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MODERN CONCRETE CROSSTIE EXPERIENCE IN FRANCE AND MEXICO

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16. Abstract

(1) Considered briefly is the history of concrete crosstie development in France. Failure of some crossties in 1973 led to a determination of the failure modes and a rigorous analysis of the service load limits to be taken into account. New crosstie designs evolved from this investigation. Technical specifications and acceptance tests for crossties fabricated according to the new design criteria are described. New-concept crossties under current assessment are also described.

(2) The reasons for the adoption of the concrete crosstie by Ferrocarriles Nationales de Mexico (National Railways of Mexico) are presented. Details of manufacture and testing of these crossties are described. Specifications for concrete crossties are presented. Consideration is given to the performance of crossties and fasteners under service conditions. Some causes of crosstie failure are identified.

17. Key Words France, Mexico, concrete crossties, mixed or two-block crossties, crosstie design, new concepts, crosstie fabrication, failure inducing conditions, acceptance tests, performance requirements, concrete constituent analyses.

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PREFACE

Many railroad administrations abroad have made substantial commitments to the inclusion of concrete crossties within the trackage of their networks. In the United States, only the Florida East Coast Railway Company and the National Railroad Passenger Corporation (Amtrak) in the Northeast Corridor have made similar decisions. In Canada, Canadian National Railways has installed many concrete crossties in its western lines, where curved track leads to frequent rail renewal.

Several U.S. railroads are sufficiently interested in the potential of concrete crossties to have installed test sections. At the same time, the Facility for Accelerated Service Testing (FAST) at the Transportation Test Center near Pueblo, Colorado, includes under present-test several varieties of stressed-concrete, mono-block concrete crossties, which are being subjected to a maximum U.S. wheel loading environment.

While it seems to be evident that concrete crossties, either monolithic or two-blocked, have performed successfully outside the United States, the question is still open in the United States as to how well these track system components will perform, over the long term, under the accepted loading environment of current U.S. operating practice. This service regime can include heavy wheel loads along with unsuspended load characteristics, such as wheel flats that contribute to a shock magnitude not known outside of North America.

The following text, specifically the report of French experience, in part, does consider an analysis of shock input to concrete crosstie survival. Mexican experience, with a load environment that can be expected to approximate that of the United States under similar operating conditions, indicates the nature of problems that can develop during the fabrication and use of concrete crossties and what was done about those problems.

Both reports present discussions of the concrete crosstie survivability question in an English-language version not available hitherto. The Federal Railroad Administration believes that making these data and viewpoints accessible to the general railroad community could facilitate further understanding of concrete crosstie application in the United States. In doing this, no endorsement of the reports' contents by the Federal Railroad Administration is implied.

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REPORT NUMBER I

THE NEW CONCRETE CROSSTIES OF THE SNCF*

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February, 1976

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SUMMARY

The Société Nationale des Chemins de Fer Français (SNCF) has recently supported important improvements of concrete crossties, in the form of two reinforced concrete, block-like shapes joined by a steel connection, which are used now in all the routes of the railway system. SNCF has developed a test which is designated "behavior under exceptional loads" in order to guarantee performance of this type of crosstie when subjected to shock. At the same time, SNCF has placed in service a new type of prestressed, monoblock concrete crosstie (based on adequate bond of stressing strands to concrete) which meets the same test requirements as the two-block type. Having a lesser vertical dimension (thickness) than the two-block ties (17 cm versus 22 cm [6.75 in versus 8.69 in]), SNCF will use them, for the most part, in regions where the subgrade or track soil foundation is poor and particularly in areas where it is not desirable to raise the longitudinal level of the track (electrified territory, for example).

The text describes these two types of concrete crossties and mentions other types of solutions to the crosstie question which are being examined in the laboratory at this time.

THE NEW CONCRETE CROSSTIES OF THE FRENCH NATIONAL RAILWAY (SNCF)

REVIEW OF PAST USAGE OF CONCRETE CROSSTIES BY THE SNCF

The use of concrete as a railroad track crosstie material became fully satisfactory only after the appearance of long welded rail and the attachment of rail-to-tie by an elastic fastener associated with a grooved rubber pad between the rail and tie. Although more than a million reinforced concrete crossties, of the type VAGNEUX, with rigid fastenings were installed in the track between 1927 and 1947, it is only with the appearance of the elastic rail fastenings in 1947 that concrete ties achieved widespread utilization.

The concrete crossties were first employed in noninsulated track, without automatic signals and having relatively light traffic. Then, after development of satisfactory insulating devices, their use was progressively extended to automatically signaled track equipped with track circuits and sustaining heavy traffic.

By 1967, there had been installed in the network of the SNCF:

- 230,000 monoblock, prestressed ties of the type SCOP (between 1948 and 1950);
- 870,000 prestressed monoblock ties of the type VW (between 1950 and 1966) (see figure 1);
- 5,260,000 reinforced, two-block crossties joined by a metal connecting bar (see figure 2);

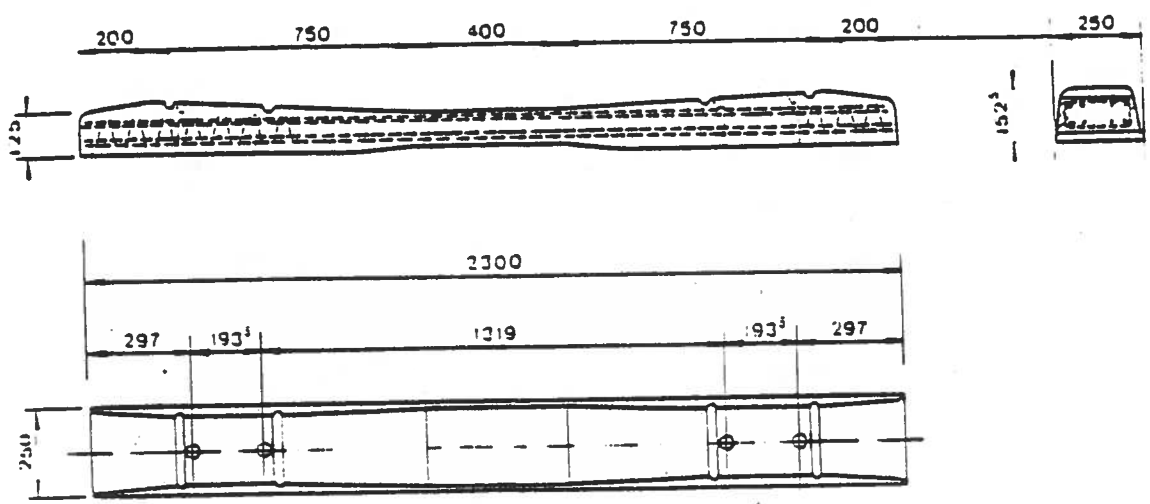


FIGURE 1. PRESTRESSED MONOBLOCK CROSSTIE, TYPE VW
(DIMENSIONS IN MILLIMETERS)

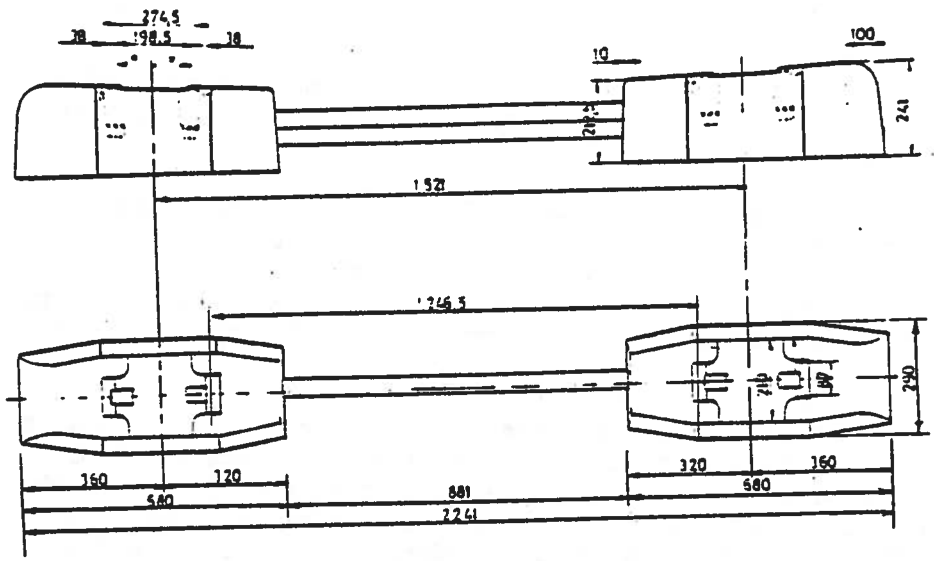


FIGURE 2. TWO-BLOCK CROSSTIE, TYPE U2 (PRIOR TO 1974)
(DIMENSIONS IN MILLIMETERS)

The manufacture of the VW prestressed concrete tie, which was more expensive to fabricate than the two-block tie without offering greater advantages, was suspended at the end of 1967. From that point on only the two-block, reinforced ties of the types VAGNEUX or SNCF-RS (replaced in 1969 by SL), were used.

The concrete crosstie offers definite advantages when compared with the timber crosstie:

- longer life, approximately twice that of the timber tie;
- minimal maintenance required by rail-tie fastenings;
- greatly increased lateral track resistance due to the greater weight of the concrete tie.

But concrete ties also display disadvantages:

- susceptibility of the material to shock;
- material handling problems because of the weight of the ties;
- in locations where the track rests on a foundation of poor quality, preservation of longitudinal level is difficult because of important inertial forces developed during the passage of rolling loads.

But the most important disadvantage was the price of the concrete tie which remained for a long time notably higher than that of the hardwood tie, France having the good fortune to possess abundant resources of hard wood (oak and beech). It is for this reason that the number of concrete ties put in the track each year did not exceed 400,000 until 1968.

Following a progressive increase in timber tie prices drastically effected in 1973, this earlier situation was totally reversed and SNCF was led to expand considerably the use of concrete crossties; 930,000 in 1974, more than 1 million in 1975.

Formerly, it was the practice to install concrete ties principally in lines having moderate traffic where the life of the rail was about equal to that of the crossties (40 to 50 years), but without any restriction as to maximum speed limit assigned to a line. Recently, concrete crossties have been used in all lines at the time of track renewal where curve radii allow the use of long welded rails.

Fortunately, and at the same time, the quality of rail manufactured by the oxygen process was greatly improved particularly with respect to the cleanliness of the metal and tests recently made in the loop track at Velim in Czechoslovakia, showed that this type of rail ought to be able to support at least 350 million tonnes before renewal. Thus, even on tracks where traffic reaches 8 million tonnes per year, the rail will have a life comparable to that of concrete crossties. Only on lines having very heavy traffic will an intermediate renewal of rails be necessary.

DISCOVERY OF FAILURES IN CONCRETE TIES

It must be emphasized, that, under *normal* traffic conditions, the use of concrete crossties installed according to prevailing regulations under long welded rails on the SNCF has not presented any problem.

Two-block ties are used where train speeds commonly attain 160 km/hr (100 mph). They are used in the Paris-Bordeaux and Paris-Toulouse lines in areas where train speeds reach 200 km/hr (125 mph), and the reader's attention is directed to the numerous test runs of the turbine-driven train, TGV 001, at 300 km/hr (188 mph), between Bordeaux and Morcenx, carried out during a 3-year period on a line-segment fitted with reinforced, two-block concrete ties manufactured before 1974. In this location, as elsewhere, concrete crosstie track has behaved very well and the high lateral stability of the track, resulting from the tie weight and the engagement of ballast resistance afforded by dual-end regions of the two-block ties, was strongly confirmed in the course of these tests.

In 1973, on an important line where trains operated at 160 km/hr (100 mph), it was discovered that certain concrete crossties recently installed in the track were cracked, vertically, at the rail seat.

Subsequent investigation quickly revealed that, at the locations in question, the running surface of the rail displayed indentation marks which were attributable to the crushing by wheels of ballast particles remaining on the rail following the unloading of ballast. This specific incident led to an expanded inquiry carried out on other high-speed lines. Other defective ties were revealed, displaying cracks of varying seriousness, and directly associated either with engine burns which had recently been repaired by arc welding or butt-welds abnormally dipped (or drooped).

Except for the concrete crossties which had sustained violent shock consequent to the crushing of ballast particles, for example, the apparent cracks were hairline-sized and did not require replacement of the ties. The evolution of these cracks was closely followed and it was determined that there was no growth. Some traces of carbonation appeared, very similar to that often produced in reinforced concrete beams. Moreover, it was perceived that the cracks most often involved crossties installed in the track a very short time after their manufacture. It was decided to establish a minimum period of stockpiling of 3 months. Even so, given the overriding necessity of strongly supporting the use of concrete ties, a strengthening of these ties became a subject of investigation.

It will be seen that the resulting strengthening was very substantial without leading to negative cost-effectiveness.

CHARACTERISTICS OF TWO-BLOCK, REINFORCED CONCRETE TIES USED UP TO 1974. ACCEPTANCE REQUIREMENTS. LOAD ACCOMMODATING LIMITS.

Crosstie Characteristics

The two-block ties used by the SNCF are of two types, differing essentially, one from the other, by the system of bolt-anchorage assuring elastic attachment of the rails and by the shape of the connecting bar. They are manufactured by private companies which divide the market (in actuality, there are six factories). Up to 1974, these factories produced the following tie types:

- VAX U2, for which the producer is the firm, SATEBA (Société Anonyme de Traverse en Béton Armé);
- SL U2, developed jointly by SNCF and the firm, STEDEF (Société d'Etudes Ferroviaires).

These two-block ties, each block of which is octagonally shaped, and each block of which has a length of 0.68 m (26.9 in), and a width of 0.29 m (11.5 in) and a height under the rail of 0.22 m (8.7 in), are joined by a steel connecting bar formed from material reclaimed from old rails. The weight of these ties is approximately 180 kg (397 lbs). (See figure 2.)

The reinforcing of each block may be described as follows:

- an upper grid located at 30 mm (1.2 in) from the top of the tie;
- that segment of the steel connecting bar cast into each block;
- a lower grid located 30 mm (1.2 in) from the bottom of the tie;
- a spiral-steel loop in each block (see figure 7).

The reinforcing steel is smooth according to specification FeE22. The weight of reinforcement in each block, not including the segment of the connecting bar, is 3 kg (6.6 lb); the elastic limit must be at least 24 hbar (34,064 lbs/in^2).

The comparative characteristics of the two tie-types, U2, manufactured up to 1974, is given in table 1.

These crossties, "Model U2," resulted from successive refinements brought to bear by SNCF and the manufacturers following acquisition of experience.

A shape and reinforcing being defined, the quality of crosstie fabrication as specified by SNCF assures that the manufacturer complies with standards (control of concrete quality, control of reinforcement, dimensional control, and control of final product by load tests).

TABLE 1
CHARACTERISTICS OF TWO TYPES OF U2 CROSSTIES
(manufactured up to 1974)

Type of Crosstie			SL U2	VAX U2
Block Shape			Octagonal	Octagonal
Dimensions of a section under rail	Width of the top surface Width of the bottom surface Height	(in) (in) (in)	8.3 11.15 8.7	8.7 11.15 8.7
Upper reinforcement	Longitudinal	(in)	2 @ 0.3 (dia.) L = 17.4 2 @ 0.3 (dia.) L = ~23	2 @ 0.4 (dia.) L = 19.8 2 @ 0.3 (dia.) L = 19.8
	Transversal	(in)	3 @ 0.2 (dia.) L = 5.3	2 @ 0.2 (dia.) L = 6.3 1 @ 0.2 (dia.) L = 7.3
Lower reinforcement	Longitudinal	(in)	4 @ 0.3 (dia.) L = 24.7 2 @ 0.3 (dia.) L = 17.4	2 @ 0.3 (dia.) L = 24.7 4 @ 0.3 (dia.) L = 19.8
	Transversal	(in)	2 @ 0.2 (dia.) L = 8.7 2 @ 0.2 (dia.) L = 6.3	2 @ 0.2 (dia.) L = 8.7 2 @ 0.2 (dia.) L = 7.3
Connecting bar	Form		<	Y
	Vertical moment of inertia	(in^4)	1.66	1.56
	Distance between C.G. and bottom surface	(in)	4.3	2.8
	Length	(ft)	6.8	6.3
	Weight	(lbs)	25.7	25.9

Acceptance Requirements

Controls exercised by SNCF are carried out at several different stages:

- materials (components)--these must satisfy the requirements established by SNCF (Cahier des Charges) for reinforced concrete construction in force at the time of the order;

- materials (assembled)--the concrete must meet the requirements of Class B 410 (capable of sustaining a compressive force of 410 kg/cm^2

[5,819 lb/in^2]). An acceptance document would indicate (typically): aggregate size distribution curves, density, specific weight, void volume, nature and amount of cement, amount of water, results of tension and compression tests and duration, frequency, and amplitude of vibration of the concrete in the moulds.

These tests are conducted by the manufacturer, under observation by SNCF, at least once a month.

The strength required at 28 days is, as a minimum:

- in compression, 350 bars (4,967 lb/in^2);
- in tension, 28 bars (398 lbs/in^2).

These requirements are determined according to ministerial demands relating to public works transactions, section 21.55 of the catalogue of general specifications of the SNCF:

- dimensional verification of the crossties--this is carried out for all ties.
- control test based on static load applied to the blocks--one tie from each lot of 100 is subjected to (block) upright and reversed tests; the test set-ups (prior to 1974) are shown in figure 3.

Relevant to these tests, the load-involved supports are what might be called pivot joints, and there are plaster bearing seals at the points of load contact. Under these conditions, the crosstie partially functions as a dually articulated arch. Consequently, the test is conventional and its specific objective is control of the consistency of as-manufactured quality.

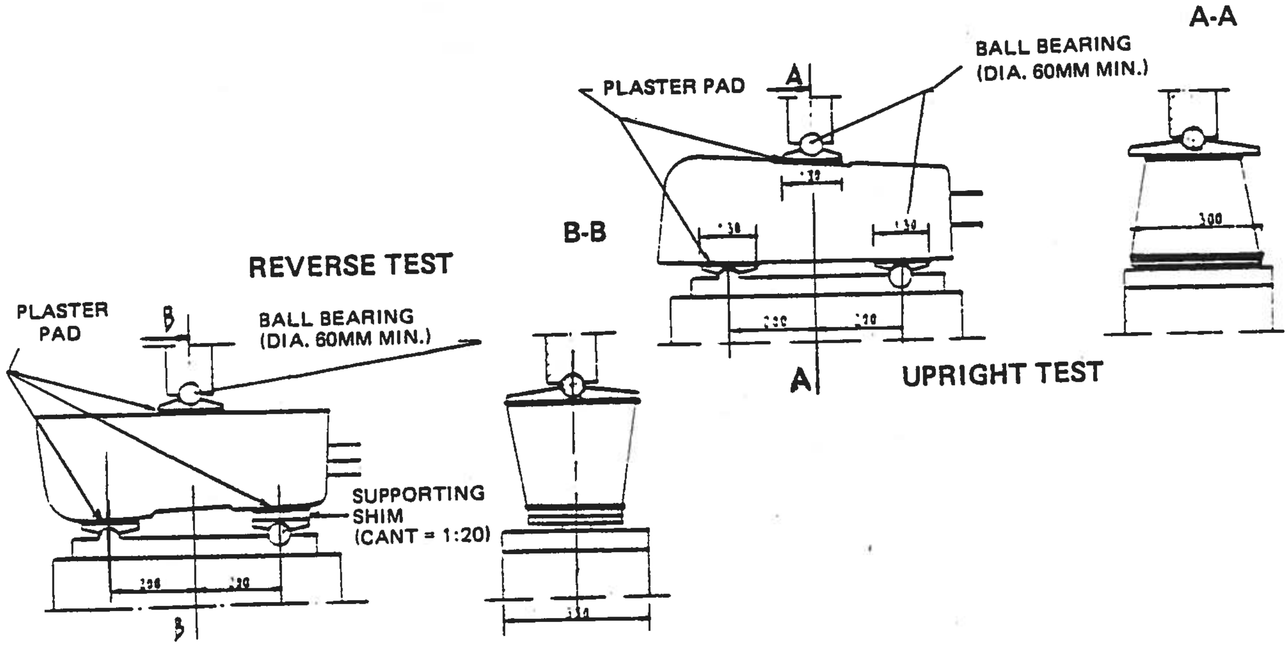


FIGURE 3. ACCEPTANCE TEST (PRIOR TO 1974)
(DIMENSIONS IN MILLIMETERS)

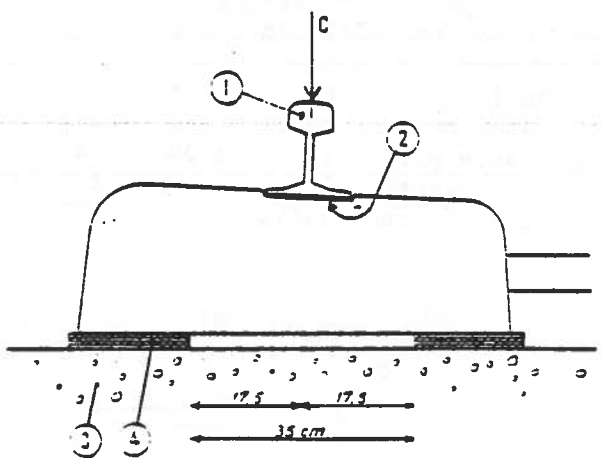
The maximum load is 300 kN (33.6 tons) applied to the block, upright, and 250 kN (28 tons) applied to the block, reversed. Each load is sustained for 3 minutes. No crack must occur before a load level of 280 kN (31.4 tons) is attained in the upright block test and 230 kN (25.8 tons) for the reversed block test. Cracks appearing at this load level or higher must close after complete load release and not be visible, under magnification, as a continuous line.

Limits of Mechanical Resistance Guaranteed by Reinforced, Two-Block Concrete Crossties Used Prior to 1974

When the cracked ties were discovered in the track in 1973, surveillance was immediately applied to these ties as well as to others manufactured during the same period. All ties so scrutinized showed a concrete quality complying with specifications and attainment of typical, conventional acceptance load tests.

Description of a Destructive Test, "Test Under Extraordinary Load"

As first steps, it was necessary to simulate, in the laboratory, defects similar to those appearing in the track, to normalize test conditions, and to assure, under these conditions, adequate reliability of measurement values. This simulation was achieved by means of a cyclical test load applied by a pulsator at a frequency of 250 cycles/min. Test features were as follows:



1. U36 RAIL
2. GROOVED PAD OF 4.5 MM. THICKNESS
3. RIGID SUPPORT (CONCRETE PEDESTAL OF THE PULSATOR)
4. ELASTIC LAYER

FIGURE 4. ACCEPTANCE TEST. ARRANGEMENT OF THE TEST OF A BLOCK UNDER EXTRAORDINARY LOAD

- a maximum dynamic vertical load, R_{max}, applied through a short section of rail attached conventionally to the tie block;

- placement of the tie block on elastic supports inserted under the ends of the block leaving a gap of 35 cm (13.8 in) under the rail seat which simulates an in-track condition wherein the tie block is not firmly supported beneath the rail. (See figure 4.)

Used as an elastic support was a pad of the type "Isolif Triplex," a pad consisting of three rubber layers 30 mm (1.2 in) thick.

The set-up shown in figure 4 led to the definition of a test resulting in the destruction of test ties. This exercise has come to be called, "Test Under Extraordinary Load" and it is discussed later.

Results Obtained from the Extraordinary Load Test

These tests have shown, typically, that under the test conditions described above:

- the first block crack visible to the unaided eye was produced when the load, R_{max}, reached 110 to 120 kN (12.5 to 13.5 tons);

- the crack exhibited a residual opening apparent to the unaided eye, following removal of load, of 0.05 to 0.10 mm (0.002 to 0.004 in) where the load, R_{max}, was between 125 and 130 kN (14 and 14.6 tons);

- the largest crack achieved a residual separation, after release of load, of 0.5 mm (0.02 in) for a R_{max}, generally lying between 140 and 175 kN (15.7 and 19.6 tons);

- the destruction of the tie block was then rather rapidly achieved, usually for a load, R_{max}, of between 175 and 200 kN. (19.6 and 22.4 tons).

Each test was carried out for 5,000 cycles.

The load corresponding to the appearance of the first visible crack is of no great interest. In fact, in the following these tests up to 100,000 cycles, it was not possible to discern crack evolution; the crack closed and was not visible after unloading. Moreover, with respect to the new generation of reinforced concrete ties, of which more will be said later, it was discovered that the load under which this cracking occurred was practically the same.

On the other hand, the load level corresponding to the appearance of a residual crack, barely visible to the unaided eye, is of interest because it defines the elastic limits of the steel or the concrete-steel bond. Indeed, to the extent that these limits are not exceeded, the excursions of the crack edges are, theoretically, fully reversible and the cracks must close. In actuality, there is a slight attrition of the concrete and particles of concrete torn loose or dislodged, causing a certain separation of the crack faces which remains less than a value lying between 0.05 and 0.1 mm (0.002 in and 0.004 in).

Analysis of Results

Under a minimum load of 125 kN (14 tons), noted previously as the most characteristic, the bending moment of the block at the rail seat is 10.3 m-kN (7,578 ft/lbs). This value will serve as a reference in the following reinforcement studies.

The technological differences displayed by the crossties of the types VAX U2 and SL U2, as well as by the older types tried under the same conditions, have permitted an appreciation of design variations. It has become evident that even slight structural variations can introduce important differences in the behavior of the tie-blocks when the load becomes high and the state of destruction is approached.

One may offer as evidence the following parameters, of which the influence is certain:

- the cross section and elastic limit of the steel grid elements, especially for the lower grid;
- the length of the reinforcing members which affects concrete bond;
- the proper location of the lower grid;
- the length of the connecting bar (within the block) under conditions where the concrete enclosing this length is adequately strengthened by the spiral reinforcing;
- the nature of aggregates employed--crushed stone assures a better bond of the steel than unbroken, rounded aggregate particles.

EVALUATION OF FORCE LIMITS TO BE TAKEN INTO ACCOUNT

The study of reinforcement has required that an understanding of forces be taken into account.

Under Conditions of Conventional Traffic, in the Absence of Shock

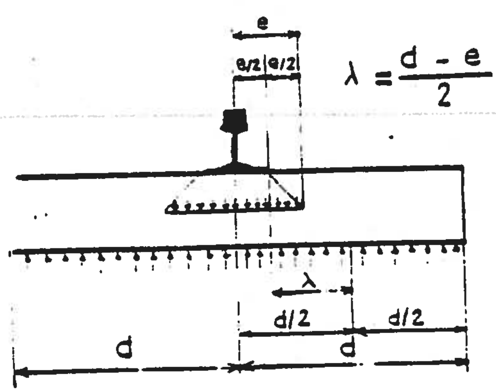
The tests undertaken by the ORE Committee of Experts, relevant to Question D 71, Stresses of the Track, the Ballast and the Foundation under Rolling Loads, concerning the stresses in concrete ties permit an understanding of the realistic distribution of these stresses.

A number of important random factors influences the design of crossties and an understanding of their range makes rather illusory all deterministic stress calculations. Nevertheless, the tests undertaken permit description of a statistical envelope.

In the conclusions of the Interim Report No. 9, the specialists of Committee ORE D 71 suggested the following recommendations:

If one assigns these symbols--

Q_n,	Nominal wheel load;
R,	The reaction of the crosstie;
$\overline{A}$,	The relationship of $\frac{R}{Q}$ as a dynamic mean;
$2\lambda = d-e$,	The cantilevered portion of the tie, less half the developed distribution of the rail load at the location of the neutral axis;
ϕ,	Coefficient of the dynamic impact factor;
χ,	The overload coefficient of the crossties, taking into account the successive but unequal reactive support of the ties by the ballast;
ψ,	The coefficient of increased, theoretical bending moment at the rail seat of the tie taking into account the crosstie-ballast support variations in a transversal sense (longitudinal axis of the tie).



A statistical estimate leads to the following approximate formulae:

- Dynamic wheel load;

$$Q_m = \phi \, Q_n,$$

- Dynamic reaction of the crosstie;

$$R_m = \phi \, \chi \, \overline{A} \, Q_n,$$

- Dynamic bending moment under the rail;

$$M_r = \psi \, R_m \, \frac{\lambda}{2}.$$

The values of the various coefficients are:

$$\phi \begin{cases} 1.5 \text{ for } V = 140 \text{ km/hr (87 mi/h)} \\ 1.75 \text{ for } V = 200 \text{ km/hr (125 mi/h)} \end{cases}$$

(These values result from the measurement of locomotive dynamic wheel loads.)

$\bar{A} = 0.4$

$\chi = 1.35$

$\psi = 1.6$

For an axle load of 22 tonnes (24.2 tons) at 200 km/hr, one would have:

Q_m = 192 kN (21.54 tons)

R_m = 104 kN (11.66 tons)

M_r = 7 m-kN (5.120 ft/lbs)

(For a single concrete block of the two-block tie type, SNCF-U2.)

According to this calculation, the tie-type SNCF-U2, for which the experimentally determined resisting moment is at least 10.3 m-kN (7,578 ft/lbs), corresponding to a dynamic wheel load of 280 kN (31.4 tons), is capable of accommodating the greatest dynamic surcharge normally encountered in trackage carrying locomotive-powered train sets traveling at 200 km/hr (125 mi/h). Experience has confirmed these analyses.

Following tests more recent than those carried out in the earlier work of ORE Committee D 71, it is possible to ascertain the dynamic wheel load with greater certainty.

Dynamic wheel load is composed of three terms:

$$Q_{dyn} = Q_n + \Delta Q_i + \Delta Q_a$$

in this case;

Q_n = the nominal wheel load,

ΔQ_i = the quasi-static dynamic augment attributable to insufficient superelevation.

$$\Delta Q_i = \frac{2Ih}{e^2} Q_n,$$

Where:

I = the superelevation insufficiency (or unbalance in metric units),

h = height (above the rail top) of the vehicle center of gravity,

e = the distance between the vertical axes of the rails, (not the track gage),

ΔQ_a = randomly distributed dynamic augment for which the standard deviation is:

$$\sigma(\Delta Q_a) = \sqrt{\sigma^2(\Delta Q_s) + \sigma^2(\Delta Q_{ns})},$$

given that:

ΔQ_s = the dynamic augment attributable to the suspended mass,

ΔQ_{ns} = the dynamic augment attributable to the unsuspended mass.

For ΔQ_a, the 2-sigma value ($2\sigma\Delta Q_a$) corresponds, practically, to the maximal values.

It may be stated, then, that:

$$Q_{dyn\ max} = Q_n(1 + \theta + 2s)$$

considering that:

$$\theta = \frac{\Delta Q_i}{Q_n} \qquad \text{and}$$

$$s = \frac{\sigma(\Delta Q_a)}{Q_n}$$

The evolution of $\sigma(\Delta Q_s)$ with velocity varies greatly from one vehicle type to another depending on the effectiveness of vehicle suspensions. The evolution of $\sigma(\Delta Q_{ns})$ is always proportional to speed:

$$\sigma(\Delta Q_{ns}) = km \frac{V}{1{,}000}$$

where:

$\sigma(\Delta Q_{ns})$ is expressed in kilonewtons,

m is quantified as the unsuspended mass per wheel, in kilonewtons,

V is the speed in kilometers per hour, and

k is a function of the short wave-length profile variations of the rail surface.

For an established track having some loading experience, one may assume that k = 12.

From a comparison of two different types of track loading situations, a high-speed locomotive and a heavy axle load merchandise vehicle, one may arrive at some interesting relationships:

In the case of a locomotive applying 22 tonnes per axle while negotiating a curve at 200 km/hr (125 mi/h) with an unbalanced superelevation, I, of 150 mm (5.9 in);

the unsuspended mass, m, is equal to 1,500 kg (3,300 lbs),

$$\sigma(\Delta Q_{ns}) = \frac{12 \text{ X } 15 \text{ X } 200}{1,000} = 36 \text{ kN (4 tons)},$$

$$\sigma(\Delta Q_s) = 0.16\ Q_n = 17.5 \text{ kN (1.96 tons)}$$

According to the SNCF tests, it follows that:

$$\sigma(\Delta Q_a) = 40 \text{ kN}$$

$$s = \frac{\sigma(\Delta Q_a)}{Q_n} = 0.36$$

where:

$$I = 150 \text{ mm (5.90 in)}$$

$$h = 1.5 \text{ m (59.04 in)}$$

$$\theta = 0.20 \ (\theta = \frac{\Delta Q_i}{Q_n})$$

leading to:

$$Q_{dyn}\ max = 110\ (1 + 0.20 + 0.72) = \underline{210 \text{ kN}} \text{ (23.56 tons)}$$

This value is 10 percent higher than that earlier calculated. It corresponds to an increase of more than 100 percent of the nominal load, one which occurs only occasionally.

Take the case of a freight car having modern (two-axle) trucks of 22 tons per axle operating at 100 km/hr (62.5 mi/h) in a curving situation where there is a superelevation unbalance of 80 mm (3.77 in) [a currently acceptable value].

In this case, the unsuspended mass is equal only to 600 kg (1,320 lbs),

$$\sigma(\Delta Q_{ns}) = \frac{12 \text{ X } 6 \text{ X } 100}{1{,}000} = 7.2 \text{ kN (0.8 tons)}$$

$$\sigma(\Delta Q_s) \approx 0.11 Q_n \approx 11 \text{ kN (1.23 tons)}$$

According to the results of tests made by SNCF for ORE Committee C 113 it was determined that:

$\sigma(\Delta Q_a)$ = 13.1 kN (1.47 tons), and,

s = 0.13, where

E = 80 mm (3.15 in), h = 2.00 m (78.7 in), θ = 0.14,

and it follows that:

$$Q_{dyn} \max = 100\ (1 + 0.14 + 0.26) = \underline{140 \text{ kN}} \text{ (15.7 tons)}$$

a value substantially less than that found for the high-speed locomotive.

It might be concluded that the crossties of the type SNCF-U2, which can resist, without cracking, the loads imposed by 22 tonne-per-axle locomotives running at 200 km/hr, would be able to withstand the loads imposed by freight cars running at 100 km/hr and having more than 20 tonnes per axle--a simple rule of three would give 30 tonnes--in the absence of abnormal shock.[1]

But, as will be seen, shocks lead to excessively high loads that the U2-type crosstie cannot sustain without cracking.

Extreme Values to be Considered in Case of Shock

When wheels show flat spots of 60 mm (2.36 in) in length (limit established by RIV), then we know that the force on the rail at low speed, (15 km/h) can reach close to three times the nominal wheel load.

Such flat spots never occur on the wheels of locomotives, but they do occur on the wheels of cars. With a load of 20 tonnes per axle, the force on the rail can therefore be close to 300 kN (33.7 tons). We have seen that the U2 ties crack under a repeated load of slightly more than 280 kN (31.4 tons). Fortunately, such forces are not often repeated at one single point on the track. This explains why, until now, we have observed few cracks, but this risk cannot be considered as negligible.

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[1]Refers to an article published in Railway Engineering Journal, January, 1974, and another, in a Rail International in October 1974 on the subject: The Effect of Track and Vehicle Parameters on Wheel/Rail Vertical Dynamic Forces. Authors: H. Jenkins, et al.

In case of a low joint, it is known that the impact is proportional to the speed and the angle formed by the two rail ends. The outstanding studies made by BR[2] show that with a low joint having an angle of 0.02 radians, the dynamic impact at 200 km/h (125 mph) can reach seven times the nominal wheel load. The SNCF has arrived at values of similar magnitude, by different calculations.

Since the concrete ties are always installed with long welded rails, the possibility of a dipped weld is much more frequent. The impact forces are certainly less than with a bolted joint, and assuming three times the nominal wheel load for an abnormally dipped weld, which appears to be a maximum, we are again in the range of a flat spot. It is not surprising that some cracks have been observed on the U2 ties, under these conditions.

Moreover, in case of impact due to crushing of a particle of ballast left on the rail, or when running across some built-up metal on a rail that has not yet been ground after welding-up of engine burns, the impact is still greater, and can result in destruction of the ties. These last two cases must be considered as very exceptional.

Finally, in order to have a certain safety margin with respect to the most frequent risk (dipped weld), consideration has been given to the fact that the ties should be able to resist a wheel load, equal to four times the nominal maximum wheel load of the locomotives, or 4 X 110 = 440 kN (49.36 tons). (Note that the load of 22 tonnes per axle will probably also apply to certain European freight cars in the future.)

DEFINITION OF NEW SPECIFICATIONS

Principle

It has been observed that the U2 ties could normally resist a dynamic wheel load of 280 kN (31.41 tons), and that, under the pulsator test conditions, as described previously, the corresponding value of the force to be applied to a block was 125 kN (14 tons) without appearance of a residual crack greater than 0.05 to 0.1 mm (0.002 to 0.004 in) in width. (See destructive test above, p. 9.)

It was therefore only necessary to modify ties so that under the test conditions, such a crack would not appear in the pulsator test, under a force R_{max}, not exceeding 125 X 440/280 = 200 kN (22.4 tons). In other words, the moment of resistance had to be increased by 60 percent.

It has therefore been decided to establish a tie acceptance procedure which not only takes into account the above conditions, (no residual crack greater than 0.05 to 0.1 mm [0.002 to 0.004 in] under pulsating load of 200 kN [22.4 tons]), but also that no trace of damage, normally considered to be a residual crack-width of 0.05 mm (0.002 in), is caused under pulsating load which is 30 percent greater than the indicated, or 260 kN (29.17 tons). It was observed that on the

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[2] It should be noted that the viewpoint expressed here is very different from one considering fatigue and, consequently, from the cost of maintaining track. Clearly, a dense freight traffic, even where axle loads do not exceed 20 tonnes, induces track fatigue much more importantly than that introduced by locomotives running less frequently at 200 km/hr.

U2 ties such a crack could appear at 140 kN (15.7 tons), the imposed increase in resistance against damage (destruction) is therefore 85 percent.

Acceptance Procedure

Before any start of mass manufacture, whether it concerns a new type of tie proposed by a supplier, a modification to the structural system of a type of tie already being manufactured, or the manufacture of an existing type of tie by a new manufacturer, the SNCF requires from now on, that, in addition to the acceptance of the materials, the ties be subjected first to the acceptance tests. These test ties must be produced under the same conditions as for those that will be mass-produced.

The acceptance test contains fatigue tests under normal operating loads and ultimate resistance tests under exceptional loads.

Fatigue Tests Under Normal Operating Loads

This is a bending test of the tie with inclined pulsating loads, performed in the pulsator with slanted arms, at a frequency of 250 cycles/minute. The tie is supported on a rubber layer, either discontinuous or continuous over the entire length (see figure 5). It is a true endurance test, because it is continued for 2 million cycles. It is completed by a fatigue test with a purely vertical load, performed in the Vibrogir, at 50 Hz, (the vertical load applied in downward direction varies between 4 and 80 kN [0.45 and 8.97 tons]). No cracks are allowed to appear during these tests.

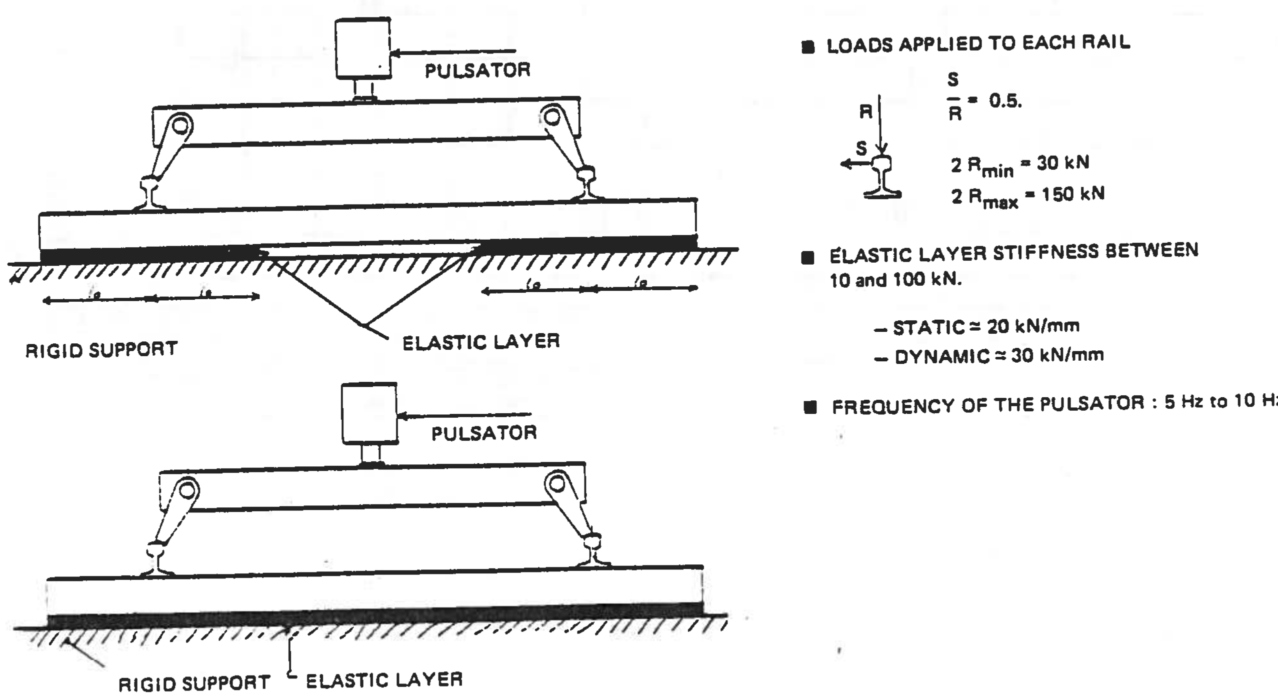

FIGURE 5. ACCEPTANCE TEST. ARRANGEMENT OF THE TEST FOR NORMAL LOAD APPLICATION THE CROSSTIE IS NORMALLY EQUIPPED WITH ITS RAIL FASTENINGS

The pulsating load, simultaneously applied by the pulsator on both rail-heads, is an inclined load with vertical component R and horizontal component S, in which S:R = 0.5 (see figure 5). Since it is a test of long duration (2 million cycles), it is not necessary to use for R_{max} and S_{max} the exceptional ultimate values, not even the maximum values of normal operating conditions, but values that occur relatively frequently. The selected values are those corresponding with an engine of 22 tonnes per axle, operating at 200 km/hr, with 150 mm lack of superelevation, but only with one standard deviation for the random dynamic alinement, which has led to Q_{dyn} = 170 kN (19 tons). For the ratio, R/Q, we have taken 0.45, a current value, from which R_{max} = 75 kN (8.4 tons). The proportion, S:R = 0.5, corresponds also to a current value. In fact, this fatigue test is only of limited value for the two-block ties, since it has appeared that the ties that pass the test under exceptional load, (described hereafter) will pass, ipso facto, the fatigue test. But it retains its importance for prestressed monoblock ties, with respect to cracking in the center portion of the tie.

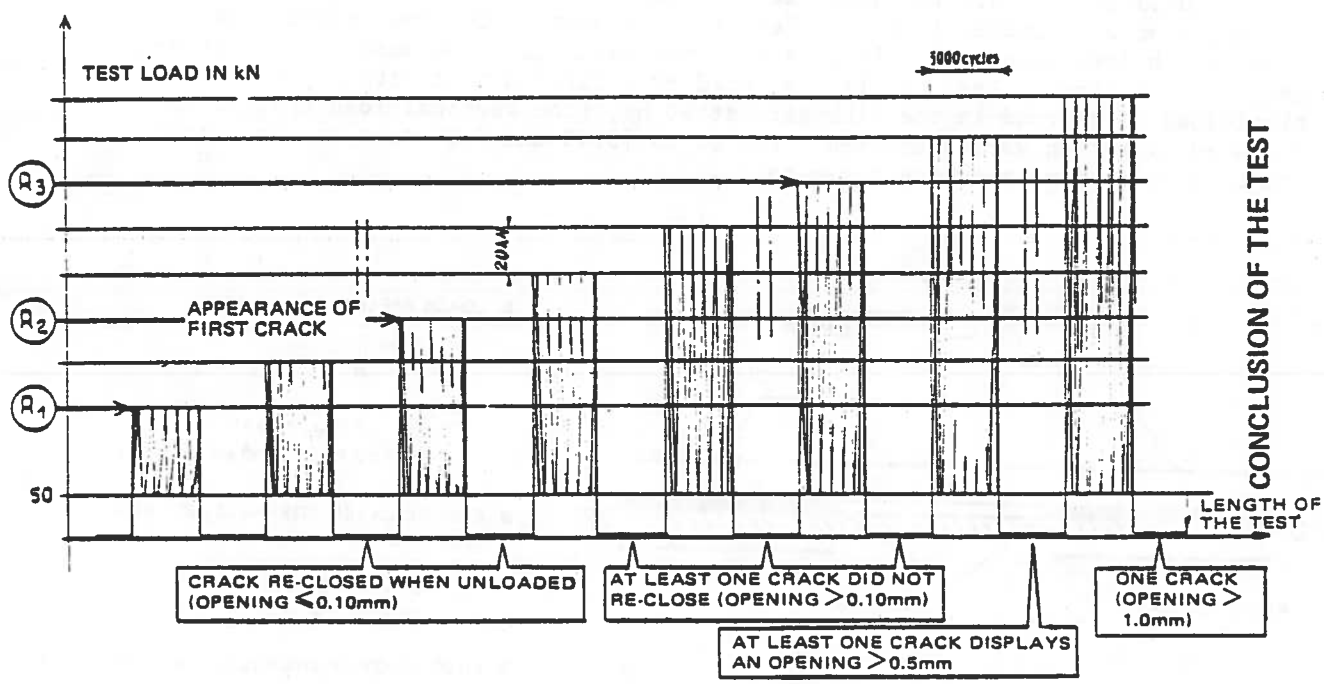

FIGURE 6. TEST UNDER EXTRAORDINARY LOAD. LOADING SCHEME

Ultimate Resistance Test Under Exceptional Loads (see figure 6)

This is a bending test of the tie block, with alternating loads between 50 kN (5.6 tons) and a variable maximum load R, increased in increments of 20 kN (2.24 tons) until destruction of the block. Each loading step is run for 5,000 cycles, beginning with a load of 120 kN (13.5 tons).

During the course of this test one must record:

- the load R_1, from which the first crack occurs;
- the load R_2, from which a crack does not close (i.e., when the width of a crack exceeds 0.10 mm after removal of load);
- the load R_3, from which a residual crack retains a width of 0.5 mm (0.02 in).

For a tie to pass, it is necessary that the loads R_2 and R_3 be greater or equal to the values already described earlier in the discussion, which are R_2 = 200 kN (22.4 tons), R_3 = 260 kN (29.17 tons). (See subsection, "Principle," p. 17.)

THE NEW CONCRETE TIES OF THE SNCF

Two-block Reinforced Concrete Ties

Modifications

The various structural alternatives that were tested have led to the choice of the following modifications, to comply with the new specifications.

Modification of the shape of the block.- A rectangular shape of the block has been chosen. With this shape it is possible to make all reinforcing bars of the lower grid of the same length, with all bars being straight. With the hexagonal blocks, in which the exterior reinforcing bars are bent to accommodate that shape, it was observed in the pulsator tests with high loads that, due to pressures towards the exterior, the sides of the tie-blocks cracked.

Bottom grid reinforcement.- The diameter of the longitudinal reinforcing bars has been increased from 8 to 10 mm (0.312 to 0.393 in), maintaining the use of plain steel of the type FeE22 (but with minimum elastic limit of 24 hbar [34,064 lbs/in^2]).[3]

Increased length of steel tiebar.- The length of the tiebar has been increased to 2 meters (78.74 in). An effective anchorage of the surrounding concrete is secured by the spiral reinforcement, with the number of loops increased. A specific proportion of crushed stone aggregate has proved to be indispensable.

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[3]However, in the future, acceptance is likely for deformed reinforcing steels having a somewhat smaller diameter. Current tests are showing that it is possible, with these types of rebars, to attain the desired levels of resistance (bond) without increasing cost.

The ties that have been modified accordingly are designated VAX U30 or SL U30 (see figures 7 and 7a). They have been produced since 1975 and substitute for the VAX U2 and SL U2 types.

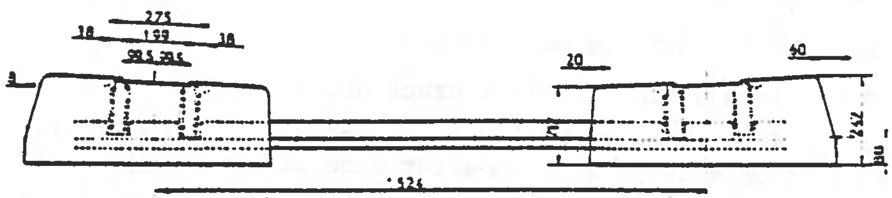
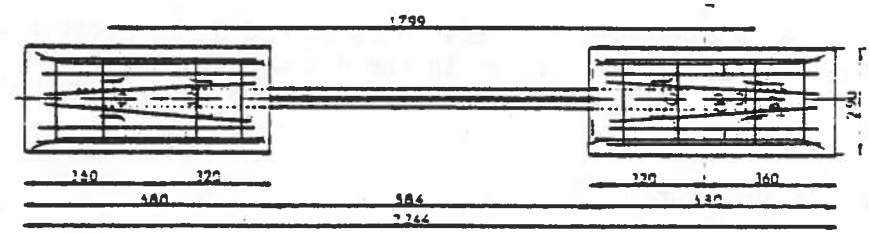


FIGURE 7. TWO BLOCK CROSSTIES, TYPE VAX U30 (AFTER 1974)



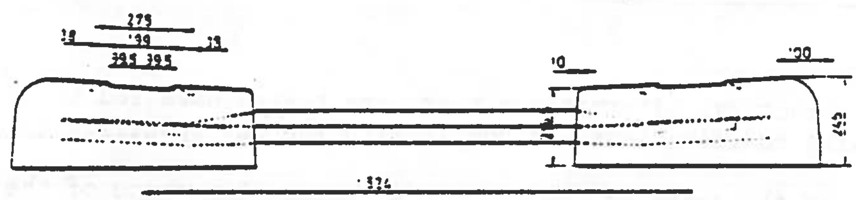
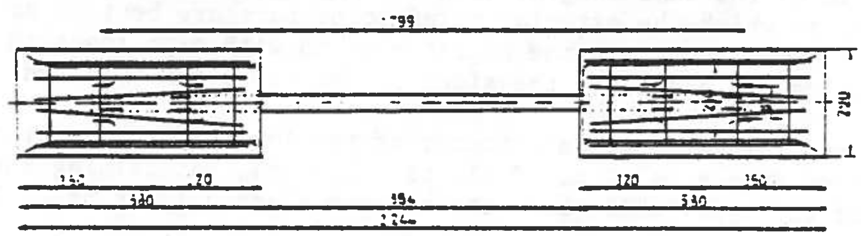


FIGURE 7a. TWO BLOCK CROSSTIE, TYPE SL U30 (AFTER 1974)



The comparative characteristics of the U2 and U30 ties are given in the following table (table 2). The depth of the block measured under the rail is 224.5 mm (8.84 in), but it can be reduced to 220 mm (8.66 in), since rubber pads of 9 mm (0.35 in) thickness are used instead of 4.5 mm (0.18 in).

It is anticipated that 9 mm (0.354 in) pads will be used on important high-speed lines, in order to increase the vertical elasticity and to reduce the dynamic surcharges due to the unsprung masses of the cars. This is also favorable in case of impact. The concrete must be of B 3 class (formerly B410.)

TABLE 2. COMPARATIVE CHARACTERISTICS OF CROSSTIE TYPES U2 AND U30

Type of Crosstie			SL		VAX	
			SL U2	SL U30	VAX U2	VAX U30
Block Shape			Octagonal	Rectangular	Octagonal	Rectangular
Dimensions of a section under the rail	Width of the top surface	(in)	8.3	8.3	8.3	8.3
	Width of the bottom surface	(in)	11.15	11.15	11.15	11.15
	Height including 0.18" pad	(in)	8.7	8.9	8.7	8.9
	Height including 0.36" pad	(in)	—	8.7	—	8.7
Upper reinforcement	Longitudinal	(in)	2 @ 0.3 (dia.) L = 17.4	4 @ 0.3 (dia.) L = ~ 23	2 @ 0.4 (dia.) L = 19.8	4 @ 0.3 (dia.) L = 22.1
		(in)	2 @ 0.3 (dia.) L = ~ 23		2 @ 0.3 (dia.) L = 19.8	
	Transversal	(in)	3 @ 0.2 (dia.) L = 5.3	2 @ 0.22 (dia.) L = 8.7	2 @ 0.2 (dia.) L = 6.3	2 @ 0.22 (dia.) L = 7.2
					1 @ 0.2 (dia.) L = 7.3	
Lower reinforcement	Longitudinal	(in)	4 @ 0.3 (dia.) L = 24.7	6 @ 0.4* L = 24.7	2 @ 0.3 (dia.) L = 24.7	8 @ 0.4 (dia.) (1) L = 24.7
		(in)	2 @ 0.3 (dia.) L = 17.4		4 @ 0.3 (dia.) L = 19.8	
	Transversal	(in)	2 @ 0.2 (dia.) L = 8.7	4 @ 0.22 (dia.) L = 8.7	2 @ 0.2 (dia.) L = 8.7	4 @ 0.22 (dia.) L = 8.7
		(in)	2 @ 0.2 (dia.) L = 6.3		2 @ 0.2 (dia.) L = 7.3	
Total length of spiral reinforcement		(ft)	10.24	10.37	8.34	10.27^{+}
Diameter of spiral reinforcement		(in)	5.06	5.1^{+}	4.9^{+}	5.02^{+}
Connecting bar	Moment of inertia	(in^4)	1.66	1.76	1.56	1.70
	Distance between C.G. and bottom surface	(in)	4.3	4.3	2.8	2.8
	Length	(ft)	6.8	6.58	6.3	6.58
	Weight	(lbs)	25.7	29.2	25.9	31.0^{-}
Weight of the reinforcing for each tie block (not including the connecting bar)		(lbs)	6.6	8.8	6.6	8.8

* Also tested have been indented reinforcing bars, which provide a better bond than plain (smooth) bars, and these tests have shown that it is possible to replace the 6 bars @ 0.4 in of the lower reinforcement by 7 hi-bond bars @ 0.21 in or, as an alternate hi-bond bar arrangement, 2 bars @ 0.4 in and 4 bars @ 0.3 in.

The U30 ties manufactured accordingly will easily comply with the standards of the acceptance test and will even do considerably better (see figure 8).

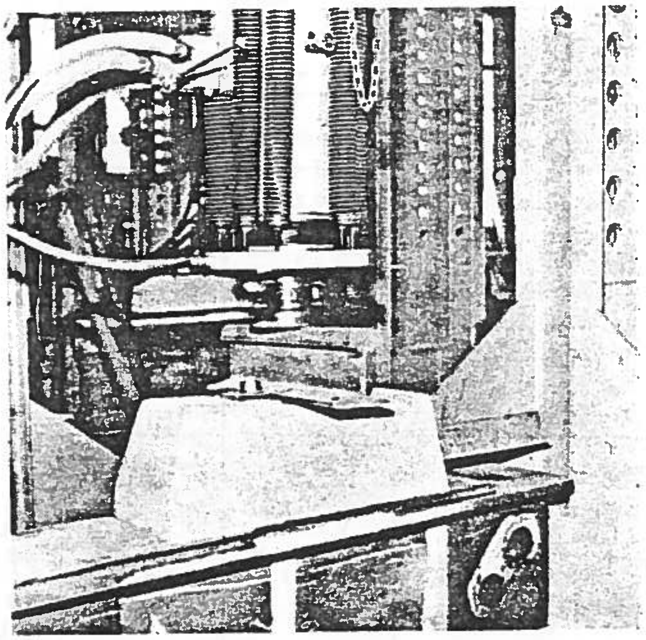


FIGURE 8. TEST OF A BLOCK, TYPE U30, UNDER EXTRAORDINARY LOAD

Acceptance Conditions of the New Two-Block Ties, Type U30

The inspection of the materials, their use, and dimensional verification, as described previously, are strictly maintained. (See "Acceptance Requirements.")

The test loading conditions have been modified. The plaster pads between the support of the block and the tie have been replaced by rubber pads of 20 mm (0.79 in) thickness, resulting in a severe test.

One tie out of every 100 is subjected to a load test. In order for a tie to be accepted, it is subjected to a 320 kN (36 tons) load applied for 3 minutes, after the removal of which no cracks must be visible.

In addition, after every 50,000 ties manufactured, a static load test of 430 kN (48 tons) is made in order to assure that the strength of the tie is adequate to resist the maximum cracking limits (a crack width equal to or less than 0.5 mm (0.02 in), after removal of load).

The New Monolithic (Prestressed) Concrete Ties of the SNCF

Expected Use for the Monoblock Ties

The Permanent Way Department of the SNCF has, since 1973, decided to resume the study of a monoblock prestressed concrete tie, adapted to the requirements of heavy loads and high-speed traffic. This decision was made a year before it was decided to increase the resistance of the two-block ties, as described above, and is based on different reasons, as discussed in the following text.

The two-block block tie shows important advantages:

- it confers a very high lateral stability to the track; with each of the blocks buried in the ballast, it provides a double abutment in each direction resisting lateral displacement. This has again been confirmed during the TGV-001 test runs at 160 mi/h and above. The systematic research of critical truck-speeds, as a function of the various parameters leading to application of large lateral track forces at the onset of vehicle instability phenomena (these forces reach a level almost twice the normally accepted value), caused no deformation of track;

- the steel connecting bar between the two concrete blocks solves the problem of center-cracking associated with monoblock concrete ties;

- the two-block tie is relatively light and easy to fabricate;

- cost of the two-block tie is less than that of the monoblock tie.

On the other hand:

- the block length dictates a limited dimension for ballast support;

- flexibility of the steel connecting bar can lead to excessive gage-widening on curves of small radius. Use of the two-block tie should be restricted to curves having a radius of not less than 350 m (1,137.8 ft), i.e., curves of approximately 5° (5° - 02') or more. A better preservation of track gage presents an advantage of interest for very high-speed lines.

When the soil foundation is satisfactory or the subballast/ballast system is adequate, longitudinal profile durability of two-block tied track is comparable to that of track including timber ties. It follows that in new line construction there will be no problem, in this regard, where the subballast is of good quality, well-compacted and of a layer-thickness appropriate to the bearing capacity of the soil support. On the other hand, where it is desirable to renew an existing track having an inferior soil support and it is not possible, short of excessive expense, to raise the track in order to increase the thickness of the subballast/ballast system--particularly where the height of concrete ties would be more than that of the timber ties in the track to be renewed--utilization of the two-block tie cannot be considered. In such cases, use of monoblock concrete, of a height not much more than the timber ties and offering a comparable ballast bearing area, would be reasonable. Another use for limited-height, monoblock concrete ties can be justified in secondary lines where it is desirable to progressively install concrete ties in place of timber ties without assuming the expense of large-scale rehabilitation for which the return on investment would not be profitable.

For these varied reasons, SNCF decided to investigate the concept of a monoblock concrete tie necessarily limited to an underrail (rail seat) height of 0.17 m (6.69 in) and having a length of 2.50 m (8.13 ft). Employing these dimensions, the mass of the tie will not be excessive. In fact, from the viewpoint of track profile retention, it is recognized that, while an enlargement of tie bearing area is favorable, augmentation of the tie mass is not. (Unfortunately, it is not possible to calculate, a priori, the interrelated influence of these two parameters).

Technical Specifications

After the new monoblock concrete ties had been the object of study and some prototypes fabricated, a regulation was put forth in 1974 requiring that they completely meet the same specifications for resistance to extraordinary load as the two-block tie (see figure 9). Acceptance tests under the pulsator applying both normal and extraordinary loads must be the same as those to which the two block tie is subjected.

As has been stated, in the case of the prestressed, monoblock concrete tie, the acceptance test under a normal load is significant in order to verify the structural integrity (resistance to cracking) of the tie's center region.

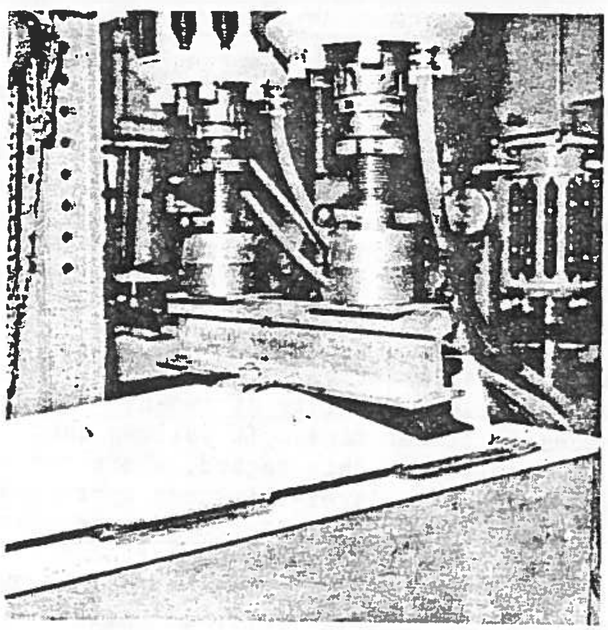
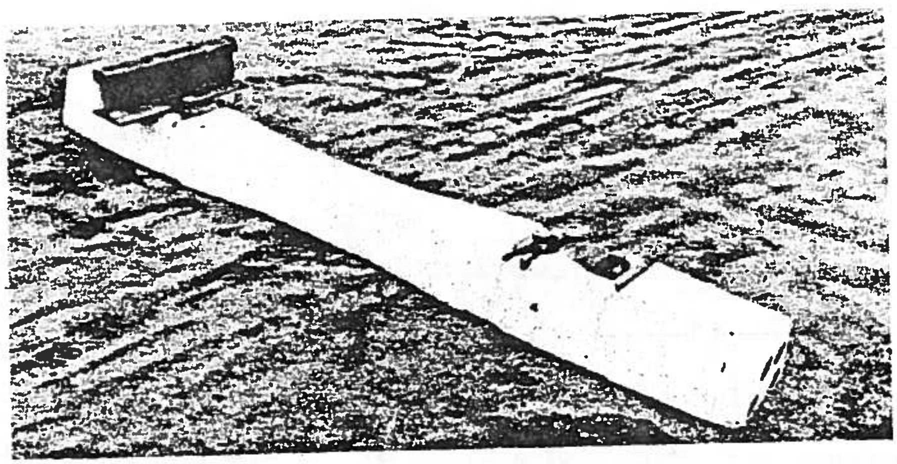


FIGURE 9. TEST OF A PRESTRESSED CONCRETE MONOBLOCK CROSSTIE UNDER EXTRAORDINARY LOAD

Current Developments

The investigation of these monoblock ties has been undertaken, in close collaboration with SNCF, by two firms: STUP (Société Technique pour l'Utilisation de la Précontrainte) and COSTAMAGNA (le Centre d'Etudes des Procédés). From the beginning, it was agreed that initial consideration would be given to prestressed monoblock ties which relied upon adequate bond between the concrete and prestressing tendons similar to the older model; SNCF-VW (see figure 1), postponing until later consideration of post-tensioned ties. Beginning in 1975, each of the two firms succeeded in producing prototype ties which satisfied the rigorous acceptance tests prescribed by SNCF.

The tie-types proposed have almost the same shape (see figures 10 and 11), differing only in the dimensions and distribution of the prestressing tendons.



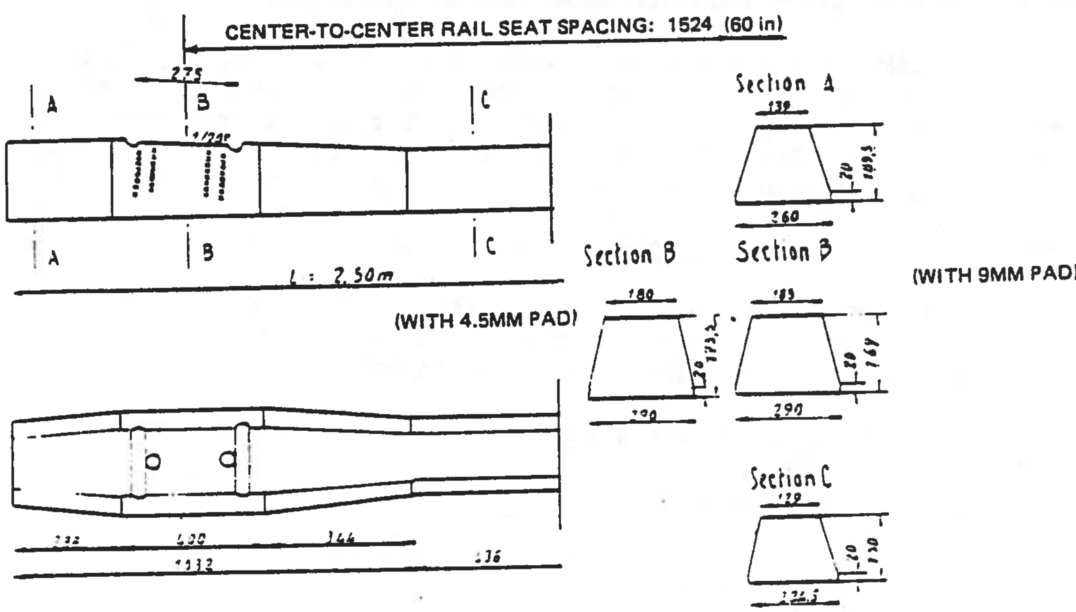


FIGURE 10. PRESTRESSED CONCRETE MONOBLOCK CROSSTIE, TYPE STUP (FREYSSINET INTERNATIONAL)

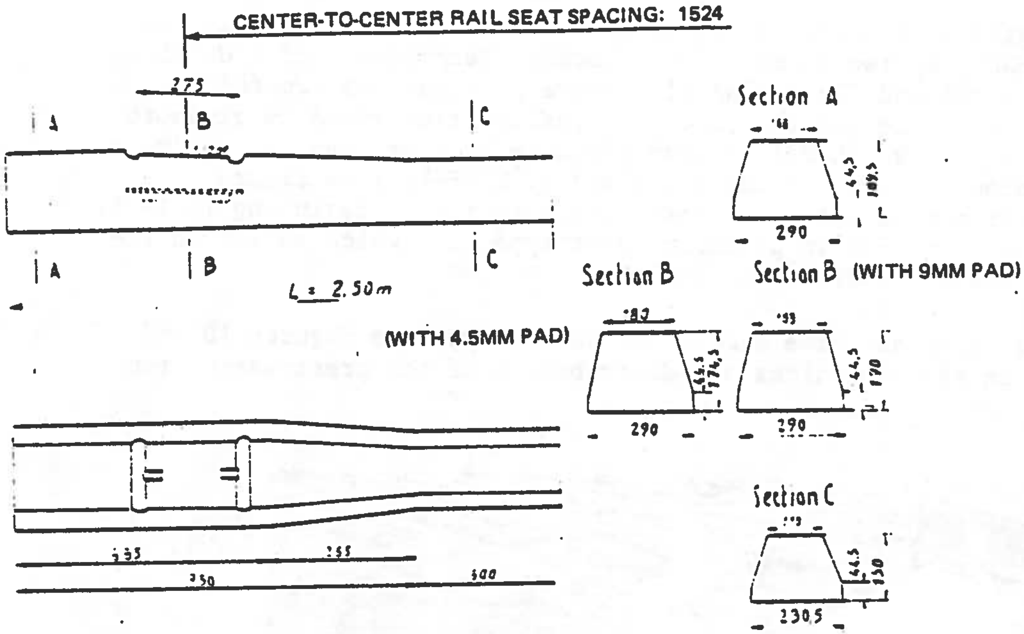


FIGURE 11. PRESTRESSED CONCRETE MONOBLOCK CROSSTIE, TYPE COSTAMAGNA

The STUP tie includes four strands of 9.53 mm (3/8 in) diameter, stressing of the concrete being 280 kN (31.41 tons). The COSTAMAGNA tie includes 18 wave-shaped wire strands of 5 mm (0.197 in) diameter providing a constraining force, after relaxation, of 330 kN (37.5 tons).

The COSTAMAGNA tie contains at each rail seat region, within the concrete, an attaching plate exhibiting two apertures for anchorage of the heads of the removable bolts securing the rail clip--similar to the arrangement within the SL two-block tie. The STUP tie allows for the inclusion of clip-restraining bolts having a dual-thread arrangement. The fastener is attached by a nut secured to the bolt by machine threads. The bolt itself is coach-screw threaded and engages a threaded, cast-in-place, steel insert.

In both cases, removable bolts or threaded in-place bolts serve to tighten the elastic rail fasteners of the typical spring type. Should it be desired, it is convenient to adapt these ties to other modes of rail fixation.

These investigations have directed particular attention to the following high-quality, bonding problems:

- adherence of the prestressing tendons;
- quality of the concrete, paying special attention to the included aggregates and their bonding qualities.

Manufacture of SNCF Monoblock Prestressed Concrete Ties

Some prototype ties were installed in March, 1973, in the Paris Belt line in a track for which the traffic has been, primarily, freight operating at a speed of 90 km/hr (56 mi/h) and accumulating tonnage at the rate of 100,000 tonnes (125,000 tons) per day. Even though these (prototype) ties did not meet the requirements of the exceptional load tests, their behavior was acceptable overall (see figure 12 for referenced installation). The production of subsequent versions having greater load resistance was undertaken and some of these were put in-track during 1976.

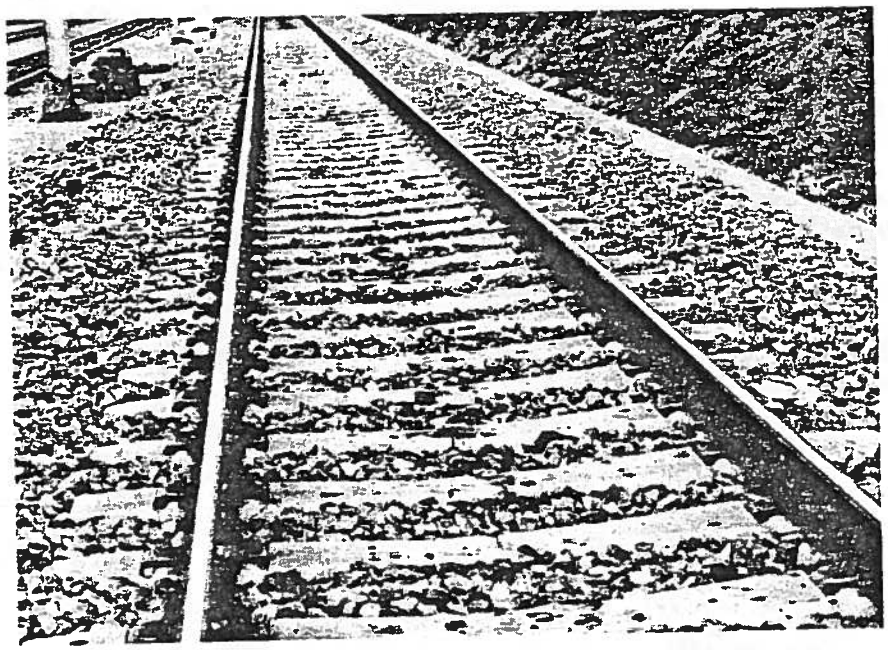


FIGURE 12. TEST ZONE IN MONOBLOCK CROSSTIE TRACK

OTHER TYPES OF CROSSTIES NOW BEING STUDIED

Two-Block Tie

Two-block ties offer important advantages, as has been previously outlined. Research leading to improvement must be directed toward an enlargement of the ballast bearing surface (extension of the block lengths), a reduction of tie height at the rail seat, and an increase in the vertical moment of inertia of the connecting steel tie-bar.

As a reinforced concrete version, one model complying with these objectives has just been proposed by Sonneville. The blocks would be 720 mm (29.5 in) long instead of 680 mm (26.8 in) as for the U30 tie, and the height at the rail seat would be 205 mm (8.07 in) instead of 220 mm (8.66 in) for the U30 with a 9 mm (0.354 in) pad. As to the steel tiebar, it is proposed as having an "S" shape and its moment of inertia would be 115 cm^4 rather than the 43 cm^4 design value for the U30 tie (respectively; 2.762 in^4 and 1.033 in^4). In order to withstand the extraordinary load test, despite a longer block length and diminished height, the blocks deploy a lower grid of two layers of reinforcement having a specific form.

As a pre-stressed concrete version, Sonneville has also proposed a model called "Pretube" (see figure 13). A tube serves as a connecting bar and provides a means of prestressing each of the blocks. The extruded steel tube is inside-threaded at one end and sealed off by a flat plate at the other end. Into this tube is introduced a cylindrical, full-length bar which bears upon a shoulder and is outside-threaded. Rotating an applied nut forces the bar against the plate at the other end of the tube and places the tube in tension. Following curing of the concrete blocks, the nut is backed-off and relaxation of tube tension develops a compression stress in the blocks. These blocks have the same underrail height as the monoblock ties, 170 mm (compared with 220 mm for type U30 reinforced, two-block ties [6.69 in compared with 8.66 in]), but their block lengths are greater: 900 mm rather than 680 mm (35.4 in versus 26.8 in). Consequently, the exposed length of the connecting bar (tube) between the blocks is not more than 651 mm (25.6 in). These characteristics are strongly favorable to satisfactory performance of the track.

The firm, SATEBA, has investigated a tie type, PREVAX, meeting the same objectives. There two tie types have not yet been accepted by SNCF.

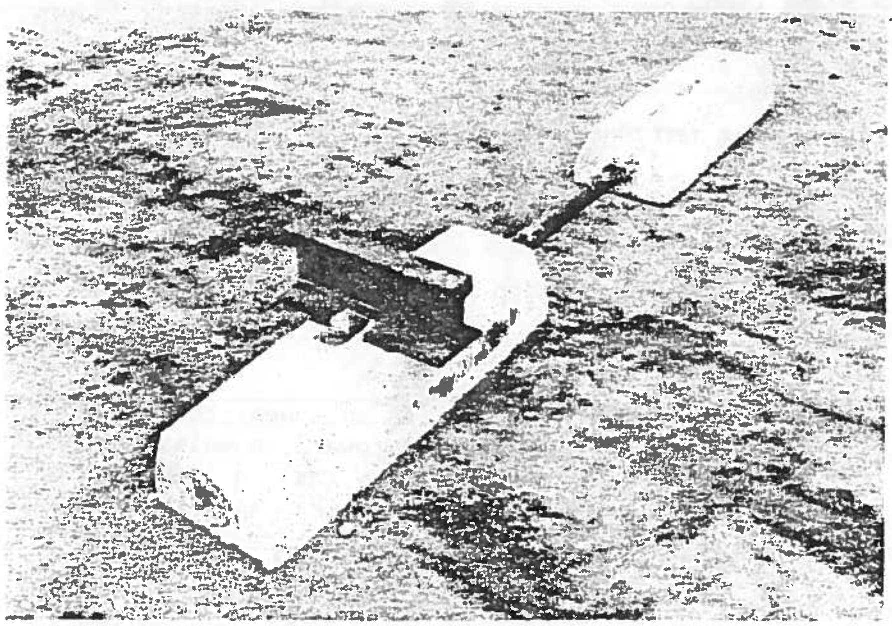


FIGURE 13. CROSSTIE OF THE TYPE, PRETUBE

Stressed Concrete Crossties

The firms of STUP and SATEBA have proposed a monoblock concrete crosstie stressed by posttensioning (after the fashion of a large part of foreign tie types). This tie, designated as "STUVAG," has only been laboratory-tested by SNCF. It is manufactured in South Africa.

Finally, in order to satisfy the requirements of certain railroad systems abroad which allow car loadings of 30 tonnes per axle (33,600 lbs per wheel of a 4-axle vehicle) on track of which the quality is often mediocre, the investigation of bonded, stressed element ties, based on similar types described previously, is an active effort. Bear in mind that the French concrete crossties, type U30 as well as the monoblock types produced for SNCF assuredly can support 30 tonne axle load vehicles running at 100 km/hr (62.5 mi/h) under normal conditions. But with the respect to exceptional shock, the calculated load must be augmented.

CONCLUSIONS

- The new French concrete crossties, whether they are of the two-block or monoblock type, are equally able to respond to harsh operating conditions (axle loads of 22 tonnes at 200 km/hr [24,640 lbs per wheel at 125 mi/h]).
- The original acceptance tests under extraordinary loads, instituted by SNCF, guarantees the resistance of these crossties to shock action which can occur, in-track, with a nonnegligible probability (dipped welds, for example). This test is certainly one of the most rigorous specifications applied by management to the acceptance of materials.
- The uniqueness of the bonded, stressed element, monoblock ties put in service by the SNCF resides in their "modest" thickness or height at the rail seat (0.17 m [6.7 in]) compared with types advocated abroad. By comparison, their weight is less and this favors a better retention of longitudinal track profile. It should be noted that some types of foreign concrete crossties having a rail seat height of 19 cm (7.48 in) have been submitted to the extraordinary load test without giving better results than the French ties.
- From the various types of concrete crossties, the investigation of which has been previously described, enhanced performance may be expected.

REPORT NUMBER II

MANUFACTURE AND BEHAVIOR OF CONCRETE CROSSTIES IN MEXICO

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MANUFACTURE AND BEHAVIOR OF CONCRETE CROSSTIES IN MEXICO

HISTORICAL REVIEW

At the end of the 19th century, during the early stages of reinforced concrete, consideration was given to the manufacture of concrete railway ties, to substitute or replace timber ties; reports are available such that during that period from 1880 to 1914, the first efforts in that direction were made, which in several instances resulted in practical tests.

As a result of the subsequent problems in acquiring adequate timber and the considerable technical advance in the development of reinforced concrete during the First World War (1914-1918), systematic studies of this problem were intensified, which culminated in the establishment of the first production of concrete ties, from 1920 to 1940.

Monolithic concrete ties, manufactured during this period, had geometric characteristics that were similar to those of timber, while also mixed (two-block) ties were manufactured consisting of two reinforced concrete blocks, tied together by a steel bar, which secures the gage of the track.

The first type concerned the ORION tie, designed by M. Lefranc, of which type approximately 200,000 were installed during the period of 1928 to 1933, in various lines, among which we mention the TOLOSA - BAYONA line; typical for the second type is the "VAGNEUX" tie, of which, from 1922 to 1934, approximately 900,000 were installed in various railway lines in North Africa, Indochina, Switzerland, Belgium, Italy, and France.

The technique of concrete tie manufacture was perfected during the Second World War (1940-1945), resulting in various systems and types, that were able to resist the load applications to which the tracks were subjected under service conditions.

With timber becoming scarcer, the product got a definite push, which resulted in the prestressed concrete tie.

We may state that from this period on, the manufacture of concrete ties achieved its objective, improving the characteristics of the original designs with respect to the required resistance, flexibility and durability of each of the following typical types of ties, and described as follows:

- The monolithic prestressed concrete tie, consisting of a concrete beam, which is precompressed by a certain number of wires which transmit the forces by direct bond, or by the stressing of bars which are anchored at the extreme ends.

- The nonmonolithic prestressed tie, consisting of two blocks and a concrete cross member with elastic joints, stressed together with steel bars.

- The mixed tie, whereby the two reinforced concrete blocks are elastically joined by a hard steel section acting as a flexible element and securing the rail gage.

From 1950 on, when the concrete tie industry in Europe had practically replaced the timber tie, the desire to adopt this technique in the Mexican Republic grew very strong. This desire grew out of a need to preserve our forest reserves, to procure better timber utilization, and to satisfy the ever-increasing demand for ties needed for maintenance and rehabilitation of railway track in service as well as for construction of new lines.

In the beginning of 1959, the Department of Public Works initiated preliminary studies to establish a plant in our country. In November of the same year, during the 12th Regional Conference of the American Concrete Institute, held in Mexico City, the distinguished Engineer Alberto Dovali Jaime presented a document. In it, he expressed the necessity to initiate the production of concrete ties with the shortest possible delay, in view of the need of 6 million ties required by 1960 for maintenance, rehabilitation, and construction of new tracks.

In February 1960, the construction of the first plant was begun in Ciudad Acuna, Coah., for the manufacture of RS two-block concrete ties. Production started in March of the same year to meet the tie requirements for the new line that connects San Carlos with Ciudad Acuna in the state of Coahuila.

Based on the results achieved with this type of tie, the Secretary of Public Works subsequently decided to use the same type in the construction and rehabilitation of the section Chihuahua-Topolobampo and Chihuahua-Ojinaga of the F.C. Chihuahua-Pacifico and the connection of the Ferrocarril Tehuano with the South-East across the Coatzecoalcos Bridge. The Ferrocarriles Nationales de Mexico use these ties in a portion of the Monterey-Matamoros line.

In 1964, the production of the SL two-block tie, (modification of RS) was begun in Dolores Hidalgo, Gto. Shortly thereafter another manufacturing plant was installed in Panzacola, Tlax., for the production of monolithic post-tensioned ties of the "Dywidag" B-58 type. Both plants were kept for the purpose of supplying the tie requirements for the section under construction from Viborillas-Villa de Reyes and for the line rehabilitation between this place and Sn. Luis Potosi.

At this time the following plants are in production: Dywidag of Panzacola, Tlax., and the recently installed plant of Monterey, N.L. Both plants have supplied ties for the sections Encantada-Saltillo, Gomez Farias-Agau Nueva, Irapuato-Ocotlan, Matrimonio-El Oro, Mexico-Huehuetoca, Mexico (Teotihuacan) Tierra Blanca-TresValles y Monterrey-Nuevo Laredo.

The present situation concerning the use of concrete ties in the railroad system of the Mexican Republic is shown statistically in a table and on a map of the National System (table 1 and map 1).

MAP 1

RAILROAD NETWORK OF THE MEXICAN REPUBLIC

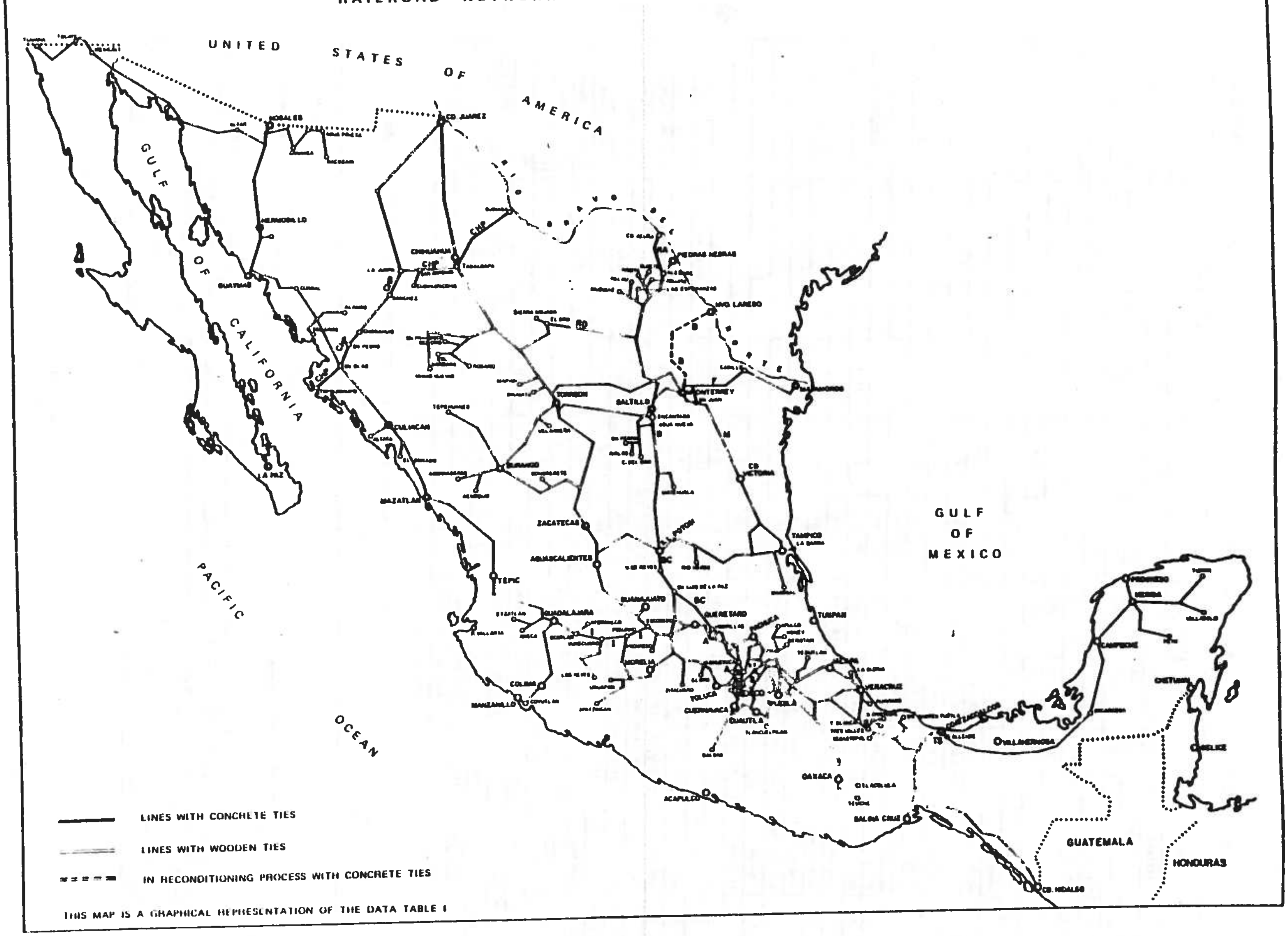


TABLE 1

QUANTITY AND TYPE OF CONCRETE TIES LAID IN THE RAILROAD NETWORK OF THE MEXICAN REPUBLIC

LINE	DIVISION	FROM Km	TO Km	KILOMETERS	QUANTITY OF TIES	TYPE OF TIES	YEAR LAID	TRAFFIC DENSITY GROSS TONS IN 1971 (10^3)	OBSERVATIONS
A	QUERETARO	206 + 240	215 + 730	9 + 490	13, 142	RS y SL	1971	11,977.6	SN. JUAN DEL RIO AHORCADO
A	MEXICO Y QUERETARO	2 + 180	47 + 000	44 + 820	71, 712	D W	1966	8,077.2	
B	MEXICO Y QUERETARO	2 + 180	47 + 000	44 + 820	71, 712	D W	1966	13,290.0	
B	SAN LUIS	485 + 720	522 + 480	36 + 760	38, 479	D W	1969	8,313.6	
B	SAN LUIS	REROUTED	REROUTED	32 + 000	53, 120	D W	1969	8,937.6	GOMEZ FARIAS – AGUA NUEVA
B C	SAN LUIS	0 + 000	114 + 330	114 + 330	189, 788	S L			
B C	SAN LUIS	114 + 330	120 + 050	5 + 720	9, 495	D W	1967	8,313.6	
B C	SAN LUIS	120 + 050	180 + 143	60 + 093	99, 755	S L			
F	MONTERREY	9 + 000	61 + 300	52 + 300	86, 818	R S			
F	MONTERREY	61 + 300	88 + 000	26 + 700	44, 322	D W			
F	MONTERREY	88 + 000	109 + 000	21 + 000	34, 860	R S	1965	2,856.0	
F	MONTERREY	109 + 000	140 + 000	31 + 000	51, 460	D W			
F	MONTERREY	140 + 000	142 + 150	2 + 150	3, 569	R S			
F	MONTERREY	142 + 150	182 + 300	40 + 150	65, 306	D W			
	MTY. y GL	REROUTED	REROUTED	16 + 000	26, 560	R S	1971		CONNECTION LINE M AND F
G	SE / VCI	104 + 500	126 + 840	22 + 340	37, 084	D W	1969	9,342.0	
I	GUADALAJARA	4 + 000	53 + 295	49 + 295	81, 828	D W		8,217.6	
I	GUADALAJARA	REROUTED	REROUTED	19 + 337	27, 253	D W			PENJAMO – LA PIEDAD
I	GUADALAJARA	77 + 250	104 + 420	27 + 170	43, 218	D W	1970	7,460.0	
I	GUADALAJARA	126 + 180	212 + 834	80 + 654	137, 921	D W			
R D	MONCLOVA	216 + 927	177 + 780	39 + 147	64, 284	D W	1971	3,380.4	
R A	MONCLOVA	79 + 200	118 + 800	39 + 600	63, 360	R S	1960	4,190.4	
S	MEXICANO	0 + 180	11 + 932	11 + 752	13, 617	D W			
S	MEXICANO	12 + 120	21 + 900	9 + 780	14, 410	D W	1970	8/320.8	
S	MEXICANO	22 + 080	59 + 550	37 + 470	54, 722	D W			
B	SAN LUIS	REROUTED	REROUTED	16 + 879	28, 020	D W	1969	9,032.8	ENCANTADA – SALTILLO
C H P	CHIHUAHUA	0 + 772.19	126 + 560.00	125 + 787.81	210, 061	R S	1966	393.6	OJINAGA – FALOMIR
C H P	CHIHUAHUA	126 + 821.60	127 + 490.00	0 + 668.40	1, 450	R S	1966	393.6	
C H P	CHIHUAHUA	127 + 767.40	239 + 372.00	111 + 604.60	186, 381	R S	1965	393.6	FALOMIR – ALDAMA
C H P	CHIHUAHUA	241 + 700.00	251 + 134.00	9 + 434.00	15, 735	R S	1965	393.6	ALDAMA – CHIHUAHUA
C H P	CHIHUAHUA	251 + 134.00	251 + 801.00	0 + 667.00	1, 114	D Y W	1970	393.6	ALDAMA – CHIHUAHUA
C H P	CHIHUAHUA	368 + 116.96	368 + 466.51	0 + 349.55	584	R S	1961	1,308.0	MESA
C H P	CHIHUAHUA	561 + 957.00	563 + 121.80	1 + 164.80	1, 945	R S	1961	1,308.0	CREELL
C H P	CHIHUAHUA	754 + 685.00	756 + 350.30	1 + 665.30	2, 781	R S	1960	608.0	BETWEEN JESUS CRUZ AND EL DESCANSO
C H P	CHIHUAHUA	774 + 642.30	779 + 483.10	4 + 840.80	8, 084	R S	1960	608.0	BETWEEN LOS POZOS AND AGUA CALIENTE
C H P	CHIHUAHUA	780 + 184.00	941 + 187.00	161 + 003.00	268, 877	R S	1960	608.0	AGUA CALIENTE A TOPOLOBAMPO
T S	COATZACOALCOS	0 + 000.00	11 + 000.00	11 + 000.00	18, 370	R S	1962		COATZACOALCOS A ALLENDE
			TOTAL	1,319+142.46	2,163 217				

DATA IN THIS TABLE WERE PROVIDED BY THE DEPARTMENT OF TRACK AND STRUCTURES OF FERROCARRILES NACIONALES DE MEXICO AND CHIHUAHUA PACIFICO

FIGURE 1. RS TYPE MIXED TIE

DESCRIPTION OF THE CONCRETE TIES MANUFACTURED IN MEXICO

The following are the types of concrete ties manufactured in Mexico: two-block ties, type RS/SL, and monolithic ties, type "Dywidag" B-58.

The two-block tie RS or SL is comprised of two reinforced concrete blocks, with reinforcing grid in the top and bottom of the blocks, and three spirals in between the grids. In this area the bolts are anchored to fix the rail, the rubber pad, and other accessories.

The two blocks are solidly connected by a hard steel tiebar, which, according to the type of tie, has a Y or L section. This tiebar maintains the proper spacing of the blocks and controls the track gage (figure 1 and plates 1 through 14).

The monolithic "Dywidag" B-58 tie has a solid center portion, without depressions, with gradually widening ends, which contain the rail-fastening components and rail seat areas of ample width. They contain a tensile reinforcement made of two hairpin-shaped steel bars. The loops of these bars are perpendicularly crossed at one end of the tie, while the stressing forces are transmitted at the other end by means of anchor plates (figure 2 and plates 15 through 26).

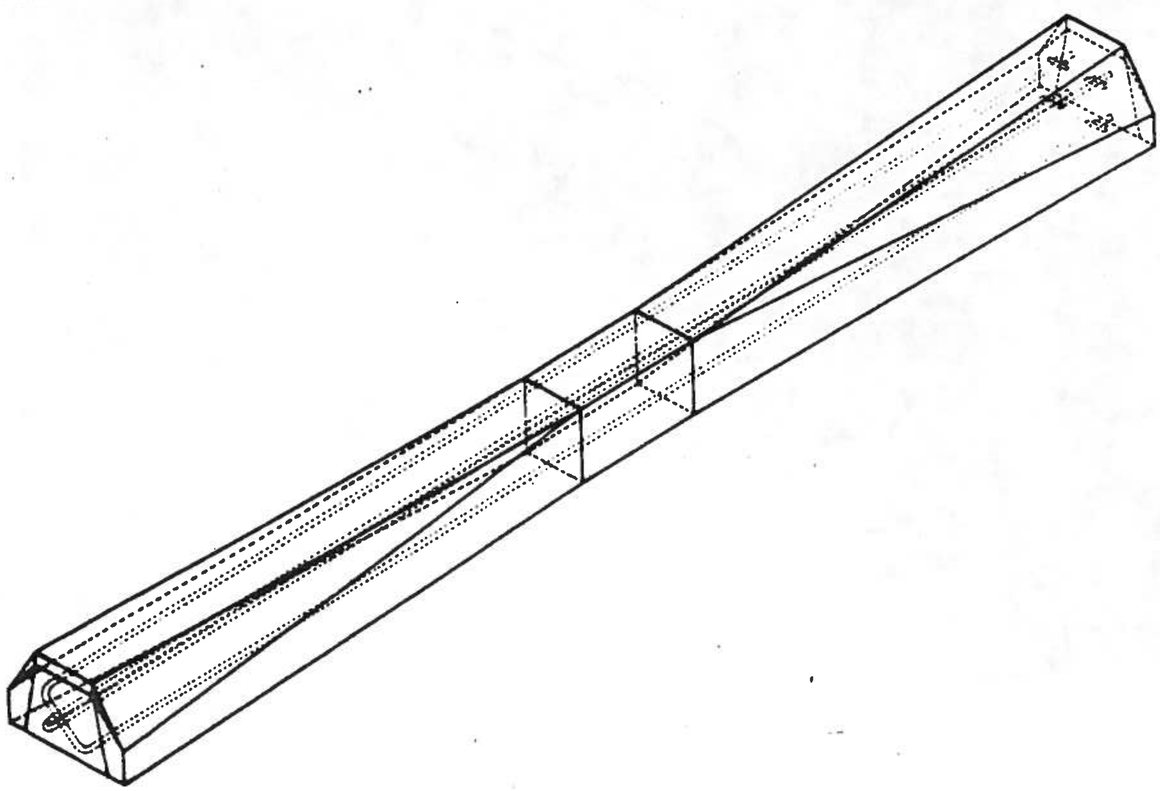


FIGURE 2. B-58 TIE WITH REINFORCING STEEL (DYWIDAG)

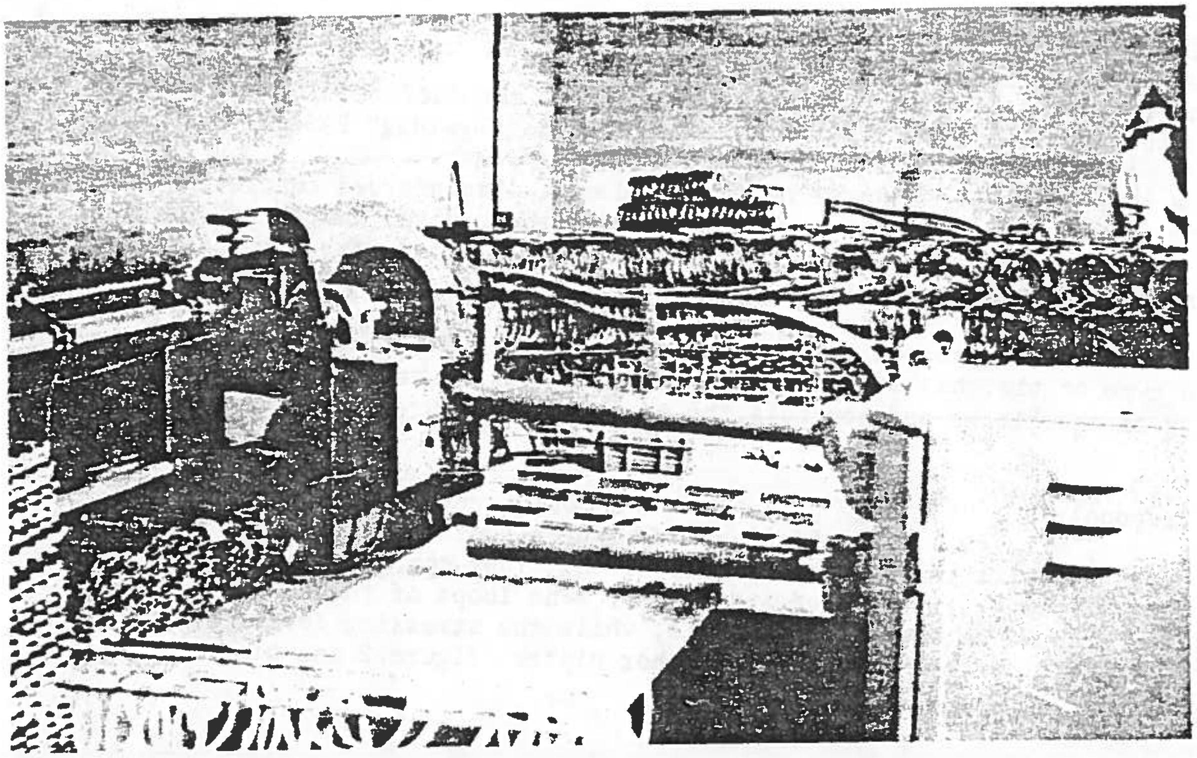


PLATE 1. BLOCK-REINFORCEMENT MANUFACTURING PLANT

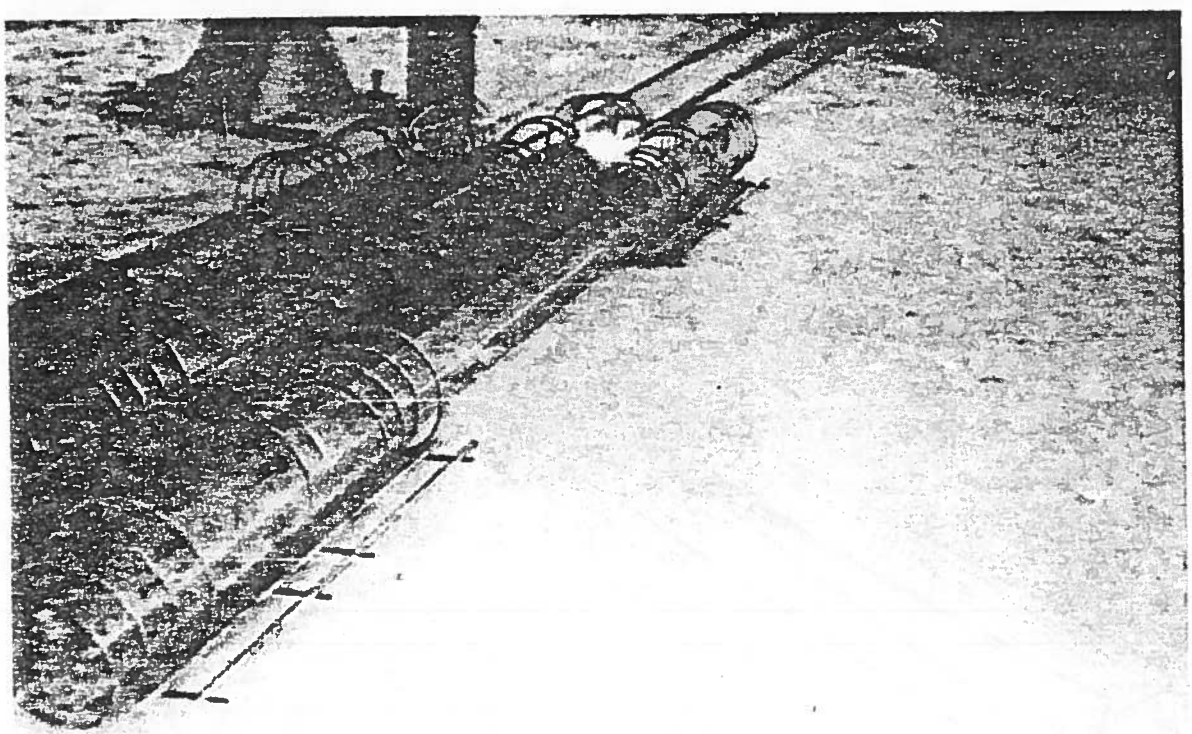


PLATE 2. BARS WITH BLOCK REINFORCEMENTS

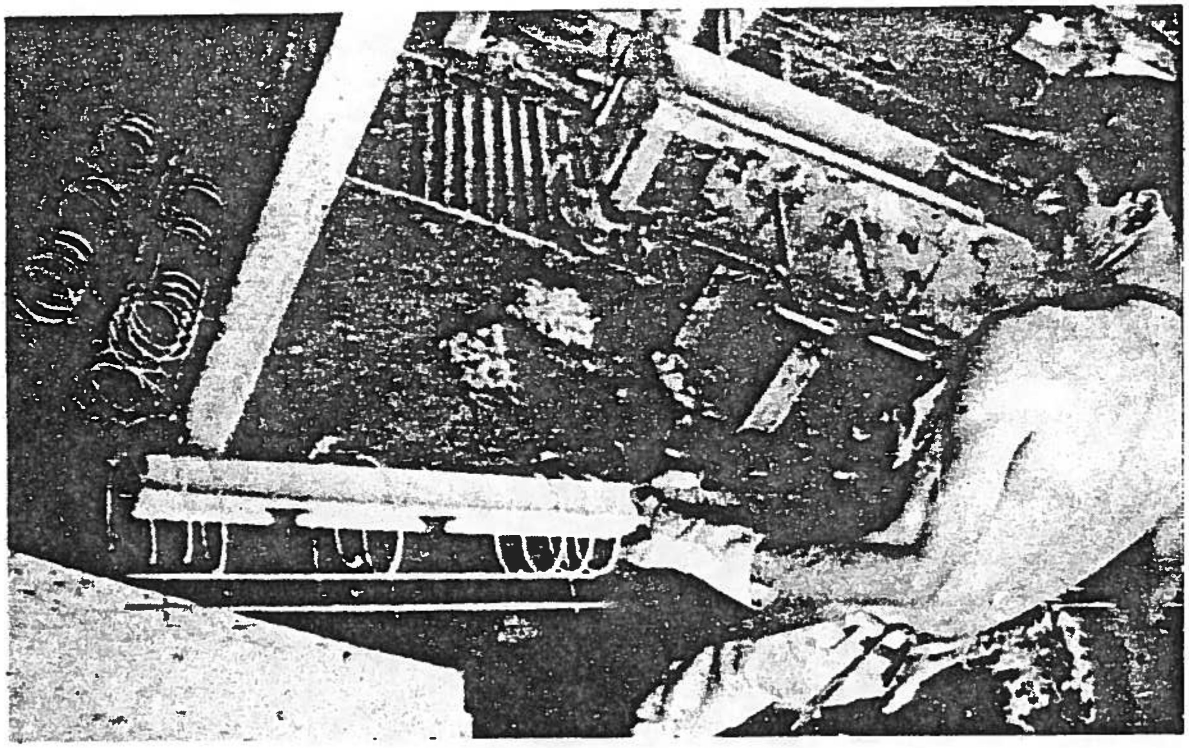


PLATE 3. BAR WITH BLOCK-REINFORCEMENT

PLATE 4. PREPARATION OF MOLDS

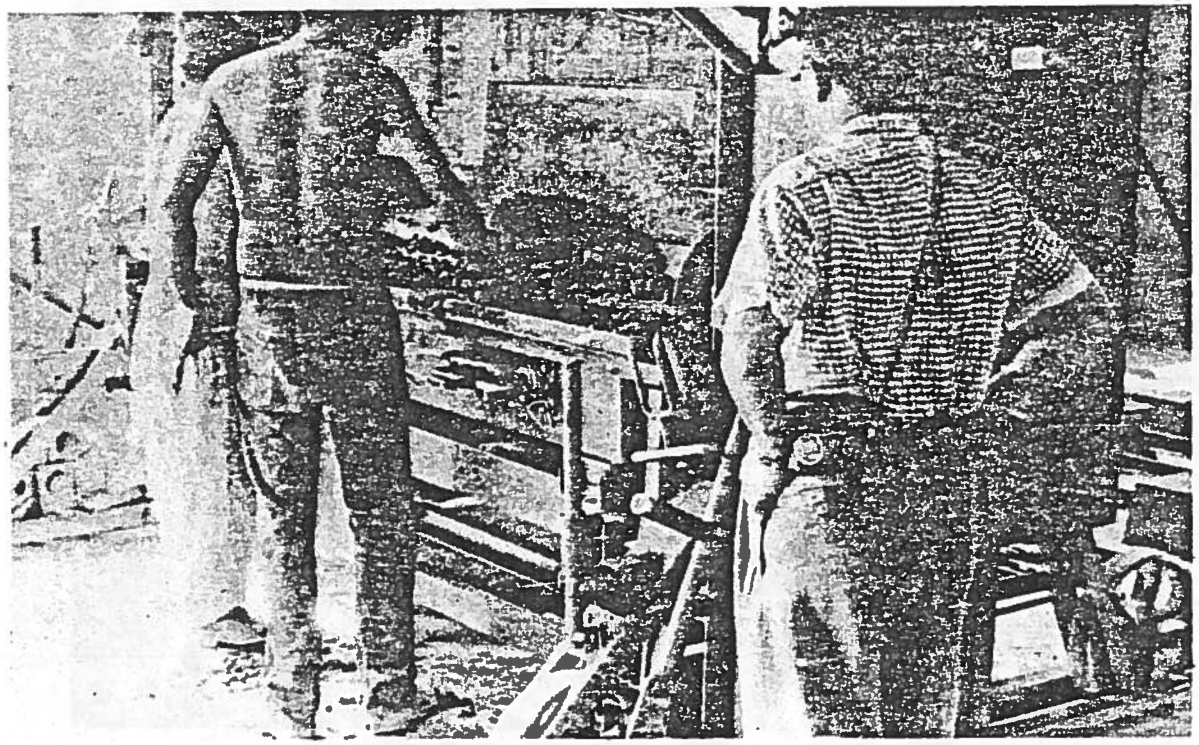


PLATE 5. CASTING OF CONCRETE INTO MOLDS

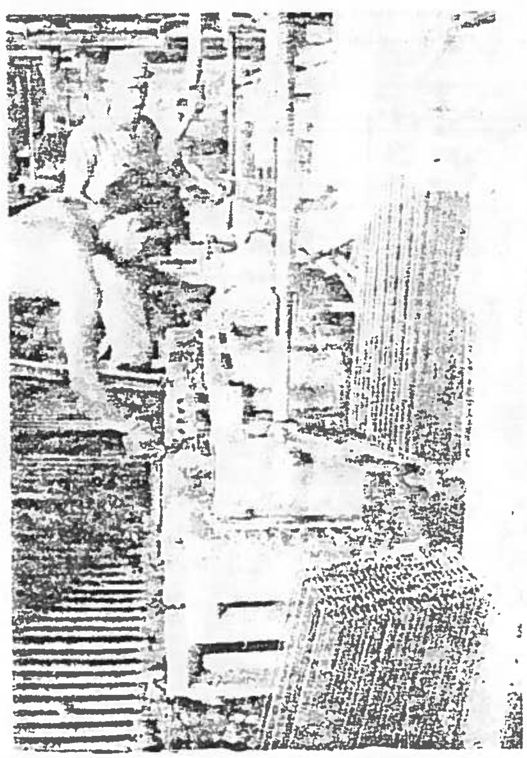


PLATE 6. COMPACTING AND VIBRATING OF TIE IN MOLD

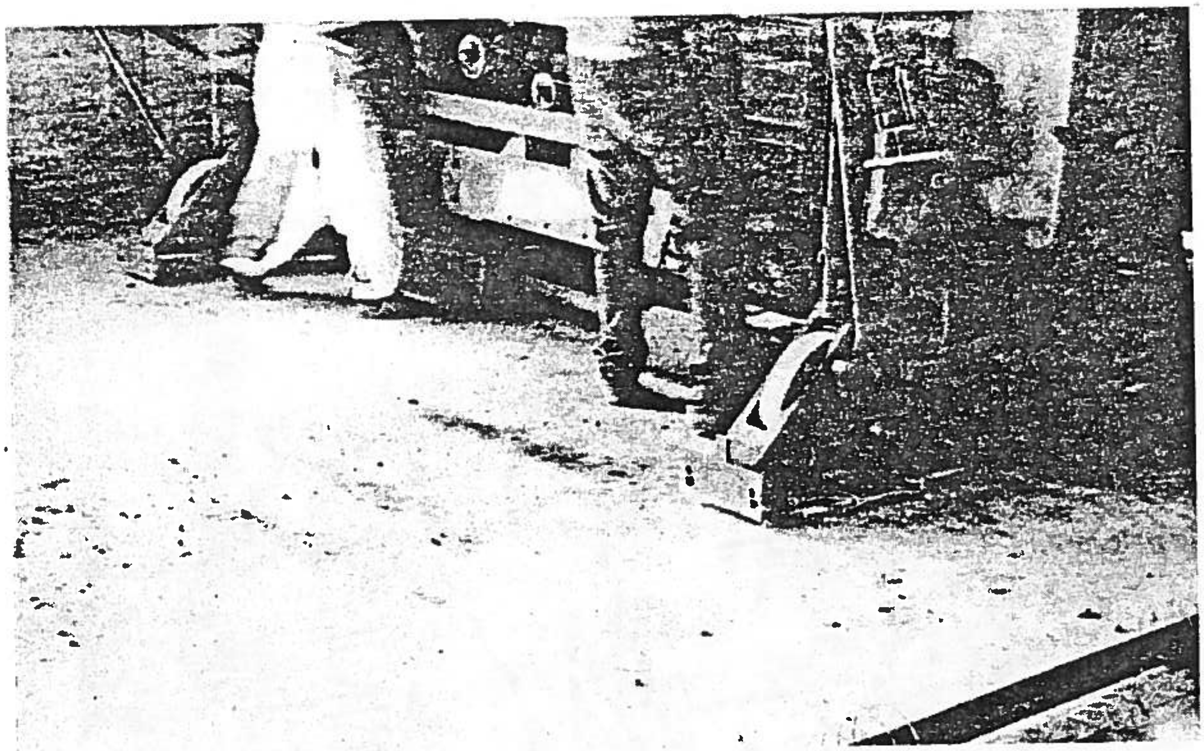


PLATE 7. DEMOULDING OF TIE ON FLOOR

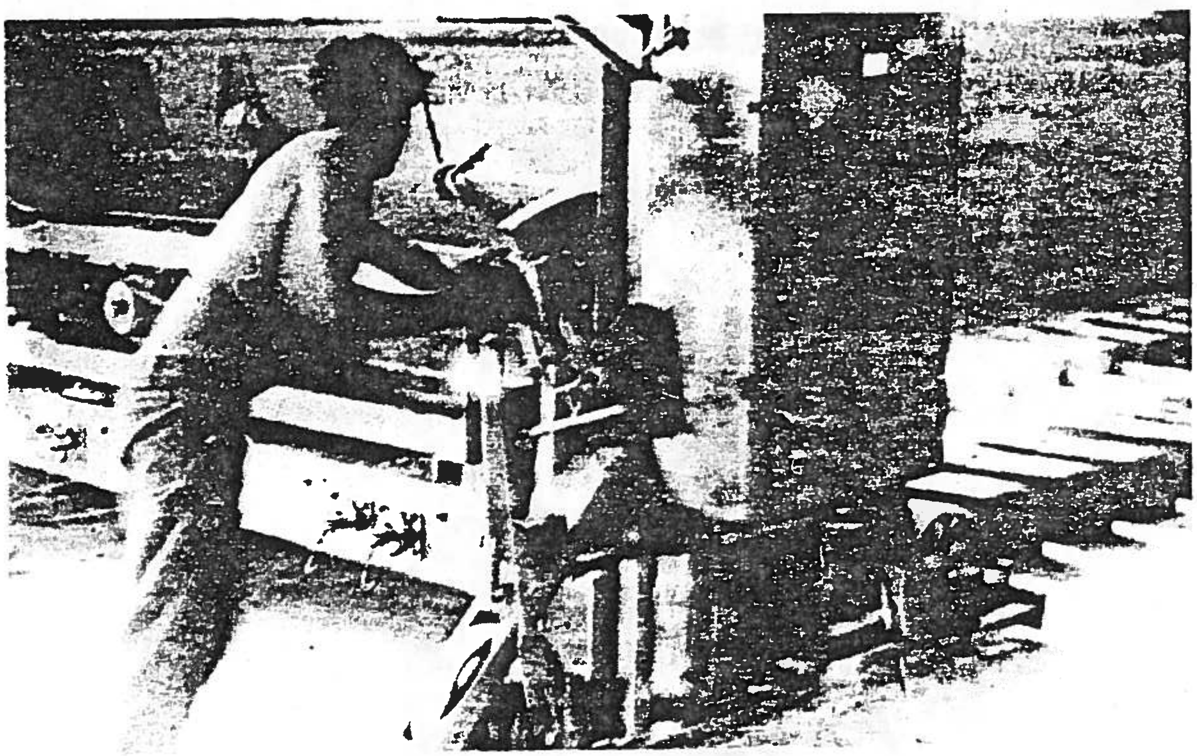


PLATE 8. SHIFTING THE MACHINE

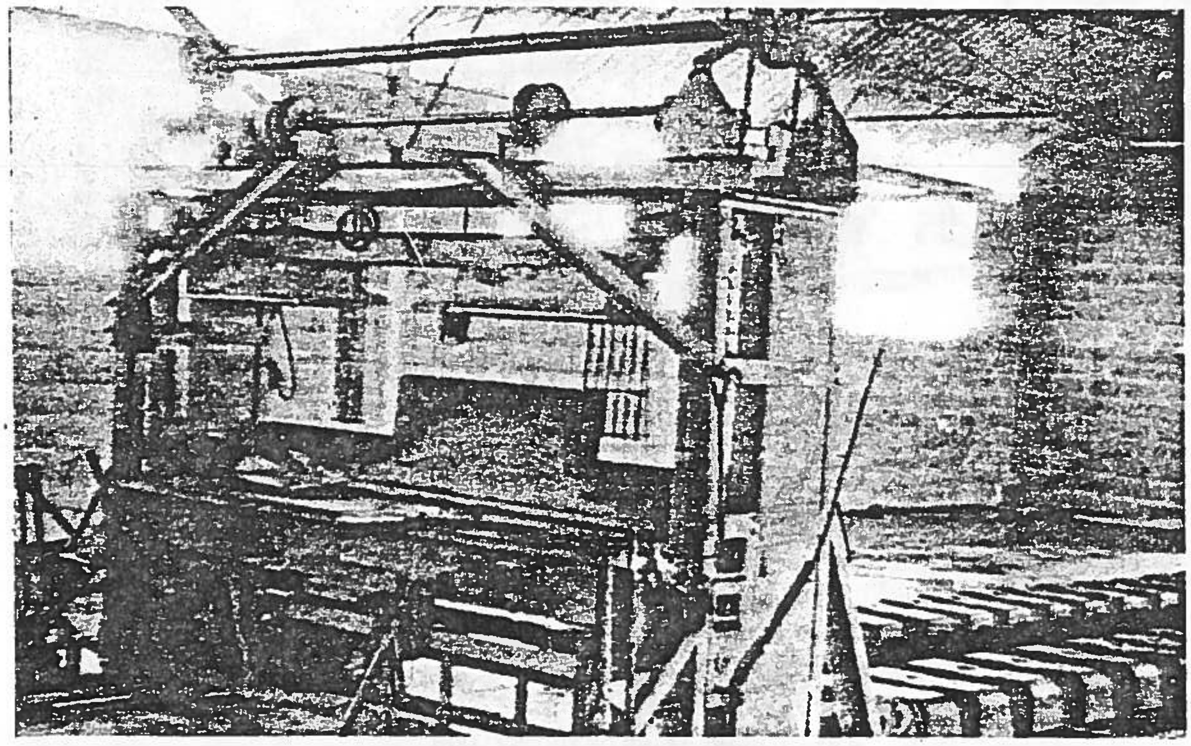


PLATE 9. SET OF NEWLY MANUFACTURED TIES

PLATE 10. RETOUCHING OF TIES

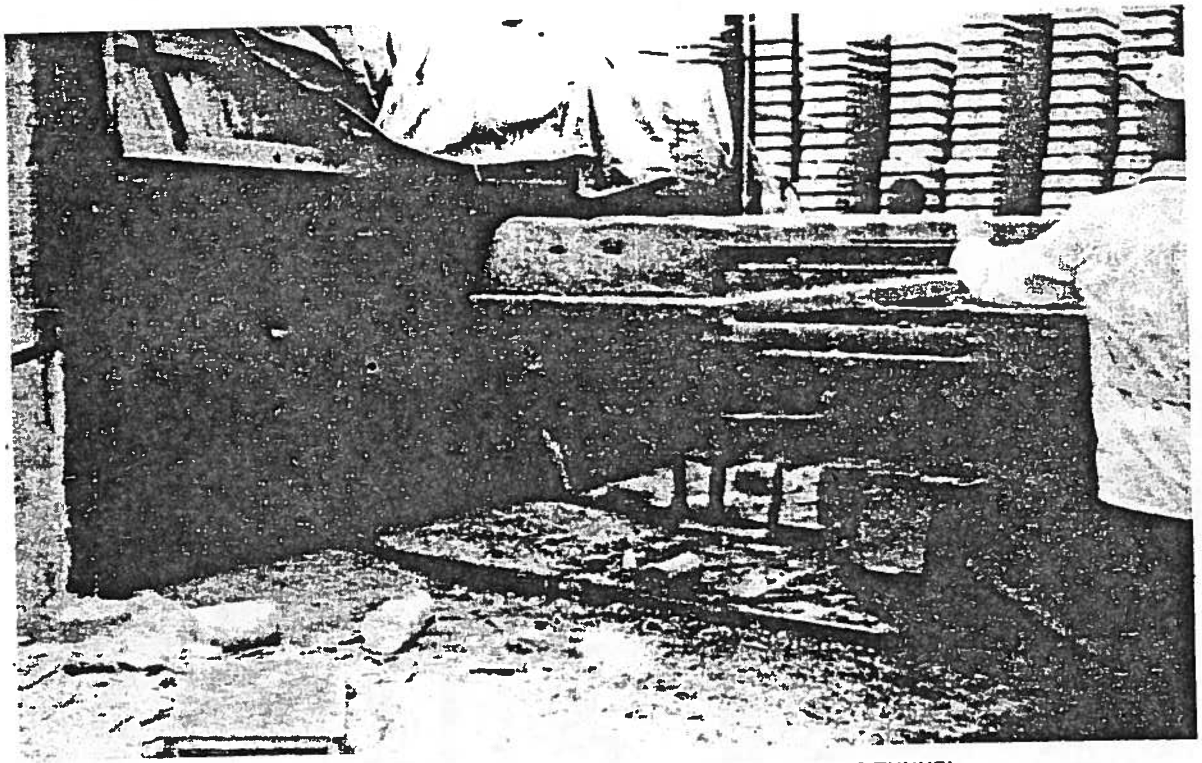


PLATE 11. A BATCH OF TIES BEING PLACED IN THE CURING TUNNEL

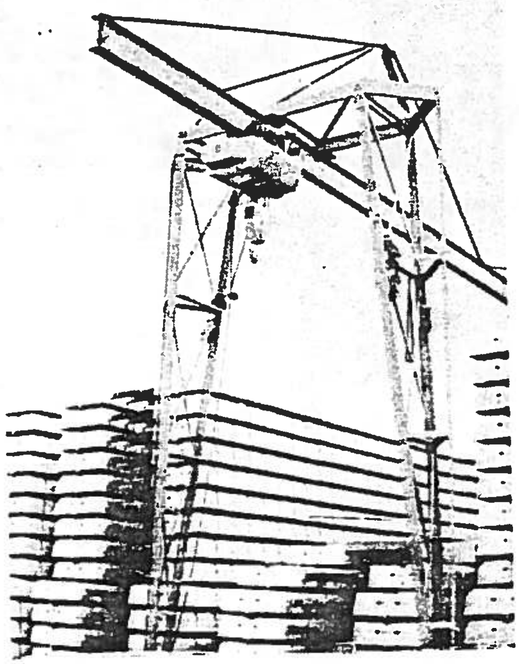


PLATE 12. STACKING OF TIES IN PREPARATION FOR WATER-CURING

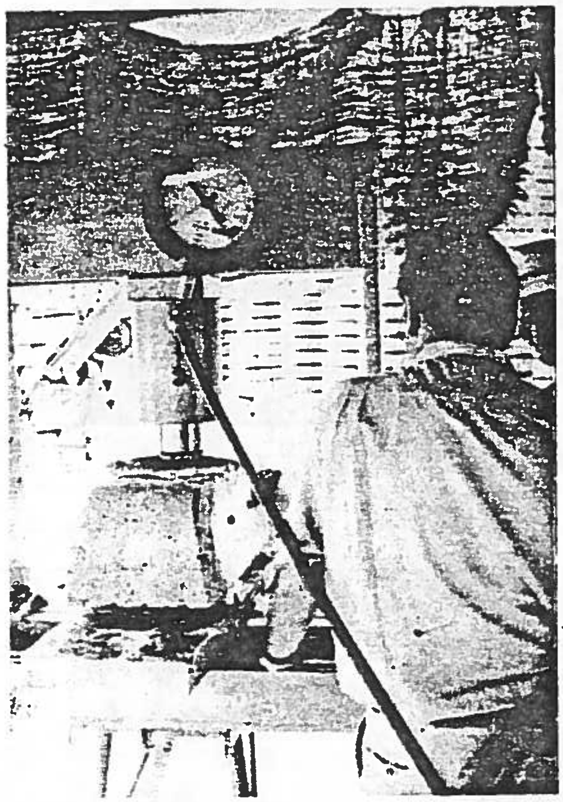


PLATE 13. BENDING TEST OF BLOCK IN NORMAL TIE POSITION

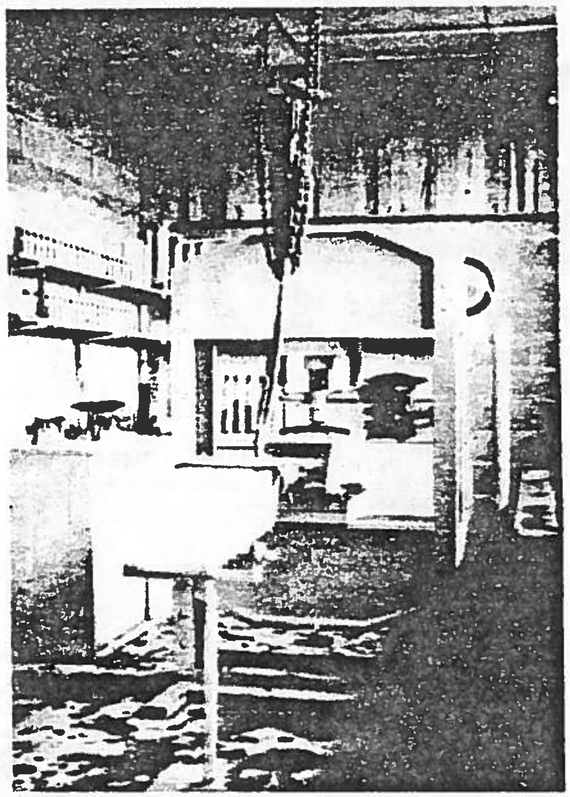


PLATE 14. BENDING TEST OF BLOCK IN REVERSE TIE POSITION

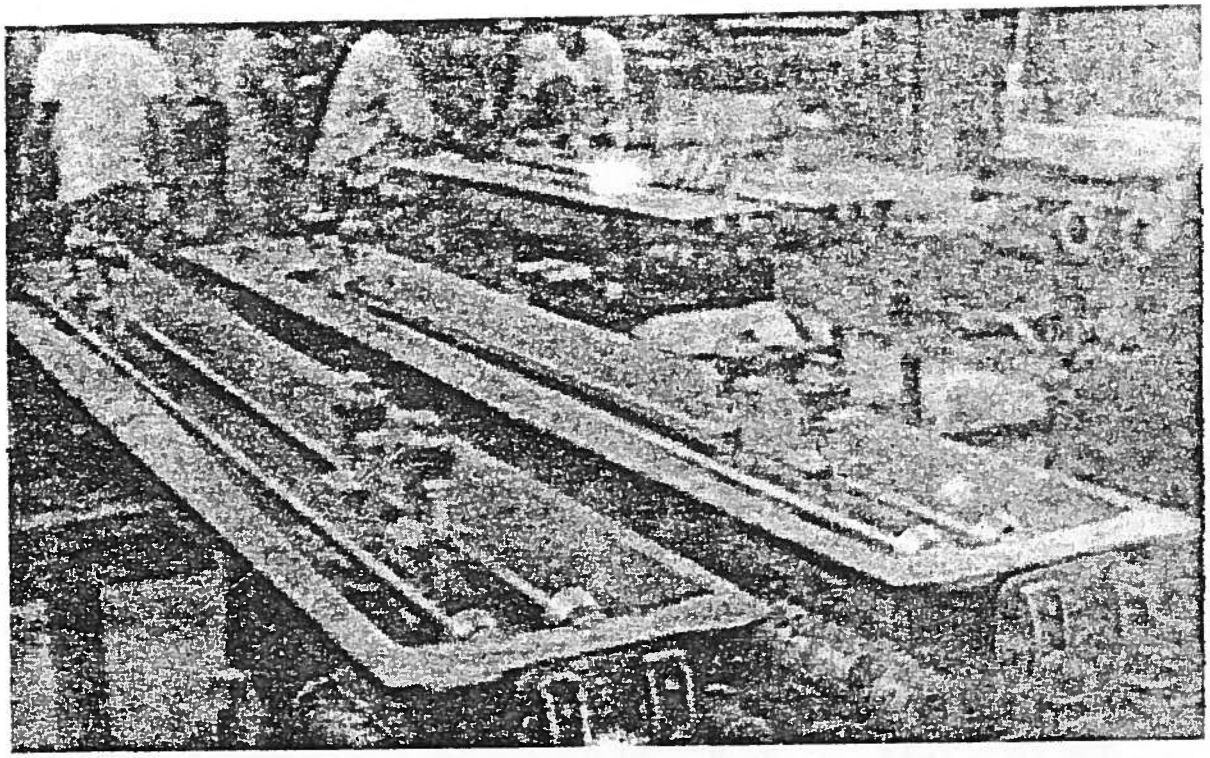


PLATE 15. MOLDS PREPARED FOR TIE-CASTING (DYWIDAG)

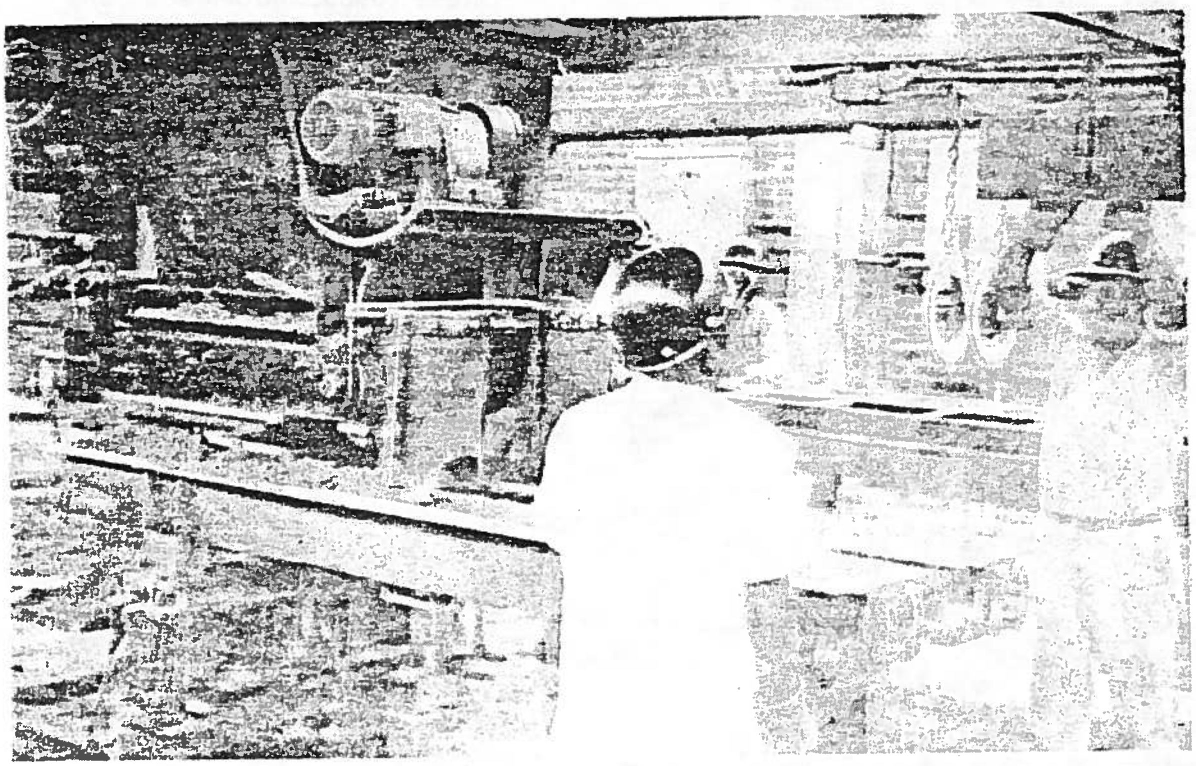


PLATE 16. START-UP OF TIE-CASTING

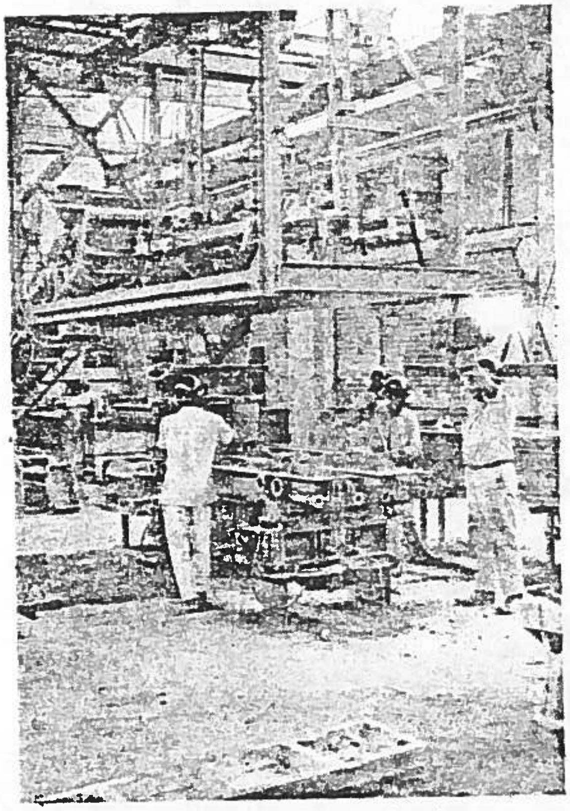


PLATE 17. COMPACTING AND VIBRATING OF TIE

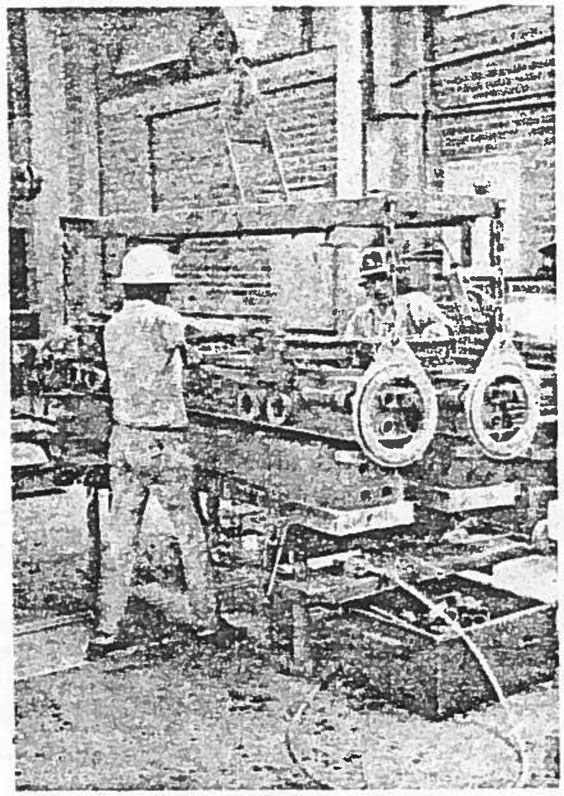


PLATE 18. DEMOULDING OF TIE

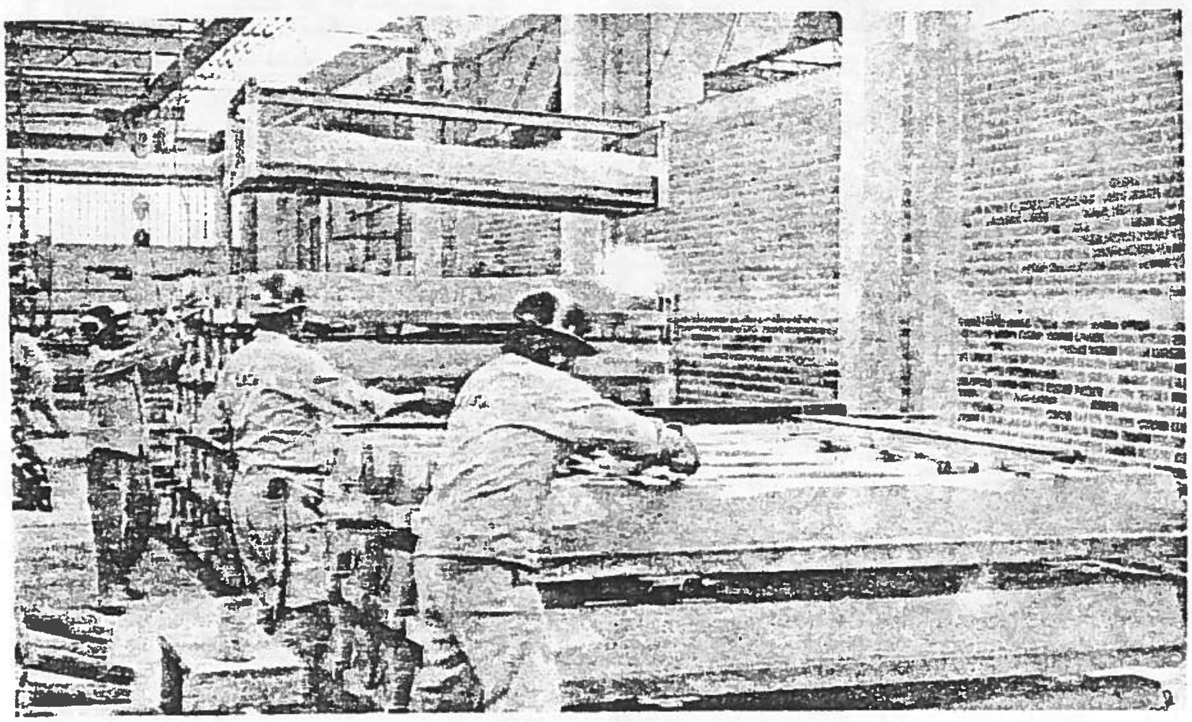


PLATE 19. RECTIFYING BEVELS AND RETOUCHING TIES

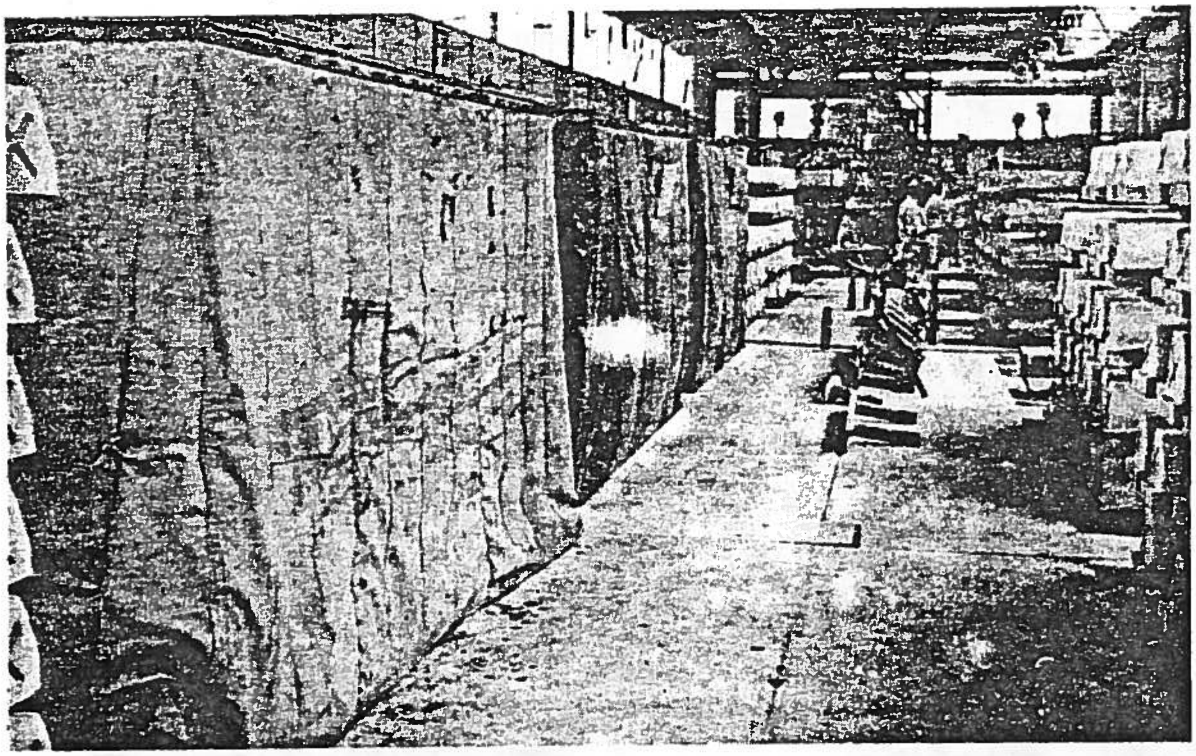


PLATE 20. ACCELERATED CURING OF TIES

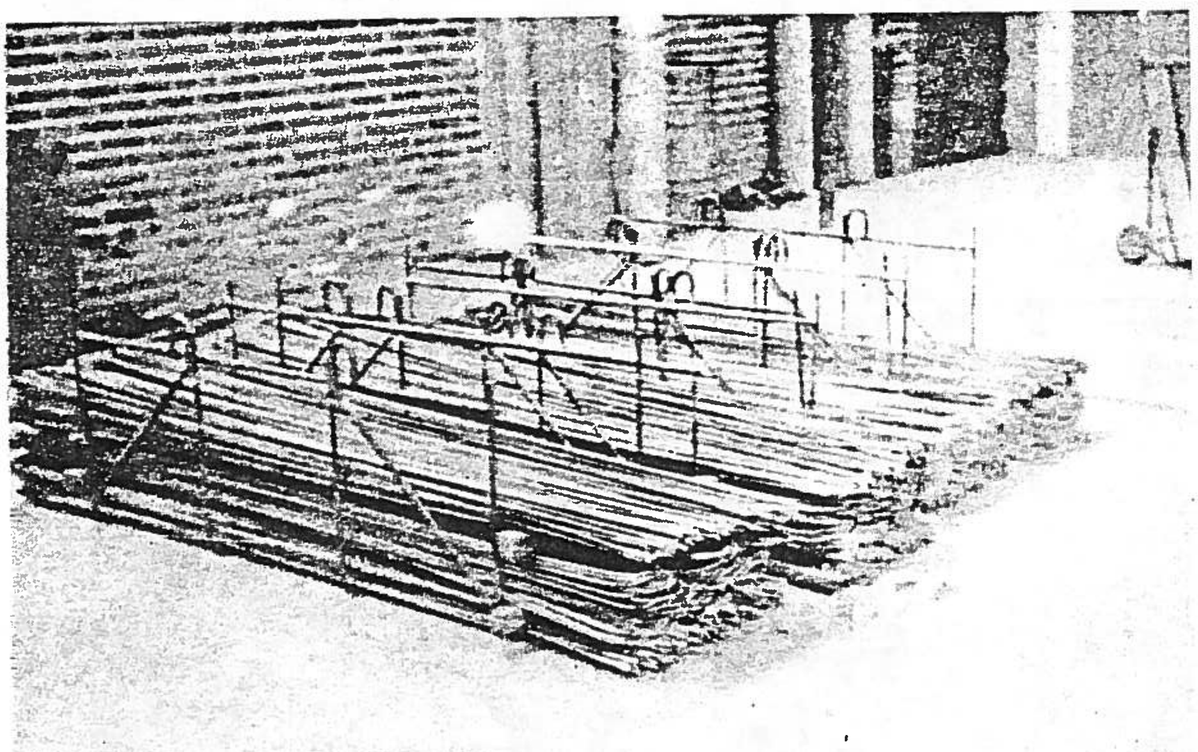


PLATE 21. STORAGE OF PRE-STRESSING STEEL REINFORCEMENTS

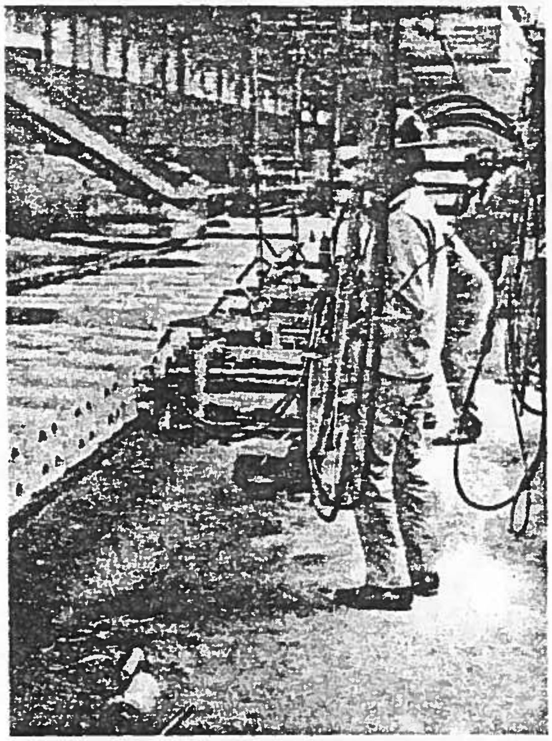


PLATE 22. TENSIONING OF PRESTRESSING REINFORCEMENTS

PLATE 23. INJECTION AND PLUGGING OF DUCTS WITH CEMENT MORTAR

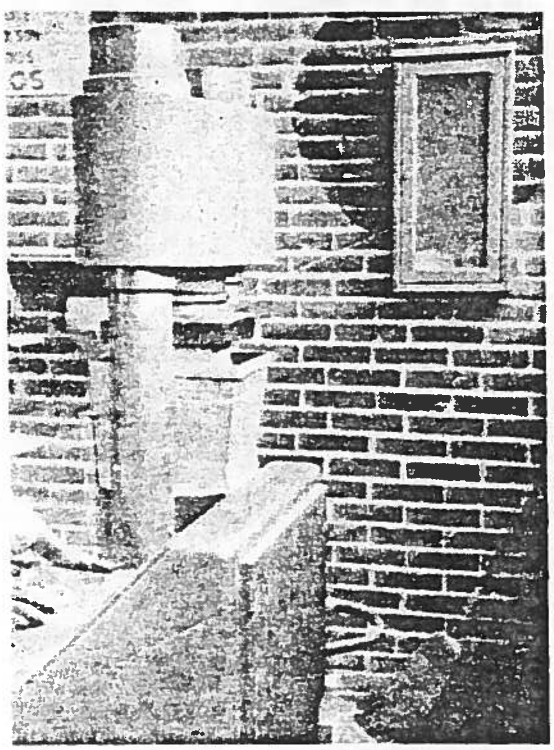


PLATE 24. COMPRESSION TEST OF CONCRETE BLOCK SAMPLES

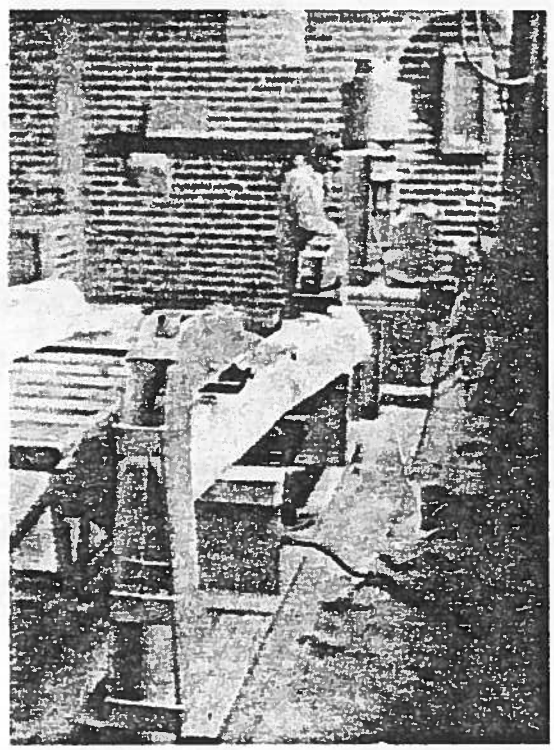


PLATE 25. TIE BENDING TEST

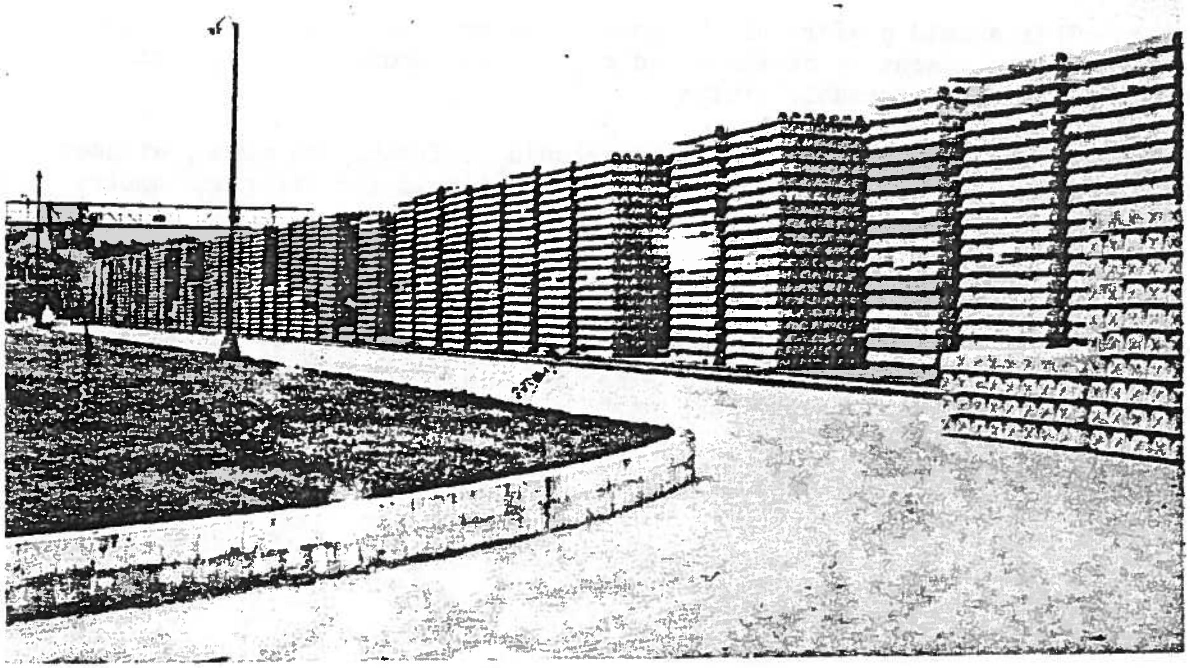


PLATE 26. STORAGE OF COMPLETED TIES

PROPERTIES, REQUIREMENTS, AND SPECIFICATIONS OF THE CONCRETE AND ACESSORIES FOR THE TIES

The manufacture of the concrete ties is a process done with equipment specially designed for mass production, with strict quality control and at low cost. In the following are listed in general form, the properties and requirements with which the concrete and its components must comply, as well as the accessories of the ties used to date.

Cement. Under normal conditions, the French, German, and National Standards apply to the use of the most suitable types of cement, and to satisfy the requirements of resistance, to establish testing procedures and precautions related to cement storage in order to guarantee its optimum condition of use.

Water. This should preferrably be potable water. If other water is used, it should always have a content of suspended materials, impurities, and organic matter less than the acceptable limits.

Sand. The shape of the sand particles should preferably be round, without deleterious material. Acceptance limits are established for its granulometry and its content of lime, clay, and organic impurities.

Coarse Aggregate. Generally speaking, coarse aggregate should be hard, resistant, chemically stable, well graded, and uniform. In respect to formation of particles, the French standards accept natural aggregates; German standards prefer that such material shall be 100 percent of crushing product. National standards adopt both criteria for each particular case.

Without considering the type of tie and its particular resistance requirements, the common properties of the concrete are as follows:

a. Dry concrete mix (consistency of moist earth).

b. Low water-cement ratio (less than 0.38).

c. Plastic and workable consistency, which shows a minimum of voids and porosity after compaction.

d. Resistance against wear, against impact, and against various kinds of attack (fire, weather, and chemicals).

e. Low thermal and electrical factors of conductivity.

In table 2 other properties and resistance requirements are given for each design.

TABLE II

SPECIAL CHARACTERISTICS OF THE CONCRETES

TYPE OF TIE	STANDARDIZING AGENCY	MIN. CEMENT CONTENT (kg/m³)	MAX. WATER/ CEMENT RATIO	MAX. SIZE STONE (mm)	MIN. COMPRESSIVE STRENGTH		MIN. BENDING STRENGTH	
					CUBIC, AT 28 DAYS* (kg/cm²)	CYLINDRICAL, AT 28 DAYS (kg/cm²)	AT 7 DAYS (kg/cm²)	AT 28 DAYS (kg/cm²)
MIXED RS	FRENCH NAT. R.R. (1957)	325	0.38	40	400			
MIXED RS	FRENCH NAT. R.R. (1960)	350	0.38	40	410			52
MIXED RS or SL	S. C. O. P. *** MEXICO			40		360		
MIXED RS or SL	MEX. NAT. R.R.	333	0.38	20		400		
DYWIDAG B – 58	GERMAN R.R.		0.36	30	600**		65	
DYWIDAG B – 58	S. C. O. P. *** MEXICO		0.36	30	600**		65	
DYWIDAG B – 58	MEX. NAT. R.R.		0.36	30	600**		65	

*THE CONVERSION FACTOR AT EQUIVALENT CYLINDRICAL STRENGTH IS 0.8.

**A MINIMUM CUBIC STRENGTH OF 450 kg/cm² IS SPECIFIED AT THE TIME OF TENSIONING.

*** SECRETARIATE FOR PUBLIC WORKS AND COMMUNICATIONS

Reinforcing Steel. For the RS or SL ties, the minimum elastic limit of the steel is 24 kg/mm^2 (34,128 lbs/in^2); 38 kg/mm^2 (54,036 lbs/in^2) as a minimum for rupture, and a minimum elongation of 20 percent before rupture.

Steel Bar. The Standards for the RS or SL ties require that the steel tie-bars are free from rolling defects and must have an elastic limit in excess of 36 kg/mm^2 (51,192 lbs/in^2).

Prestressing Steel. For the "Dywidag" B-58 ties, the Standards require the use of four rods of 9.7 mm (0.382 inches) diameter with elastic limit of 135 kg/mm^2 (191,970 lbs/in^2), a minimum resistance to rupture of 150 kg/mm^2 (213,300 lbs/in^2) and a minimum elongation before rupture of 6 percent.

TESTS PERFORMED ON FINISHED TIES

Bending Test, for RS or SL two-block ties.

The French and National Standards require, after 28 days, a bending test on one tie out of every 100 ties produced, in accordance with the following procedures:

- The ties to be tested must be painted with a lime solution, in order to facilitate the observation of cracks. One of the blocks is tested in upright position, one in upside-down position.
- Each tieblock is located in the testing press in its required position, with leather pads or any other material placed between the concrete and the supporting and loading plates, of proper dimensions, to secure the correct transmission of the load, as shown in figure 3.
- The load application is increased at uniform speed up to 30 tonnes (33.08 tons) in upright position and 25 tonnes (27.56 tons) upside down; when the total load has been applied, it must be maintained for a minimum of 5 minutes, in order to examine the block. The test is satisfactory, if no cracks appear at the designated loads in either case, or if the cracks that may appear during the load application disappear or are not visible with a magnifying glass after the load has been removed.

For the "Dywidag" B-58 tie, the German and National Standards require a bending test on one tie taken at random from the production of one day. It must be cured in water for 7 days and subsequently be subjected to a test in an upside-down position, supported on 2 seats, 1,500 mm (59.06 in) apart, with a concentrated load at midspan, as shown in figure 4. The tie satisfies the acceptance requirements if no cracks appear at any face, under a load of 4.8 tonnes (5.29 tons), (equivalent to a bending moment of 1.6 tonne-meter (5.79 ton-ft)).

Abrasion Test. The French and German Standards specify a test of one tie in the "Vibrogir," but differ in the number of hours and in the maximum percentage of loss.

In the National Standards no rules exist concerning this type of test.

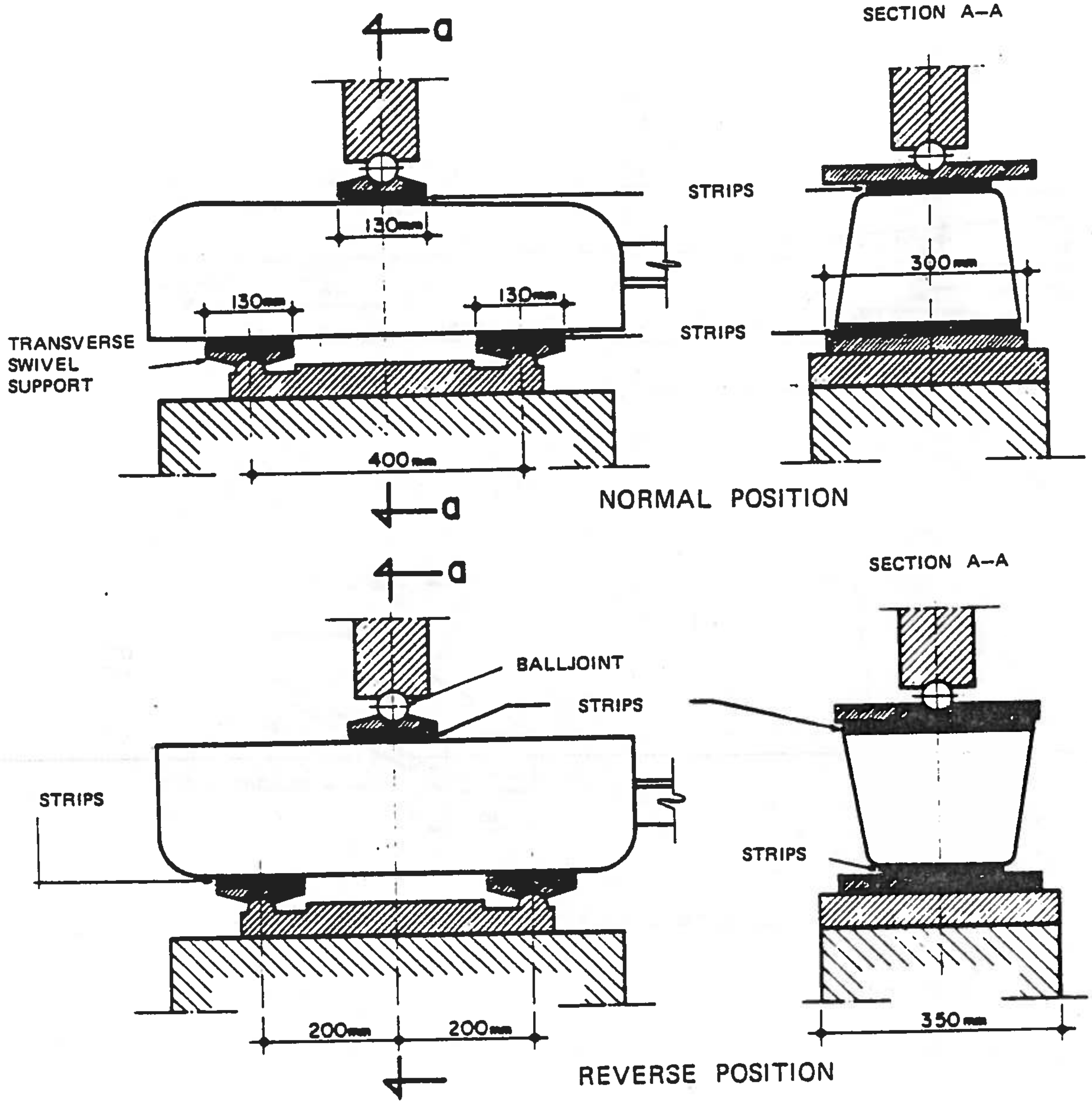


FIGURE 3. MIXED TIE BENDING TEST

Impact Test. The German specifications require a test on three ties with a mass in the shape of the rim of a railway wheel, with a weight of 500 kg (1,100 lbs), which must be dropped two times from a height of 75 cm (29.5 in), one at a distance of 50 cm (19.7 in) from the center of the tie and the other at a distance of 15 cm (6 in) from one of the extreme ends of the tie, as shown in figure 5. The tie is accepted if, after the test, only grooves or chips with minor cracks are produced; if the tie breaks, it is rejected.

No French or National Standards exist for this particular test.

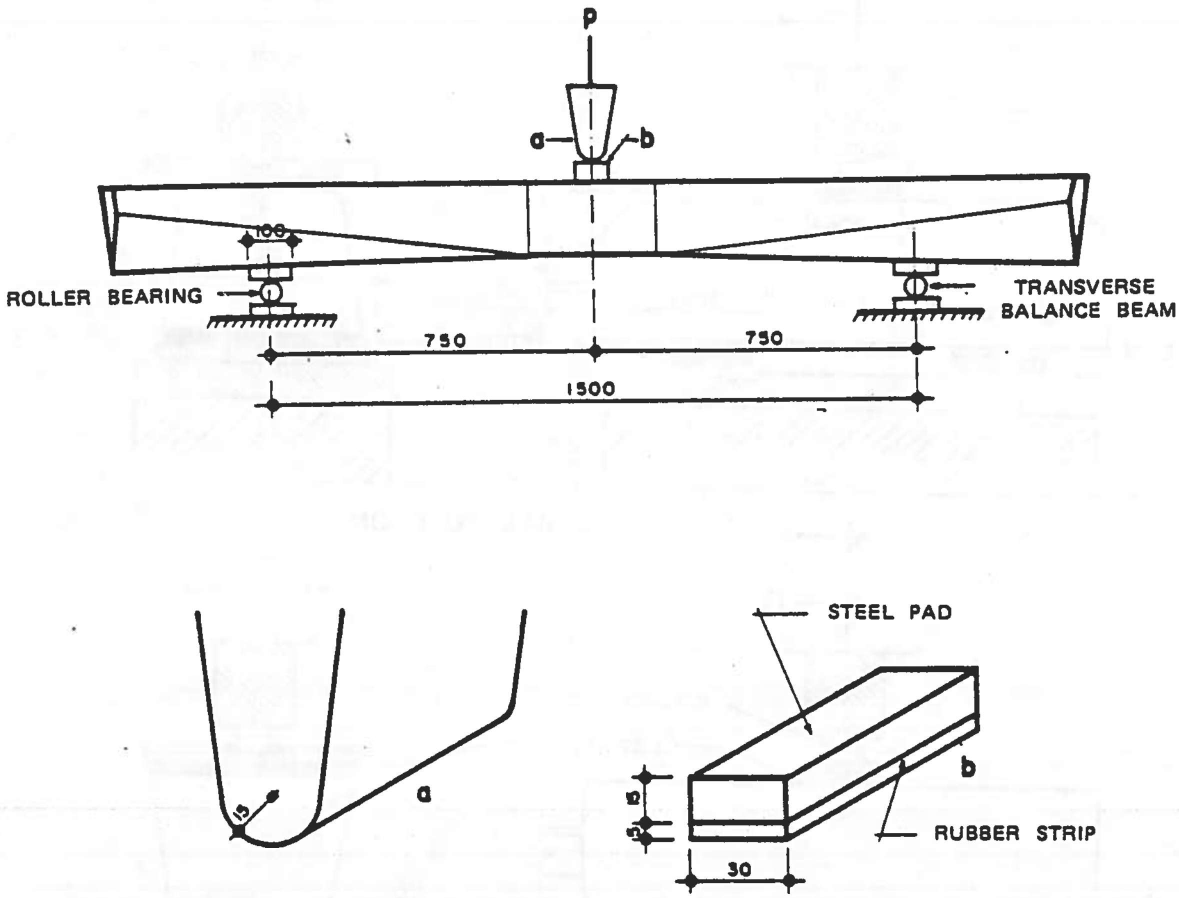


FIGURE 4. BENDING TEST IN REVERSE POSITION OF DYWIDAG TIES

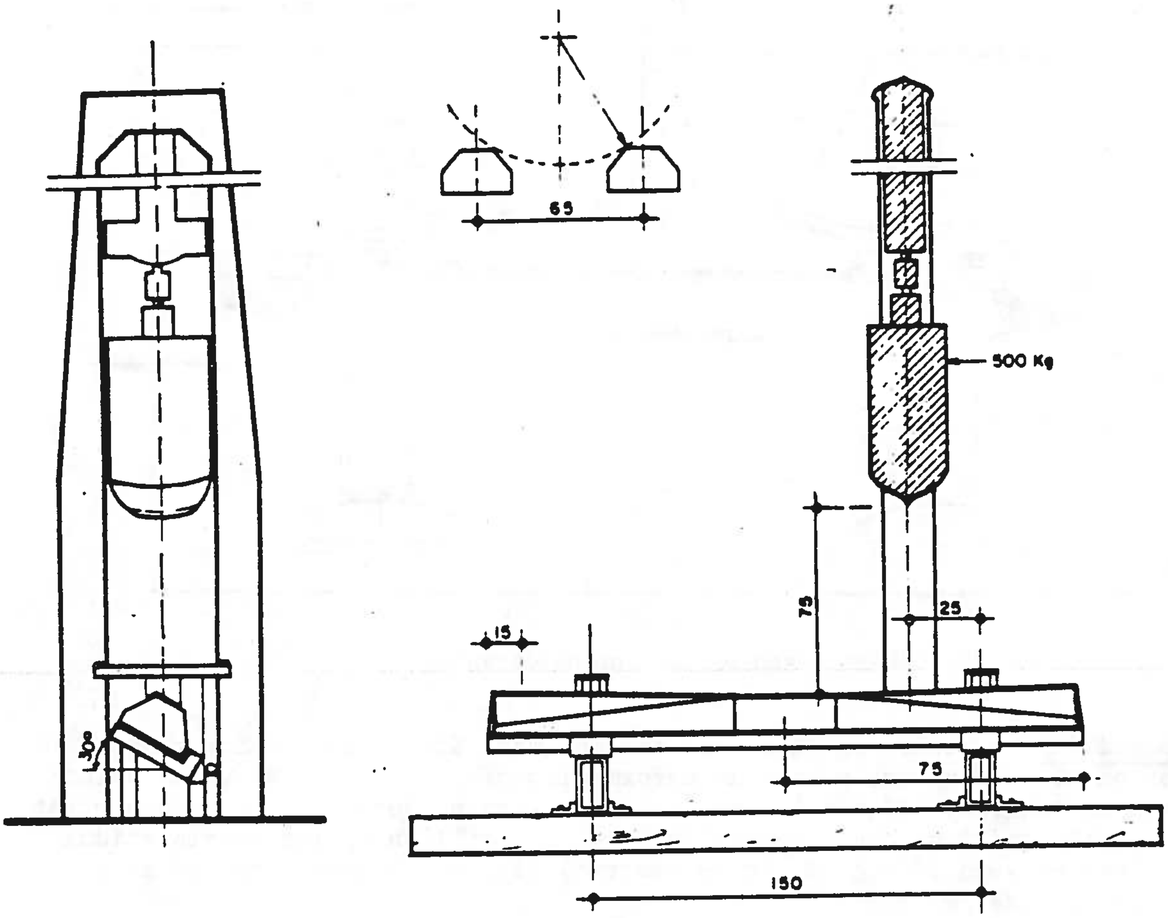


FIGURE 5. IMPACT TEST APPARATUS FOR DYWIDAG TIES

Electrical Insulation. The German Standards require a minimum electrical resistance of 10 kilo-ohms, measured between the two rail seats; the French and National Standards specifications have no such requirements.

Accessories for Rail Seat and Rail Fastening. The system of rail seat and rail fixation, with all its components, as used on the two-block ties, is shown in figure 6.

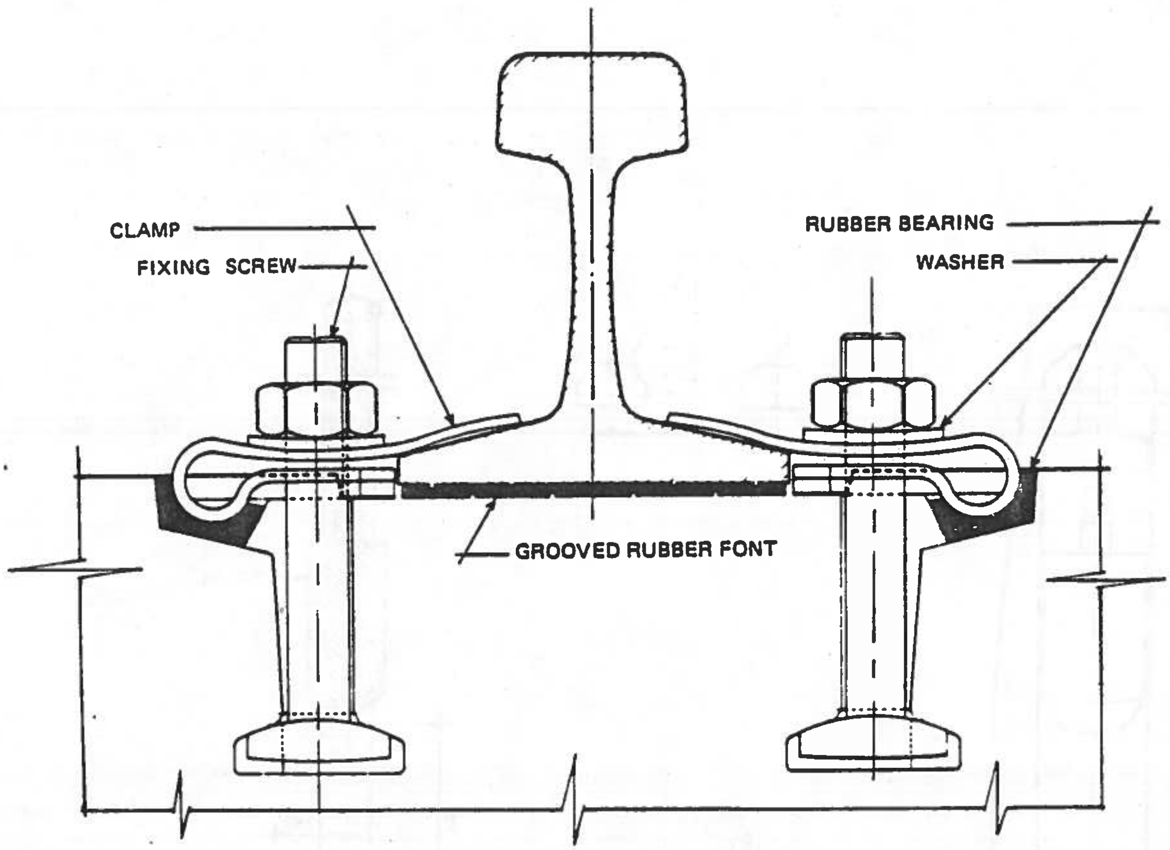


FIGURE 6. RAIL SUPPORT AND FIXING SYSTEM

Grooved Rubber Pads. In this case the National Standards require a Shore hardness of 65 as minimum, a maximum deformation of 1 mm (0.04 in) under a load of 30 tonnes (metric) (33 tons), and maximum permanent deformation of 10 percent longitudinally and 4 percent vertically after 2.4 million cycles of sinusoidal dynamic load between 10 and 30 tonnes (metric) (11 and 33 tons) applied at a rate of 250 cycles per minute.

Rubber Heel Blocks. For these items the National Standards require a minimum Shore hardness of 65, a deformation of 5 mm (0.2 in) maximum under a load of 15 tonnes (16.5 tons) and maximum permanent longitudinal deformation of 5 to 10 percent in vertical direction, after 100 thousand sinusoidal dynamic load cycles between 7 and 5 tonnes (7.7 and 5.5 tons), applied at a rate of 250 cycles per minute.

Steel Clips. The National specifications concerning this component require a Brinell hardness of 363 to 430. They also require that no fissures or visible defects occur under a deformation of 6 to 12 mm (2.4 to 4.8 in) under load.

Steel Bolts. For these components, the corresponding National Standards specify a minimum yield strength of 5,700 kg/cm^2 (81,000 lbs/in^2) and 8,100 kg/cm^2 (115,000 lbs/in^2) strength at rupture, 35 percent area reduction in the tensile test, minimum load before failure of 2,500 kg/cm^2 (35,550 lbs/in^2) in the sharp bending test.

Spring-steel Washers. For this item the National Standards specify a minimum load of 2,270 kg (4,990 lbs), before deformation of the steel.

STUDY OF THE CEMENT AND AGGREGATE PROPORTIONING OF THE CONCRETE USED IN THE MANUFACTURE OF TIES

In each of the areas where the latest manufacturing plants for the two-block RS and SL ties were installed, the necessary studies were made to determine the feasibility of a plant installation for the production of ties of the desired quality at low cost.

To this effect, the following program of preliminary studies was performed:

- Location of gravel deposits, estimating their potential volume, distance of transportation, and cost of extracting the material.
- Study of typical samples taken from the material deposit, including a composite sample from which to determine the volume in percentage of sand and of gravel, their physical and chemical characteristics, and an estimate of the cost of recommended treatment to improve its quality.
- Study of economics for alternative exploitation, such as the feasibility of acquiring crushed stone by considering the possibility of using the coarse aggregate fractions over the nominal maximum size through trituration.
- Study and cost of a typical mix-design, considering the alternative types of cement available in the area and the use of admixtures.

For the design of the mix, the initial common requirements that had to be met in each particular case were the following:

a. An average compressive strength of 400 kg/cm^2 (5,690 lbs/in^2), considering that the design strength of the concrete was fixed at 360 kg/cm^2 (5,120 lbs/in^2). For the concrete of the same quality, the coefficient of variation in the production should be low. Later, based on the first test results, this requirement was modified to include tensile strength in bending of 50 kg/cm^2 (710 lbs/in^2);

b. a concrete mix of humid earth consistency, that is of zero slump. During the period when these studies commenced (1959), there were limited means to establish the consistency. However, as other methods became known, this criteria was modified;

c. a water/cement factor equal to or less than 0.4;

d. a cement content equal to or more than 325 kg/m^3 (543 lbs/cu yd);

e. properties of plasticity and workability which guarantee the resistance and durability of the manufactured items.

To secure the compliance with this last requirement, the optimum granulometric properties of the gravel-sand mix was studied and the limits were established within which the corresponding curves had to remain. This is illustrated in figure 7. In addition, it was specified that the total volume of fines (cement, sand-dust, and pozzolan) should be no less than 400 kg (673 lbs/cu yd) per m^3 of concrete.

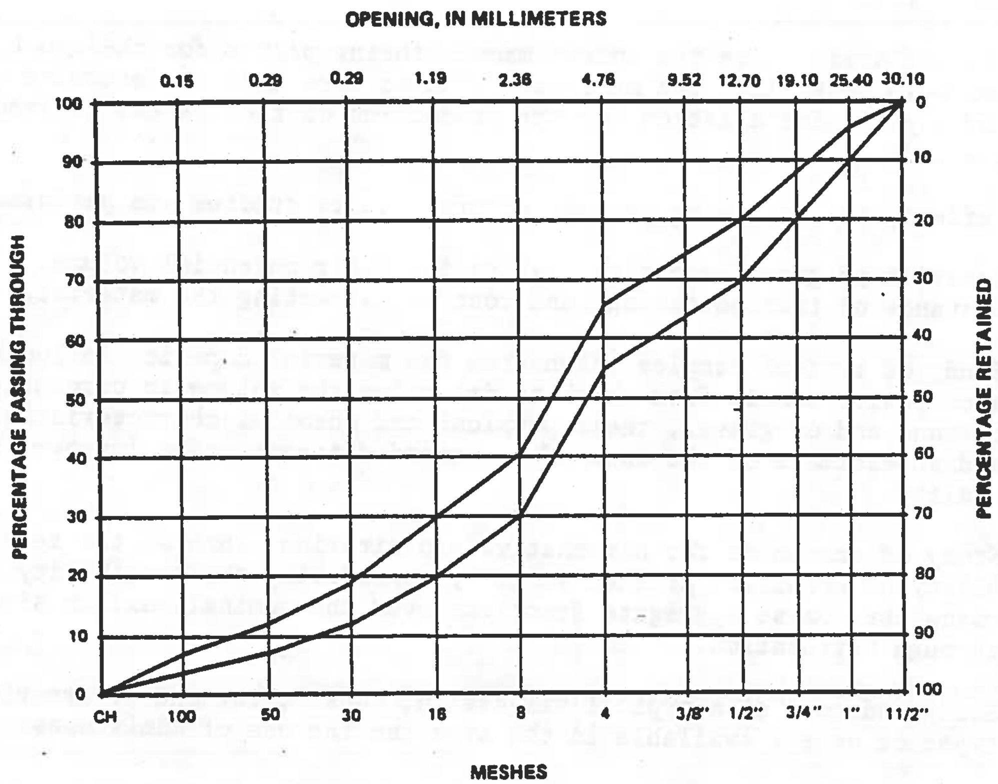


FIGURE 7. SPECIFICATION LIMITS FOR COMBINED GRANULOMETRY

The physical properties of the stone aggregate are shown in tables 3 and 4. These serve as a basis for the concrete to be used in the various plants where two-block ties are manufactured. They also are the bases for the theoretical gradation on which these characteristics are based. They are verified in a laboratory with exhaustive tests, in order to prove their correctness by means of statistical comparison.

It is understandable that necessary adjustments and modifications will be made during manufacture to compensate for variations in the aggregates and to meet the requirements with respect to the manufacturing process.

The study for the concrete granulometry for the manufacture of the "Dywidag" B-58 ties in Panzacola, Tlax., was based on the requirements of the specifications of the German Railroads. It was entirely performed in the Laboratory for Materials at the Engineering School of the Universidad Nacional Autonome de México. The basic properties are given in the following:

Water/cement ratio	0.30
Quantity of cement per m^3	400 kg (881.8 lbs)
Aggregate (sand/gravel) per m^3	1,725 kg (3802.9 lbs)
Volumetric weight of fresh concrete	2,240 kg/m^3 (3,770 lbs/cu yd)

TABLE III

PHYSICAL CHARACTERISTICS OF THE AGGREGATES

MANUFACTURING PLANT:	SAND						
	VOL. WT. LOOSE (kg/m3)	VOL. WT. COMPACT (kg/m3)	DENSITY	ABSORP-TION %	FINENESS MODULUS	PHYSICAL QUALITY	CHEMICAL QUALITY
ACUNA CITY, COAH.	1590	1826	2.51	1.93	2.54	SAFE	HARMLESS
CHARAY, SIN.	1515	1658	2.57	2.02	2.50	SAFE	HARMLESS
VILLA ALDAMA, CHIH.	1451	1653	2.41	3.97	2.83	SAFE	HARMLESS
DOLORES HGO., GTO.	1429	1634	2.44	4.09	2.96	SAFE	HARMFUL

MANUFACTURING PLANT:	RIVER GRAVEL						
	VOL. WT. LOOSE (kg/m3)	VOL. WT. COMPACT (kg/m3)	DENSITY	ABSORP-TION %	MAX. SIZE (mm)	PHYSICAL QUALITY	CHEMICAL QUALITY
ACUNA CITY, COAH.	1643	1814	2.51	1.02	38.1	SAFE	HARMLESS
CHARAY, SIN.	1640	1762	2.48	1.80	38.1	SAFE	HARMLESS
VILLA ALDAMA, CHIH.	1369	1547	2.36	3.80	38.1	SAFE	HARMLESS
DOLORES HGO., GTO.	1420	1608	2.37	3.48	38.1	SAFE	HARMFUL

MANUFACTURING PLANT:	CRUSHED GRAVEL						
	VOL. WT. LOOSE (kg/m3)	VOL. WT. COMPACT (kg/m3)	DENSITY	ABSORP-TION %	MAX. SIZE (mm)	PHYSICAL QUALITY	CHEMICAL QUALITY
ACUNA CITY, COAH.	1464	1666	2.50	1.08	38.1	SAFE	HARMLESS
CHARAY, SIN.	—	—	—	—	—	—	—
VILLA ALDAMA, CHIH.	1489	1764	2.39	3.40	38.1	SAFE	HARMLESS
DOLORES HGO., GTO.	—	—	—	—	—	—	—

TABLE IV

INITIAL PROPORTIONS FOR CONCRETE FROM THE VARIOUS R.S. & S.L. TIE-MANUFACTURING PLANTS

PLACE	UNIT PROPORTIONS BY WEIGHT				QUANTITIES PER M^3 IN Kgs				
	CEMENT	WATER	SAND	GRAVEL	CEMENT	WATER	SAND	GRAVEL	ADMIX.
ACUNA CITY, COAH.	1	0.40	2.88	3.00	314	125	904	942	0.716
CHARAY, SIN.	1	0.34	1.95	3.53	353	122	688	1220	0.916
VILLA ALDAMA, CHIH.	1	0.38	2.20	3.31	330	125	722	1095	0.860
DOLORES HGO, GTO.	1	0.37	2.03	3.14	335	125	680	1050	1.208 POZZOLANAS 75

GENERAL INSPECTION PROGRAM IN THE PLANTS

To verify the quality and uniformity of the manufactured ties in the various locations where RS or SL tie plants were established, the following inspection system was adopted:

Cement. A sample is taken of each lot received in the plant to verify its physical and chemical quality, with priority to the Blaine fineness test and accelerated behavior in autoclave. In case of lagged lots, or lots with questionable results, another sample is taken and subjected to the tests.

Water. Monthly chemical analysis is made of a sample composed of three quantities taken at random during the day.

Sand. Visual inspection is made upon delivery and a sample is taken at random from three different locations of the sand delivered to the plant. Complete physical tests are made of these samples, with priority given to the test results of organic impurities, lime, clay, friable particles, and granulometric analysis.

Gravel. Visual inspection upon delivery and a sample taken at random from three different locations of the gravel delivered to the plant. Complete physical tests are made of these samples, giving priority to the test results of friable particles, volume of dust by washing, percentage of sand, and granulometric analysis.

Admixture. Inspection consists of certification by weight upon delivery, supervision of preparation of solution, verification of concentration during its use, and control of proportioning.

Fresh Concrete. There are five different inspections, taken at random. Samples for slump test, volumetric weight, air content; and eight samples of three cylinders each are taken each production day, which are compacted in a similar way as the ties.

Initial Curing of Ties. Inspection consists of a minimum of 6 hours in water fog or sprayer, or by means of a membrane in compliance with specifications.

Complete Curing of Ties. Inspection consists of a minimum of 14 days with water spray in storage yard, or a cycle of 12 hours by steamcuring, including time for preheating and cooling, plus a minimum of 3 days of conventional curing with water.

Complete Curing of Samples. Treatment and cycle are identical to those of the ties.

Hardened Concrete. Inspection consists of a compression test of one cylinder after 1 or 7 days, and two cylinders after 7 and 28 days on each of the samples taken. The testing age depends on the curing alternative choosen.

Finished Ties. One tie is taken at random from every 100 ties produced. After 28 days the tie blocks are tested for bending in upright and upside-down position, following the method as described earlier.

ADJUSTMENTS DURING FABRICATION

During the stage of preliminary studies, it is attempted in all cases to resolve the possible problems which may occur during manufacture. Nevertheless, these adjustments appear to be inevitable, for which reason in each of the following plants, it was necessary to adopt additional means to correct certain anomalies.

Ciudad Acuna, Coah.

The slump tests did not give the expected results for the control of the consistency of the concrete, since considerable variations were found in the vibration time and final strength, in spite of the fact that the slump was identical in all cases. It was therefore necessary to exercise a stricter control on the volume of water added, by means of studying the water absorption of the aggregate and its graph of absorption versus time.

Another problem that had to be overcome in this plant was the increase of organic impurities in the sand, which frequently exceeded the acceptable limits. For this reason, washing of the sand was specified as a preventative measure. While one could not entirely depend on the necessary equipment or could not appraise the influence on the strength, it was ordered to reject those deliveries whose content was in excess of the acceptable limit. In turn, the cement content per cubic meter was increased during this period.

Charay, Sin.

Based on the experiences in Ciudad Acuna, Coah., a strict control of water proportioning was ordered in this plant, which was based on the graphical data of absorption versus time of the stone aggregate. To eliminate possible contamination and to improve the bonding of the natural aggregate used in this plant, washing of the aggregate was specified.

For the first time, use was made of accelerated curing of the ties with steam. It was necessary to calculate the length of the tunnel, the percentage of humidity in the curing chamber, the temperatures in its various sections, the time cycle, the time of conventional postcuring with water. It was also necessary to establish standards for its inspection. Since the track in which these ties were to be installed crossed a swamp with high salt content that could be damaging to the ties, an increased impermeability was specified for these ties, by using 15 percent of diatomaceous earth. In addition, the finished tie was sprayed with a film of an asphaltic derivative.

Villa Aldama, Chih.

Taking advantage of the earlier acquired experiences, this plant began its operations with a strict water control for the concrete mix. However, during this period, a report was published by Committee 211 in the ACI Journal of January 1965, in which a reference was made to new equipment for the consistency control of concrete without slump. The use of the VeBe Consistometer or, if not available, the "Thaoulow" was specified.

Because of the problems related to importation, the latter type was used, which was locally made and with which better results were obtained in controlling the volume of water, although this is not entirely satisfactory, yet. During the early stage of the operation, important variations were discovered in the granulometric properties of the stone aggregate, resulting from the improper exploitation at the quarry. In addition, it was contaminated. In order to correct these deficiencies, the exploitation of the quarry was more strictly controlled, as well as the separation of natural and crushed aggregate which were then mixed in well-controlled proportions.

From the first results of the bending tests of the ties, the need was recognized to increase the tensile strength of the concrete in bending, since a good percentage of the ties did not comply with this requirement. In view of this, it was ordered to take concrete samples for a bending test and a minimum tensile strength of 50 kg/cm^2 (710 psi) was specified. Exhaustive test criteria were also established for acceptance of the rejected lots, of which five ties were selected at random from each lot. These were to be subjected to the corresponding test, which had to satisfy all requirements of the test before being accepted.

Depending on the area where the production took place during winter time, where low temperatures were registered, it was specified to heat the mixing water, to change the kind of additive to an accelerator, and to increase the curing time when the ambient temperature in the plant was between 15 degrees and 5 degrees C. The activities had to be suspended if the prevailing temperature was below 5 degrees C.

Dolores Hildalgo, Gto.

With the knowledge of the possible problems, the necessary measures were adopted in this plant, which eventually proved to be effective, except for the following:

Being without a VeBe Consistometer, it was ordered to control the concrete consistency by the vibration time required on the vibrating table of the ties, in which the concrete of the filled cone settled to a horizontal plane within a cylindric container.

To determine the volumetric weight, concrete samples are made in a cylindrical mold, which is filled in three stages, each of which is vibrated for 25 seconds. Since pozzolan is used in the concrete mix, it is recommended that the admixture be replaced by an accelerator, to offset the retarding effect of the pozzolan.

During the preliminary studies it was observed that the selected quarry did not provide homogeneous material. It was therefore ordered that the material be shipped to the plant in two sizes, in order to better control the granulometry of the aggregate.

Due to its origin (alluvial, quartzite material) the gravel of this plant provided low bond strength, which affected the specified bending tensile strength.

Partial crushing was therefore recommended, with reduction of the maximum size from 1 inch to 3/4 inch, in accordance with the results of the tests specially made for this purpose.

In spite of all measures being taken to avoid that one or more lots did not partially or totally comply with the specifications, it was on several occasions necessary to apply the criteria of ultimate acceptance.

STATISTICAL STUDY OF THE TEST RESULTS

In the manufacturing plants for the RS and SL ties, the above described inspection program applied. The test results obtained in each of those are given in tables 5 through 9.

The inspection of the manufacture of the "Dywidag" ties in the plant at ITISA in Panzacola, Tlax., was preceded by tests on the prestressing steel, the stone aggregate, the concrete itself, and on the injection mortar. The physical properties of the stone aggregate were established from typical samples and the proportions for mixing were determined. To verify the compression strength of the concrete, tests were made at 28 days on cubes of 20 by 20 by 20 cm, (8 by 8 by 8 in), in accordance with the DIN Standard No. 1048.

The bending tensile strength was tested on beams of 10 x 15 x 60 cm, after 7 days, in accordance with the procedures described in DIN Standard No. 4225.

The quality of the injection-mortar was tested for tensile strength in bending after 7 days on beams of 4 x 4 x 16 cm, according to procedures described in DIN Standard No. 1164.

The statistical results obtained during the inspection of manufacture of a lot of 10,000 "Dywidag" ties, acquired by the Secretary of Public Works, in the previously mentioned plant, are given in table 10.

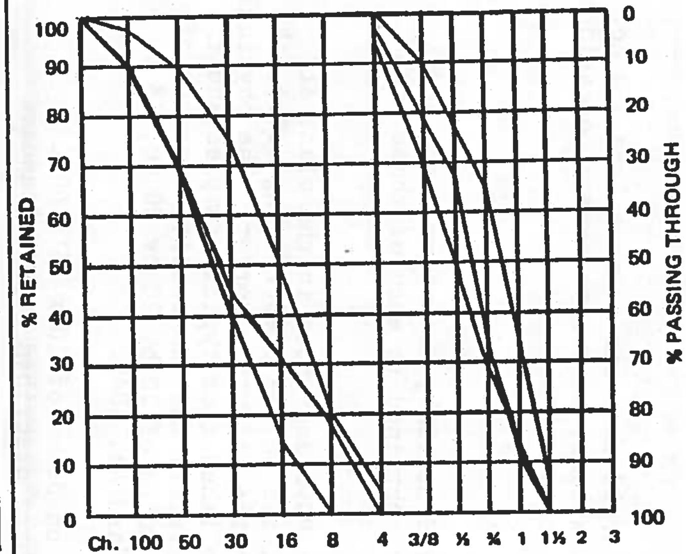
TABLE V

QUALITY CONTROL RESULTS OF ROCK AGGREGATES USED IN TIE-MANUFACTURING PLANTS

Acuna City, Coah.

Mean characteristics of sand and a mixture of crushed gravel and smooth pebbles in 50-50 proportion by weight.

SAND			GRAVEL		
MESH	% RETAINED Partial	% RETAINED Accum.	MESH	% RETAINED Partial	% RETAINED Accum.
No. 4	0	0	2"	0	0
No. 8	18	18	1½"	0	0
No. 16	15	33	1"	11	11
No. 30	11	44	3/4"	23	34
No. 50	22	66	1/2"	33	67
No. 100	25	91	3/8"	16	83
No. 200	7	98	No. 4	14	97
Ch.	2	100	Ch.	3	100
M. F.		2.54	M. F.		7.12
Vol. Wt. Loose		1590	Vol. Wt. Loose		1552
Vol. Wt. Compact		1826	Vol. Wt. Compact		1720
Density		2.51	Density		2.51
% Absorption		1.93	% Absorption		1.03
Coef. of Variation		3.30	Coef. of Variation		4.90



Charay, Sin.

Mean characteristics of river sand and gravel.

SAND			GRAVEL		
MESH	% RETAINED Partial	% RETAINED Accum.	MESH	% RETAINED Partial	% RETAINED Accum.
No. 4	0	0	2"	0	0
No. 8	14	14	1½"	9	9
No. 16	7	21	1"	19	28
No. 30	15	36	3/4"	17	45
No. 50	47	83	1/2"	22	67
No. 100	13	96	3/8"	14	81
No. 200	3	99	No. 4	19	100
Ch.	0	100	Ch.	0	100
M. F.		2.50	M. F.		7.35
Vol. Wt. Loose		1515	Vol. Wt. Loose		1640
Vol. Wt. Compact		1658	Vol. Wt. Compact		1762
Density		2.57	Density		2.48
% Absorption		2.02	% Absorption		1.80
Coef. of Variation		2.70	Coef. of Variation		2.37

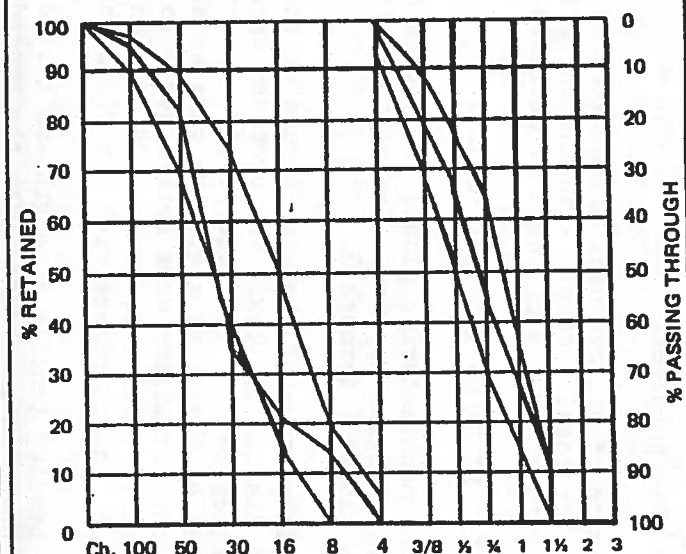


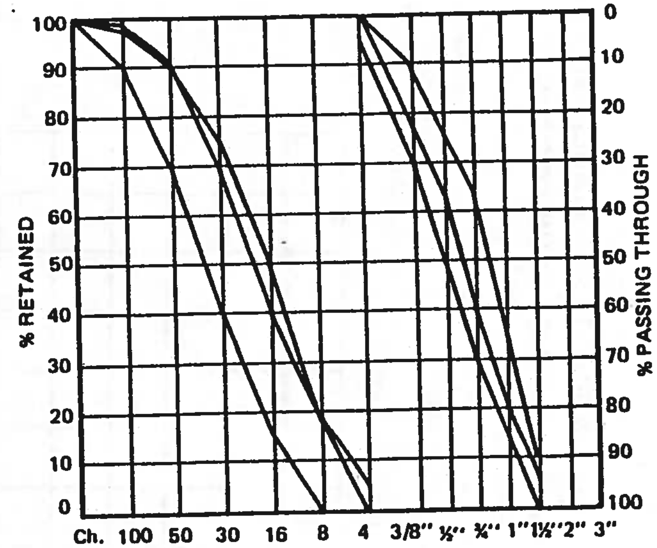
TABLE VI

QUALITY CONTROL RESULTS OF ROCK AGGREGATES USED IN TIE-MANUFACTURING PLANTS

VILLA ALDAMA, CHIH.

MEAN CHARACTERISTICS OF SAND & MIXTURES OF CRUSHED GRAVEL & SMOOTH PEBBLES IN PROPORTIONS VARYING BY WEIGHT FROM 55 – 45 TO 70 – 30.

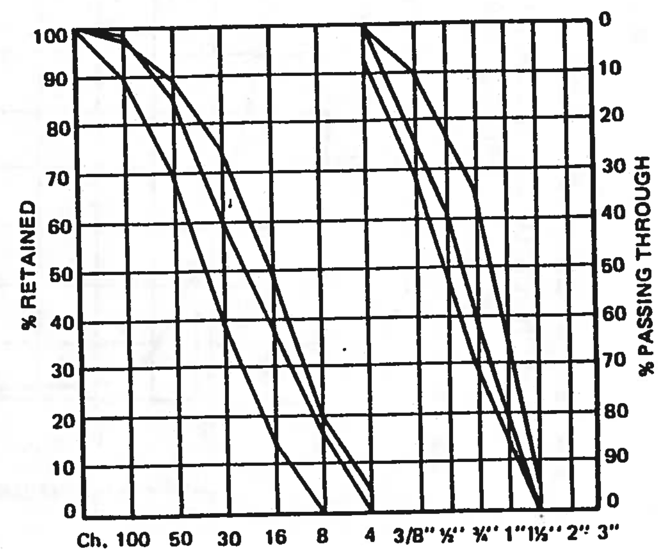
SAND			GRAVEL		
MESH	% RETAINED		MESH	% RETAINED	
	PARTIAL	ACCUM.		PARTIAL	ACCUM.
NO. 4	1	1	2"	0	0
NO. 8	18	19	11/2"	0	0
NO. 16	23	42	1"	21	21
NO. 30	26	68	3/4"	21	42
NO. 50	23	91	1/2"	21	63
NO. 100	7	98	3/8"	14	77
NO. 200	1	99	NO. 4	23	100
Ch.	1	100	ch.	0	100
M.F		3.19	M.F.		719
V.W. LOOSE*		1413	V.W. LOOSE*		1428
V.W. COMPACT*		1600	V.W. COMPACT*		1605
DENSITY		2.46	DENSITY		2.38
% ABSORPTION		3.67	% ABSORPTION		3.03
Coef. of Variation		5.15	Coef. of Variation		2.19



DOLORES HIDALGO, GTO.

MEAN CHARACTERISTICS OF WASHED SAND AND RIVER GRAVEL CLASSED AND RE-MIXED IN A PROPORTION OF 40 – 60 BY WEIGHT.

SAND			GRAVEL		
MESH	% RETAINED		MESH	% RETAINED	
	PARTIAL	ACCUM.		PARTIAL	ACCUM.
NO. 4	0	0	2"	0	0
NO. 8	16	16	11/2"	0	0
NO. 16	23	39	1"	18	18
NO. 30	22	61	3/4"	21	39
NO. 50	26	87	1/2"	24	63
NO. 100	11	98	3/8"	13	76
NO. 200	2	100	NO. 4	24	100
Ch.	0	100	Ch.	0	100
M.F		3.04	M.F.		7.16
V.W. LOOSE*		1399	V.W. LOOSE*		1390
V.W. COMPACT*		1603	V.W. COMPACT*		1573
DENSITY		2.44	DENSITY		2.39
% ABSORPTION		4.17	% ABSORPTION		3.34
Coef. of Variation		6.61	Coef. of Variation		2.16



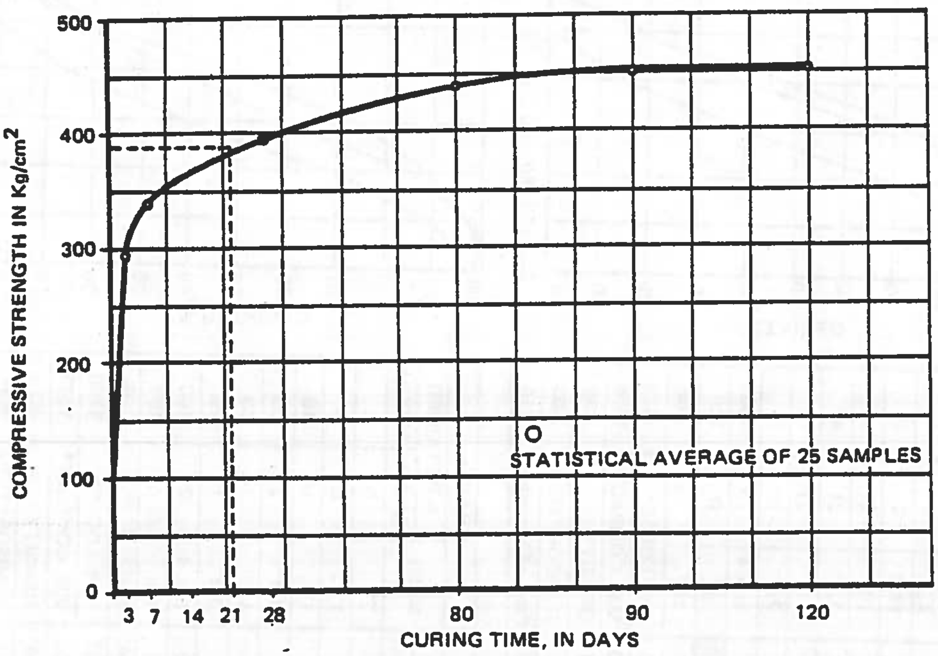
*kg/m3

TABLE VII

STATISTICAL GRAPH OF STUDIES. DEVELOPMENT OF RESISTANCE-CURING TIME IN ORDER TO ESTABLISH THE MINIMUM TIME REQUIRED TO MEET PROJECT REQUIREMENTS.

PLANT ACUNA CITY, COAH.

(CONVENTIONAL CURING WITH WATER)



PLANTS: CHARAY, SIN., VILLA ALDAMA, CHIH., DOLORES HIDALGO, GTO.

(CURING: 6 HRS. IN HUMID ATMOSPHERE + 12 HRS. STEAM REMINDER IN WATER)

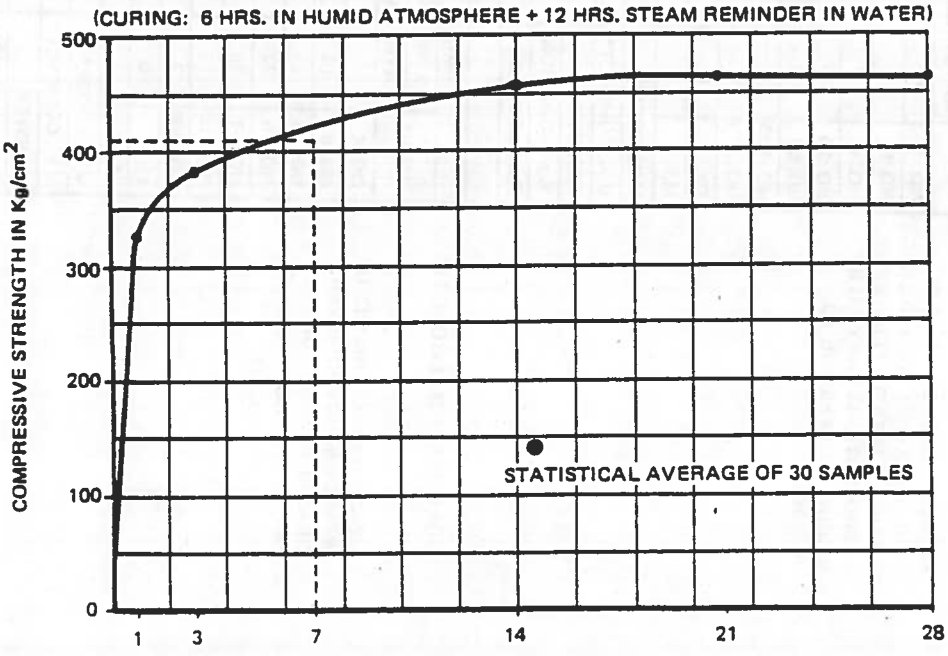


TABLE VIII

STATISTICAL SUMMARY OF QUALITY CONTROL ON CONCRETE USED IN THE VARIOUS PLANTS

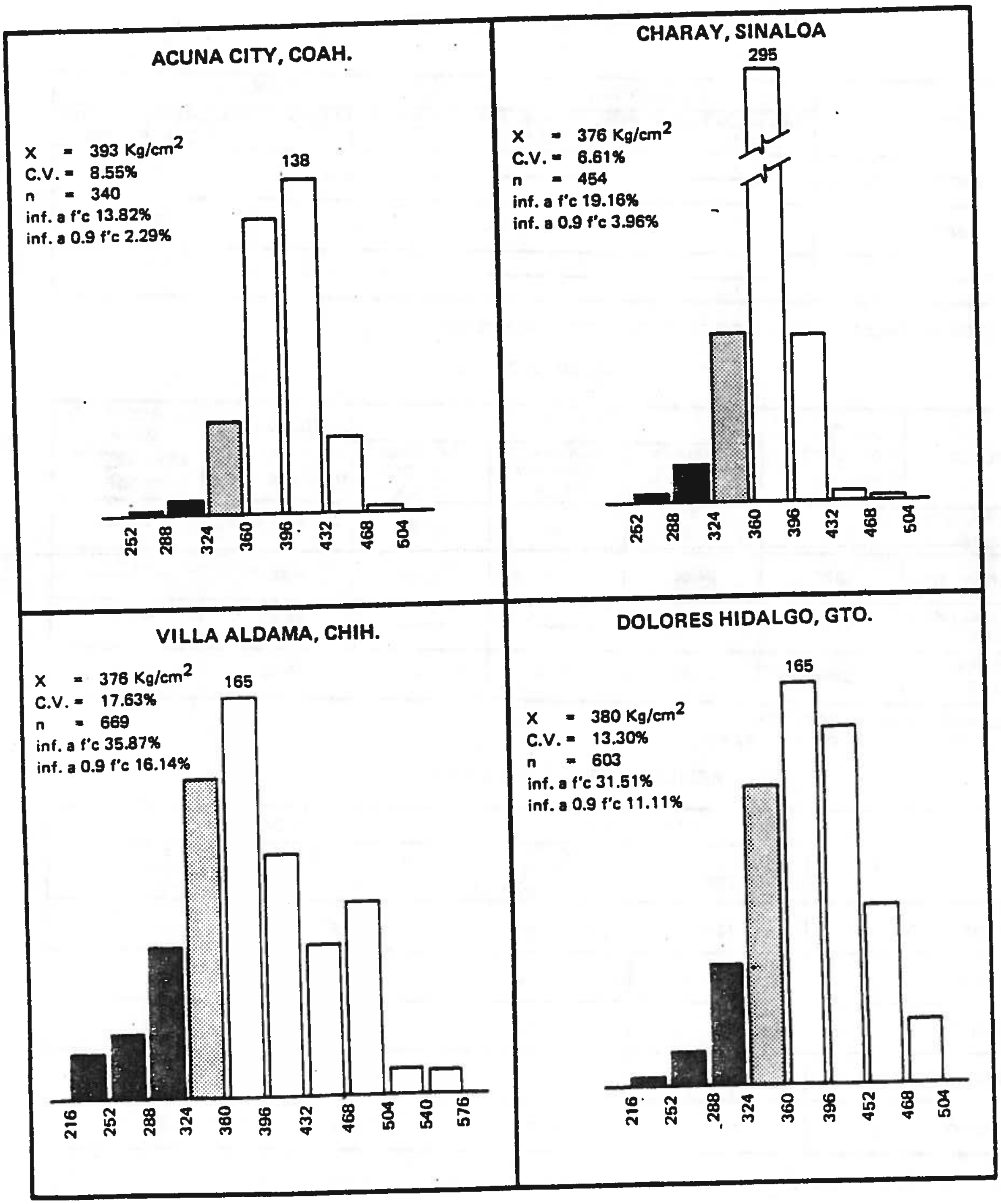


TABLE IX

STATISTICAL SUMMARY OF TESTS: REINFORCING STEEL AND TIEBARS; TIE BENDING; RESILIENT TRACK ACCESSORIES

REINFORCING STEEL AND TIEBARS

ITEM	FOREIGN MADE		DOMESTIC	
	NO. OF BATCHES TESTED	PERCENTAGE MEETING SPECIFICATION	NO. OF BATCHES TESTED	PERCENTAGE MEETING SPECIFICATIONS
1/4" SMOOTH WIRE	———	———	270	100
RS TIEBARS	15	100	-65	87*
SL TIEBARS	———	———	30	94*

*REJECTED BATCHES DID NOT MEET DIMENSIONAL SPECIFICATIONS

TIE-BENDING TESTS

PLACE	NO. OF BATCHES TESTED	% PASSING IN			% NOT PASSING IN BOTH POSITIONS	% ACCEPTED WITH EXHAUSTIVE PROOF
		NORMAL & REVERSE POSITION	NORMAL POSITION ONLY	REVERSE POSITION ONLY		
ACUNA CITY COAH.	634	63.60	7.90	20.60*	7.90**	———
CHARAY, SIN.	2820	84.08	4.74*	5.83*	5.35**	———
VILLA ALDAMA CHIH.	4136	14.15	———	———	85.85	80.90
DOLORES HGO. GTO.	2895	57.03	23.44*	3.91*	15.62	12.46

*ACCEPTED WITHOUT RETESTING
**ACCEPTED WITH RETESTING (1 PART)

RESILIENT TRACK ACCESSORIES

PART	FOREIGN-MADE		DOMESTIC	
	NO. OF BATCHES TESTED	PERCENTAGE MEETING SPECIFICATIONS	NO. OF BATCHES TESTED	PERCENTAGE MEETING SPECIFICATIONS
GROOVED BOTTOM	13	100	134	68
CLAMPS	160	100	———	———
BEARING	10	100	140	100
WASHERS	———	———	130	**
FIXING SCREWS	———	———	160	100

**PARTIALLY COMPLIED WITH SPEC. AND WERE ACCEPTED, BUT CANNOT BE IMPORTED.

TABLE X

STATISTICAL SUMMARY OF CONTROLS PERFORMED IN THE DYWIDAG ITISA TIE PLANT OF PANZACOLA TLAXCALA

ROCK AGGREGATE TESTS

EXPLANATION	RIVER SAND	CRUSHING SAND	CRUSHED GRAVEL
VOL. WT. LOOSE*	1408	1154	1238
VOL. WT. COMPACT*	1525	1285	1354
DENSITY	2.47	2.49	2.46
% ABSORPTION	3.20	2.93	2.45
FINENESS MODULUS	2.16	4.41	6.08
COEF. OF VARIATION	6.38	4.76	7.75

*kg/m^3

THE MIXTURE OF RIVER SAND AND CRUSHINGS WERE IN A PROPORTION OF 80-20 BY WEIGHT, AND THE FINENESS MODULUS OBTAINED WAS 2.59, WHICH IS WITHIN THE SPECIFICATIONS.

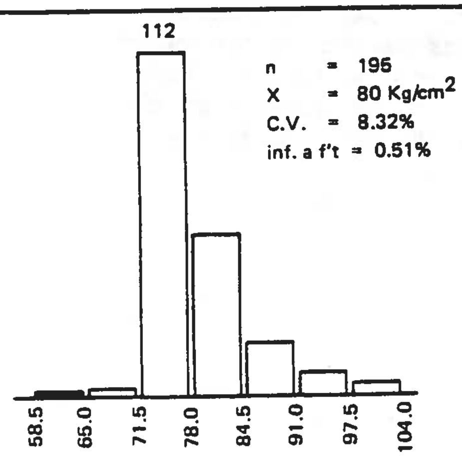
COMPRESSION TESTS – CUBES

NO. OF SAMPLES WITH COMPRESSIVE STRENGTH BETWEEN 600 AND 699 Kg/m^2.	61	46.92%
NO. OF SAMPLES WITH COMPRESSIVE STRENGTH OVER 700 Kg/m^2.*	69	53.08%
	130	100.00%

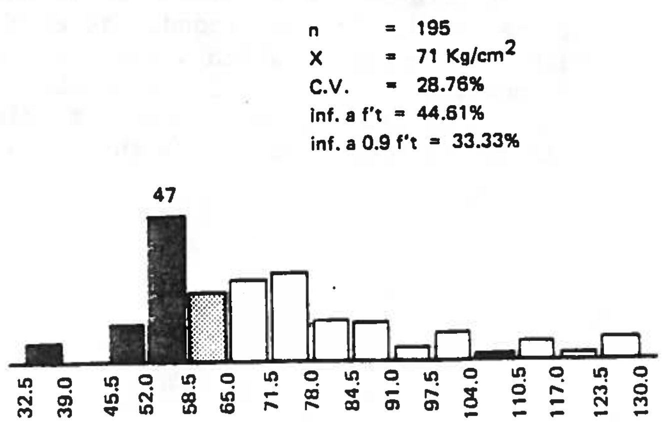
*THIS UNIT STRENGTH WAS PREFERRED AS A MAXIMUM IN ORDER TO STOP THE TEST IF THE CUBE WOULD NOT FAIL.

BENDING STRENGTH TESTS – BEAMS
(7 DAYS OLD)

CONCRETE



MORTAR



OBSERVATIONS CONCERNING THE BEHAVIOR OF THE TIES AND FASTENINGS IN TRACK UNDER SERVICE CONDITIONS

The following was observed in the inspection records of the sections:

Monterrey-Reynosa, San Carlos-Ciudad Acuna, Chihuahua-Ojinaga, Chihuahua-Topolbampo, Coatzacoalcos-Estacion, and Allendey-Viborillas-Villa de Reyes:

a. With the exception of the line Viborillas-Villa de Reyes, maintenance of the lines was generally deficient, resulting in crushed ballast, improper seating of the ties, and lack of sufficient tightening of the rail fastenings. This was more noticeable in the section Coatzacoalcos-Estacion Allende, where the tie-heads were pivoting and the track showed pumping at the passage of a train (see plates 27 through 31).

b. In spite of this, only a small number of ties in all the tracks, without exception, were found to be chipped or damaged by tools used by the track maintenance gangs in the tamping operations (plates 32 and 33).

c. Only two ties were found that had failed in bending, one of the RS type in the Monterrey-Reynosa section and one of the "Dywidag" type in the Chihuahua-Ojinago line. In both cases the failure was due to improper seating of the ties, through lack of ballast (plates 34 through 36).

d. Scaling of the tie in the interior portion near the rail seat, caused by insufficient tightening of the fastenings, was found on a limited number of ties in the section San Carlos-Ciudad Acuna. Chipping of the exterior part of the tie, caused by lateral forces, was observed in a curve of over 2 degrees, in the section Chihuahua-Ojinaga (plates 37 and 38).

e. Corrosion of tiebars of the RS ties was detected in certain sections of the lines San-Carlos-Ciudad Acuna, Chihuahua-Topolobampo and Coatzacoalcos-Estacion Allende. In the first case it commenced with oxidation of the bar in several sections of the track. In the second, the effect was severe in the swamp near Topolobampo in which a considerable percentage of the bars was badly corroded. A limited number of ties was damaged at the entrance of the bar in the concrete block, which affected the reinforcing steel (plates 39 through 42).

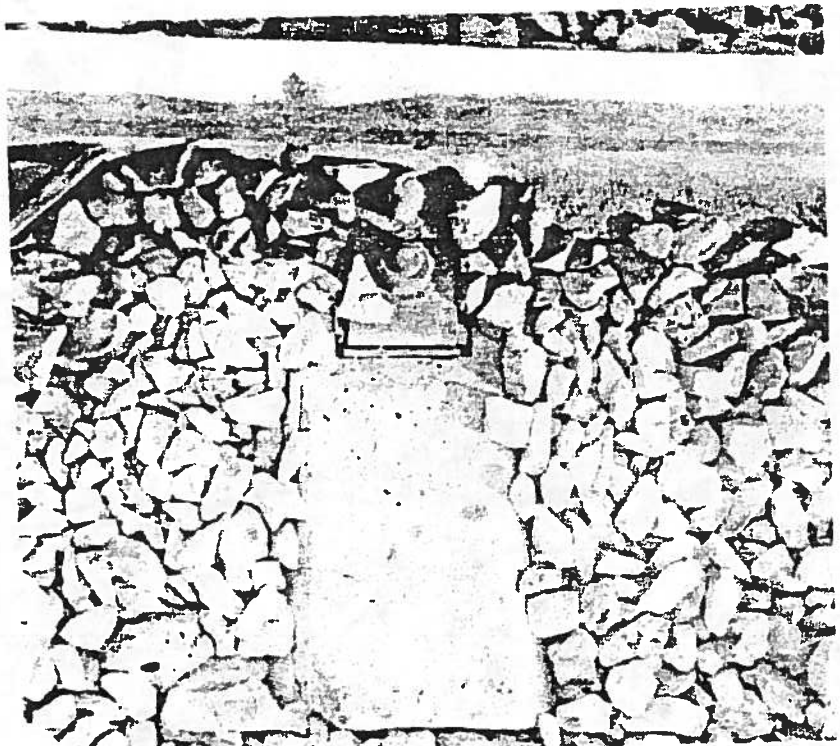


PLATE 27. CHIHUAHUA - OJINAGA. CRACKING CAUSED BY LACK OF TIE-SUPPORT

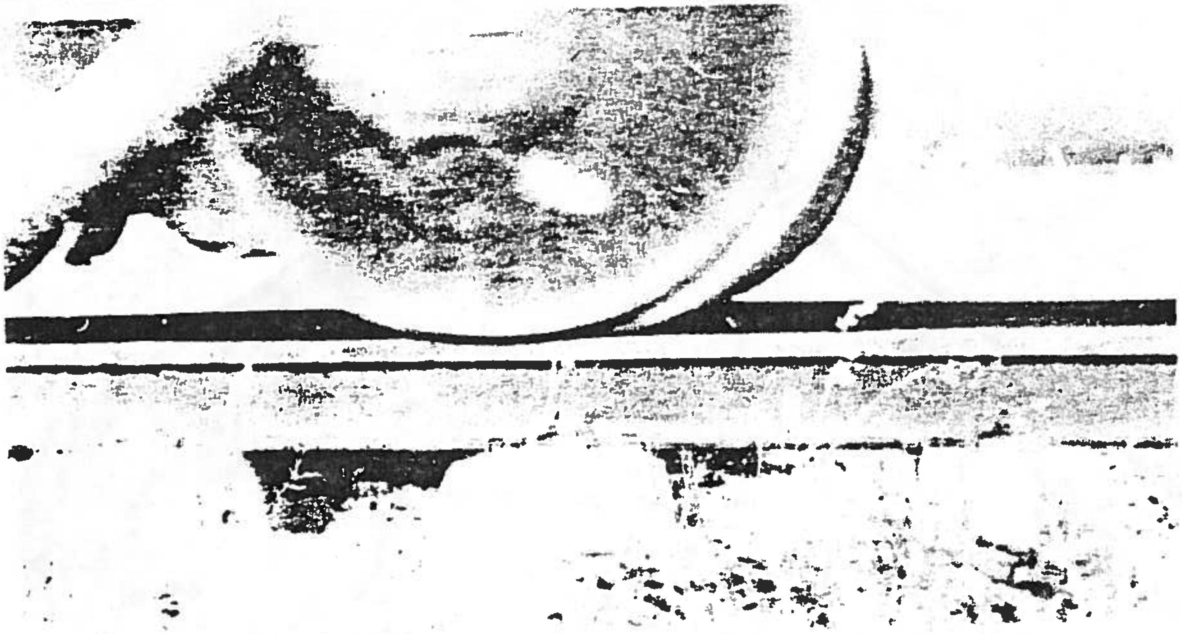


PLATE 28. COATZACOALCOS ALLENDE STATION. INSUFFUCIENT AND FOULED BALLAST

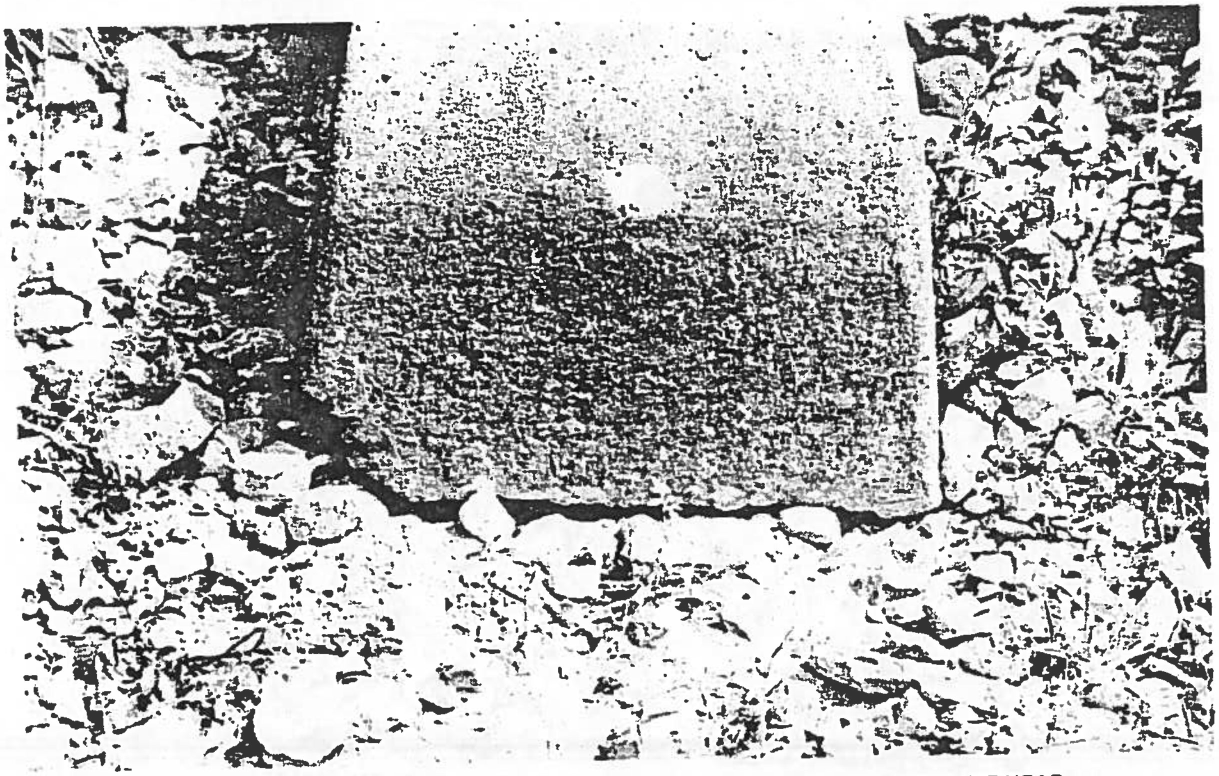


PLATE 29. COATZACOALCOS ALLENDE STATION. INADEQUATELY BALLASTED TIE-HEAD

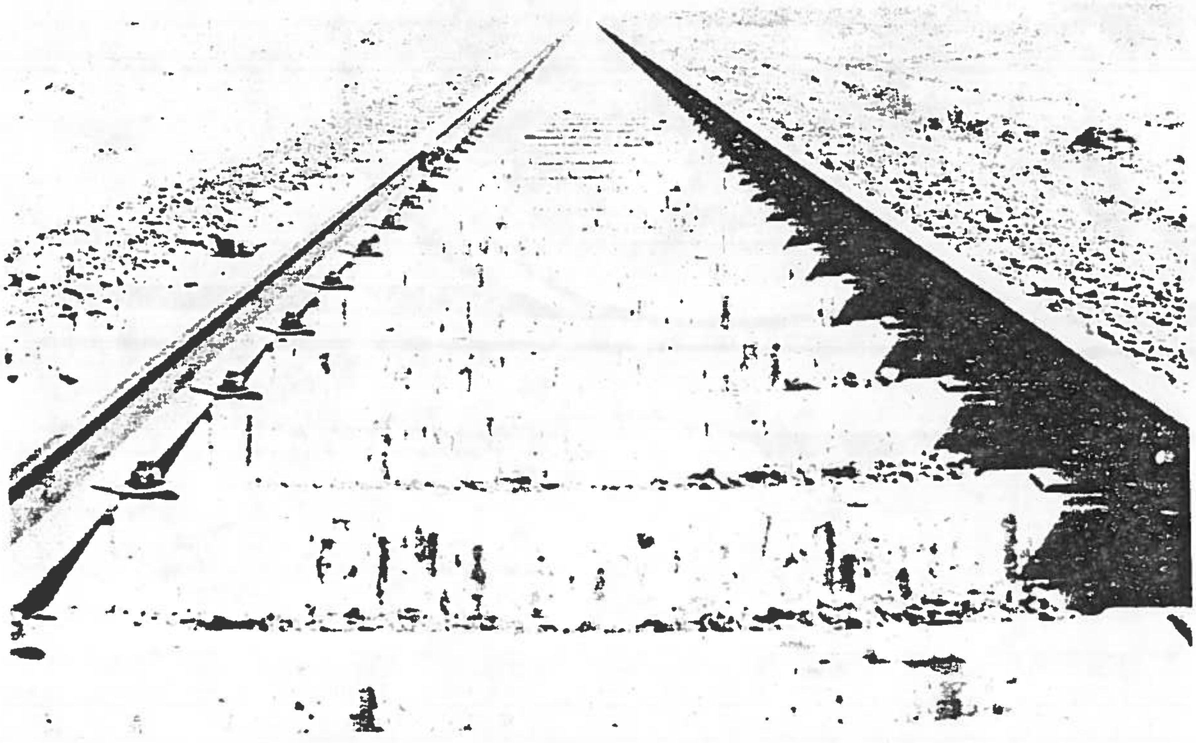


PLATE 30. CHIHUAHUA - OJINAGA. INADEQUATELY BALLASTED TRACK, WITH "DYWIDAG" B-58 TIES

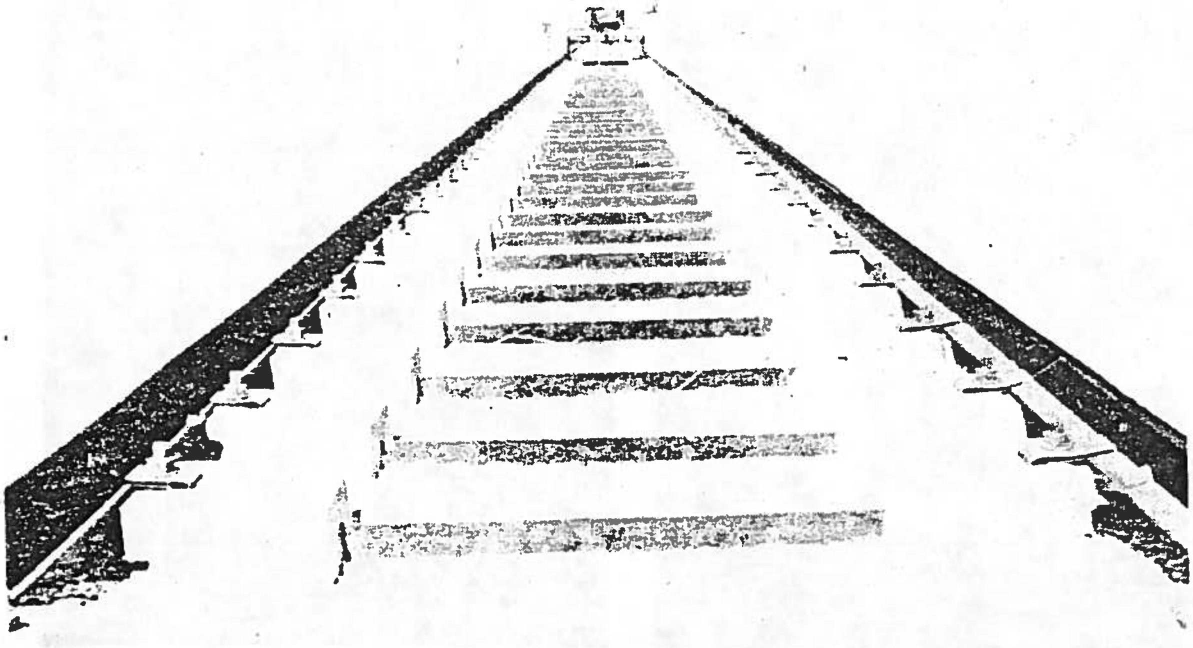


PLATE 31. SAN CARLOS ACUNA CITY. INADEQUATELY BALLASTED TRACK, WITH RS-TYPE TIES

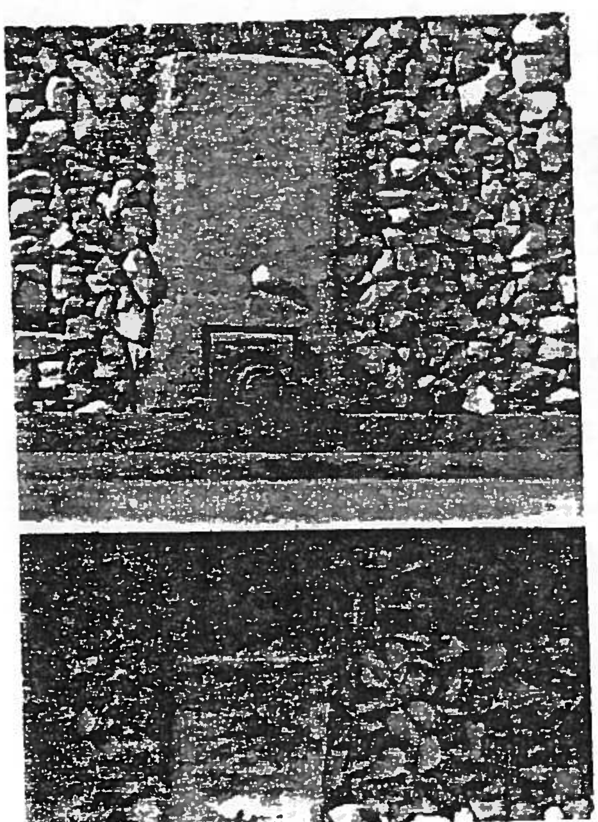


PLATE 32. TIE DAMAGE RESULTING FROM TAMPING OPERATIONS

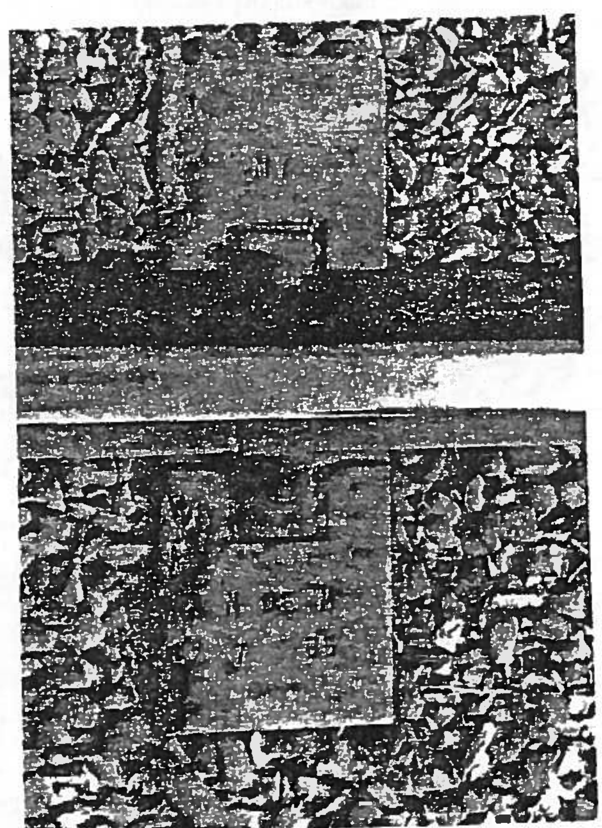


PLATE 33. TIE DAMAGE RESULTING FROM TAMPING OPERATIONS

PLATE 34: TIE DAMAGE ATTRIBUTABLE TO INSUFFICIENT BALLAST

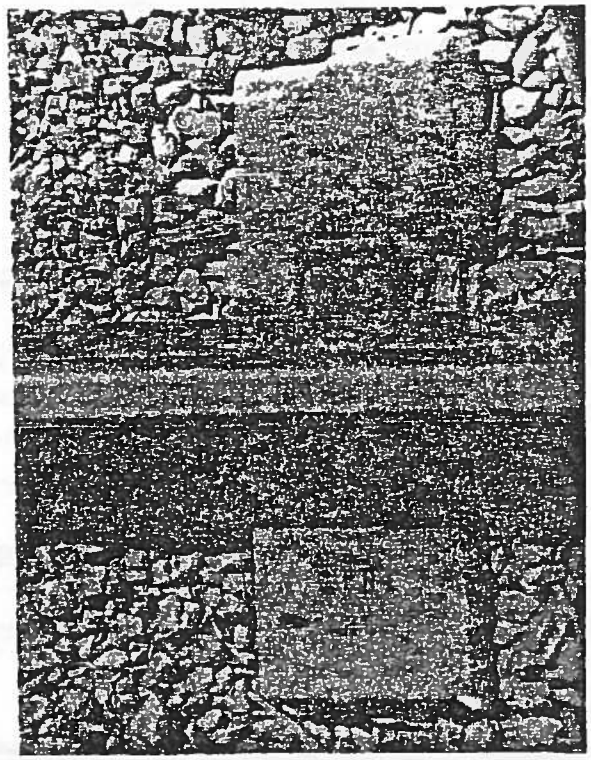


PLATE 35. TIE DAMAGE ATTRIBUTABLE TO INSUFFICIENT BALLAST

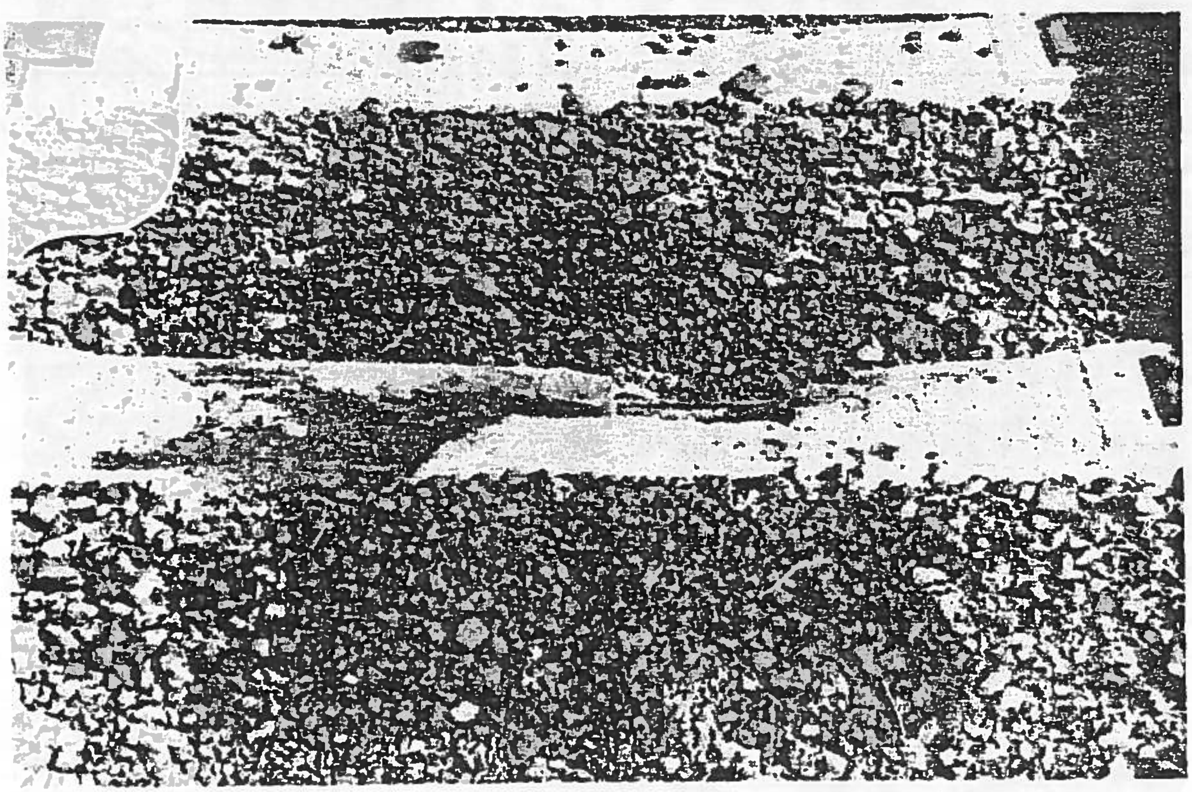


PLATE 36. TIE DAMAGE ATTRIBUTABLE TO INSUFFICIENT BALLAST

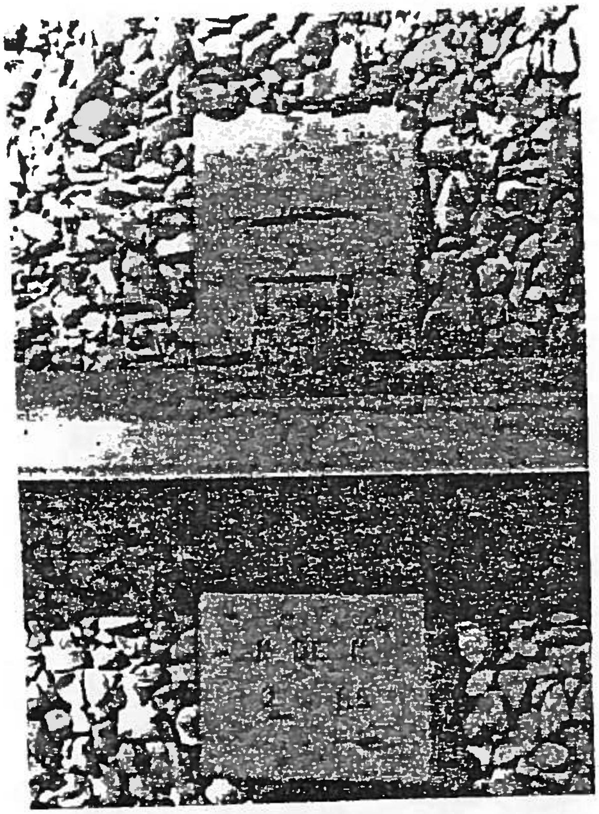


PLATE 37. DAMAGE TO CONCRETE AT SEAT OF RAIL CLIP CAUSED BY SLACK IN FASTENING

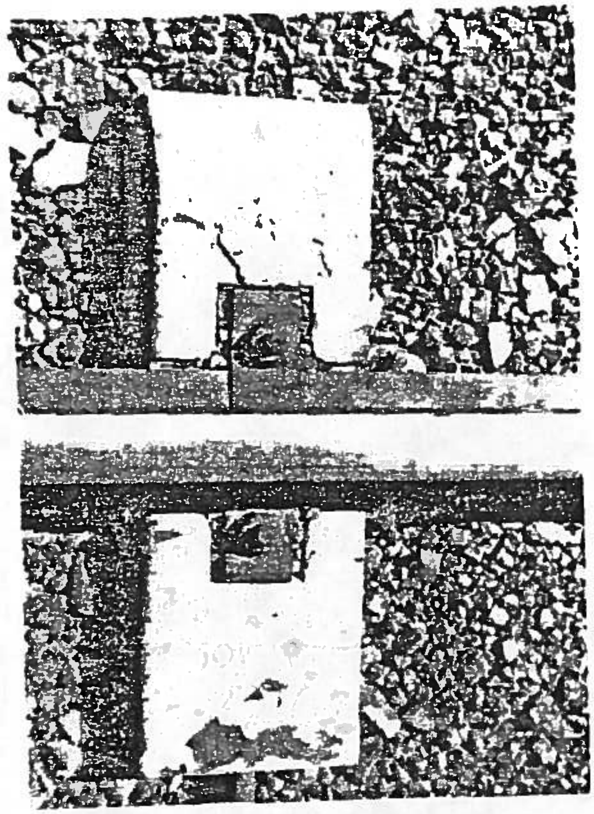


PLATE 38. DAMAGE TO CONCRETE AT SEAT OF RAIL CLIP CAUSED BY SLACK IN FASTENING

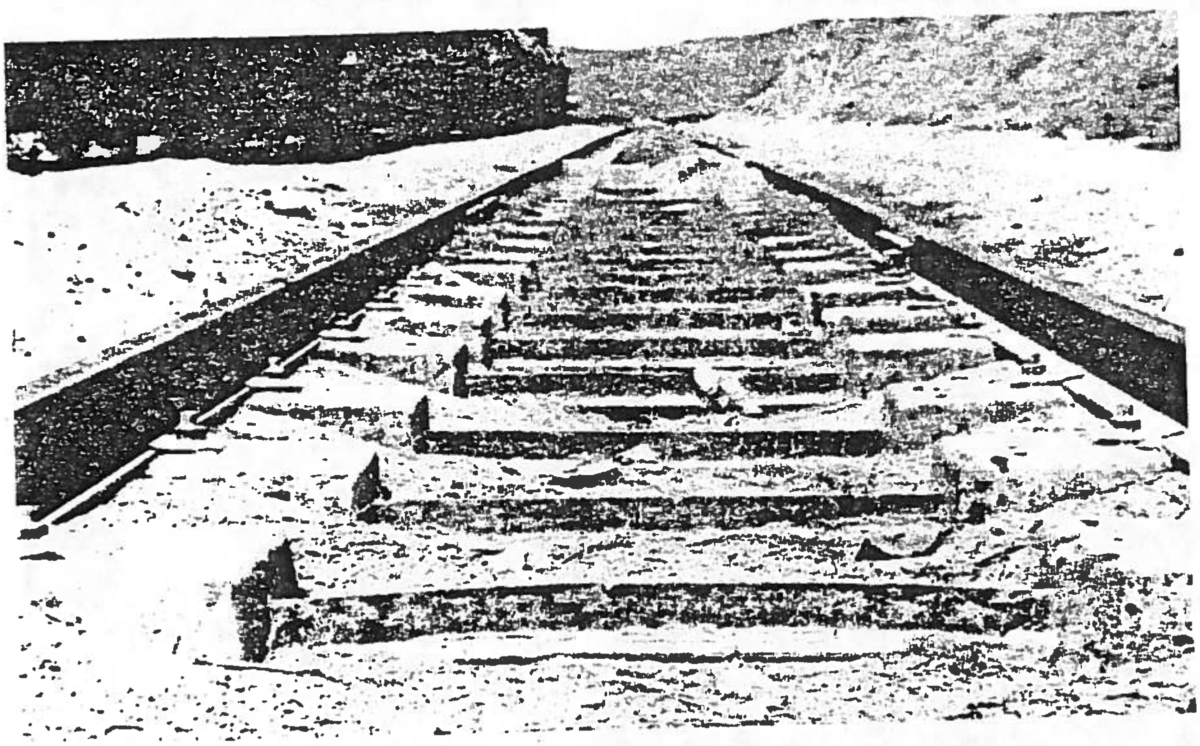


PLATE 39. CORROSION OF STEEL TIEBAR IN SWAMPY REGION

PLATE 40. CORROSION OF STEEL TIEBAR IN SWAMPY REGION

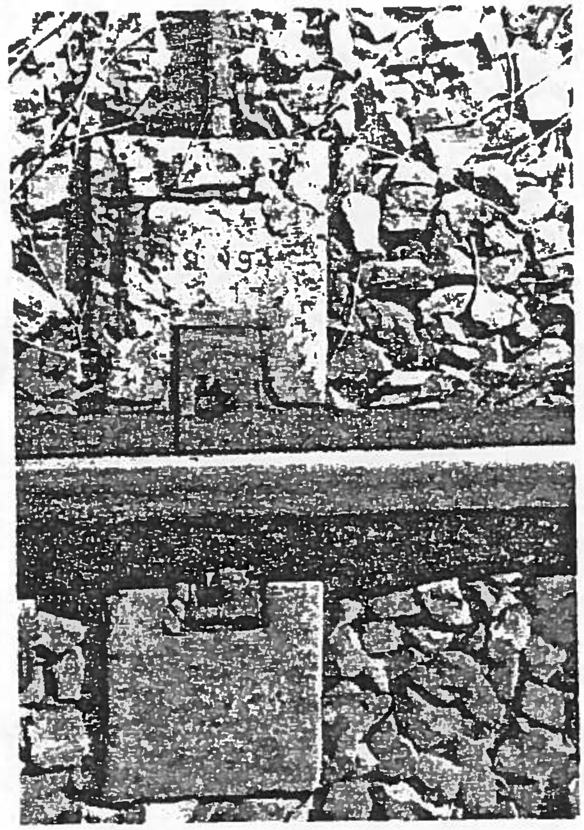


PLATE 41. REINFORCING STEEL AFFECTED BY CORROSION

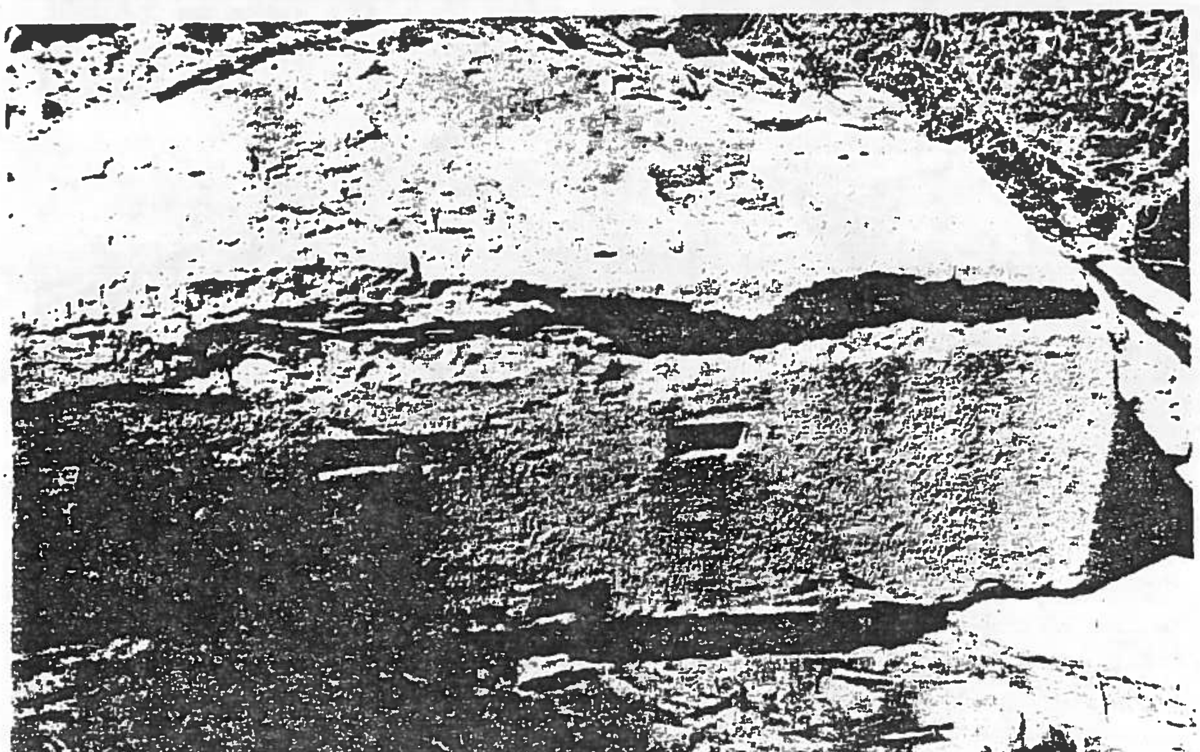


PLATE 42. REINFORCING STEEL AFFECTED BY CORROSION

FINAL COMMENTARY

Taking into account that the number of ties damaged by the causes previously described is small in comparison with the total number of ties installed, and that the observed damage is due to lack of maintenance, it is concluded that the behavior of both types of ties is generally satisfactory.

It is considered that the service life of the concrete tie can be longer than theoretically assumed, if some improvements are made in the design and manufacture, which affect resistance and durability, or both. Service life can also be extended by adopting additional, adequate standards for each particular type, in addition to strict quality control.

As a result of the experience acquired, the following recommendations are made:

For the RS or SL ties:

a. A minimum of 50 percent of the aggregate must be crushed stone.

b. Increase the minimum cement content to 350 kg/m^3 of concrete.

c. Specify the use of a minimum of 20 percent pozzolan for the ties to be installed along the seashore or in a chemically aggressive area. Specify that the tiebar and the concrete faces, where they enter the block, be protected with a synthetic resin coating (epoxy) of uniform thickness.

d. Modify the acceptance requirements for the cured concrete, by specifying a minimum bending tensile strength of 50 kg/cm^2. If this cannot be met, it is proposed to use the bending test of the finished ties in upright and upside-down position, using three ties out of every rejected lot of 100 ties.

For the "Dywidag" ties:

a. Specify for the concrete and injection mortar, the use of a minimum of 20 percent pozzolan, and the sealing of the tieheads with epoxy paste or mortar, if the manufactured ties are to be installed in areas with aggressive atmosphere or climate.

b. Adopt as an obligatory standard what is contained in the German Specification with reference to the electrical resistance, which is closely related to the corrosion of the prestressing steel.

The fundamental disadvantages of the two types of ties are:

a. Of the RS or SL ties: its low mass, its small bearing area, and the possibility of corrosion of the tiebar.

b. Of the "Dywidag" ties: its fragility, which can cause cracking and breakage on poorly compacted ballast and in track sections that are insufficiently tamped.

CONCLUSIONS

In spite of the mentioned disadvantages, the two types of concrete ties presently in use in our railway system have demonstrated to be adequate. They are superior to conventionally impregnated timber ties, for which reason they will be definitely adopted.

The impregnated timber tie is not cheap; its cost is about half that of a concrete tie. The timber tie is in short supply and the actual service life, depending where the installation is located, fluctuates between 3 and 20 years in the most favorable case. The service life of the concrete tie is estimated at a minimum of 45 years.

The cost of maintenance of track on concrete ties can attain a reduction of 40 percent. The production cost of concrete ties can be reduced if freight costs are reduced, or they can be eliminated by locating the plants at strategic points near the lines under construction or rehabilitation. Therefore, it is necessary to develop a plan, which includes the projected lines and the rehabilitation priorities of the existing lines, with relation to the traffic intensity on the system.

Finally, it is considered necessary to develop and adopt a maintenance plan that includes the training of personnel in charge of the upkeep of the track, which overcomes the present deficiencies, in order to improve the economics of the conversion.

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