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The Effect of Particle Distribution on Permeability of the Base Coarse Class A

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ABSTRACT: *The objective of this study is to measure the effect of Aggregate Base Coarse class A (BCA) gradation to permeability. In order to achieve this objective, an analysis related to the effect of compaction to gradation changes was conducted. In addition to analyzing the influence of average diameter (D_{50}) to horizontal permeability coefficient (k_h) and analyzing the influence of gradation coefficient (C_c) and uniformity coefficient (C_u) to k_h. The materials used were the BCA from Mount Kayangan and Katunun, South Borneo, and were compacted based on the OMC. Various mixed gradations were referred to the specifications of Bina Marga 2010 3rd Revision. The method employed in this study was laboratory-scale permeability test with horizontal flow direction using fabrication equipment which calibrated by sand samples. Sieve analysis test was conducted after the compaction and permeability testing in order to measure the actual granules after the compaction.*
The result of this study showed that the actual gradation would expand from the specification after the compaction due to the different abrasion values. Therefore, a design for reverse specification was required with expectation that the gradation would shrink into the specification. The equation $y = 0.00018x^2 - 0.02674x + 0.95229$ could be used for reverse gradation curve design. The average diameter (D_{50}) influenced the horizontal permeability coefficient (k_h). From these two materials, the graphics showed that the increase of D_{50} was followed by the gradual increase and decrease of k_h and reached its maximum under condition of optimum D_{50}. Nevertheless, the gradation coefficient (C_c) and uniformity coefficient (C_u) did not significantly influence the horizontal permeability coefficient (k_h). BCA granular gradation affected the drainage quality. According to Holtz & Kovacs (1981) most of the researches showed bad quality of drainage, yet some were considered having good quality of drainage. Granular gradation that were restrained by Sieve No. 40 tended to have the highest permeability coefficient, i.e. 5.52 x 10^{-2}cm/s. During field implementation, with 3% slope of BCA surface on road class 1 with 7m width and 3.5m length of water trajectory, the puddles would disappear in 2.45 days. According to AASHITO (1993) the drainage was categorized as good to moderate quality.

***Keywords**: Aggregate Base Coarse class A (BCA), horizontal permeability, variation of gradation, abrasion.*

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I. INTRODUCTION

Highway network is a land transport infrastructure which play an important part in transportation sector, especially for the continuity of goods and service distribution (Hendarsin, 2000). One type of transportation which is currently developing in Indonesia is land transportation, where the community activities highly depend on its facilities and infrastructures. As the result, there are movements from one place to another and affect the traffic volume. Traffic volume is directly proportional to community activities. The increase of community activities will cause the increase of traffic volume (Aminsyah, 2013). Such condition generates construction works of highway pavement in almost every region. There are two pavement methods commonly used in Indonesia: the flexible pavement and the rigid pavement. According to Razali (2012), one type of pavement frequently used in Indonesia is AC (Asphalt Concrete). This pavement needs base coarse, like mixed aggregate, which located between wearing course and subgrade.

Base Coarse consists of Base Coarse class A (BCA) and Base Coarse class B (BCB). According to Sukirman (2010), BCA was functioned as pavement structure to resist vertical force from vehicle weight and spread it to the underneath layer, that is BC-B or subgrade. Besides, BCA is also functioned as the pad or surface course and as infiltration layer or subsurface drainage ystem. This layer should be stable enough and have CBR ≥ 20%, and plasticity index (I_p) ≤10%.

According to Bina Marga (2010), BCA consists coarse and fine aggregate. Coarse aggregate retrained on sieve No. 4 (4.75 mm) should consist of particles or hard and durable rock fragments which meet the requirements. Meanwhile, fine aggregate is natural sand particles or fine crushed stone and other fine particles retrained from sieve No. 4 and meet the latest requirement from the specifications of Bina Marga 2010 3rd Revision. Bina Marga has specified the lower and upper bounds for the BCA as shown on Figure 1.

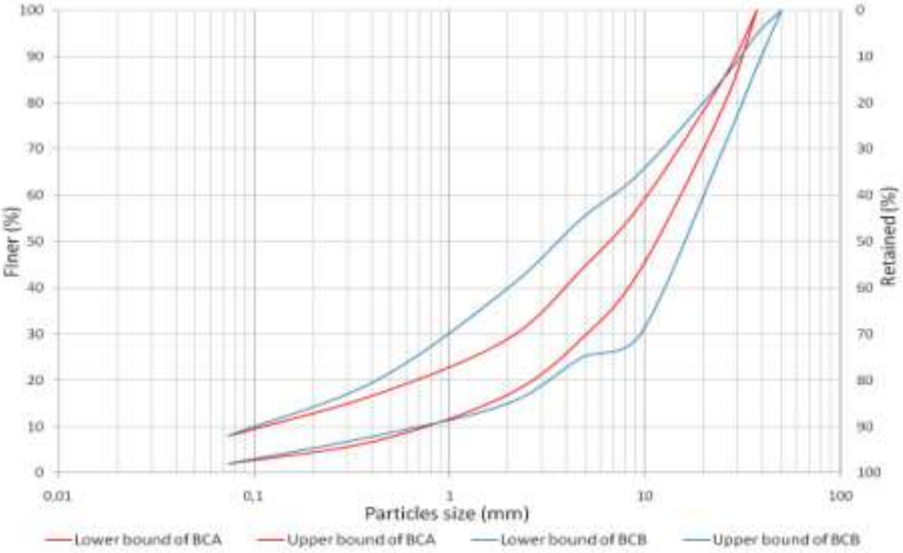


Figure 1. The Lower and Upper Bounds for the BCA and BCB
(Bina Marga, 2010)

Basically, every road pavement would experience progressive damage since it is first opened for public. The damages that commonly happened to asphalt concrete are cracking and/or degranulation (Razali, 2012). If the asphalt is cracked, the rainwater infiltrates and will be trapped inside the base coarse layer. As a result, when vehicles pass the road, a pumping phenomenon occurs and causes a sudden increase in pore water pressure inside the base coarse. This decreases stress among the particles of the base coarse and the underlying soil. The bearing capacity of the soils will drastically decrease and fails to sustain the vehicle burden. This could also affect the surface layer and make the road cracked and damaged. According to Sukirman (2003), aggregate would possibly degrade due to crushed aggregate granules. Such damage caused by mechanical process like forces during pavement (landfilling, spreading, and compacting), maintenance service of traffic loads, and chemical process. As shown on Figure 2.

The seepage of rainwater and its stream through aggregate base coarse to side drainage are highly related to the aggregate permeability. According to Halauddin (2011), the soil permeability coefficient highly depends on the average pore size which is affected by the particle size distribution, viscosity, particle shape and soil structure. The smaller the particles, the smaller the pore size and the lower the soil ability to pass the fluid. The particle size distribution is highly related to the gradation curve. The different gradation curve would give the different uniformity coefficient (C_u) and gradation coefficient (C_c). According to Artika (2016), the greater the C_u, the permeability coefficient will be greater too, and vice versa.

Figure 1. Example of asphalt damage after being passed by vehicles because of wet BCA before pavement.

Based on the aforementioned background, some problems arose, such as how effective the aggregate base coarse in functioning as underneath drainage system seen from various aggregate distribution (Figure 1)? Is there any effect of average granular diameter (D_{50}), gradation coefficient (C_c), and uniformity coefficient (C_u) to aggregate permeability? From these problems, a deeper research is required. In this stage, the focus of this study is the BCA because it directly contacts the surface layer as the impact of seepage of surface water. In the future, it is expected that there will be follow-up study focusing on BCB as the foundation layer which played as drainage system as the impact of underwater raising. Such study is expected to provide input or consideration on field implementation and substantial contribution academically and practically.

II. LITERATURE REVIEW

According to Sukirman (2010), aggregate base coarse have several functions, namely as pavement structure to restrain vertical force from vehicle loads and spread it to sub base coarse. In addition, base-coarse also functioned as drainage system for underneath foundation and pad for surface layer. According to Bina Marga (2010), aggregate base coarse (BCA) consist of the combination between coarse and fine aggregate fraction. The coarse aggregate restrained on sieve 4.75mm should consist of particles or hard and durable rock fragments which meet the requirements. Meanwhile, fine aggregate is natural sand particles or fine crushed stone and other fine particles restrained from sieve 4.75 mm and meet the latest requirement from the specifications of Bina Marga 2010 3rd Revision. BCA functioned as foundation for pavement and as drainage layer to prevent puddles on road base coarse. According to Sukirman (2003), aggregate would possibly degrade due to crushed aggregate granules. Such damage caused by mechanical process like forces during pavement (landfilling, spreading, and compacting), maintenance service of traffic loads, and chemical process like humidity, heat, and temperature changes throughout the day. According to Aminsyah (2013), the basic process of aggregate making is the testing of aggregate strength to collision. Where the aggregate impact value based on BS 812 part 112: 1990 is 30%. According to Melawar et al. (2017) there are several types of gradation, namely uniformly graded, open graded, and gap graded. According to Adithya et al. (2016) aggregate planning might change due to the percentage increase of materials passed the sieve no. 200. It is because the aggregate did not meet the technical specification seen from the abrasion testing, Aggregate Crushing Value (ACV), angularity with cavity test, clay and fragile granules in aggregate and aggregate passed sieve no. 200.

According to Sukirman (2010), the ability of the pavement structure to pass the water is a crucial thing in pavement thickness planning. Water goes into pavement structure through many ways, such as road surface, connection, and pavement infiltration due to capillarity or local spring. The water trapped in road pavement structure could cause the decrease of carrying capacity with bindless materials. Besides, it could also decrease carrying capacity of the subgrade and the raise of soft granules as the effect of pumping to road pavement. Another possible impact is the disconnection of asphalt bond from aggregate and cause the hole. According to AASHTO (1993), the quality of drainage is determined based on its ability to remove water from the pavement structure. The quality referred to this following Table 1.

Table 1. Category of Drainage Quality (AASHTO, 1993)

Drainage Quality	Water disappeared in
Very Good	2 hours
Good	1 day
Moderate	1 week
Bad	1 month
Very bad	Water doesn’t flow

According to Directorate General of Natural Resources (2005), the permeability or hydraulic conductivity is the prominent behavior of materials in doing the analysis and seepage control, which obtained from permeability testing in laboratory (k) with air-free water on 20^{o}C and saturated laminar flow conditions. Permeability is divided into two types: primary and secondary permeability. Primary permeability is related to the stream through material grain structures. It could also be defined as the water flow capacity through soil grain structure. Meanwhile, secondary permeability is related to the stream through fracture or other materials cavity. Head (1981), Bowles (1991) and Das (1995) stated that the water flow underground is highly influenced by the soil characteristics: type of soil, size and grain shape, mineral composition, void ratio, saturation level, and streams type, could be seen on Figure 3. According to Wilkinson and Shipley, based on the stream direction, there are two permeability, i.e. vertical permeability (k_v) and horizontal permeability (k_h). Some natural soil types have greater k_h rather than k_v. It was proved by Kenney (1964), Raymond and Azzouz (1969), Norman (1964), and Wit (1967).

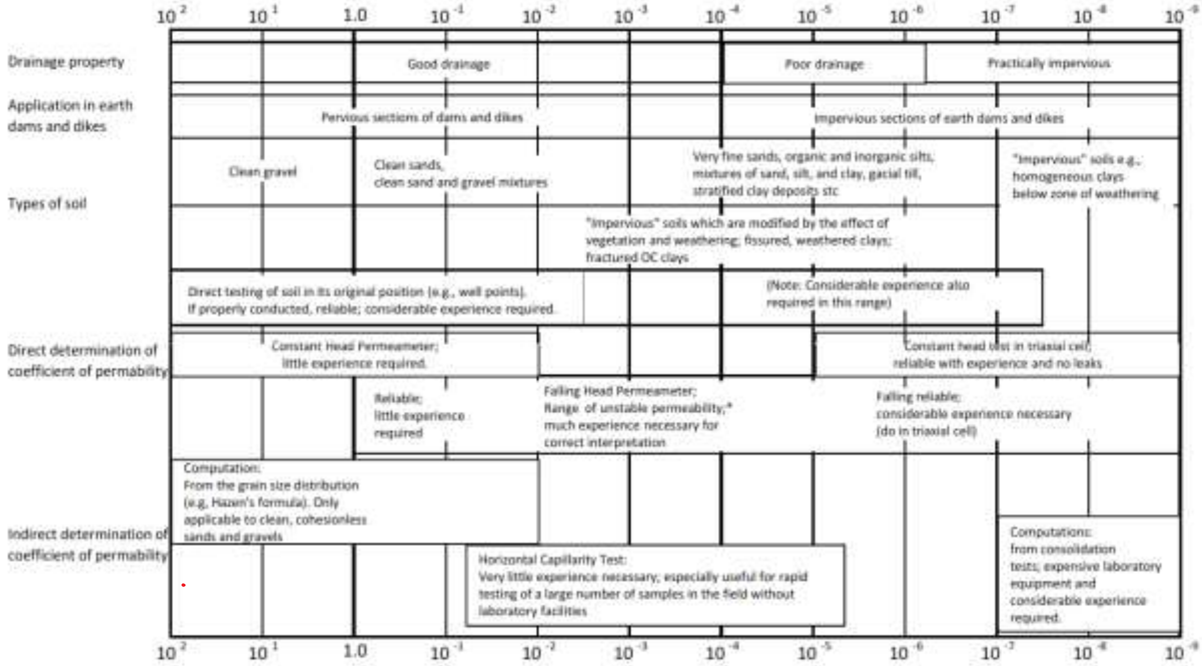


Figure 2. Permeability, drainage, soil type, and method used to determine soil permeability (Holtz & Kovacs, 1981)

RESEARCH METHOD

This research was conducted in several steps, started off the topic determination and preparation. In preparation steps, some literatures reviewing has been conducted with appropriate references. The next step is field stage which consisted of determining location and the specimen taking. In this study, the location were Mt Kayangan and Katunun, Tanah Laut, South Kalimantan. After the field stage completed, the next step is laboratory stage. This stage comprised of equipment inventory and calibration, and equipment fabrication of horizontal permeability testing. Due to the unavailability of BCA horizontal permeability testing, the equipment of fabrication was first preceded by equipment design stage. The design could be seen on Figure 4. After the fabrication, the next step is initial testing to calibration. The calibration was using sand samples, in this case two types of sand which classified as SW and SP. After making sure the availability and calibration, the next step is checking the specimen requirement. It consisted of aggregate grain analysis test, not all checking were tested because the main focus of this study is the k_h. The checking comprised of abrasion checking from coarse aggregate, liquid limit, plasticity index with passing percentage of sieve no. 200, result of multiplication of plasticity index and percentage of sieve no. 200, and the comparison of passing percentage of sieve no.200 and no.40. After checking, the next step is determining whether the specimen meet the requirement from the specifications of Bina Marga 2010 3rd revision. If the specimen did not meet the requirement, the specimen would be substituted and there would be re-checking to the new specimen. If it has met the requirement, the next step is determining the composition of mixed aggregate based on the requirement of mixed gradation in the specifications of Bina Marga 2010 3rd revision. The design could be seen on Table 2 and the curve design could be seen on Figure 5.

After determining the mixed design, the next step is Horizontal permeability testing. From this testing, the horizontal permeability coefficient (k_h) was derived, which then evaluated to measure the drainage quality. If the quality is moderate to very bad, redesigning of mixed aggregate composition is needed, and then the same steps as previously mentioned would be re-conducted. After the Horizontal permeability testing, sieve analysis testing was conducted to measure the gradation after compaction. If the quality of drainage is good to very good, the next step was analyzing the correlation with horizontal permeability. The analysis comprised of: analysis of compaction effect to BCA gradation change, analysis of average diameter (D_{50}) effect to BCA horizontal permeability coefficient (k_h), analysis of gradation coefficient effect (C_c) to BCA k_h, analysis of uniformity coefficient (C_u) to BCA k_h. After the analysis, the next step was drawing conclusion, suggestion, and recommendation.

Figure 3. Fabrication equipment of Horizontal permeability. Left: Constant Head. Right: Falling head

Table 2. Mixed BCA design

Sieve passing (%) No Sieve	Specification Max	Min	BCA sample code 1	2	3	4	5	6	7	8	9	10
1½”	100	100	100	100	100	100	100	100	100	100	100	100
1”	85	79	79	79	79	79	79	79	79	85	79	85
$^{3}/_{8}$”	58	44	47	44	47	47	44	47	47	57	47	44
No.4	44	29	44	30	44	44	30	44	44	29	29	34
No.10	29	17	25	28	18	18	28	19	0	0	0	19
No.40	17	7	8	8	8	7	8	15	0	0	0	16
No.200	8	2	2	2	2	0	0	0	0	0	0	2

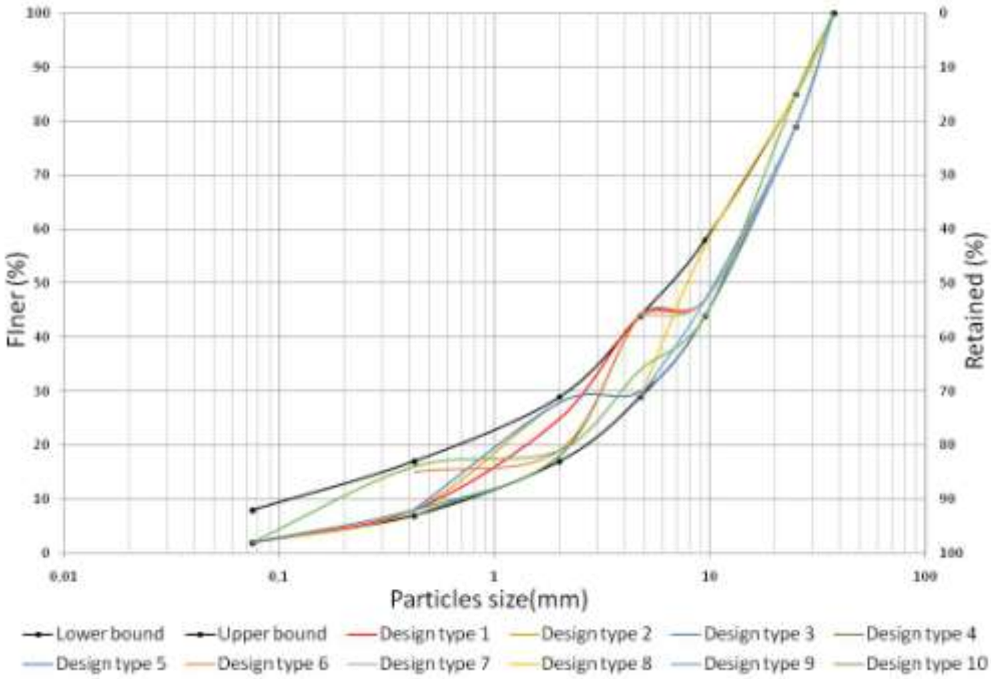


Figure 4. BCA gradation curve design

III. RESULTS AND DISCUSSION

Samples

The BCA sample used in this study should have met the technical requirement based on the specifications of Bina Marga (2010). The results were presented in Table 3 to Table 6. Table 3 presented the result of abrasion testing from BCA aggregate – Mt. Kayangan and Katunun, i.e. 38.65% and 22.20% respectively. Thus, these two materials have fulfiled the requirement of maximum abrasion that is 40%. Table 4 presented the fluid limit testing result which ranged from 0 – 25%. Table 5 presented the plasticity index of BCA – Mt. Kayangan which ranged from 0 – 13.94%. From 10 gradation types, six of them did not fulfilled the specification requirement 0 – 6%. Table 6 presented the multiplication of plasticity index and passing percentage from sieve no. 200 of BCA – Mt. Kayangan ranged from 0 – 27. 87%. The overall have fulfilled the requirement, except two gradation types which did not fulfilled the maximum specification requirement 25%. Table 7 showed the comparison of passing percentage of sieve no 200 and no 40 BCA – Mt. Kayangan, ranged from 0 – 1/8, the overall has fulfilled the requirement, that is 2/3.

Table 3. Result of abrasion testing BCA aggregate – Mt. Kayangan and Katunun (SNI 2417:2008)

Sample	Weight (gr) Sieve ½"	$^3/_8$"	Total	Retained No. 12	Abrasion (%)	Specs (%)	Annotation
Mt. Kayangan	2.500	2.500	5.000	3067,64	38,65	40	Fulfilled
Katunun	2.500	2.500	5.000	3.890	22,20	40	Fulfilled

Table 4. Liquid limit testing result BCA-Mt.Kayangan (SNI 1967:2008)

Sample	Liquid limit (%)	Specs of Bina Marga (2010) %	Annotation
BCA-1 Mt. Kayangan	21,00	0 – 25	Fulfilled
BCA -2 Mt Kaya.ngan	21,00	0 – 25	Fulfilled
BCA -3 Mt. Kayangan	21,00	0 – 25	Fulfilled
BCA -4 Mt. Kayangan	21,00	0 – 25	Fulfilled
BCA -5 Mt. Kayangan	21,00	0 – 25	Fulfilled
BCA -6 Mt. Kayangan	21,00	0 – 25	Fulfilled
BCA -7 Mt. Kayangan	0	0 – 25	Fulfilled
BCA -8 Mt. Kayangan	0	0 – 25	Fulfilled
BCA -9 Mt. Kayangan	0	0 – 25	Fulfilled
BCA -10 Mt. Kayangan	21,00	0 – 25	Fulfilled

Table 5. Plasticity Index BCA-Mt.Kayangan (SNI 1966:2008)

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Specs (%)	Annotaton
BCA-1 Mt. Kayangan	21,00	12,83	8,17	0 – 6	Not fulfilled
BCA -2 Mt. Kayangan	21,00	7,89	13,11	0 – 6	Not fulfilled
BCA -3 Mt. Kayangan	21,00	16,82	4,18	0 – 6	Fulfilled
BCA -4 Mt. Kayangan	21,00	9,56	11,44	0 – 6	Not fulfilled
BCA -5 Mt. Kayangan	21,00	13,10	7,90	0 – 6	Not fulfilled
BCA -6 Mt. Kayangan	21,00	10,31	10,69	0 – 6	Not fulfilled
BCA -7 Mt. Kayangan	0	0	0	0 – 6	Fulfilled
BCA -8 Mt. Kayangan	0	0	0	0 – 6	Fulfilled
BCA -9 Mt. Kayangan	0	0	0	0 – 6	Fulfilled
BCA -10 Mt. Kayangan	21,00	7,06	13,94	0 – 6	Not fulfilled

Table 6. Multiplication of plasticity index and passing percentage sieve no. 200 BCA–Mt. Kayangan

Sample	Plasticity Index (%)	% Passed No 200	Multiplication of PI % and Passed No. 200	Specs %	Annotation
BCA-1 Mt. Kayangan	8,17	2	16,35	Max. 25	Fulfilled
BCA -2 Mt. Kayangan	13,11	2	26,23	Max. 25	Not fulfilled
BCA -3 Mt. Kayangan	4,18	2	8,36	Max. 25	Fulfilled
BCA -4 Mt. Kayangan	11,44	0	0,0	Max. 25	Fulfilled
BCA -5 Mt. Kayangan	7,90	0	0,0	Max. 25	Fulfilled
BCA -6 Mt. Kayangan	10,69	0	0,0	Max. 25	Fulfilled
BCA -7 Mt. Kayangan	0	0	0,0	Max. 25	Fulfilled
BCA -8 Mt. Kayangan	0	0	0,0	Max. 25	Fulfilled
BCA -9 Mt. Kayangan	0	0	0,0	Max. 25	Fulfilled
BCA -10 Mt. Kayangan	13,94	2	27,87	Max. 25	Not fulfilled

Tabel 7. Comparison of passing percentage of sieve no 200 and no 40 BCA – Mt. Kayangan

Sample	% Passed No. 200	% Passed No. 40	Comparison % passing No. 200 & No.40	Specs Bina Marga	Annotation
BCA-1 Mt. Kayangan	2	8	1/4	Max. 2/3	Fulfilled
BCA -2 Mt. Kayangan	2	8	1/4	Max. 2/3	Fulfilled
BCA -3 Mt. Kayangan	2	8	1/4	Max. 2/3	Fulfilled
BCA -4 Mt. Kayangan	0	7	0	Max. 2/3	Fulfilled
BCA -5 Mt. Kayangan	0	8	0	Max. 2/3	Fulfilled
BCA -6 Mt. Kayangan	0	15	0	Max. 2/3	Fulfilled
BCA -7 Mt. Kayangan	0	0	0	Max. 2/3	Fulfilled
BCA -8 Mt. Kayangan	0	0	0	Max. 2/3	Fulfilled
BCA -9 Mt. Kayangan	0	0	0	Max. 2/3	Fulfilled
BCA -10 Mt. Kayangan	2	16	1/8	Max. 2/3	Fulfilled

Horizontal Permeability Testing

Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and Horizontal permeability coefficient from the testing could be seen on Table 8 and Table 9. Table 8 showed that the variation of MDD of Mt. Kayangan ranged from 2.16 to 2.28 gram/cm^3, the OMC ranged from 4.11 to 5.63%, and the horizontal permeability coefficient ranged from 1.6 x 10^{-6} to 6.8 x 10^{-4} cm/s. Table 9 showed that the variation of MDD of Mt. Katunun ranged from 1.91 to 2.11 gram/cm^3, the OMC ranged from 2.71 to 6.08%, and the horizontal permeability coefficient ranged from 5.4 x 10^{-5} to 5.5 x 10^{-2} cm/s. The BCA gradation curve of horizontal permeability testing resulted D_{10}, D_{30}, D_{60}, C_u, C_c. These could be seen on Table 10 for BCA – Mt. Kayangan and Table 11 for BCA – Mt. Katunun.

Table 8. Result of MDD, OMC and Horizontal Permeability Coefficient BCA-Mt. Kayangan.

Sample	MDD (γ_{RDax})	OMC (%)	Horizontal Permeability k_h (cm/s)
BCA-1 Mt. Kayangan	2,23	4,33	1,6 x 10^{-6}
BCA -2 Mt. Kayangan	2,20	4,80	1,5 x 10^{-5}
BCA -3 Mt. Kayangan	2,28	4,56	2,4 x 10^{-5}
BCA -4 Mt. Kayangan	2,25	4,65	4,0 x 10^{-5}
BCA -5 Mt. Kayangan	2,25	5,63	2,4 x 10^{-5}
BCA -6 Mt. Kayangan	2,19	4,22	8,1 x 10^{-6}
BCA -7 Mt. Kayangan	2,16	5,48	6,7 x 10^{-4}
BCA -8 Mt. Kayangan	2,18	4,11	6,8 x 10^{-4}
BCA -9 Mt. Kayangan	2,22	4,70	6,0 x 10^{-4}
BCA -10 Mt. Kayangan	2,24	5,14	2,5 x 10^{-5}

Table 9. Result of MDD, OMC and Horizontal Permeability Coefficient BCA-Mt. Katunun

Sample	MDD (γ_{RDax})	OMC (%)	Horizontal Permeability k_h (cm/s)
BCA-6 Katunun	2,11	6,08	5,4 x 10^{-5}
BCA-7 Katunun	1,94	5,98	6,6 x 10^{-3}
BCA-8 Katunun	1,91	5,24	6,3 x 10^{-3}
BCA-8 Katunun RD	2,02	2,71	5,5 x 10^{-2}
BCA-9 Katunun	1,97	4,58	4,5 x 10^{-3}
BCA-10 Katunun	2,00	5,70	1,7 x 10^{-4}

Tabel 10. Result of D_{10}, D_{30}, D_{50}, D_{60}, C_u, dan C_c BCA-Mt. Kayangan

Sampel	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
BCA-1 Mt. Kayangan	0,55	2,60	10,80	15,00	5,77	0,82
BCA -2 Mt. Kayangan	0,53	4,70	11,30	15,00	3,19	2,78
BCA -3 Mt. Kayangan	0,70	3,10	10,80	14,90	4,81	0,92
BCA -4 Mt. Kayangan	0,79	3,13	10,80	15,00	4,79	0,83
BCA -5 Mt. Kayangan	0,51	4,80	11,30	15,00	3,13	3,01
BCA -6 Mt. Kayangan	0	0,32	2,44	3,90	12,19	n/a
BCA -7 Mt. Kayangan	0	0,86	2,76	4,00	4,65	n/a
BCA -8 Mt. Kayangan	0	0,92	2,70	3,85	4,18	n/a
BCA -9 Mt. Kayangan	0	1,07	2,85	3,95	3,69	n/a
BCA -10 Mt. Kayangan	0	0,44	2,60	4,30	9,77	n/a

Table 11. Result of D_{10}, D_{30}, D_{50}, D_{60}, C_u, dan C_c BCA-Mt. Katunun

Sampel	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
BCA-6 Katunun	0,22	2,15	4,30	9,10	4,23	2,31
BCA-7 Katunun	0,73	2,85	4,79	9,50	3,33	1,17
BCA-8 Katunun	0,75	2,97	5,00	6,90	2,32	1,70
BCA-8 Katunun RD	2,00	5,00	8,50	11,80	2,36	1,06
BCA-9 Katunun	0,70	3,00	5,50	9,50	3,17	1,35
BCA-10 Katunun	0,20	2,60	6,50	10,00	3,85	3,38

The Effect of Compaction to Aggregate Curve Design

The compaction conducted to sample caused the aggregate to break into smaller particles. It can be proved by conducting sieve analysis testing after the compaction process. Meanwhile, the change of grains size could be seen from the change of shape and gradation curve position of both BCA for each type. In this study, the sieve analysis testing was conducted after the compaction of BCA sample – Mt. Kayangan and BCA sample of Mt. Katunun only conducted on gradation type 6 to 10. The design of curve gradation indicated by red line. The curve of gradation change after the compaction for BCA sample – Mt. Kayangan indicated by blue line. The curve of gradation change after compaction for BCA sample – Mt. Katunun indicated by yellow line. If they were seen based on the shift of curve position, these two materials on mixed type were actually located outside the upper limit of the provided specification. Such condition caused the actual gradation not accordance with the gradation design. BCA sample – Mt. Kayangan tended to stray away, shifted to the left side compared to BCA sample – Mt. Katunun. Thus indicated that BCA sample – Mt. Kayangan more worn out. The appropriate parameter to describe aggregate abrasion is aggregate abrasion value. It could be seen there was an effect of aggregate abrasion to grain size (due to the compaction). The gradation before and after the compaction could be seen on Figure 6 to Figure 8.

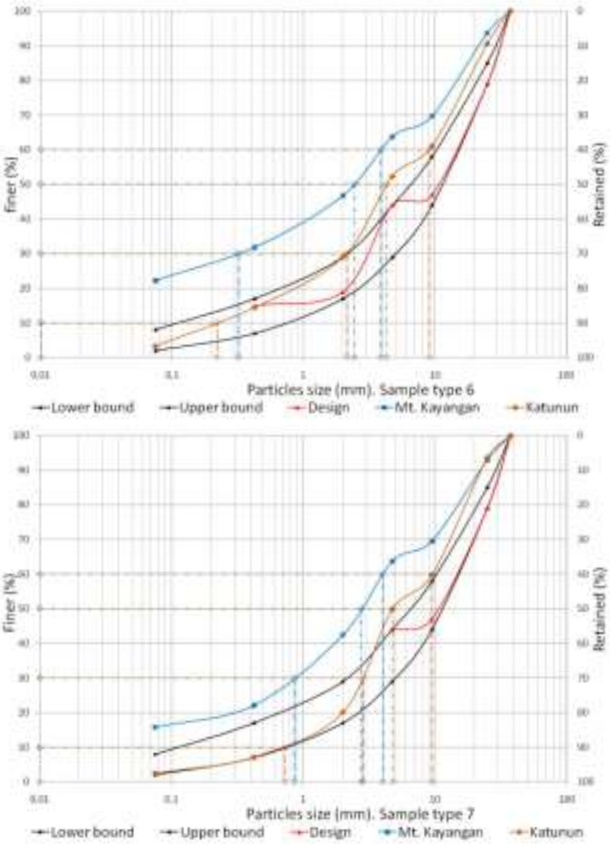


Figure 5. Gradation Before and After Compaction Left: Gradation type 6, Right: Gradation type 7

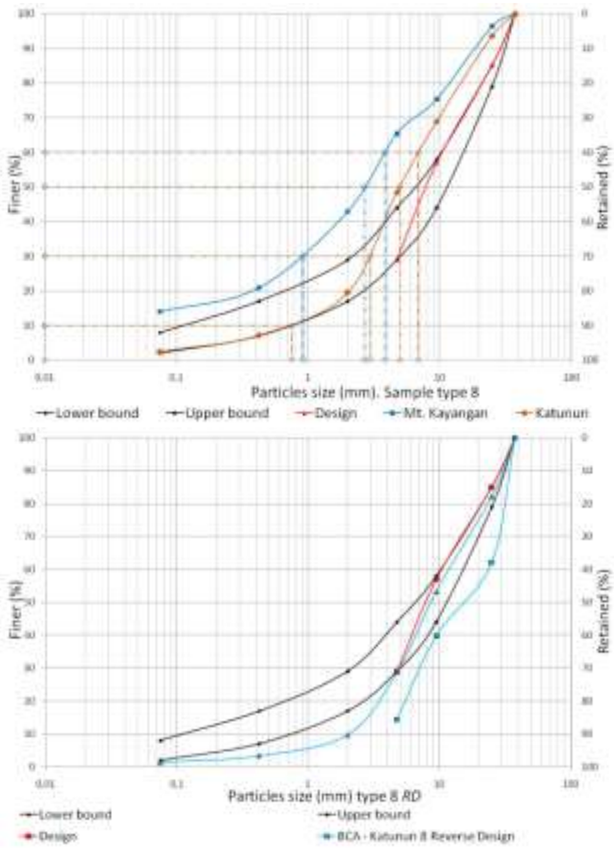
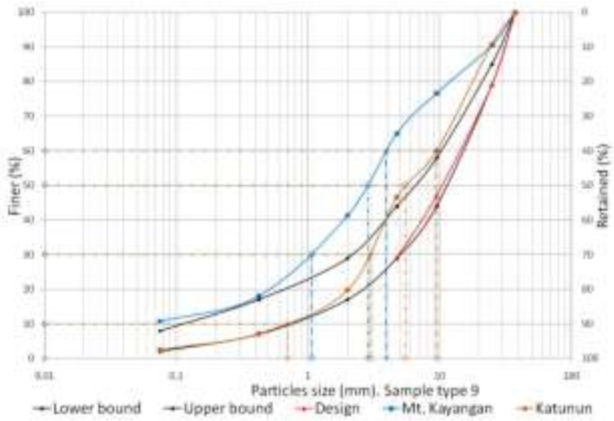


Figure 6. Gradation Before and After Compaction Left: Gradation type 8, Right: Gradation type 8 RD

Based on the data presented on Figure 6 to Figure 8, a recapitulation drawn to see the correlation between gradation design and actual gradation after compaction. The samples were decreased by selecting from these two sources with indicator of k_h value. The material source which had greater k_h tended to have follow-up analysis and testing. Table 7 and 8 showed the material tendency of Katunun had greater k_h compared to Mt. Kayangan. Thus, it generated follow-up analysis using materials from Mt. Katunun. It resulted similar correlation if seen from the comparison of restrained percentage between design gradation and actual gradation after the compaction. The ratio of recapitulation between restrained percentage of design gradation and actual gradation could be seen on Table 12.



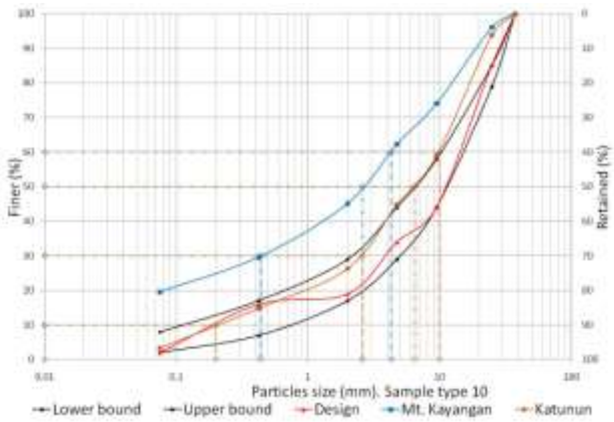
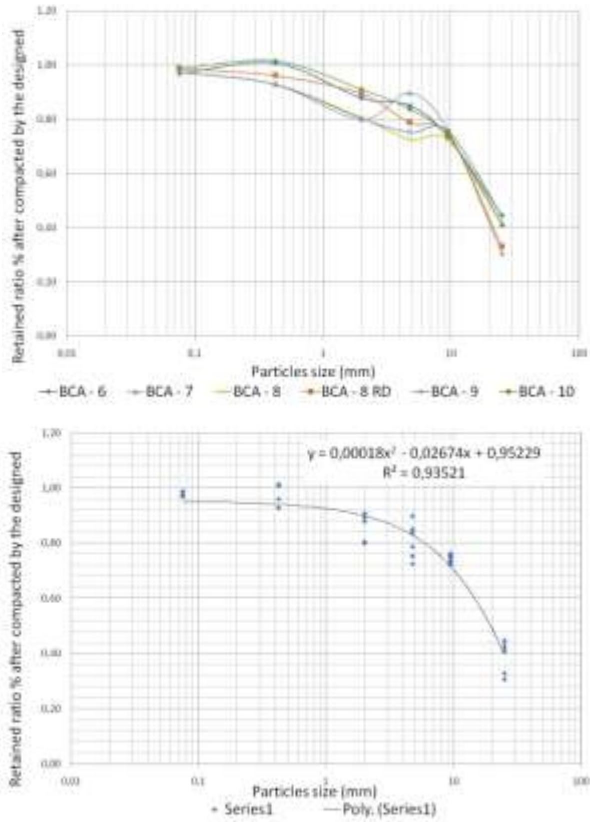


Figure 7. Gradation Before and After Compaction Left: Gradation type 9, Right: Gradation type 10

Table 12. Recapitulation of restrained percentage ratio of design gradation and actual gradation

Sieve No.	Opening (mm)	Ratio (actual/design) BCA-6	BCA-7	BCA-8	BCA-8	BCA-9	BCA-10
1½”	37,5	0	0	0	0	0	0
1”	25	0,45	0,31	0,43	0,33	0,44	0,41
3/8”	9,5	0,73	0,76	0,72	0,75	0,76	0,73
No. 4	4,75	0,85	0,90	0,73	0,79	0,75	0,84
No. 10	2	0,88	0,80	0,80	0,89	0,80	0,91
No. 40	0,425	1,01	0,93	0,93	0,96	0,93	1,01
No. 200	0,075	0,97	0,98	0,98	0,99	0,97	0,99
pan	-	1,00	1,00	1,00	1,00	1,00	1,00

If the ratio was described in a graphic, the curve would be similar to the description on Figure 9. Then, data approach was conducted by using polinominal graphic to produce line equation (Equation 1).



(a) (b)

Figure 8. (a) Correlation between particles diameter and retrained percentage ratio, (b): Polinomial line equation particles diameter and retrained percentage ratio

$$y = 0{,}00018\,x^2 - 0{,}02674\,x + 0{,}95229 \quad (1)$$

Where:

x = Grains diameter or sieve Opening (mm)

The line equation then used to plan the passing percentage which has been reduced or shifted backwards before the testing. Therefore after the compaction, the gradation curve shape would shift into the specification. The passing percentage plan which has been reduced or pushed backward called as reverse design (RD). The passing percentage of reverse design then could be downgraded to restrained percentage, thus the required weight for each sieve during mixing could be obtained. One mixing was selected as having the highest k_h on Katunun materials, i.e. BCA Katunun 8 (Table 13). From this reverse design, compaction testing was conducted in laboratory, followed by horizontal permeability testing and sieve analysis testing which resulted curve on Figure 5 right. From this figure, it could be seen the result realization of reverse design was almost similar t expected design that is located in specification. Nevertheless, the smaller grain from sieve no. 4 still located outside the specs.

Table 13. Reverse Design (RD) Calculation BCA-Katunun 8 RD

Sieve No.	Opening (mm)	Ratio a	Passing design (%) b	Restrained design (%) c = 100 - b	Restrained Reverse Design (%) d = c/a	Passing reverse design (%) e = 100 - d
1½”	37,5	0,20	100	0	0	100
1”	25	0,40	85	15	37,85	62,15
3/8”	9,5	0,71	57	43	60,18	39,82
No. 4	4,75	0,83	29	71	85,61	14,39
No. 10	2	0,90	0	100	100	0
No. 40	0,425	0,94	0	100	100	0
No. 200	0,075	0,95	0	100	100	0
pan	-					

The Influence of average diameter (D_{50}) to horizontal permeability coefficient (k_h)

The average of grains diameter (D_{50}) of BCA sample – Mt. Kayangan ranged from 2.44 mm to 2.85 mm (Table 14). The (D_{50}) of BCA sample – Katunun ranged from 4.30 mm to 8.50 mm (Table 15). The D_{50} scores were arranged from the lowest to the highest, the correlation between these two parameters could be seen on Figure 10. From these two correlation graphic on Figure 10, it could be seen that the increase of D_{50} was followed by the gradual increase and decrease of k_h and reached its maximum under condition of optimum D_{50}.

Table 14. Recapitulation of D_{50} vs k_h BCA – Mt. Kayangan

Sample	D_{50} (mm)	Horizontal Permeability k_h (cm/s)
BCA-6 Mt. Kayangan	2,44	$8{,}1 \times 10^{-6}$
BCA-7 Mt. Kayangan	2,76	$6{,}7 \times 10^{-4}$
BCA-8 Mt. Kayangan	2,70	$6{,}8 \times 10^{-4}$
BCA-9 Mt. Kayangan	2,85	$6{,}0 \times 10^{-4}$
BCA-10 Mt. Kayangan	2,60	$2{,}5 \times 10^{-5}$

Table 15. Recapitulation of D_{50} vs k_h BCA – Mt. Katunun

Sample	D_{50} (mm)	Horizontal Permeability k_h (cm/s)
BCA-6 Mt. Katunun	4,30	$5{,}4 \times 10^{-5}$
BCA-7 Mt. Katunun	4,79	$6{,}6 \times 10^{-3}$
BCA-8 Mt. Katunun	5,00	$6{,}3 \times 10^{-3}$
BCA-8 Mt. Katunun RD	8,50	$5{,}5 \times 10^{-2}$
BCA-9 Mt. Katunun	5,50	$4{,}5 \times 10^{-3}$
BCA-10 Mt. Katunun	6,50	$1{,}7 \times 10^{-4}$

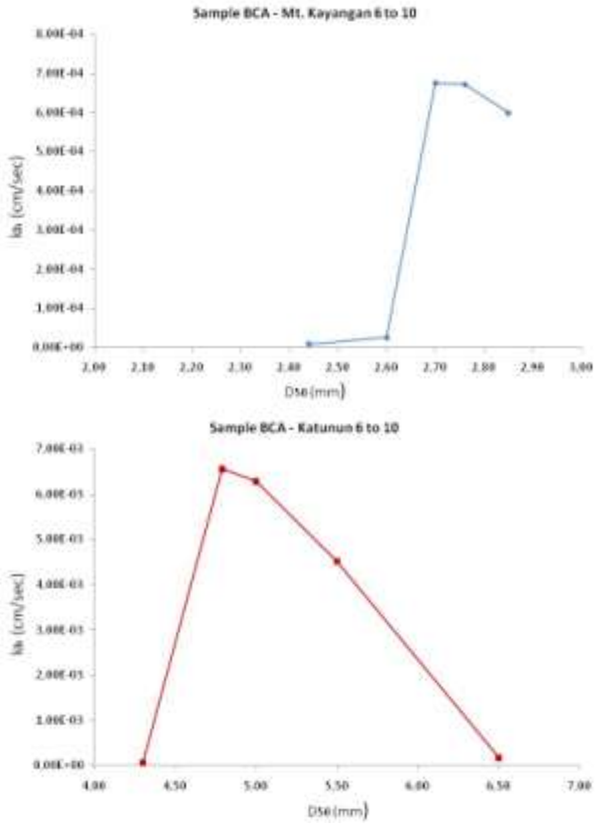


Figure 9. Correlation Graphic of D_{50} vs k_h. Left: BCA – Mt. Kayangan 6 to 10. Right: BCA – Katunun 6 to 10

The influence of Uniformity Coefficient (C_u) and gradation coefficient (C_c) to horizontal permeability coefficient (k_h)

According Bowless (1984), if the passing percentage from sieve no. 200 less than 12%, the C_c and C_u is required to determine whether the gradation is good or bad. Meanwhile, if it is more than 12%, the C_c and C_u is no longer required. The correlation graphic between C_u to permeability could be seen on Figure 11. The recapitulation of C_u and C_c to k_h on each material could be seen on Table 16 and Table 17.

Table 16. Recapitulation of C_u, C_c dan k_h sample BCA – Mt. Kayangan

Sampel	C_u	C_c	Horizontal Permeability k_h (cm/s)
BCA-6 Mt. Kayangan	12,19	n/a	$8,1 \times 10^{-6}$
BCA-7 Mt. Kayangan	4,65	n/a	$6,7 \times 10^{-4}$
BCA-8 Mt. Kayangan	4,18	n/a	$6,8 \times 10^{-4}$
BCA-9 Mt. Kayangan	3,69	n/a	$6,0 \times 10^{-4}$
BCA-10 Mt. Kayangan	9,77	n/a	$2,5 \times 10^{-5}$

Tabel 17. Recapitulation of C_u, C_c dan k_h sample BCA – Mt Katunun

Sampel	C_u	C_c	k_h (cm/s)
BCA-6 Mt. Katunun	4,23	2,31	$5,4 \times 10^{-5}$
BCA-7 Mt. Katunun	3,33	1,17	$6,6 \times 10^{-3}$
BCA-8 Mt. Katunun	2,32	1,70	$6,3 \times 10^{-3}$
BCA-9 Mt. Katunun	3,17	1,35	$4,5 \times 10^{-3}$
BCA-10 Mt. Katunun	3,85	3,38	$1,7 \times 10^{-4}$

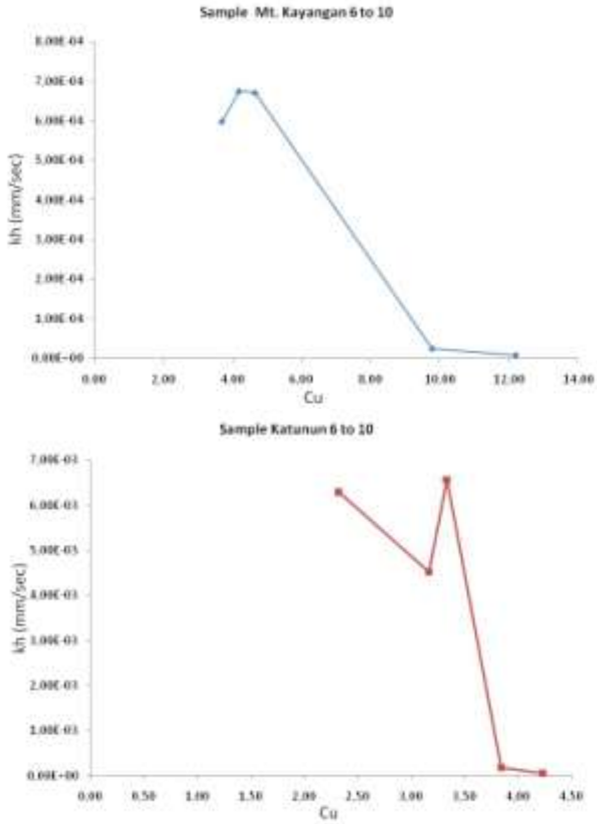


Figure 10. Correlation Graphic k_h vs C_u. Left: Mt – Kayangan. Right: Mt. Katunun

The influence of BCA grain gradation variation to drainage quality

From several mixed variation presented on Table 2, it was resulted different permeability coefficients. Based on the sub discussion about the effect of compaction to gradation curve design, the grain gradation used to determine the correlation of drainage quality is the gradation after compaction. From 17 different testing, it was resulted that the different grains distribution influence the k_h value. The highest k_h was resulted by gradation type 8 RD, i.e. 5.52 x 10^{-2} cm/s. The gradation curve and k_h graphic could be seen on Figure 12 and Figure 13. The recapitulation of testing result could be seen on Table 7 and Table 8. The highest k_h was when it was modelled in a calculation to obtain the length of streaming time on cross-section on road class 1 with 7m width as presented on Figure 14. The road consisted of abrasion layer with 3% slope, BCA with 3% surface slope, resulted that water would disappeared in 2.45 days. Based on Table 1, the drainage is categorized as good to moderate quality because the water disappeared in less than a week but more than a day.

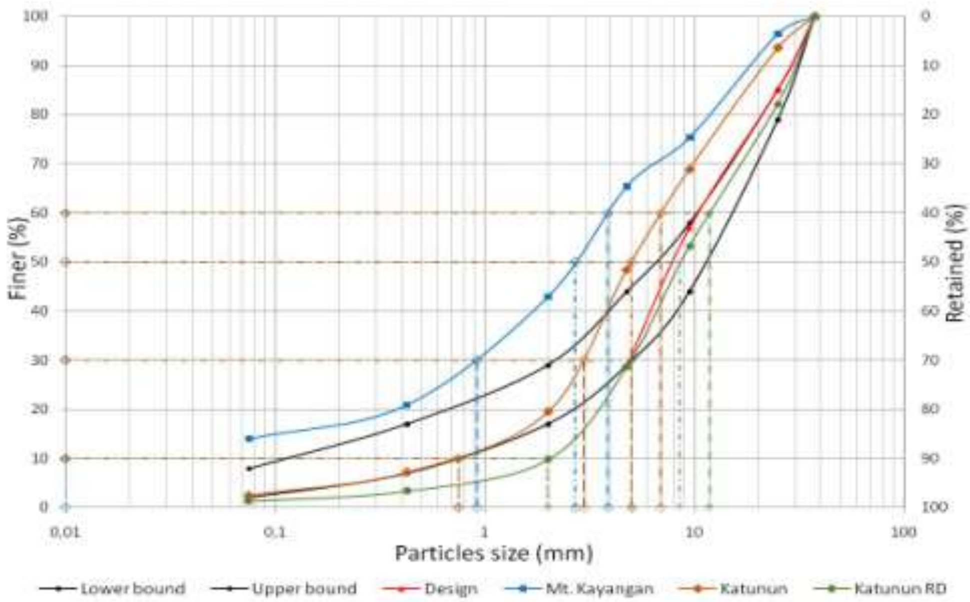


Figure 11. Design gradation and gradation after sample testingBCA – Mt. Katunun 8, BCA – 8 Mt. Katunun RD dan BCA – 8 Mt. Kayangan

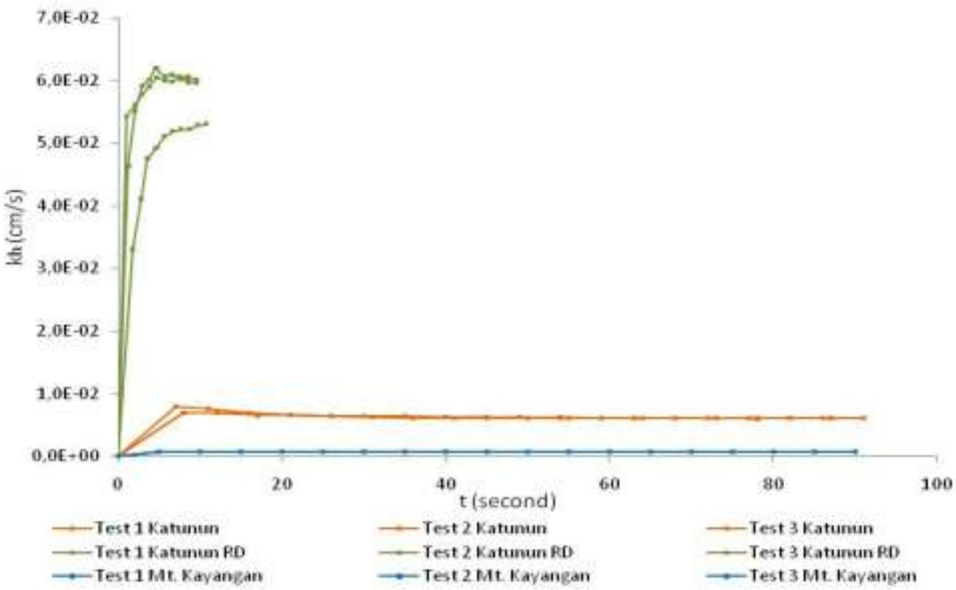


Figure 12. Horizontal permeability of sample BCA – 8 Mt. Katunun, BCA – 8 Mt. Katunun RD and BCA – 8 Mt. Kayangan

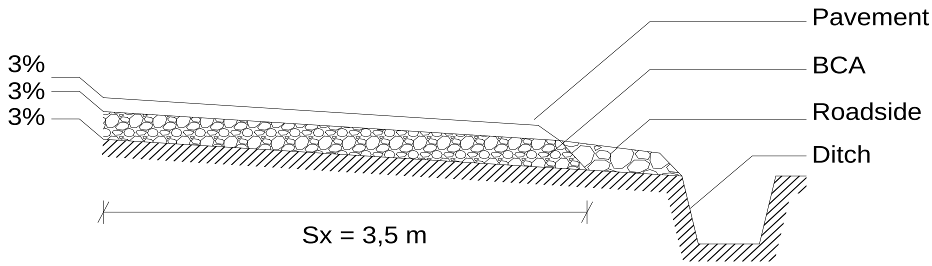


Figure 13. Cross section of Road Class 1 with 3% subgrade slope

IV. CONCLUSION

From the study through 10 various of mixed BCA, some conclusions were drawn as follows:

1. There was an effect of compaction to grains size which affected the shape change of gradation curve design. Such effect was indicated by the cracking of bigger grains to smaller grains and made the actual gradation no longer similar to the gradation design.
2. There was different behavior on the two different materials with similar gradation design and affected the stone abrasion to shape changes of gradation curve.
3. After the addition of stone ash, sand, and gravel on BCA due to the compaction as an effect of pulverization, which made the pores filled with fine grains.
4. Actual gradation could be predicted by applying reversed designed gradation using the equation $y=0.00018x^2 - 0.02674x + 0.95229$. However, this equation could only be tested on materials from Mt. Katunun with abrasion value of 22.2%.
5. The abrasion value affected the k_h value. The smaller abrasion value resulted the relatively greater k_h value.
6. There was average diameter (D_{50}) effect to k_h. Rom these two materials, the graphic showed that the increase of D_{50} was followed by the gradual increase and decrease of k_h and reached its maximum under condition of optimum D_{50}.
7. The C_c and C_u did not significantly affect the k_h.
8. The grain gradation of BCA affected the drainage quality. Most of them had bad drainage, yet some samples have good drainage. The restrained grain gradation on sieve no. 40 tended to have higher permeability.
9. In field case, a road of class 1 with 7m with and streaming water flow 3.5m with 3% slope. Material Katunun type 8 RD gradation design had abrasion of 22.20% and k_h = 5.52 x 10^{-2} cm/s, resulted that the water would disappeared in 2.45 days. According to ASSHTO (1993), it was categorized as drainage with good to moderate quality.

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