Assessment of Wooden Sleepers Replacement with Synthetic Sleepers Case Study on A Railway Bridge Using Analytical Hierarchy Process (Ahp)

Nova Ernanda[1*], Wahyu Tamtomo Adi[2] and David Malaiholo[3]

[1,2,3] Construction and Railway Technology, Indonesian Railway Polytechnic, Madiun, Indonesia
ernanda.tbjp20201217@taruna.ppi.ac.id

Abstract. Planning to replace wooden sleepers with synthetic sleepers on bridge BH 534 must be done because using wooden sleepers on this bridge is less efficient. The inefficient use of sleepers on the BH 534 bridges is because the sleepers on this bridge still use the type of wood sleeper where the nature of the wood is not resistant to weather changes, so it is easily weathered and needs to be replaced. Therefore it is necessary to plan the replacement of wooden sleepers with synthetic sleepers where the properties of synthetic sleepers are resistant to weather changes and have a longer service life. This study aims to plan the replacement of wooden sleepers with synthetic sleepers on bridges BH 534 by considering several things. The results showed that synthetic sleepers obtained a safety factor value (SF) of 6.36, which met the safety requirements. The calculation of the cost budget plan indicates that for 50 years of use, synthetic sleepers need a smaller budget than wooden sleepers. The assessment using the AHP method showed that synthetic sleepers were preferred. It can be concluded that replacing wooden sleepers with synthetic sleepers on bridges BH 534 is recommended.

Keywords: Assessment, wooden sleepers, synthetic sleepers, AHP

1 INTRODUCTION

Railway bridges are part of the railway operational system in the infrastructure field that supports the structure of the railway road on the bridges. There are several constituent components, one of which is the sleepers**.** The sleepers function as a rail mount so that the rail position becomes sturdy and strong [1]. Railway bridges generally use wooden sleepers because of their mechanical properties [2]. Even though wooden sleepers have good mechanical properties, wooden sleepers also have several weaknesses, such as damage due to weather changes. Wood is expensive because wood is starting to become scarce; this will be detrimental to the surrounding environment if wood continues to be used [3]. This is not only experienced by railways in Indonesia but also in Japan. In the 1970s, Japanese Railways (JR) made many observations on the maintenance of wooden sleepers and realized that about 70% of wooden sleepers installed had a short life service. The weather caused the wood to degrade, so the replacement of wooden sleepers had to be done frequently [4].

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Fig. 1. Degradated wooden sleepers

Based on the shortcomings possessed by wooden sleepers, Japan continues to make observations and trials to create new types of sleepers that can be used instead of wooden sleepers [5]. In 1978, a company in Japan called Sekisui succeeded in creating synthetic sleepers as an alternative to wooden sleepers [6]. Synthetic sleepers are a new type of cushion made of urethane foam resin-reinforced glass fibre [7]. A piece of glass thread pulled through an extrusion machine is then coated with *polyurethane* and hardened at high temperature to produce a high-grade and non-porous material, resistant to corrosion from chemicals deposited on passing railway tracks, so it has a long service life even up to 50 years [8]. The use of synthetic sleepers (FFU) has also been investigated by several researchers to be used as a substitute for wooden sleepers due to the advantages possessed by synthetic sleepers [9][10][11].

Fig. 2. Synthetic sleepers

Until now, for the use of sleepers in Indonesia, many still use wooden sleepers compared to synthetic sleepers, although synthetic sleepers have several advantages that are not owned by wood sleepers [12]. For a study case on the BH 534 bridges of the Sasaksaat-Cilame plot across Jakarta-Padalarang, the sleepers on these bridges still use wood types. Wooden sleepers are still considered efficient compared to synthetic sleepers that do not have factories in the country, so it should be purchased from abroad [13]. However, based on sleepers data from the DAOP 2 Bandung Rail Road and Bridges Resort, wooden sleepers on the BH 534 bridges continue to experience sleepers replacement every year with different sleeper numbers. This indicates the lack of function and budget efficiency in using wood sleepers. The more often the sleeper is replaced, the more budget will be spent. Based on the inefficient use of wooden sleepers on the BH 534 bridges, which continues to be replaced, it is necessary to plan the replacement of wooden sleepers with synthetic sleepers on the BH 534 bridges to increase the efficiency of function and budget for the BH 534 bridges.

2 METHOD

This study aims to plan the replacement of wooden sleepers with synthetic sleepers because the use of wooden sleepers has been less efficient. In designing the replacement of wooden sleepers with synthetic sleepers is carried out by considering several things, namely the value of safety factors, budget plans for costs that must be incurred, and the use of the Analytical Hierarchy Process (AHP) method for decision-making in planning sleepers replacement based on expert opinions. From the results of several things that have been calculated and analyzed, the results will be obtained for planning the replacement of wooden sleepers with synthetic sleepers recommended or continuing to use wood sleepers only.

2.1 Safety Factor

The use of sleepers on bridges must be adjusted to the angle-to-angle relationship (SKS) between the size of the longitudinal bearer. The size of the angle to the angle of the stringer consists of 110 cm to 165 cm. This difference in size will later affect the size of the sleepers to be used. The difference in the length of the stringer on the bridges causes the size of the sleepers to vary. The size of sleepers on the bridges consists of sizes 18x22x180 cm to 32x22x220 cm, commonly referred to as special sleepers. The varying size of sleepers and longitudinal bearers that are interrelated causes the determination of the sleepers installed on the bridges cannot be arbitrary. Still, it must go through calculations first to determine the safety value obtained in selecting these sleepers. The formula for calculating the safety factor is as follows:

Moment of inertia = $B\, x\, \frac{1}{12} H^3$

Resistance Moment = Wx = Ix ÷ (H : 2)

Maximum Moment = RA × X

Safety Factors (SF) = Allowable Stress ÷ Bending Stress

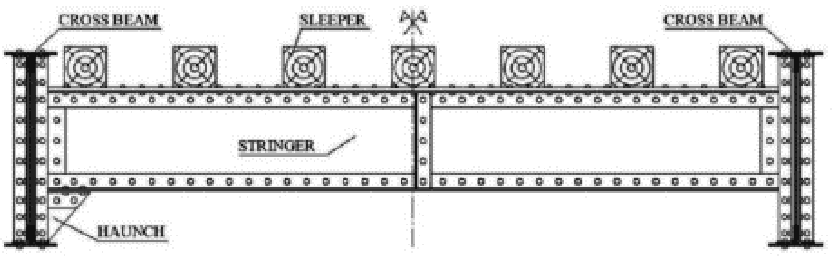


Fig. 3. laying of sleepers and stringers

2.2 Cost Budget Plan

Cost Budget Plan (CBP) is the budget or funds needed for a construction project, both wages and materials. In preparing the cost budget plan, there is an analysis of the unit price of work (AHSP), namely the analysis of materials and wages to make a particular type of work. Cost budget planning is related to the volume of work [14]. The quantity of work is a count of the number of jobs in a unit. In comparison, cost is the amount of each volume with the unit price of the work concerned. Therefore, it can be concluded that the cost budget plan is the sum of the volume of work multiplied by the unit price of work, as follows:

$$CBP = \sum \text{Volume x Unit Price of Work} \quad (1)$$

2.3 Analytical Hierarchy Process

The Working Principle of the Analytical Hierarchy Process (AHP) Method simplifies an unstructured and dynamic complex problem into its parts and arranges them in a hierarchy. The importance of each variable is given a value compared to other variables [15]. From these various considerations, a synthesis is then carried out to determine variables that have high priority and play a role in influencing system results. The stages of using the Analytical Hierarchy Process (AHP) method are to define the problem and determine the desired solution, conduct interviews, create a hierarchical structure, create a pairwise comparison matrix, and process the Expert Choice application.

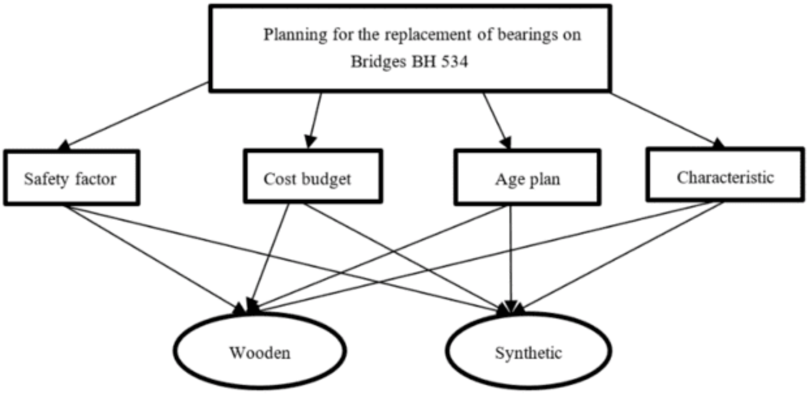


Fig. 4. hierarchical structure

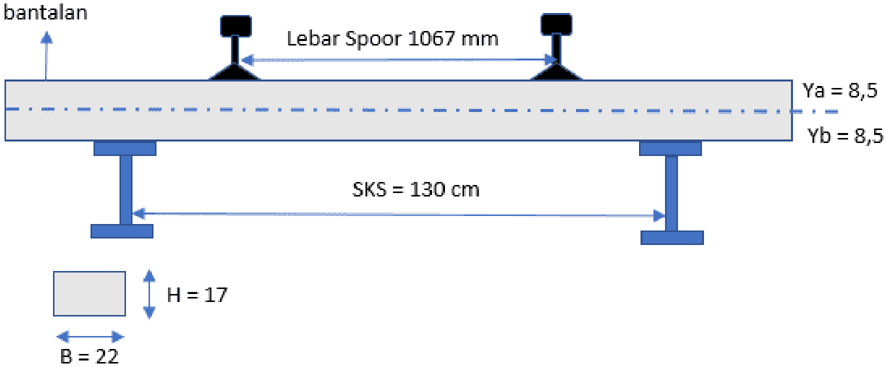
3 RESULTS

3.1 Use of sleepers on bridges

The sleepers' safety factor (SF) on the bridges can be calculated by knowing the size of the angle to the width of the angle (SKS) of the stringer and the size of the sleepers to be installed. The BH 534 bridges have an angle width to an elongated angle (SKS) of 130 cm. Generally, bridges with an SKS size of 130 cm use sleepers measuring 20 cm, but currently, in Indonesia synthetic sleepers that enter only 18 cm in size; in this study, a synthetic sleepers size of 18 cm is used.

- Synthetic sleepers size:
  - Depth 18 cm
  - Width 22 cm
  - Length 180cm
- The size of the angle to the angle of the stringer of the bridges is 130 cm.
- The clearance voltage based on the technical specification of synthetic sleepers document no.17/ST/TRK/LDE/2016 is 70 N/mm2.
- Spoor width 1067 mm.
- SF safety factor requirements > 1. The requirements for safety factor values are regulated in AVBP 1932 concerning bridges and iron poles for railway bridges and trams in Indonesia.

- The load of 1 gandar based on RM 1921 is 20 tons without considering shock load and shock load.



Inertial moment Ix = $B\,x\,\frac{1}{12}H^3$

$= 22\,x\,\frac{1}{12}17^3$

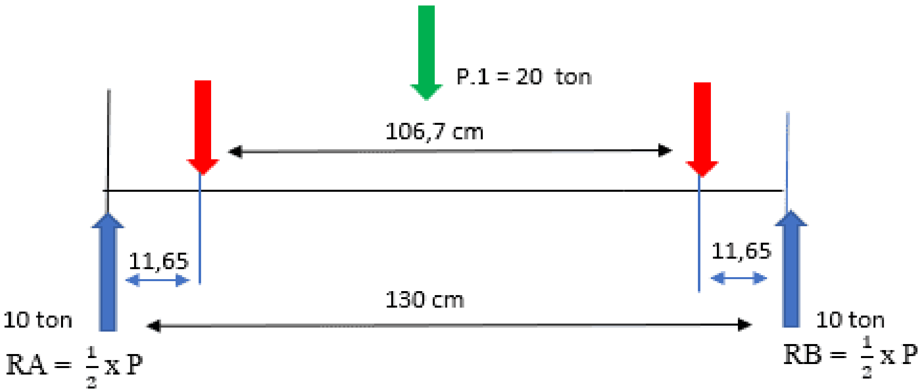
$= 9007{,}167\ Cm^4$

Resistence moment Wx = Ix x $\frac{H}{2}$

$= \frac{9007{,}167\ cm4}{8{,}5\ cm}$

$= 1059{,}667\ cm^3$

Moment Max = RA x X. 1
= 10000 kg x 11.65 cm
= 116500 kg. Cm



Moment Max = RA x X. 1
= 10000 kg x 11.65 cm
= 116500 kg. Cm

Bending Stress σ $= \frac{Mmax}{Wx} \leq$ s permission

$$= \frac{116500\ kg.Cm}{1059,667\ Cm^3}$$

$$= 109.94\ \frac{Kg}{Cm^2}$$

Synthetic sleepers clearance voltage min 700 $\frac{Kg}{Cm^2}$

The safety factor value must be greater (>) than 1. Safety factor value (SF) = 700 : 109.94 = 6.36 (meet the requirement)

3.2 Cost Budget Plan

Materials in a construction project. The calculation of the cost budget plan in the study is based on several things as follows:

1. BH 534 bridges length of 60 meters with a number of sleepers 100 units.
2. Do not replace railway components other than sleepers.
3. The service life plan of each sleepers.

The service life plan shows wooden sleepers can last 5 to 8 years. Because wood sleepers material is natural wood that is not resistant to weather changes, causing a short service life. Synthetic sleepers can last up to 50 years, and this is because the material of synthetic sleepers is a mixture of urethane foam resin. Based on the calculations that have been made on the budget plan for the use of wooden sleepers and synthetic sleepers, the following results are obtained:

1. The initial cost of installing synthetic sleepers is Rp. 965,645,642.00.
2. The initial cost of installing wooden sleepers Rp.184,358,491.00.
3. The cost of maintaining wooden pillows for damage yearly is 14 units, with the costs Rp. 31.00.702,00.

From the calculation results can be concluded for the comparison of the budget plan, the cost of using wood sleepers and synthetic sleepers when compared for the lifecycle as in the table below:

Table 1. Cost budget plan

Types of sleepers	Age plan	Cost budget	Total budget 50 years Fore
Synthetic sleepers	50 year	IDR 965,645,642	IDR 965,645,642
Wooden sleepers	5-8 year	IDR 31,000,702	IDR 1,550,035,100

Based on the calculations above, it can be concluded that the use of wood sleepers for the next 50 years has a larger budget than the use of synthetic sleepers. This is because wood sleepers are natural, so they are easily weathered due to weather changes. Therefore, sleepers replacement must be carried out. Repeated sleepers replacements result in a larger budget than synthetic sleepers that can withstand the planned life of the next 50 years.

3.3 Decision Making Using Analytical Hierarchy Process (Ahp) Method

The hierarchical analysis process in this study was used to make decisions in planning the replacement of BH 534 bridge sleepers to overcome the problem of frequent sleepers replacements on bridges based on expert assessments. In this study, four experts were selected as respondents with the following assessment results:

Table 2. Respondents Consistency

Pairwise comparison	Consistency value	Information
First responders	0,08	Consistent
Second responders	0,06	consistent
Third responders	0,06	Consistent
Fourth responder	0,02	consistent

The ranking is done by combining the assessments made by all respondents against the matrix criteria with criteria and criteria with alternatives. The ranking by combining the evaluations made by all respondents, the most superior alternative results were obtained for planning the placement of sleepers on the BH 534 bridges as in the following graph:

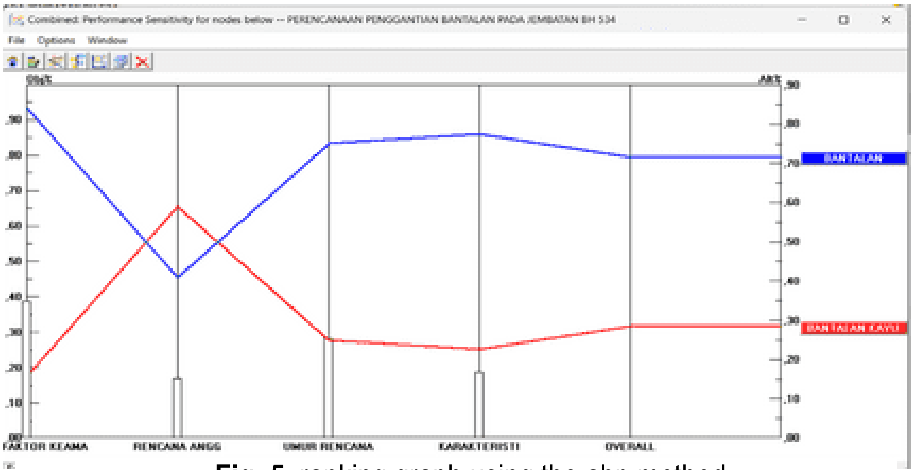


Fig. 5. ranking graph using the ahp method

Based on the analytical hierarchy method results, synthetic sleepers are preferred as a substitute for sleepers on the BH 534 bridge. These results are relevant to other studies using timber sleepers to provide high maintenance costs, which provides the importance of alternative sleepers [5].

4 CONCLUSION

Based on the calculations and analysis that have been done, it can be concluded that the planning to replace wooden sleepers with synthetic sleepers on the BH 534 bridges is recommended because synthetic sleepers are superior and better when used on the bridges. Based on the calculation results, synthetic sleepers with a sleepers size of 18 x 22 x 180 cm, when used on BH 534 bridges, have met the safety factor value of 6.36. Synthetic sleepers on a budget are also more economical than wood sleepers. This is seen in the next 50 years, for the initial installation of synthetic sleepers does have a more expensive price than wood, which is Rp. 1xxx, but for long-term use, synthetic sleepers have a smaller total budget value compared to wood sleepers. For the next 50 years of use, synthetic sleepers have a budget of Rp. 2xxx, while wooden sleepers have a value of Rp. 3xx, where the value is much greater. This is because synthetic sleepers can last 50 years without sleepers replacement maintenance because of the excellent material. In addition, based on decision-making using the analytical hierarchy method, the process by relying on experts' opinions, synthetic sleepers are preferred as a substitute for sleepers on the BH 534 bridges. Overall, synthetic sleepers are recommended as a replacement for wooden sleepers on BH 534 bridges to solve the problem of frequent sleeper replacements.

REFERENCES

[1] S. A. P. Rosyidi, *REKAYASA JALAN KERETA API Tinjauan Struktur Jalan Rel*, IV. Yogyakarta: Lembaga Penelitian, Publikasi & Pengabdian Masyarakat (LP3M) dan Jurusan Teknik Sipil Fakultas Teknik Universitas Muhamadiyah Yogyakarta, 2020.

[2] M. Muttashar and C. Salih, "From the SelectedWorks of Wahid Ferdous," *16th East Asia-Pacific Conf. Struct. Eng. Constr.*, no. January, 2019, doi: 10.1007/978-981-15-8079-6.

[3] M. Papaelias and S. Kaewunruen, "Damage Detection in Fiber-Reinforced Foamed Urethane Composite Railway Bearers Using Acoustic Emissions," pp. 1–18, 2020.

[4] G. Koller, "FFU synthetic sleeper - Projects in Europe," *Constr. Build. Mater.*, vol. 92, pp. 43–50, 2015, doi: 10.1016/j.conbuildmat.2015.03.118.

[5] W. Ferdous, A. Manalo, G. Van Erp, T. Aravinthan, S. Kaewunruen, and A. Remennikov, "Composite railway sleepers - Recent developments, challenges and future prospects," *Compos. Struct.*, vol. 134, no. August, pp. 158–168, 2015, doi: 10.1016/j.compstruct.2015.08.058.

[6] G. The use of sleepers made of FFU synthetic wood in EuropeKoller, "The use of sleepers made of FFU synthetic wood in Europe," *Railw. Tech. Rev.*, vol. 2, no. September 2008, pp. 28–32, 2009.

[7] E. Ferro, J. Harkness, and L. Le Pen, "The influence of sleeper material characteristics on railway track behaviour: concrete vs composite sleeper," *Transp. Geotech.*, vol. 23, 2020, doi: 10.1016/j.trgeo.2020.100348.

[8] G. Koller, "Synthetic wood in Europe," pp. 28–32, 2009.

[9] G. Q. Jing, L. Zong, Y. Ji, and P. Aela, "Optimization of FFU synthetic sleeper

shape in terms of ballast lateral resistance," vol. 28, pp. 3046–3057, 2021, doi: 10.24200/sci.2021.56898.4970.

[10] P. Yu *et al.*, "Failure analysis and the effect of material properties on the screw pull-out behaviour of polymer composite sleeper materials," *Eng. Fail. Anal.*, vol. 128, no. March, p. 105577, 2021, doi: 10.1016/j.engfailanal.2021.105577.

[11] I. Sola, J. Yaben, P. Monreal-perez, D. Elduque, L. David, and I. Clavería, "Full-scale dynamometer tests of composite railway brake shoes including latxa sheep wool fibers," vol. 379, no. October, 2022, doi: 10.1016/j.jclepro.2022.134533.

[12] D. Fokus, "www.railwaygazette.com | Agustus 2010 DESAIN TRACK," 2010.

[13] F. Ramadhan, "Kajian Penggunaan Bantalan Kayu Dan Bantalan Sintetis Pada Jembatan Di Lintas Kiaracondong – Cicalengka," pp. 5–65, 2021.

[14] Oni Widiantoro, "Buku Ajar Rencana Anggaran Biaya (Contruction Cost Estimate) Fakultas Teknik Universitas Negeri Surabaya," pp. 1–81, 2017.

[15] G. T. Supriadi, A., Rustandi, A., Komarlina, D. H., & Ardiani, *Analytical Hierarcy Process (AHP) Teknik Penentuan Strategi Daya Saing Kerajinan Bordir.* Tasikmalaya, Jawa Barat, Indonesia: DEEPUBLISH, 2018.