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Gas Insulated Switchgear (GIS) Building Concrete Cracks Causes, Testing and Repair Procedures

By Saeed S. Alshahrani, Anwar K. Bloch, Abdullah S. Algrayan & Ziyad F. Alzamil

Introduction

There are several methods available for concrete cracks repair such as gravity filling, routing and sealing, grouting, stitching, drilling and plugging. In this paper, we are going to discuss a specific case of concrete cracks development in load bearing basement walls that appeared in a double story Gas Insulated Switchgear (GIS) building as well as the process of identifying the nature of cracks, testing and application of epoxy grout injection for the repair of these horizontal & diagonal sever cracks to verify serviceability of the GIS building.

Problem Statement

During construction of GIS Building, numerous vertical and diagonal cracks appeared in the basement concrete walls and roof slab after the removal of the formwork. In order to resolve these cracks, various tests were conducted to check and verify the nature of the cracks (structural/non-structural) by doing Root Cause Analysis (RCA) with repair procedures to fully rectify the cracks.

Figure 1: GIS Basement Floor

Root Cause Analysis (RCA) of Concrete Cracks

Crack status and Pattern

- The cracks occurred in the upward direction from the lower foundation constraint surface of the basement wall, and were generated at a certain distance between the pillars (see Figure 2). Additionally, most of the crack widths observed by the crack gauge were 0.5 to 0.7 mm.

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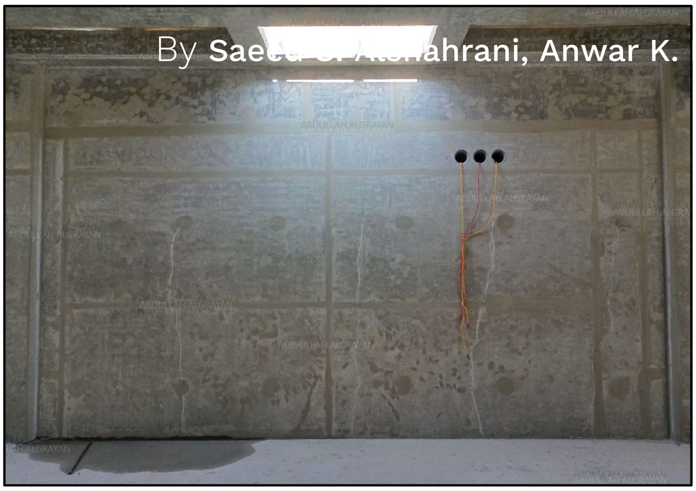

Figure 2: Cracks Pattern

- A core sample was collected to check the crack depth, and a maximum of 70 mm was checked to minimize damage to the reinforcing bars. (see Figure 3)

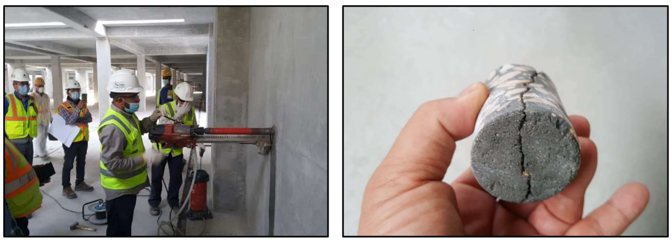

Figure 3: Core Sampling

Possible Causes According to Cracking Time

- The concrete of the basement walls was poured and demolding took place after one month. Outside wall backfill and Compaction were carried out after one month of demolding of formwork. As mentioned in the previous section, the cracks pattern was uniformly generated around the boundary of the pillars between the wall panels.
- Figure 4 defines the causes of cracks over time. As the basement wall is a vertical structure, the possibility of cracking due to plastic settlement or plastic shrinkage that occur in the early stage of curing seems very low. Also, since the cross section of the wall is 300 mm, the possibility of cracking due to heat of hydration is also low. Therefore, the cause of cracks in the basement wall is considered to be caused by dry shrinkage or loading service condition when considering the pattern and timing.

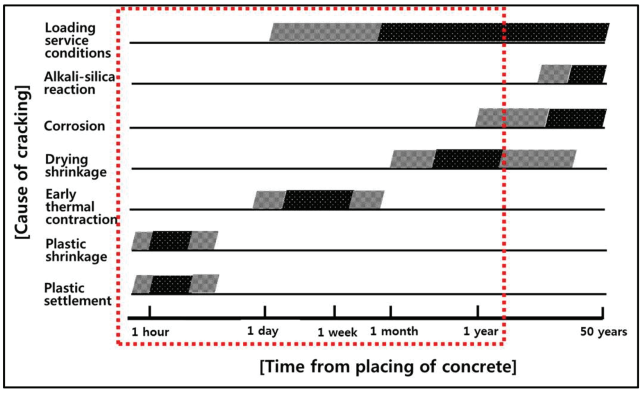

Figure 4: Causes of Cracking Against Time

Dry Shrinkage and Earth Pressure:

- Dry shrinkage cracks occur due to the volume change as a result of moisture losses. If the concrete is unrestrained, no shrinkage cracking occurs. However, the combination of shrinkage and sufficient restraint produces tensile stresses. When these stresses exceed the tensile strength of concrete, cracks occur over time.

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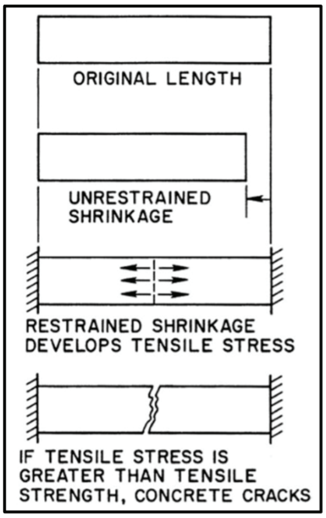

Figure 5: Concrete Cracking Due to Shrinkage

According to ACI 224R-01, the lower the relative humidity, the greater the ultimate shrinkage and rate of shrinkage in Figure 6. Actually, since formwork removal, the relative humidity has dropped down up to about 10%. It can be estimated that the lower relative humidity has influence on the additional crack propagation after dry shrinkage cracks.

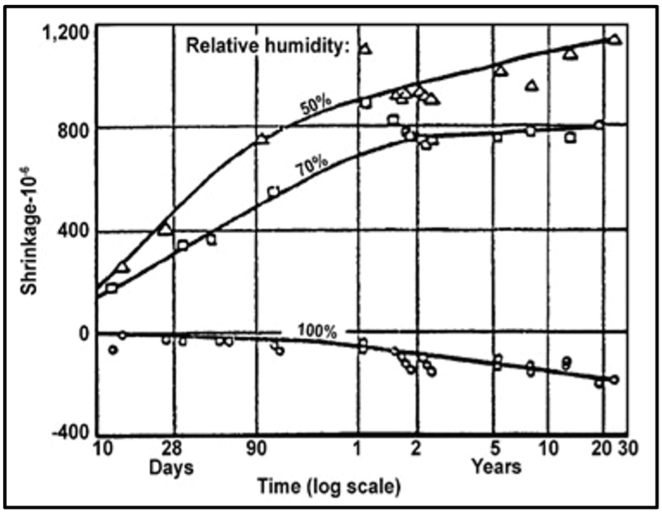

Figure 6: Effect Humidity on Shrinkage Against Time

- As mentioned above, the initiation of cracks was caused by dry shrinkage. However, the crack width seems to be larger than the width of general dry shrinkage cracks. The range of crack width was inspected mainly with 0.6 mm wide, and sparsely with 0.7 mm wide. Because of low relative humidity and earth pressure due to the backfilling soil compaction, the cracks seem to be additionally propagated after dry shrinkage cracks were initiated.
- The concrete of the basement walls was poured and demolding took place after one month. Outside wall backfill and Compaction were carried out after one month of demolding of formwork. As mentioned in the previous section, the cracks pattern was uniformly generated around the boundary of the pillars.

Testing Procedures

Installation of crack gauges (tell-tales glass) before Repair

Cracks would be continuously extended from the end of existing crack limits. Therefore, the cracks were physically marked on the surface of concrete until finishing the monitoring of crack growth and after that width and length of cracks was re-measured. The cracks monitoring was carried out with crack measuring gauges (tell-tales glass) and crack mapping to confirm that there is no crack propagation.
Table 1 shows in example of monitoring a crack using crack gauge (tell-tales).

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Photos	Tag Number	Date				Remarks
		5-Feb-2022 Result (mm)	12-Feb-2022 Result (mm)	19-Feb-2022 Result (mm)	26-Feb-2022 Result (mm)	
	GIS-T-001	0	0	0	0	No movement in cracks.

Table 1: Example of crack monitoring using tell-tales

The propagation of wall cracks had been monitored for over two months and there was no observed crack growth. Therefore, the cracks repairing work started.

3D MIRA & UPV results before Repair

The purpose of this test is to assess the Internal Quality of the Concrete in beams and walls at the GIS substation. To check the repaired concrete crack quality the Ultrasonic Pulse Velocity (UPV) was utilized. 3D MIRA Tomography system is used to check the internal quality of the concrete and to detect if there are any internal defects in the form of voids, cracks, and honeycombs.

The Ultra sonic pulse velocity (ASTM C597)

Ultrasonic inspection gives an indication about concrete uniformity, quality, internal discontinuities concrete, and crack depth in concrete. The Ultrasonic Pulse velocity tests was performed according to ASTM C597.

Figure 7: Ultrasonic scanning apparatus

Ultrasonic Echo Scanning

The Ultrasonic echo technology is excellent for detecting internal defects inside concrete in the forms of cracks, voids, honeycombs. The transmission range of pulse instruments depends on the quality of the concrete and the amount of reinforcement steel and it may reach up to 1.2m as an effective depth in solid concrete.

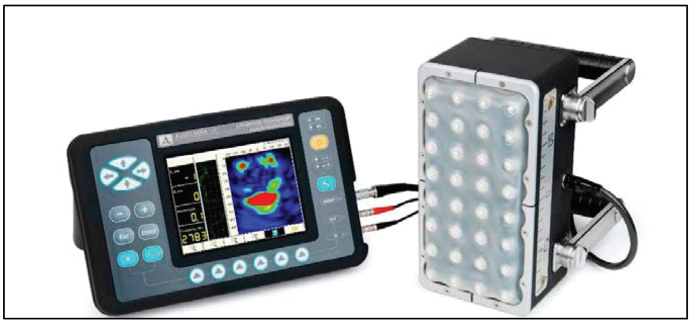

Figure 8: Ultrasonic Pulse Echo Scanning -MIRA

Ultrasonic Pulse Velocity (UPV)

Ultrasonic Pulse Velocity were conducted on the extracted cores, the test was performed according to ASTM C597. Results of UPV which testing are shown in Table 2. The UPV results was conducting on the smooth clean surface of the concrete to check the quality of the repaired area compared to the sound concrete.

S. N	Testing Point S.N	Zone & Type of Surface	TC	TS	X (mm)	Cracks Depth (mm)
1	Point #1	Zone A (Wall)	37.2	25.4	50.0	53.5
2	Point #2	Zone A (Wall)	42.4	26.4	50.0	62.8
3	Point #3	Zone A (Wall)	43.2	26.5	50.0	64.4
4	Point #4	Zone A (Wall)	45.6	27.4	50.0	66.5
5	Point #5	Zone A (Wall)	36.1	26.7	50.0	45.5
6	Point #6	Zone A (Wall)	32.1	26.4	50.0	34.6
7	Point #7	Zone A (Wall)	44	27.3	50.0	63.2

8	Point #8	Zone A (Wall)	35.7	25.7	50.0	48.2
9	Point #9	Zone A (Wall)	31	26.3	50.0	31.2
10	Point #10	Zone A (Wall)	46.3	28.2	50.0	65.1
11	Point #11	Zone A (Wall)	33.7	28.4	50.0	31.9
12	Point #12	Zone A (Wall)	41	28.3	50.0	52.4
13	Point #13	Zone A (Wall)	49.8	27.4	50.0	75.9
14	Point #14	Zone A (Wall)	39.6	28.2	50.0	49.3
15	Point #15	Zone A (Wall)	37.8	26.3	50.0	51.6
16	Point #16	Zone A (Wall)	40.6	27.3	50.0	55
17	Point #17	Zone A (Wall)	58.4	28.6	50.0	89
18	Point #18	Zone A (Wall)	49	27.7	50.0	73
19	Point #19	Zone A (Wall)	37.8	28.7	50.0	42.9
20	Point #20	Zone A (Slab)	30.4	26.3	50.0	29
21	Point #21	Zone A (Slab)	36.1	25.3	50.0	50.9
22	Point #22	Zone A (Slab)	39.1	27	50.0	52.4
23	Point #23	Zone A (Slab)	35.3	27.6	50.0	39.9
24	Point #24	Zone A (Slab)	41	28.5	50.0	51.7
25	Point #25	Zone A (Slab)	40.2	28	50.0	51.5
26	Point #26	Zone A (Slab)	42.3	27.6	50.0	58.1
27	Point #27	Zone B (Slab)	38.6	28.5	50.0	45.7
28	Point #28	Zone B (Slab)	37.3	27.6	50.0	48.8
29	Point #29	Zone B (Slab)	37.6	27.1	50.0	48.1
30	Point #30	Zone B (Slab)	45.6	28.7	50.0	61.7
31	Point #31	Zone B (Wall)	34	26.4	50.0	40.6
32	Point #32	Zone B (Wall)	35.1	26.8	50.0	42.3

Table 2: Crack depths in GIS basement

As summarized in Table 2 the concrete crack depth ranged between 29mm as in shown in Point #20 Zone A -Slab and 89mm as shown in Point #17 Zone A -Wall and the average crack depth for all points was 52mm. It is recommended to repair all the observed cracks using special cementitious repair mortar to assure the filling of the small voids and cracks, that hard to fill using normal concrete.

"MIRA Tomography" was used to inspect the internal quality of concrete and detect any internal voids, cracks or honeycombs. The test results for most MIRA readings showed that the internal quality of the concrete is in good condition. However, some test results revealed major internal defects in the form of internal voids and cracks. The summary of all results from tested concrete beams is summarized in Table 3. Also, some figures show the ultrasonic echo images for some point.

S.N	Testing Point S.N	Zone & Type of Surface	Test Results	Remarks
1	Point #1	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
2	Point #2	Zone A (Wall)	No defect	Sound concrete
3	Point #3	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
4	Point #4	Zone A (Wall)	No defect	Sound concrete
5	Point #5	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
6	Point #5A	Zone A (Wall)	No defect	Sound concrete
7	Point #6	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
8	Point #7	Zone A (Wall)	No defect	Sound concrete
9	Point #8	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
10	Point #9	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface

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By Saeed S. Alshahrani, Anwar K. Bloch, Abdullah S. Algrayan & Ziyad F. Alzamil

11	Point #10	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
12	Point #11	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
13	Point #12	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
14	Point #13	Zone A (Wall)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
15	Point #14	Zone A (Wall)	No defect	Sound concrete
16	Point #14A	Zone A (Wall)	No defect	Sound concrete
17	Point #15	Zone A (Wall)	No defect	Sound concrete
18	Point #16	Zone A (Wall)	No defect	Sound concrete
19	Point #17	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
20	Point #18	Zone A (Slab)	No defect	Sound concrete
21	Point #19	Zone A (Slab)	No defect	Sound concrete
22	Point #20	Zone A (Slab)	No defect	Sound concrete
23	Point #21	Zone A (Slab)	No defect	Sound concrete
24	Point #22	Zone A (Slab)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
25	Point #23	Zone A (Slab)	No defect	Sound concrete
26	Point #23A	Zone A (Slab)	No defect	Sound concrete
27	Point #24	Zone B (Slab)	No defect	Sound concrete
28	Point #25	Zone B (Slab)	No defect	Sound concrete
29	Point #26	Zone B (Slab)	No defect	Sound concrete
30	Point #27	Zone B (Slab)	No major defect (sound concrete)	Some minor defects in forms of small voids and non-structural cracks were noticed at the surface
31	Point #28	Zone B (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
32	Point #29	Zone B (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory

Table 3: Summary of Echo Scanning Results

As summarized in Table 2, most MIRA readings show no major imperfections in the concrete, however, some of the tested points showed internal major imperfections in the form of voids and cracks in the concrete and can be summarized as in Table

S. N	Testing Point S. N	Zone & Type of Surface	Test Results	Remarks
1	Point #1	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
2	Point #7	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
3	Point #9	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
4	Point #13	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
5	Point #19	Zone A (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
6	Point #31	Zone B (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory
7	Point #32	Zone B (Wall)	Different defects at several depths, minor voids due to concrete consolidation	Concrete considered not satisfactory

Table 4: Summary of Echo Scanning Results for Defected Structures

Gas Insulated Switchgear (GIS) Building Concrete Cracks Causes, Testing and Repair Procedures

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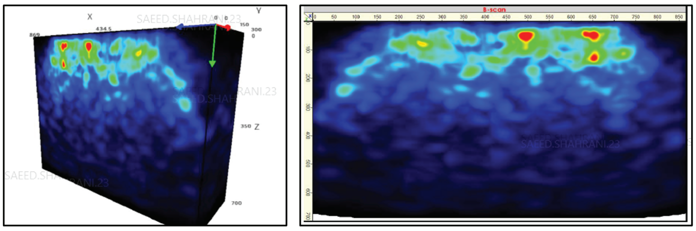

As summary of the tests result and according to the tests report, the average crack depth was 83 mm, and the quality of the concrete was mostly evaluated as sound.

Repair Procedures

Based on the test results, it was recommended to repair the cracks using epoxy grout injection method. In GIS basement, Nitomortar TC 2000 epoxy with CONBEXTRA EP 10 was used. It is high strength epoxy resin grout. It shall provide good general chemical resistance, and a 7-day compressive strength of at least 93 N/mm2.

Properties	
Pot life:	150 minutes at 20°C 25 minutes at 40°C
Density:	Approx. 1060 kg/m^3
Tensile strength:	30 N/mm^2 at 7 days
Flexural strength:	55 N/mm^2 at 7 days
Compressive strength:	55 N/mm^2 at 1 day 68 N/mm^2 at 3 days 93 N/mm^2 at 7 days
Modulus of elasticity: (ASTM C580 7 days)	16 KN/mm^2
Viscosity:	256 Cps at 35°C

Table 5: Material Properties

3D MIRA & UPV result after Cracks Repair

S.N	Location	Point #	Ultrasonic Pulse Velocity (m/s) in sound area	Concrete Quality in sound area	Ultrasonic Pulse Velocity (m/s) in repaired area	Concrete quality in repaired area
1	Slab	Point #1	5150	Excellent	4650	Excellent
2		Point #2	4460	Good	4220	Good
3		Point #3	5050	Excellent	4900	Excellent
4		Point #4	4810	Excellent	4180	Good
5		Point #5	5050	Excellent	4690	Excellent
6		Point #6	4880	Excellent	4200	Good
7		Point #7	4370	Good	4030	Good
8	Beam	Point #1	5130	Excellent	4480	Good
9		Point #2	4900	Excellent	4720	Excellent
10		Point #3	4520	Excellent	4220	Good
11		Point #4	5350	Excellent	4740	Excellent
12		Point #5	5130	Excellent	4370	Good
13		Point #6	4810	Excellent	4220	Good
14		Point #7	4370	Good	4050	Good
15		Point #8	4630	Excellent	4440	Good
16		Point #9	5430	Excellent	4880	Excellent
17		Point #10	4900	Excellent	4520	Excellent
18		Point #11	4880	Excellent	4570	Excellent
19		Point #12	5430	Excellent	4410	Good
20		Point #13	4440	Good	4220	Good
21		Point #14	5520	Excellent	5030	Excellent
22		Point #14A	4310	Good	4170	Good
23		Point #15	5050	Excellent	4150	Good
24		Point #16	4670	Excellent	5050	Excellent
25		Point #5A	4980	Excellent	4390	Good
26		Point #17	4900	Excellent	4570	Excellent
27	Wall	Point #4	4520	Excellent	4050	Good
30		Point #10	4520	Excellent	3890	Good
31		Point #11	4460	Good	3770	Good
32		Point #13	5130	Excellent	4810	Excellent
33		Point #14	4980	Excellent	4590	Excellent
34		Point #15	5710	Excellent	5260	Excellent
35		Point #16	4900	Excellent	4370	Good
36		Point #17	4880	Excellent	4670	Excellent
37		Point #18	4780	Excellent	4590	Excellent
38		Point #19	5080	Excellent	4780	Excellent
39		Point #20	5050	Excellent	4760	Excellent
40		Point #21	5710	Excellent	4880	Excellent
41		Point #22	4830	Excellent	4390	Good
42		Point #23	5050	Excellent	4570	Excellent

Table 6: Ultrasonic Pulse Velocity Test Results

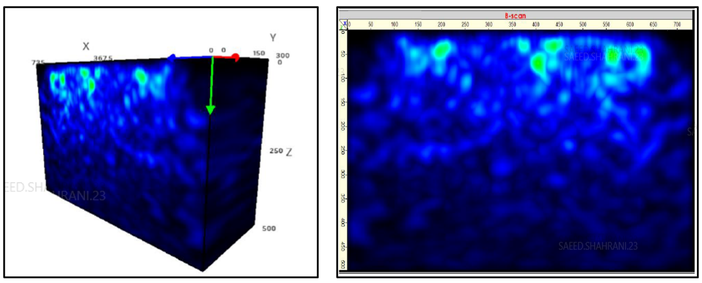

Figure 10: 3D MIRA Scanning Result for point 19 after repair

Gas Insulated Switchgear (GIS) Building Concrete Cracks Causes, Testing and Repair Procedures

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The quality of the concrete may considered as follows:

Excellent	> 4500 m/s
Good	3500-4500 m/s
Fair	3000-3500 m/s
Poor	2000-3000 m/s
Very Poor	< 2000 m/s

Table 7: Quality of concrete

Ultrasonic Echo Scanning Results (MIRA)

MIRA Tomography was used to inspect the internal quality of concrete to detect any internal voids, cracks or honeycombs after repairing. The test results for most of MIRA readings showed that the internal quality of the concrete is in good condition. Except testing point #3, in the beam and point #5 in the slab revealed some minor internal defects in the form of voids.

Table 5 summarizes all test results in various location of the GIS building.

S. No	Location	Point #	Test Results	Remarks
1	Slab	Point #1	No defect	Sound concrete
2		Point #2	No defect	Sound concrete
3		Point #3	No defect	Sound concrete
4		Point #4	No defect	Sound concrete
5		Point #5	Minor defect in form of internal voids	Some minor defects
6		Point #6	No defect	Sound concrete
7		Point #7	No defect	Sound concrete
8	Beam	Point #1	No defect	Sound concrete
9		Point #2	No defect	Sound concrete
10		Point #3	Minor defect in form of internal voids	Some minor defects
11		Point #4	No defect	Sound concrete
12		Point #5	No defect	Sound concrete
13		Point #5A	No defect	Sound concrete
14		Point #6	No defect	Sound concrete
15		Point #7	No defect	Sound concrete
16		Point #8	No defect	Sound concrete
17		Point #9	No defect	Sound concrete
18		Point #10	No defect	Sound concrete
19		Point #11	No defect	Sound concrete
20		Point #12	No defect	Sound concrete
21		Point #13	No defect	Sound concrete
22		Point #14	No defect	Sound concrete
23		Point #14A	No defect	Sound concrete
24		Point #15	No defect	Sound concrete
25		Point #16	No defect	Sound concrete
26	Basement	Point #7A	No defect	Sound concrete
27		Point #9A	No defect	Sound concrete
28	Wall	Point #4	No defect	Sound concrete
29		Point #10	No defect	Sound concrete
30		Point #11	No defect	Sound concrete
31		Point #11B	No defect	Sound concrete
32		Point #11C	No defect	Sound concrete
33		Point #11D	No defect	Sound concrete
34		Point #11EA	No defect	Sound concrete
35		Point #11EB	No defect	Sound concrete
36		Point #13	No defect	Sound concrete
37		Point #14	No defect	Sound concrete
38		Point #15	No defect	Sound concrete
39		Point #16	No defect	Sound concrete
40		Point #17	No defect	Sound concrete
41		Point #18	No defect	Sound concrete
42		Point #19	No defect	Sound concrete
43		Point #21	No defect	Sound concrete
44		Point #22	No defect	Sound concrete
45		Point #23	No defect	Sound concrete

Table 8: Ultrasonic Echo Scanning Results

Conclusion

GIS building cracks in basement walls and beams were identified, monitored and checked utilizing various testing procedures. The cracks were repaired through epoxy grout injection. The building was tested by a specialized 3rd party lab and found sound adequate.

Sources

1. CEB (Comité Euro-International du Béton) (1992), Durable concrete structures.
2. ACI 224R.01 (2001), Control of cracking of concrete structures.
3. B. Klemczak and A. Knoppik-wrobel (2011), Early age thermal and shrinkage cracks in concrete structures-description of the problem, ACEE, Vol.4, No.2, pp.35-48.