AN EXAMINATION OF AAR MITIGATION MEASURES USING FLY ASH

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Abstract

In the neighborhood of Niigata Station in the center of Niigata-City, construction is underway to construct new railroad continuous viaducts. However, in the neighborhood of Niigata Station, it is difficult to obtain aggregates that are non-reactive. Thus, we decided to build these viaducts using highly reactive Highly-reactive aggregates by providing appropriate Alkali-Aggregate Reaction (AAR) mitigation measures. We considered whether we controlled AAR using fly ash. At first we identified a highly-reactive aggregate among available aggregates near Niigata Station. We changed the mixed ratio of the highly-reactive aggregates and made concrete in which we substituted 10%, 20%, 30%, 40% of cement with fly ash and evaluated the AAR characteristics. As a result, we were able to control expansion when 40% of the highly-reactive aggregates were used, by substituting fly ash for at least 20% of the cement. In addition, we examined the strength properties and construction characteristics of the concrete of this combination and confirmed that it was combination suitable for use. Therefore, using concrete of this mix design, the new railroad viaducts were constructed.

Keywords: fly ash, AAR mitigation measures, Highly-reactive aggregates, coefficient of expansion, railroad viaducts

1 BACKGROUND

The Niigata station is located in the city area of Niigata prefecture and base station on the Sea of Japan coast. At the Niigata station, we planned a construction project of new railroad viaducts for the purpose of unification of the city area and removal of the railroad crossings. These new railroad viaducts are to be constructed using a volume of about 140,000 m^3 of concrete. This is therefore a very large construction project.

The challenge in the Niigata area, however, is to find aggregates of suitably low reactivity levels. But there are many damaged structures of railroad viaduct because of AAR in this region. It was decided to use fly ash in concrete as an AAR mitigation measure; thus, currently new railroad viaducts are being constructed using fly ash. In this paper, an outline of the examination of fly ash as AAR measure is shown.

2 MATERIALS AND METHODS OUTLINE OF THIS CONSTRUCTION PROJECT "NIIGATA CONTINUOUS RAILROAD VIADUCTS"

The Niigata station is the terminal station of JOETSU-SHINKANSEN and 5 conventional railway lines. The average daily number of passengers of Niigata station in 2012 was about 37,000 persons. This number is the greatest number of passengers of all stations located in the mainland of Japan and coastal Japan.

This construction project is promoted by Niigata city and the JR-East company to relocate about 2.5 kms of conventional lines near the Niigata station to a higher position, above the current tracks, with continuous railroad viaducts (Figure 1). In this construction project, we remove two railroad crossings road for the purpose of safety of trains and cars and tie-ins between south and north side sides of the railroads. Through this construction project, the Niigata stations changed 4 platforms and 7 railroads to 3 platforms and 5 lines. The reduced facility of 1 platform and 2 lines added to the next station (HAKUSAN) and a platform of the conventional lines becomes same platform of the SHINKANSEN station for ease of changing trains (Figure 2). New structures are viaducts and PC-girders and made with about 140,000 m^3 of concrete.

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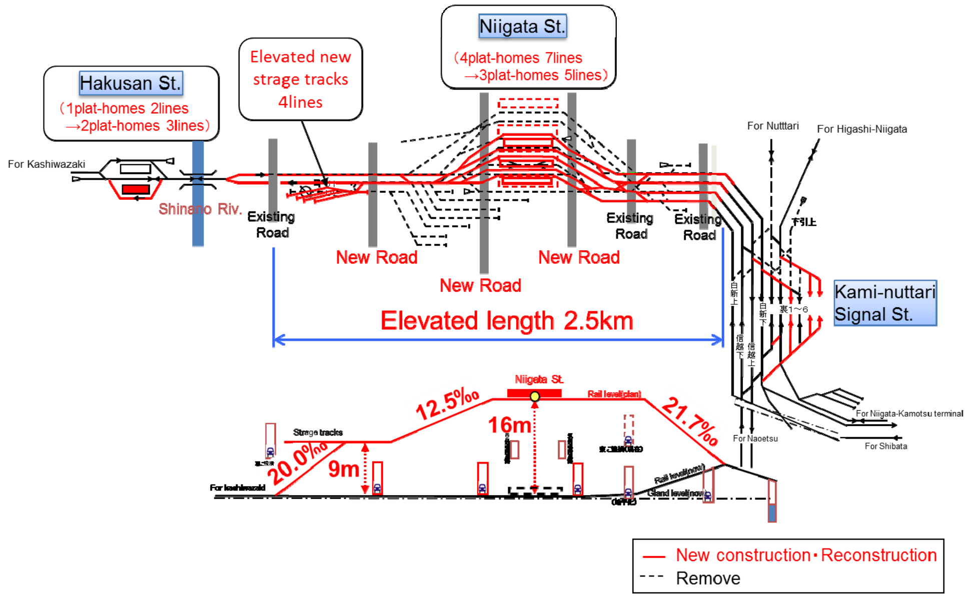


FIGURE 1: The Plans of Elevating railroad project near Niigata St.

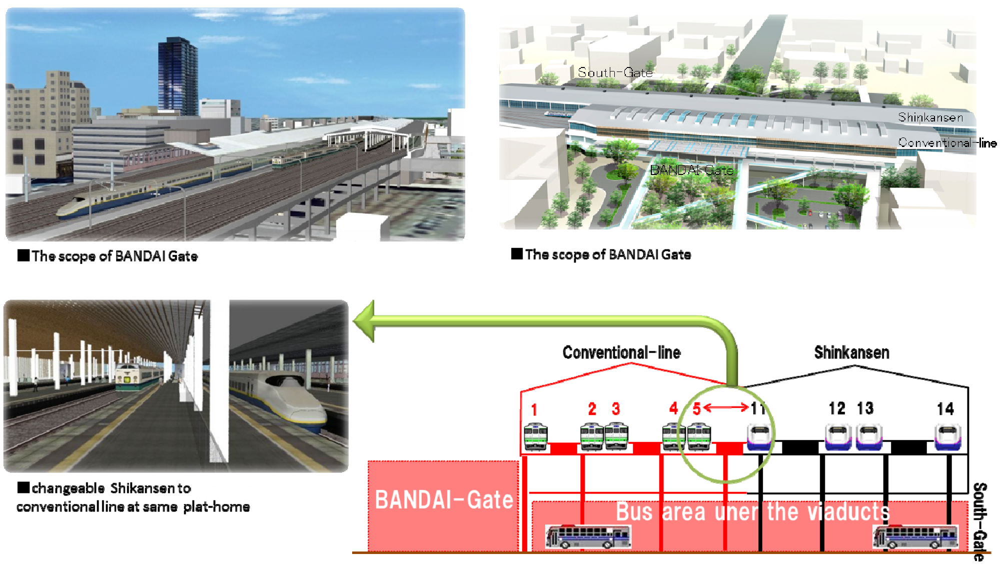


FIGURE 2: Same home of SHINKANSEN and conventional line

3 SOME EXAMPLES OF STRUCTURES DAMAGED BY AAR AND USEABLE AGGREGATES NEAR THE NIIGATA STATION

3.1 Some examples of AAR-damaged structures

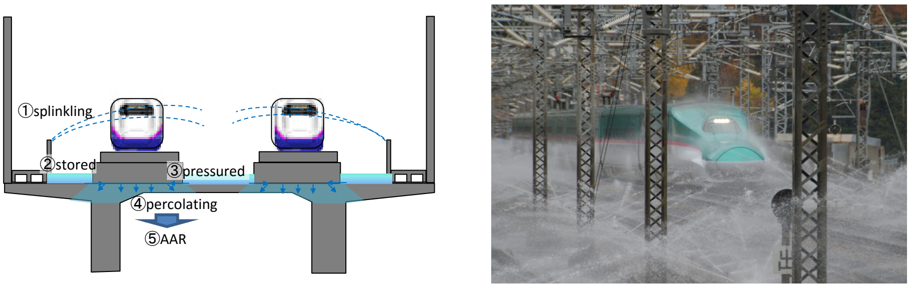
In Niigata area, many reinforced concrete (RC) structures currently in service have been damaged by AAR. For example, Figure 3 shows RC viaducts which exhibit many pop-outs under the slab. The Niigata area is subject to significant snow. At SHINKANSEN, railroad viaducts have snow melting equipment with water. This equipment made upper face of the slab wet every winter. The water percolates through concrete and promotes AAR (Figure 4). Therefore, in the RC viaduct which was constructed as part of this project, it was necessary to implement AAR mitigation measures.

3.2 Performance of the aggregates available in the Niigata area

(1) The location of production of aggregates

a) Under the slab   b) Column

FIGURE 3: Examples of AAR-damaged railway viaducts structure



a) Mechanism of AAR   b) Sprinkling situation

FIGURE 4: Mechanism of AAR promoted on the slab of SHINKANSEN viaduct's slab

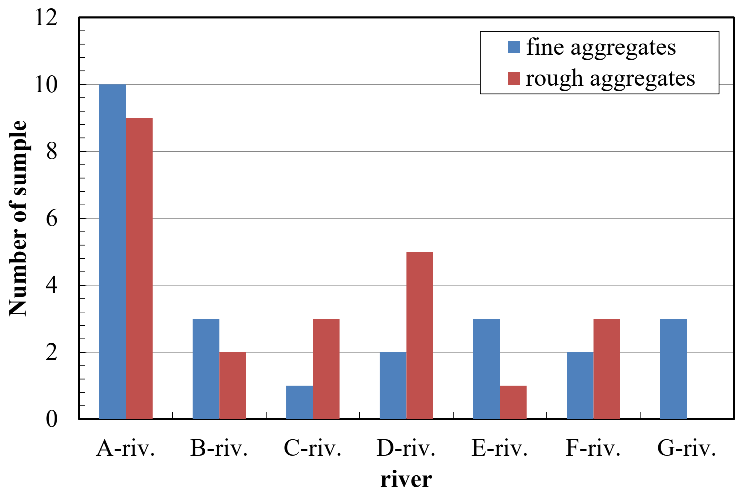


FIGURE 5: Ratio of aggregates usable in Niigata area

We investigated the location where aggregates used in Niigata area are produced, by surveying aggregates used with past constructions in Niigata area. Forty-nine data points representing 11 previous construction projects from 1997 to 2003 were selected (Figure 5). The A-river's aggregates were used for about 40% of these projects in the Niigata area.

(2) AAR reactivity of aggregates

Figure 6 shows AAR reactivity of available aggregates near Niigata Station by the "Chemical method" which is a standard of JIS A 1145. This figure shows that some of A-riv.'s and E-riv.'s

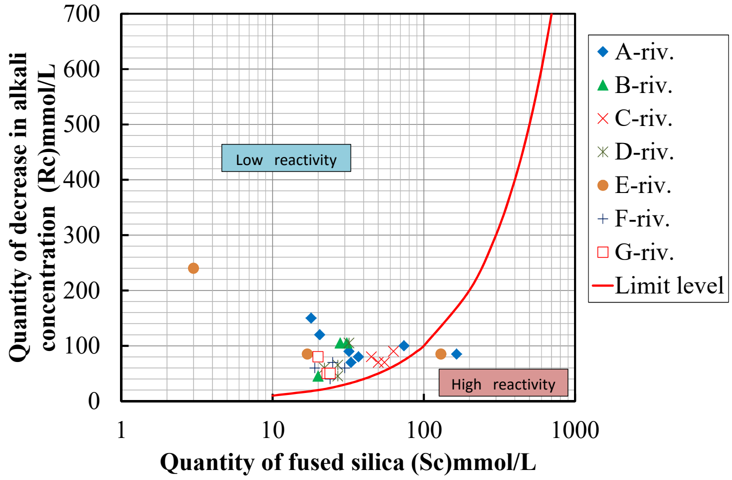


FIGURE 6: AAR reactivity of Chemical method (JIS A 1145)

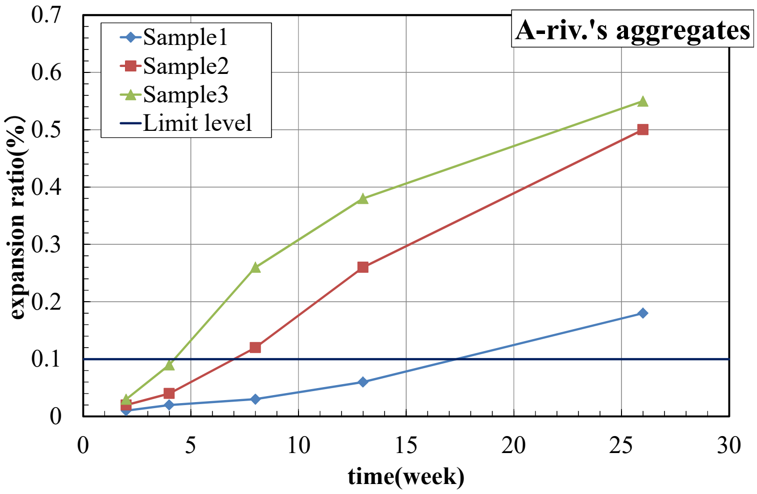


FIGURE 7: AAR reactivity of Mortar bar method (JIS A 1140)

aggregates were classified as being of high reactivity. On the other hand, other aggregates exhibited low reactivity.

Figure 7 shows AAR reactivity of A-riv.'s aggregates by the "Mortar bar method". Mortar bar method is a standard of JIS A 1140. Two samples of A riv.'s aggregates produced an expansion over the 0.1% expansion limit. This is the expansion limit given in JIS A 1146, and classifies this aggregate as having a very high AAR reactivity. It was recognized that much of this highly reactive aggregate might be included in concrete used in the Niigata Station project.

4 EXAMINATION OF AAR MITIGATION MEASURES USING FLY ASH

4.1 Examination background of AAR mitigation measures

As described above, in this project, it was difficult to obtain "low reactivity aggregates" for use in all of the approximately 140,000m^3 concrete that was required, and it was not feasible to avoid the use of "highly reactive aggregates". Fortunately, we examined AAR control measures using fly ash, because sources of fly ash were available from regional thermal power stations at Sakata or Noshiro.

4.2 Examination of fly ash mixture proportions with the AAR suppressant effect

TABLE 1 shows the rock types included in three kinds of "highly reactive aggregates" (S1, S2-1, S2-2) that are available in Niigata area, and "low reactivity aggregates (S3)" for comparisons. The criteria here are based on testing by the chemical method. The S2-1 and S2-2 aggregate sources are located within the same fluvial deposits, but vary on the basis of not only deposition but also by location within the watershed/fluvial system.

TABLE 1: Rock type included in the aggregates

		S1	S2-1		S2-2		S3	
		Fine aggregates	Fine aggregates	Rough aggregates	Fine aggregates	Rough aggregates	Fine aggregates	Rough aggregates
ASR-reactivity	Method of Mortar-bar	B (High)	B (High)	B (High)	B (High)	B (High)	A (Low)	A (Low)
	Method of Chemical	A (Low)	B (High)	B (High)	B (High)	B (Highe)	A (Low)	A (low)
Rock type		%	%	%	%	%	%	%
Rock piece	Chert	51.0%	6.0%	0.4%	5.0%	5.0%	1.0%	–
	Sandsone	13.0%	2.0%	27.6%	6.0%	29.2%	9.0%	8.6%
	Shale	3.0%	1.0%	5.3%	2.0%	10.2%	12.0%	8.4%
	Conglomerate	–	–	–	–	4.5%	–	–
	Quartzite	7.0%	14.0%	16.1%	2.0%	10.2%	12.0%	8.4%
	Pelitic schist	1.0%	4.0%	18.1%	9.0%	5.9%	23.0%	40.2%
	Gabbro	–	4.0%	2.6%	–	2.7%	–	–
	Granite	–	14.0%	15.8%	11.0%	8.8%	14.0%	8.8%
	Andesite	–	2.0%	4.7%	8.0%	1.2%	0.6%	–
	Tuff	–	–	6.5%	–	7.5%	–	–
	Diorite	–	–	2.9%	–	–	–	7.3%
	Others	7.0%	7.0%	–	10.0%	–	4.0%	–
Crystalline Rock	Quartz	12.0%	13.0%	–	9.0%	–	8.0%	–
	Orthoclase	5.0%	17.0%	–	10.0%	–	10.0%	–
	Anorthoclase	–	6.0%	–	3.0%	–	1.0%	–
	Biotite	–	2.0%	–	2.0%	–	2.0%	–
	Others	1.0%	3.0%	–	3.0%	–	1.0%	–

Chert or andesite are said to be highly reactive rock types. It was determined that the S1 fine aggregates contained 51% chert. But S1 was classified as of “low reactivity” by mortar bar method, because of S1’s low expansion. On the other hand, S2-1 and S2-2 have high andesite contents, and this was thought to contribute their ranking as being of "high reactivity", by both the chemical method and the mortar bar method. Thus, the AAR-responsive rock type of Niigata area aggregates was proved to be andesite.

(2) Relationship of the ratio and the coefficient of expansion of the aggregates

Because it was recognized that andesite was a primary reactive rock type, we separated andesite from bulk aggregate samples and produced mortar bars for tests with ratios of andesite of 0%, 10%, 20%, 30%, 40%. Using the mortar bars for the tests, we measured expansions using the mortar bar method (Figure 8). This Figure shows that mortar bars made with 10% andesite without fly ash expanded 0.46% at an age of thirteen weeks. By contrast, mortar bars made with 40% andesite and 20% fly ash expanded 0.02%. Because the andesite content of the actual aggregates was about 5-10%, the coefficient of expansion was reduced by incorporating fly ash replacement of more than 15% of the cement. From the above result, we decided to use a replacement value of 20% of fly ash, in order to provide an added safety factor for the actual construction.

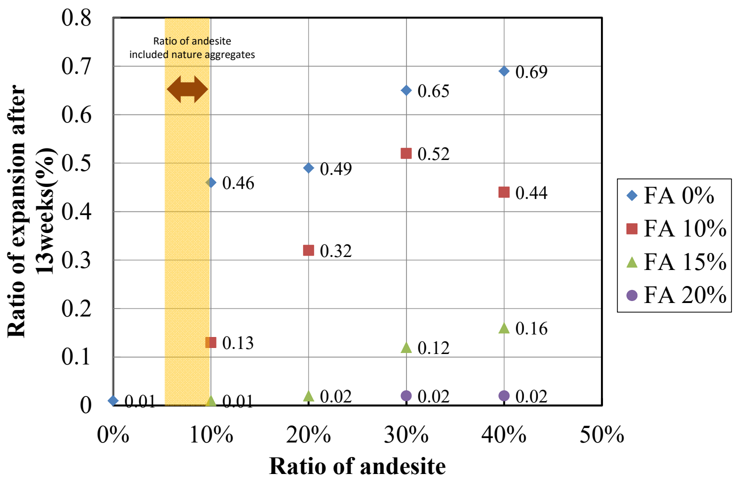


FIGURE 8: Expansion after 13 weeks with variable ratios of andesite (mortar bar method)

4.3 Curing method

(1) Background

For concrete in which fly ash was incorporated, it is generally recommended that the curing period be extended beyond that used for concretes made with only Portland cement. In addition, after demoulding, we used appropriate curing methods to minimize moisture loss when a wrap was applied. Therefore we examined various self-cure methods by examination, after adequate self-curing had been done for a sufficient period of time, after demoulding of specimens.

(2) Influence of curing method to produce a concrete surface quality

We changed the curing period and curing conditions by using four patterns as follows: ① humid curing 0 days, ② humid curing 3 days, ③ humid curing 7 days, ④humid curing 7 days and lapped curing 21 days, after which we confirmed the surface quality of the test column (Figure 9).

Curing conditions

① Humid curing : 0days

② Humid curing : 3days

③ Humid curing : 7days (Standard curing periods of concrete with mixture cement)

④ Humid curing : 7days + lapped curing(21days)

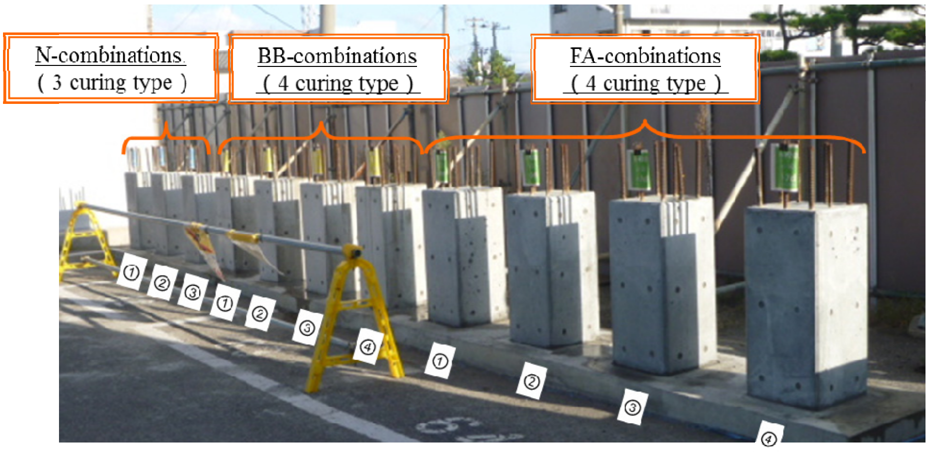


FIGURE 9: Curing conditions and test columns (400×400×900mm)

TABLE 2: Combination of test columns

Blend name			N-blend	BB-blend	FA-blend
Design strength(N/mm^2)			27	27	27
Weight(kg/m^3)	Cement		450	450	360
	Mixture materials	Fly-ash (Grade II SAKATA)	—	—	90
	Water		170	170	165
	Fine aggregates	Rough sand (Agano Riv.)	660	654	654
		Fine sand (Tainai Riv.)	165	163	163
	Rough aggregates	Gravel (Agano Riv.)	838	833	833
	Admixture	Water reducing agent	5.625	5.625	5.625
Condition of fresh concrete	Slump-flow(cm)		54.5×53.0	63.5×62.0	62.5×59.0
	Air ratio(%)		4.0	5.5	5.5
	Tempurture (℃)		31	31	31

For comparison, we used a typical Portland cement combination (N) with Blast furnace slag cement combination (BB) in addition to fly ash combination (FA). We show the mix designs used for each combination in Table 2. After six months, many small cracks were observed on the surface of the test columns, which were not protected by wrapping, and which were cured for a short period. Then we measured the length of the cracks of the test column's surface and defined the length of the cracks to occupy in a unit area as quantity of crack and compared it (Figure 10). As a result, in curing condition ③, it became 0.23 m/m^2 with fly ash concrete, whereas common concrete was 0.0 m/m^2. However, we were able to decrease quantity of cracks by using curing condition ④. Thus, in the actual construction, the quality that concrete that was desired was possible assuming curing condition ④ was used.

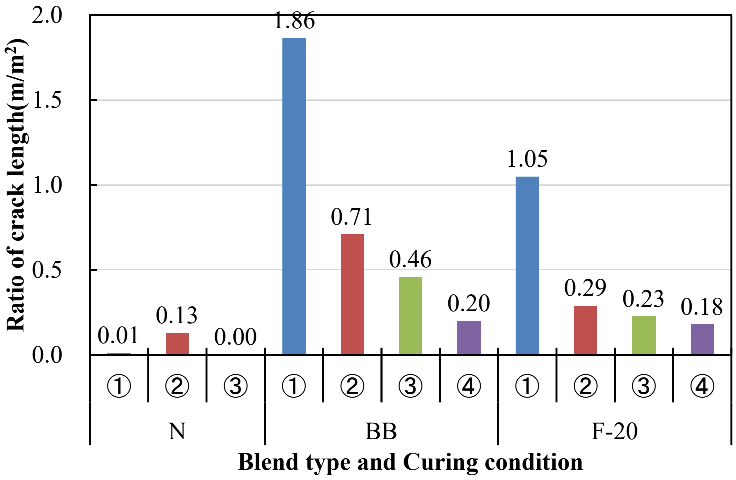


FIGURE 10: Ratio of crack length

5 TEST CALCULATION OF THE ENVIRONMENTAL LOAD REDUCTION EFFECT

In the approximately 140,000 m^3 of concrete required to undertake construction by this project, the environmental load reduction was calculated on the basis of reduction of CO_2 due to the use of concrete in which we replaced 20% of cement with fly ash (Table 3). As a result, it is thought that we can reduce CO_2 emissions by 5,500 t, which is approximately 1,000 double of the general domestic CO_2 discharge (about 5.5t/ year).

TABLE 3: Environmental Load reduction quantity

			CO_2	SOx	NOx	Soot
			kg-CO_2	kg-SOx	kg-NOx	kg-PM
Down	Original Plan	Cement 1.0t	766.6	0.122	1.55	0.036
	Changed Plan	Cement 0.8t	613.3	0.098	1.24	0.029
		Fly ash 0.2t	3.9	$1.24*10^{-3}$	$1.51*10^{-3}$	$2.50*10^{-4}$
		Total	617.7	0.099	1.242	0.029
	Environmental load reduction quantity (per cement 1.0t)		149.4	0.023	0.308	0.007
Up	Enviromental Load increment quantity (per fly ash 0.2t)		2.5	$1.92*10^{-3}$	$1.87*10^{-2}$	$1.57*10^{-3}$
Enviromental Load reduction quantity (per cement 1.0t)			146.9	$2.12*10^{-2}$	$2.90*10^{-1}$	$5.34*10^{-3}$
Enviromental Load reduction quantity (per this project)			5,552,858	803	10,955	202

6 CONCLUSIONS

This project will be commissioned by a new route in 2021, with a current target for provisional opening is 2018, while the construction of the viaduct advances (Figure11). We aim to construct a durable high concrete structure by carrying out the measures discussed above and will be happy in future if we can contribute to environment load reduction.

FIGURE 11: Under construction now

6 REFERENCES

[1] JSCE (2005): Environmental performance collation guidance of the concrete structure（Tentative Plan, Concrete library No.125.

[2] Cement & Concrete (2014): The construction of continuous railway viaducts at the Niigata Station, Shigenobu Iguchi, Cement & Concrete No. 805, pp 48.