Indirect estimation of railway ballast strength by conducting point load test on rock cores and irregular-shaped particles

Massoud Palassi & Mehdi Koohmishi
University of Tehran, Tehran, Iran

ABSTRACT
Ballast layer comprised of coarse-grained aggregate facilitates drainage of rainwater from the railway track and distributes the stresses transmitted by the sleepers to the underlying layers. Breakage of ballast aggregate is mainly influenced by the properties related to the parent rock type. To evaluate the quality of parent rock used for producing crushed ballast aggregate, the strength of rock is estimated by conducting uniaxial compressive strength (UCS) test. Also, the point load test (PLT) could be used to indirectly estimate the strength of parent rock. In the present study, the strength of ballast material is evaluated by conducting UCS test and PLT on rock cores as well as irregular-shaped ballast particles to investigate the effectiveness of PLT as a simple test for estimation of strength of ballast particles. For this purpose, PLT as well as UCS test is carried out on rock specimens obtained from different quarries. Obtained results show that strong linear relationships exist between the strength estimated from diametral PLT and UCS test conducted on rock cores with the strength determined from PLT conducted on irregular-shaped particles.

RÉSUMÉ
La couche de ballast constituée d'agrégats à grains grossiers facilite le drainage de l'eau de pluie de la voie ferrée et répartit les contraintes transmises par les traverses aux couches sous-jacentes. La rupture des agrégats de ballast est principalement influencée par les propriétés liées au type de roche-mère. Pour évaluer la qualité de la roche-mère utilisée pour la production d'agrégats de ballast broyés, on évalue la résistance de la roche en effectuant un essai de résistance à la compression uniaxiale (UCS). En outre, le test de charge ponctuelle (PLT) pourrait être utilisé pour estimer indirectement la force de la roche mère. Dans la présente étude, la résistance du ballast est déterminée en effectuant des essais UCS et PLT sur des noyaux de roche ainsi que des particules de ballast de forme irrégulière pour déterminer l'efficacité du PLT en tant que test simple pour estimer la résistance des particules de ballast. A cet effet, le test PLT ainsi que le test UCS sont effectués sur des échantillons de roches provenant de différentes carrières. Les résultats obtenus montrent qu'il existe de fortes relations linéaires entre la force estimée à partir du test diamétral PLT et UCS effectué sur des noyaux de roche avec la force déterminée à partir du PLT conduit sur des particules de forme irrégulière.

1 INTRODUCTION

Ballasted railway track is a conventional structure used to provide facility for passing train. Ballast course comprised mainly of coarse aggregate plays an important function to enhance the performance of the structure. Providing sufficient drainage capacity as well as transmitting applied loads into the underlying soil is the main functions of this layer (Selig and Waters 1994).

The strength of parent rock is an important property which influences the performance of railway ballast aggregate. Determination of the uniaxial compressive strength (UCS) of parent rock is a conventional testing procedure to evaluate the quality of ballast materials (Indraratna et al. 2011). Also, conducting Los Angeles abrasion (LAA) test is another index test to further illuminate the quality of the ballast aggregate. Furthermore, measuring the strength of single ballast particles is a viable method to characterize the railway ballast aggregate.

The strength of single ballast particles has been indirectly measured in the various studies to evaluate the strength of each aggregate individually. In this relation, Lim et al. (2004) determined the strength of single particle for various size fractions by conducting single particle crushing test on each aggregate. Al-Saoudi and Hassan (2012) established the same method to elaborate the strength of ballast with different sieve sizes. In both researches, it was observed that increasing the size of aggregate led to the decreasing the strength of each single particle (Lim et al. 2004, Al-Saoudi and Hassan 2012). Also, LAA test is conventionally carried out on mass of the ballast sample to evaluate the performance of ballast against degradation. In the research work conducted by Qian et al. (2017), the changes in gradation of ballast aggregate was evaluated by conducting Los Angeles abrasion test for rock types of granite and limestone.

Point load test (PLT) is another economical index test for indirect estimation of the parent rock strength. In this relation, Koohmishi and Palassi (2016) conducted point load test on single ballast particle to consider different irregular shapes of ballast aggregate including hexahedron, pentahedron and tetrahedron. The estimated values of the point load strength index of railway ballast showed that the particle shape had no specific effect on the strength (Koohmishi and Palassi 2016).

Generally, PLT and the other simple testing methods are conducted to investigate the strength of rock and granular materials used in the layers of the highway pavement. Kahraman (2001) carried out simple methods (including point load, Schmidt hammer, sound velocity and impact strength) to evaluate the uniaxial compressive strength of rocks. Furthermore, Alitalesh et al. (2015) developed a correlation between the uniaxial compressive strength and the point load index of rocks to assess the effectiveness of the PLT for evaluation of the other important features of the rock materials.

Present study evaluates the strength of railway ballast materials by determination of the strength of rock cores and irregular-shaped ballast particles. The main purpose is to investigate the effectiveness of point load test for characterization of quality of railway ballast materials.

2 METHODOLOGY

In this research, the quality of railway ballast material is evaluated by conducting laboratory tests on rock cores as well as crushed ballast aggregate. The strength of irregular-cubical shaped ballast particles is determined by conducting a series of point load tests. While, the diametral PLT as well as uniaxial compressive test is carried out on rock cores obtained from parent rock. Ballast samples have been collected from four quarries in Iran. The considered irregular-shaped particles are hexahedron (as shown in Figure 1) with sieve size fractions 19-25 mm, 25-37.5 mm, 37.5-50 mm and 50-62.5 mm. The general descriptions of the rock types used in this study are shown in Table 1.

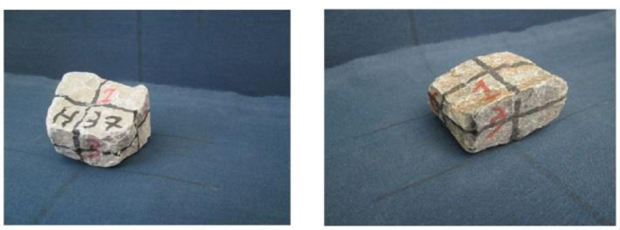


Figure 1. Ballast aggregates with irregular-cubical shape (Hexahedron shape)

Table 1. General descriptions of ballast particles from different quarries

Quarry name	Fariman	Azadvar	Bajestan	Torbat-e Heydarieh
Rock type	Basalt	Marl	Dolomite	Trachyte
Color	Gray	Grayish white	Gray	Grayish yellow
Bulk dry specific gravity	2.72	2.58	2.79	2.42
Water absorption (%)	0.56	0.32	0.18	1.73

3 POINT LOAD TEST ON RAILWAY BALLAST

As part of the present study, a series of point load tests has been carried out on ballast particles with various sieve size ranges. The PLT is performed by subjecting a single rock specimen to an increasing concentrated load until failure occurs by splitting the specimen. The concentrated load is applied through coaxial, truncated conical platens (ASTM D 5731 2002). The failure load is used to calculate the point load strength index by Eq. (1):

$$I_{S,Hex} = \frac{P}{D_e^2} \quad [1]$$

$I_{S,Hex}$ = Point load strength index (PLSI) for hexahedron shaped aggregate (MPa)
P = Failure load (N)
D_e = Equivalent particle diameter (mm)

To determine D_e for irregular ballast particles, Eq. (2) is used (ASTM D 5731 2002):

$$D_e^2 = \frac{4WD}{\pi} \quad [2]$$

D = Distance between loading points (mm)
W = Smallest specimen width perpendicular to the line joining the loading points (mm)

20 PLT is carried out on aggregate with hexahedron shape for each rock type and size fraction.

Diametral point load is applied on rock cores obtained from parent rock. The point load strength index is computed based on the obtained failure load during diametral PLT by Eq. (3):

$$I_S = \frac{P}{D_e^2} \quad [3]$$

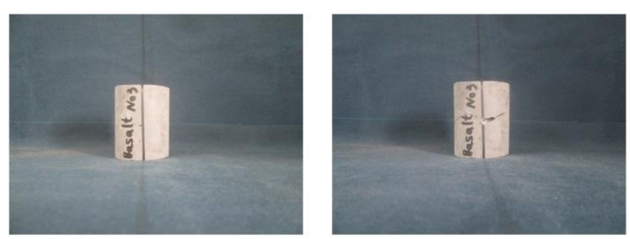
I_S = Point load strength index (MPa)
P = Failure load in PLT (N)
D_e = Rock core diameter used for diametral PLT (mm)

To determine the strength of rock core for standard core (with diameter of 50 mm), the following equation is applied (ASTM D 5731 2002):

$$I_{S(50)} = \sqrt{D_e/50}\, I_S \quad [4]$$

$I_{S(50)}$ = Point load strength index for rock core with 50 mm diameter (MPa)

Figure 2 illustrates rock core before and after carrying out diametral PLT.



Before PLT | After PLT

Figure 2. Rock core specimen obtained from ballast parent rock before and after diametral PLT

4 UNIAXIAL COMPRESSIVE STRENGTH TEST

To directly determine the strength of parent rock, uniaxial compressive test is conducted on cylindrical cores. The UCS test is carried out on trimmed core sample in which axial load is continuously increased on the specimen until peak load and failure are obtained. The UCS is calculated according to the maximum compressive load applied on sample as follows (ASTM D 2938 2002):

$$UCS = \frac{P}{A} \quad [5]$$

UCS = Uniaxial compressive strength (MPa)
P = Maximum applied load (N)
A = Cross sectional area of rock core (mm^2)

In the present study, the diameter of rock core sample is 44.5 mm with a length to diameter ration of 2 (ASTM D 2938 2002). To estimate the uniaxial compressive strength of rock core for standard core (with diameter of 50 mm), the following equation is applied on UCS (Hoek and Brown 1980):

$$UCS_{(50)} = (D/50)^{0.18}\, UCS \quad [6]$$

$UCS_{(50)}$ = Uniaxial compressive strength for rock core with 50 mm diameter (MPa)
D = Rock core diameter used for uniaxial compressive strength test (mm)

For each specific rock type, five rock cores are tested to determine the average value of UCS. Figure 3 shows the rock core before and after conducting uniaxial compressive loading test.

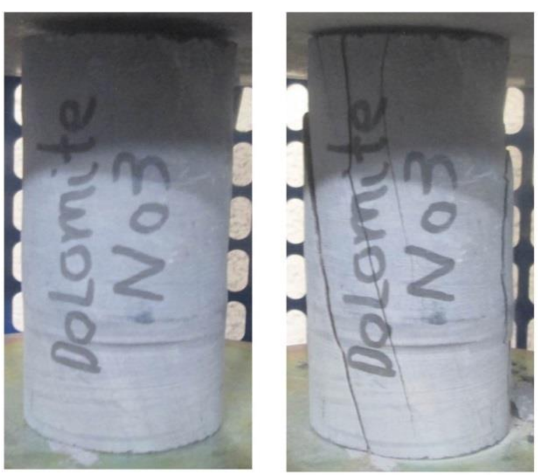


Figure 3. Rock core specimen of ballast parent rock before and after UCS testing

5 RESULTS

In this section, the obtained results from conducting point load test on irregular-shaped ballast aggregates and diametral point load test as well as uniaxial compressive strength test on rock cores is presented.

5.1 Point load test on ballast aggregate

Based on the conducted PLT on ballast aggregate with different sieve size ranges, linear equations are developed between the average D_e and average $I_{S,Hex}$ for each specific rock type. Figure 4 shows the relationship between average values of PLSI and average equivalent diameter for hexahedron-shaped particles. The developed equations are used to estimate the point load strength index of ballast aggregate with standard equivalent diameter (i.e. 50 mm).

Table 2 presents the summary results obtained from carrying out PLT on ballast aggregate in which average and standard deviation values of point load strength index is presented. Furthermore, the estimated values of PLSI for equivalent diameter of 50 mm are presented.

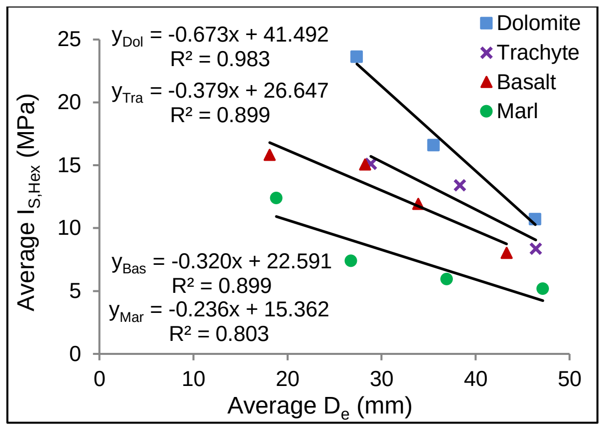


Figure 4. Correlation between average PLSI and average equivalent diameter for different rock types (PLT on hexahedron-shaped aggregate)

Table 2. Summary of test results from conducting PLT on hexahedron-shaped ballast aggregate

Rock type	Sieve size range	Average D_e	Average $I_{S,Hex}$	St. Dev. $I_{S,Hex}$	$I_{S,Hex(50)}$
	mm	mm	MPa	MPa	MPa
Basalt	50-62.5	43.30	8.01	3.73	
	37.5-50	33.93	11.93	3.47	6.59
	25-37.5	28.27	15.07	5.49	
	19-25	18.11	15.82	5.38	
Marl	50-62.5	47.16	5.16	1.10	
	37.5-50	36.95	5.92	1.18	3.56
	25-37.5	26.76	7.39	1.91	
	19-25	18.81	12.37	4.86	
Dolomite	50-62.5	46.36	10.70	3.29	
	37.5-50	35.53	16.58	8.01	7.84
	25-37.5	27.38	23.62	11.95	
Trachyte	50-62.5	46.41	8.36	2.76	
	37.5-50	38.34	13.40	5.14	7.70
	25-37.5	28.86	15.12	5.86	

5.2 Diametral point load test on rock cores

Limited number of rock cores is tested diametrally by point load test to indirectly evaluate the strength of parent rock. Table 3 shows the average values as well as the standard deviation values of point load strength index obtained for different rock types. As shown, rock types of marl and dolomite have the minimum and the maximum values of strength, respectively.

Table 3. Summary of results from diametral PLT on rock core samples (Number of tested specimens for each rock type: 6 rock cores)

Rock type	Core diameter	Average I_S	Average $I_{S(50)}$	St. Dev. $I_{S(50)}$
	mm	MPa	MPa	MPa
Basalt	44.5	5.8	5.5	0.9
Marl	44.5	3.4	3.2	0.5
Dolomite	44.5	8.2	7.8	0.8
Trachyte	44.5	8.0	7.5	1.5

5.3 UCS test on rock cores

Table 4 summarizes the results derived from conducting uniaxial compressive strength test on rock cores prepared from parent rock of ballast materials. The presented results include the average and the standard deviation values of uniaxial compressive strength for four different rock types. Again, rock type of marl shows the least compressive strength, while rock type of trachyte demonstrates the maximum strength.

Table 4. Summary of results from UCS test on rock core samples (Number of tested specimens for each rock type: 4 rock cores)

Rock type	Core diameter	Average P	Average UCS	Average $UCS_{(50)}$	St. Dev. $UCS_{(50)}$
	mm	kN	MPa	MPa	MPa
Basalt	44.5	165.3	106.3	104.0	13.6
Marl	44.5	152.3	97.9	95.9	14.2
Dolomite	44.5	193.0	124.1	121.5	13.2
Trachyte	44.5	180.5	116.1	113.6	8.3

5.4 Comparison of obtained results

To further illuminate the correlation between results obtained from different conducted tests, Figure 5 shows variation of strength from diametral PLT with the strength obtained from carrying out PLT on irregular-shaped aggregate. The relationship between the strength determined from diametral PLT and the point load strength index derived from irregular-shaped aggregate is as follows:

$$I_{S(50)-Diametral\ PLT} = 0.942 I_{S,Hex(50)-PLT\ on\ ballast\ aggregate} \quad [7]$$

The coefficient of determination (R^2) is 0.944 which characterizes that the strength estimated from PLT on irregular-shaped aggregate correlates well with the strength determined from diametral PLT. Also, this figure illustrates the 95% confidence limit of derived equation. To establish the confidence interval, the following equation was applied on measured and predicted data:

$$\hat{y} \pm t_{(n-2)} \cdot \sqrt{\frac{\sum(y_i - \hat{y}_i)}{n-2}} \cdot \sqrt{\frac{1}{n} + \frac{(x-\bar{x})}{\sum(x_i - \bar{x})^2}} \quad [8]$$

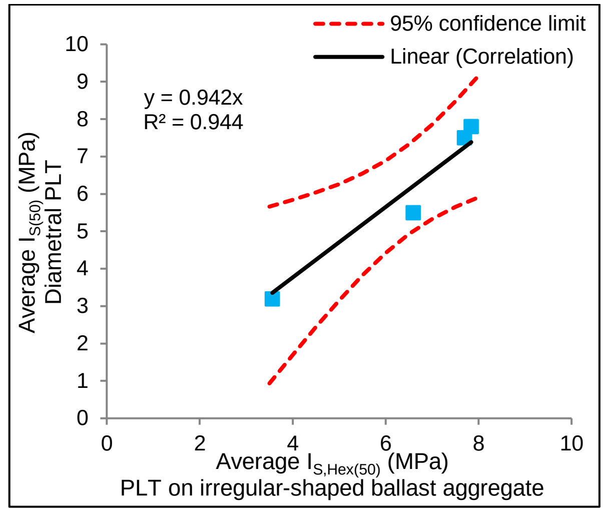


Figure 5. Relationship between results from diametral PLT and PLT on irregular-shaped ballast aggregate

In a similar manner, Figure 6 illustrates the relationship between average strength determined by uniaxial compressive strength test and the average strength indirectly estimated by conducting point load test on hexahedron-shaped ballast aggregate. The derived equation is as follows:

$$UCS_{(50)} = 5.08\ I_{S,Hex(50)-PLT\ on\ ballast\ aggregate} + 76.101 \quad [9]$$

The value of coefficient of determination demonstrates that the obtained strength from uniaxial compressive loading test is correlated well with the strength value derived from PLT on irregular-shaped particles.

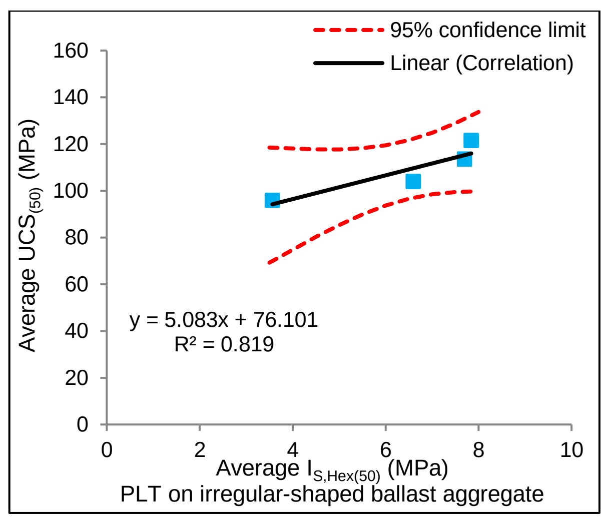


Figure 6. Relationship between results from UCS and PLT on irregular-shaped ballast aggregate

6 CONCLUSIONS

In this study, the strength of ballast aggregate was evaluated by conducting uniaxial compressive strength test and point load test on rock cores as well as hexahedron-shaped ballast particles. To investigate the effectiveness of PLT for estimation of strength of ballast materials, four different rock types were gathered from various quarries. Comparison of average values of strength obtained for tested ballast aggregate and standard rock cores indicates that PLT on irregular-shaped ballast particles could be considered as an effective simple test method to assess the strength of railway ballast materials.

REFERENCES

Alitalesh, M., Mollaali, M. and Yazdani, M. 2015. Correlation between uniaxial strength and point load index of rocks. The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Japanese Geotechnical Socienty Special Publication.

Al-Saoudi, N.K.S. and Hassan, K.H. 2012. Evaluation of indirect tensile strength of track ballast using Weibull statistics. *Geotechnical and Geological Engineering*, 30:1097-1102.

ASTM D 2938. 2002. Standard test method for unconfined compressive strength of intact rock core specimens. ASTM International, West Conshohocken, USA, ASTM D 2938-02.

ASTM D 5731. 2002. Standard test method for determination of the point load strength index of rock, American Society for Testing and Materials, West Conshohocken, USA, ASTM D 5731-02.

Hoek, E. and Brown, E.T. 1980. *Underground excavations in rock*. Institution of Mining and Metallurgy, CRC Press, London.

Indraratna, B., Salim, W. and Rujikiatkamjorn, C. 2011. *Advanced rail geotechnology: Ballasted track*. Taylor and Francis Group, CRC Press/Balkema, Rotterdam, Netherlands.

Kahraman, S. 2001. Evaluation of simple methods for assessing the uniaxial compressive strength of rock. *International Journal of Rock Mechanics and Mining Sciences*, 38: 981-994.

Koohmishi, M. and Palassi, M. 2016. Evaluation of the strength of railway ballast using point load test for various size fractions and particle shapes. *Rock Mechanics and Rock Engineering*, 49(7): 2655-2664.

Lim, W.L., McDowell, G.R. and Collop, A.C. 2004. The application of Weibull statistics to the strength of railway ballast, *Granular Matter,* 6: 229-237.

Qian, Y., Boler, H., Moaveni, M., Tutumluer, E., Hashash, Y.M.A. and Ghaboussi, J. 2017. Degradation-related changes in ballast gradation and aggregate particle morphology, *Journal of Geotechnical and Geoenvironmental Engineering,* 143(8): 04017032.

Selig E.T. and Waters J.M. 1994. *Track geotechnology and substructure management*. Thomas Telford, London.