PRESTRESSED CONCRETE TIES IN PERU

By Héctor Gallegos Vargas*

1. FUNCTION OF TIES

The structure of a railway line is made up by rails, support and fastening system, ties, ballast bed and sub-base. In this, the ties have a multiple function: distribute the load of the wheels into an allowable pressure over the ballast bed, maintain the railway gage, provide stability to the railway, and minimize the risk of derailment. To this purpose, ties must feature rigidity, elasticity, hardness, structural strength, weathering resistance, animal- and vegetal-organisms attack resistance qualities, and the highest possible weight while compatible with the handling system.*

2. THE WOODEN TIE

The traditional material for ties, in almost all countries, has been wood. This, having the proper quality and being chemically and mechanically treated, reasonably meets the requirements of a good tier; a paper of the Australian Railroad System makes a clear-cut summary: "*Wooden ties are light and easy to handle, having low compressive strength perpendicular to grain and, consequently, subject to mechanical damage under the rail seat. Its longitudinal shape is prone to concentrate reactions in the middle of the tie, but since wood has a good tensile and compressive bending strength, it is able to stand the higher induced moments. The wood's shock resistance is good and damage arising from a derailment is usually light. Rigidity and abrasion resistance are just satisfactory and gauge could be lost due to wearing out of the fastening holes. On the other hand, being light, they don't exert an effective clamping action and are prone to be raised due to crowning of the sub-base or because of the load-wave in the rail. Wood is under risk of attack from animal and vegetal organisms, and weathering, which could bear destruction in terms as short as 2 years*".

3. ALTERNATIVE MATERIALS

As a consequence of these obvious weaknesses of the wooden tie, designers have always bore in mind the search for materials more suitable than wood to stand for the tie. In 1884, Monier, the French gardener claimed by some as inventor of reinforced concrete, designed and patented the first concrete tie (see Figure 1). Previously, in 1840, the English and German railroads had left off the use of natural-stone ties, regarding them unsuitable. Likewise, in 1870 the use of steel ties was started, in spite of their higher cost (nowadays they are still being used by the Swiss railroads, which have about two-thirds of their system outfitted with steel ties). Finally, in 1910, the Sweden, French and German railroads encouraged the use of bi-block-type reinforced concrete ties with limited success; and the Italians, the use of asbestos-cement with satisfactory results.

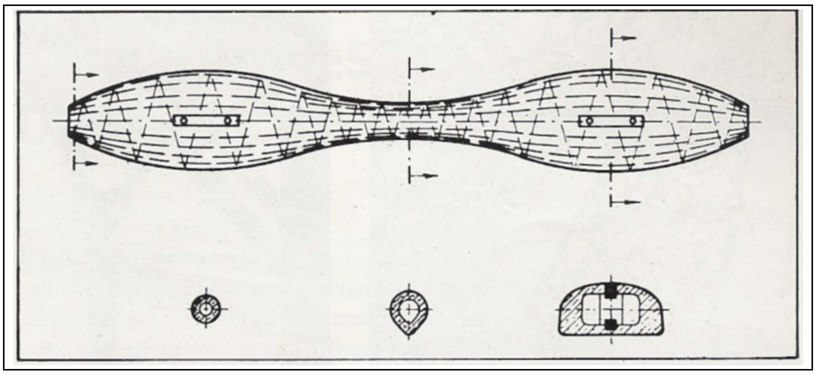

Fig. 1.- The Monier's design (year 1884)

4. THE PRESTRESSED CONCRETE TIE

In every case this search for new materials was made having no "need to" pressure and negligible research resources. The real thrust occurred at the beginning of the Second World War, the year 1939, and was of economic character. The shortage of wood and its higher and unsteady price encouraged the Britain, German and French railroads to daringly face the search for a new material. In that very moment prestressed concrete was already an actual fact, and some English and French manufacturers had previous designs. What happened? First, a precautious use of

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prestressed concrete; and then, in the 1950 decade, the definitive substitution of the wooden tie by the prestressed concrete tie. Today, more than half the length of the European railways use prestressed concrete ties installed and its use, in practice, excludes other materials. Every country has designs of their own, and the manufacturing methods optimize in each case the local technologies.

In the United States, the prestressed concrete ties incorporation process has been delayed. In the year 1970 Gerwick cites as a factor of this delay: "… *in the first place cost, along with the fact that many railroad companies are owners of woods, sawmills and treating plants; as a result, the cost assessment has been performed using unreal low cost figures regarding the wooden tie. However, a comparison against market-prices shows that the pre-stressed concrete tie's price is competitive*", and adds "*… the increasing shortage, decreasing quality and higher costs of wood make that their full replacement by prestressed concrete ties be only a matter of time*".

Ten years after, the year 1980, Venuti, in a paper for Concrete International, reports that over 4 million ties have already been installed and the annual production rate has already reached one million ties.

5. ADVANTAGES OF THE PRESTRESSED CONCRETE TIE

The advantages of the prestressed concrete tie are clearly defined. The Cembureau of Sweden gives the following relationship:

a) "Huge weight, which is favorable for the permanence and steadiness of the railway.

b) Reduction of stresses and, consequently, strain of the rails.

c) Excellent maintenance of the gage and location of rails.

d) Weather-resistant.

e) Not affected by the attack of animal and vegetal organisms.

f) Unlimited production potential.

g) Non-fluctuating costs as a result of no shortages and no jobbing, and accurately analyzable.

h) Over 50-year proven service-life.

i) Smoother and quieter railway traveling and derailment possibility decreased.

j) Service-life increase of the rolling material and rails.

k) 4% fuel-consumption reduction".

In summary, although the use of prestressed concrete ties has come from economic gains and wood shortage, its superiority over wood in order to provide a steady, durable and substantially lower-cost maintenance railway, is already out of discussion.

It is convenient here to quote what was stated by the Director of Britain Railroads: "*The prestressed concrete tie for railroads was introduced in Great Britain during the 1939-1945 war, when there was a wood shortage. Being deemed with disfavor, it was tolerated unwillingly. Few years later, however, the prestressed concrete tie has become acknowledged as that providing an even performance, that which once installed maintains a better alignment, that which promises a longer life and could be designed specifically for any circumstance*".

6. THE PRESTRESSED CONCRETE TIE IN PERU

The year 1958, this paper's author designed the first pre-stressed concrete tie for the conditions of the Peruvian Central Railroad (in that time a property of The Peruvian Corporation, Ltd.). The year 1961, 58 ties were manufactured as per that design by the firm Precomsa, and sold to The Peruvian Corporation, Ltd. at a price of US$ 10 each, including the fastening system which was imported from Great Britain, and installed in the Km. 58 of the Peruvian Central Railroad (currently equivalent to Km. 42 of the Central Highway, in Ricardo Palma) (see Figure 2). Each one weighted 232 kg t (70 kg is the weight of one very-good-quality wooden tie). Since then the railway has been repeatedly inspected; the last official report of the year 1995 states that "*… that stretch nowadays keeps being in excellent state, specially as regards to alignment and surface… the concrete of the pre-stressed ties is in perfect conditions and no-doubt will last longer*".

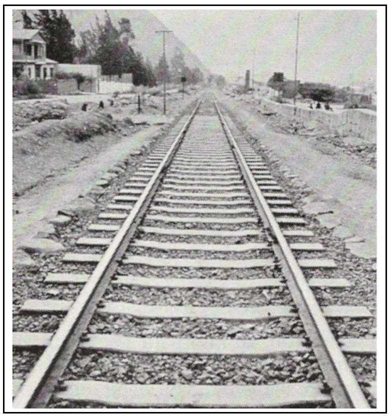

Fig. 2.- Ties installed the year 1961 in the 58th km of the Central Railroad

The year 1969 the conversations with The Peruvian Corporation were resumed, and a new design was prepared (incorporating the Pandrol fastening) for the ALCO-560 locomotive, with a six-axle load train, 18.5 ton each, and 13 m total length. The design was submitted to the revision of Livesey and Henderson, British consultants, who approved the design provided that "*…a certain number of trial ties be prepared, so as to ensure that any manufacturing and production weakness found could be overcome prior to entering into the high-scale production…*"

On the other hand, the proposed fastening system, being already commonly used in the Britain railroads, was rejected because of its higher cost and, a proposal to insert wooden blocks in the tie and the indirect fastening of the rail was made, by means of the same plates and wood-screws which the railroad company had in stock for the wooden ties.

Thus, a comprehensive research on the types of wood and wooden-block shapes was started, putting them under stress tests in order to determine the maximum loads they could resist. The final result was the manufacturing of about 5,000 ties in Lima, and in Arequipa which were installed in the Central Railroad and the South Railroad. Results were not fully satisfactory; even though the pre-stressed concrete member had not but localized failures always attributable to defective ballast, the failures of the fastening system were significant. Even so, there exist railway spans in the surroundings of Lima (see Figure 3) and Arequipa which are operating and which, as a whole, show a good behavior. Anyway, it was still an experimental phase, together with an increasing shortage of suitable wood and the gradual recognition, on the part of the railroad technicians, that the prestressed concrete tie was already cheaper, had a probable service-life undoubtedly longer than those of wood, and that the bi-block concrete tie with used rails, with which the problem was pretended to be solved, was not technically nor economically suitable.

The year 1971 Eng. Angel Bottino prepared a research for The Peruvian Corporation Ltd., in which he recommended as follows: "*A tie-renewal program should be immediately started which will allow to correct and resume a delayed maintenance schedule; the annual-cost analysis dares to recommend two types of ties: pre-stressed concrete and pressure-treated wood. Since the pre-stressed concrete has longer service-life and lower annual-cost than that of treated wood, tests shall be performed in order to determine the feasibility of using the former in curves having a less-than-400 m radius; the pre-stressed concrete tie must be provided with a Pandrol fastening*…" Eng. Bottino's recommendations, wise in regards to defining a railway structure policy, could not foresee the increasingly poor supply of wooden ties, the boisterous and absolute unfulfilments of suppliers, nor the spectacular increase in the cost of wood. This situation arose swiftly in the subsequent years and allowed to see clearly the cleverness of such report's core: the pre-stressed concrete tie was indispensable.

Meanwhile, the concrete member designs were improved, thus increasing its efficiency, the American Railway Engineering Association (AREA) standard was adopted as a basis for the design, in order to match the tie with the traditional practices in Peru and the manufacturing was continued in low-scale in Lima, and in increasing quantities in Arequipa.

In both plants testing frames were installed to check the resisting capacity of tie samples from each bedframe, performing moment and shear tests on the rail seat and in the center of the tie. These tests supplemented the periodical materials tests (see Figure 4).

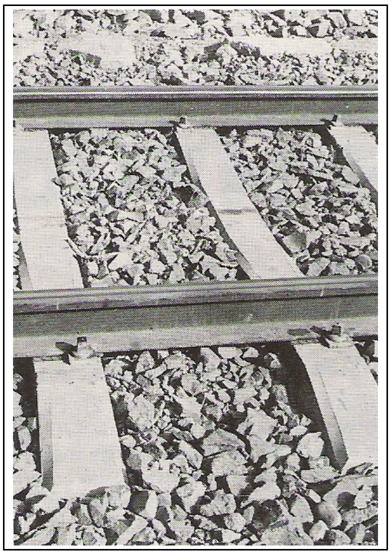

Fig. 3.- Ties installed since the year 1974 in many areas of the Central Railroad (anchoring by wooden blocks).

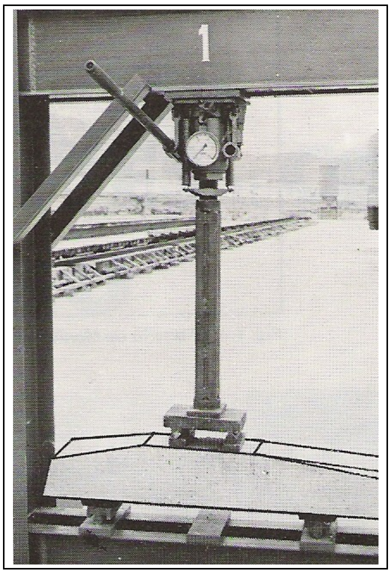

Fig. 4.- Static Load Test in the Precomsa's Plant, in Lima

To meet the requirements of the AREA standard and ensure the design and manufacturing quality, supplementing the static tests, a tie was randomly selected and sent to the laboratories of the Association of American Railways (AAR) in Chicago, USA. for them to be cyclically tested. The test was performed in August, 1976, putting the tie under cyclic loads; it was loaded over the rail seat (see Figures 5 and 6) until the tie got cracked, which occurred with a 13,636 kg load. Then, a 1,820 kg to 7,095 kg cyclic variable load (which is equivalent to a load 10% higher than the effective load resulting from the train's wheel) was applied 3,000,000 (three million) times. The tie stood the test successfully; the final AAR's report states: "*The prestressed concrete tie No. 39 submitted by Gallegos, Casabonne, Arango, Ingenieros Civiles, from Lima, Peru, meets the requirements of the AREA's 644 Bulletin regarding the repeat-load test on the rail seat*".

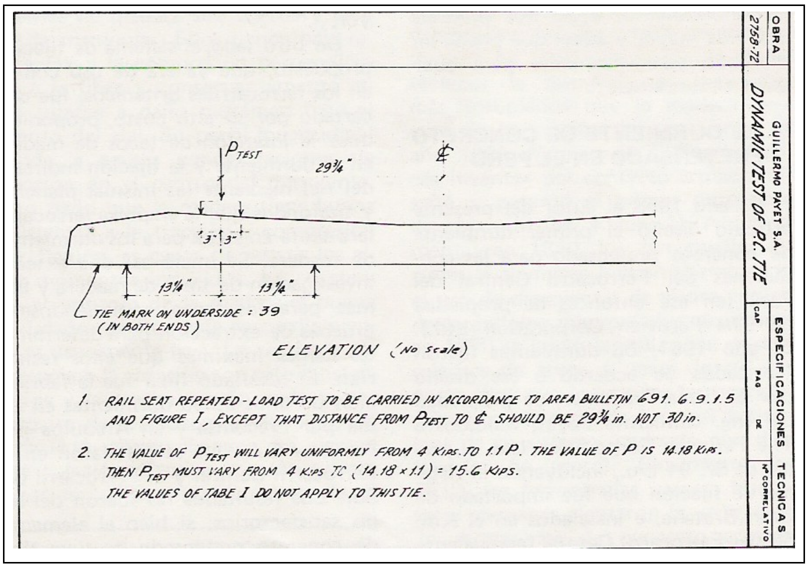

Fig. 5.- Instruction sheet for the cyclic test

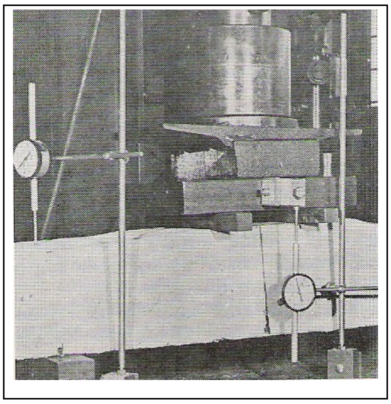

Fig. 6.- Cyclic Test in the AAR's Laboratories (Chicago): The tie is ready to be pre-cracked.

A short time later, ENAFER, which since 1971 had undertaken the control of the railroads expropriated to The Peruvian Corporation Ltd., made the first import of Pandrol fastenings. Due to financial difficulties the manufacturing was stopped in Lima, for the Central Railroad, while in Arequipa, Preconar continued the manufacturing incorporating by now the Pandrol fastening. The South Railroad has, at this time, a total of 40 km of pre-stressed concrete railway, which is equivalent to one-tenth of the railway between Mollendo and Cusco, with a total of over 60,000 ties already installed. The longer span is in the Saracocha, Santa Lucía and Maravillas area, having 10 km – almost uninterruptedly – of pre-stressed concrete ties, at a height of more than 3,500 m above sea level (see Figures 7 and 8).

In the Central Railroad the use of prestressed concrete ties us bow standard, specially at altitudes over 3,000 m,

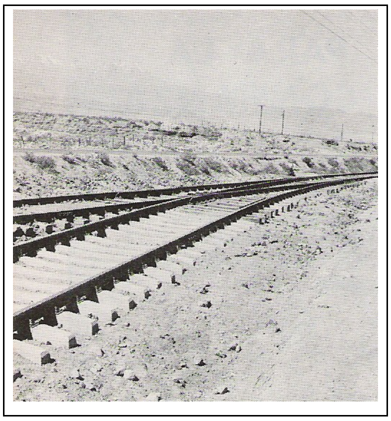

Fig. 7.- Installation in the suburbs of Arequipa, South Railroads.

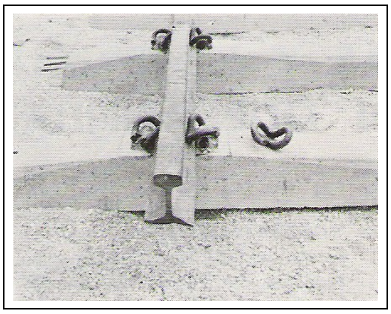

Fig. 8.- Pandrol fastening, Preconar's Plant, Arequipa

7. ADVANTAGES OF PRESTRESSED CONCRETE TIES IN PERU

Besides the inborn basic advantages of prestressed concrete ties (referred to in the item 5), there exist additional specific advantages applicable to the Peruvian reality:

a) Use of local resources. Currently, less than 15% of the tie cost is spent in imported materials (only prestressing steel).

b) Lower initial and annual cost than a wooden tie that meets the AREA's standard, which, furthermore, should be imported.

c) Lower annual cost than non-treated wooden ties or short-lasting wooden ties or those mixed bi-block ties (rail-concrete) manufactured by ENAFER.

d) Manufacturing procedure that optimizes the use of local resources and – intensively – labor.

e) Substantial reduction of maintenance needs.

f) Supply of permanently controlled and tested units.

g) Within the context of the South-American wood-industry reality, that is, variability and scarcity, the pre-stressed concrete tie ensures, on the contrary, evenness and immediate supply according to requirements.

8. DESIGN

One of the advantages of the prestressed concrete tie is that it can be designed specifically for the load, impact and reaction modulus conditions that really exist. On the other side, the design is one of the most sophisticated the structural designer faces both because of the complexity of the analysis and the need to optimize the use of materials and manufacturing simplicity, having in mind the huge amount of repetitions involved. It is, indeed, an industrial design.

The structural problem lies in the design of a beam over elastic bearings which support dynamic loads from the railway system, which is a beam over elastic bearings, too. This situation creates a moments-envelope which generates bending stresses above and below the tie in the rail seat and in the middle of the tie, thus requiring variable longitudinal and transverse cross-sections, with variable eccentricities, in turn, in every section of the prestressing force resultant. Additionally, if the pr-stressing steel anchoring is by adhesion, the pre-stressing force is variable along the tie's axis.

A copy of a ties simplified verification notice is enclosed (see Figure 9).

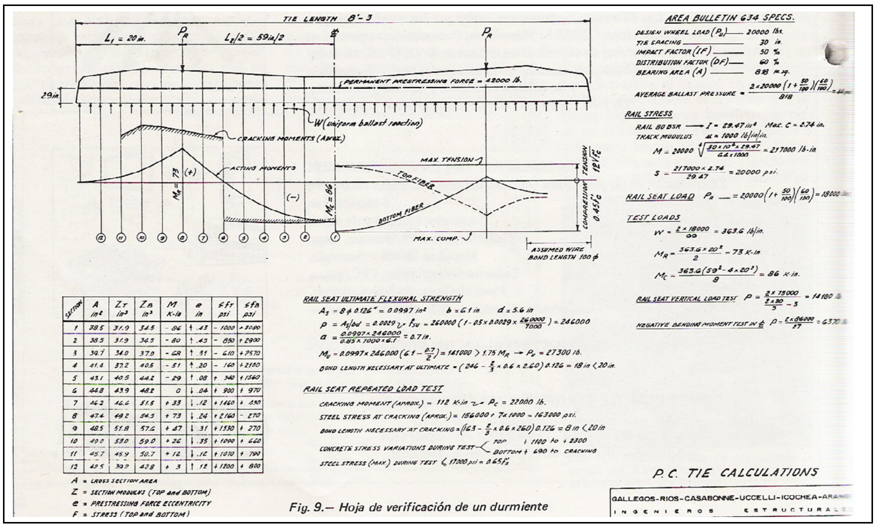

Fig. 9.- A tie's verification sheet

9. MANUFACTURING

The manufacturing system chosen as the most advantageous for the Peruvian reality is that of pre-manufacturing by the long-line and anchoring-by-adhesion method, with individual forms and units pulled out without stripping.

These conditions match perfectly with the need to manufacture the tie in an inverted position, so that the surfaces requiring high accuracy (gage and seat slope) are produced directly from the forms and depend, therefore, only on the quality of the form. This is why forms should be particularly rigid and has minimum wearing off; only the steel form meets these requirements (see Figure 10).

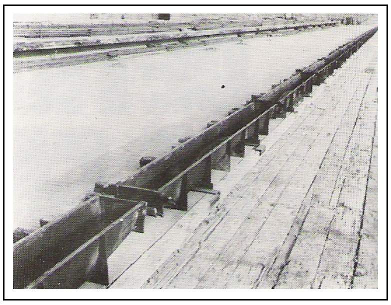

Fig. 10.- A forms line in the Guillermo Payet S.A.'s plant (Precomsa) in Lima

Starting from this basis, the problem of industrial production has two great variables. First, the rate of production, linked to the un-stressing and un-stripping term, for which it is necessary to solve the second great variable: the concrete. The strength requirements for a prestressed tie's concrete involve the need to continuously produce a cylindrical strength concrete, in 28 days, of 560 kg/cm², statistically assessed with a 95% probability to attain such strength or more. With the proper control, this means the permanent production of concretes with an average cylindrical strength, in 28 days, of about 600 kg/cm². Furthermore, high percentages of such strength should be quickly attained, typically half within 36 hours. As previously mentioned, this is possible because of the periodical tests of the concrete structure's members in order to define their suitability, the daily concrete tests to maintain the control levels and reduce the variability, and the finished tie tests.

10. THE FUTURE

Even though there's no doubt that the prestressed concrete tie is today the best technical and economical solution for the railway, the serious financial and economical troubles found by the railroad companies, have not allowed – in the proper manner – this investment. Regrettably, by not doing it there is an increase in maintenance costs or railway problems (such as derailments), wearing off and abuse of the rails and rolling material.

On the other hand, there's no doubt too that a comprehensive technology to produce a prestressed concrete ties has already been developed in Peru, and that there exists the basic facilities and equipment to produce the required quantities.

Then, the question could be: What is the future of the prestressed concrete tier? The answer is obvious; such a future is closely related to the Peruvian railroad future. If the center and south railroads are important for our development, and if the railroad-expansion need becomes a reality, then it is for sure that the prestressed concrete tie will be present.