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STUDY OF EARTHQUAKE-RESISTANT DESIGN ON THE BRIDGE SUPPORT OF RAILWAY CONCRETE GIRDER BRIDGES

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SYNOPSIS

As a result of the Miyagi Prefecture offshore earthquake (1978), the bridge shoes (especially cast iron shoes) of the Tokohu SHINKANSEN's beam type concrete bridge were damaged. Through factor analysis of the damage such as a failure test and an earthquake response analysis, the cause of the failures were identified.

Side block strengthened cast steel shoes, steel rectangle stoppers were then subjected to a loading test, a finite element method analysis, and an earthquake response analysis. As a result, a new type of support structure with steel rectangle stoppers was proposed. A new design method that is referred to as earthquake load instead of "seismic coefficient method", based upon the spring coefficient of the stopper or the side block of the shoe that determines their necessary energy absorption capability, was also proposed.

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I. Introduction

Concrete bridges are used extensively because of their ease of maintenance and their ability to reduce noise and vibration. The simple beam has been especially easy to use in areas where complex geographic and geological conditions exist. Because of this ease of use, the simple beam can be used with various methods that are successful when work is being conducted within a limited space and a limited time frame in urban areas, methods such as incremental launching, prefabrication, movable form and support. Also, the adoption of the box-hollow-section girder makes the simple beam quite economical when used in longer spans.

Project	Construction Period	Total Length	Viaduct	Simple Beam Type Viaduct
Tokaido SHINKANSEN	1959-64	515km	116km	13.0km (11.1%)
Sanyo SHINKANSEN				
Osaka-Okayama	1967-72	160km	77km	7.5km (10.0%)
Okayama-Hakata	1970-75	400km	87km	18.5km (21.4%)
Tohoku SHINKANSEN	1971-1981	470km	249km	67km (26.9%)

Recently, the beam-type viaduct has been used rather extensively. Not only has it been used for crossing rivers and in grade separation works, but also for elevated structures which need bridge supports.

Considering the background of this increased use of the beam-type viaduct, I can point out the following situations:

(1) High speed passenger rail condition (i.e., strict restriction of displacement--bent up angle or a gap in the centerline of the structure)

(2) Social condition

(i) Environmental Problems - noise and vibration mitigation
(ii) Maintainability - viaduct is much better than an earth structure such as cut and fill which takes more time to stabilize.

As a measure for noise and vibration mitigation, recent experiments have found the beam-type viaduct to be superior.

(iii) Improvement of the beam-type viaduct construction method

(a) Adoption of box-hollowed-section beam -- good appearance
(b) Incremental launching methods -- movable staging method
(c) Prefabrication method -- safety, speed

In general, the beam-type viaduct makes these methods economical.

The bridge support connects the upper structure with the substructure, transmitting the load from the bridge girder to piers and abutments. This generates elongation and contraction due to temperature change and loading-unloading which dissolves the stress. When an earthquake occurs, the bridge support bears the bridge momentum. Yet for the most part, so as to move freely, the friction between the bridge support and the substructure is required to be small. Therefore, as a support for the middle span of the bridge (about 100 feet), cast iron shoes are used.

Because Japan is referred to as earthquake country, high grade shoes have been developed like a dampered support in accordance with long bridge construction based upon earthquake resistant design.

At the same time, the concrete slab bridge with a rubber sheet is used for small bridges such as those less than 35 feet.

<u>1-2</u> In this study, I would like to explain the earthquake resistance of crosswise bridge supports including FC shoes and BP shoes which have been used as sliding shoes. In addition, I would like to explain the method of estimating the balanced steel rectangle stopper with sliding shoes, possessing the necessary energy absorption capability.

<u>1-3 Rule for Bridge Shoe Application</u>

<u>1-3-1 Girder Shoes on the Tokaido SHINKANSEN</u>

(1) Steel girder bridge shoes
i. Sliding Shoes
(i) The shape is eliptical and the sole plate is made of cast iron which has a better quality than that of FC15 to FC25. The concrete bearing strength at the shoe bed has been increased from 40kg/cm to 60kg/cm. The SHINKANSEN bridges have to bear larger horizontal forces such as centrifugal, long-rail longitudinal, and the forces that come with braking and accelerating. These are applicable up to the 35 meter span bridge shoe.
(ii) Bearing plate shoes are made of copper alloy and the bearing plate is made of cast steel (SC55). It is applicable beyond the 35 meter girder shoe and to moveable shoes of a continuous girder which have much more bearing power as well as extension and contraction length.
ii. Roller Shoes
These are made of a roller or locker. Therefore, there is less friction with these than with any other shoes. Usually they are applied to the bridge support of continuous truss bridges and are hardened if necessary.
(2) Shoes for Reinforced Concrete Beams

Skewed Angle \ Span Length (meters)		3-6	7-9	10-12.5	15-20	22.5	25 or more
Rectangular	Fixed End	Hinge /Rubber	Hinge	Steel Plate	FC or	Hinged	Hinged
0 75	Movable "	Synth Rubber	Steel Plate		FC	FC	Rocker
Skew	Fixed "	"	Synthetic Rubber			BP(SC)	BP(SC)
0 75	Movable "	"	"			"	"

(3) Shoes for Prestressed Concrete Beam
When the skewed angle (O) is less than 60 degrees, synthetic rubber shoes are used. When the angle (O) is larger than 60 degrees, rectangular FC shoes are used for the span less than 25 meters in length and rocker shoes are used for the span longer than 25 meters.

1-3-2 Shoes For the Tohoku SHINKANSEN

(1) Shoes for Reinforced Concrete
In the case of the single web T-beam, steel plate shoes are used for spans of 9.3, 11.1 meters in length, where horizontal force is transmitted by the block of the shoes. For spans of 14.1 - 24.1 meters, FC shoes (FC-15) are used. And for spans of 28.1 - 34.1 meters, rocker shoes are used for the movable side and cast steel shoes (SC-49) for the fixed side.

(2) Shoes for Prestressed Beam
In the case of the prestressed I-shape beam, FC shoes (FC-15) are used for spans of 10 - 25 meters in length with a bearing power of 100 - 180 tons. For spans of 25 - 50 meters with a bearing power of 100 - 300 tons, BP shoes (SC-49) are used.

In the case of the hollow-box-shape beam, roller shoes are used for spans of 30 - 58.6 meters in length with a bearing power of 500 - 1000 tons.

2 Statistics of Shoe Damage by Miyagi Earthquke

As a result of Earthquakes offshore from Miyagi Prefecture, bridge supports have suffered damage. Two such earthquakes occurred in 1978: February 20, 13:36, with a magnitude of 6.7, and June 12, 17:14, which was recorded at 7.7 on the Richter Scale.

(1) Damage from the February 20th earthquake that was suffered along the Tohoku SHINKANSEN extended 100 kilometers. The rate of damage of the FC shoe bridge support was 16.6% in total, including 33.8% in the northern part of Miyagi Prefecture and only 1.9% in Iwate Prefecture.

(2) Damage suffered from the June 12th earthquake extended some 120 kilometers along the Tohoku SHINKANSEN, however, the heaviest portion was about 70 kilometers.

Prefecture	Fukushima	Miyagi			Iwate
Distance from Epicenter (Estimation)	50km	South 150-120	Central 120-110	North 110-125	125km
Shoes Completed	2904	1834	658	2696	2934
Damages Shoes	13	411	265	500	37
Rate of Damage	0.4%	22.4%	40.3%	18.5%	1.3%
Line Length	102km	46km	19km	61km	96km

(3) FC Shoe - Statistical Analysis of FC Shoe Damage
a) Condition of Support: Movable or Fixed Shoe
In the northern part, the movable shoes suffered considerable damage. On the other hand, fixed shoes suffered major damage in the southern region. This tendency coincides with the direction in which a tombstone falls. Movable shoes are on the flexible, slender pier and are more apt to move crosswise Fixed shoes are on the rigid pier which are on the layout of the F.F. M.M.

b) Adjacent Beam: Existing or Nonexisting

	Adjacent Beam	Total Shoes	Damaged Shoes	% of Damage
South	Incomplete	45	89	49.4%
	Complete	551	654	28.4
North	Incomplete	21	62	73.8
	Complete	453	860	47.4
Total	Incomplete	66	151	57.2
	Complete	1004	1514	36.7

Although there is a distinct difference in the number of each type of adjacent beams (incomplete or complete), the rate of damage suffered by the shoes which were adjacent to incomplete beams was much greater than those adjacent to completed ones.

c) Number of Beams in the Bridge

Area	Type of Beams	Bridge	Total Shoe	Failured Shoe	Rate of Damage
South	2	502	2008	543	27 %
	4	54	216	88	41 %
	5,6,7,8	40	262	112	43 %

A standard of four beams, for double track bridges, to eight beams has been adopted. As the number of beams increased, the rate of damage also increased.

d) Height of Bridge Pier

Area	Height	Bridge	Total Shoe	Failured Shoe	Rate of Damage
South	8meter or less	299	i1264	270	21 %
	betw.8 & 12	242	986	340	34 %
	more than 12	65	236	133	56 %

Higher piers appeared to suffer more, especially those on bridges higher than 12 meters. The rate of damage is as high as 65%. This tendency was confirmed when classified according to ground conditions. In a good rigid foundation, low bridges show a low rate of damage, and high bridges show a high rate.
e) Ground Condition

Area	Ground Condition	Bridge	Total Shoe	Failured Shoe	Rate of Damage
South	Hard	261	1050	65	6.2 %
	Medium	215	956	378	40 %
	Soft	120	480	300	63 %

In general, weak or soft ground yields a high rate of damage. Pile foundations were applied in unusually soft ground.
f) Acceleration
Classified by the estimated acceleration contour, the area of 350 gal experienced the highest rate of damage.

(4) The General Description of the Earthquake Damage That Resulted in February and June 1978 on Railroad Bridges That Were Opened to Traffic

Generally speaking, the rate of damage for existing railroad bridges was less than that of road bridges or SHINKANSEN bridges that were under construction. Major damage occurred only in June. The total number of cases was 32, including some failure of bridge abutments.
Major damage is as follows:

The Eaigawa Bridge, comprised of eight 19.20 meter spans, totaling 160 meters, experienced a horizontal shearing-off at the construction joint of the plain concrete bridge piers. It's interesting to note that newly built reinforced concrete bridge piers show no damage.

The Narusegawa Bridge on the Senseki Line experienced a broken bridge support bed and shifted about 60 cm.

The Tsuyagawa Bridge, on the Kesenuma Line, is comprised of one 35 meter span and five 40 meter spans of pre-stressed concrete girder, as well as one 22 meter span and twelve 15.8 meter spans of reinforced T-beam concrete. Among these, the beam end of 12 prestressed concrete bridges with 40 meter spans were crushed, slightly in some areas, more heavily in others. This reveals the problem that exists in connecting the upper shoe with the PC fastener.

3 Material Test and Engineering Test for FC and BP Shoes

3-1 It is necessary to perform a material test and an engineering test that corresponds to the statistical failure factors so as to study and identify the analytical cause and result.

For the material test, specimens were taken from both new and broken shoes. Casting pieces of the same materials were also used. The following test items were included: chemical components, tensile test, bending test, Brinnel hardness test, Charpie impact test, and a micrograph organization analysis. The following items were included in the engineering test: loading test for the actual shoes of three kinds of beams, FC-1-T, FC-180, BP-175, by way of special loading equipment.

(1) Ultimate Bearing Power
The ultimate bearing power of each specimen is shown in Table 4.7 and 4.8, and Fig 4.10. FC-1-T, which has a design force of 21.5 tons, has withstood 28.5 tons at the side block with a bolt hole, and 39.4 tons without a bolt hole.

Table 4.7 Ultimate Strength of Shoe

Shoe (quality) Designed Bearing Power		Side-A Vert.load	Side-A Test	Side-B Vert. load	Side-B Test	Height of Lateral force
FC-1-T	1	50 ton	37,4	50 ton	25.2	h= 30 mm
(FC 15)	2	50	39.4	50	28.5	17.5
20 tons	3	100	28.9	--	---	17.5
FC-180	1	50	30	50	32.1	h= 98 mm
(FC 15)	2	50	49	100	51.6	47.5
36 tons	3	100	53.5	50	55.0	47.5
BP-175	1	100	113	100	120	h= 64 mm
(SC 49)	2	100	193	100	190	40.5
35 tons	3	100	140	100	147	40.5

The loading force is applied on the top of the side block. There is little difference between the loading place and the ultimate strength because the shearing force dominates the bending force.

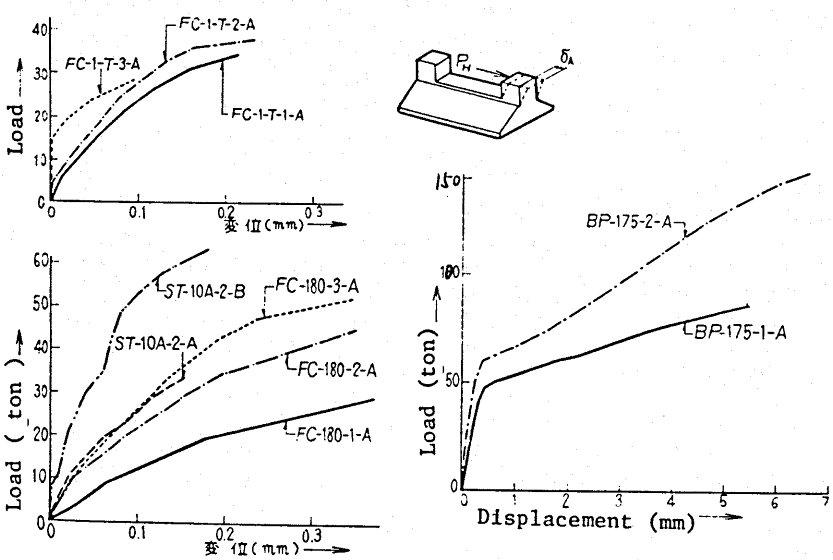


Fig 4.10 Load--displacement Curve

Table 4.8 Calculated Bearing Power

Specimen	Calculated Strength		(2)	(3)	(4)	(5)	(6)
	Shear	Bend	Test Result	Design Force	(1)/(3)	(2)/(3)	(2)/1
FC-1T	40.1 tons	85.9 ton	28.5 ton	21.5 ton	1.87	1.33	0.71
FC-180	67.7	87.8	49.0	36.6	1.88	1.36	0.72
BP-175	310	174.	140.	35.0	4.97	4.00	0.81

FC-180, which has a force design of 36.0 tons, has shown an ultimate strength of 49 tons at the minimum with a few deviations from different vertical loads.

BP-175 has shown quite a different response from those described above. As shown in the load-displacement curve in Fig 4.10, the change from the elastic state to the elastoplastic state and the high displacement is clear. The bending movement is affected much more than the shear force. Yet it is notable that according to the same loading point, there exists a large variation of ultimate strength, 140 tons - 193 tons, due to the influence of the manufacturing process and heat treatment.

(2) Energy Absorbed By Displacement

Table 4.9 Absorbed Eneergy by the Side Block

Specimen	Side Block A t·m	Side Block B t·m
Fc-1-T	6.41 6.97 4.69	10.78 9.06 —
FC-180	6.64 15.80 12.63	1.36 10.26 7.32
BP-175	447 922 632	595 1012 —

When the upper shoe hits the side block of the lower shoe, the energy absorption calculated from the load-displacement diagram is important in deteemining the characteristics of side block. Comparing the /energy absorption, Fc shoe is much less than BP, which reveal us the need for support of heavy bridge.

(3) Spring Coefficent of Shoe Block in Elastic and Elastoplastic Area

As a fundamental point, the spring coefficient can be obtained from the load-displacement diagram, shown Table 4.11. The spring coefficient of FC is much larger than that of the BP.

Table 4 11 Spring Coefficient of Shoe

Shoe	Displacement (mm)		Elastic	Elsstoplastic
	Yield	Failure	K1 ton/cm	K2ton/cm
FC-1-T	0.086	0.21	2800	950
Fc-180	0.135	0.35	2440	730
BP-175	0.420	7.20	1710	180

(4) Micrographic Consideration of Failure Faces

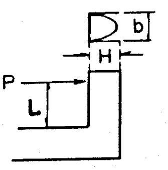
Material is cast iron made of graphite crystal spread on a metal foundation. Major failure occured at the boundary of the graphite crystal and metal foundation, where both were peeled off from each other.

As a result of these tests, the safety factor for failure of the actual shoes that is as low as FS = 1.3. when considering the elastic coefficient, extension and Charpie value.

The test results show that these specimens, as cast products, are of good quality. The 1.3 factor of safety is based upon the stress concentration on the bottom part of the shear block of the shoes as determined by the finite element method analysis.

The degree of concentration is approximately 1.5 - 2.0. As a result of this study, the following equations have been proposed:

$$P = \frac{1}{K_{b+s}} \cdot \frac{\sigma_0}{\sqrt{\left[\left(\frac{L}{W}\right)^2 + \frac{3}{A^2}\left(\frac{G}{F}\right)^2 \right]}}$$



where Kb+s: coefficient when both bending and shearing forces are acting.

when H/L 1 Kb+s = 1.0 X F

when 1.0 H/L 10, Kb+g = [1.0+log(H/L)] X F

F: will be determined by the shape of the section
G: is the corrective coefficient for sectional area
A: sectional area of shear block
W: sectional modulus of shear block
L: height of acting force at shear block
H: depth of beam of shear block

3-2 Response Analysis of Bridge Support with Earthquake

3-2-1 Major Factors Related to the Earthquake Response of Shoes on the Pier

Table 4.17 Load and Displacement of Shoe

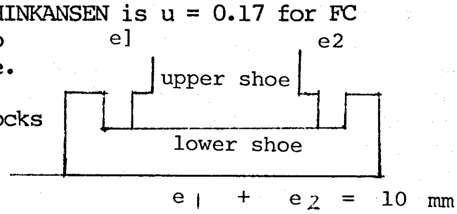
Kind of Shoe	Yield Load Displacement	Failure Load Displacement	Elastic K1 t/cm	Elastoplastic K2 t/cm
FC-1-T	24.1 tons 0.0086 cm	35.9 tons 0.0210 cm	2800	950
FC-180	32.9 tons 0.0135 cm	48.6 tons 0.0350 cm	2440	730
BP-175	71.8 tons 0.042 cm	193.9 tons 0.72 cm	1710	180

(1) Spring Force of Shoe Block
The results of the failure test show a large elastic coefficient value like K1 = 1710-2800 ton/cm, such as that indicated in Table 4.17 .

For comparison purposes, when a single column of a brige pier is 8 meters high, the span length is 20 meters, and the N value for the foundation is N = 30, the spring coefficient for the horizontal direction is about 1500 ton/cm, the rotative spring coefficient is 3 ton-cm/rad, crossword direction is 250 ton/cm, and the longitudinal direction is 130-100 ton/cm for the whole bridge pier. These values mentioned above are the values when loading begins. When deflections are large, spring coefficients become small. Here the high value of the shoe shearing block is clear and a larger force will be acting.

(2) Frictional Coefficient Between Upper and Lower Shoes
Through the use of solid lubricants, much of the friction can be reduced. These have been developed to the point that they can be used as BP shoes (plate shoes). With plate shoes, the frictional coefficient is u = 0.06 - 0.1. If the number of sliding repetitions becomes large and the plate shoes are clean, the frictional coefficient can be kept at about 0.1. However, if sand, rust or other elements get in between the frictional faces, the coefficient gets as much as 2.5 times larger. (u = 0.2)
When the line touches at a curved face and a plane, inversely, while it is clean, u varies widely, 0.1 - 0.7. When lightly rusted, u = 0.2 - 0.4. After a number of repetitions, it has a tendency to get smaller. The friction coefficient of the shoes used on the Tohoku SHINKANSEN is u = 0.17 for FC shoes, and u = 0.07 fpr BP shoes, according to the indoor test performed after the earthquake.

(3) Gaps Between Upper and Lower Shoe Side Blocks
(see illustration e1 and e2)



Usually e1 = e2 = 5mm. This is the result of allowing crosswise movement by prestressed creep or dry contration of concrete beam end and allowing some freedom considering the width is almost as large as 10 meters. Although the setting of the shoes is treated very cautiously, the variation of gaps exist, and according to our measurement, the mean value of variation, that is e1 - e2, is about 6.2mm.

According to the static loading test for the BP shoes, elastic displacement of its side block is 1 mm, and the maximum displacement at failure is about 7 mm. With the difference between the maximum and the minimum gap e at 6.2 mm, usually every side block will act unanimously. On the other hand, for FC shoes, given the maximum displacement of 0.3mm, it is rather impossible for each side block of each beam to act unanimously.

<u>3-2-2 Dynamic Analytical Model</u>

(1) Bridge Condition
(i) Girder length : L = 15, 20, 25, 35, 45 meter for concrete girder
20, 32 meter for steel girder
(ii) Pier height : h = 8, 11, 14 meter
(iii) Foundation : Footing foundation (N = 20, 50), Pile foundation
(iv) Kind of shoes: Fc-180, Fc-1-T, Fc-2-T, Bp-175 for concrete. Fc-15 for steel girder.

The above mentioned kinds are picked up as representative and they are analyzed. Beam, Bridge piear are represented by mass, spring coefficients, sectional area etc. of each segment and they have been analysed as amulti mass system.

(2) Input Condition

(i) Earthquake wave

June 12th 1978 JNR Sendai Office Bldg, 1st basement (EW)
Feb 20th 1978 JNR Sendai Office Bldg, 1st basement (EW)
June 12th 1978 Sumitomo Sendai Bldg 2nd basement(NS)

(ii) Maximum acceleration input

For FC shoe : 150, 200 gal. For BP shoe : 200 gal

(iii) Frictional Coefficient

FC shoe ; =0.15, 0.17, 0.2, 0.25, 0.3, 0.4. For BP shoe : = 0.07

(iv) Gap

FC shoe : e=5 mm, 0, (2,8), (2,4,6,8). BP shoe : e=5 mm, (19), others

(v) Damping constant : h = 5 % (in case of 19 only h = 10%)

(vi) Vertical reaction for superstructure per shoe in calculation

FC-1-T	Reinforced Concrete Beam Span	L = 15 meter	P = 49.9 ton
		L = 20 meter	P = 76.0 ton
FC -180	Prestressed Concrete Beam	L = 25 meter	P = 83.5 ton
BP-175	Prestressed Concrete Beam	L = 35 meter	P = 79.2 ton

(3) Result of analysis

(i) FC shoe

In case of e = 5 mm, 150 gal input does not give rise to failure even friction coefficient = 0.15, but 200 gal input both movable and fixed shoes broken when = o.17, only movable shoe are broken when = 0.2 - 0.4.
In case of e = 2,4,6,8mm, that is gap is more than max. displacement at failure naturally each block is broken one by one. (see case 9, 23).
When input is 150 gal and if friction is = 0.25 Or more both girder and piers vibrate in the same mode. There is no relative speed among them, therefore no collision.

(ii) BP Shoes

If the gap is widened more than the standard e total = 24 mm instead of 10 mm like in case 36 the failure occured by collision one by one.
When the weight of the super structure is 175 ton which is the max. designed load, failure occurs with both standard and widened gap.(case 17, 25)
Supposing low temperature britleness, kl = k2 = 175 ton, p2 115 ton, = 0.7 mm. (case 20) The 200 gal input with = 0.07 gives rise to failure.

<u>3-2-3 Problems of FC,BP Shoes</u>

(i) Gap between upper and lower shoes

Gap should be carefully controlled according to the standard value so as to act at the same time, the placing of shoes should be with enough accuracy so as to corresponding with each engineering characteristics. On the other hands, from the Prestressed Concrete's creep and dry contraction of concrete, the gap should be more than 2 mm.
For FC shoes, allowable dislacement is as small as 0.3 mm so the 1/10 mm accuracy is needed, but for BP shoes the allowance is 3-4 mm so 1 mm order accuracy is enough.

There are different ideas as to wether the gap should be wide enough so as not to collide the side block of upper and lower shoes according to the amplitude of earthquake responces.As the gap widens , the impact force at collision becomes larger.Therefore, it is necessary to absorb the foce by way of damper like rubber etc. However, in railroad with rail as a guide line, the displacement in a crosswise direction is limited, therefore this idea of room to be free is not applicable to railroad design.

(ii) Energy Absorption Capacity
From the result of the failure test, the FC1-T shoe has 4.70-10.78 kg meter, avarage 7.6 kg-meter, FC 180 shoes has 4.36-15.80, avarage 9.50 kg-meter, BP 175 shoes has 417-1012 kg-meter, avarage 606.9 kg-meter
The result shows a large variation, 30%-60%.

(iii) Quality control of casting material especially total carbon content and silicon varies quite a bit. This causes a lot of mechanical characteristic variation.

(iv) Poor Ductility of FC and BP. It is apt to be broken one by one, especially for FC shoe.

For each side block coacting, upper and lower shoe should be in the right center, and the gap should exactly 5 mm. Another way is to take e=o,which makes the displacement small and is endurable up to a 150 gal input.

In these propotions, the roll of the side block is effective untill 150 gal input.Meanwhile, if there issome spring besides friction in the sliding in gap, displacement will be further limited. In actuality,on the revenue line, rigidity of the raile is acting in this roll, which restricts the movement so as not to collide. This may be the reason for no failure in the operating line.

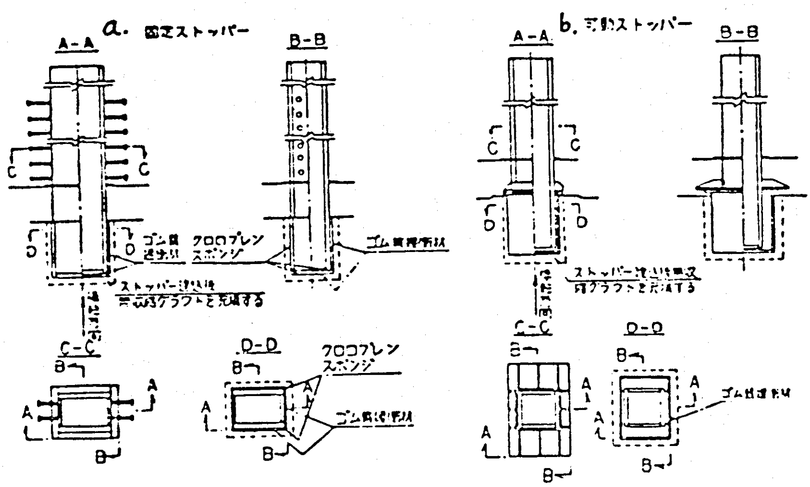


Fig 5.2 Structure of Steel Rectangle Stopper

4. Steel Rectangular Stopper Accompanied Shoe

4.1. Outline

FC,BP shoes have a lot of merits therefore they have been existing for a long time; the merits are as follows: (1) cheap and easy to get; (2) friction coefficient is rather low, the only demerit is its weakness in earthquakes.

BP shoes are applied to a longer girder, about 35 meters long span or more, however, if there exists sone variation in cast steel quality or some lack of accuracy in the product because of height collision of the upper and lower shoes, or the variation of gaps among the shoes,there is still a possibility of failure by one by one. And also there is a chance that they could experience failure due to an even more severe earthquake than this time, too.

Shoes with steel rectangle stoppers are the convined shoes of the conventional FC or BP shoes and steel rectangles as a stopper - instead of side blocks of FC or BP shoes, where the steel rectangle inserted into the end of the beam and the bridge pier and by which super and sub-structures are connected, and to perform the roll that was formerly done by side block of shoes.

The function of the bridge support has been classified two elements and two members are convined and coacting bringing about the possibility of economization.

As for the philosophy of an earthquake resistant design of railroad in JNR, formerly mainly depending upon the class of the line by traffic volume the seismic coefficient to be applied to design is determined from 0.10 to 0.25. In some cases 0.30. Recently it has depended upon the maximum train speed in the line, with some variation. The current tendency shows the idea of minimizing the expected damage on the train, which will be increased much by the speed, and also the importance of the value of human life. According to this policy, high speed mass transportation like the SHINKANSEN must maintain safety even during an earthquake.

According to the researches and regulation at highspeed area, the design criteria of bend-up angle or gaps of centerline of track at highspeed is quite severe. Horizontal gaps of the neighboring span bridges are 6mm and the vertical gap is 11mm at V = 250 km/h, that is, horizontal restriction is almost half of the vertical one. The tendency of horizontal severity is fundamental for railroad and which will be the major difference between the highway where the automobile is running with rubber tire freely instead of being guided by rail.

4.2. Structure of the Steel Rectangle Accompanying Shoe.

4.2.1 Outline of the Structure

Steel-rectangle-stopper-accompanying-shoe is made as shown in Figure 5.1 of steel rectangle stopper placed between the two end beams. There exists no side blocks with the shoe.

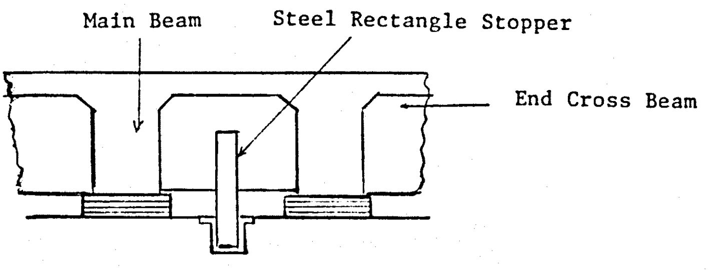


Figure 5.1

Detailed structure of fixed stoppers on fixed side of bridge is as follows: the upper end of stopper is anchored to the end cross beams, and the lower end is inserted in the sub-structure, being covereed by a synthetic rubber plate reinforced by stainless steel (PTFE sheet) expecting a damping effect even though it may be small. The movable stopper corresponds to the movable support is fixed at the upper end simmilarly with the fixed one. And the lower end is made to allow a slide in a longitudinal direction by providing movable room, and in a cross direction, to bear the transmitting horizontal force throulgh PTFE sheet at stopper surface.

4.2.2. Confirmation Failure Test

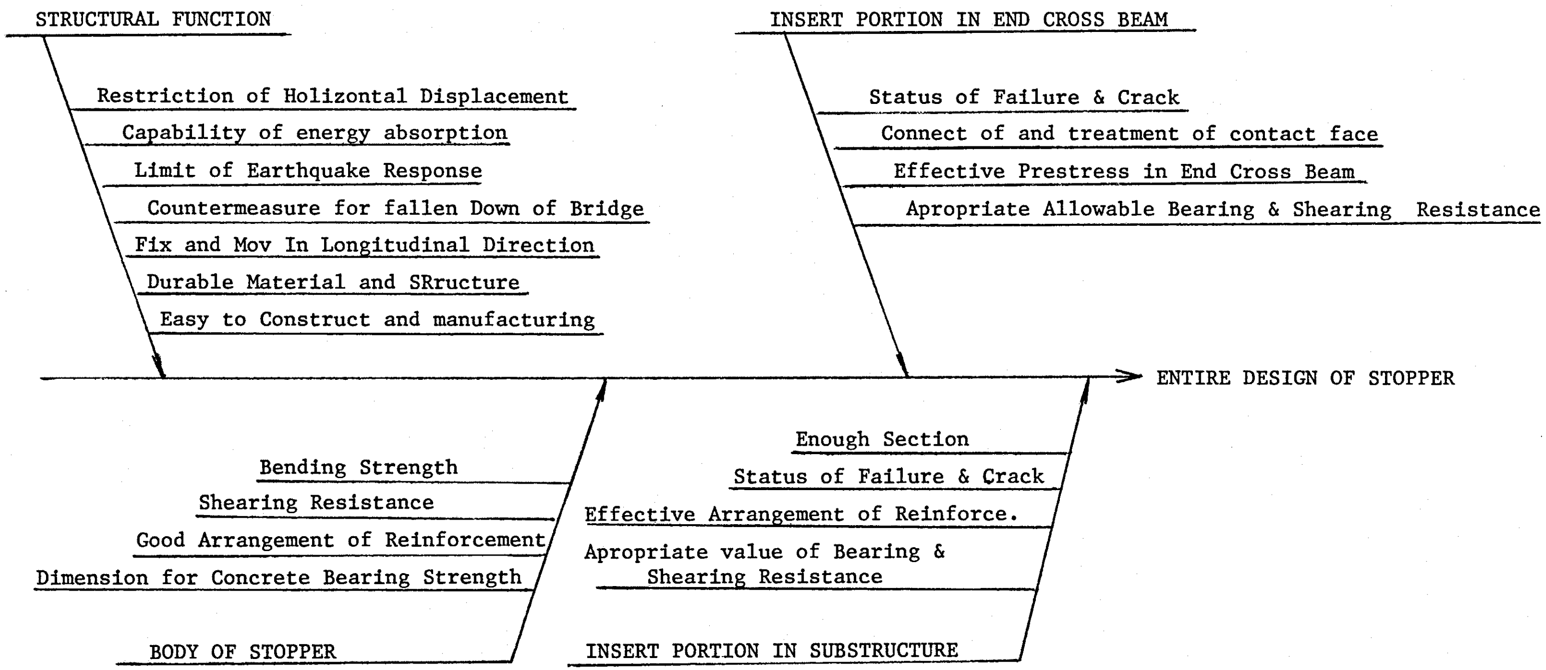
When designing the steel rectangle stopper to gather the necessary information, the confirmation test has been done by making six kinds of specimens and conducting a loading test. Six kinds of specimens are made for discussion of reinforcement of the pier top the end cross beam, the mecessary length of insertion of steel rectangle stopper and the effects of standing dowels.

Table 5.3 Kinds of Specimens

Purpose	Insertion	Length of Insert	Nominate	Standing Dowel
For Super	PC	35mm total 90.5	PC-1	22-150 3rows,3steps
Structure	Beam	60mm total 120.5	PC-2	22-150 3rows,5steps
		90mm total 150.5	PC-3	22-150 3rows,7steps
		90mm total 150.5	PC-4	None
	RC Beam	90mm total 150.5	RC-5	22-150 3rows,7steps
Sub-Structure	RC Pier	35mm	P-1	None

The design components to be considered can be shown in Figure 5-14 which will indicate that there exists alot of branches of design components.

Fig 5.14 Design Components Of Stopper



While testing specimens, displacement, shape and size of cracks and etc. are measured at each step of loading as shown in table.

Table 5.4 Item of Measurement

Kind of Measurement	Major Item
Strain Measurement	1. Steel rectangular stopper. 2. Reinforcement at inserted portion 3. Surface strain of concrete surface (PC-3 only)
Displacement Measurement	1. Steel Stopper 2. Horizontal displacement of end cross beam.
Observation	Shape and size of hair cracks of inserted portion of concrete.

4.2.3. Consideration on test results

(1) Design method

Every necessary dimension is based on the assumption that steel rectangle is rigid, there is a straight line distribution of strain, and that there is an equilibrium condition of outer forces acting to steel rectangle and inner stress of concrete.

With the standing dowels placed at the stopper body is expected that there will be a widening of stress distribution area or width of shearing resistance and bearing power. By the test result the effectiveness of dowels was clear.

<u>a. Insert Length of Stopper</u>

Insert length is determined so as to satify the concrete bearing strength and to have enough room for the reinforcements for shearing resistance surrounding the inserted stopper.

Figure 5.15 Shows the relation between load and displacement at loading point (point D1) for each specimen.

Table 5.6 shows permissibles loads compared with that determined by allowable stress of concrete and steel rectangle. Every permissible load by test result in this table is determined by the crack width of 0.2mm wide. Which is the least amount among the steel rectangle strength, reinforcements and crack width.

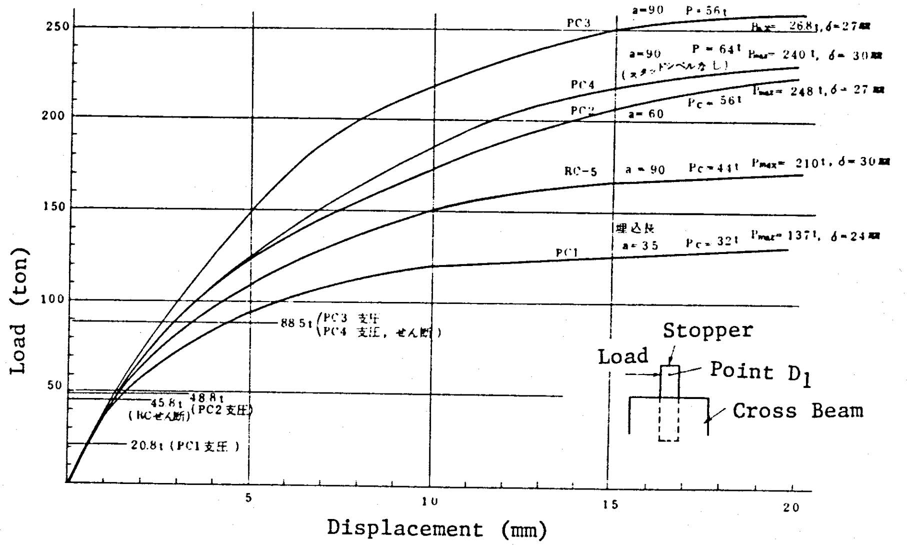


Fig 5.15 Load Displacement Diagram (point

Table 5.6 Permissible Load (Ton)

Specimen	From Concrete Bearing	From Concrete Shear	From Steel Bearing	From Steel Shear	From Test Result	F.S.
PC1 (35mm)	20.8	48.0	145	72.3	48	2.31
PC2 (60mm)	48.8	86.1	138	112.0	97	1.99
PC3 (90mm)	88.5	130.8	129	151.0	180	2.03
PC4 (90mm)	88.5	84.8	129	151.0	68	0.77
RC5 (90mm)	70.8	45.8	129	151.0	81	1.77

( ) Inserted length in cm.

For determining the most appropriate insert length for this kind of stopper, the design requirement to be fullfilled is a horizontal displacement allowance of bridge in an earthquake at high speed and the state and width of the crack, concrete bearing stress which should be within the limitation and provision of the standing dowels at the upper stopper insert portion so as to reduce the crack width of the beam's concrete and shearing stress maintained within the limit.

b. Bending of Steel Stopper

By comparison of the bending amount among the measured test results calculated elastic displacement and the result of Finite Element Method analysis. The usual elastic displacement calculation shows very conservative numeric figures.

c. Inserted Portion In An End Cross Beam

The maximum strain give rise to a U-shaped reinforcement around the stopper through lateral force. However, the magnitude for the design load is according to the measurement far short of their limit. So the traditional way of design will be applicable for safety.

d. Inserted Portion in a Sub-Structure (Bridge Pier)

An initial hair crack occured at about 40 tons far less than the design load of 88.5 tons. The reasons is the shear stress along the failure line is not the same value at the same time. However, the width of 88.5 tons is 0.3mm wide and after de-loading the crack almost closed,this shows th reinforcement is well enough for design load, provided that the direction of the final failure line from the bottom of the steel rectangle to the forward face is inclined about 20 degrees.

(2)Comment on Structural Shape of Stopper

The transmission of lateral force through rubber sheet by steel rectangle stopper among sub-structure and super structure is a special feature.

a. Function of rubber sheet
The bearing strength for the vertical load is about 2000 or 3000 Kg/cm2. While the acting load is low the stress distribution is not very good, yet for a large force, stress is well distributed.

b. Factor of safety of the stopper for failure
From the end cross beam portion the ratio of the ultimate load and design are 2.99 for PC-3, 2.7 for PC-4 and 6.6 for PC-1, this being the largest. However, for the bridge pier, the same ratio is only 1.55 but this includes a 1.25 factor for a distribution load by the FM-FM shoe layout. Therefore 1.25 x 1.58 =1.98) 1.75 of maximum response for input, therefore the safety against failure will be kept.

4.3 Energy absorption capability of bridge support accompanied with steel rectangle stopper.

The characteristics of earthquake resistance of the accompanied shoes are obtained by dynamic analysis and then the items of frictonal influence on sliding shoes the differences between slide shoes and rubber shoes as accompanied shoes are discussed.
Then based upon the results of dynamic analysis absorbed energy by the steel stopper was estimated and further the design criteria such as enveloping the necessary energy absorption capability was estimated. Then similar criteria for FC and BP shoes ar obtained.

4.3.1. Dynamic Analysis

(1) Representing Structure

As a typical structure an RC T-beam with a span of 20 meters and a PC beam with a span of 30 meters were selected. Since the dynamic response is almost corresponding to their natural frequency, the shortest case of l=20 meter, H=5 meter and the longest case of l=30 meters H=16 meter N = 30 kg/cm3 was discussed.

(2) Analytical Model

Relative displacement between pier and beam acting by lateral force to the steel stopper is to be the sum of (1) rotation of steel rectangle (2) Elasto-plastic displacement by bending and (3) compressive strain of hard rubber sheet inserted in the gap between the box and the steel rectangle.
At first the coefficient of spring was obtained as the beam on the elastic slab and K2 = 1/20 x K1. But later based upon the result of the test K2 is approximately 2/3 of K1.

Friction of sliding shoes was considered as bi-linear hysteresis spring of $\pm$ 0.1 mm at $\pm$ MRd; where M: frictional coefficient Rd: deadload. Rubber shoes have no friction though, shear deformation is considered where the coefficient of spring is 25.2 ton/km, l=20 meter RC beam for both ends respectively.
Bending rigidity of the sub-structures is expressed by degrading tri-linear, with the bent point of the yielding point of reinforcement and the crack point of concrete.
Springs of the bottom and side face of the footing are calculated from measured example and based upon the criteria of the JNR Structural Design Standard and earthquake resistance design.

(3) Input earthquake wave, The input wave includes the following four waves. a. JNR Office Bldg (E-W) at Sendai, Miyagi-oki Earthquake [Sendai(Feb)]. b. Imperial Valley Earthquake(1940. May 18) El Centro (N-S) [El-Centro], c. Tokachi-oki Earthquake (May 10, 1968) Hachinohe Harbour (EW), d. Miyagi Prefecture Off-shore Earthquke (June 12 '78) JNR Office Bldg (EW) [Sendai (Jun)].

Sendai (Feb) has a lot of short period components, but small responces. However, in late June, we got a responces in Sendai(Jun), which wave used with El-centro and Hachinohe.

(4) Analytical case (Table 6-4) Steel rectangle accompanied by FC,BP and Rubber shoes cases are included, totalling 22 cases.. Major components are the rigidity of steel rectangle stopper (0.25, 0.30, 0.38), span length(20, 30 meters), height and style of pier, foundation, ground condition(n=30, 100, 300, and soft ground), Friction coefficient(0.0, 0.05, 0.1, mainly 0.05) and 4 waves of earthquake, and the input acceleration (mainly 200, 300 gal).

(5) Result of Analysis.

a. Effect of Friction As the friction coefficient increases, 0, 0.05, 0.010, the lateral force acting on the stopper decreases. There is a tendency to decrease the exchanged seismic coefficient by the corresponding amount of the friction coefficient. (Table 65)

Table 6.5 Crosswise Response by the shoe condition

Case	Friction Coeff.	Beam Acc gal		Beam Disp cm		Stopper Rel.Dis. mm		Stopper Exch. Sies Coeff.		Plastic Ratio	
		F	M	F	M	F	M	F	M	F	M
1	0.1	2.61	3.81	1.37	2.15	0.9	2.1	0.17	0.22	0.20	0.50
2	0.05	2.70	3.63	1.47	2.18	1.2	2.4	0.22	0.255	0.27	0.58
3	0.00	2.77	3.74	1.63	2.29	1.6	3.0	2.91	0.32	0.35	0.72

Earthquake wave ; Sendai (Feb) (EW)

b. Effect of Rigidity of the stopper The acting force on the stopper, that is the exchanged seismic coefficient, is increasing some extent with the rigidity of the stopper, but the rate of increase is about 10 % of the increase rate of the stopper rigidity. At the same time, however, the rate of plasticity, relative displacement, strain energy tend to decrease. In particullars, the plastic rate is exceding far more than unity, it can be lowered efficiently according to the additional rigidity of the stopper.

Table 6.6 Crosswise Response by the Rigidity of Stopper

Case	Seismic Coeff. for stopper gal	Beam Acc gal		Beam Disp cm		Stopper Rel.Dis. mm		Stopper Exch. Sies Coeff.		Plastic Ratio	
		F	M	F	M	F	M	F	M	F	M
2	0.38	270	363	1.47	2.18	1.2	2.4	0.225	0.255	0.27	0.58
4	0.25	263	372	1.37	2.08	1.3	3.5	0.196	0.233	0.34	0.94

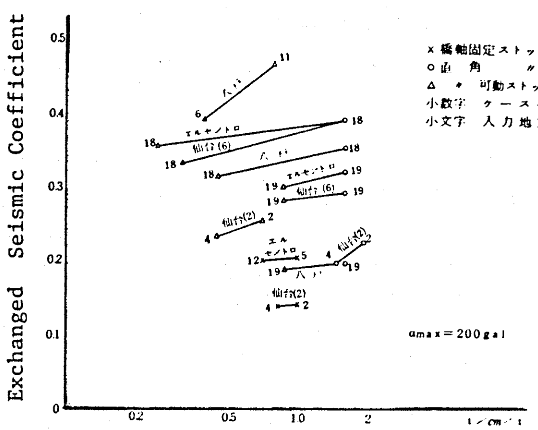
c. Foundation As the height of pier increases, and the ground becomes softer, the exchanged seismic coefficient, though not of a certainty tends to increase. The plastic rate of the longitudinal direction is 0.5-0.6 for Fixed,and the cross direction is 0.9-1.6 for Mov. and 0.37-0.39 for Fix. The possible reason for this can be that there are differnces in the pier rigidity by FF MM shoe lay-out, where the dimensions of Fixed and Movable piers are different. This gives rise to a difference in the phase of shake, so through friction, some damping effect will occur. Although for the crosswise direction, piers can be considered rigid, for longitudinal direction, a concrete hysteretic damping effect will be acting.

d. Longitudinal Response. If the factors of friction or crack in concrete body are neglected, the exchanged seismic coefficient, plastic rate and srain energy increase up to almost the value the crosswise direction.

e. Accompanied rubber shoe Comparing the corresponding sliding shoe, the exchanged seismic coefficient, thatis, the lateral force to stopper,increase because of a lack of friction.
In the case of a 300 gal input the exchanged seismic coefficient is o.75 and the plastic value still remains 2.1 and also crosswise relative displacement keeps less than 13 mm. Therefore it can be safe.

4.3.2 Conclusion of this article.
(1) In case of sliding shoe the acting force to steel rectangle stopper is reduced by about an amount corresponding to the friction coefficient.(crosswise direction).
(2) As the rigidity of the steel rectangle stopper increases, the force acting on them tends to increase.
(3) As the pier height increase and the ground becomes softer, the forces acting on the steel rectangle stopper are likely to increase, but not remarkable.
(4) The forces acting on the steel rectangle stopper depend upon the shoe lay-out, In the case of the FF.MM lay-out with wall-type pieres, the crosswise force is larger than longitudinal force by 20-40 %. In the case of the FM.FM shoe lay-out, the exact same response is obtained.
(5) If the ground surface is very soft, its response is amplified or damped in some cases.
(6) New steel rectangle stopper accompanied by rubber shoes designed in accordance with the Earthquake Resistant Design Standard (draft) do not fail and crosswise displacement is about 1cm with a max. 300gal input.

4.3.3 Necessary Capability of Energy Absorption of the Stopper
The relative displacement between beam end and pier top is exactly the same as the displacement of the operating point of and operating direction of the force acting on the steel stopper.



Exchanged Equivalent Linear Unit Spring Coefficient k

Fig 6.3 Rigidity of Stopper & Exchanged Seismic Coefficient

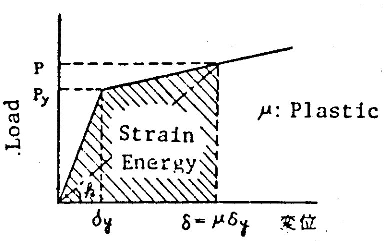


Fig 6.2 Load Displacement

Therefore, in the case of the shoe accompanied by the steel rectangle stoppeer,using a spring coefficient and a yield point of load as shown in Fig. 6.2 the strain energy in the steel stopper can be calculated for each analytical case. On the other hand, in the case of the BP.FC shoes, there are gaps between upper and lower shoes, so displacement of the operating point is the remaining amount from the relative displacement between the beam end and pier top reduced by the amount of gap mentioned above. Using the real displacement and acting force, the strain energy can be calculated. Thus we can dicuss the necessary capability of energy absorption of steel rectangle stoppeer and also side block of sliding shoe.

(1) Equivalent linear spring coefficient and exchanged seismic coefficient.

After the steel rectangle bing deformed in plastic area, for the purpose of evaluating its rigidity as like as elastic area the idea of equivalent linear spring coefficient was introduced as shown in Fig 6.2. The exchanged seismic coefficient is the quotient of the acting force on the stopper divided by W'. The exchanged equivalent linear spring coefficient is difined as

k = K / W', where K = equivalent linear spring coefficient(P/)
W'= exchanged weight of beam (W), crosswise W'=W/2, longitudinal W'=W.

Comparison of the rigidity and the acting force is shown in Fig 63, where the condition other than rigidity is the same. The figure shows as k increases the acting force on the steel rectangle increases.

(2) Strain Energy and Rigidity of Steel Rectangle Stopper

According to the same combination in Fig 63, the relation between strain eneergy and the equivalent linear spring coefficient k as shown in Fig 64. Where the exchanged unit strain energy is defined as e = E / W' , where E: strain energy.

From Fig 64, as the rigidity of the steel rectangle stopper increases,the strain energy clealy decreases. The reason is that as the rigidity of the steel rectangle stopper increases, exchanged seismic coefficient increases only a little as shown in Fig 63. Inversly the displacement decreases quite a bit.

Assume that the rigidity variation has negligible small impact for entire system, and the input is the same.

e = 1/k exp(n) n=positive figure. less than unit, for elastic area.
more than unit, for plastic area. n=1, for force is const.

(3) Relation between k and e on the analytical results of each response.

Plotting all results of dynamic responses classified by input acceleration, Fig 66 for 200 gal input and Fig 67 for 300 gal are drawn.Then making an envelop curve in the max. value, we got the following equation for the input acceleration of 200 gal.

b, Longitudinal direction, slide shoe e=0.9/k exp(1.25).
Therefore,if the input increases from 200 gal to 300 gal, the strain energy increases about 1.5-2.5 times.

(4) Necessary energy absorption capability.

]n Fig 69 the necessary capability of energy absorption which envelopes all 300 gal input responces is shown.

By using Table 6.9, we can determine the energy absorption capability e of steel rectangle or side block of BP FC shoes. It can be constructed in safety enough for bridge support.

Table 6.9 Necessary Energy absorption Capability by Input Accereletion

Input Acc.	Crosswise	Longitudinal		M≦0.1	M≧0.2
		FF.MM	FM.FM		
150 gal					≒o.1
200 gal	1.5/k	0.6/k	0.8/k	≒0.4	≒0.25
300 gal	3 /k	1 /k	1.5/k	≒0.8	≒0.5

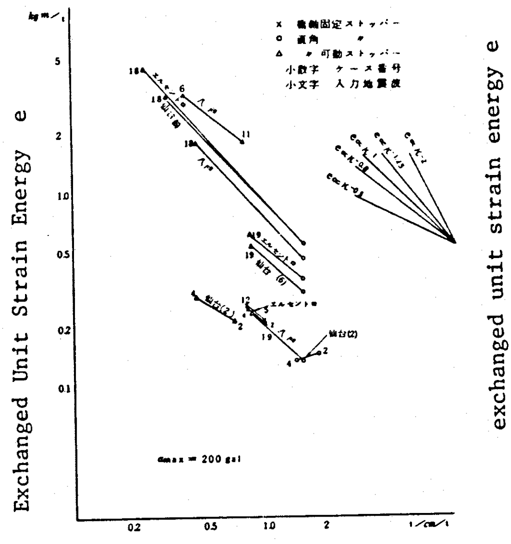


Fig 6.4 k & e of the same conbination except rigidity of stopper

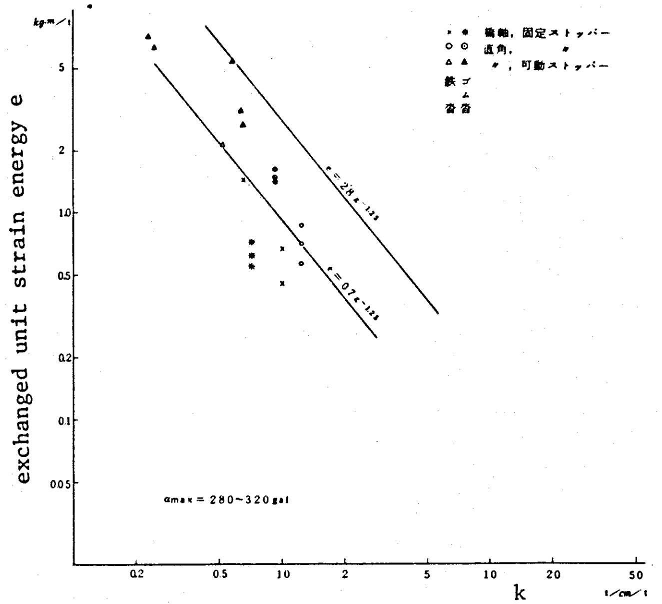


Fig 6.7 Relation between k and e (max. 300 gal input)

5 Application to Railroad Bridge

As areas for major application of this study, I picked up the following items.

(1) As a fundamental solution of side block of FC.BP shoes,the steel rectangle stopper accompanied shoes are proposed, by which the roll of them are highly improved.

(2) Economical application can be considered by accompanied shoes.

(3) For existing railroad bridge, if we considered the function of the spring of the rails, not only will the light steel bridge be safe, but also concrete bridges with a ballasted track be safe for a 200 gal input.

5.1 Application Rule in JNR

This shoes accompanied by steel rectangle can be applied to middle span concrete bridges. As an accompanied shoe, in order of optimal economy, there are rubber shoes, FC shoes, and BP shoes. In the case of the rubber shoe the height of the shoe will be lowered, so the bending moment to the steel rectangle will be reduced and it will become economical

I will introduce the one of the application rule as shown in Table 7.1

Table 7.1 Application of steel rectangle accompanied shoe

kind of beam	span in meter	Reation in ton	Convination of shoe
RC T-beam PC Slab beam	10 < l = 25	R ≦ 150	ES + As
		R > 150	LSn+ As/or LS(SCW)
RC Box beam PC I-beam PC Box beam	l < 25	R ≦ 150	ES + As
		R ≧ 150	LSn + As/or LS(SCW)
PCthrough girder PC slab beam	45=l > 25		BPn + As/or BP(SCW)

where ES; rubber shoe AS; steel rectangle stopper LSn; FC shoe without side block Bpn; BP shoe without side block LS(SCW), BP(SCW); new strengthened side block shoes, applied in low speed track only.

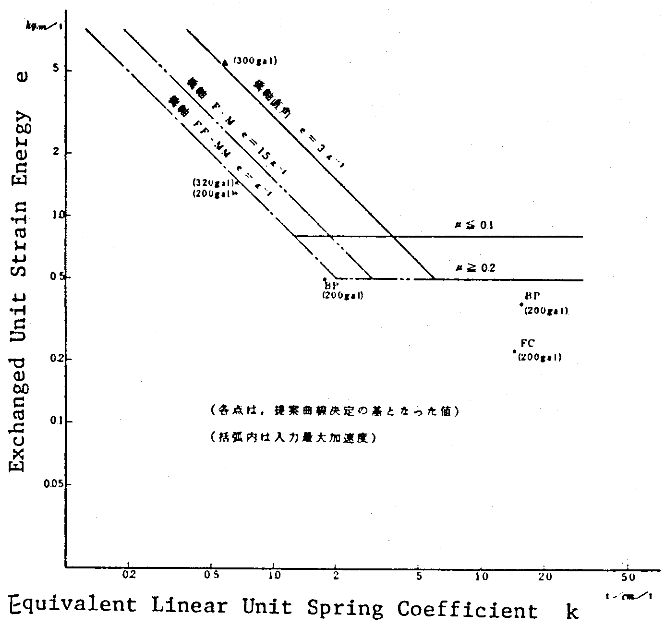


Fig 6.9 Proposed Necessary Strain Energy

The rule of application is as follows;
(1) In the case of span of 10 meters to 25 meters and with reaction up to 150 tons, Rubbershoes and steel rectangle stoppers should be adopted for both reinforced concrete beams and prestressed concretebeam.
(2) In the case of spans less than 25 meters and where reaction exceeds 150 tons, FC shoe without side block and steel rectangle stopper should be adopted for all beams.
(3) In the case of spans from 25 meters to about 45 meters, BP(cast steel) shoes and steel rectangle stopper should be adopted for both reinforced concrete and prestressed concrete beams.

¨6 Conclusion

FC shoes, formerly used as slide shoes, have a long history in Japan. After suffering damage from the Great Kanto Earthquake, Fc shoes were improved. However, in the case of inducing large displacement by train load, sometimes they experienced cracks. Further, in the case of the Miyagi Prefecture Offshore Earthquake they experienced a large rate of damage.

According to the study of the failure of FC shoes, in the case of the large response of bridge piers, that is, earthquake movement,and where pier was heigh, the rate of failure will increase. Therefore it appears that it is necessary for the capability of deformation corresponding to the amount of displacement of response to be given to the shoe design. This measure that was identified by itself, also effectively reduces the chance of shoe failure.

After designing by conventional method, using the seismic coefficient, and then confirming the capability of energy absorption (Eab), the steel rectangle or side block of shoe exceeds the necessary energy (W' e) given by Table Fig

Also, the inserted portion of the steel rectangle stopper shall be reinforced enough. Good distribution of stress by standing dowels for the upper stopper or the end cross beam portion is prefarable. For the lower or the bridge pier head portion adequate reinforcement against longitudinal force is important.

According to the procedures for design mentioned above, the steel rectangle accompanied shoes will be the struture that restricts the severe horizontal displacement for design load on heigh speed railroads. Even with an earthquake movement that exceeds the design load that has an adequate capability for energy absorption, failure won't occure although the displacement becames large.