Condition Assessment of The Deteriorated Reinforced Concrete Bridge: Jambatan Sungai Senduk Ulu, Jambatan Sungai Cheh, Jambatan Bukit Gantang

by

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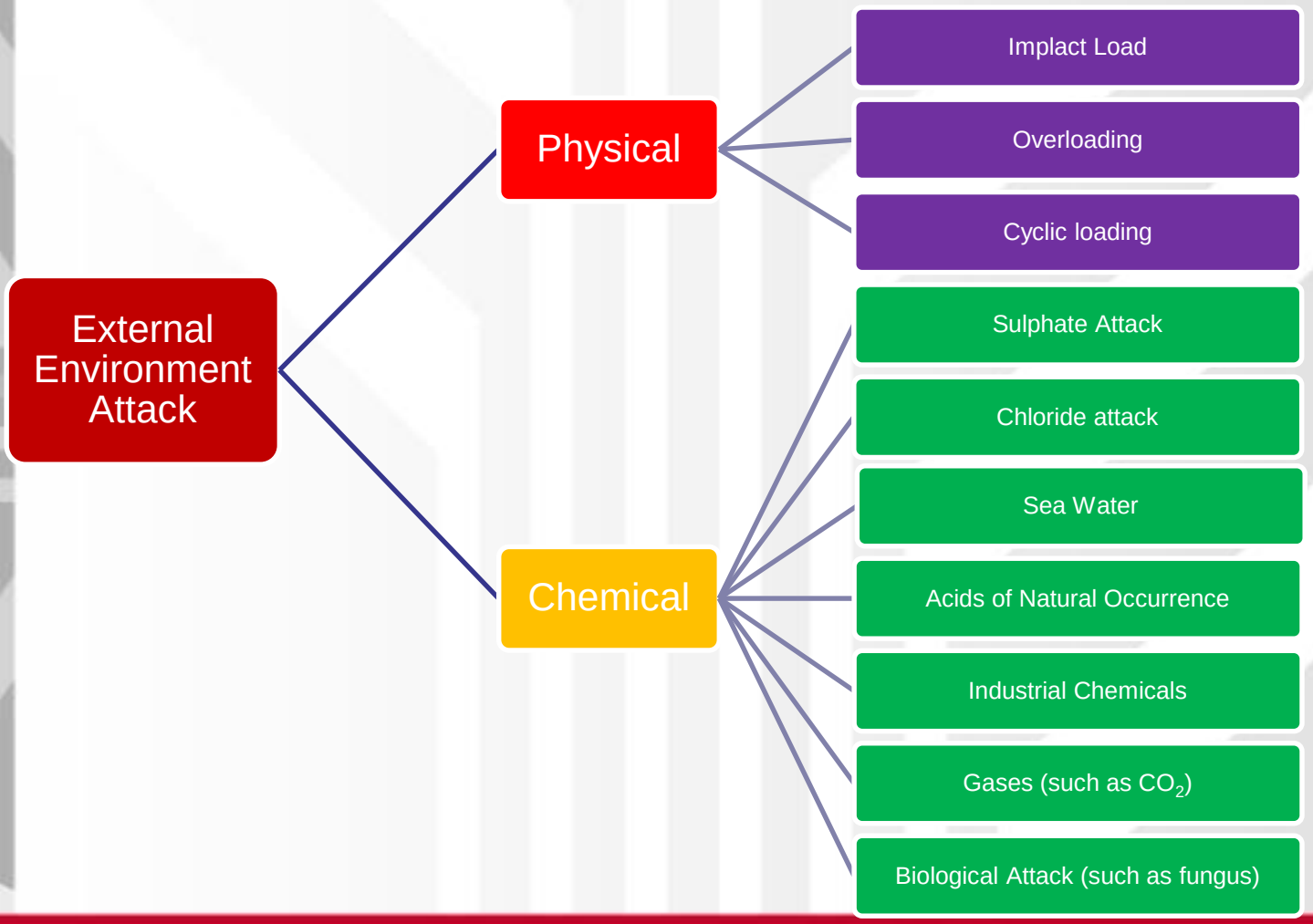
Introduction:

- Public Works Department is a custodian for more than 7000 federal bridges in the country
- More than 70% bridges are made of concrete, with an average of 250 bridges built beginning 60's.
- In 1978 – 1979 alone, 1000 bridges were built which now reach 40 years old.
- 40 years of age reach mid life age for typical bridge which major rehabilitation required;
- 75 years is the useful life of a typical bridge

- *(Source: REAM(2004), Dr. Ng. See King (1998)*

Principle of Deterioration: External Attack



Principle of Deterioration: External Attack

Carbonation

- Calcium carbonate exists in three crystallographic forms, **aragonite, vaterite** and **calcite**. Calcite and vaterite are commonly found in carbonated concrete (Mobin Raj T & Dr.P.Muthupriya, 2016). The carbonation reaction can be shown as follows:

$$Ca(OH)_2 + CO_2 \Rightarrow CaCO_3 + H_2O$$

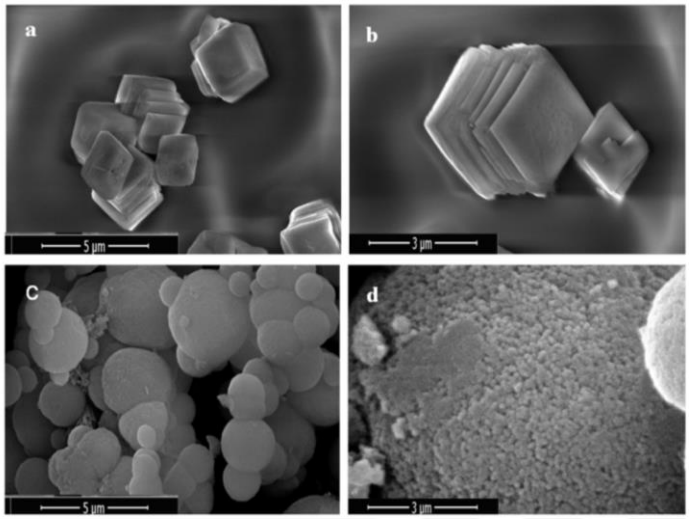


Fig 1: SEM images of CaCO3 samples (**a, b**) calcite particles and (**c, d**) vaterite particles (Source: Saraya & Rokbaa,2016)

- The carbonation rate may range from 1 – 50µm/year with the highest rates of carbonation occur when the relative humidity is maintained between **50% and 75%. Below 25%** relative humidity, the degree of carbonation that takes place is considered **insignificant**. Above **75%** relative humidity, moisture in the pores **restricts** CO_2 penetration. (A. M. Neville, 2005).

Principle of Deterioration: Internal Attack

ASR (Alkali-Silica Reaction)

- The aggregate used in the concrete must contain reactive siliceous mineral phases. The concrete must have a high alkali concentration and presence of a high relative humidity.

  1.Alkalies + Reactive Silica => Gel Reaction Product

  2. Gel Reaction Product + Moisture => Expansion

Figure 3: Indicator of ASR sources: (Portland Cement AssociationDeterioration, Attack, Reactivity, & Defects, n.d.)

Principle of Deterioration: Internal Attack

DEF (Delay Ettringite Formation)

- After hardened concrete complete the primary ettringite formation at hydration stage the improper process of curing contribute to DEF.
- First, internal temperature of material must be above 70^{o}C in sufficient length of time, and second after the material back to normal temperature, this materials need experience of wet or moist environment for intermittently or permanently but if enough sulphate is present.
- Low temperature ettringite disappear because CSH and pore solution compete for sulphate.

Figure 4: Indicator of DEF, source: CivilDigital.com

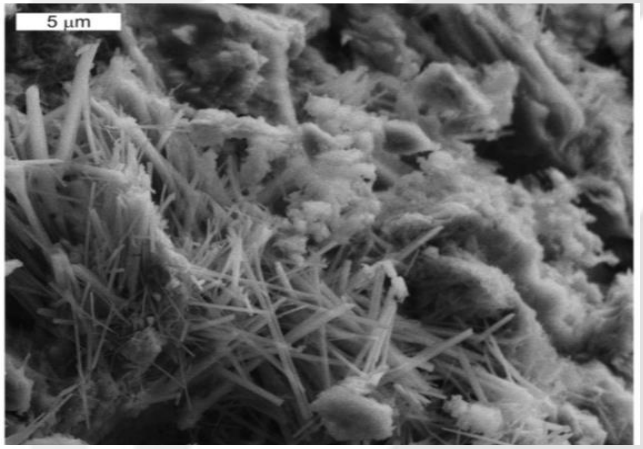


Figure 5: Ettringite needles under Scanning Electron Microscope

Principle of Deterioration: Internal Attack

ISA (Internal sulphate Attack)

- Another deterioration also had a product of ettringite is ISA.
- The chemical process of ISA starts with sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = ettringite (calcium sulphoaluminate hydrate).
- chemical reaction continue develop the sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = gypsum (calcium sulphate hydrate).

Figure 6: Indicator of ISA, source www.civilengineeringforum.me

Case Study

- This is a case of deterioration Reinforce Concrete (RC) Beam acting as bridge component. Focusing on diagnosing deterioration of three bridges in same road alignment.

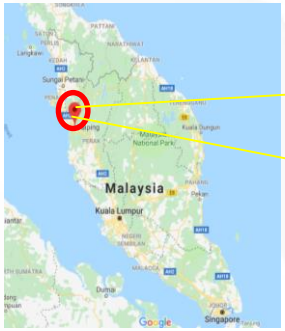
- The site studied are at State Road, Taiping Perak under custodian of Public Work Department (PWD). This bridges approximately build 60 years ago.

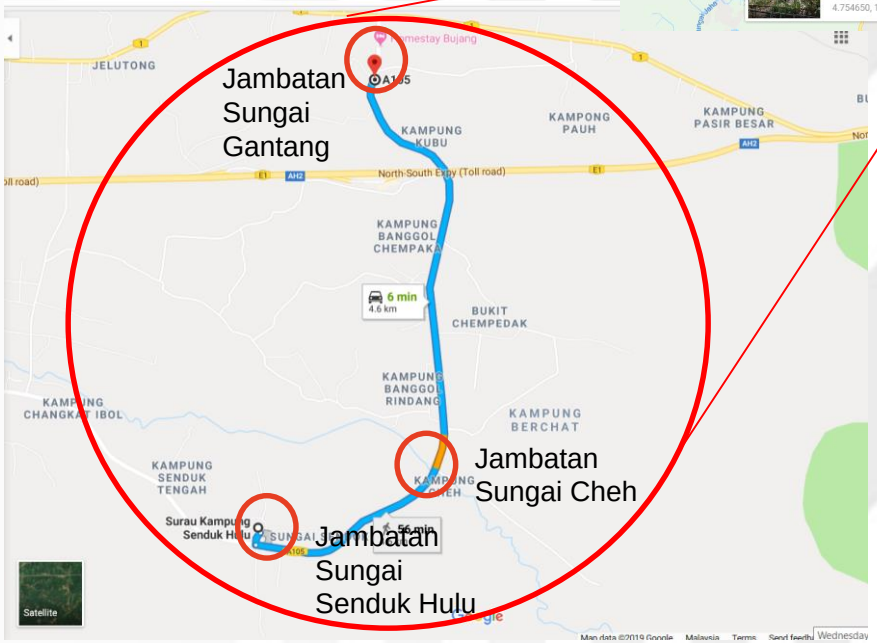
- This bridges consist of multiple span of bridge, use of RC beam as superstructure and probably simply supported system. There is no defect or distress observed from the top of bridge but from below the bridge, deterioration of RC beam deterioration are noticeably observed (e.g cracking, delamination, spalling and discoloration).

Assessment : Visual Inspection

- Execution of the bridge condition assessment is based on a national guide by **Road Engineering Association of Malaysia, 2004.**
- All structural components which is accessible were measured including bridge spans, pier head, pier column and slope profile.
- History information not accessible. Therefore, bridge measurements were performed prior to defect mapping.

Site's Location

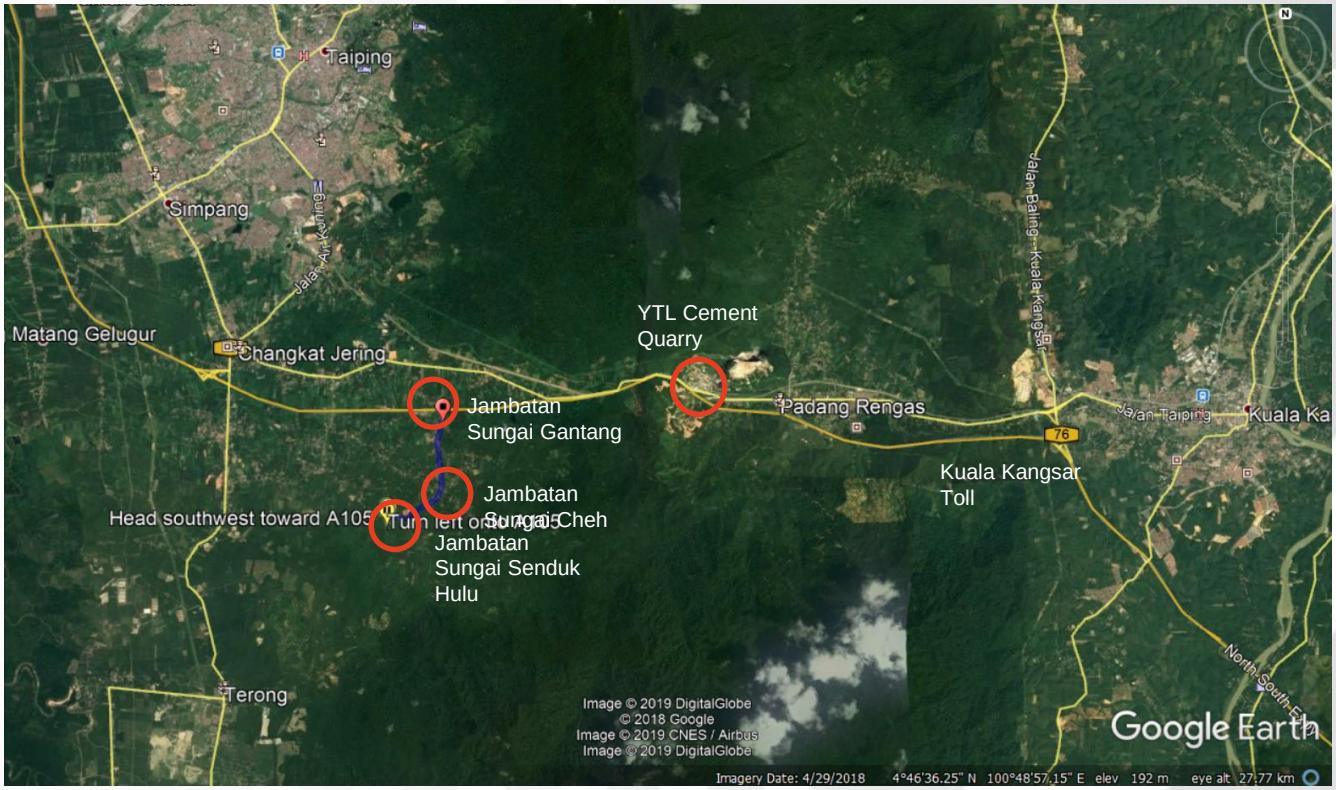




Location:

- Changkat Jering, Distict of Larut, Matang dan Selama, Perak.
- Rural area surrounded with plantation farm.
- Mean temperature* – 27.1^{o}c
- Mean Relative Humidity* – 82.7%
- Mean rainfall* – 2176mm
- **Source : 2018 data from Meteorological Department (station Lubok Merbau, 20km from Taiping)*

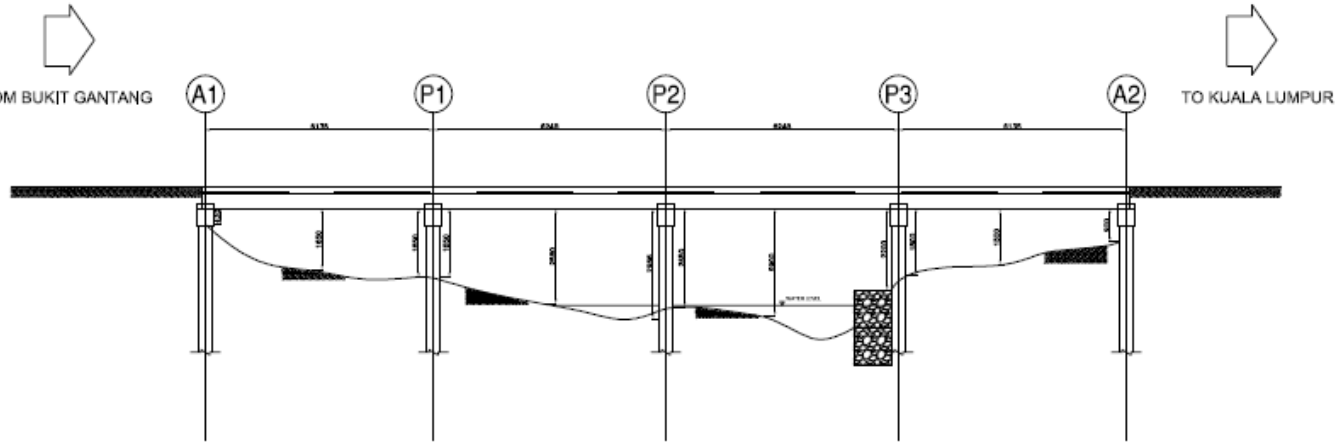
Site's Location



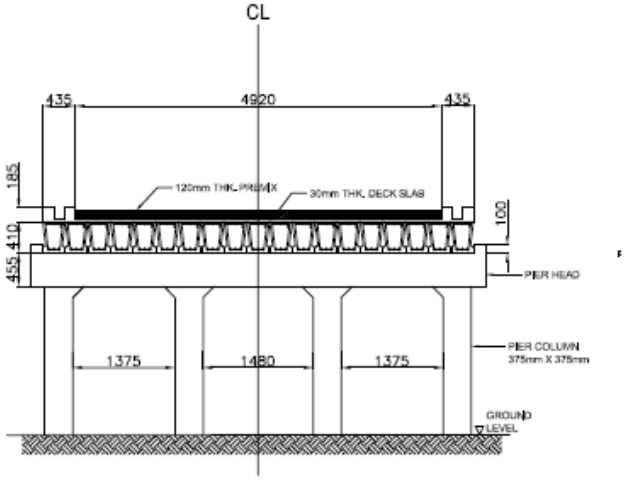
Location:

- Route A105, Jalan Bendang Siam to Bukit Gantang
- 16km to Taiping
- Sg. Senduk Hulu – Sg. Cheh (1.7km)
- Sg. Cheh – Sg. Bukit Gantang (2.9km)

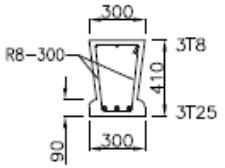
Jambatan Sungai Senduk Hulu



ELEVATION OF STRUCTURE



TYPICAL CROSS-SECTION AT PIER



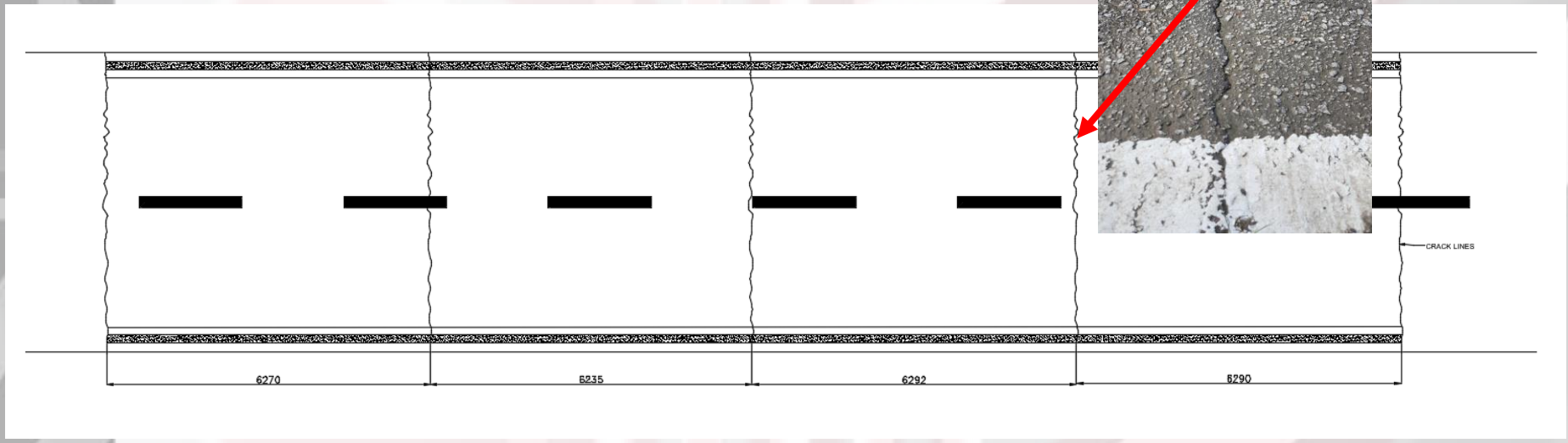
TYPICAL CROSS SECTION OF BEAM

TYPICAL CROSS-SECTION OF PIER HEAD

TYPICAL CROSS SECTION OF PIER COLUMN

JAMBATAN SUNGAI SENDUK ULU

Jambatan Sungai Senduk Hulu



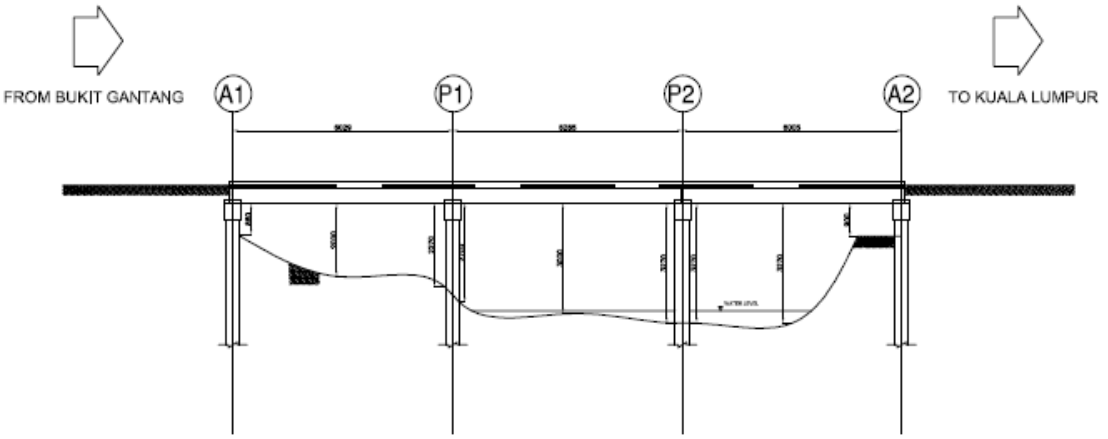
Transverse crack observed on the pavement indicates simply supported beam girder. Possible penetration of water to the structure.

Jambatan Sungai Cheh

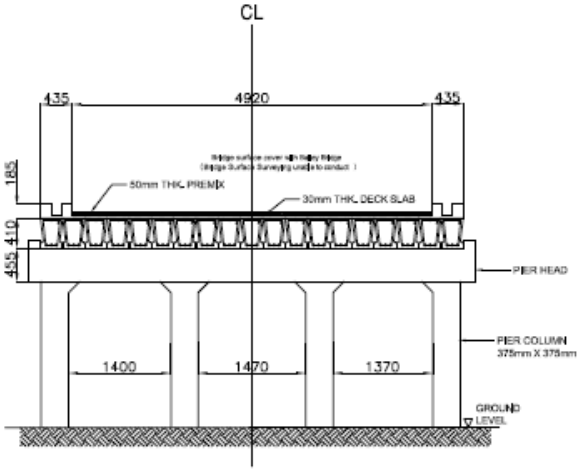
Jambatan Sungai Cheh

22nd OCTOBER 2018

2nd DECEMBER 2018
(After Bailey Bridge installation)



ELEVATION OF STRUCTURE



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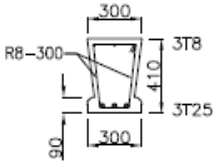

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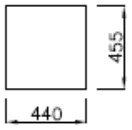
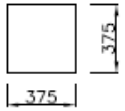


TYPICAL CROSS-SECTION OF PIER HEAD



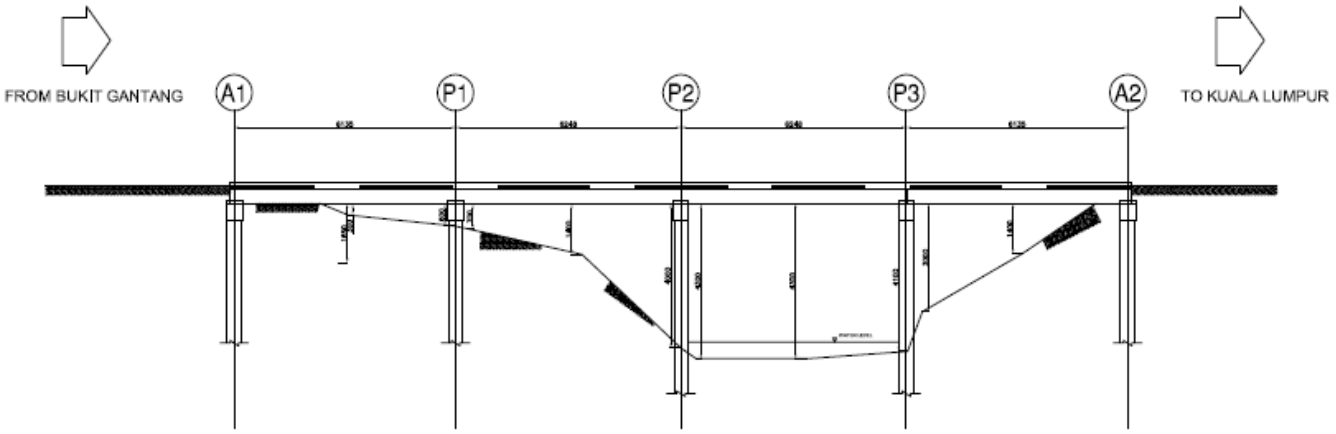
TYPICAL CROSS SECTION OF PIER COLUMN

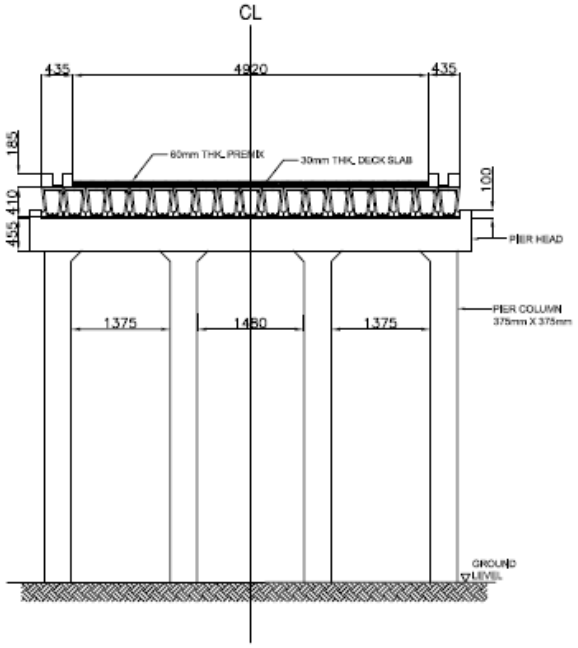
JAMBATAN SUNGAI CHEH

Jambatan Sungai Bukit Gantang

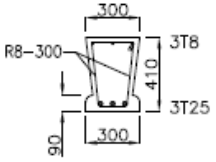
Sg. Bukit Gantang Bridge Elevated View

Sg. Bukit Gantang Bridge General View

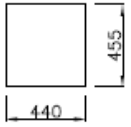




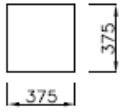
TYPICAL CROSS-SECTION AT PIER



TYPICAL CROSS SECTION OF BEAM



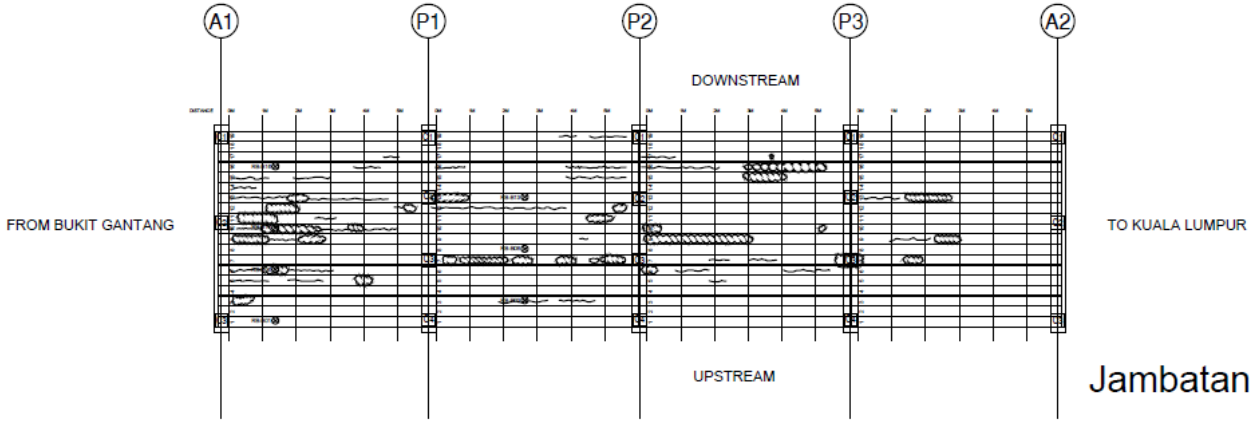
TYPICAL CROSS-SECTION OF PIER HEAD



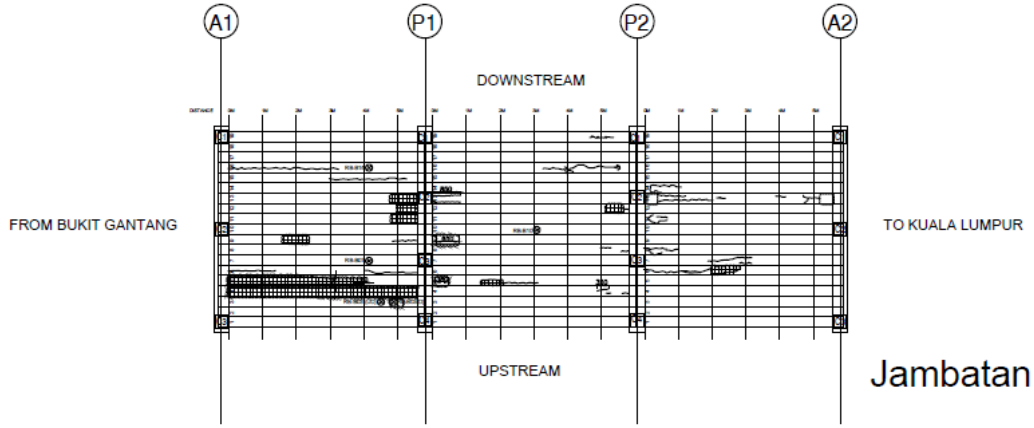
TYPICAL CROSS SECTION OF PIER COLUMN

JAMBATAN SUNGAI BUKIT GANTANG

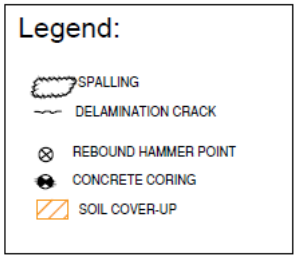
Defect Mapping of all three bridges

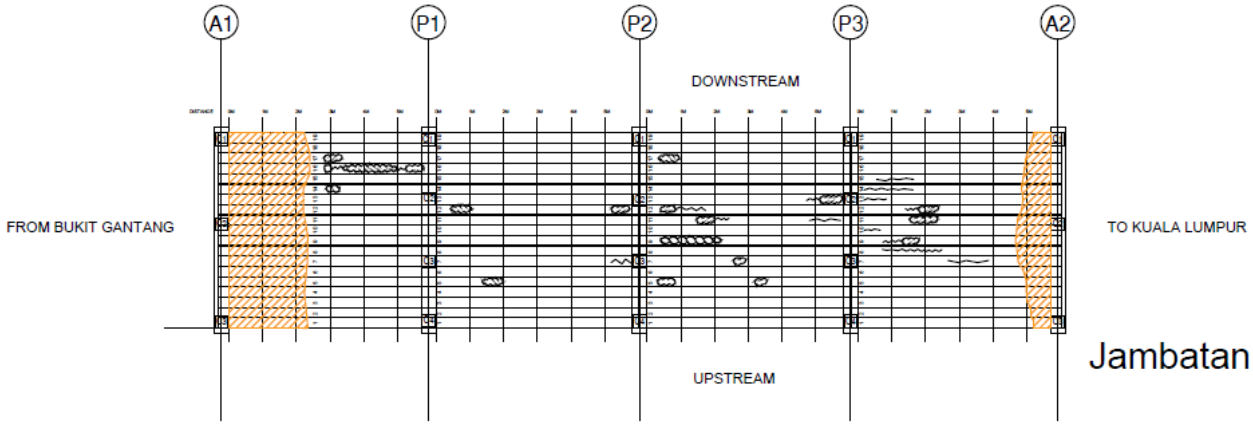


Jambatan Sg. Senduk Ulu



Jambatan Sg. Cheh





Jambatan Sg. Bukit Gantang

Assessment

Bil	Defect / Component	Cracking	Delamination	Spalling
1.	Deck	Transverse cracks were observed on the pavement deck about 6.2m spans c/c	No sign	No sign
2.	Girders	Most cracks were found along the reinforcement bar. These may be associated with stresses created during the embedded metal corrosion process	Delamination areas were observed from 0.15m^2 to as large as 1.2m^2 which is equivalent to three quarter spans of the girder.	Concrete spalling exposing severely corroded rebars were found in many locations on the girder, showing serious concerns in its structural integrity. The depth of detached concrete cover measured are varies, from 25mm to 65mm.
3.	Piers	No sign	No sign	No sign
4.	Abutments	No sign	No sign	No sign

Non-Destructive Test (NDT): Rebound Hammer

- Surface hardness test is done to predict the compressive strength of concrete by using rebound hammer.

Site	Location	Orientation	Surface condition	Measurement			Fcu (Mpa)
				High	Low	Ave	
Sungai Senduk Hulu	Beam Girder 01 (Span 1)	Overhead	Dry	47.5	70.8	62.0	62.0
	Beam Girder 06 (Span 1)	Overhead	Dry	22.7	65.7	50.4	50.4
	Beam Girder 10 (Span 1)	Overhead	Dry	5.6	39.0	21.15	21.15
	Beam Girder 03 (Span 2)	Overhead	Dry	48.6	73.5	61.2	61.2
	Beam Girder 03 (Span 2)	Overhead	Dry	37.0	67.5	55.8	55.8
	Beam Girder 03 (Span 2)	Overhead	Dry	44.2	67.5	55.1	55.1
	Pier Head 1 (Col 3) @ Pier 1	Horizontal	Dry	33.3	63.9	47.6	47.6
	Column 3 @ Pier 1	Horizontal	Dry	26.7	66.0	52.2	52.2
	Column 2 @ Pier 2	Horizontal	Dry	31.2	60.4	46.2	46.2
	Pier Head 1 @ Pier 2	Horizontal	Dry	47.5	56.9	52.3	52.3
Sungai Cheh	Beam Girder 07 (Span 1)	Overhead	Dry	72.4	62.7	66.6	66.6
	Beam Girder 16 (Span 1)	Overhead	Dry	54.1	38.0	48.4	48.4
	Pier Head (Col 1) @ Pier 1	Horizontal	Dry	49.0	32.0	39.9	39.9
	Column 3 @ Pier 1	Horizontal	Dry	59.9	35.5	47.9	47.9
	Column 2 @ Pier 2	Horizontal	Dry	46.8	26.5	33.1	33.1

Laboratory Test: SEM/EDX Testing (Concrete)

Concrete Microstructure

- CSH gel, calcite and ettringite crystals are present in the sample as shown in Fig. 7 and 8. The presence of calcite (Calcium Carbonate) indicates signs of carbonation.

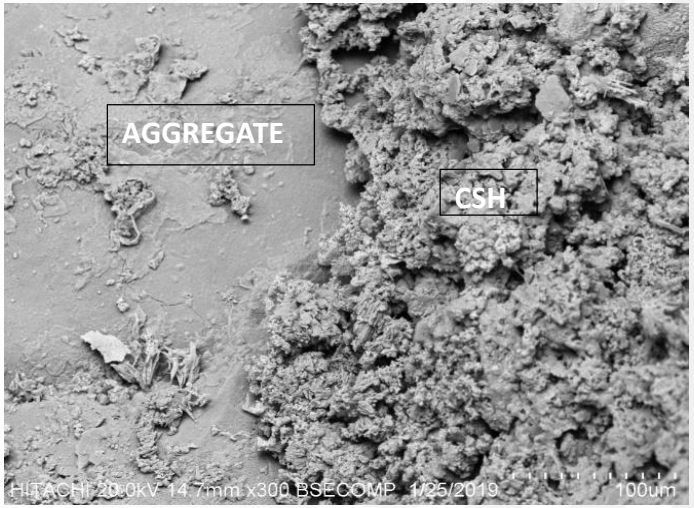


Figure 7: The bind between CSH and aggregate is sufficient

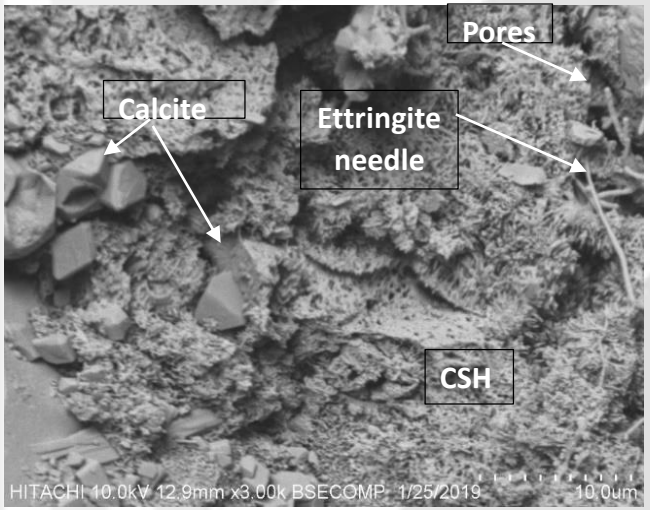


Figure 8: Calcite and ettringite crystal are present. Minimal ettringite crystals demonstrate minimal porous volume.

Laboratory Test: SEM/EDX Testing (Concrete)

Concrete Microstructure cont:

- Concrete sample shows very dense and perfect bond of hydrated cement paste with less air void are observed.
- The microstructure between cement paste and aggregate also show sufficient bonding characteristic.

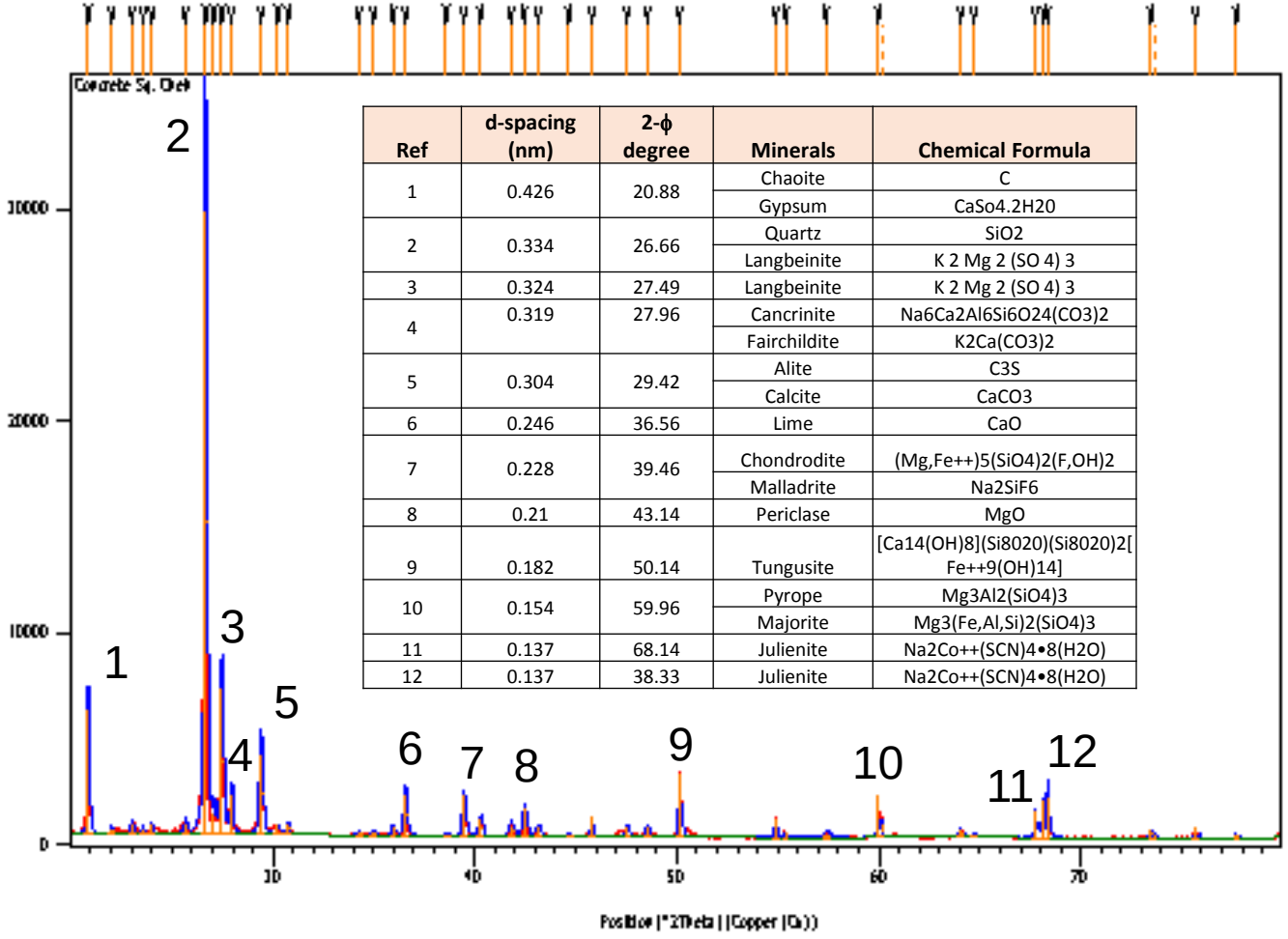
Element	Weight %	Atom %	Formula	Compnd %
C	36.04	52.72	C	36.04
O	24.94S	27.39		---
Al	4.39	2.86	Al2O3	8.29
Si	9.53	5.96	SiO2	20.38
S	0.34	0.18	SO3	0.84
Cl	0.51	0.25	Cl	0.51
Ca	24.26	10.63	CaO	33.94
Total	100.00	100.00		100.00

Table 1 Concrete mineralogy (sample 'a') at the surface of corroded reinforcement

Element	Weight %	Atom %	Formula	Compnd %
O	45.88S	62.29		---
Al	7.15	5.76	Al2O3	13.51
Si	28.06	21.70	SiO2	60.03
Si	---	---		---
Ca	18.91	10.25	CaO	26.45
Total	100.00	100.00		100.00

Table 2 Concrete mineralogy (sample 'b') at surface of concrete cover

Laboratory Test: XRD Testing (Jambatan Sg Cheh)



Ref	d-spacing (nm)	2-ϕ degree	Minerals	Chemical Formula
1	0.426	20.88	Chaoite	C
			Gypsum	CaSo4.2H20
2	0.334	26.66	Quartz	SiO2
			Langbeinite	K 2 Mg 2 (SO 4) 3
3	0.324	27.49	Langbeinite	K 2 Mg 2 (SO 4) 3
4	0.319	27.96	Cancrinite	Na6Ca2Al6Si6O24(CO3)2
			Fairchildite	K2Ca(CO3)2
5	0.304	29.42	Alite	C3S
			Calcite	CaCO3
6	0.246	36.56	Lime	CaO
7	0.228	39.46	Chondrodite	(Mg,Fe++)5(SiO4)2(F,OH)2
			Malladrite	Na2SiF6
8	0.21	43.14	Periclase	MgO
9	0.182	50.14	Tungusite	[Ca14(OH)8](Si8020)(Si8020)2[Fe++9(OH)14]
10	0.154	59.96	Pyrope	Mg3Al2(SiO4)3
			Majorite	Mg3(Fe,Al,Si)2(SiO4)3
11	0.137	68.14	Julienite	Na2Co++(SCN)4•8(H2O)
12	0.137	38.33	Julienite	Na2Co++(SCN)4•8(H2O)

Environmental Testing-Soil
SEM/EDX Testing (Soil)

Soil Microstructure

- No trace of sulphate and chloride substances in the soil which subsequently the probability of sulphate attack and chloride attack from the external environment is low.

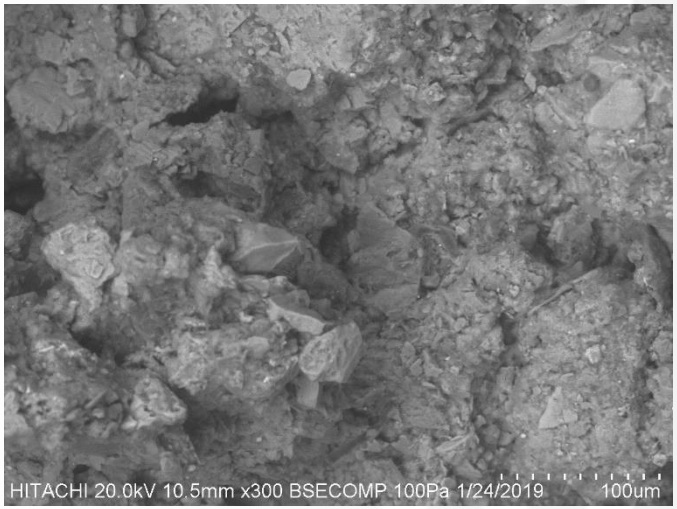


Figure 9: SEM Image for Soil Sample at Sg. Senduk Ulu

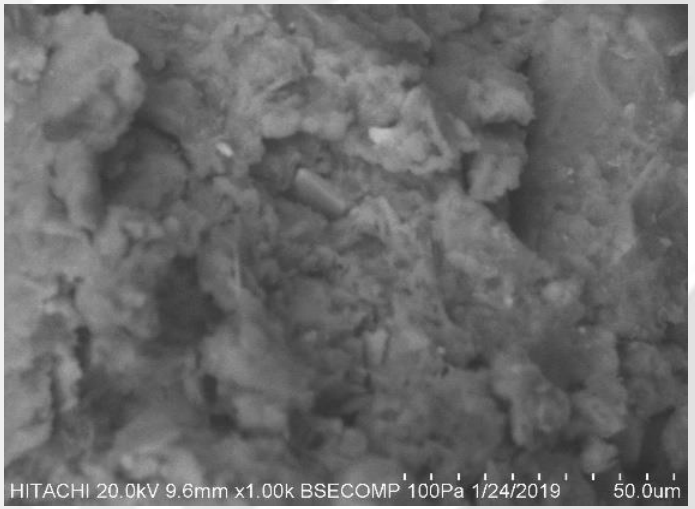


Figure 10: SEM Image for Soil Sample at Sg. Senduk Cheh

Environmental Testing-Soil
SEM/EDX Testing (Soil)-Sg. Senduk Ulu

Element	Weight %	Atom %	Formula	Compnd %
O	50.92S	64.83		---
Al	14.63	11.04	Al2O3	27.64
Si	30.25	21.94	SiO2	64.72
Si	---	---		---
K	4.21	2.19	KO2	7.65
K	---	---		---
Fe	0.00	0.00	Fe2O3	0.00
Fe	---	---		---
Total	100.00	100.00		100.00

Table 3 Soil mineralogy at Sungai Senduk Ulu (point 1)

Element	Weight %	Atom %	Formula	Compnd %
O	43.57S	63.40		---
Al	12.89	11.12	Al2O3	24.35
Si	25.82	21.40	SiO2	55.23
Si	---	---		---
K	3.29	1.96	KO2	5.98
K	---	---		---
Tb	14.44	2.12	Tb	14.44
Tb	---	---		---
Total	100.00	100.00		100.00

Table 4 Soil mineralogy at Sungai Senduk Ulu (point 2)

Environmental Testing-Soil
SEM/EDX Testing (Soil)-Sg. Cheh

Element	Weight %	Atom %	Formula	Compnd %
C	9.69	12.70	C	9.69
N	49.68	55.82	N	49.68
O	20.58S	20.25		---
Al	7.63	4.45	Al2O3	14.42
Si	11.33	6.35	SiO2	24.23
Si	---	---		---
K	1.09	0.44	KO2	1.98
K	---	---		---
Total	100.00	100.00		100.00

Table 5 Soil mineralogy at Sungai Cheh (point 1)

Element	Weight %	Atom %	Formula	Compnd %
C	9.72	12.98	C	9.72
N	50.73	58.11	N	50.73
O	18.26S	18.31		---
Al	7.22	4.30	Al2O3	13.65
Si	10.39	5.93	SiO2	22.22
Si	---	---		---
Tb	3.68	0.37	Tb	3.68
Tb	---	---		---
Total	100.00	100.00		100.00

Table 6 Soil mineralogy at Sungai Cheh (point 2)

Environmental Testing-Soil
CHN-S Test

CHN-S	Sg. Senduk Ulu	Sg. Cheh	Sg. Bukit Gantang
Carbon (%)	2.195	1.189	-
Hydrogen (%)	4.017	1.779	-
Nitrogen (%)	0.0689	0.0657	-
Sulphur (%)	0.0149	0.0068	-

* Sulphur content is very low, hence possibility of external sulphate attack from soil can be excluded

Environmental Testing-Soil
pH Test

	Sg. Senduk Ulu	Sg. Cheh	Sg. Bukit Gantang
pH	7.5	7.5	-

* Soil pH 7.5 is slightly alkaline but close to neutral which is normal

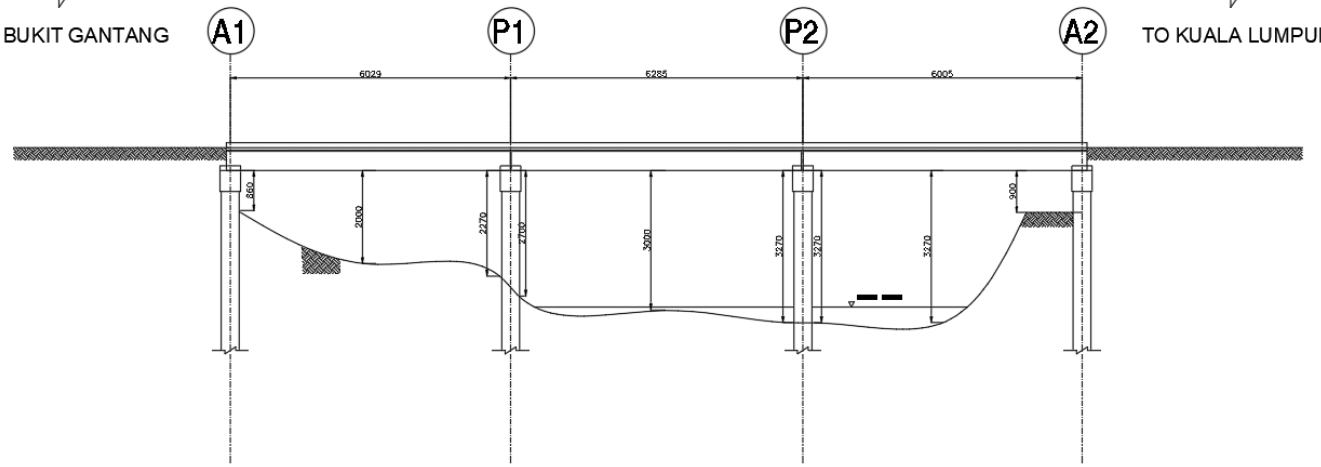
Environmental Testing-Water ICP Test (Ca, K, Mg, Na)

Elements	Concentration (ppm)		
	Sg. Senduk Ulu	Sg. Cheh	Sg. Bukit Gantang
Ca	4.325	6.524	12.870
K	5.050	4.240	4.380
Mg	1.970	2.600	2.890
Na	2.330	4.010	0.460

Environmental Testing-Humidity

Location- Bridge Surface	Span 1		Span 2		Span 3	
Time	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)
08:00	27.1	79.9	27.2	80.3	27.3	75.1
09:00	28.9	74.8	29.7	73.3	29.3	70.6
10:00	30.5	65.6	31.8	61.6	33.2	59.2
11:00	31.8	63.0	33.2	57.7	34.3	57.3
12:00	34.5	57.5	36.4	51.4	38.5	47.5

FROM BUKIT GANTANG

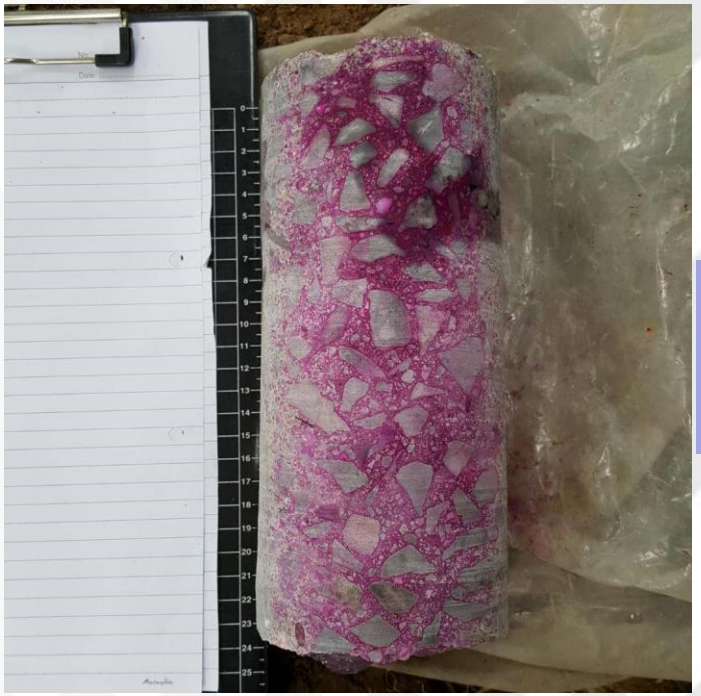


TO KUALA LUMPUR

Location- Bridge Deck	Span 1		Span 2		Span 3	
Time	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)
08:00	27.4	79.5	26.9	80.0	27.2	79.2
09:00	29.1	71.3	28.9	75.4	29.3	75.6
10:00	30.8	67.7	30.2	67.4	30.2	68.2
11:00	30.9	66.3	31.2	66.0	31.1	66.3
12:00	33.4	60.2	32.0	64.9	31.6	66.1

Carbonation Test

- Structure where exposed to environment are often to affected by carbonation and subsequent to reinforcement corrosion.
- Concrete field sample was drop by 1% Phenolphthalein solution to indicate carbonation depth to the concrete coring specimen of the bridge girder.



No trace of carbonation attack as specimen turn to purple color.

Conclusion

- Based on the severity of spalling, delamination and corroded steel bar, the three bridges rated as 5 with definition as follows:

"Being heavily and critically damaged and possibly affecting the safety of traffic, it is necessary to implement emergency temporary repair work immediately or rehabilitation work without delay after the provision of a load limitation traffic sign".

- There is evidence of precipitation of chloride found on surface of steel bar, but none was found in other sample. Further test on chloride contamination is required.

- There is no harmful external agents found in the soil for all three sites.

- No carbonation attack occur to the specimen tested. Further testing required to identify cause of concrete deterioration.

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Thank You