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Feasibility Study on Production and Sustainability of Poly Propylene Fiber Reinforced Concrete Ties Based On a Value Engineering Survey

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ABSTRACT

A preliminary value engineering study is conducted in order to reduce manufacturing costs of the railroad concrete ties as well as running costs of the country's railroad network. The study is based on making use of potentially better running performance of poly propylene fiber reinforced concrete concept regarding the recent research of the authors of this paper, which was performed on durability and mechanical characteristics of concrete for application in concrete ties. Findings indicate that under existing running condition in Iran, a value index of 1.36 may be obtained in a comparison with conventional concrete tie, which seems to lead to a significant saving. It is also found that poly propylene based fiber concrete technology may well secure savings in manufacturing wastage, and running or maintenance costs as well which can provide sustainable development.

Keywords. Value engineering, Poly propylene, fibre reinforced concrete tie, Durability, Mechanical characteristics, Sustainable development.

INTRODUCTION

Current railroad development plan of the country necessitating construction of about 500 km of new railroads requires some 833000 ties to be used in super structure each year. The Unit Costs Breakdown for producing each tie, follows to ease future comparisons: 6 kg Ø 7 mm bars; 8nuts of M16 type; 2 large roll plugs; 4 small roll plugs; 60 kg Portland cement; enough coarse and fine aggregates. The price of each tie, without transportation costs, can be consequently calculated US$50 (based on contractors' tariffs). To add transportation costs to the estimated manufacturing costs it may be assumed that each ready-to-install couplings, i.e. rails and ties, weighs about 13tons the distance between two subsequent ties in a standard railroads is 600mm (AREMA, 2006) and a standard carriage wagon can carry 4 couplings containing 30 ties of about 280 kg each, the estimated transportation costs for a single tie over a distance of 1000km, is about US$13 (based on the2012 Iran's railroad tariffs). To

include replacement costs for the damaged units, a 10 percent replacement of damaged ties per year may be assumed reasonable that leads to a replacement cost of US$0.52M.

Apart from development project costs, maintenance costs of existing 10000km railroads in the country which contains some 16325000 concrete ties should be taken into account. Again a 10 percent replacement of ties may be assumed that leads to a total ties' maintenance costs of US$ 0.1M. The overall estimated annual costs of needed ties for development projects and maintenance of existing networks indicate a significant potential savings if the manufacturing techniques are to be reviewed, and strength and durability of ties increase by means of a more economic method.

A literature review on increasing concrete strength and durability shows that prestressed concrete ties in comparison with other types of tie is a better alternative. They are inflammable and cannot be damaged by insects or other animals, have high lateral resistance, their smooth surface help better maintenance, and can be mass produced at vicinity of railroad. However, to overcome durability constraints in adverse operation environment neither using FRP in high-tension regions increases durability, nor the epoxy resins containing by nano structures coating of ties for the same purpose are recommendable as these methods are too expensive and only suitable for certain special situations (P.Mehta, 2005). A promising alternative to overcome the problem has been found to be making use of fiber concrete technology by means of polypropylene fibers (PPFRC). Numerous research works have proved that the PPFRC suffers less surface cracks (S. Kurtz et al., 2000), with better structural performance. Such a performance may be attributed to the fibers role in gradually filling micro-cracks that leads to increased bonding in concrete micro structure that leads to increased resistance to fire and higher tensile and flexural strengths, according to SEM micrographs (Yao, 2007).

Making use of PPFRC technique in manufacturing railroad ties, therefore, formed the core of a value engineering study performed by authors of this article to secure direct economic gains as well as indirect savings due to the environment subsequent of dumping rejected ties. Although there are several benefits in using PP fibers in concrete, economical aspects should be considered as well in order to assess the implementation of PPFRC Ties. Many other researches have been performed on value engineering concepts especially in construction. In fact, by providing a balance between cost and performance, value engineering helps gaining the value of the money that is spent (Ray R. Venkataraman et al., 2008); However, non of them have been considered the production of PPFRC Ties. Other researchers have mentioned that independent value study should be done on each construction contracts in order to bring the most of benefits to the general contractors (Bringham, 2008). To quantify the extent of economic gains and savings, authors had to take into account majority of affecting items which are addressed briefly below.

METHODOLY

After an extensive literature review and brain storming sessions, value engineering steps should be taken in value studies of the project.

Selecting Fiber Type, Its Mechanical Characteristics and Amount in the Mixes

Based on reported research findings on PPFRC following ACI standards (ACI 544.3R, 1998) and the PP fibers effects on concrete, it was concluded that mixes should contain less than 2 kg/m^3 of fibers to avoid high porosity and dramatic strength reduction though, surface cracks

may be reduced. The adverse effects of high porosity concrete on ties' durability due to freezing and thawing should be taken into account as well. The physical and chemical characteristics of these monofilament polypropylene fibers, manufactured from 100% virgin homopolymer polypropylene resins, are illustrated in Table.1. Optimum fibers content of 0.7 kg/m^3 was used in order to have suitable strength and durability.

Elastic Modulus (N/mm^2)	3500-3900
Density (kg/dm^3)	0.91
Diameter (μm)	18
length (mm)	12
Tensile strength (N/mm^2)	400
Melting temperatures (℃)	160-165
Ignition temperatures (℃)	360
Electrical acid/alkali resistance conductivity	Very low
Ultimate elongation (%)	15
Water absorption	0

Table 1. Physical and chemical characteristics of PPF

In order to signify the permeability of the concrete durability, its pore structure, and permeability, the following tests have been performed. Reported test results from the authors of the paper (A.A. Ramezanianpour et al., 2013) show that ultrasonic frequency, sorptivity, and charge passed in the rapid chloride penetration test (RCPT) may be reduced as much as 37%, 18.7%, and 36%, following (ASTM C579, 2009), (BS EN 480-5, 1997), and (ASTM C1202, 2012), respectively. The results of durability tests are shown in Table 2. Specimen C1 is ordinary concrete tie, and specimens P05, P07, P09, and P1.5 are concrete ties with 0.5, 0.7, 0.9, and 1.5 kg/m^3 amount of fiber respectively. It is noteworthy that, for certain parts of the networks, such as south railroad region, where harmful ions adversely affect concrete ties more severely, the sole solution to maintain sustainable development seems to be adoption of PPFRC ties that supports findings of this study. Obviously, by controlling surface cracks harmful materials do not penetrate into the concrete, therefore, prolonged maintenance free operation becomes possible.

	Specimen				
	C1	P05	P07	P09	P1.5
Amount of Fiber (kg/m^3)	0	0.5	0.7	0.9	1.5
Ultrasonic frequency (kHz)	34.3	24.1	21.6	22.7	25.1
Sorptivity (m/s$^{0.5}$)	3.26	2.68	2.51	2.42	2.63
Charge Passed (RCPT) (Coulomb)	2496	1863	1589	1634	1673

Table 2. Results of durability tests

The results show that implementing PP Fibers in concrete tie production may increase the durability of ties, which can improve life cycle of concrete tie for at least 3 years not only because of improving the durability but also because of the fact that the other benefit of using such fibers is significant reduction in crack propagation (A.E.Richardson, 2005) which is vital for concrete ties since many ties may not be operated due to the presence of too many cracks.

Defining Tie's Specifications

Based on the environmental and operating conditions, axle load and velocity, exact dimensions, quality of materials and manufacturing procedures were determined as follows. The tie's dimensions are in order of 220x210x2600 mm as illustrated in Fig.1. A tolerance of 2mm for positioning of rail seats should be observed. The reinforcing bars should meet DN-St160 (DIN-EN 13230-2, 2003) specifications and have standard chemical and mechanical properties. Besides that, a curing procedure preventing crack development must be undertaken. Moreover, minimum coverage on reinforcing bars has to be maintained in accordance to the design specifications, and porosity should be kept at minimum. Other specifications ought to meet AREMA (AREMA, 2006) standards. There are also some hints for mass production of ties, based on value engineering. Using concrete ties in railroads usually lead to certain running problems such as crack propagation due to thermal and cyclic loading and corrosion of reinforcing bars as a result of chlorine attack as well as high concentration of carbon dioxide in its surrounding. Therefore, certain precautions are necessary. In a shop manufacturing of PPFRC ties, followings should be cross checked: Molding details, aggregate quality, mix design and use of adequate additives, setting/hardening duration before removing moulds, curing procedure.

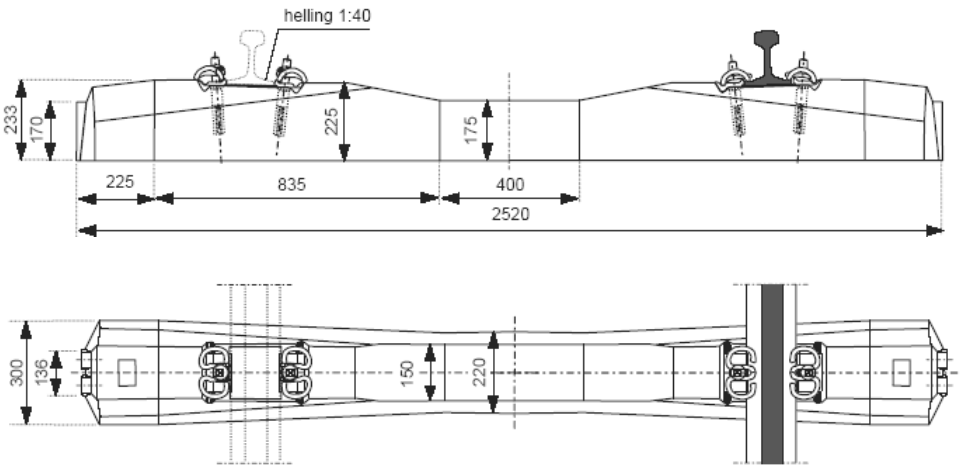

Fig 1. Concrete tie plan and cross section.

Economic Evaluation of the Selected Alternatives

Production Costs Estimation

Selected statistics of major railroad tracks and its number of ties have presented in table2.Currently two concrete-tie manufacturing sites are active in the country- namely Karaj and the Andimeshk factories- with a total production capacity of about 914735 ties per year (Annual Report of Islamic Republic of Iran Railways, 2010). Unit production costs of various types of concrete tie at above mentioned sites have been roughly estimated to be in order of US$ 50 per tie.

Description	unit	Year				
		2002	2004	2006	2008	2010
Major railroad tracks length	km	7268	7608	8595	9079	9795
Number of ties	thousands	12114	12680	14325	15132	16325

Table 2. Statistics of major railroad tracks length and number of ties used

Costs Estimation for Assembly and Installation

In order to signify the potential of reducing the production cost, Value Index (VI) should be calculated. If the amount of value index is more than 1, it means that the actual price is extravagantly higher than the minimum price, which shows need of reducing prices. This index is obtained by indicating actual and minimum price, which is obtained as follows. As a common practice usually assembly and installation costs are estimated on needed labor. For long railroad tracks in the US a 90-personnel-team is expected to install about 470 m of tracks in a working shift of 10 hours by means of couple rail installation, i.e. 4 rails in each side (Federal Railroad Administration, 2003); However, over here in Iran, a 10-personnel team, may install only 150m of couplings. This is mainly due to the fact that each 18m of rails needs to be welded and each welding point needs about 40 minutes for pre and post warming plus 20 minutes for related preparations. Therefore, it may be worked out that each 18m of welding takes 1 hour with an overall length of 150m of rail installation or 8 welding points per working shift leading to an estimated installation costs of US$ 13 for each installed concrete tie. If the sum of overhead, tax& fees, and contingency costs are assumed to be in order of 15%, 7%, and 10% of the tie cost respectively, the actual price of each tie (C) may exceed US$ 83. On the other hand, an internet-based search for the minimum price (i.e. worth) of a tie leads to a figure of about US$35 (alibaba.com, 2012) that corresponds with US$35 (W). By using these two parameters, i.e. actual price and worth, a value index (VI) of 2.37 for concrete tie is calculated using equation 1.

$$VI = C\,(W)^{-1} \quad (1)$$

where (VI) is value index, (C) is the actual price, and (W) is the minimum price of a tie. The more the value index is higher than 1, the more it is likely to reduce the costs. This value index indicates that under current conditions in Iran, even optimistic cost estimation shows a good potential for reduction in related costs. It is noteworthy that, damaging and/or rehabilitating environment costs have not been considered in that estimation.

Cost estimation using PP fiber concrete

In order to compare value indexes of ordinary concrete tie and polypropylene concrete tie production, all costs of adding such fibers should be considered as well. By adding PP fibers to concrete mixture for manufacturing tie, the costs of production will undoubtedly increase. A comparison with other applications of PPFRC shows that an average increase of about 30% in production of concrete ties should be expected (Federal Aviation Administration, 1992). Consider the cost of each tie without transportation costs, i.e. US$50, this increase should be added. Therefore the actual price will be considered US$65 after adding PP fibers. By adding transportation and other costs to the above prices, cost of each ordinary and PPFRC tie is calculated US$83 and US$102.9 respectively. Hence, the increased cost of concrete in PPFRC tie (PW) is about 20% or US$20. In order to consider relative worth of the money that is spent for the increased cost, interest rate of 27%, the current interest rate in Iran, should be implemented in the calculation as well. However, much longer service-life expectancy for PPFRC tie, supposing only 3 years more than that of ordinary tie, offsets the increased production cost. Therefore, it is necessary to rework potential savings if PPFRC tie technique is to be adapted. Besides, the increase in cost is considered for life cycle of tie. To do so, equation (2) may be employed as follows:

$$VI= [C – (PW (1+i)^n)] (W)^{-1} \quad (2)$$

where (VI) is value index, (C) is the actual price of PPFRC Tie, (PW) is the increased cost of concrete used in tie production due to adding PP fiber to the mixture, (i) is the interest rate, (n) stands for actual life cycle of PPFRC tie, and (W) is the minimum price of a tie. Rough estimations leads to a Value Index of 1.36 that is about 50% less than previously stated VI for ordinary concrete ties.

SUSTAINABLE DEVELOPMENT ASPECTS OF THIS STUDY

A powerful sustainability defines the ecological services, so that natural capital stocks may not be dependable on capital that is made by human (Wackernagel et al., 1996). There should be a harmony between the conflicting demands so that the process of making a decision may not become complicated. In fact, sustainable development should form the harmony between ecological, social, and economical demands (Klass De Brucker, 2013), and is totally in accordance with the religion of the people of the country (Koran,2001).
With regard to the geographic distribution of the national railroad networks in the country, apart from severe environmental consequences of dumping ties manufacturing wastes, replacing and disposing of damaged ties at the side of railroads causes many direct and indirect dramatic environmental damages, i.e. effect on streams hydraulic parameters, agriculture activities at the vicinity of tracks, etc. Such direct and/or indirect environmental damages, therefore, should be taken into account in the special planning for sustainable development. As environmental remediation projects are costly and time consuming, it becomes clear that it would be much economical to avoid environmental damages by employing long run alternatives. A quantitative saving analysis of environmental

remediation project cannot be performed under current condition due to the lack of reliable data. However, its qualitative consequences are well understood.

CONCLUSIONS

It has been shown that some1.7 million damaged ties should be disposed of annually that imposes overall costs of about US$ 0.145M, to the mono-product economy of the country. To secure some savings in such an unfavorable condition concrete ties of the new railroad project as well as required replacements for maintenance in the existing networks may be made more durable by manufacturing them from PPFC. Although using more durable PPFC alternative leads to some increase in production costs, it makes a saving of 50% on a life cycle costing calculation. Regarding other benefits of implementing PPF in concrete ties, i.e. savings in manufacturing wastage, and running or maintenance costs, sustainable development can be achieved as well.

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