Analysis of Railroad Ballast Deficiencies Using Total Station and Ballast Regulator

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Abstract. This research aimed to inspect the ballast volume to determine the ballast volume deficiencies based on the initial ballast condition from the railroad As-built drawing by using Total Station and Ballast Regulator. The case for this study is a 1.007 km long railroad in which the analysis and calculation were conducted using Autocad Civil 3D software and Microsoft Excel. The result of ballast volume can be used as a reference for the maintenance of the PPI Madiun railroad ballast profile. Another purpose of this research was to compare the two instruments in terms of cross-sectional measurement of the railroad using normality tests, analysis of variance, and scoring with rating scale parameters. The total volume of ballast deficiencies calculated by Autocad Civil 3D outcomes was 627.14 m^3. Meanwhile, the volume calculation result from Ballast Regulator was 591.95 m^3. The required ballast volume to repair the ballast profile is derived from the difference between the cut and fill volumes of 230.80 m^3. Normality test results state that volume calculation data from both instruments were Normally distributed. The graphical comparison showed a similar volume pattern, but ANOVA resulted in a significant difference between the ballast volume calculation results of the total station and ballast regulator. After comparing these parameters, it can be suggested that Total Station provides an accurate and suitable function for measuring railroad ballast profiles.

Keywords: Inspection · Ballast Volume · Instrument Comparison · Total Station · Ballast Regulator · Autocad Civil 3D

1 Introduction

Ballast is one of the main components in railway infrastructure because it has the primary function of continuing and spreading the load of the train from the sleepers to the ground, holding the position of the sleepers and circulating the water so that there is no water trapped around the sleepers and rails[1]. Based on the regulations, the shape and size of the ballast profiles have been determined and grouped into five classes with different minimum heights and widths according to the passing tonnage of the railway operation [2].

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Over time, the ballast profile experienced deformation caused by various factors such as vibrations of passing trains, weather, and land subsidence that often happens on the railroad during operation [3]. Therefore, an inspection of the ballast profile is needed to determine the changes in the shape of the ballast profile and volume.

In the Railway Infrastructure Inspection Standards and Procedures, the ballast inspection procedures are carried out using a measuring tape and visual observations [4], which makes it considerably difficult to estimate the quantity of ballast volume deficiencies. Based on this background, this study aimed to conduct a ballast inspection to determine the quantity of ballast deficiency volume using measuring instruments [5]. This study used measuring instruments Total Station and Ballast Regulator.

This study aims to determine the amount of ballast volume deficiencies that can be used as a reference for maintaining railroad ballast. Another purpose of this study is to identify which measuring instrument [6] is more reliable for a ballast volume inspection.

2 Methods of Measurement and Processing Data

2.1 Measurement Using Total Station

The research is conducted with a case study of a circular railroad 1 km long in the Indonesian Railway Polytechnic Madiun (PPI Madiun) laboratory. The measurement of the ballast profile coordinate aimed to obtain the coordinate data of the ballast profile to create a model of the ballast surface. The measurement is conducted by using a Total Station Sokkia CX-102 with 2" angle measurement accuracy and distance measurement accuracy of 2 + (2ppm x D) mm [7].

The methods started by sorting coordinate data to create a surface from the railroad ballast profile. The data was processed using Ms Excel and AutoCAD Civil 3D 2020 student version software. As in previous research, the measurement used five Benchmark Monument as the location of the Total Station occupy point and used the adjacent monument as the backsight coordinate. The measurement used a moving prism at the ballast surface along the railroad at five points of the ballast surface from the center, right ballast shoulder, left ballast shoulder, right ballast foot, and left ballast foot [8]. The measurement resulted in 477 coordinate points of the ballast surface, with the highest elevation at 94,235 m and the lowest elevation at 93,322 m. These points are processed to create a ballast surface using Autocad Civil 3D software, as shown in Fig. 1.

Figure 1 shows the ballast profile surface with 66,593 m2 area with an average elevation of 93,643 m and an average gradient of 1.65%, which means the average change in vertical height every 100 m was ± 1.65 m. The contour lines on the surface illustrate the same elevation with 10 cm differences.

2.2 Measurement Using Ballast Regulator

One of the railroad maintenance equipment which can be used to shape and distribute the stone ballast is a ballast regulator [9]. This research used a simple ballast regulator, a tool to maintain the stone ballast height (Simple Ballast Regulator). As in Fig. 2, the device can measure the size of the ballast and is used as benchmarking for repairing the ballast

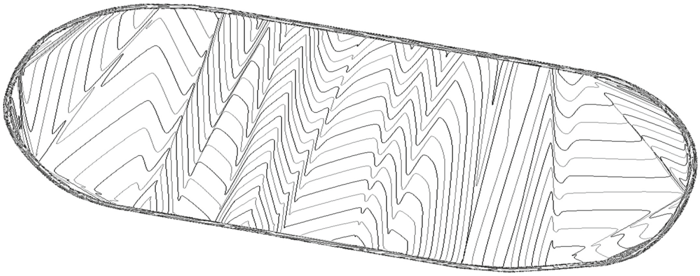

Fig. 1. Ballast Surface Results from Total Station

Fig. 2. Measurement using Ballast Regulator

profiles using a galvanized sleeve designed to be used on any railroad classification with a track gauge of 1,067 mm.

The simple ballast regulators, as in Fig. 2, can be used to measure the ballast dimension, which consists of six parameters to be measured: ballast height (left and right), ballast shoulder length (left and right), and ballast foot length (left and right) measured from the center of the ballast. For this study, ballast profile measurements with ballast regulators were carried out every 6 m. The result can be seen in Table 1, consisting of 167 measured ballast profiles.

The results can be used to calculate the ideal ballast volume according to the initial railroad classification. From the measurement results, the average ballast height was 30.6 cm, indicating a 20.9 cm difference. Therefore, it meant a 40% degradation from the constructed ballast structure.

3 Estimation of Ballast Deficiencies

3.1 Ballast Volume Deficiencies from Ballast Regulator Instrument

Ballast volume deficiences will be calculated based on comparing the initial ballast profile and the inspected profile using Ballast Regulators (BR) and Total Station (TS). The measurement results of the ballast regulator consist of the right side and the left side

Table 1. Measurement Results using Ballast Regulator

KM	**Ballast Height (cm)**		**Ballast Shoulder Length (cm)**		**Ballast Foot Length (cm)**	
	Right	Right	Right	Left	Right	Left
0 + 000	28	20	144	130	219	235
0 + 006	31	29	136	131	228	217
0 + 012	29	28	142	143	236	230
0 + 018	31	29	131	115	225	242
Etc.						
Average	30.6					

Table 2. Calculation of Ballast Volume Deficiencies (Ballast Regulator)

KM	**Ballast Regulator Volume (m^3)**		
	V_{BR}	V_i	**Deficiency**
0 + 000	5.29	11.28	5.98
0 + 006	5.83	11.28	5.45
0 + 996	5.23	11.28	6.05
1 + 002	5.27	11.28	6.01
TOTAL			591.95

of the ballast. Therefore, the right and left areas must be added up in the calculation, and the average between the first and the next point area must be calculated. Then the average calculation result will be multiplied by the value of 6 m (distance between points).

The average ballast volume is 6.35 m^3, the most significant ballast volume is at km 0 + 306 – km 0 + 312 with a value of 7.59 m^3, and the smallest ballast volume is at km 0 + 762 to km 0 + 768 with a value of 2.75 m^3. Therefore, the next step is to find the ballast volume deficiency, which is done by looking for the difference between the ballast volume of the ballast regulator measurement results and the initial ballast volume per 6 m. The result can be seen in Table 2, which shows for an overall 1,002 km railroad length, the need for ballast to repair the existing ballast is 591,95 m^3.

3.2 Ballast Volume Deficiencies Based on Total Station Instrument

From the cross-section of the ballast surface drawing, the ballast cut and fill volume can be obtained automatically using volume report functions in AutoCAD Civil 3D. In the calculation of the ballast volume from the Total Station measurements, it is known that the average ballast volume for a 6 m section is 6.05 m^3, the highest ballast volume is 8.82 m^3 (Km 0 + 330 - Km 0 + 336), and the smallest ballast volume is 2.23 m^3 (KM 0 + 762 - KM 0 + 768) which linear to the results from ballast regulator estimation.

Table 3. Calculation of Ballast Volume Deficiencies (Total Station)

KM	Volume Ts & Civil 3D (m^3)		
	V_{TS}	V_i	Deficiency
0 + 000	4.89	11.28	6.39
0 + 006	5.49	11.28	5.79
0 + 996	4.76	11.28	6.51
1 + 002	4.82	11.28	6.45
TOTAL			627.14

Table 4. Normality Test

Total Station (TS)		Ballast Regulator (BR)
D_{Result}	0.111979	0.077626
$D_{Critical}$	0.123754	0.123754
Conclusion	Normal	Normal

The ballast volume deficiency is calculated by finding the difference between the ballast volume from the Total Station measurement and the ballast volume for every 6 m of the railroad estimated previously.

The result can be seen in Table 3, which shows for an overall 1,002 km railroad length, the need for stone ballast to repair the existing ballast is 627,14 m3. The result was 5.94% higher than the estimation result from the ballast regulator (Table 4).

3.3 Graphical Comparison of Ballast Volume Calculation Result

The data on the volume estimation results were presented graphically to illustrate the comparison of the initial ballast volume, the ballast volume from Total Station results, and the ballast volume from ballast regulator results. The difference between calculating the ballast volume of the two tools will also be seen in the following graph as in Fig. 3.

Figure 3 shows the stone ballast quantity needed to create the ballast profile to follow the railroad ballast specification according to its classification. It shows variation along the railroad with a similar pattern. However, statistical analysis is required to compare the results numerically.

4 Statistical Comparison of the Measuring Instruments

4.1 Normality Test

Data of ballast volume from both instruments were analyzed using the Kolmogorov-Smirnov normality test to determine whether the following normal distribution. In the

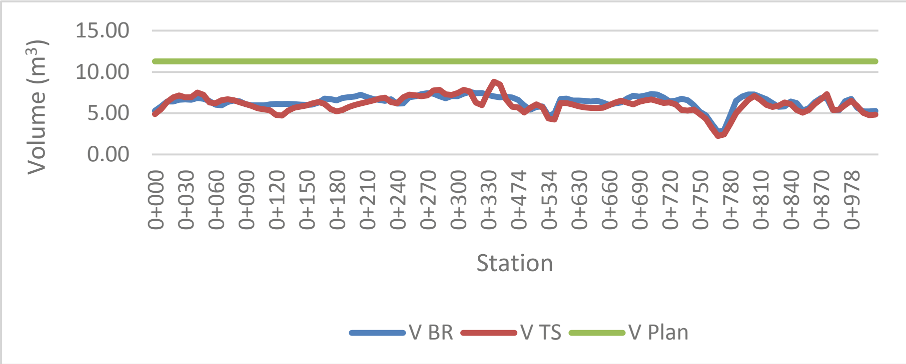

Fig. 3. Chart of Ballast Volume Calculation Result

Table 5. ANOVA Test Results

SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
TS	120	726.279	6.052325	1.057813		
BR	120	761.4654	6.345545	0.677729		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F Crit***
Between Groups	5.15868	1	5.15868	5.944749	0.015494	3.880827
Within Groups	206.5295	238	0.867771			
Total	211.6882	239				

Kolmogorov-Smirnov test, the data given were compared with the normal distribution using the sample mean and sample variance [8]. In this test, the significance level is $\alpha = 5\%$.

The D_{Result} value of the two groups of data is smaller than the value of the D_{Critical}, so the data from the calculation of ballast volume from both tools are normally distributed, and the data can be processed using the analysis of variance (ANOVA).

4.2 Analysis of Variance

The variance test is analyzed using a one-way analysis (One Way ANOVA) because both data groups only have one category. The category mentioned results from ballast volume calculations using the following formula. $H_0 : F < F_{Crit}$, there are no significant differences. $H_1 : F > F_{Crit}$, there are significant differences, and if $F > F_{Crit}$, refuse H_0.

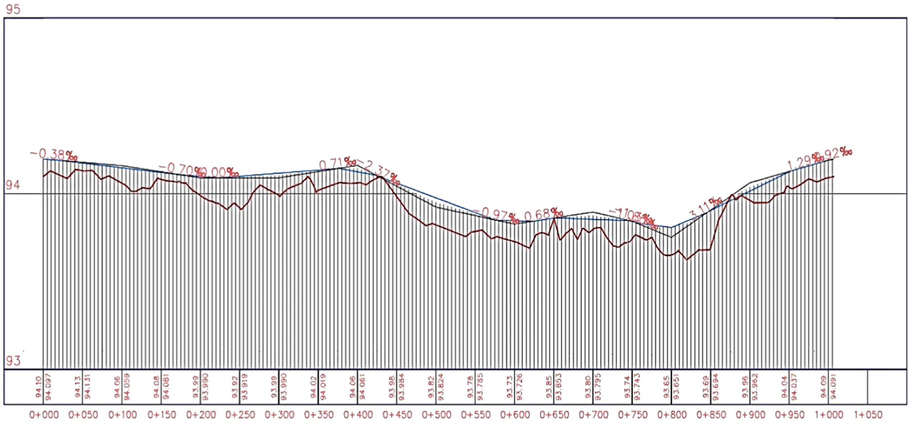

Fig. 4. Profile of the Ballast Surface

The results of the ANOVA test of the ballast volume from the two measurement devices in Table 5 resulted in the rejection of H_0 and approval of H_1. From this result, it can be concluded that there is a significant difference between calculating the ballast volume using the total station and the ballast regulator.

5 Ballast Volume Deficiencies from the Initial Alignment

5.1 Vertical Alignment of the Railroad Ballast

The cut and fill volume is calculated from the intersection between the ballast profile of the Total Station measurement results and the initial ballast profile from the as-built drawing. Unlike the previous ballast volume calculation, which calculated the total volume of the entire cross-section, the following analysis estimates the cut and fill volume based on each cross-section. This method determines how much ballast volume is needed to repair the existing ballast to meet the initial condition based on the railroad alignment. Horizontal alignment is made using the results of ballast center line coordinates. The vertical ballast alignment showing the railroad in this case study was 1007 m long. This alignment will also be used as a reference line for making a long section profile of the ballast surface.

Figure 4 shows the long section of the ballast surface from the measurement indicated by the red line and the initial vertical alignment indicated by the blue line. The black line along the alignment was tangent to the tangent line intersection, which created the alignment. The maximum gradient of vertical alignment was $3.11°/_{oo}$, which was classified as a flat railroad according to the specification [2], which a maximum gradient of $10°/_{oo}$.

5.2 Cross Section of the Railroad Ballast

Cross sections were made of each 6 m ballast profile alignment. The initial ballast profile was created using menu Assembly on AutoCAD Civil 3D, which has 1400 mm of ballast

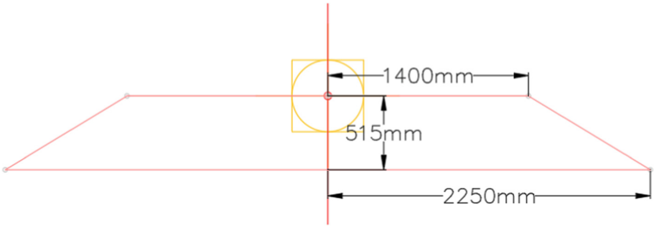

Fig. 5. Initial Ballast Profil

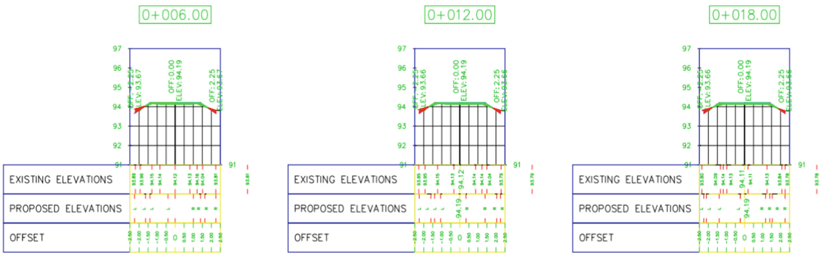

Fig. 6. Cross Section of Ballast Surface

shoulder, 2250 mm of ballast foot, and 515 mm of height which can be seen in Fig. 5. The difference between the existing profile obtained from the inspection with the designed profile on the constructed drawing will be compared in this section.

The cross-section is processed to create the initial ballast surface using the Corridor Surface menu. Next, the cross-section of the ballast was placed along the alignment to form a ballast surface. In the next step, sample lines for every 6 m of the ballast alignment with 4 m width to the right and left from the ballast center is used by the Multiple Section Views Menu resulting in Fig. 4. The Figure shows the cross-section for every 6 m of the ballast surface. The green color indicates the fill volume, and the red one indicates the cut volume of the ballast to create the ideal ballast profile to meet the specification (Fig. 6).

Autocad Civil 3D software can generate a table of cut and fill ballast volumes, By using the menu Compute materials and Total Volume Table. The summary results can be seen in Table 6.

Table 6 shows the total ballast volume in the fill area is 347m^3, while the total volume in the cut area is 116 m^3. Therefore, from the calculated differences, the need for ballast volume for repair on this railroad to match the initial ballast profile is 230 m^3. This result suggested that by using Total Station, the calculation of the ballast volume can be conducted to compare the existing ballast surface with the initial ballast condition as on the As-built drawing of the railroad alignment.

Based on Fig. 7, the distribution of cut and fill volume to repair the ballast to its initial alignment condition can be examined. The graphic shows the quantity for fill is more than the cut quantity, which means many stone ballast should be allocated along the railroad to maintain the ballast profile according to the initial alignment.

Table 6. Cut and Fill of Ballast Volume

Station	Area		Volume		Cumulative Volume		
	Cut $(m)^2$	Fill $(m)^2$	Cut (m^3)	Fill (m^3)	Cut (m^3)	Fill (m^3)	Deficiency (m^3)
0 + 006	0.09	0.21	0	0	0	0	0
0 + 012	0.09	0.2	0.52	1.22	0.52	1.22	-0.7
0 + 018	0.07	0.24	0.46	1.31	0.98	2.53	-1.55
0 + 990	0.07	0.25	0.5	1.58	115.58	344.5	-228.92
0 + 996	0.06	0.21	0.4	1.38	115.98	345.88	-229.9
1 + 002	0.07	0.22	0.39	1.29	116.37	347.17	-230.8

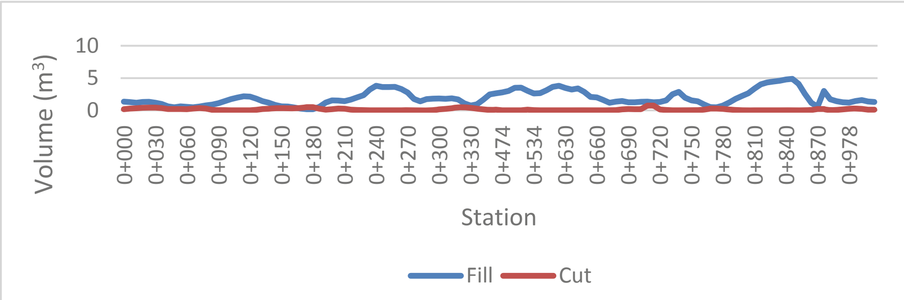

Fig. 7. Cut and Fill Chart

6 Conclusion

There is a significant difference in the ballast volume deficiencies between measurement using Total Station (627.14 m3) and Ballast Regulator (591.95 m3). With a 35.19 m3 difference, the total Station estimation is 5.94% higher than the result from the ballast regulator. In addition, the results of the ANOVA test also emphasize that there are significant differences between the volume calculation results of the two measuring instruments. However, the two measuring instruments have shown the exact location of the minimum ballast volume. Furthermore, the results are also significantly different according to ANOVA Test. When the analysis is conducted to maintain the ballast to meet the initial alignment according to the As-Built Drawing, the volume estimation using Cut and Fill for the whole six-meter ballast segment results in a 230.8. m3 ballast deficiencies. This study suggested using Total Station to measure the railroad ballast surface can be conducted to obtain an accurate result that can be stored automatically and can be analyzed by using alignment and cross-section of the ballast surface as well as can be illustrated graphically.

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