a temperature of 850 to 900°C for 12 to 14 minutes and kept as it is for 20 minutes, then cooled naturally
Time for work	30 ∿ 45 minutes	75 ∿ 90 minutes

[Advantages and disadvantages]

- Allows welding rails in use
- Greater mobility
- Simple equipment with no electric power required
- Shorter welding time
- Less reliability of welded parts

2. Use of welding processes in Japan

Fig. 2 shows the number of welded parts for each welding process in the Shinkansen at the time of its completion and that in conventional lines as of the end of March, 1983.

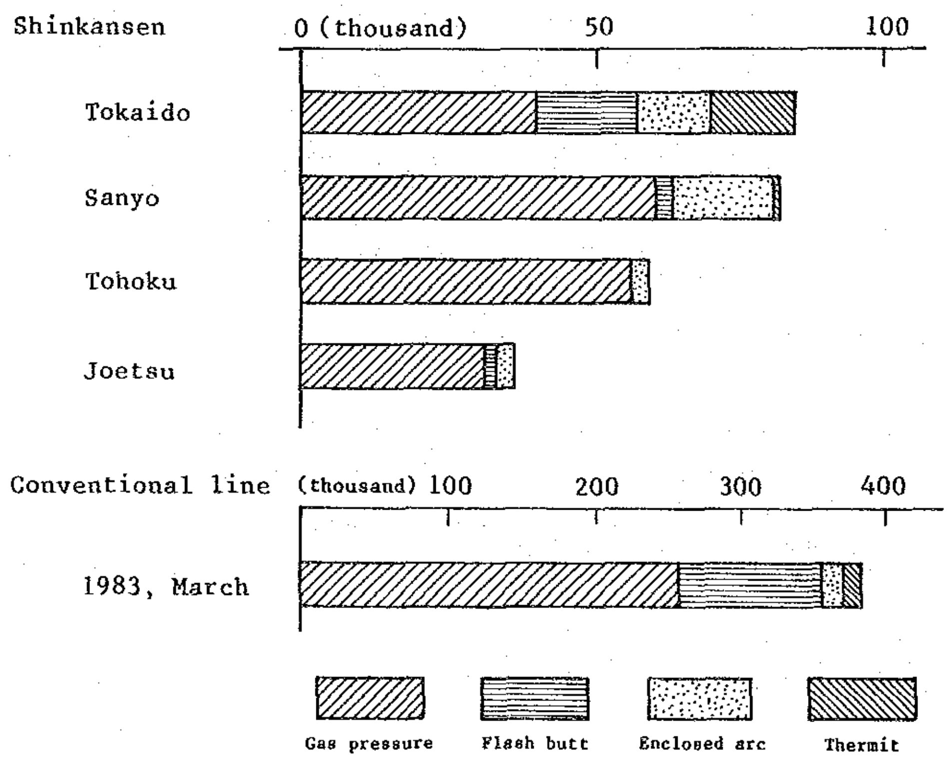


Fig. 2 Number of Welded Parts for Each Welding Process

The total number of welded parts in JR was approximately 52,000 in 1984. Among them, gas welding accounted for 46%, flash butt welding 32%, enclosed arc welding 17%, and thermit welding 5%.

The number of flaw in the welded parts which occurred in the past is generally as shown below.

Gas pressure or flash butt welding --- One per 100,000
Enclosed arc welding --- One per 10,000
Thermit welding --- One per 1,000

For reference, Table 3 shows the change in the number of rail flaw in the Tokaido Shinkansen.

Table 3 No. of Rail Flaw Cases In New Tokaido Line (515 km between Tokyo and Osaka)

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Passing tonnage (up and down)	119	157	192	228	264	299	333	367	401	434	466
No. of rail flaw at the welded part	43	25	12	9	6	2	1	0	3	0	1
Other rail flaw	33	57	56	36	10	2	1	12	7	8	3

Unit of passing tonnage is million tons.

Note 1: The thermit-welded parts were re-worked with other welding for the period from 1966 to 1976.

Note 2: 50 kg T rails (53.3 kg/m) were replace with 60 kg rails in the period from 1971 to 1981.

4-9 General Requirements of Turnouts

Compared with ordinary track, the turnout has the following structural weak points, giving in high-speed running and maintenance.

(i) The tongue rail cross section is small.

(ii) It is not possible to firmly retain the whole tongue rail.

(iii) Since the joint at the heel of the tongue rail is articulated, the rail cannot be firmly jointed.

(iv) The switching facility is located at the toe of the switch, hinders tamping work.

(v) There is a gap in gauge line.

Because of such a structural weak points a speed restriction has been applied in Japan even to the straight direction of the turnout. For speeding up the train, however, the structure of the turnout is improved in strength to withstand the high speed operation. In Europe also, reinforced turnouts are used where high-speed trains operate.

The structure of the high-speed turnouts in Japan and Europe are as shown in Table 1.

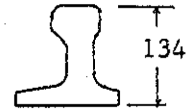
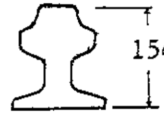
(i) The switch is of a flexible type.

(ii) Tongue rails include special rails such as 90s, UIC61, UIC71, etc.

(iii) The crossing is of the manganese steel monoblock crossing, welded crossing, or forged crossing.

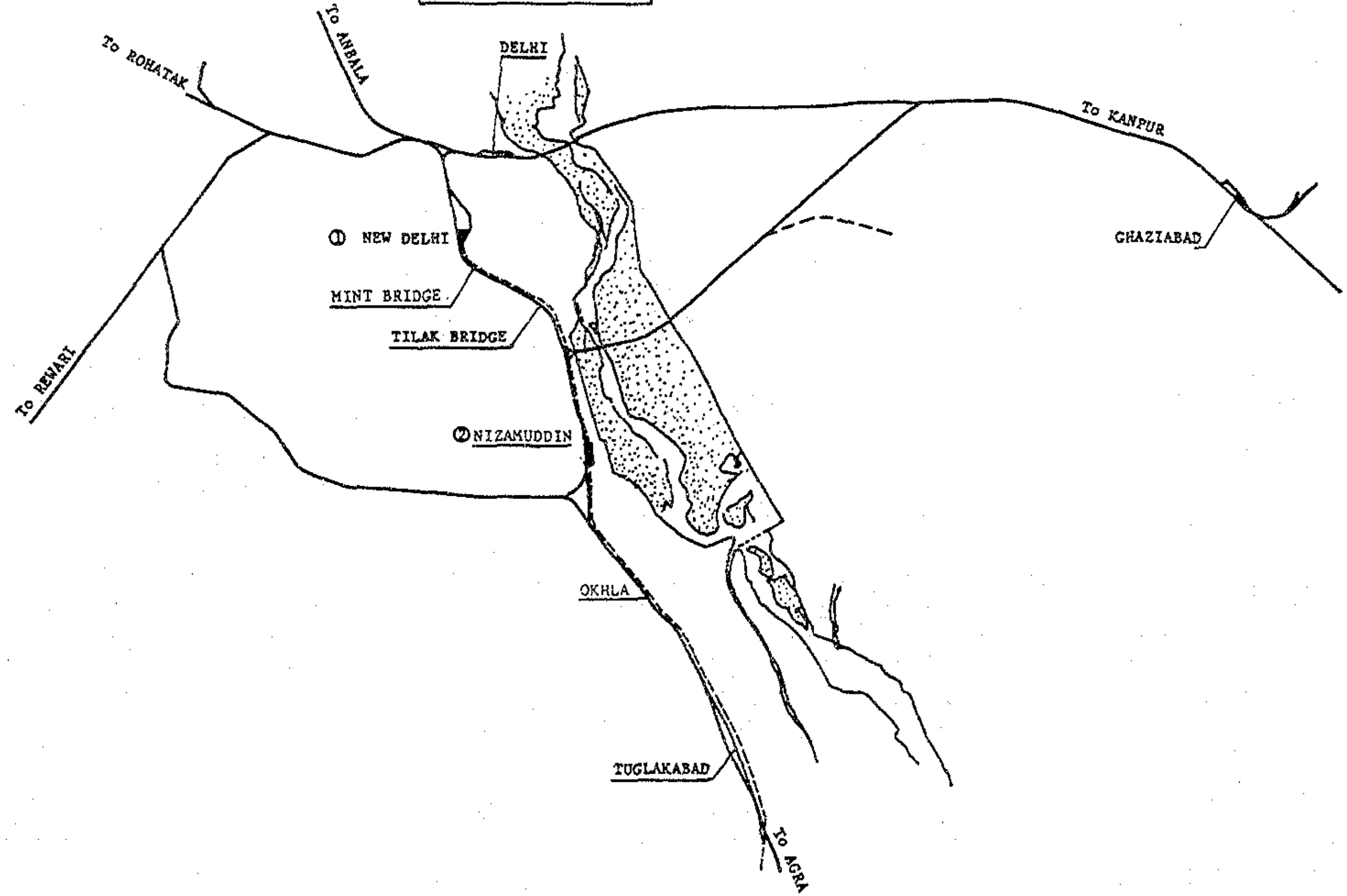
(iv) The guard is of H-type or elastic fastening type.

Table 1 Structure of Turnout on Railways Abroad

Item	Railway of country	BR	SNCF	DB	JR Group: Narrow gauge, Ordinary, N-type	JR Group: Narrow gauge, For high-speed	JR Group: Shinkansen
Switch	Type	Flexible	Flexible	Flexible	Articulated	Flexible	Flexible
	Tongue rail	110A, 113A	UIC61(S) 	UIC71(S) 	70S 	90S 	do -left-
	Stock rail	110A, 113A	UIC60	UIC60	50N	60	60
Crossing	Rigid type	. Manganese steel mono-block crossing . Semi welded crossing	. Manganese steel mono-block crossing	. Semi welded crossing	. Manganese steel mono-block crossing	. Welded and forged crossing	do -left- (<110 km/h) . Manganese steel monoblock crossing (70 km/h)
	Movable nose type	. Flexible	. Flexible	. Flexible . Articulated	-	. Articulated (1 in 8)	. Flexible
Guard	Type	C-type	H-type	Elastic fasten-ing type	C-type	H-type	H-type (blanch side)
	Guard rail	110A, 113A	 Section	 Section	50N Rail	60 Rail	60 Rail
Rail joint on turnout	Ordinary joint				○	○	
	Oblique joint						○
	Welded joint	○ (Thermit)	do	do		○ (main track)	○ (main track)
	Glued joint	△ (Future)	○	○			

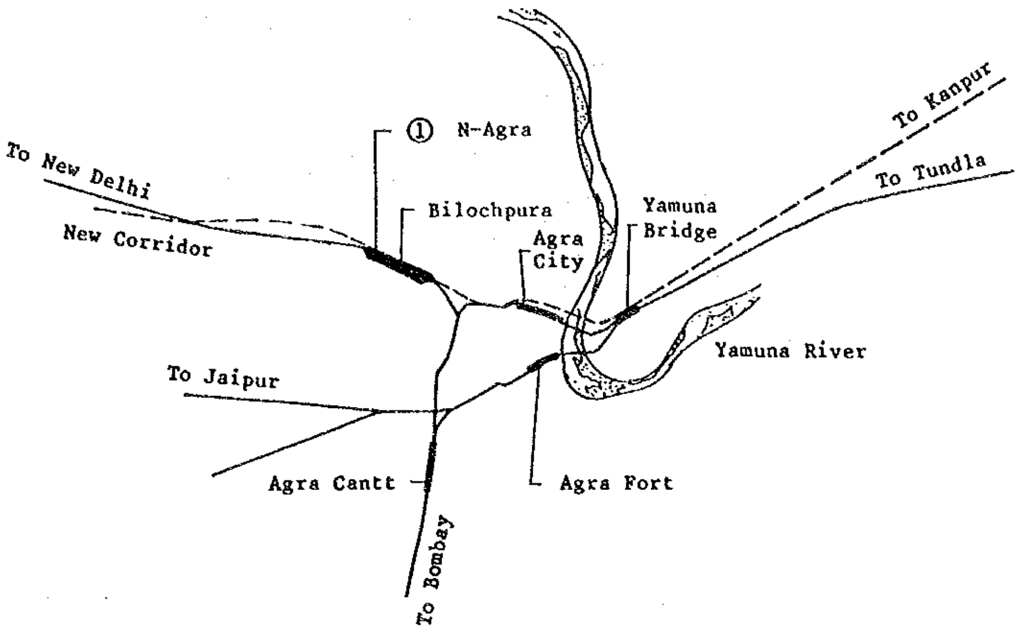
4-10 Comparison of the New Corridor Terminals

Delhi Area

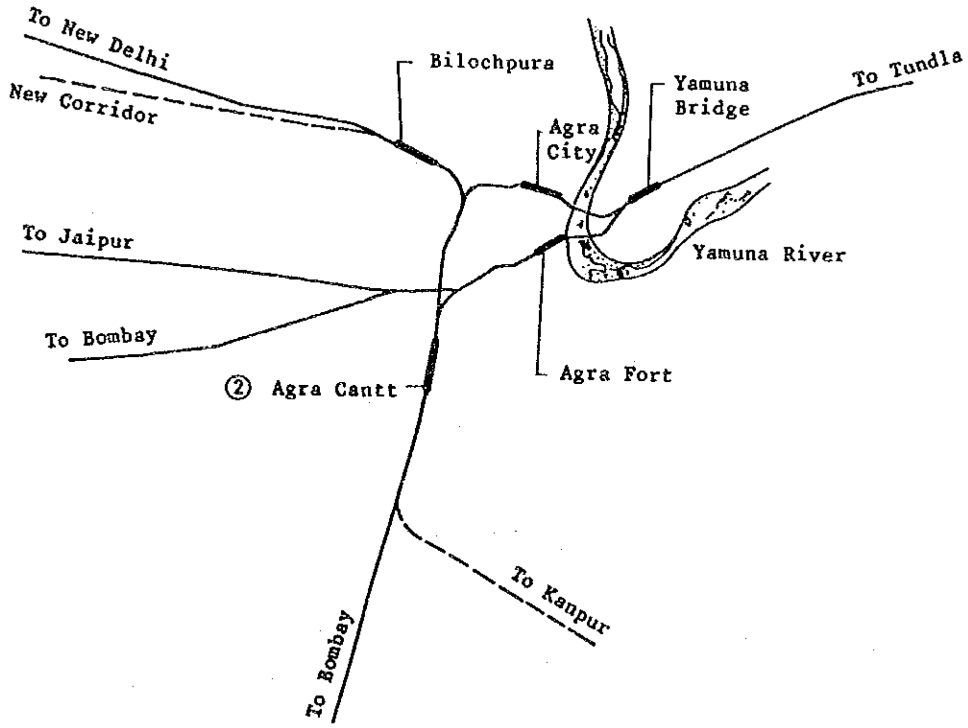


New Terminal in Delhi Area

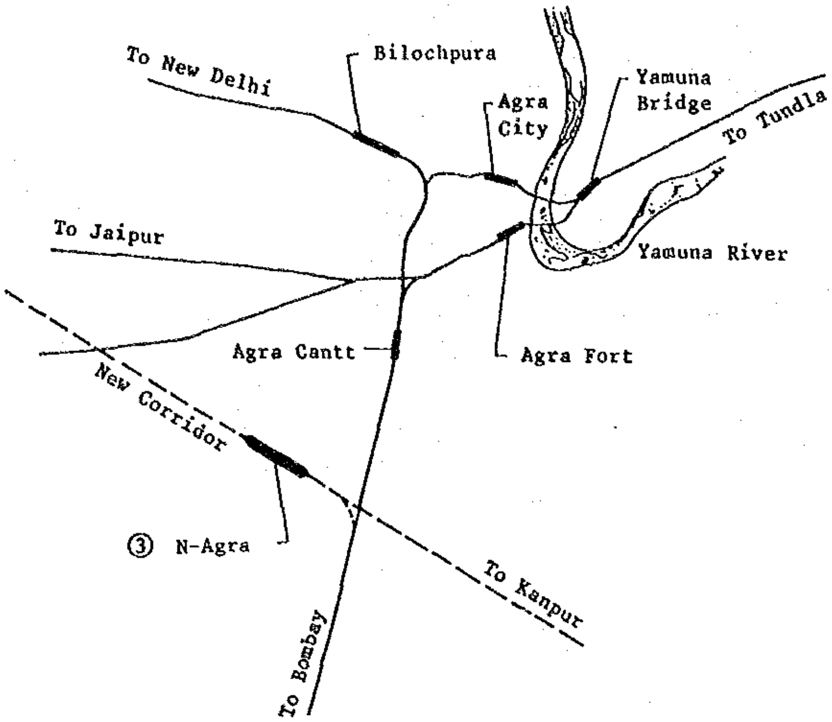
Agra Area



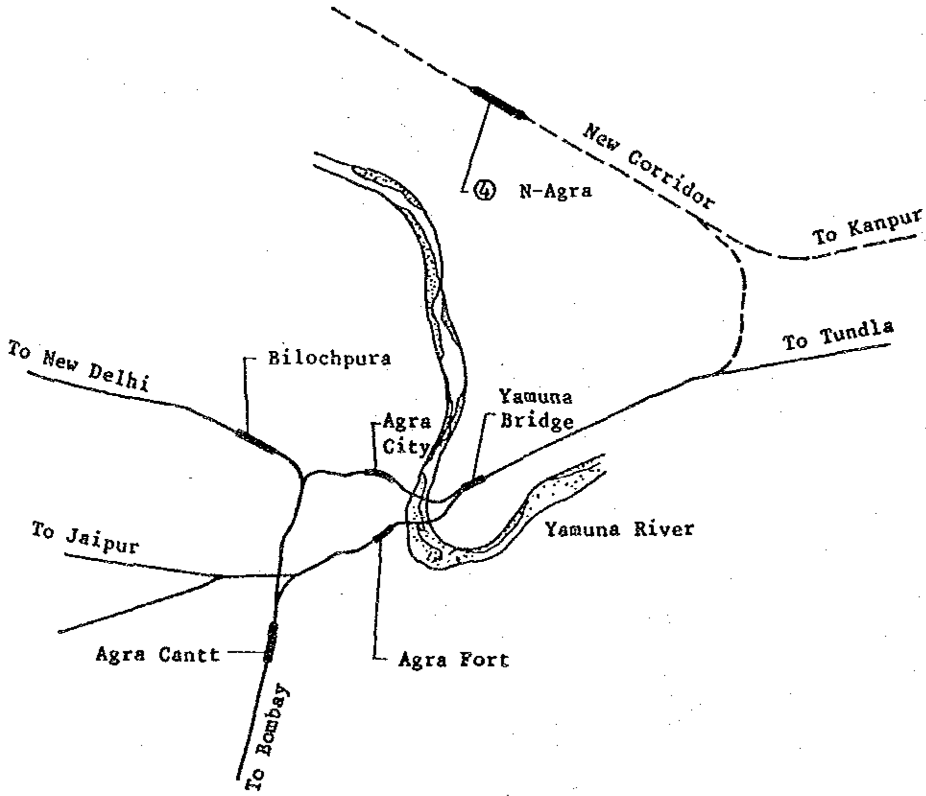
New-Agra at Bilochpura



Utilization of the Agra Cantt St.

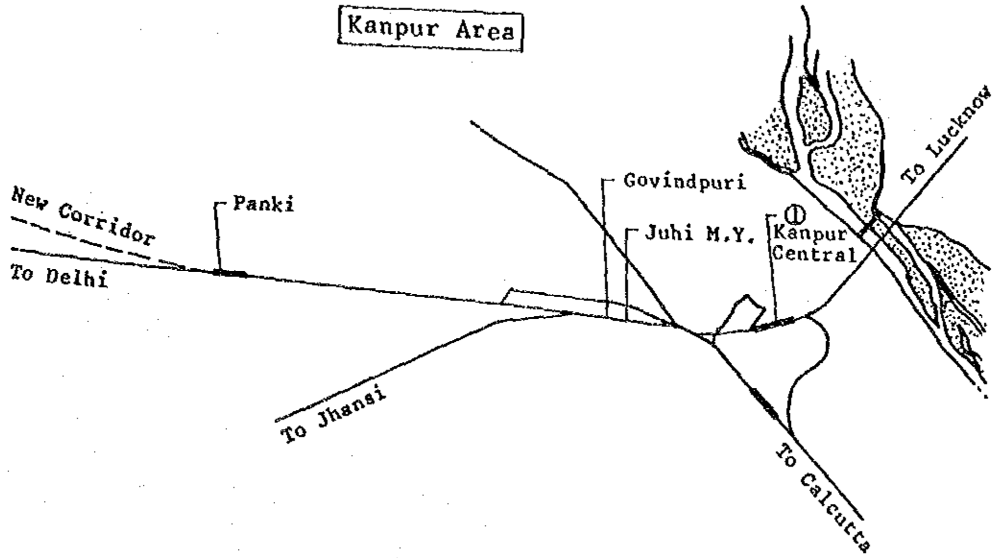


New-Agra (Southern Part of Agra)

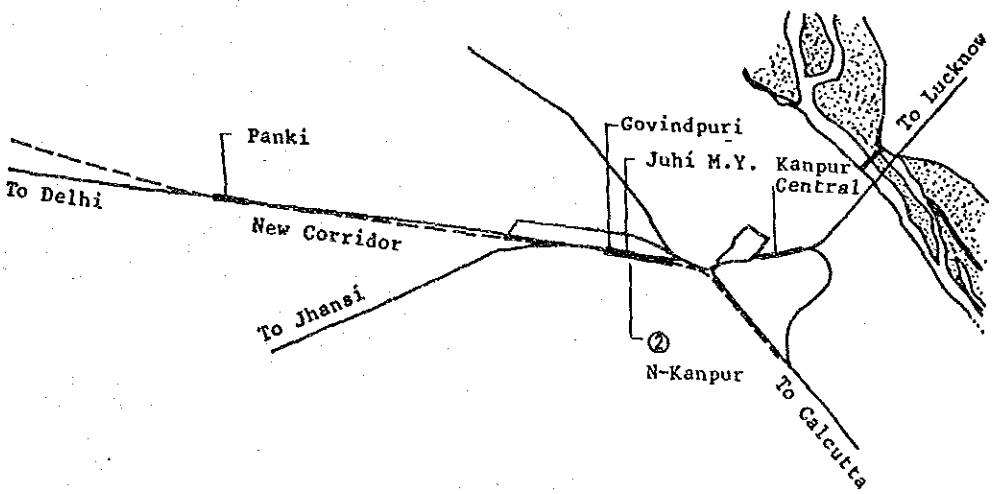


New-Agra (Northern Part of Agra)

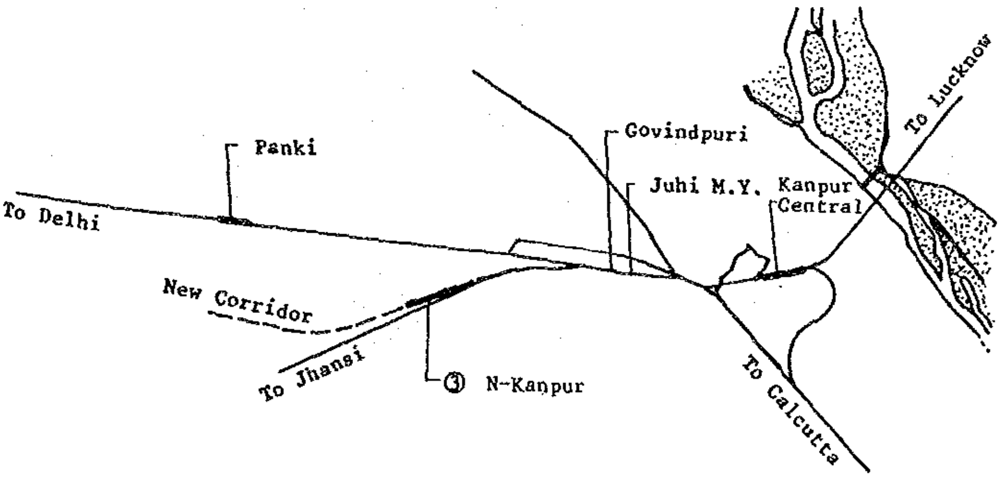
Kanpur Area



Utilization of the Kanpur Central

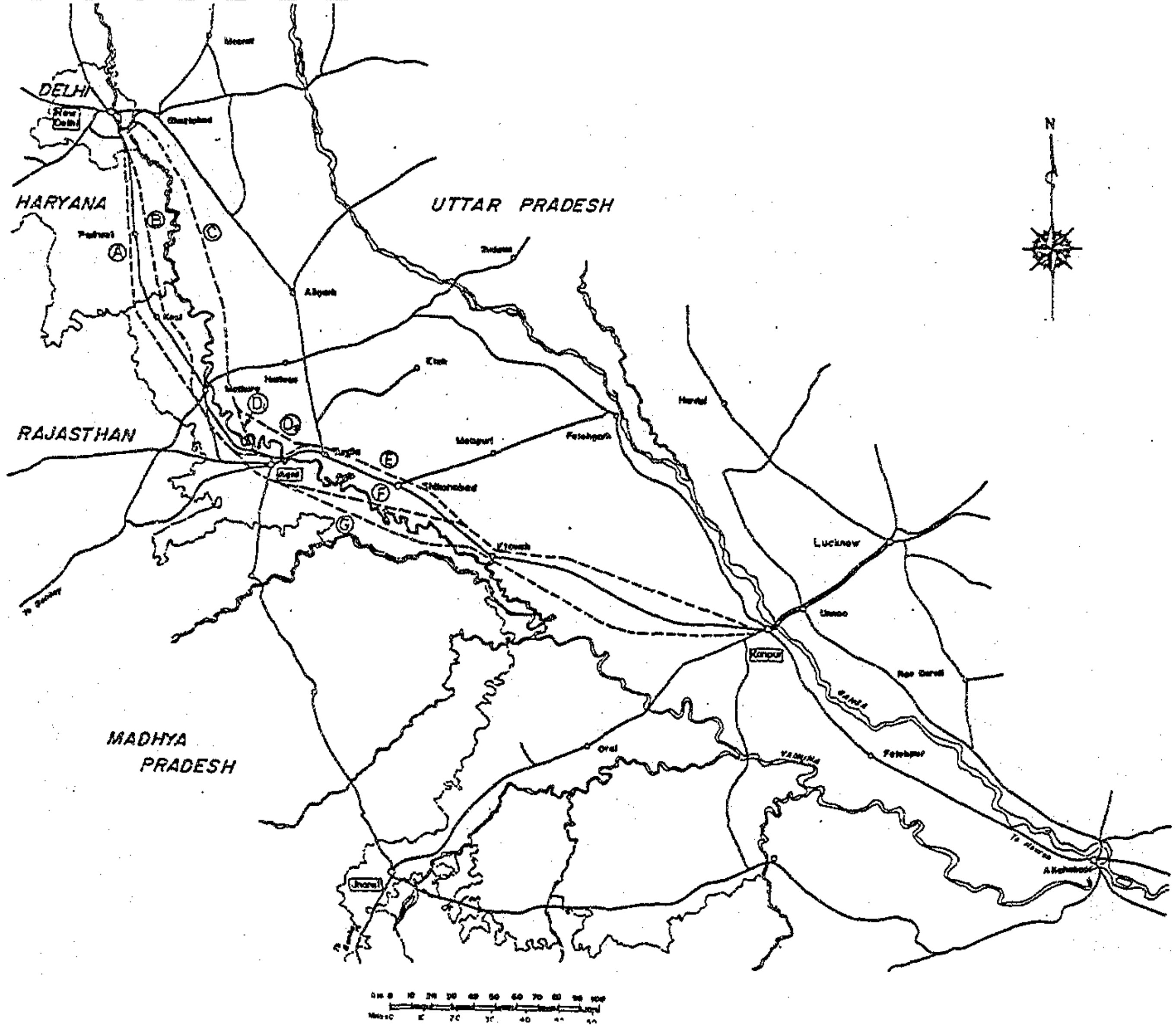


New-Kanpur (Govindpuri)



New-Kanpur (Jhansi Line)

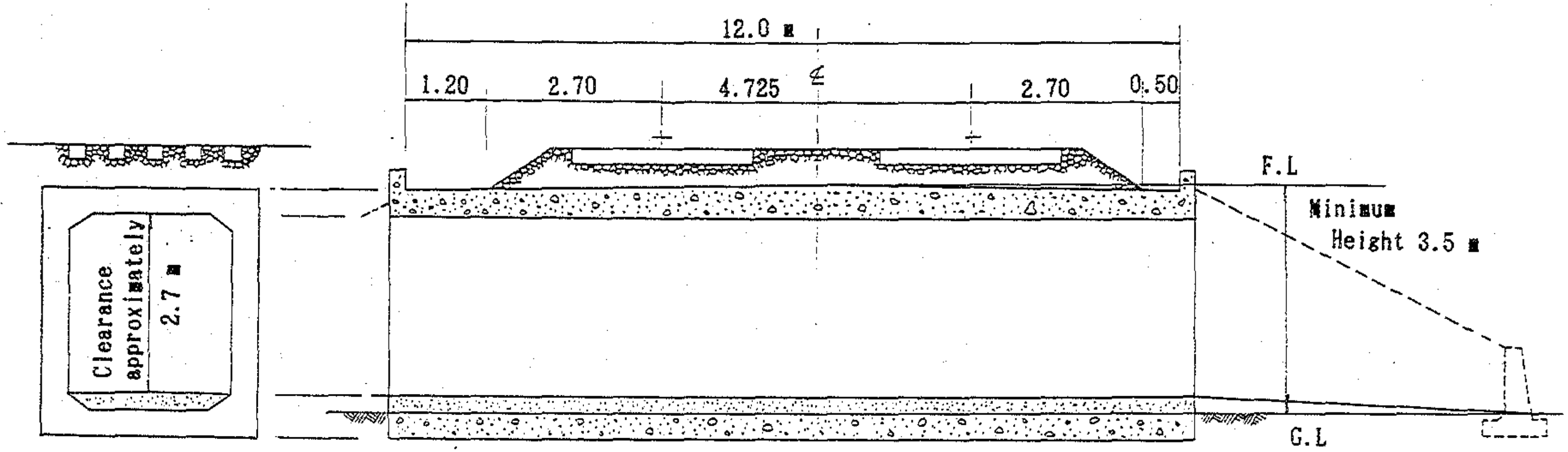
4-11 Alternative Routes for New Corridor



Comparison of Routes

Route	Location of new terminal			Route length			No. of crossings			Note
	Delhi	Agra	Kanpur	Delhi - Agra	Agra - Kanpur	Delhi - Kanpur	Yamuna river	Railway	Main road and canal	
1 (A)-(E)	New Delhi	Bilochpura St.	Govindpuri St.	km 191	km 257	km 448	1	7	49	
1' - do -	do	do	Kanpur Central St.	191	260	451	1	5	47	
2 (A)-(G)	do	Agra Cantt St.	Govindpuri St.	197	255	452	1	3	45	
2' - do -	do	Southern Agra	do	192	254	446	1	6	50	
3 (A)-(F)	do	do	do	192	255	447	1	8	52	
4 (B)-(E)	do	Bilochpura St.	do	188	257	445	1	8	50	
5 (B)-(G)	do	Southern Agra	do	189	254	443	1	7	46	
6 (B)-(F)	do	do	do	189	255	444	1	9	53	
7 (C)-(D_1)-(E)	do	Bilochpura St.	do	198	257	455	2	7	42	
8 (C)-(D_2)-(E)	do	Northern Agra	do	200	244	444	0	5	42	

4-12 Agricultural Road on Embankment Section



4-13 Location of Transition Curve Improvement

Up Line

No.	Between station	Location in kms		Length in actual metres	Radius in metres	Actual transition length	Right or left or reverse sides	Cant	Permissible speed	Improvement for 160 km/H			
										Cant			Transition length
		From	To							Cm	Ca	Cd	
1	AAP-JJK	1,079.75	1,079.95	118.00	10,476		R	Nil	130 km/h	33	10	23	20
2	JJK-KNS	1,081.38	1,081.56	259.60	10,476		L	Nil	130 km/h	33	10	23	20
3	KNS-PHD	1,098.75	1,099.03	188.80	3,500		L	Nil	130 km/h	100	38	62	50
4	KNS-PHD	1,099.03	1,099.50	283.20	3,500		L	Nil	130 km/h	100	38	62	50
5	PTX-ULD	1,116,35	1,116.45	177.00	11,640		L	Nil	130 km/h	30	10	20	20
6	PTX-ULD	1,116.45	1,116.75	259.60	11,640		R	Nil	130 km/h	30	10	20	20
7	ULD-SHW	1,118.02	1,118.19	94.40	11,640		R	Nil	130 km/h	30	10	20	20
8	ULD-SHW	1,118.33	1,118.53	141.60	11,640		L	Nil	130 km/h	30	10	20	20
9	SB-JGR	1,166.25	1,166.48	230	4,828	23.6	Rev (R)	6	110 km/h	72	29	43	35
10	SB-JGR	1,166.615	1,166.815	236	4,828	23.6	Rev (L)	6	110 km/h	72	29	43	35
11	KAA-SKB	1,211.67	1,211.97	300	2,315	70	L	25	130 km/h	151	58	93	75
12	SKB YARD	1,375.09	1,375.30	210	3,625	30	R	25	130 km/h	97	35	62	50
13	SKQ-CHL	1,376.07	1,376.25	180	3,930	40	L	20	130 km/h	89	33	56	45
14	AJR-DER	1,407.07	1,407.21	140	3,500	40,50	R	20	130 km/h	100	38	62	50

Note:
1. Cm: Balanced cant for 160 km/h Ca: Resetting cant Cd: Cant deficiency (Max. 100 mm)
2. Minimum transition curve length is 20 m (one side)
3. The value of Ca and Cd are decided aiming at minimizing "L" by the following formulas.
   Cm = Ca + Cd L1 = 0.005CdV (V = 160 km/h)
   L2 = 1.2Ca
   $$L = Cm \div \left(\frac{1}{0.8} + \frac{1}{1.2}\right)$$
4. *Improvement of transition curve in Aligarh, Tundla and Etawah station are included the Station improvement planes.*

Down Line

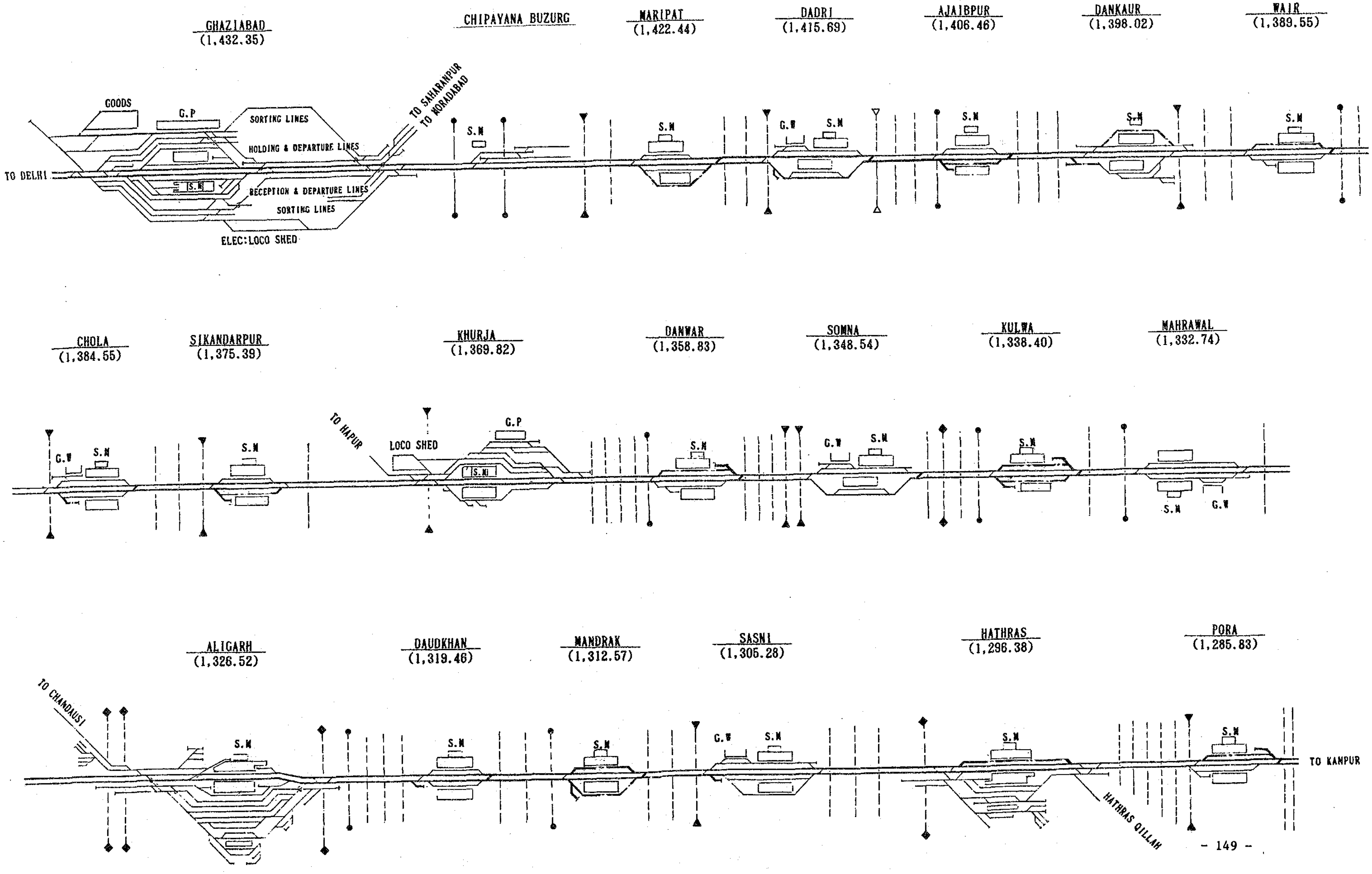
No.	Between station	Location in kms		Length in actual metres	Radius in metres	Actual transition length	Right or left or reverse sides	Cant	Permissible speed	Improvement for 160 km/H			
										Cant			Transition length
		From	To							Cm	Ca	Cd	
1	KNS-PHD	1,098.78	1,099.15	188.80	3,500		L	Nil	130 km/h	100	38	62	50
2	KNS-PHD	1,099.15	1,099.99	283.20	3,500		R	Nil	130 km/h	100	38	62	50
3	PTX-ULD	1,116.31	1,116.50	177.00	11,640		L	Nil	130 km/h	30	10	20	20
4	PTX-ULD	1,116.50	1,116.50	259.60	11,640		R	Nil	130 km/h	30	10	20	20
5	ULD-SHW	1,118.03	1,118.31	94.40	11,640		R	Nil	130 km/h	30	10	20	20
6	ULD-SHW	1,118.45	1,118.56	141.60	11,640		L	Nil	130 km/h	30	10	20	20
7	ETW YARD	1,156.05	1,156.22	170	3,493	35	R	25	100 km/h	100	38	62	50
8	ETW-SB	1,156.96	1,157.33	370	2,777	40	R	30	100 km/h	126	45	81	65
9	SB-JGR	1,166.25	1,166.48	230	4,828	23.6	R	6	110 km/h	72	29	43	35
10	SB-JGR	1,166.615	1,166.815	236	4,828	23.6	R	6	110 km/h	72	29	43	35
11	KAA-SKB	1,211.67	1,211.97	300	2,315	70	L	25	130 km/h	151	58	93	75
12	DAQ-ALJN	1,325.34	1,325.45	110	3,500	40	L	15	130 km/h	100	38	62	50
13	DAQ-ALJN	1,325.50	1,325.58	80	3,500	40	R	15	130 km/h	100	38	62	50
14	DAQ-ALJN	1,325.88	1,325.98	100	3,500	40	R	15	130 km/h	100	38	62	50
15	ALJN-HWUE	1,328.96	1,329.13	170	3,000	50	L	15	130 km/h	117	42	75	60
16	ALJN-HWUE	1,329.19	1,329.36	170	3,000	50	R	15	130 km/h	117	42	75	60
17	ALJN-HWUE	1,331.86	1,332.01	150	2,941	50	L	20	130 km/h	119	44	75	60
18	ALJN-HWUE	1,332.03	1,332.18	150	2,941	50	R	20	130 km/h	119	44	75	60
19	AJR-DER	1,407.05	1,407.22	170	3,888	60,50	R	20	130 km/h	90	20	70	55
20	AJR-DER	1,407.25	1,407.41	160	3,215	50,40	L	20	130 km/h	112	44	68	55

4-14 Railway Diagram of the Section (in 1990) (Ghaziabad - Pore)

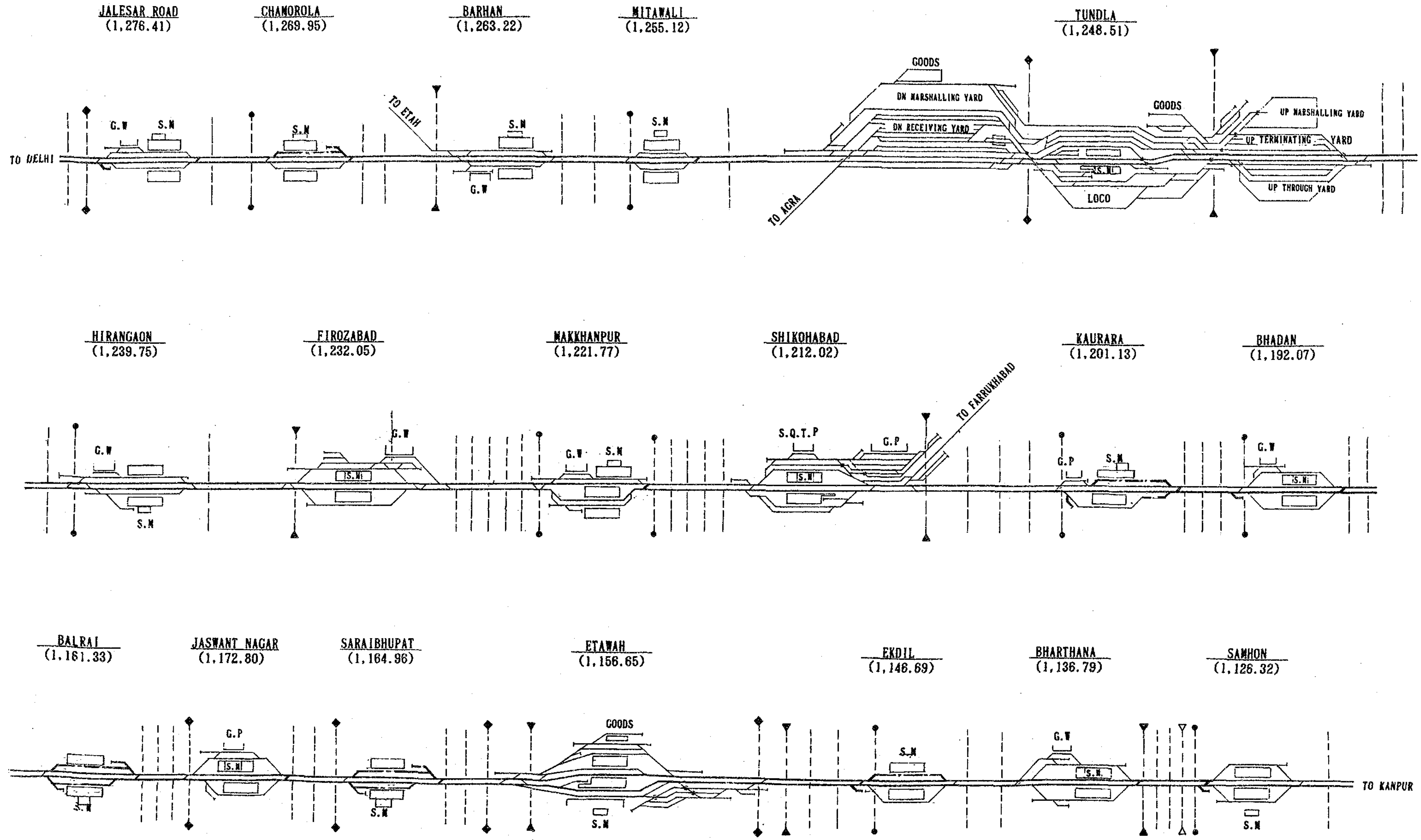
Legend

----------	Planned in the 7th Five Year Plan
S.M	Station Masters Room
G.W	Goods wharf
G.P	Goods platform

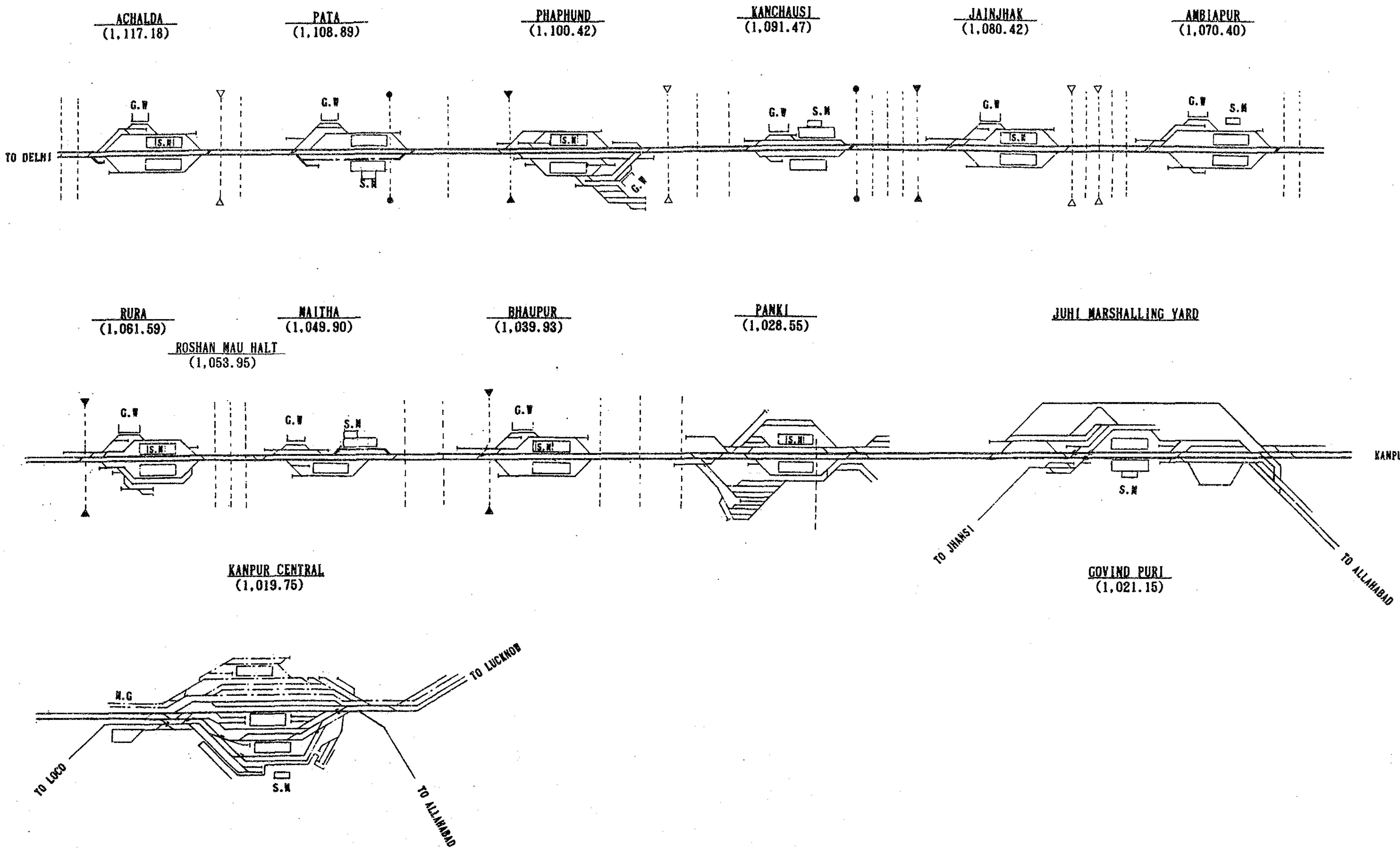
Class \ Level crossings	Barrier without inter locking	Barrier interlocked with gate signal
A	◇---------◇	◆---------◆
B	▷---------◁	▶---------◀
C	---------	●---------●



(Jalesar road - Samhon)



(Achalda ~ Kanpur)



4-15 Rail Replacement Cycle in JR

The target of the rail replacement cycle in Japan is in accordance with the following calculation and standards.

When an off-center load is given on a straight part of a 50T (53.3 kg/m) continuous welded rail section of Shinkansen track, the sectional stress at the upper fillet of the rail web is 6.7 kgf/mm2 obtained through calculation. This is defined as the fundamental stress. Then, consideration is made on the influence of unevenness on the upper surface of the rail.

Assuming that there is a 0.7 m span and 0.3 mm concave on a welded part of a continuous welded rail, an additional coefficient of the rail bending stress is calculated in the following formula.

$$K = 1 + 0.000085aV^2/\ell$$

where

K: Additional coefficient of rail bending stress

a: Depth of concave: 0.3 mm

V: Running speed (km/h): 200 km/h

ℓ: Pitch of concaves: 0.7 m

$$K = 2.45$$

The influence by wheel flatting cannot be defined uniformly, since it is related with conditions of generating flat and train running speed. Assuming a fairly disadvantageous case, however, the following value is employed from actual measurement.

$$K' = 2.3 \sim 2.5$$

Therefore, assuming either K or K' exists, the mean tensile stress is found as follows.

$$6.7 \times 2.4 = 16.1 \text{ kgf/mm}^2$$

As shown in Fig. 1, this value of stress is a tensile stress for one side amplitude. Therefore, it is converted into a symmetrical amplitude stress.

$$\delta m = \delta \cdot \frac{\delta d}{\delta d - \delta}$$

δd: true-stress of fracture: 150 kgf/mm^2 from experiment

δ : stress measurement amplitude

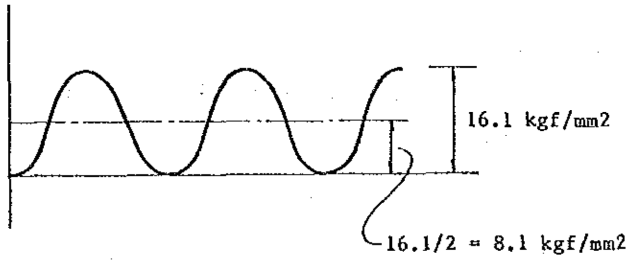


Fig. 1

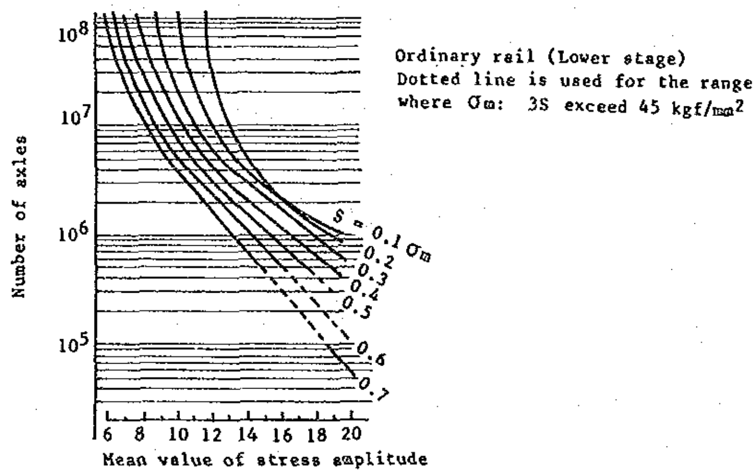


Fig. 2 Number of Axles needed till the Rail is Damaged by Endurance Limit

$$\delta m = 8.1 \times \frac{150}{150 - 8.1} = 8.6 \ kgf/mm^2$$

From Fig. 2, and using the standard deviation S = 0.4 δm, the number of axles is obtained.

$L = 3.6 \times 10^7$

Assuming the axle load is 15 tons, the passing tonnage to cause the endurance limit is

$$3.6 \times 10^7 \times 15 = 5.4 \times 10^8 \text{ (ton)}$$

Since the stress generated in the rail is inversely proportional to the section modulus of the rail, the data for rails other than 50T rail are calculated from those of 50T rail based on the endurance limit of the 50T rail. The data from calculations is shown in Table 1.

Table 1 Rail Replacement Cycle by Tonnage

Type of rail	60	50T	50N	40N
Section modulus (cm^3)	397.1	311.2	273.9	200.1
Replacement cycle by calculation (100 Mton)	6.8	5.4	4.7	3.4
Standard of replacement cycle (100 Mton)	6	5	4	3

Standard values are shown for the rail replacement cycle in Table 1. In addition, rail replacement standards are determined from the viewpoint of wear, cross section erosion, and corrugation wear. Table 2 shows this data.

Table 2 Standards for Rail Replacement

(a) Wearing

(mm)

Class of railway / Kind of rail	Class A	Class B	Class C	Class C simplified
37 kg and 40N	10	12	14	15
50 kg and 50T	11	13	15	16
60 kg	14	15	16	17

(b) Loss of section by wearing and eroding

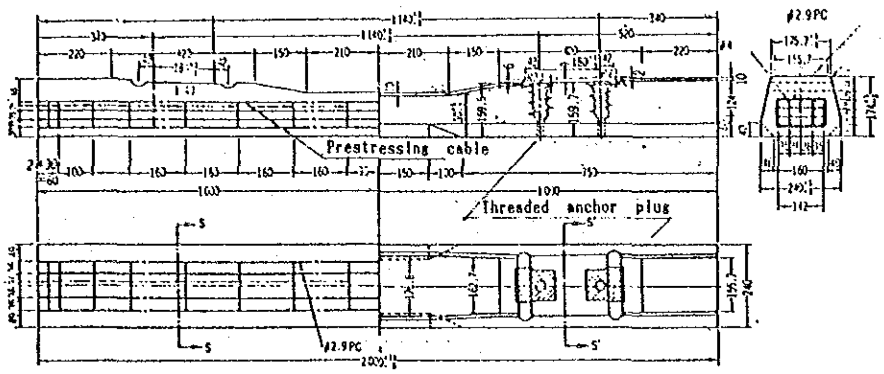
(Loss in section %)

Class of railway / Kind of rail	Class A	Class B	Class C	Class C simplified
37 kg and 40N	18	22	26	28
50 kg and 50T	20	24	28	30
60 kg	22	26	30	32

(c) Depth of corrugation is 1.5 mm more.

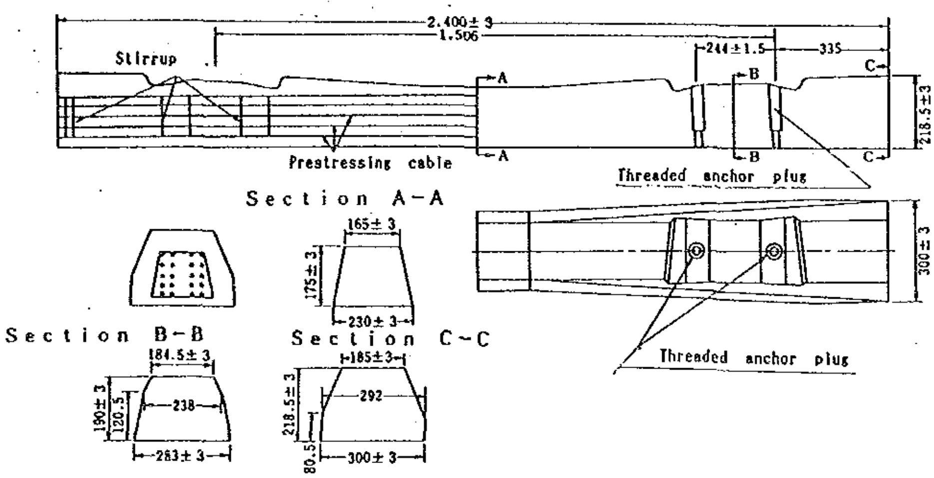
4-16 Design of PRC Sleeper in JR

1067mm Gauge

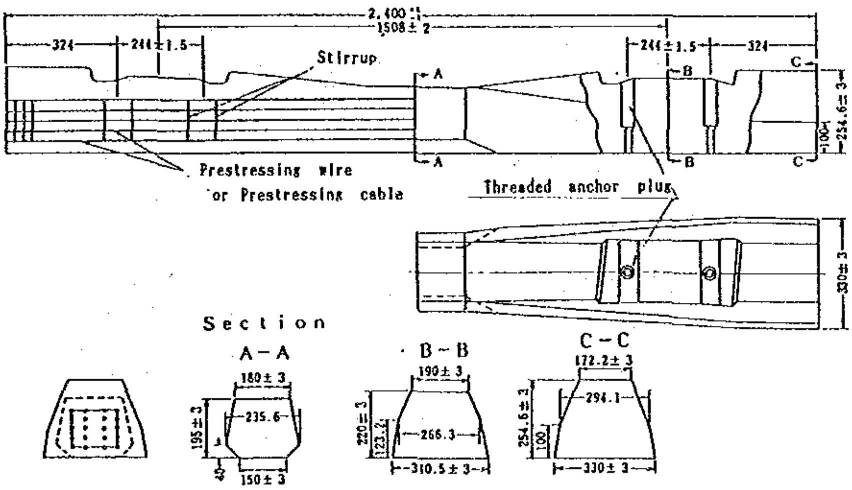


Post-tention No. 3

Shinkansen

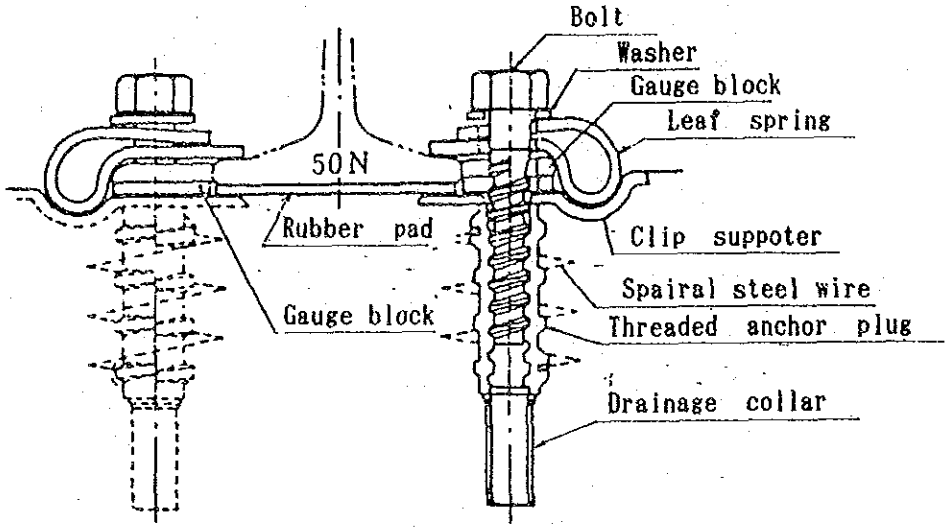


No. 3Tc (for less 210km/h)

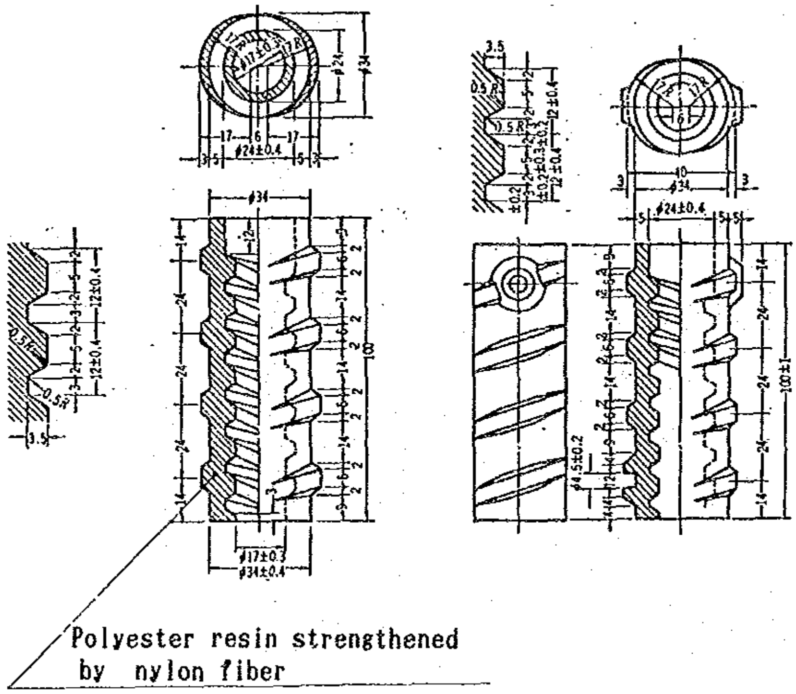


No. 3Hc (for more 210km/h)

Detail of Rail Fastening



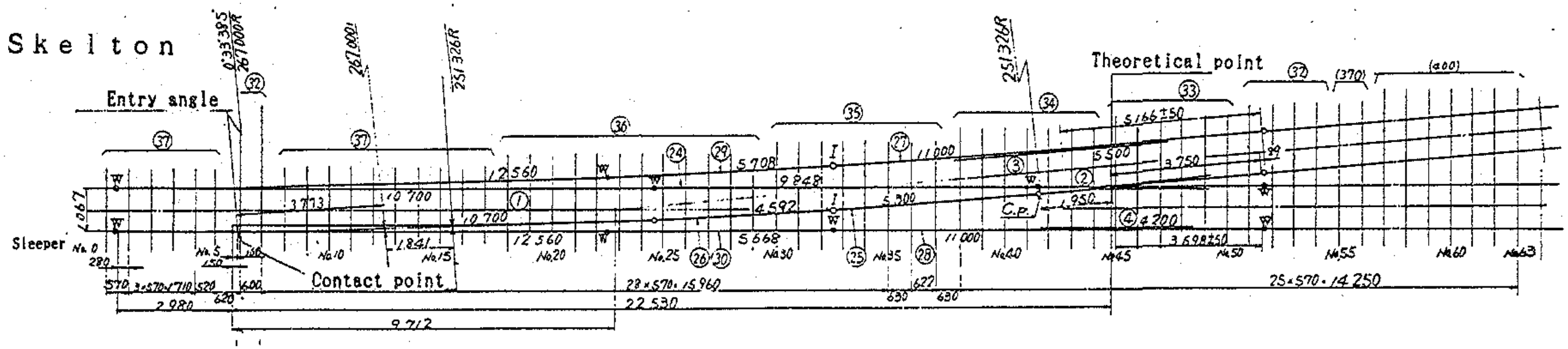
Detail of Threaded Anchor Plug



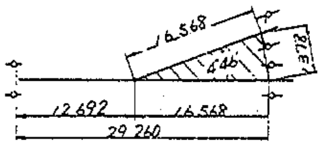
4-17 Design of Turnout in JR

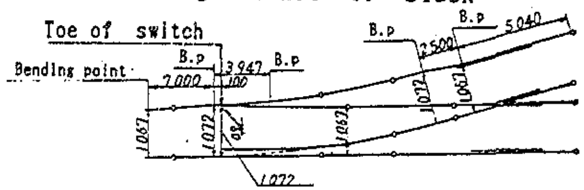
1 in 12 Turnout for high speed (1067Gauge) 60kg Rail

(1) Skelton



Seting method of slack





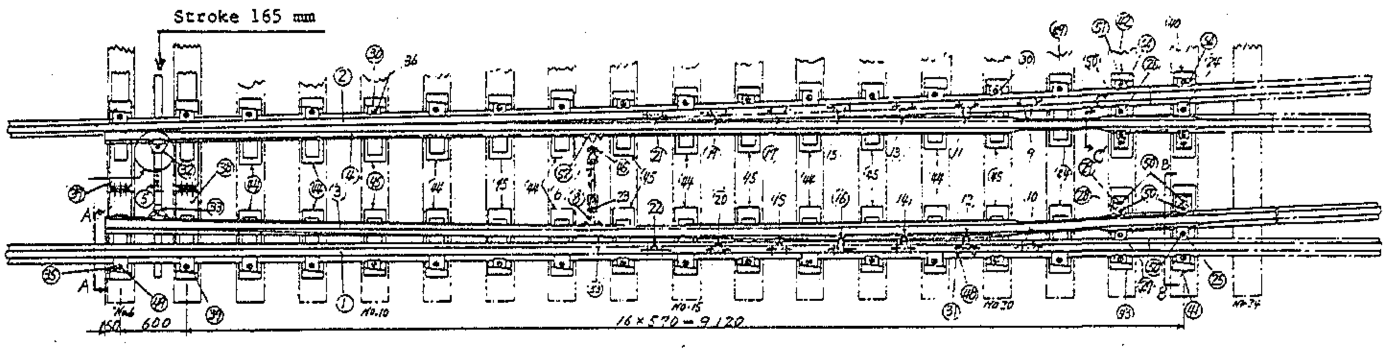
note

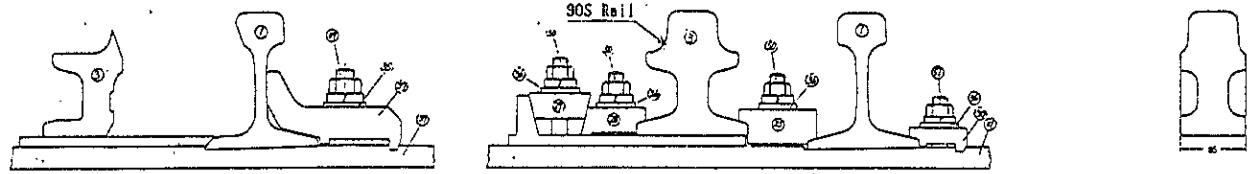
—o— Ordinaly joint

—W— Insulated joint

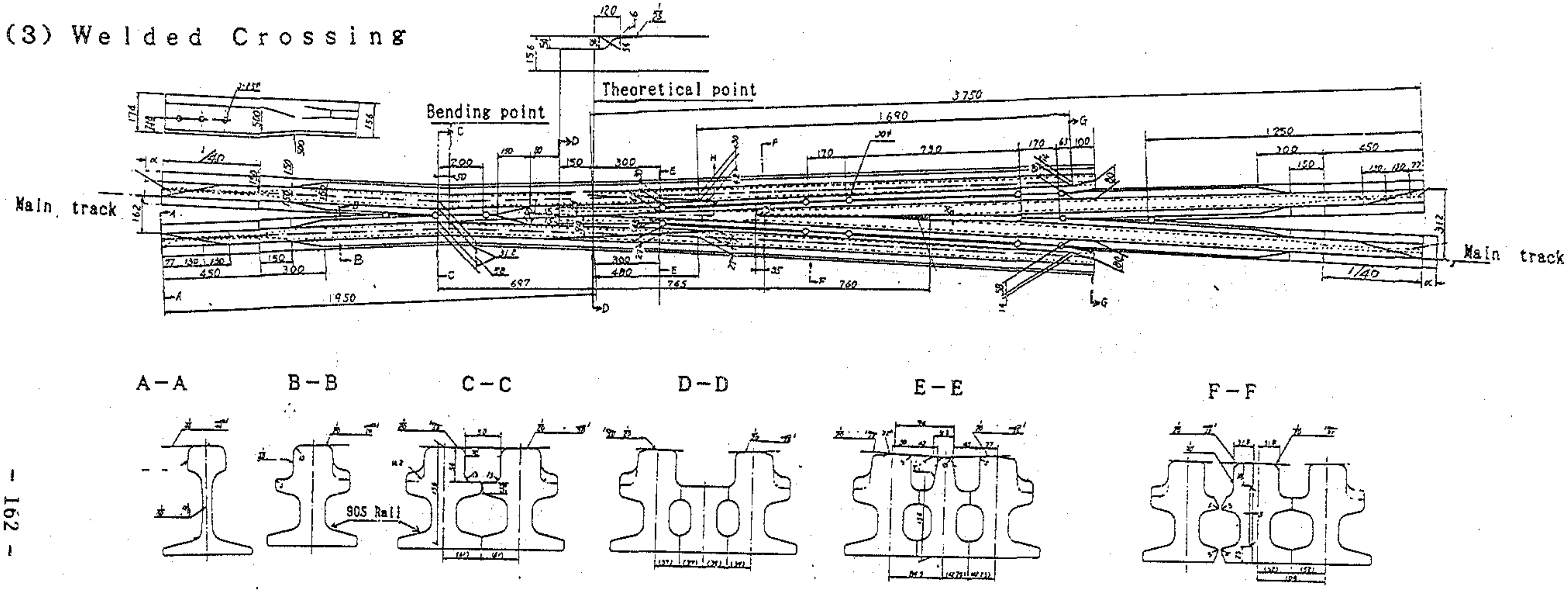
—I— Welded joint

(2) Switch

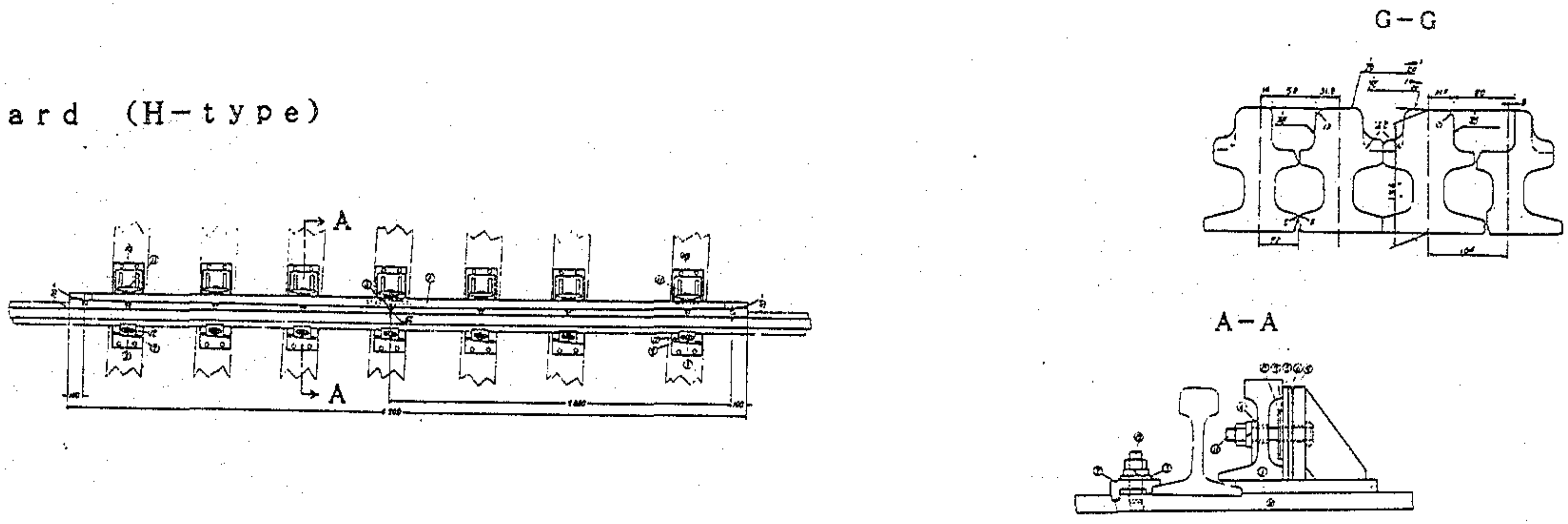




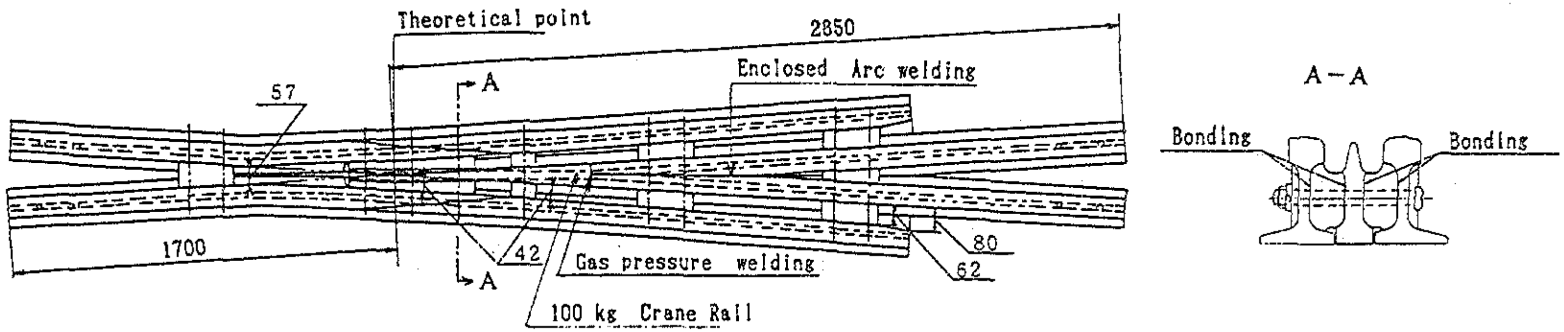
(3) Welded Crossing



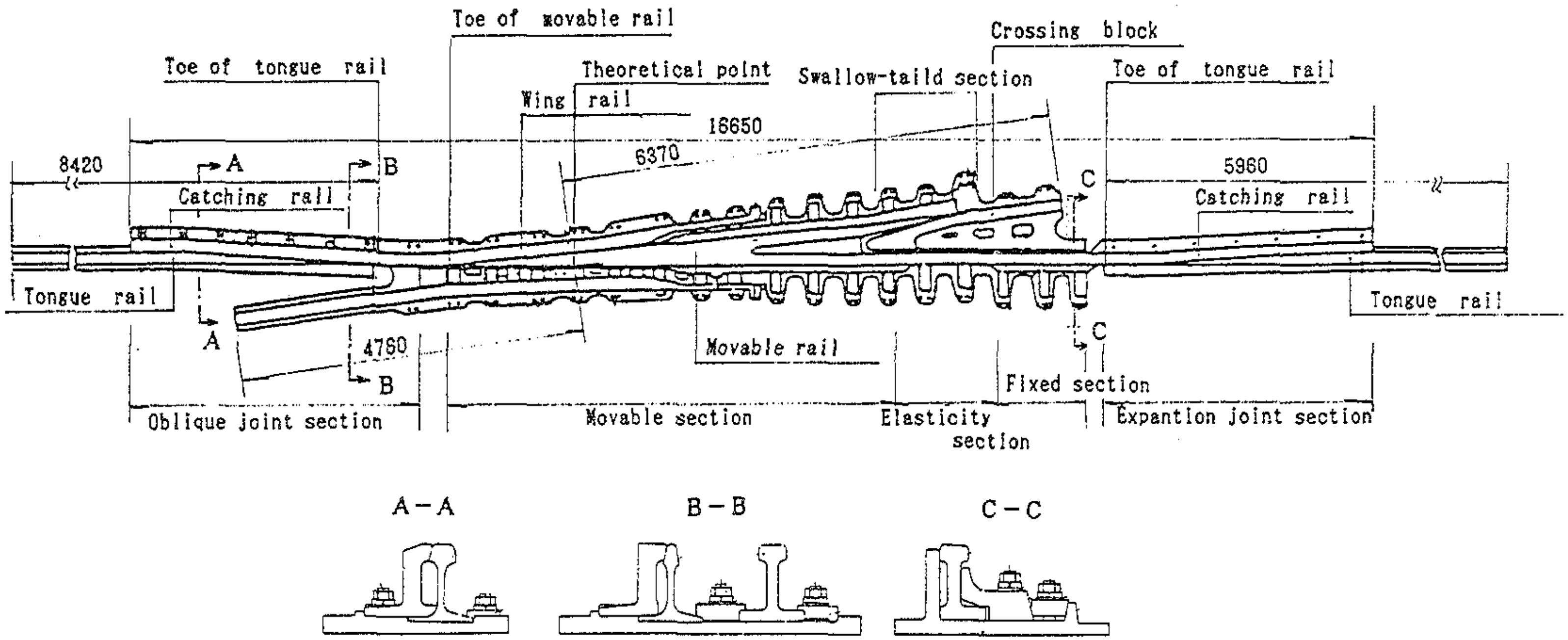
(4) Guard (H-type)



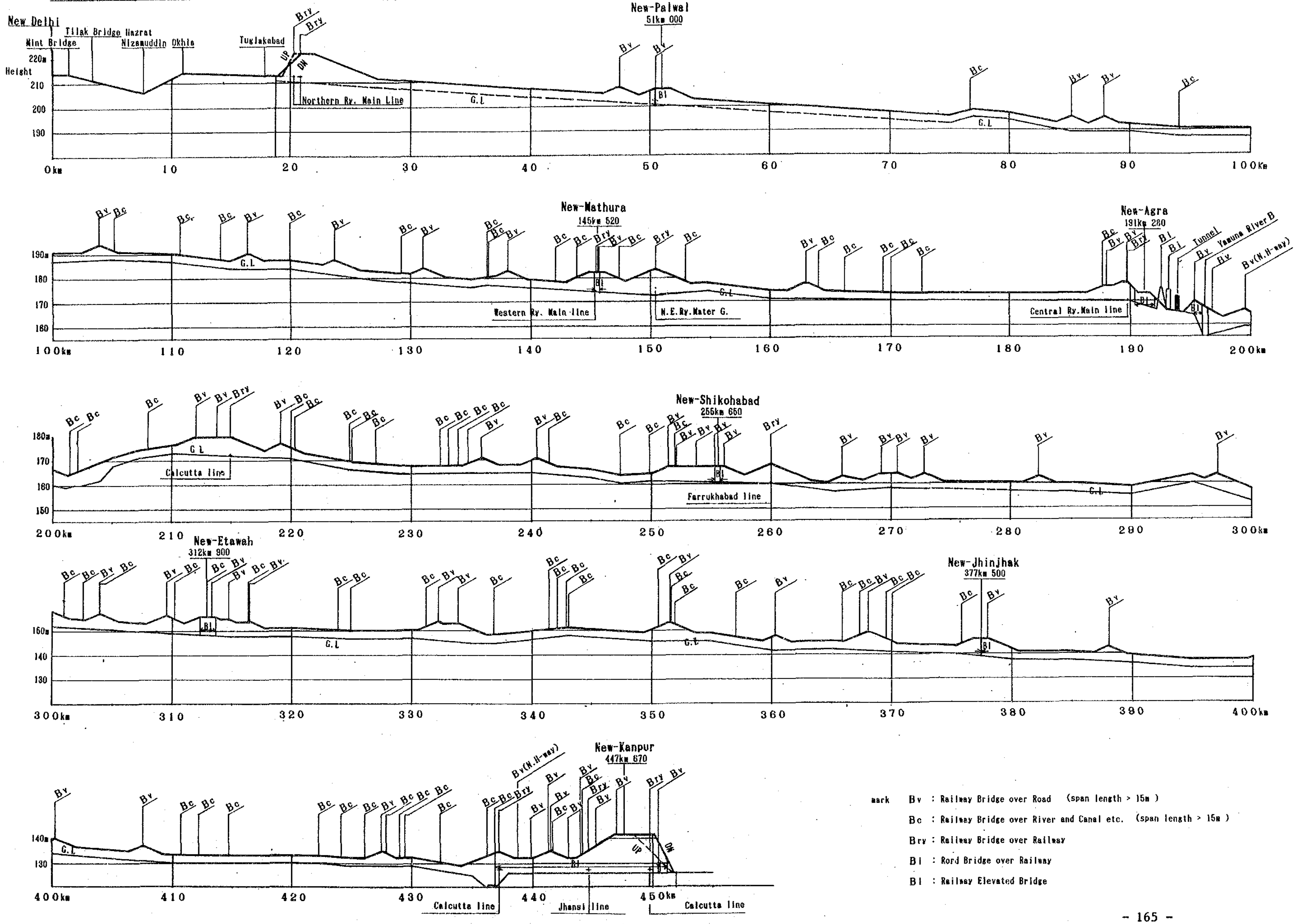
Gas pressure welded Crossing



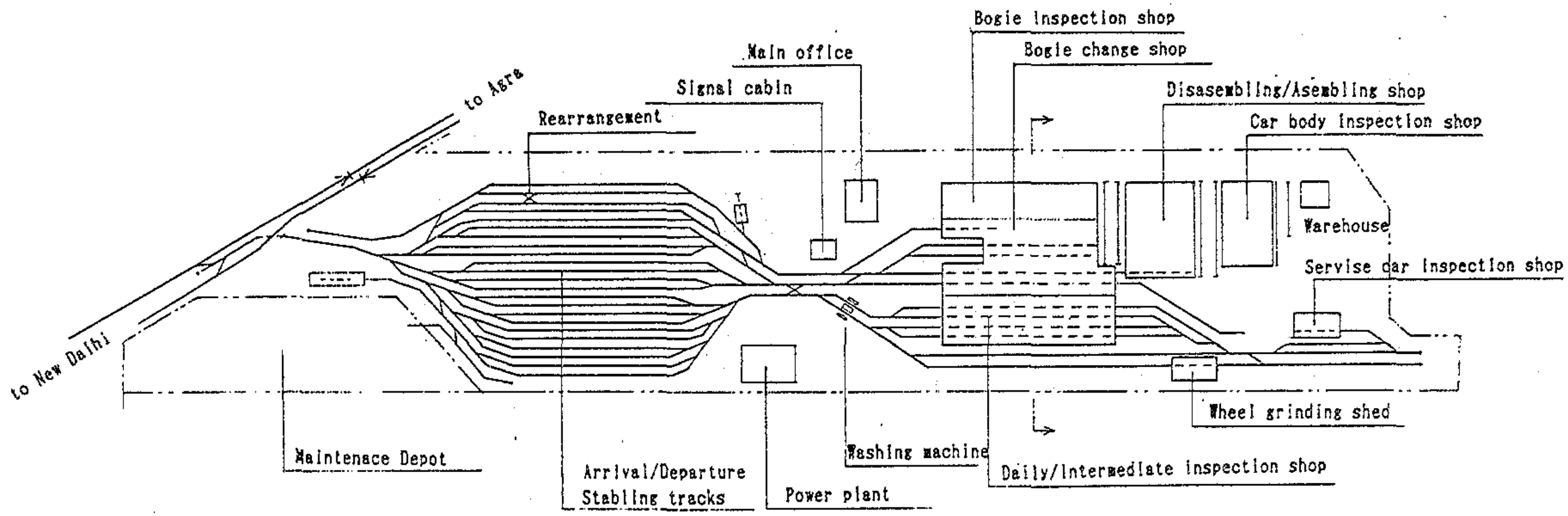
Movable Manganese Steel Crossing

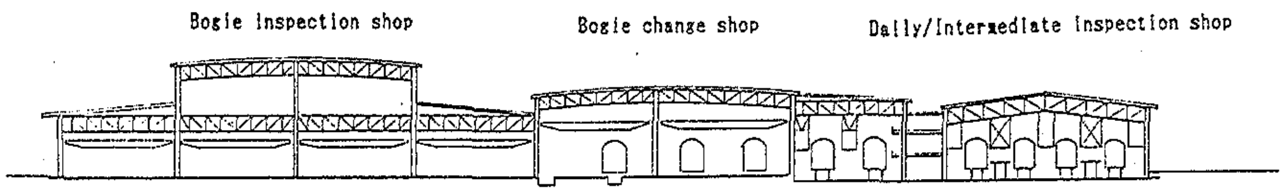


4-18 General Longitudinal Section of the New Corridor



4-19 Outline of Proposed Workshop for the New Corridor





4-20 Track Maintenance Standards in Japan

The maintenance standards in Japan for conventional lines and Shinkansen are as follows.

(1) Conventional lines

Basically the standard values are prepared in the following three steps based on past experience and from the viewpoint of periodical track maintenance and safety in train operation. The standard values for each class of railway are as shown in Table 1.

1) Finishing target values

Finishing target values are standard values below which the tolerances of track repair and new line construction should be kept. By determining the cycle of track destruction from the initial target values to the type B repair & maintenance standard values as per 2) below, periodical repairs can be executed.

2) Type B repair & maintenance standard values

Type B repair & maintenance standard values are mainly for maintaining riding confort and also for making systematic track maintenance. The standard values are determined in such a manner that non-periodical works stipulated in the type C repair & maintenance as per 3) below should not occur very often. More concretely, a test chart is prepared by a high-speed track inspection car for every 500 m, and the maintenance work is made in compliance with the type B standard for the section where a few repair items exceeds the B standards values. (As to gauge irregularities, if the standard values are continuously exceeded for over 30 m in one 500 m section.) Such irregularities are adjusted by way of type B repair & maintenance.

Table 1 Ordinary Track Maintenance Standards (Conventional Line)

Type / Class of railway / Type of track irregularity	Type B repair & maintenance standard values				Type C repair & maintenance standard values				Finishing target value	
									Common to all types of railways	
	Class A	Class B	Class C	Class C simplified railway	Class A	Class B	Class C	Class C simplified railway	Ordinary sections	Concrete ballast section
Track gauge	+10 (+6) -5 (-4)								(+1) (-3)	(0) -3
Cross level of track	11 (7)	12 (8)	13 (9)	16 (11)					(4)	(2)
Track unevenness	13 (7)	14 (8)	16 (9)	19 (11)	23 (15)	25 (17)	27 (19)	30 (22)	(4)	(2)
Track alignment	13 (7)	14 (8)	16 (9)	19 (11)	23 (15)	25 (11)	22 (19)	30 (22)	(4)	(2)
Twist of track					23 (18) (Including reduction of superelevation)				(4) (Not including reduction of superelevation)	

Remarks:
(1) The figures are dynamic values measured by means of the high-speed track inspection & measurement wagon. The figures enclosed with parentheses, however, are static values.
(2) The twist of track indicates the cross level variation throughout a 5 m interval.
(3) The gauge slackening, superelevation and the mid-ordinate (including longitudinal curves) in curved sections are not included.
(4) Side tracks are regarded as equivalent to Class C.

3) Type C repair & maintenance standard values

Type C repair & maintenance are made adjust spot irregularities, to secure safety of train operation. A repair must to be made within 15 days in the case where track irregularity reaches the type C maintenance standard values shown in Table 1, or the progress of track irregularity is particularly rapid although its values are still below the maintenance standard, or a train's motion reaches the values shown in Table 2.

Table 2 Maintenance Standard Values for Train Motion

Species of motion / Measurement of car	Vertical direction	Transversal direction
High speed track inspection car or highly efficient car	One side amplitude 0.13 g	One side amplitude 0.13 g
Other passenger coach	One side amplitude 0.20 g	One side amplitude 0.20 g

The urgent maintenance value of gauge is obtained from the dimensions of wheels and rails considering the maximum width between rails which can support wheels without letting them derail from the gauge, and taking slack and margin in account. Table 3 shows the dimensions.

Table 3 Urgent Maintenance Value of Gauge

Maintenance value / Location	Ordinary section with standard slacks		Section with reduced slacks	
	Dynamic measurement	Stasticical measurement	Dynamic measurement	Stasticical measurement
Straight track or more 600 m curve	20 mm	14 mm	20 mm	14 mm
From 200 m to 600 m curve			25	19
Less 200 m curve	15	9	20	14

4) Compound track irregularity

To prevent derailing of freight trains, the maintenance standard values for compound track irregularity in alignment and cross level are determined as shown in Table 4. (Compound irregularity = alignment - 1.5 x cross level) A compound track irregularity must be adjusted within one month after discovery.

Table 4 Maintenance Standards of Compound Track Irregularity

Item / Class of irregularity	Range of irregularity	Irregularity	
		Value	Number
1	80 m	18 mm	4
2	60 m	21 mm	3
3	30 m	25 mm	2
4	-	35 mm	1

Notes:

- Sections of maximum speed lower than 45 km/h are excluded.
- Irregularity of both rails should be checked. Compound irregularity of both rails located over 10 m apart should be regarded as separate irregularity.

5) Maintenance standard of turnout

a) Gauge of crossing

Ordinary crossing +5 mm, -3 mm High speed crossing ±3 mm

b) Back gauge

i) Turnouts for N rail and 60 kg rail

More than 1,022 mm, less than 1,030 mm

ii) Other turnouts

More than 1,020 mm, less than 1,032 mm

c) Maintenance standards of turnouts for high speed trains running at 120 km/h.

Table 6

Item	Maintenance standard	Remark
1. Contact of stock and switch rail	3 mm less	
2. Flangeway width at switch	65 mm + S more	s: slack (60 kg; 7 mm)
3. Flangeway width at end of guard	56 mm more	
4. Flangeway width at guard	$a_1 + a_2 \geq 84$ mm	a_1; Flangeway width at Guard a_2; Flangeway width at Crossing
5. Difference of rail alignment at rail joint	1 mm less	

d) Other maintenance standards

Other maintenance standard values are based on static standard values of Type B Repair & Maintenance Standard values.

Table 6

(mm)

Class of Railway / Item	Type B repair & maintenance standard values			
	Class-A	Class-B	Class-C	Other
Gauge	+6	-4		
Cross level	7	8	9	11
Unevenness	7	8	9	11
Alignment	7	8	9	11

6) Track inspection system

The cycle and content of track inspection in JR's conventional lines are as shown in Table 7.

Table 7

<table>
<tr><th colspan="2">Inspection item</th><th>Classify</th><th>Inspection cycle
(No. of times/year)</th><th>Content</th></tr>
<tr><td rowspan="4">Track mainte-nance inspec-tion</td><td rowspan="2">Track irregularity inspection</td><td>Ordinary track
(Gauge, Cross level, Unevenness, Alignment, Twist)</td><td>Class A, B 4
Class C, D 2</td><td>. 120 km/h train operating section 6 times/year
. Almost section is measured with the High-Speed inspec-tion Car.</td></tr>
<tr><td>Turnout</td><td>4</td><td>. Manual; Gauge, Cross level, Unevenness, Alignment</td></tr>
<tr><td>Train vibration inspection

Joint clearance inspection

Low rail joint inspection</td><td></td><td>Class A, B 4
Class C, D 2

2

1</td><td></td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="2">Track materials inspec-tion</td><td rowspan="2">Rail inspection</td><td>Ordinary inspection</td><td>1</td><td>State of rail flaw, wear, and erosion</td></tr>
<tr><td>Detail inspection</td><td colspan="2">Inspection with Ultrasonic detector
<table>
<tr><th>Class of Railway</th><th>Ordinary section</th><th>Particular section</th></tr>
<tr><td>A</td><td>1</td><td rowspan="2">1</td></tr>
<tr><td>B</td><td>1</td></tr>
<tr><td>C</td><td>1/2 Year</td><td rowspan="2">1/2 Year</td></tr>
<tr><td>D</td><td>1/3 Year</td></tr>
</table>
Inspection cycle of new rail are able to extend.</td></tr>
<tr><td rowspan="4"></td><td rowspan="3">Turnout inspection</td><td>Ordinary inspection</td><td>1</td><td>State of rail flaw, wear, and erosion</td></tr>
<tr><td>Detail inspection</td><td colspan="2">
<table>
<tr><th>Class of Railway</th><th>Main line and main loop line</th><th>Other loop line</th></tr>
<tr><td>A.B</td><td>1</td><td rowspan="3">1/5 Years</td></tr>
<tr><td>B</td><td>1/2 Years</td></tr>
<tr><td>C</td><td>1/3 Years</td></tr>
</table>
. Eye measurement or color check (Difficult parts for checking are taken apart.)
. The cycle of new rail are able to extend.</td></tr>
<tr><td>Function test</td><td>1/3 month</td><td>Contact of Switch, Back gauge, and other principle parts.</td></tr>
<tr><td>Sleeper, Ballast and Other materials inspection</td><td></td><td>1</td><td>Ballast; mud mixing, insufficiency</td></tr>
</table>

(2) Shinkansen

For safety, riding comfort, and periodical maintenance, the following 4 standard values are determined as shown in Table 8. Shinkansen track inspection is made every 10 days only in dynamic measurement by a high-speed track inspection car. Based on the inspection data, planning, command, and approval of the track maintenance are executed.

1) Finishing target values

Finishing target values, like those for conventional lines, are values below which tolerances for track repair and construction should be kept.

2) Riding comfort target values

The target values have been determined through measurement regarding the shaking of vehicle attributable to track irregularity and riding comfort obtained from the model test section of the Tokaido Shinkansen. The relationship between unevenness irregularity and the corresponding vertical vibration acceleration is as shown in Fig. 1. Accordingly, it is possible to draw the upper limit line of vertical vibration acceleration corresponding to a certain unevenness irregularity. The frequencies of the shaking of vehicle of the Shinkansen are in the ranges of 1 - 2 c/s and 7 - 10 c/s. as shown in Fig. 2, and it is found that the 1-2 c/s vibration is caused from track irregularity.

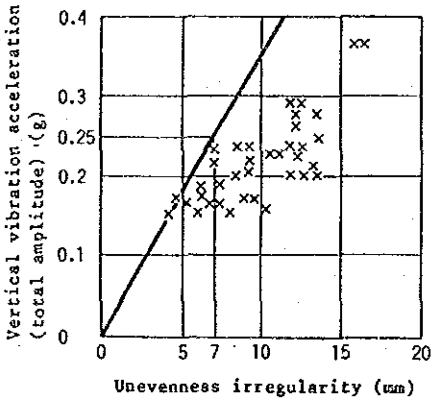


Fig. 1 Relations between Unevenness and Vertical Vibration

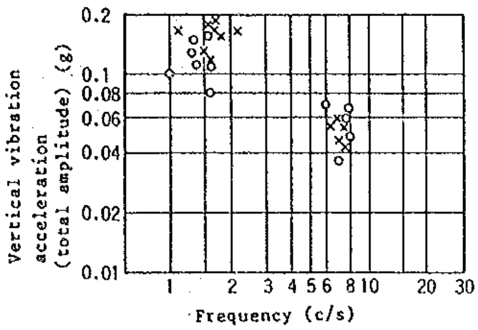


Fig. 2 Frequency of Vertical Vibration and Acceleration

The ride index of the Shinkansen has been designed to be within 1 ∿ 2 from the beginning. To restrict motion of 1 ∿ 2 c/s frequency within ride index of 1 ∿ 2, it is required to keep the vertical vibration acceleration (total amplitude) under 0.25g or so as clearly shown in Fig. 3.

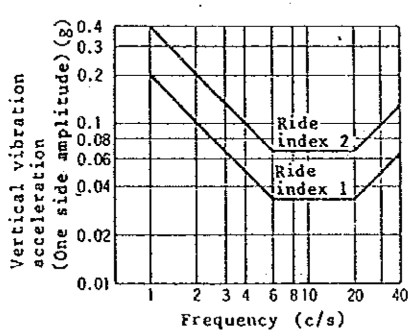


Fig. 3 Vertical Vibration and Riding Comfort

A unevenness irregularity of 7 mm corresponding to vertical vibration acceleration of 0.25g as per Fig. 1 is taken as the target value for riding.

The same study was made on alignment irregularity. The relationship between transversal direction and alignment irregularity is plotted as shown in Fig. 4. To keep the riding comfort from transversal direction under a ride index 1 ∿ 2, it is prescribed to keep the transversal vibration acceleration near 1 ∿ 2 c/s under 0.20g the riding comfort target value at 4 mm.

Since the track maintenance values obtained when the unevenness and the alignment in the model test section was kept under the riding comfort target value were all acceptable, the actual values of the gauge irregularity, cross level irregularity and twist irregularity are taken as riding comfort target values.

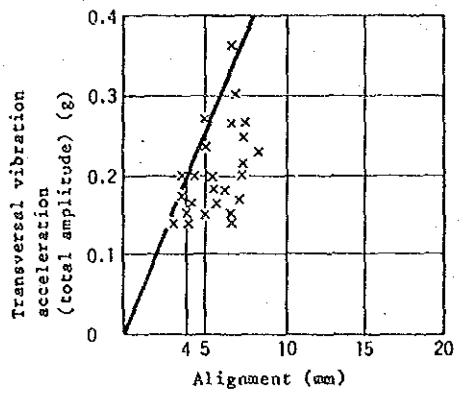


Fig. 4 Relations between Alignment and Transversal Vibration

3) Maintenance planning target values

For execution of track correction work, it is necessary to have standard values determined for the correction work. If the riding comfort target values are taken for the standard values for track adjustment, the riding comfort may be poor until the track is adjusted. To avoid this, to give some margin to the maintenance period, and also to enable the work to progress systematically in a certain range, maintenance planning target values, which are a little tighter than the riding comfort target values, are determined.

4) Safety control target values

Since Shinkansen trains run at extremely high speed, poor riding comfort may give passengers increasing unpleasantness and a feeling of uneasiness. Consequently, if necessary, a slow speed limit is provided to maintain an acceptable level of riding comfort. As a preventive measure to be taken before such a slow speed limit is reached, track irregularities to be corrected are determined by the safety control target values so that urgent adjustments can be made. A serious track irregularities (over 15 mm unevenness, and over 9 mm alignment), for instance, are repaired on the night of the same day in principle.

Table 8 Target Values for Track Control

Type		Unit	Finishing target values (1)	Maintenance planning target values (2)	Riding comfort target values (3)	Safety control target values (4)	Target values for slow running control (5)			
							210 km/h slow running	*160 km/h slow running	*110 km/h slow running	70 km/h slow running
Track irregularity	Unevenness of track	mm/10 m	4	6	7	10	Min. 16 mm	Min. 18 mm (Min. 18 mm)	Min. 23 mm (Min. 22 mm)	Min. 27 mm (Min. 27 mm)
	Track alignment	mm/10 m	3	4	4	6	Min. 9 mm	Min. 10 mm (Min. 10 mm)	Min. 12 mm (Min. 12 mm)	Min. 14 mm (Min. 14 mm)
	Track gauge	mm	±2	+6 -4	+6 -4	+6 -4				
	Cross-level of track	mm	3	5	5	7				
	Twist of track	mm/2.5 m	3	4	5	6				
Acceleration vibration	Vertical direction	g (Total amplitude)		0.25	0.25	0.35	0.45	(0.45)		
	Transversal direction	g (Total amplitude)		0.20	0.20	0.30	0.35	(0.35)		

* Figures enclosed in parentheses refer to the Tokaido and Sanyo Shinkansen lines. In these cases figures contained the "160 km/h" column correspond to 170 km/h and those contained in the "110 km/h" column correspond to 120 km/h speed.

Notes:
1. Finishing target values
   Target values of the finished state, after completion of the work and/or construction.
2. Maintenance planning target values
   Target values to determine places with track irregularity, object of rectification, as basis for drawing up the maintenance plan.
3. Riding comfort target values
   Target values to secure satisfactory riding comfort.
4. Safety control target values
   Target values used for preventive control, before it becomes necessary to carry out a slow running operation.
5. Target values for slow running control
   Target values beyond when it becomes necessary to carry out a slow running operation in order to maintain safety control.

4-21 Progress of Track Breaking

The progress of track breaking varies depending on the passing tonnage, train speed, type of rolling stock, track structure, and road-bed condition.

Related with the future track upgrading between Ghaziabad and Kampur, a calculation is made to estimate to what extent the track breakage will increase owing to the increased passing tonnage and train speed with assumption that the train composition and the road-bed condition will remain as it is.

Formula:

$$S \propto N \cdot M \cdot V^{1.2}$$

where

S: Track breaking progress factor

N: Number of loading = directly proportional to passing tonnage, since the train composition stays unchanged.

M: Track structure index

V: Average train speed

(1) Passing tonnage (both way)

1985: 60.9 GMT

2000: 142.3 GMT

Increase rate in 2000 to 1985: 2.34

(2) Average train speed

A ratio is obtained from maximum speeds and number of various trains.

1985: 1.00

2000: 1.19

(3) Track structure index

1987	Rail:	52 kg/m
	PRC sleeper:	1540 km
	Ballast thickness:	25 cm
2000	Rail:	60 kg/m
	PRC sleeper:	1660 km
	Ballast thickness:	30 cm

Given the current track structure index M = 1.00, the track structure index in 2000 will be improved to M = 0.63. A calculation is shown in Table 1.

(4) Calculation result

Progress of breaking of track in 2000:

$$S \propto 2.34 \times 0.63 \times 1.19^{1.2} = 1.82$$

Even with reinforcement of the track, there will be approximately 80% increase in the track breakage.

Table 1 Track Structure Index

Calculation formula	Present state	Post-improvement
Conditions: Rail PRC sleeper Ballast thickness	52 kg/m 1,540 sleepers/km 25 cm	60 kg/m 1,660 speepers/km 30 cm
Support area on the side of the sleeper $B = \frac{1b\ell}{2} = \frac{1}{2} \times 25 \text{ cm} \times 275$	3,437.5 cm^2	3,437.5 cm^2
Ballast coefficient C, 10 kgf/cm^3 in the case of ballast thickness of 15 cm $C = \alpha/15$	25 cm 16.7 kgf/cm^3	30 cm 20.0 kgf/cm^3
Sleeper compressibility coefficient D1 In the case of PRC sleepers, the elasticity of the pad is 100 tf/cm	100 tf/cm	100 tf/cm
Ballast sinking coefficinet $D_2 = B \times C$	57.4 tf/cm	68.8 tf/cm
Composed spring coefficient $D = I/(1/D_1 + 1/D_2)$	36.5 tf/cm	40.8 tf/cm
Spring coefficient of unit rail support $K = D/a$ a: Sleepers spaces	a = 65 cm K = 561 kgf/cm^2	a = 60 cm K = 680 kgf/cm^2
Rail pressure P $P = 1 - \psi_4(\beta \cdot \frac{a}{2})$ $\beta = \sqrt[4]{K/4ErIr}$ $\psi_4(\beta \cdot \frac{a}{2}) = e^{-\beta \cdot \frac{a}{2}} \cos \beta \cdot \frac{a}{2}$	$\beta = 1.33 \times 10^{-2} cm^{-1}$ $\psi_4(\beta \cdot \frac{a}{2}) = 0.589$ P = 411 kgf	$\beta = 1.27 \times 10^{-2} cm^{-1}$ $\psi_4(\beta \cdot \frac{a}{2}) = 0.634$ P = 366 kgf
Ballast pressure Pb $Pb = \eta \cdot P/B \quad \eta = 1.0$	Pb = 0.120	Pb = 0.106
Supporting mass m Experimentally	PRC sleepers 404 kg	PRC sleepers 463 kg
Ballast acceleration $\ddot{y}$ $\ddot{y} = \sqrt{D_1}/\sqrt{m}$	0.498	0.465
Impact factor S $S = 1/(ErIr\beta^2)$	1.25×10^{-6}	0.955×10^{-6}
Track structure index value $M = Pb \cdot \ddot{y} \cdot S$	0.747×10^{-7}	0.471×10^{-7}
Track structure index ratio	1.00	0.63

4-22 Calculation of the Optimum Rail Structure

A study is made on the most economical track structure in terms of renewal and maintenance costs at the time when the passage tonnage between Ghaziabad and Kanpur increases in the future.

(1) Kinds of track structure

As for the track structure, 9 cases are set as seen in Table 1.

Table 1 Track Structure

Case	Rail (kg/m)	No. of sleeper	Ballast thickness (cm)
1	52	1,540	25
2	52	1,660	30
3	60	1,660	30
4	60	1,740	30
5	60	1,820	30
6	65	1,660	30
7	65	1,820	30
8	75	1,660	30
9	75	1,820	30

(2) Renewal cycle

The renewal cycle is set for accumulated passage tonnage of 500 GMT in the case of 52 kg rail, and 800 GMT in the case of 60 kg rail. The figures for 65 kg and 75 kg rails are calculated on the assumption that they are proportional to the section modulus.

Table 2 Track Renewal Cycle

GMT/Year	52 kg/m	60 kg/m	65 kg/m	75 kg/m
40	12.5	20.0	23.2	29.0
50	10.0	16.0	18.5	23.2
60	8.3	13.3	15.4	19.3
70	7.1	11.4	13.2	16.6
80	6.3	10.0	11.6	14.5
90	5.6	8.9	10.3	12.9
Section modulus	285.5	377.4	436.8	547.3
Passing tonnage for renewal cycle (GMT)	IR Standard 500	IR Standard 800	926	1160

(3) Cost

In conducting the comparative study, a model section with a length of 124 km is set, and the following cost is calculated accordingly.

1) Renewal cost

The renewal cost is divided by the renewal cycle to obtain the per-year figure.

As for interest, average interest during the cycle year are shown in the case of 5% and 8.5% interest rates.

Regarding sleepers, service life is set at 40 years to obtain the per-year figure for the renewal cost involving the interest.

Table 3 Renewal Cost

(lakhs)

Case	Track structure	Rail, ballast		Sleeper	
		Unit price per Km	Renewal cost	Unit price per km	Sleeper cost
1	52 kg rail 1540, 25 cm	13.7	1698.8	8.25	1023.0
2	52 kg 1660, 30 cm	14.2	1760.8	8.90	1103.6
3	60 kg 1660, 30 cm	17.9	2219.6	8.90	1103.6
4	60 kg 1740, 30 cm	18.1	2244.4	9.33	1156.9
5	60 kg 1820, 30 cm	18.2	2256.8	9.76	1210.2
6	65 kg 1660, 30 cm	20.6	2554.4	8.90	1103.6
7	65 kg 1820, 30 cm	20.9	2591.6	9.76	1210.2
8	75 kg 1660, 30 cm	25.1	3112.4	8.90	1103.6
9	75 kg 1820, 30 cm	25.3	3137.2	9.76	1210.2

Unit price

Rail	52 kg 8,900 Rs/ton	Ballast	220 Rs/m^3
	60 kg 10,075 Rs/ton	Sleeper	536 Rs
	65 kg 11,180 Rs/ton	Other material	20 Rs/m
	75 kg 12,300 Rs/ton		

The rate of renewal cost including interest is as shown in Table 4.

Table 4 Rate of Renewal Cost per Year

Case / GMT	52 kg Rail Case-1, 2		60 kg Rail Case-3, 4, 5		65 kg Rail Case-6, 7		75 kg Rail Case-8, 9	
	Renewal cycle	Rate of cost per year	Renewal cycle	Rate of cost per year	Renewal cycle	Rate of cost per year	Renewal cycle	Rate of cost per year
Interest 5%								
40	12.5	0.1069	20	0.0763	23.2	0.0692	29	0.0604
50	10	0.1275	16	0.0891	18.5	0.0804	23.2	0.0692
60	8.3	0.1486	13.3	0.1021	15.4	0.0916	19.3	0.0781
70	7.1	0.1694	11.4	0.1150	13.2	0.1027	16.6	0.0867
80	6.3	0.1879	10	0.1275	11.6	0.1133	14.5	0.0957
90	5.6	0.2078	8.9	0.1402	10.3	0.1246	12.9	0.1044
Interest 8.5%								
40	12.5	0.1258	20	0.0946	23.2	0.0875	29	0.0785
50	10	0.1468	16	0.1077	18.5	0.0988	23.2	0.0875
60	8.3	0.1683	13.3	0.1210	15.4	0.1102	19.3	0.0965
70	7.1	0.1894	11.4	0.1341	13.2	0.1216	16.6	0.1052
80	6.3	0.2083	10	0.1468	11.6	0.1322	14.5	0.1143
90	5.6	0.2282	8.9	0.1596	10.3	0.1439	12.9	0.1233

The cost rate for sleepers is as follows:

5% 0.0506

8.5% ... 0.0686

2) Loss of revenue due to traffic block

The renewal work will be carried out with a 2-hour traffic block time specially set. The loss of revenue during the period will be calculated.

Trains wait at adjacent stations until the block is lifted. Therefore, the marginal time for the arrival and departure is added to the 2 hour loss time.

The time required for the renewal work is 248 days for 124 km at the work enforcement capability of 0.5 km a day.

Table 5 Loss of Train Hours (IR data)

GMT	No. of train (2 hours)	Calculate of train hours	Loss of train hours	Average load per train (in 4-wh.)
40	6	6 x 2 = 12	2976	99
50	8	8 x 2 + 20% = 19	4712	104
60	10	10 x 2 + 30% = 26	6448	107
70	12	12 x 2 + 40% = 34	8432	110
80	14	14 x 2 + 50% = 42	10416	112
90	16	16 x 2 + 60% = 51	12648	114

The loss of revenue can be obtained based on the following formula.

$$\text{Loss of Revenue} = \frac{\text{Loss of train hours}}{\text{Renewal cycle}} \times 30 \text{ km} \times (\text{Average load per train}) \times 2.60 \text{ Rs/wagon.km}$$

The results of the computation for the 52 kg rail are shown in Table 6.

Table 6 Loss of Revenue due to Traffic Block

GMT	Renewal cycle	Train hour lost per year	WGN kms lost per year ($\times 10^3$)	Loss of revenue (lakhs)	Remark
40	12.5	238.1	707.1	18.4	2.6 Rs/WGN.kms
50	10	471.2	1,470.1	38.2	
60	8.3	776.9	2,493.7	64.8	
70	7.1	1,187.6	3,919.1	101.9	
80	6.3	1,653.3	5,555.1	144.4	
90	5.6	2,258.6	7,724.4	200.8	

3) Loss due to speed restriction

During the renewal work period, speed restriction of all trains is necessary at work sections. The total number of speed-restricted days will be the total number of work days plus 6 days, totalling 254 days for this section. The loss time is assumed to be 36 minutes for each train (according to IR data). The loss of revenue for freight trains is calculated on this basis.

Table 7 Train Hours Lost per Renewal by Speed Restriction

GMT	No. of goods trains	Train hours lost per renewal	Remark
40	30	4572 hours	30x36'x254 days
50	36	5486	
60	43	6553	
70	49	7468	
80	55	8382	
90	61	9296	

The loss of revenue is calculated through the same formula as in 2).

4) Maintenance cost

The maintenance cost is obtained through calculation based on the following formula using the current cost of 30,000 Rs/km.Year (Rail structure: 52 kg rail, 1,540 sleepers and ballast 'thickness' of 25 cm).

$$S \propto N \cdot M$$

S: Maintenance volume
N: Passing tonnage
M: Track structure index

The Track Structure Index (M) for each rail structure is obtained through calculation as shown in Appendix 4-21. The results of the calculation are shown in Table 8.

Table 8 Track Structure Index

Case	Track structure			M value	M ratio
	Rail	Sleeper	Ballast		
1	52	1540	25	0.747×10^{-7}	1.00
2	52	1660	30	0.610×10^{-7}	0.82
3	60	1660	30	0.473×10^{-7}	0.63
4	60	1740	30	0.452×10^{-7}	0.60
5	60	1820	30	0.429×10^{-7}	0.57
6	65	1660	30	0.422×10^{-7}	0.56
7	65	1820	30	0.385×10^{-7}	0.52
8	75	1660	30	0.354×10^{-7}	0.47
9	75	1820	30	0.318×10^{-7}	0.43

With regard to the maintenance cost, 30,000 Rs/km is set as a minimum cost.

(4) Computation results

Table 9 Total Renewal Cost and Maintenance Cost (Interest 5%)

(lakhs)

Classification / Cost item / GMT	Case 1 52 kg 1540			M=1.00 25 cm		Case 2 52 kg 1660			M=0.82 30 cm		Case 3 60 kg 1660			M=0.63 30 cm	
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	233.4	18.4	28.2	37.2	317.2	244.0	18.4	28.2	37.2	327.8	225.2	11.5	17.7	37.2	291.6
50	268.4	38.2	44.5	46.5	397.6	280.3	38.2	44.5	38.1	401.1	253.6	23.9	27.8	37.2	342.5
60	304.2	64.8	65.9	55.8	490.7	317.5	64.8	65.9	45.8	494.0	282.4	40.5	41.1	37.2	401.2
70	339.6	101.9	90.2	65.1	596.8	354.1	101.9	90.2	53.4	599.6	311.1	63.5	56.2	41.0	471.8
80	371.0	144.4	116.2	74.4	706.0	386.7	144.4	116.2	61.0	708.3	338.8	91.0	73.2	46.8	549.8
90	404.8	200.8	147.6	83.7	836.9	421.7	200.8	147.6	68.6	838.7	367.0	126.4	92.9	52.7	639.0
Classification / Cost item / GMT	Case 4 60 kg 1740			M=0.60 30 cm		Case 5 60 kg 1820			M=0.57 30 cm		Case 6 65 kg 1660			M=0.56 30 cm	
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	229.7	11.5	17.7	37.2	296.1	233.4	11.5	17.7	37.2	299.8	232.6	9.9	15.2	37.2	294.9
50	258.5	23.9	27.8	37.2	347.4	262.3	23.9	27.8	37.2	351.2	261.2	20.7	24.1	37.2	343.2
60	287.7	40.5	41.1	37.2	406.5	291.6	40.5	41.1	37.2	410.4	289.8	34.9	35.5	37.2	397.4
70	316.6	63.5	56.2	39.7	476.0	320.7	63.5	56.2	37.2	477.6	318.1	54.8	48.5	37.2	458.6
80	344.7	91.0	73.2	45.4	554.3	348.9	91.0	73.2	42.4	555.5	345.2	78.4	63.1	41.6	528.3
90	373.2	126.4	92.9	51.1	643.6	377.6	126.4	92.9	47.7	644.6	374.1	109.2	80.3	46.8	610.4
Classification / Cost item / GMT	Case 7 65 kg 1820			M=0.52 30 cm		Case 8 75 kg 1660			M=0.47 30 cm		Case 9 75 kg 1820			M=0.43 30 cm	
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	240.5	9.9	15.2	37.2	302.8	243.8	7.9	12.2	37.2	301.1	250.7	7.9	12.2	37.2	308.0
50	269.5	20.7	24.1	37.2	351.5	271.2	16.5	19.2	37.2	344.1	278.3	16.5	19.2	37.2	351.2
60	298.6	34.9	35.5	37.2	406.2	298.9	27.9	28.3	37.2	392.3	306.2	27.9	28.3	37.2	399.6
70	327.4	54.8	48.5	37.2	467.9	325.6	43.6	38.6	37.2	445.0	333.2	43.6	38.6	37.2	452.6
80	354.8	78.4	63.1	38.6	534.9	353.7	62.8	50.5	37.2	504.2	361.4	62.8	50.5	37.2	511.9
90	384.1	109.2	80.3	43.4	617.0	380.7	87.2	64.1	39.4	571.4	388.7	87.2	64.1	37.2	577.2

Table 10 Total Renewal Cost and Maintenance Cost (Interest 8.5%)

(lakhs)

Classification / Cost item / GMT	Case 1 52 kg 1540		M=1.00 25 cm			Case 2 52 kg 1660		M=0.82 30 cm			Case 3 60 kg 1660		M=0.63 30 cm		
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	283.9	18.4	28.2	37.2	367.7	297.2	18.4	28.2	37.2	381.0	285.7	11.5	17.7	37.2	352.1
50	319.6	38.2	44.5	46.5	448.8	334.2	38.2	44.5	38.1	455.0	314.8	23.9	27.8	37.2	403.7
60	356.1	64.8	65.9	55.8	542.6	372.0	64.8	65.9	45.8	548.5	344.3	40.5	41.1	37.2	463.1
70	392.0	101.9	90.2	65.1	649.2	409.2	101.9	90.2	53.4	654.7	373.3	63.5	56.2	41.0	534.0
80	424.1	144.4	116.2	74.4	759.1	442.5	144.4	116.2	61.0	764.1	401.5	91.0	73.2	46.8	612.5
90	457.9	200.8	147.6	83.7	890.0	477.5	200.8	147.6	68.6	894.5	429.9	126.4	92.9	52.7	701.9

Classification / Cost item / GMT	Case 4 60 kg 1740		M=0.60 30 cm			Case 5 60 kg 1820		M=0.57 30 cm			Case 6 65 kg 1660		M=0.56 30 cm		
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	291.6	11.5	17.7	37.2	358.0	296.5	11.5	17.7	37.2	362.9	299.2	9.9	15.2	37.2	361.5
50	321.0	23.9	27.8	37.2	409.9	326.1	23.9	27.8	37.2	415.0	328.1	20.7	24.1	37.2	410.1
60	350.9	40.5	41.1	37.2	469.7	356.0	40.5	41.1	37.2	474.8	357.2	34.9	35.5	37.2	464.8
70	380.3	63.5	56.2	39.7	539.7	385.6	63.5	56.2	37.2	542.5	386.3	54.8	48.5	37.2	526.8
80	408.8	91.0	73.2	45.4	618.4	414.3	91.0	73.2	42.4	620.9	413.4	78.4	63.1	41.6	596.5
90	437.5	126.4	92.9	51.1	707.9	443.2	126.4	92.9	47.7	710.2	443.3	109.2	80.3	46.8	679.6

Classification / Cost item / GMT	Case 7 65 kg 1820		M=0.52 30 cm			Case 8 75 kg 1660		M=0.47 30 cm			Case 9 75 kg 1820		M=0.43 30 cm		
	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total	Renewal cost	Loss of revenue (Block)	Loss of revenue (speed rest-ricted)	Mainte-nance cost	Total
40	309.8	9.9	15.2	37.2	372.1	320.0	7.9	12.2	37.2	377.3	329.3	7.9	12.2	37.2	386.6
50	339.1	20.7	24.1	37.2	421.1	348.0	16.5	19.2	37.2	420.9	357.5	16.5	19.2	37.2	430.4
60	368.6	34.9	35.5	37.2	476.2	376.0	27.9	28.3	37.2	469.4	385.7	27.9	28.3	37.2	479.1
70	398.1	54.8	48.5	37.2	538.6	403.1	43.6	38.6	37.2	522.5	413.0	43.6	38.6	37.2	532.4
80	425.6	78.4	63.1	38.6	605.7	431.4	62.8	50.5	37.2	581.9	441.6	62.8	50.5	37.2	592.1
90	455.9	109.2	80.3	43.4	688.8	459.5	87.2	64.1	39.4	650.2	469.8	87.2	64.1	37.2	658.3

According to the computation results, the combination of 60 kg rail, 1,660 sleepers, and 30 cm ballast is most economical in the case of up to 50 GMT for interest of 5% and up to 70 GMT for interest of 8.5%. In the case of a greater GMT, the combination of 75 kg rail, 1,660 sleepers and 30 cm ballast thickness is most economical. No superiority in the case of 65 kg rail is found. (Fig. 1)

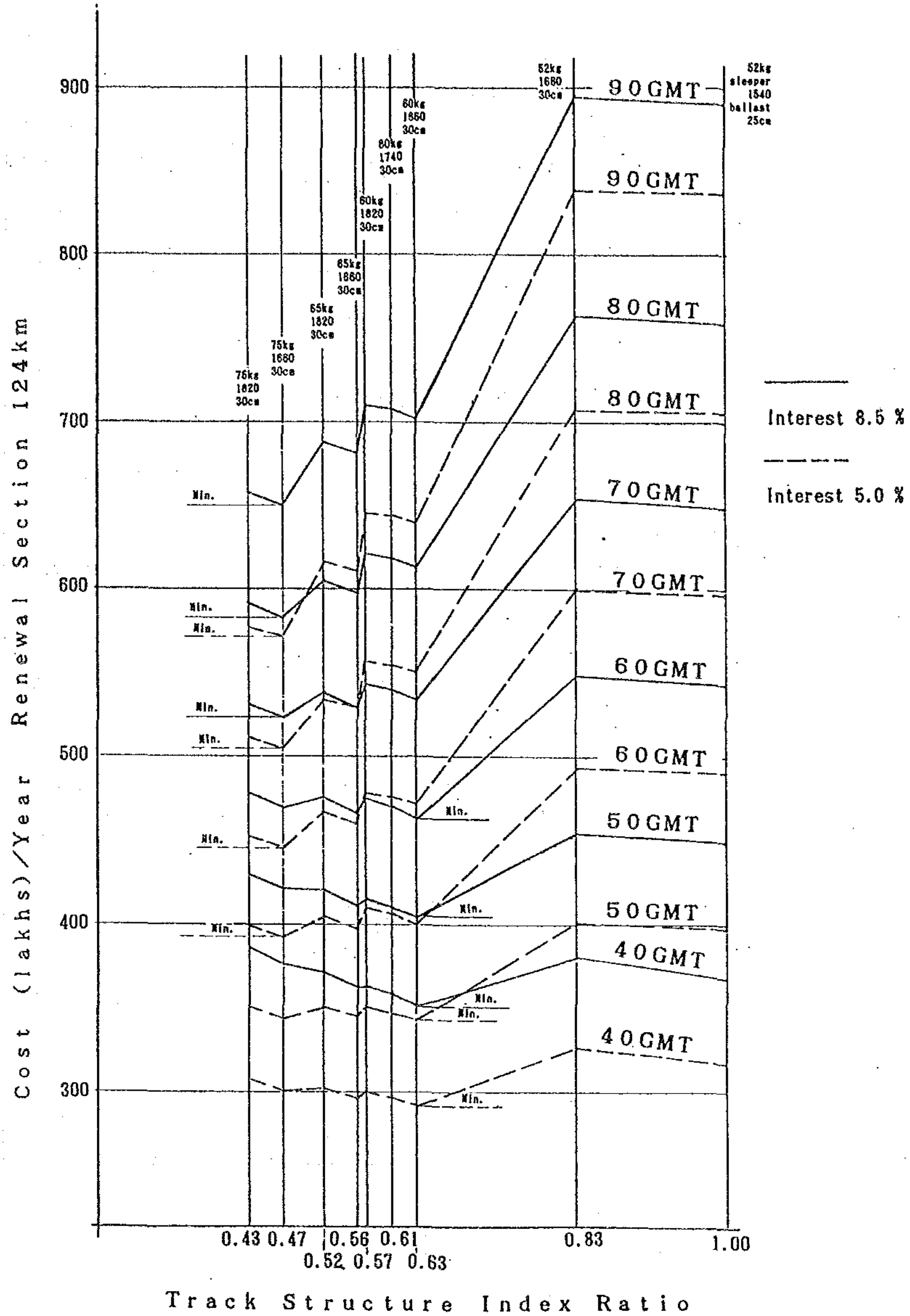


Fig. 1 The Relation between Track Structure and Total Cost

(Reference)

Renewal Cost per KM

(lakhs)

Case	Rail	Ballast 1/2 addition	Other materials	Labor, machine, etc.	Total	Sleeper cost
Case-1 52 kg 1540, 25cm	9.26	2.17	0.2	2.1	13.7	8.254
Case-2 52 kg 1660, 30cm	9.26	2.41	0.2	2.3	14.2	8.898
Case-3 60 kg 1660, 30cm	12.09	2.41	0.2	3.2	17.9	8.898
Case-4 60 kg 1740, 30cm	12.09	2.39	0.2	3.4	18.1	9.326
Case-5 60 kg 1820, 30cm	12.09	2.38	0.2	3.5	18.2	9,755
Case-6 65 kg 1660, 30 cm	14.53	2.41	0.2	3.5	20.6	8,898
Case-7 65 kg 1820, 30cm	14.53	2.38	0.2	3.8	20.9	9,755
Case-8 75 kg 1660, 30cm	18.45	2.41	0.2	4.0	25.1	8.898
Case-9 75 kg 1820, 30cm	18.45	2.38	0.2	4.3	25.3	9,755

4-23 . Maintenance Work System in JR

(1) Outline

In Japan, track maintenance work is carried out under the system shown in Fig. 1. Correction of track irregularities is fundamentally taken care of under T.T.M.

Maintenance of way depot

Maintenance of way branch depot. (2 ∿ 3 depots)

Inspection group (3 ∿ 4 Groups) | Mechanical group (1 ∿ 2 parties)

Maintenance of way depot mainly handles approximately 120 km (single track) areas, mainly conducting desk work incluidng work schedule formulation, control, and operation of maintenance machinery and conclusion of maintenance work contracts.

Actual maintenance work is the responsibility of the maintenance of way branch depots.

Particularly in the maintenance work, the working schedule is formulated with emphasis placed on high-speed track inspection cars, and active work mainly be means of T.T.M. is carried out by the mechanical group.

Accordingly, one T.T.M. is assigned to the mechanical group of each maintenance of way branch depot. In order to raise the working efficiency of the T.T.M., stabling track is laid in station compounds at the intervals of 4 ∿ 5 km.

The actual work of the maintenance of way branch depot will be explained hereinunder.

(2) Work of model depot

1) Area of maintenance and state of transportation

a) Operating km — 20 km (double track km)

Track km	Main line	39.5 km	(60 kg Rail PRC 1760 Ballast 25 cm)
	Sub-main line	6.8 km	
	Loop line	1.3 km	
	Total	47.6 km	
No. of turnouts		55	

b) Number of trains and annual passing tonnage

146 down trains including 40 freight trains
144 up trains including 42 freight trains

Passed tonnage	Down	32.1 GMT
	Up	31.9 GMT

2) No. of maintenance workers

Maintenance of way branch depot 5 members
- 4 inspection groups 18 members (intervals of about 5 km)
- 1 mechanical group 14 members (one T.T.M. operating by 2 parties)

Total 37 members

In addition, an average of 60 private contract workers are engaged in the work daily.

3) Inspection and maintenance work

The work volume of the maintenance of way branch depot is as follows:

a) Content of work by the inspection group

Table 1

Work item	Ratio (%)	Remark
1) Maintenance inspection		
- Track irregularity inspection	3	6 times per year
- Rail joint clearance inspection	3	Jointed rail; Spring, Autumn CWR 4 times
2) Materials inspection		
- Rail	1	Once per year
- Turnout	8	4 times per year
- Other materials	3	
3) Patrol on foot or by train	27	
4) Supervision and investigation	16	
5) Precaution	5	
6) Manual maintenance work	34	
Total	100	

b) Content of work by the mechanical group

Table 2

Work item	Ratio (%)	Remark
1) T.T.M. work	46	
2) Manual maintenance work	19	
3) Carrying materials	13	
4) Repair of machine	9	
5) Supervision and investigation	11	
6) Other	2	
Total	100	

c) Maintenance work volume

Table 3

(1987 schedule)

Work item	Work volume per year			Remark
	Direct	Contract	Total	
1) T.T.M. work	57,100m	0	57,100m	1.4 times/year Also engaged in work at other sections 18,500 m in length
2) Correction of gauge	3,490m	0	3,490m	Manual work
3) Raising of the track	2,260m	0	2,260m	Manual work
4) Lining alignment	3,650m	1,200m	4,850m	Manual work
5) Adjustment of joint	1,980m	4,000m	5,980m	Manual work
6) Refastening-down		380m	380m	Manual work
7) Tie-tamping (hand type)	670m	4,800m	5,470m	
8) Ballast trimming		57,100m	57,100m	After T.T.M.
9) Repair of fastening	5,524m	20,000m	25,524m	
10) Addition of ballast	0	3,027m^3	3,027m^3	63.6m^3/Km

4) Methods of various maintenance work

a) Overall ballast tamping and raising of the track

The places for tamping and raising by means of T.T.M. -- which is the most important track maintenance work -- for the month are decided on the basis of the data collected by the high-speed track inspection car run 6 times a year.

The T.T.M. work done on the section in 1986 amounted to 129 times covering a total track length of 61,542 m. An average of 1.5 tampings were carried out for the entire line, maintaining a good track condition.

The T.T.M. work in the Maintenance of way branch depot was carried out for an average of 477 meters in a 2-hour maintenance block at night daily.

The stabling track capable of accommodating the T.T.M. is laid every 4 km on average in the area covered by the Maintenance of way branch depot. In conducting the work, the T.T.M. is driven to the nearest stabling line in advance so that the maintenance block can be utilized to the greatest possible degree. The rate of operation of the T.T.M. is 56% -- 129 actually-operated days in relation to 230 days available for such work annually -- with sufficient room thus secured.

Manual maintenance work not using the T.T.M. is executed during the daytime train block. Movement of workers and transportation of equipment are enforced by means of vehicles on road.

b) Ballast renewal and slow train operation

In the case that ballast is aggravated in Japan, screening of ballast is not conducted and renewal of ballast is carried out instead. The latter method is generally to renew the ballast for 1 ∿ 2 sleepers in the maintenance block or train block, solidity the ballast.

Sufficiently with tie tampers and adjust tracks to the fixed standard values. Accordingly, slow train operation is carried out only during the work period, with normal operation speed restored following the end of the work.

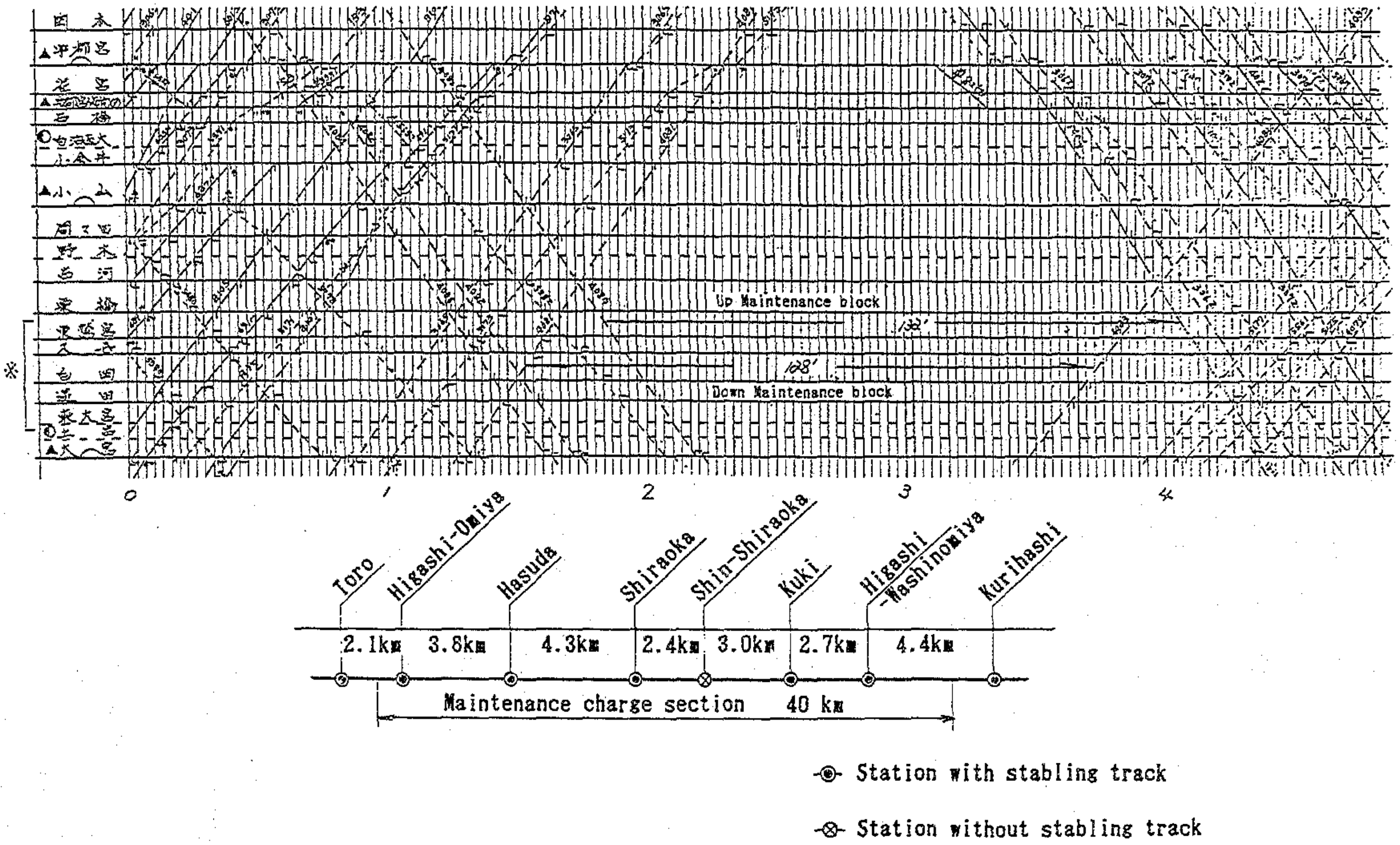
5) Main fitting machinery and equipment

The main fitting machinery and equipment are as shown in Table 4.

Table 4

Sort	No.	Sort	No.
T.T.M.	1	Tie-tamper (Hand type)	18
Track mortor car	2	Portable grinding machine	1
Various automobile	7	Ultrasonic detector	1
Ballast sweeper	1	Various measuring instrument	-
Various trolly	6	Various maintenance tool	-
Rail carrier	4		
Portable engine generator	8		

Maintenance Block on Tohoku Line



4-24 Improvement of Insulation Characteristics of the P.S.C. Sleeper

1. Background

In IR, insulation of a P.S.C. sleeper is secured by the liner of the rail fastening device.

However, the resistance of the insulating liner varies over a wide range due to damage and weather conditions.

Therefore, it is necessary to improve the insulation characteristics inside the P.S.C. sleepers in order to always keep the leakage conductance of track circuit within the standard value.

2. Improved Method (Refer to Appendix 4-16)

For reference, in Japan, the plug of the fastening is covered with such insulating material as polyester resin strengthened by nylon fiber so that the value of insulation resistance in the sleeper is kept infinite, thus eliminating the necessity of insulating liner.

5-1 80 Hz AC Code Track Circuit System

a) Abstract

The 80 Hz AC code track circuit system, applicable to non-electrified as well as electrified section, is capable of long control length of track circuit, signal transmission to cab, and multiple aspect signal indication, and has a good train shunting sensitivity. To secure the anti-interference characteristic against return current from motive units, low-frequency amplitude modulation is applied for the 80 Hz carrier frequency.

The construction and the applicable conditions for the 80 Hz AC code track circuit are shown in Fig. 1 and Table 1, respectively.

b) Main features

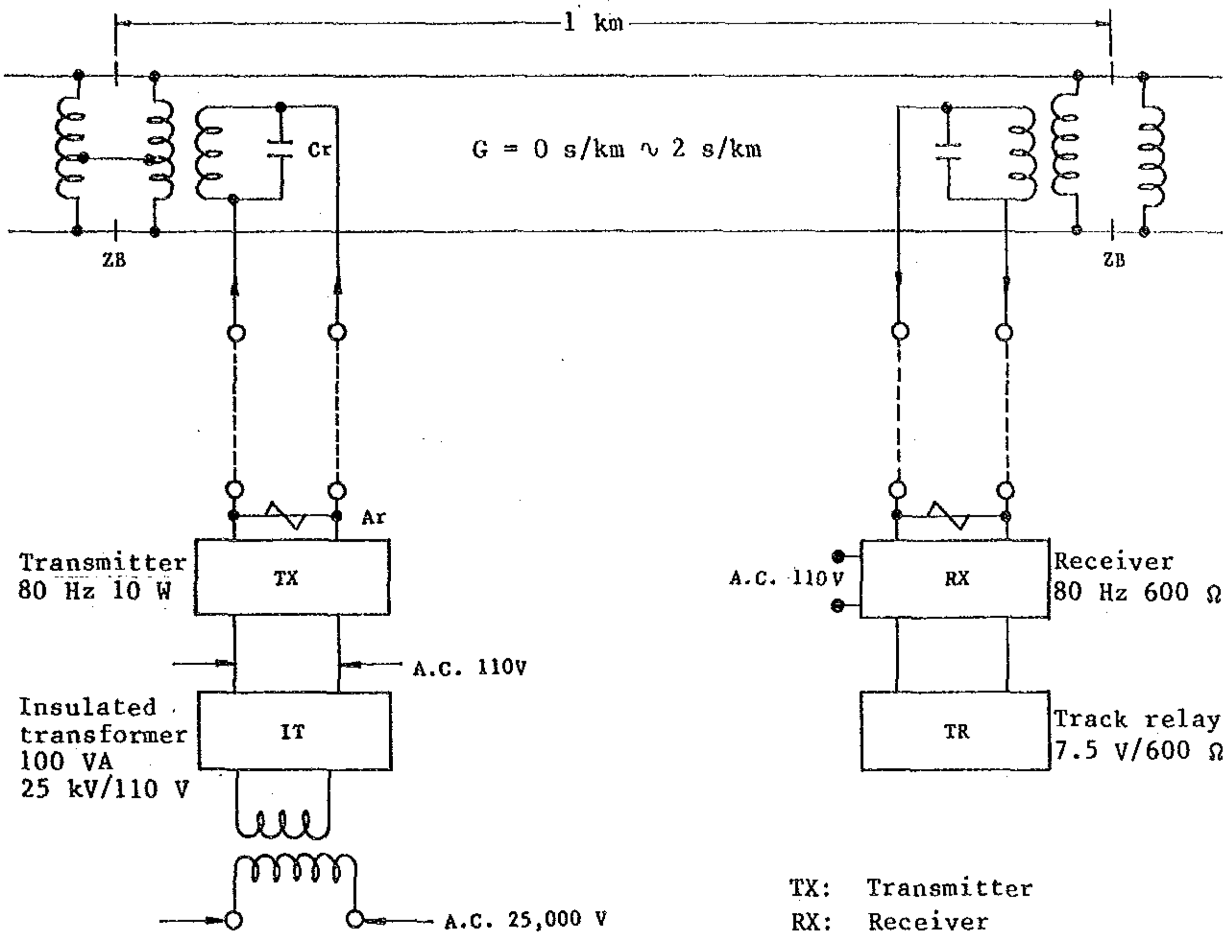
. Under bad track conditions (with leakage conductance 0 ∿ 2 s/km), a shunting sensitivity of 0.5 ohms, and a control length of track circuit of 1,000 m can be secured. (Refer to Fig. 2)

. Cab signal or ATC is available.

. Max. 4 signal aspect indication is possible.

. Under the non-concentrated device system, conditions of forward track circuit can be indicated without their cable transmission.

. The anti-interference characteristics are improved by separating the carrier frequency from the fundamental and high harmonics of the traction current.



TX: Transmitter
RX: Receiver
TR: Track Relay
IT: Insulated Transformer
ZB: Impedance Bond
Ar: Arrester
Cr: Resonance Capacitor

Fig. 1 80 Hz AC Code Track Circuit Configuration

Table 1 Major Characteristics of LF Code Track Circuit (80 Hz)

Items	Conditions
Classification of electrification	A.C.
Variable range of leakage conductance	0 ∿ 2 s/km
Control length of track circuit	Max. 1 km
Shunting sensitivity	0.5 ohms
Max. traction current	800 A
Allowable interference current	50 Hz 40 A 80 Hz 50 mA
Rail breakage detection	Possible
Non-insulation	Difficult (Boundary is not sharp.)
Concentration of devices	Possible
Number of signal aspect indication	4 aspect
Transmission of multiple information to the cab	Possible
Type of impedance bond	Resonance type with external condensor
Surrounding temperature range	-10°C ∿ 70°C
Humidity	$\leqq$ 95% (45°C)
Power source	A.C. 110 V (90V∿120 V) D.C. 24 V ± 10%

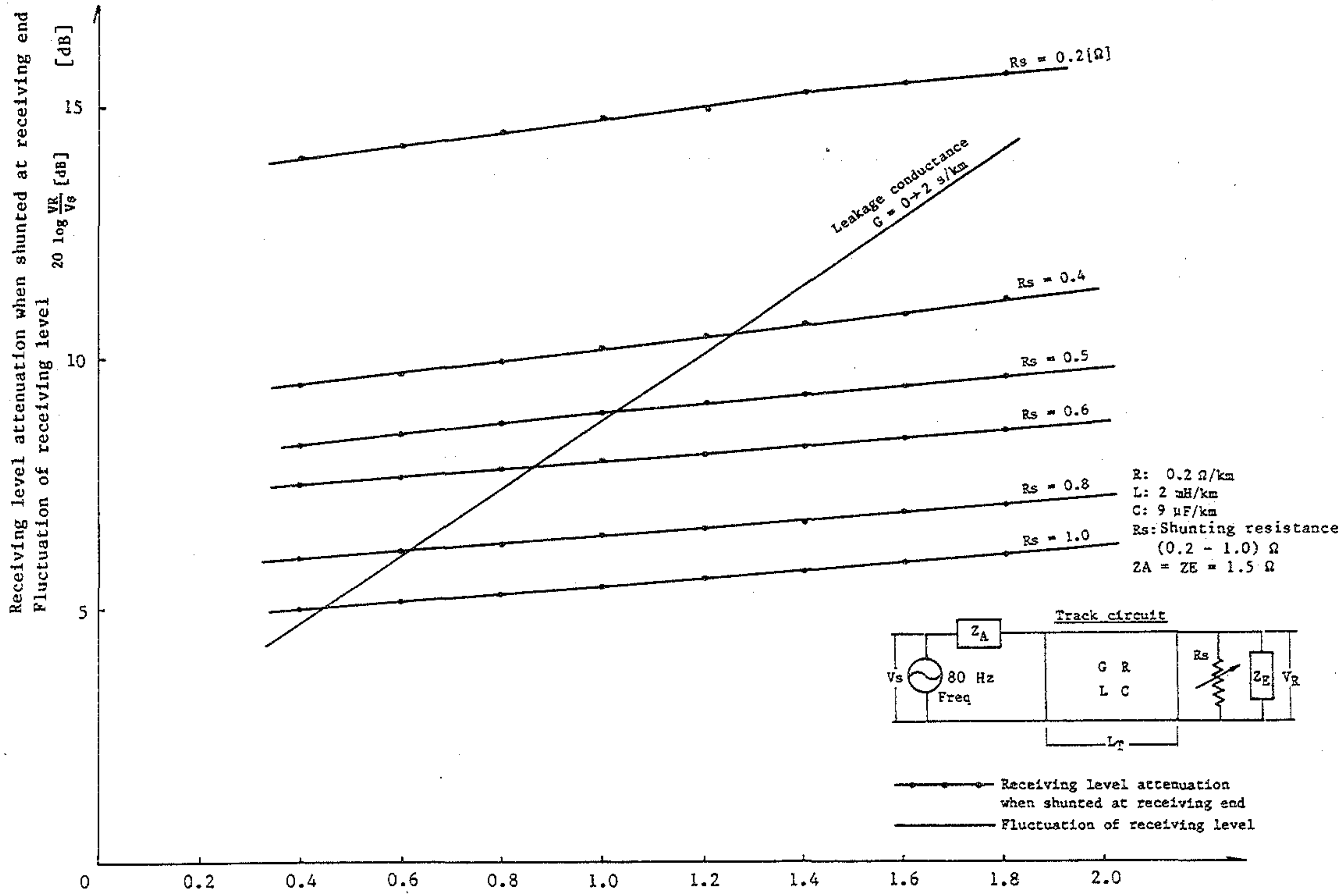


Fig. 2 Fluctuation of Receiving Level & Receiving Level Attenuation When Shunted at Receiving End (Normal Condition G = 0 s/km)

5-2 Design of the Jointless A.F. Track Circuit

a) Conditions for track circuit

Items	Conditions
Classification of electrification	A.C.
Variable range of leakage conductance	0 ∿ 0.5 s/km
Max. control length of track circuit	1.2 km * with end sending
Shunting sensitivity	0.5 ohms
Max. overlap section	100 m
Max. value of traction current	A.C. 800 A
Allowable harmonics interference current	$6/_{f}1.65$(A) ** f: kHz
Unbalanced current factor	≦ 5%
Rail breakage detection	Possible
Range of device concentration	Within 5 km
Number of signal aspect indication	Max. 6 aspect
Pararell condensor	None

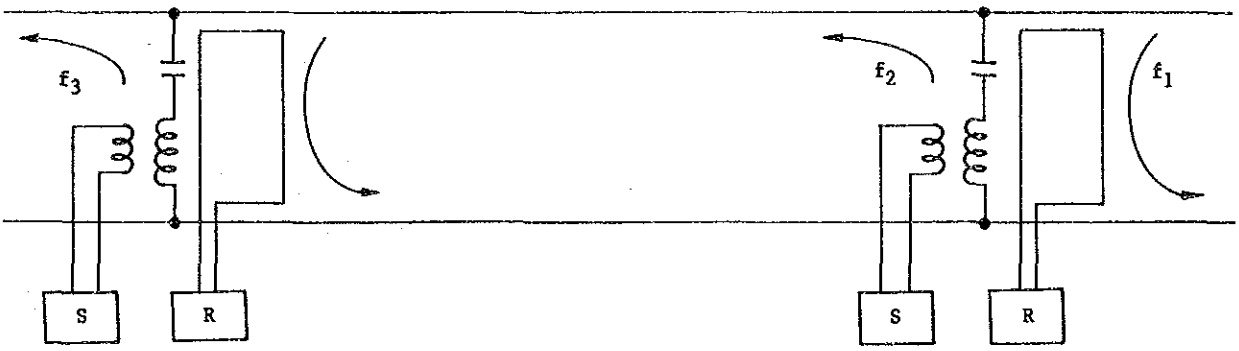
* Refer to Fig. 1

** Refer to Fig. 4

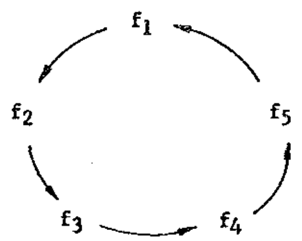
b) Environment conditions

Items	Conditions
Surrounding temperature range	-10°C ∿ 70°C
Humidity	$\leqq$ 95% (45°C)
Power source	A.C. 110 V (90 V∿120 V) D.C. 24 V $\pm$ 10%

c) Configuration



Cyclic combination of frequency



S Transmitter: Voltage sending

R Receiver : Voltage & current receiving

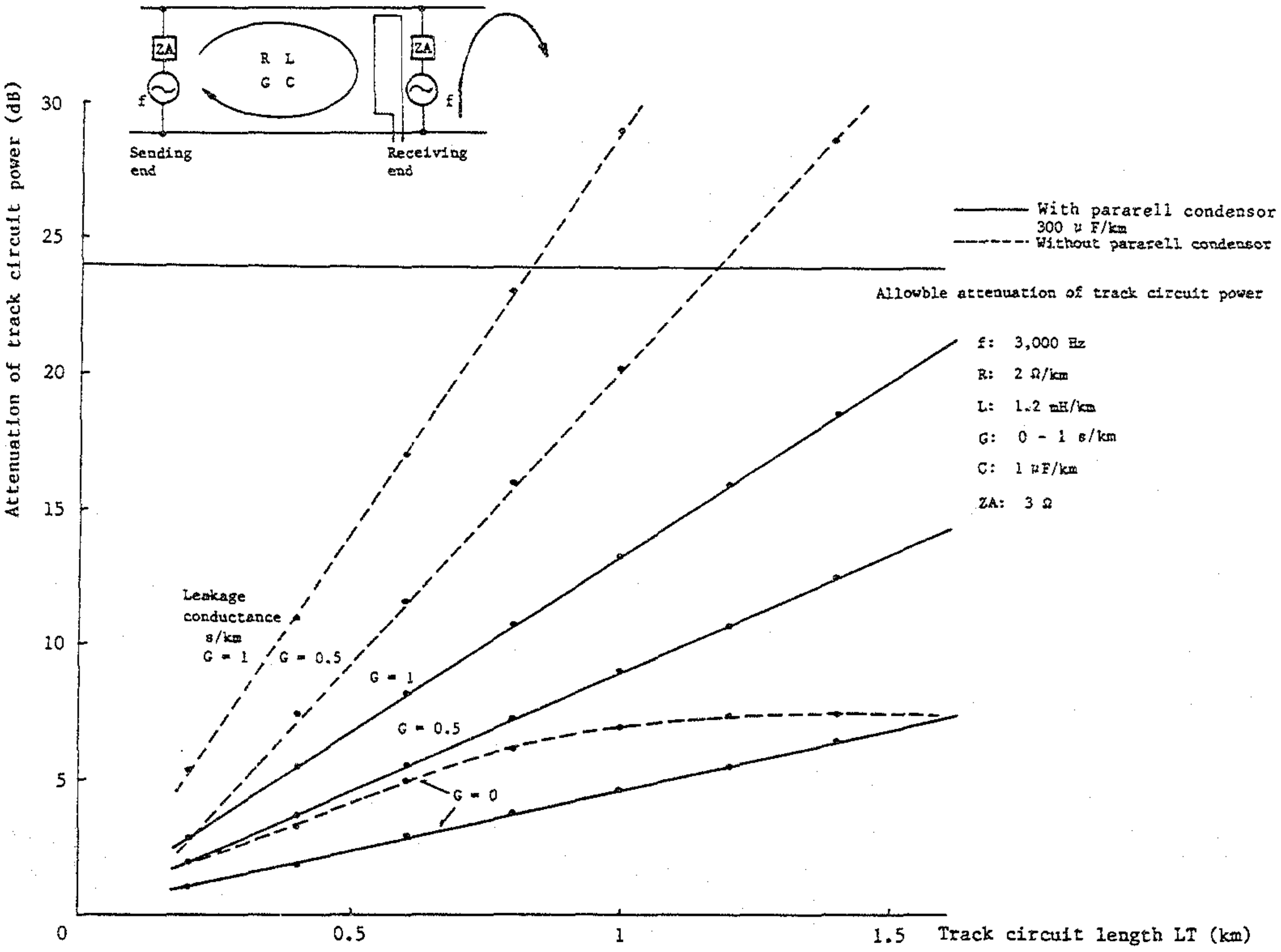


Fig. 1 Attenuation Characteristics of Jointless A.F. Track Circuit Current

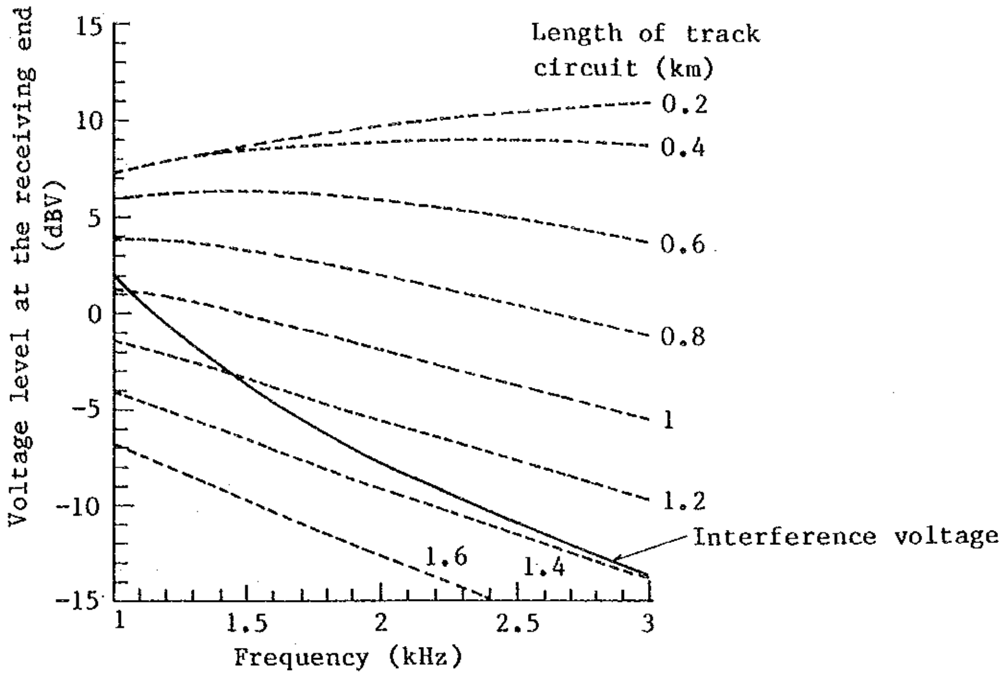


Fig. 2 Relation between Frequency and Length of Track Circuit (Sending impedance 3Ω/-60°)

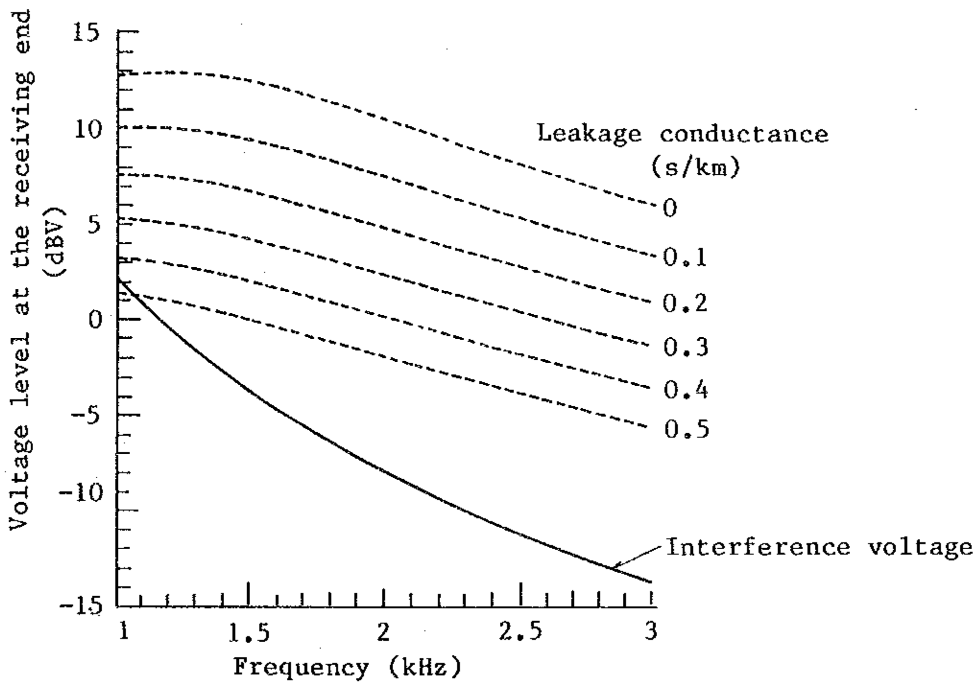


Fig. 3 Relation between Frequency and Leakage Conductance (at track circuit length of 1 km and sending impedance of 3Ω/-60°)

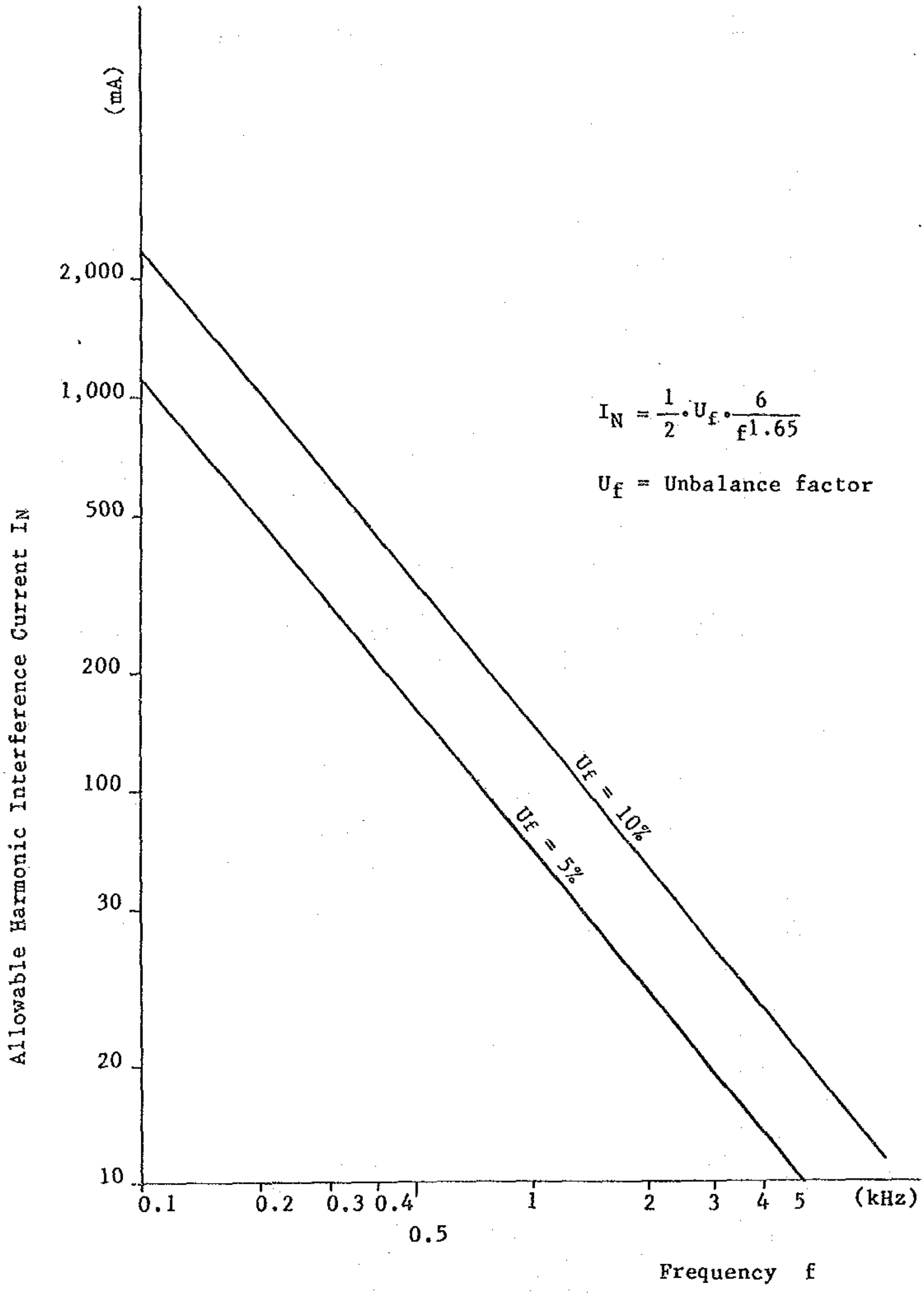


Fig. 4 Allowable Harmonic Interference Current

5-3 Distinction Method between Train and Trolley Using the Axle Counter

1) Purpose

In the block section based on the Axle Counter, distinction between train and trolley has so far been made by additionally providing a short-track circuit to avoid erroneous counting of trolleys. However, some improvement made to the present Axle Counter method allows distinction between them without such track circuit.

2) Outline of the distinction method

According to this method, the train (with wheel rim diameter of L_1) is detected because the wheel detection range (ℓ_1) of both the axle counters A and B overlaps each other, while the trolley (with wheel rim diameter of L_2) is not detected because the wheel detection range of the two axle counters does not overlap.

This is made possible by adjusting the distance d between the two sets of axle counters A and B. See Fig. 1, 2, 3.

3) Requisite for distinction between train and trolley

$$\ell_2 < d < \ell_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and

$$T = \frac{\ell o}{Vmax}$$

$$= \frac{(\ell_1 - d)}{Vmax} > To \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Vmax: Maximum train speed

To : Scanning time of the processing device

Satisfying (1) and (2) as above is a necessary and sufficient condition.

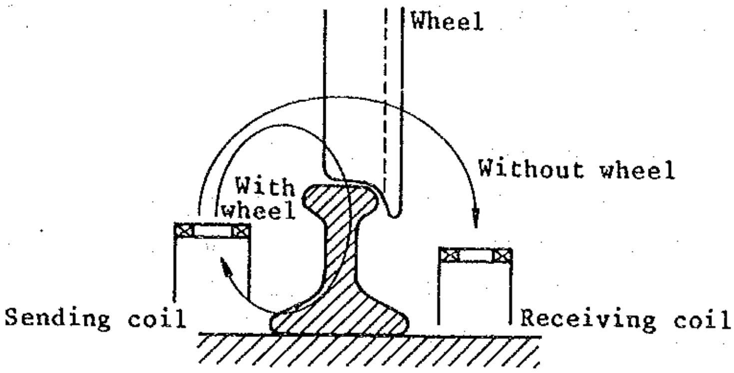
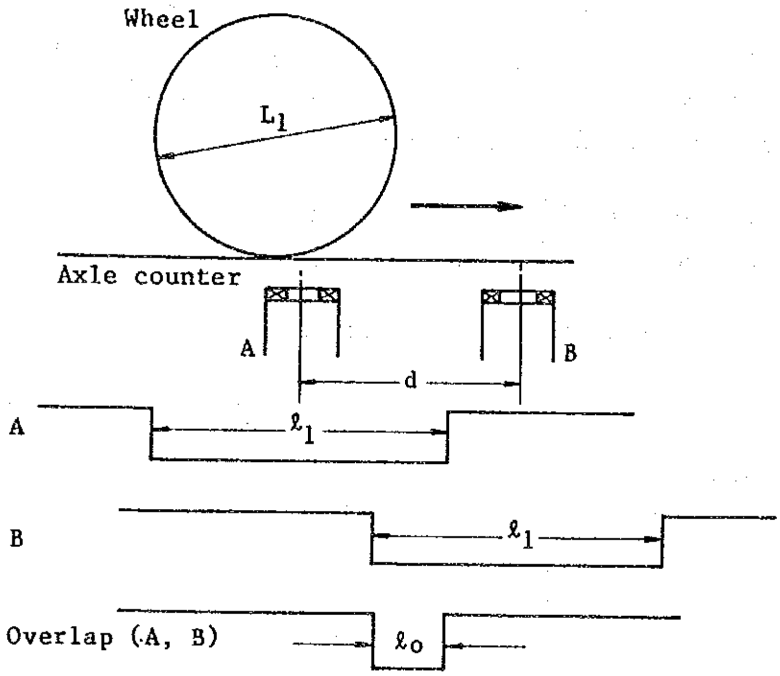


Fig. 1 Detection Principle



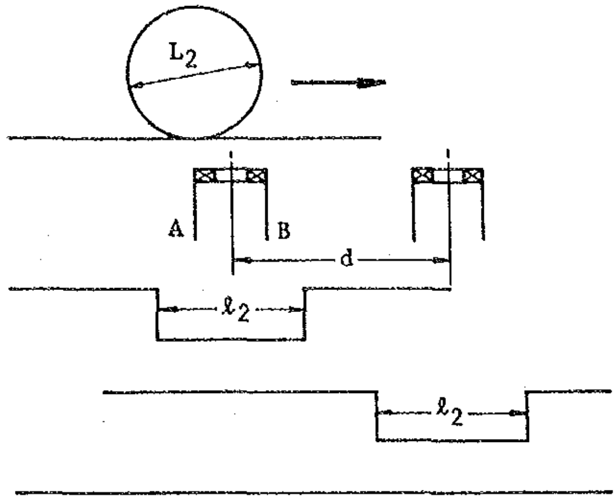
L_1: Wheel rim diameter

ℓ_1: Wheel detection range of L_1

d : Distance between axle counters

ℓ_o: Overlap range of wheel detection of L_1

Fig. 2 Relations between the Detection Range of the Wheel with the Diameter of L1 and Distance of d



L_2: Wheel rim diameter

ℓ_2: Wheel detection range of L_2

d : Distance between axle counters

Fig. 3 Relations between the Detection Range of the Wheel with the Diameter of L2 and Distance of d

5-4 Comparison of Continuous Speed Detection and Spot Speed Control Methods

1) Continuous speed detection method with use of track circuit

a) Function

To improve the accuracy of the unified alarm time (Tw), train speed is continuously monitored, the optimum alarm starting time is calculated and the barrier is automatically controlled.

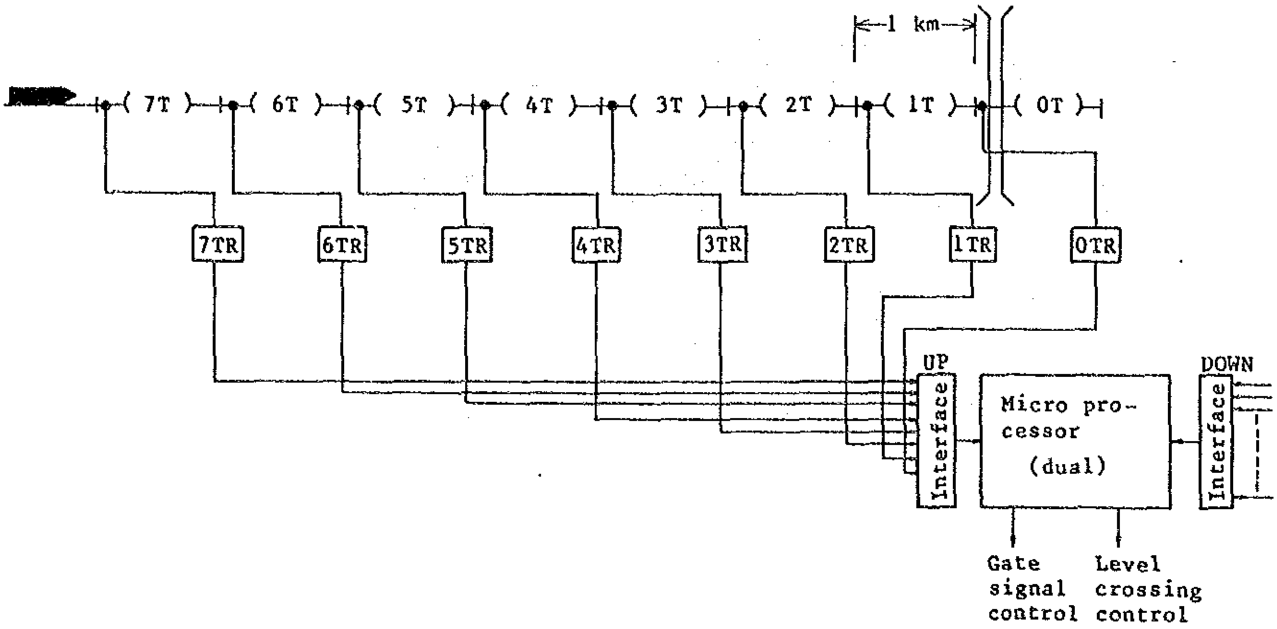
b) System configuration

<Prerequisite>

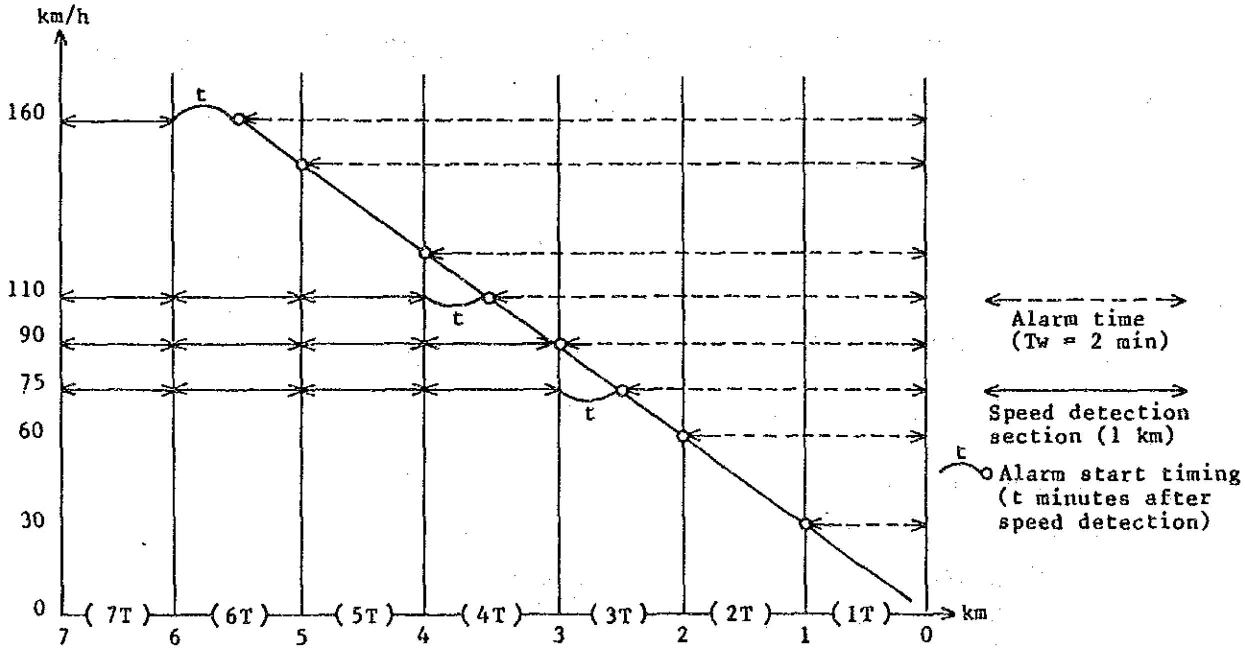
Max. speed: 160 km/h

Alarm time: 2 min

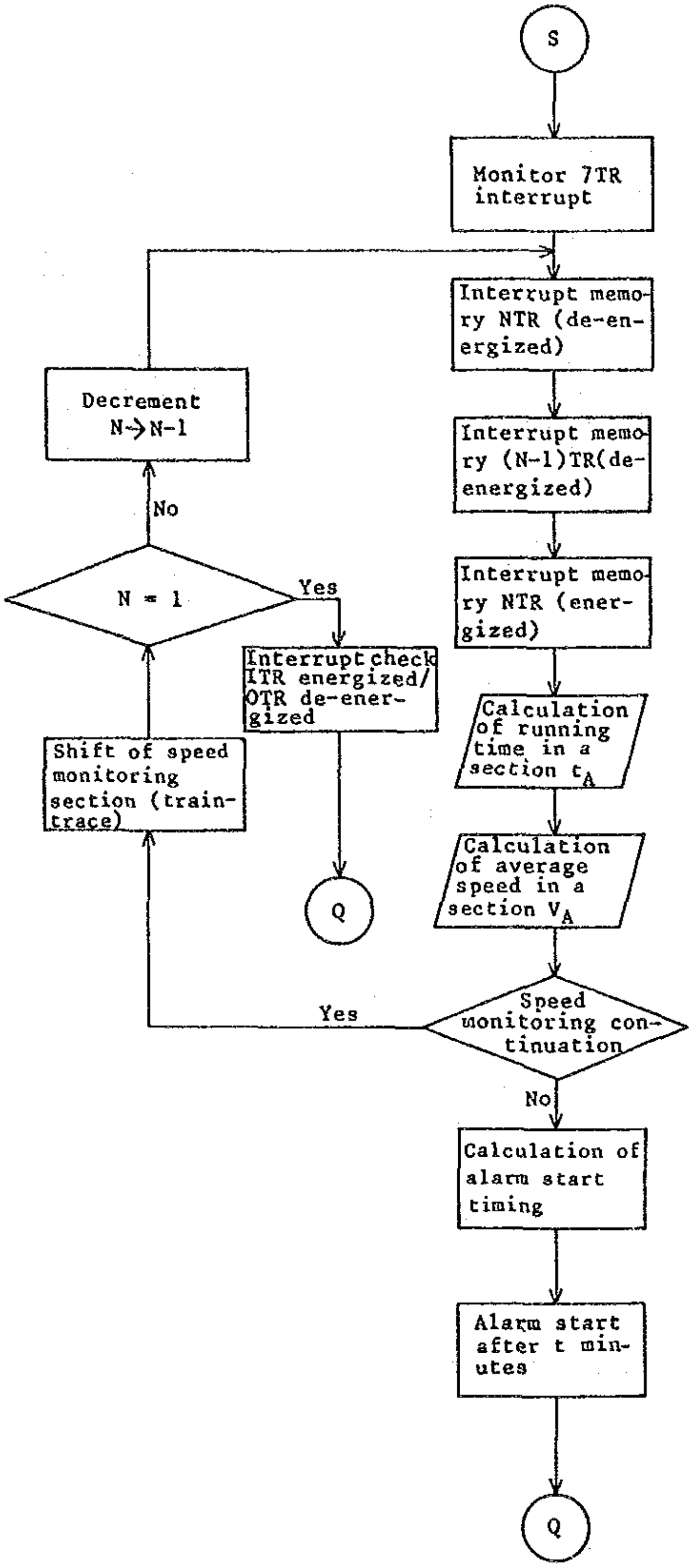
Number of track circuits required for speed detection: 8 sets (0TR ∿ 7TR)



c) Time chart of speed detection and alarm starting



d) Control algorithm (Normal process)

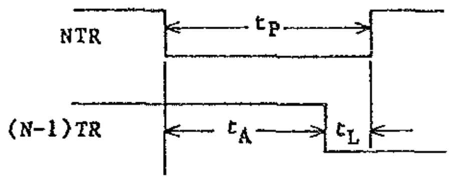


Interrupt drive system

(S): Start

(Q): Quit

Sequence of TR function



$t_A = (t_p - t_L)$ t_L: Running time of the train length distance

$V_A = (\frac{L_{BL}}{t_A})$ L_{BL}: Block length (1 km)

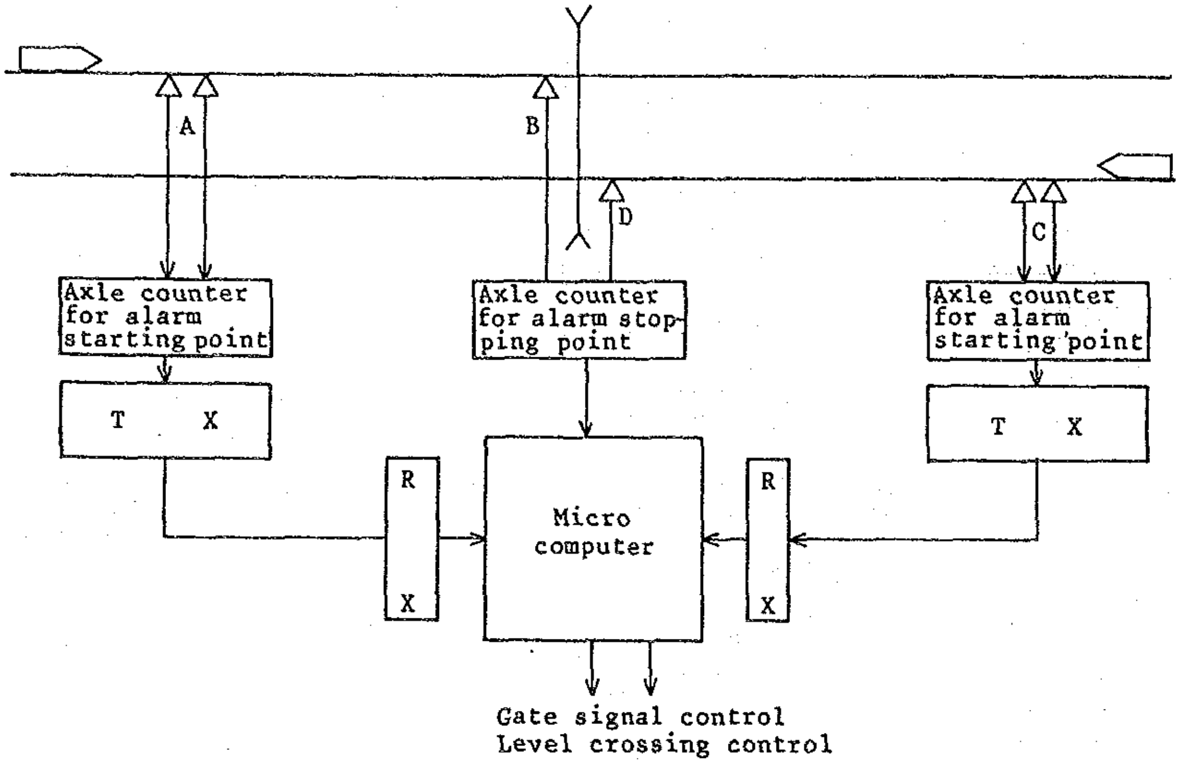
L(N): Distance between (IT) and (NT)

$\frac{L(N-2)}{(\frac{V_A}{60})} > 2$

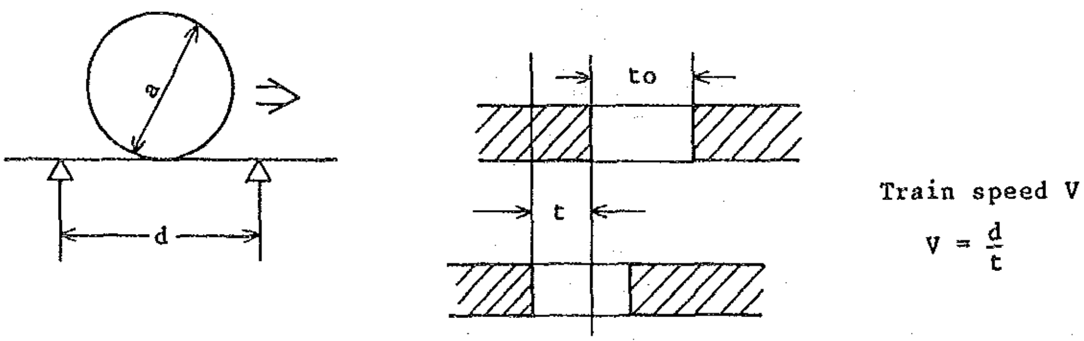
$t = \frac{L(N-1)}{(\frac{V_A}{60})} - 2$

2) Spot control method (Axle counter system)

a) System configuration



b) Speed detection signal



5-5 Transponder

1. Preface

The Transponder is a device to transmit safety data between ground and train through a cab coil and wayside coils.

The Transponder developed by JR has the following features.

. High quality (bit error rate: less than 3×10^{-5})
. High-speed transmission (max. 64k bps)
. Bidirectional transmission (ground ↔ cab)
. Power transmission (cab → ground)

These features make it possible to compose various signal systems. Examples are given below.

- AWS (Signal data and speed restriction data are transmitted from ground to the cab to control the train speed.)
- Train describer (Train number is transmitted from the cab to the ground and indicated at the dispatcher center.)
- Signal indication system to correspond with train types (Train type data is transmitted from the cab, and a signal indication which is fit for brake performance of each train type is indicated.)

The Transponder described here is the one used for JR's ATS-H (Automatic Train Stop with speed checking). The wayside coil to transmit several kinds of data is provided with a power source and that for fixed data is of powerless type. The reason why the former is provided with a power source is that a power cable, if installed together with the control cable, would not push up the cost so much, and that the power source can facilitate to always check the functioning conditions of ground devices. If required, wayside coils of the latter type can easily be converted into the former type.

2. Principle of Transponder

The principle of the Transponder is shown in Fig. 1. The information wave transmitted from the wayside transmitting coil is received by the receiving cab coil and demodulated. Simultaneously, the information wave transmitted from the transmitting cab coil is received by the wayside receiving coil and demodulated. The wayside coil without a power source receives the power wave transmitted from the cab coil and uses it as the power source to generate information wave.

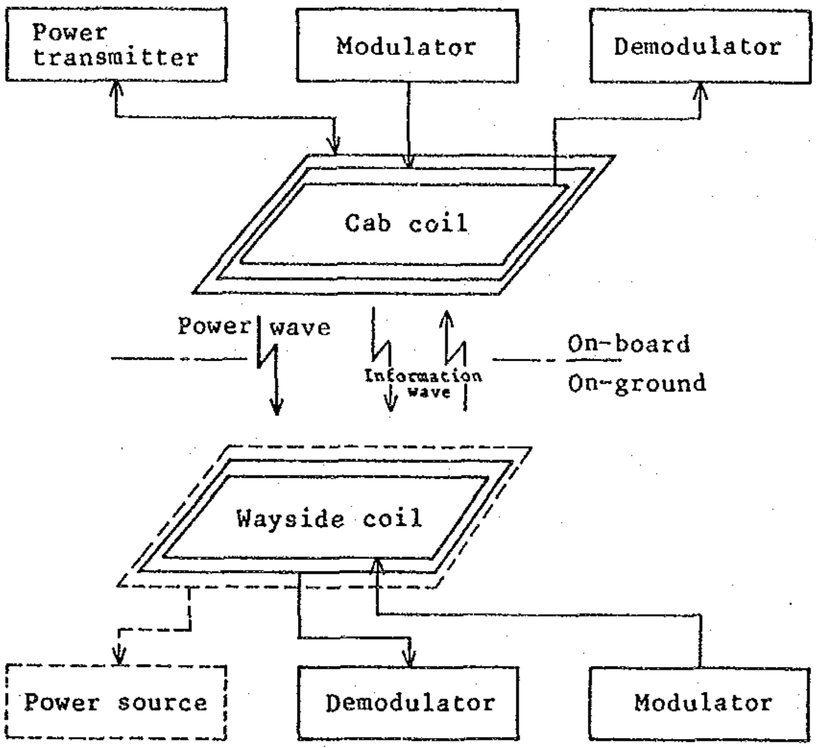


Fig. 1 Principle of Transponder

3. Transponder for ATS-H

(1) Component devices

The on-ground devices include the encoder, repeater, wayside coil with power source, and wayside coil without power source. The on-board devices include the cab coil, connecting box, and transmitter/ receiver.

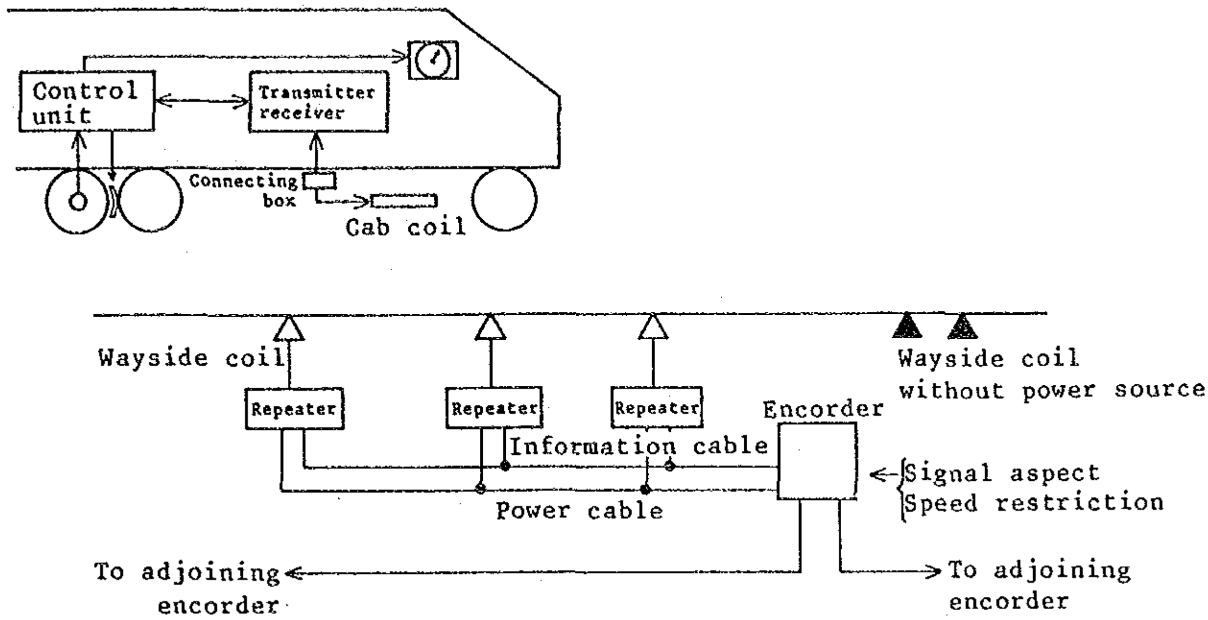


Fig. 2 System Configuration of Transponder for ATS-H

1) The encoder encodes the input data and modulating it in FSK mode transmits it to the repeater. Transmitted signal data includes signal aspect, distance to the stop signal, switch speed restriction, length of speed restricted section, distance to the switch, down gradient speed restriction, and distance to the down gradient. The encoder monitors the functioning conditions of the repeaters and the wayside coils. It also receives a telegram from the cab through the wayside coil and repeater, and decodes it.

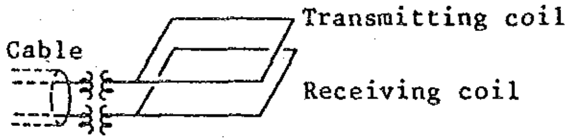
   The process unit is composed of two microcomputers working in parallel so that it can detect any fault and cut the output when data on the bus line are inconsistent.

2) The repeater is located near the wayside coil. After receiving a telegram from the encoder, the repeater changes it into a form to be transmitted to the cab coil, and transmits it to the wayside coil (Fig. 3). The telegram output from the wayside coil is received by the receiving coil of the same wayside coil, and fed back to the encoder through the repeater. Thus, the encoder can check if the correct telegram is transmitted to the wayside coil.

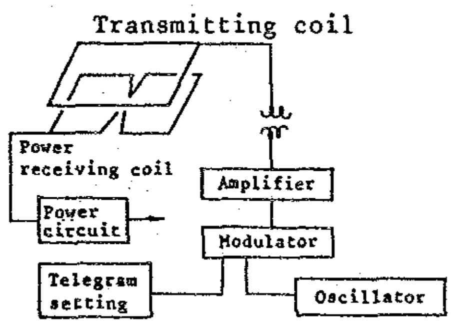
The repeater can also temporarily store telegrams transmitted from the cab coil.

3) There are two types of wayside coils. One transmits varying data such as signal indications, and also receives data from the cab coil. The other transmits fixed data such as curve distance. The former is the wayside coil with a power source, and incorporates the transmitting/receiving coils as shown in Fig. 3 (a).

The latter is without a power source and composed of the telegram setting/transmitting circuit, transmitting coil, power wave receiving coil and power circuit as shown in Fig. 3 (b).



(a) Coil with power source



(b) Coil without power source

Fig. 3 Configuration of Wayside Coil

4) The on-board transmitter/receiver communicates data with the control unit and also transmits a power wave to the wayside coil without a power source.

The cab coil consists of the transmitting/receiving coil, and power wave transmitting coil as shown in Fig. 4.

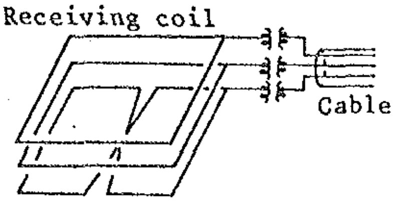


Fig. 4 Structure of Cab Coil

4. Transmission Characteristics

Table 1 shows particulars of the transmission. A 1.7 MHz FSK-modulated signal is used for data transmission from the train to the ground, and a 3.0 MHz FSK-modulated signal is used for data transmission from the ground to the train. For power transmission, a 245 kHz monotone signal is used.

The transmission power of the 1.7 MHz, the 3.0 MHz and the power wave are approx. 40 mW, 3 mW and 7W respectively, within the stipulated power in the Wireless Telegraphy Act in Japan.

Thus, these waves can be used freely without getting official frequency allocation.

Table 1 Particulars of Transmission

Information transmission	Ground → vehicle	1.7 MHz (FSK modulation) max. 64 kbit/s
	Vehicle → ground	3.0 MHz (FSK modulation) max. 64 kbit/s
Power transmission	Vehicle → ground	245 KHz

The transmission procedure is based on HDLC, and the telegram format, which is repeated cyclically, is as shown in Fig. 5. On signal reception, the encoder on the ground, and the transmitter/receiver on board, will execute an error check with CRC code. Among telegrams received more than 4 times, those which are repeated more than twice with the same contents are taken as correct ones.

Synchro-nization	Information	Check bits	Synchro-nization
8 bits	48 bits	16 bits	8 bits

Fig. 5 Telegram Format

Transmission between the encoder and the repeater is made with an FSK-modulated 1700 Hz signal at a speed of 1200 bits/s. The transmission format is the same as shown in Fig. 5. The telegram transmission/reception is of the polling selection system which regards the encoder as the 1st station, and the repeater as the 2nd station.

5-6 Solid-state Interlocking Device

1. Preface

The relay interlocking device is popularly used and has been highly evaluated in the improvement of transportation efficiency and safety level. But in terms of designing, operation and maintenance there remains some deficiencies such as; (1) Circuit design, manufacture and test are required to be made for each station. (2) Some problems related with the safety and operability are attributed to the relay circuit theory itself. (3) Complicated procedures are required for trouble shooting. (4) It lacks adaptability and extendibility in connecting to other solid-state devices.

The solid-state interlocking technology can not only cover such disadvantages but realize more compact and economical device.

The development of the solid-state interlocking device took time than the other systems because interlocking should be a fail-safe system. Fail-safe characteristic like that of a relay is not expected for a microprocessor itself, which is the nucleus of the solid-state interlocking device. It took long time for each country to solve this problem, and various systems have been developed so far.

JR firstly developed a solid-state interlocking device for a large scale station, installed it at Higashikanagawa Station in March, 1985. Since then, 12 similar devices have been installed to major stations with functioning satisfaction.

Lately solid-state interlocking system for small scale stations was developed, and installed at 3 stations in March, 1987.

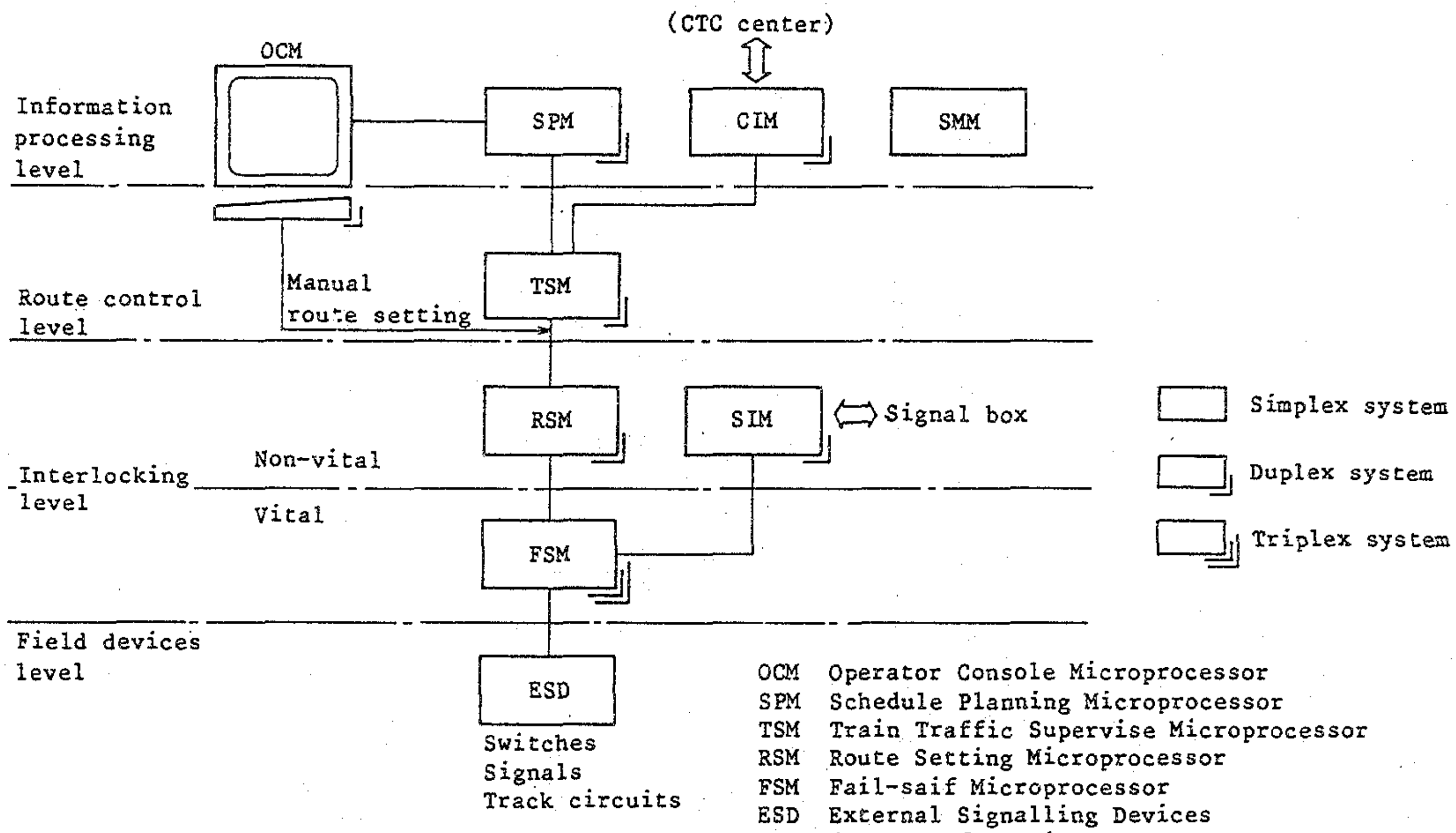
At present, solid-state interlocking device is interfaced with field devices utilizing the existing relays, but in near future, the direct interface with solid-state interlocking and field devices will be put into use.

Mentioned below is an outline of JR's solid-state interlocking device SMILE (Safe Multiprocessor System for Interlocking Equipment) and μ-SMILE.

2. Solid-state Interlocking Device for Large Stations (SMILE)

(1) Hierarchical structure multiprocessor

An interlocking function is indispensable at any station. Based on experience with the relay interlocking equipment, its standardization is comparatively easy. However, the traffic control system and the shunting control system are different at each station, depending on the function and track layout of each station. To flexibly comply with the particular performance and function required at each station, the hierarchical structure as shown in Fig. 1 is selected. By means of this, the system structure can be achieved to fit to the characteristic of each station. In the case of an extremely large scale station, the interlocking device is divided into two, and each of which is controlled from the center. Thus, an economical system can be achieved.



OCM Operator Console Microprocessor
SPM Schedule Planning Microprocessor
TSM Train Traffic Supervise Microprocessor
RSM Route Setting Microprocessor
FSM Fail-saif Microprocessor
ESD External Signalling Devices
CIM CTC Interface Microprocessor
SIM Signal Box Interface Microprocessor
SMM System Monitoring Microprocessor

Fig. 1 Hierarchical Structure of SMILE

(2) Philosophy of safety

The most serious question about the solid-state interlocking is how safety should be secured in the system composed of semiconductors including microprocessors as major elements.

The basis of safety of the relay interlocking has been placed on the fail-safe signal relays. The nonsymmetrical failure characteristic of signal relays cannot be expected of general purpose microcomputers. However, since the microcomputer has a high-speed, intelligent processing capability, it can be used to diagnose the system function at high frequency, and enable to take a prompt countermeasure for any failure before the system reaches a vital state. Thus, higher safety level than expected from the relay interlocking can be achieved by the solid-state interlocking system.

As to a concrete structural method, various systems are used in many countries. Solid-state interlocking systems used in Sweden, Denmark, and the U.S.A. adopt a redundant software system (2 version programming system) which equips one computer with two different sets of software. In Japan, West Germany, and U.K., on the other hand, solid-state interlocking systems adopts a redundant hardware system which equips a plural number of computers with one set of software. In France, the software redundant system and the hardware redundant system are used in parallel.

Considering the following fact, JR has employed the hardware redundant system.

1) A large volume of software required to be developed for the software redundant system. In the reliability and the development cost, therefore, this system is disadvantageous.

2) The share of the computer cost in the total cost is rather small. In addition, the hardware cost is expected to be lowered in the future.

(3) Fail-safe system structure

The block diagram of the fail-safe system is shown in Fig. 2. Data of 3 systems output to the bus are compared by each bit. By the majority voting circuit, data, if coincident in 2 or 3 systems out of 3, is judged as correct. An inconsistent system, if any, is detected without failure by the fail-safe comparator. If an inconsistency should happen in one system more often than specified rate, this system is cut off.

The output circuit uses a fail-safe output voting circuit to keep itself free from unsafe output.

When 1 system is cut off for its failure, the other 2 systems will keep functioning. If an inconsistency should happen in the 2 systems, the whole system will go down at last.

The error rate of this system is calculated in the Markov process model as follows.

$Pd = 1.6 \times 10^{-10}/h$, $Ps = 1.0 \times 10^{-7}/h$

where Pd is unsafe error rate, and Ps is safe error rate. The mean time to the first unsafe error rate Td is given as follows:

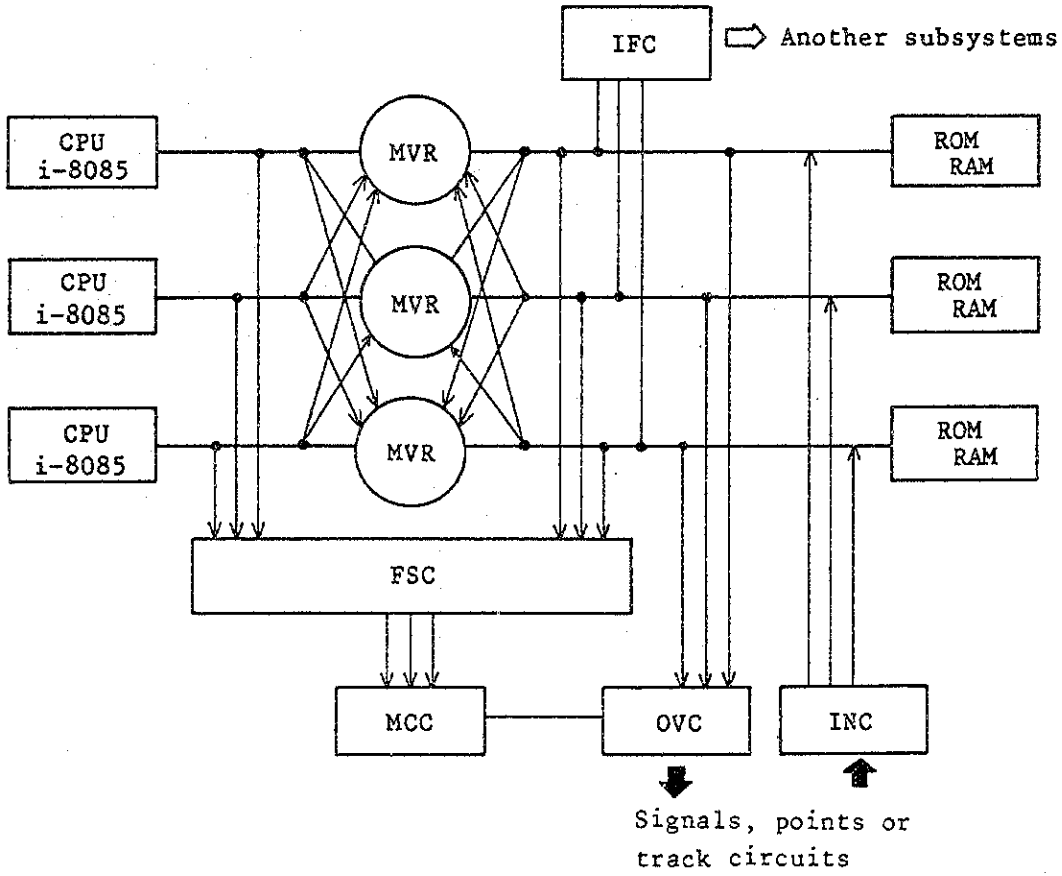
$Td = 6.1 \times 10^{11}(h)$

These figures are more than 2 digits higher compared with $Pd = 1.5 \times 10^{-8}/h$, $Td = 2.0 \times 10^{8}(h)$ of the relay interlocking device.

(4) Interlocking software

The basic theory of interlocking software is based on the algorithm of the relay interlocking equipment. The interlocking theory (interlocking program) applicable to route selection, point control, and approach locking is the same at any station, and is standardized. Locations of signals, points and track circuits, however, are different at each station, and special interlocking data must be prepared for each station.

Consequently, in solid-state interlocking device, hardware and programs are commonly applicable to any station, and only data should be prepared to fit special requirements of each station.



MVR Majority Voting restorer
FSC Fail-safe Comparator
OVC Output Voting Circuit
INC Input Circuit
MCC Mode Control Circuit
IFC Interface Circuit

Fig. 2 Structure of Fail-safe Microprocessor Subsystem for SMILE (FSM)

(5) Control capacity

Maximum control capacity of the solid-state interlocking device for large scale stations is shown in Table 1. This table shows the actual example used as Hiroshima Station.

Table 1 Control Capacity of SMILE

Devices	at Hiroshima	Maximum limit
Routes	567	2000
Main signals	35	255
Shunting signals	38	255
Shunt indicators	53	255
Points	71	255
Track circuits	80	255

3. Solid-state Interlocking Device for Small Station (μ-SMILE)

(1) Necessity

The solid-state interlocking device for large scale stations is a comprehensive automatic train route control system. However, its application to small scale stations is not economical. It is preferable, therefore, to provide economical and simply structured solid-state interlocking device to small stations.

(2) System structure

The system structure of the μ-SMILE (abbreviation for electronic interlocking equipment for small scale stations) is shown in Fig. 3. The processor unit is divided into the interlocking processor and the interface processor. The former performs a fail-safe interlocking process, and the latter functions as the pre-processor of the interlocking system performing data intput/output to/from the display/control unit as well as the monitoring processor.

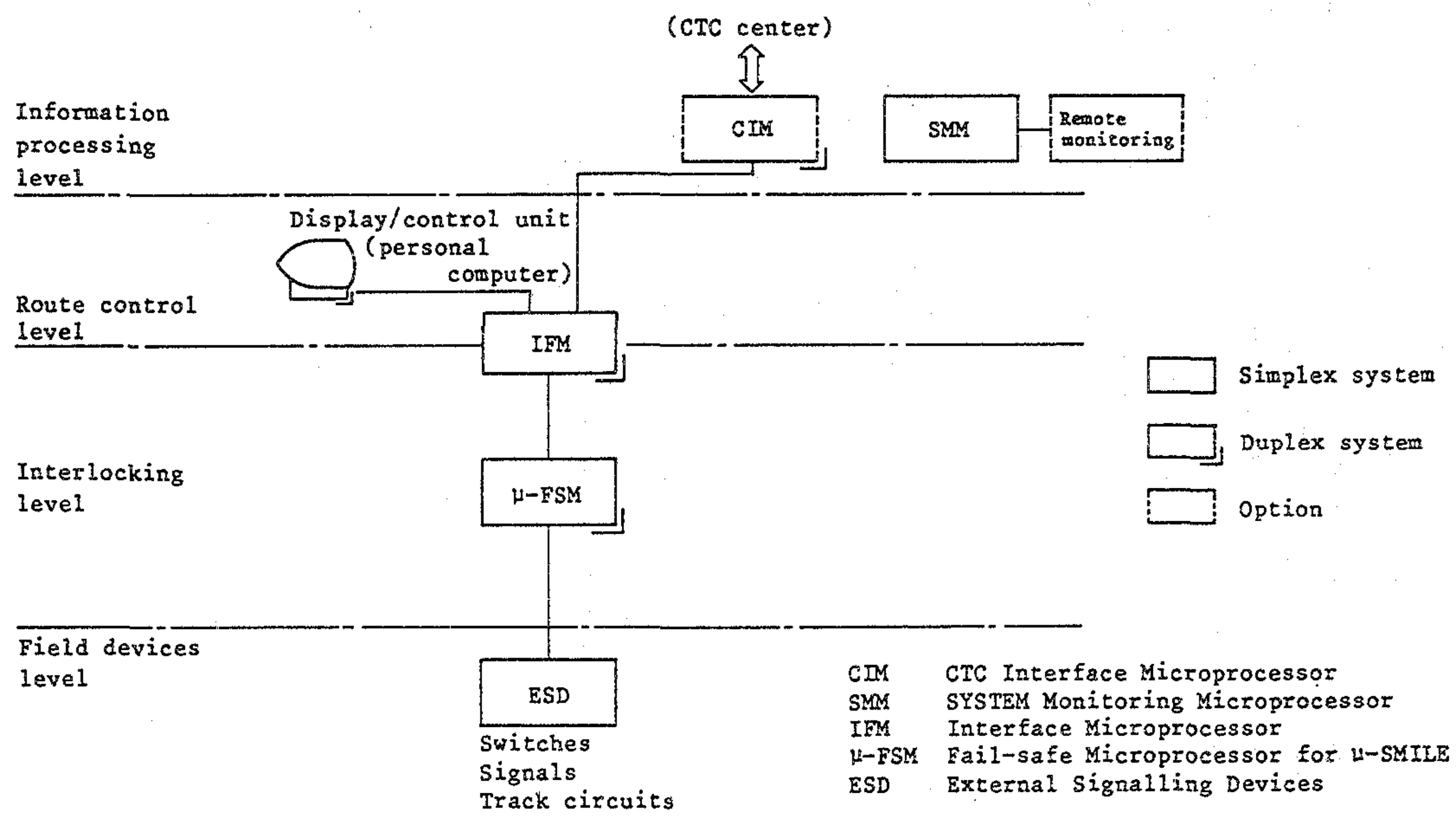


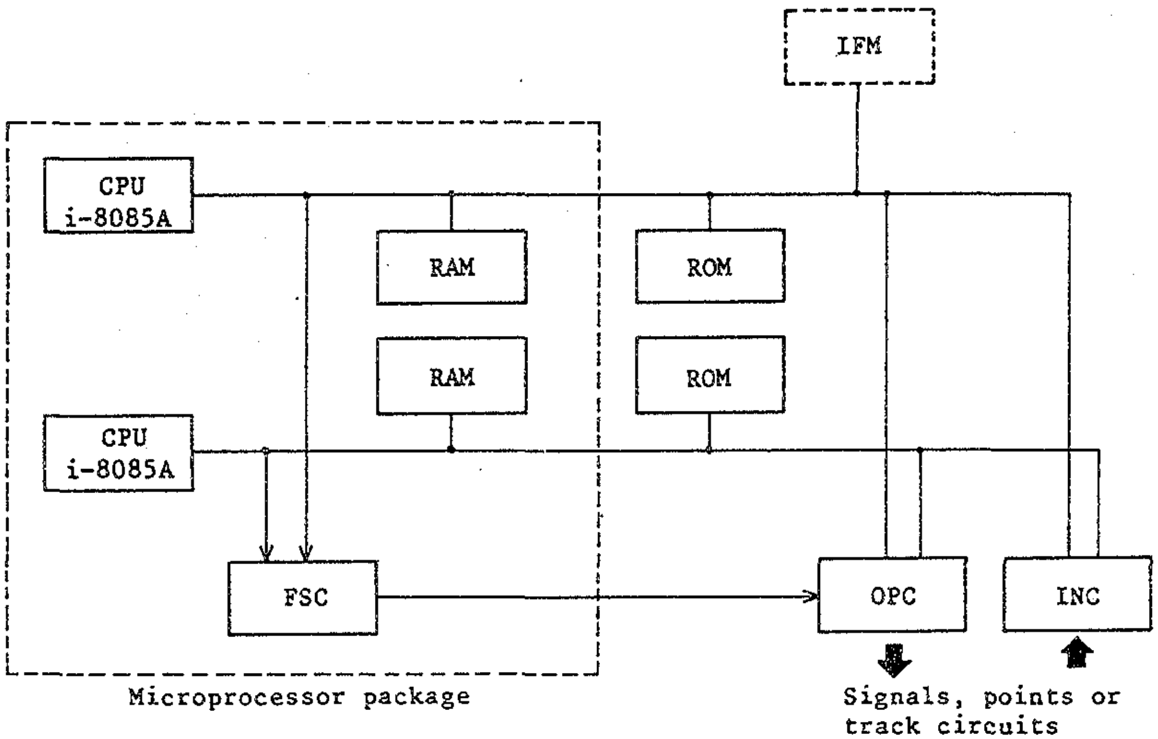
Fig. 3 Structure of μ-SMILE

Output to signals is divided into fail-safe data and other data. The former uses a fail-safe output circuit, and the latter uses a low-cost general purpose output circuit.

The interlocking system shall be of the hot-standby system, and the slave system is automatically selected when the master system fails. The interface processors are of twin parallel system. The display control board shall be of the cold-standby system, and the spare unit is switched-on by operator when a failure should happen. The display control board is a combination of a commercial use personal computer and a colour VDU. Instead of the VDU, application of a panel system is possible. For data transmission, fibre optics is used.

(3) Safety assurance

As the safety system, the same bus-level comparison and fail-safe input/output systems of SMILE are employed in principle. As for the hardware, however, the microprocessor package called "SPAC-8" is used. This is a custom-built multi-chip LSI, composed of 2 Intel-8085A microprocessors and a fail-safe comparator (FCS) as the major components (Fig. 4). The 2 processors are synchronized with the master clock, data on the bus is compared by FSC, and any inconsistency is detected without fail. This LSI can be used for various kinds of equipment which would need fail-safe functions. By adding ROMs and input/output circuits, fail-safe interlocking function can be achieved.



FSC Fail-Safe Comarator
OPC Output Circuit
INC Input Circuit
IFM Interface Microprocessor

Fig. 4 Structure of Fail Safe Microprocessor for μ-SMILE (μ-FSM)

(4) Software for interlocking processor

Basically, the software construction of the μ-SMILE is the same as that of the SMILE. However, the former is simplified.

(5) Control capacity

The control capacity of the μ-SMILE is shown together with the example of Anegasaki Station in Table 2.

Table 2 Control Capacity of μ-SMILE

Devices	at Anegasaki	Maximum limit
Routes	9	80
Main signals	9	48
Shunting signals		48
Shunt indicators		48
Points	6	48
Track circuits	13	48

4. Conclusion

The solid-state interlocking device has the advantages mentioned below. Considering the further developments expected, it will be widely used replacing the relay interlocking devices in the near future.

(1) Work conditions of every field and central equipment are monitored.

(2) The cost can be reduced by means of standardization of both software and hardware.

(3) Almost all tests are made by automatic testers at factory, and the construction period at the site can be shortened.

(4) The compact size will reduce the cost of the building.

(5) As for safety and reliability, it is superior to the relay interlocking device by 2 digits.