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A CASE STUDY OF CONDITION ASSESSMENT OF 210 MW RCC STRUCTURE OF TURBINE-GENERATOR SET IN THERMAL POWER PLANT

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Abstract :

The reinforced concrete structure undergoes deterioration because of several operational impacts of Turbine-Generator like turbine blade failure, Bearing failure, casing failure, sudden impact on mechanical assembly due to mechanical problems like rotor deformation, shaft bending, high temperature effect and electric short circuits on stationary parts.

These operational impacts develops undesirable stresses on rigid RCC Structure which develop cracks in RCC Pedestals, RCC beams, RCC Columns which could result in catastrophic failures, if not attended, hence for continued operation of Turbine-Generator set, structural health assesssment needs to be carried for to determine the soundness of concrete. The severity of the distress and the requirement for strengthening are then deduced. Each problem will be different and need to be solved using a special methodology suitable for the circumstances.

A case study is discussed for the restoration of concrete structures using modern NDT methods to minimise the vibrations in the Turbo-Generator set using modern methodology to measure the premature outages.

***Keywords**:* Turbo-generator(TG)Foundation, Reinforced Cement Concrete(RCC), Static and Dynamic evaluation

1. Introduction:

A Turbine-Generator set is the power generating high speed machinery that converts pressurized steam's thermal energy into mechanical energy. The pressurised steam exerts a tangential force on the moving blade and impact energy on it. This mechanical energy is then transferred to electrical energy by electric generator through drive shaft. The operating speed of Steam turbine may exceed more than 3000 rpm depending upon the design parameters. Turbine, generator and various auxiliary components like condenser & steam pipelines carrying superheated steam make up a turbo-generator.

Technical Challenges include rotor imbalance, vibration,bearing wear and uneven expansion of mechanical components.

Turbine-generator foundation is a complex engineering structural component. It is typically housed inside the Turbo-Generator structure. Depending on their capacity, geometrical sizes, and constructional qualities, many types of turbine foundation are utilized for various machines. A RCC table top foundation are commonly adopted.

The TG deck, RCC columns and bottom raft together constitute the turbo-generator foundation. Sometimes the turbo-generator set is mounted on vibration isolator also.

A sturdy support is necessary for a turbo-generator machines that can withstand static and dynamic loads as well as the consequent vibrations.

The basic principal of TG foundation that No resonance should occur and therefore, the inherent frequency of the foundation system shouldn't match the machine's working frequency.

The limiting amplitudes provided by the machine manufacturers should not be exceeded by vibration at operating frequencies.

The permissible excetricity of 3% of foundation base with refrence to the centre of gravity.

The tabletop turbine-generator should be built to keep the amplitude of rotary shaft and turbine bearing vibration within acceptable limit.

If there is any eccentricity or severe vibration, it could seriously harm the turbine casing and rotor blades.

Fig. 1: Photographic view of TG Machine

On the top of TG deck, where the turbine, generator, governor and other mechanical-electrical instrumentations are installed.

2. Dynamic Analysis :

Theoretical formulation

The natural frequency of rotary machines should be less than 20% of the operational machine frequency, according to BIS 2974-3 (1992), a code of practice for designing the foundation of rotary machines.

fi < 0.8 fm or fi > 1.2fin

where,

fn - foundation's natural frequency at its core.

fm - machine's frequency of operation.

However, keeping the frequency ratio at 50% is doable.

3. Structural Analysis :

The main force acting on the foundations is :

(i) Dead load
(ii) Live load
(iii) Static load
(iv) Constant torque load
(v) Blade circulation loss
(vi) Load for thermal expansion
(vii) Dynamic load
(viii) Low-voltage load
(ix) Temperature load
(x) Shrinkage load
(xi) Seismic load

4. RCC Structure of TG Deck consider for Inspection – A Case Study of the Thermal Power Plant's 210 MW Turbine Generator Deck Foundation is discussed.

The following structural members were assessed for the condition assessment with testing without disruption:

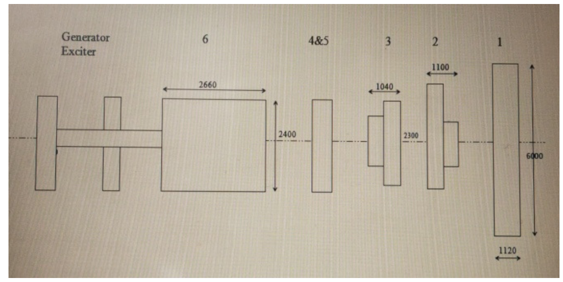

Fig. 2: Schematic view of TG Deck Bearing RCC pedestals

The details of TG Deck foundations assessed are described below :

1. Bearing Pedestal No.1(RCC) : HP front Bearing
2. Bearing Pedestal No.2(RCC) : HP-IP Rear Bearing
3. Bearing Pedestal No.3(RCC) : LP Rear Bearing
4. Bearing Pedestal No. 4 &5: Mounted on MS Frame
5. Bearing Pedestal No.6(RCC) : Generator Exciter Block
6. Height of Pedestal No.1 : 860mm
7. Height of Pedestal No.2 : 650/750mm
8. Height of Pedestal No.3 : 950mm
9. Height of Pedestal No.4&5 : Mounted on MS steel frame
10. Height of Pedestal No.6 : 1270mm (Generator Exciter)

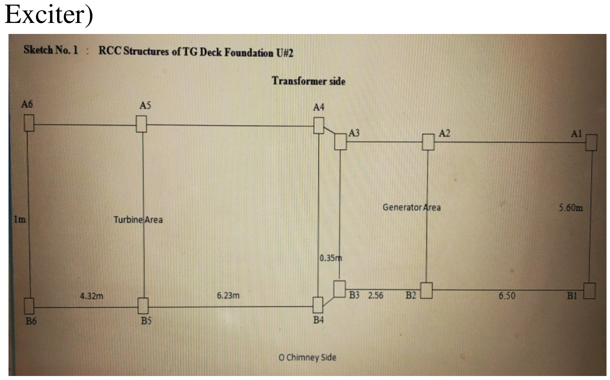

Fig. 3: Schematic view - Arrangment of TG Deck RCC Columns

Table-1: Legends of TG deck RCC columns:

S.N	Description	Dimension mm
1.	A1, A3	1200 x1200
2.	A2	1000 x1200
3.	A4, A5, A6	800 x 1600
4.	B1, B3,	1200 x1200
2.	B2	1000 x1200
3.	B4, B5, B6	800 x 1600

Figure No. 3 : The HP turbine rotor is installed in the cutout on the front pedestals, IP turbine rotor on the elevated pedestal in middle and the generator assembly on the end pedestal.
The combined assembly should be set up so that the center of gravity of the RCC deck base and the Turbo Generator set are exactly aligned.

5.0 Method of Assessment:
The Non Destructive Testing of the RCC members of turbo generator deck foundation were adopted for assessment. The following probing tests were carried out :

5.1 Visual examination:
The initial phase in structural assessment & evaluation is visual examination, which provides crucial information regarding the physical condition of the structure i.e. normal or abnormal condition, severity and extent of distress occurred in the structure.

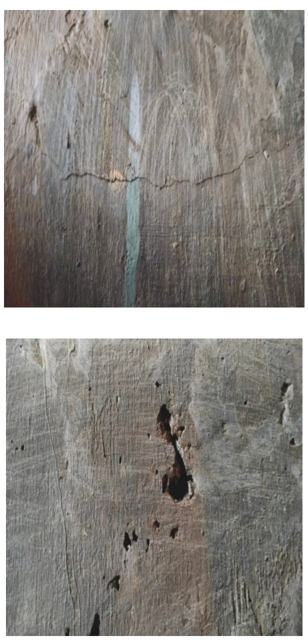

Fig. 4: Cracks & Porosity found in TG deck Pedestal

Fig. 5: Honeycombed Concrete observed

5.2 Ultrasonic Pulse Velocity Test (USPV) :
The path length and transit time are measured to obtain the Pulse velocity of concrete. The transducers & receiver of 54KHZ frequency probe used for the study. Direct and Semi-direct methods are used to determine the Pulse Velocity.

The pulse velocity is determined by the equation:

$$\text{Pulse Velocity} = \frac{\text{Path Length(m)}}{\text{Transit Time(s)}} \text{ - m/s}$$

Table -2 : T.G. RCC Columns at +6.0m lvl.

S. N	Particulars	Path Length mm	Transit Time µs	Velocity m/s
1.	Column A1	1200	507	2370
		1200	348	3450
2.	Column A2	1000	953.0	1050
		1000	262.0	3820
3.	Column A3 400X500	640	318	2670
4.	Column A4 400x800	894	272	2440
5.	Column A5 400X400	565	368	1540
6.	Column A6 400X500	640	550	1160
7.	Column B1	1200	534	2250
8.	Column B2 300X600	670	294.0	2280
9.	Column B3 600x600	848	466	1820
10.	Column B4 400x400	565	159.5	3540
11.	Column B5 400x600	721.0	513.0	1410
12.	Column B6	800	211.0	3790
		1600	420.0	3810
13.	Av. Value			2493

Table-3: T.G. Deck RCC Beams at +10.0m lvl.

S.N	Particulars	Path Length mm	Transit Time µs	Velocity m/s
1.	A1-A2			
	400 X 400	565	327	1730
2.	400 X 400	565	303	1870
	400 X 400	565	211	2680
3.	400 X 400	565	229	2470
4.	A2-A3			
5.	500X500	707	580	1220
	A3-A4			
	400X400	565	408	1390
	A1-B1			
	500 X 500	707	373	1900
	400 X 400	565	442	1280
	500 X 500	707	418	1696
	500 X 500	707	574	1230
	B1-B2			
	500 X 500	707	368	1920
	500 X 500	707	340	2080
	500 X 500	707	293	2410
	B5-B6			
	900 X 1000	1345	989	1360
	900 X 1000	1345	840	1600
	900 X 400	985	958	1030
	B4-B5			
	900 X 1000	1345	895	1500
	900 X 1000	1345	819	1640
	900 X 1000	1345	905	1490
	Average Value			1710

Table-4 : Turbine casing Bearing Pedestals : **Tabl**

S. N	Particulars	Path Length mm	Transit Time µs	Velocity m/s
1.	Generator Exciter Pedestals Transformer side			
	500x500	707	464	1520
	500x500	707	312	2270
	1000x1000	1414	746	1990
	1000x1000	1414	777	1820
	Chimney side			
	500x500	707	535	1320
	500x500	707	203	3480
2.	Bearing No. 4 & 5 Supported on steel frame			
3.	Bearing Pedestal No.3			
	LP rear-Transformer side			
	300x700	761	603	1260
	300x700	761	654	1160
	LP Rear - Chimney Side			
	300x400	500	402	1240
	300x400	500	339	1480
	Supporting Beam			
	400x400	565	233	2430
	LP Turbine casing Support			
	Transformer side			
	300x700	761	698	1090
	300x700	761	894	850
	LP Turbine casing Support			
	Chimney side			
	300x700	761	698	1110
	300x700	761	894	910
	Supporting Beam			
	400x400	565	173.3	3260
	Av. Value			1699

Fig. 6: **Ultrasonic Pulse Velocity data**

Table - 5 : The reference Concrete quality grading for various velocities is taken from Table 2 of IS: 13311(Part-1) 1992.

S.N	Pulse Velocity (km/sec)	Concrete Quality Grading
1.	Below 3.0	Doubtful
2.	3.1 to 3.5	Medium
3.	3.6 to 4.5	Good
4.	Above 4.5	Excellent

5.3 Schmidt Rebound Hammer Test :

The surface hardness of the concrete is measured using fixed impact energy & measuring the average rebound number.

Table-6: The Schmidt Rebound hammer test **is** used for the study:

S.N.	Particular	Rebound Value	Impact Direction	fck N/mm 2
1.	RCC Columns			
	A1	21R	Horizontal	12.5
	A2	24R	Horizontal	16.1
	A3	21R	Horizontal	12.1
	A4	23R	Horizontal	15.1
	A5	22R	Horizontal	13.5
	A6	23R	Horizontal	13.5
	B1	21R	Horizontal	14.6
	B2	23R	Horizontal	15.1
	B3	23R	Horizontal	17.1
		24R	Horizontal	15.6
	B4	22R	Horizontal	14.6
	B5	23R	Horizontal	15.1
	B6	21R	Horizontal	14.0
2.	RCC Beams			
	A1-B1	21R	Vertical	13.5
	B1-B2	22R	Vertical	13.5
	A1-A2	21R	Vertical	12.1
	A2-A3	26R	Vertical	17.1
	B4-B5	24R	Vertical	16.1
	Deck Slab			
	B1-B2	17R	Vertical	16.1
		15R	Vertical	15.0
	A1-B1	16R	Vertical	15.1
		17R	Vertical	16.5
	A1-A2	17R	Vertical	15.7
		16R	Vertical	16.0
	A3-A4	20R	Vertical	18.3
		17R	Vertical	16.7
	Av. Value			15.02

The curves for evaluating the in-situ compressive strength of concrete using rebound hammer and combined ultrasonic pulse velocity testing

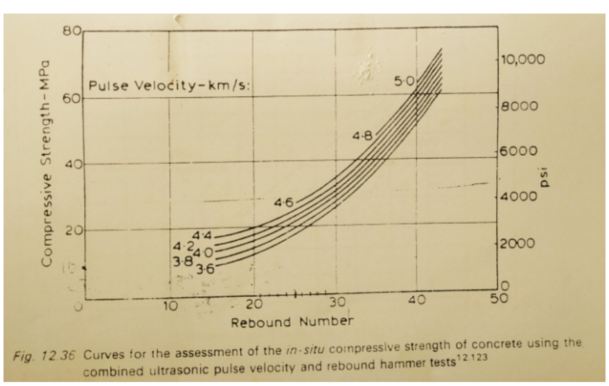

Fig. 7 : Combined curves for assessment of surface strength

5.4 Carbonation Test (CT)

To determine the extent of carbonation in the RCC members, a carbonation test is performed. In this method, small drilled holes are sprayed with Phenolphthalein indicator for finding the depth of carbonation

Table-7: Depth of Carbonation

Sl. No	Description	Depth of Carbonation	
		up to 40 mm	up to 80 mm
1.0	Generator Exciter	No carbonation	No carbonation
2.0	Bearing Pedestal 1	No carbonation	No carbonation
3.0	Bearing Pedestal 2	No carbonation	No carbonation
4.0	Bearing Pedestal 3	No carbonation	No carbonation

5.4.1 Stipulation of Carbonation Test :

Determination of carbonation depth in hardened concrete by the phenolphthalein method
British standard : BS EN 14630:2006

Depth of carbonation (D)

$D = Kt^{0.5}$

Where,

K = Carbonation factor in millimeters per year (3 to 4mm/year)

t = years of exposure time.

5.5 pH & Potential tests :

The pH value of ordinary Portland cement is usually between 12.5 to 13. It can reduce due to deterioration mechanism such as chloride ingress, carbonation or acid attack.

Fig. 8: pH & Potential tests of samples collected

Table-8 : Test Result of pH and Potential Test

Test Object : TG Deck structure					
Method : Titration					
Instrument : EI Digital pH meter					
Ultrasonic probe frquency : 54KHZ					
S. N	Particular	pH	Potential (mV)	pH	Potential [mV]
		40mm depth		80mm depth	
1.	TG Deck Columns				
	A1	11.18	-250	11.47	-267
	A2	11.26	-255	11.35	-260
	A3	10.93	-235	10.92	-235
	A4	11.21	-252	11.65	-277
	A5	11.03	-241	11.43	-265
	A6	10.70	-221	11.77	-286
	B1	10.41	-204	11.44	-266
	B2	10.14	-188	11.41	-264
	B3	10.80	-227	11.49	-269
	B4	11.07	-244	11.51	-270
	B5	9.61	-156	11.29	-257
	B6	11.20	-252	10.87	-232
2.	TG Beams				
	A1-A2	10.58	-215	11.08	-244
	A2-A3	10.77	-226	11.61	-276
	A3-A4	10.03	-132	11.49	-269
	A5-A6	10.20	-191	11.21	-252
	A1-B1	11.19	-251	-	-
	A2-B2	10.99	-239	-	-
	A6-B6	10.25	-195	-	-
	A5-A6	10.25	-195	-	-
		11.06	-243	-	-
	B1-B2	10.54	-212	11.51	-270
		10.79	-227	11.35	-261
		11.09	-244	11.17	-250
	B3-B4	9.37	-142	11.29	-257
				10.46	-207
	B4-B5	9.94	-177	10.93	-235
		10.09	-185	-	-

The fresh concrete should have a pH value between 12 and 13.
The Concrete will experience a carbonation impact if the pH value is significantly below 10, which indicates concrete carbonation.

The measurement of carbonation depth in mm in accordance with BS: 1881 Part 201 1986 :

$D = Kt^{0.5}$

Where,

K = Carbonation factor in millimeters per year,

t = Years of exposure time.

(K = 3 to 4 mm/year)

5.6 : Vibrations measurement:

The amplitude of the oscillation is the manifestation of the vibration measurement. The extreme vibration points to rotary components losing their integrity and generating less power as a result of forced outages.

5.6.1 Vibration Standards – ISO 10816 :

The ISO 2372 (10816) Standards gives recommendation for assessing the level of vibration in machinery working at frequencies between 10 and 200 Hz (600 and 12,000 RPM).

These devices include steam and gas turbines, turbo-compressors, generators, turbo-pumps, and fans. Other examples are small, direct-coupled electric motors and pumps, production motors, and medium motors. Some of these devices can be connected via gears, rigid or flexible coupling, or both. The spinning shaft's axis can be vertical, horizontal, or inclined at any angle. To assess the overall vibration intensity of a high speed rotating machine, refer to the chart below.

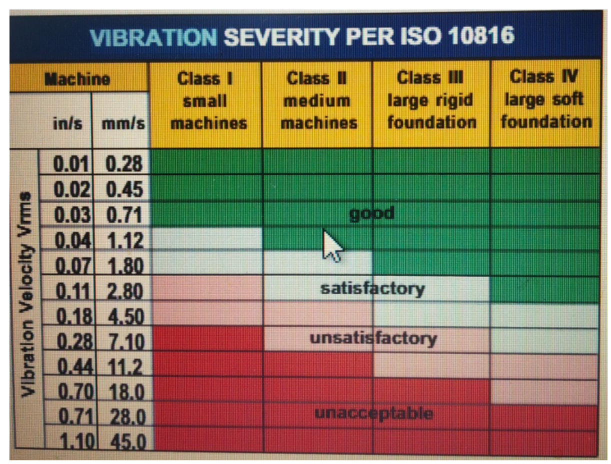

Figure 9: Vibration severity chart

5.6.2 Records from the control room indicate that 14.5mm/s of turbine vibrations were measured before structural assessment and retrofitting.

Figure 10: TG deck Vibration data before restoration

6.0 Analysis & Observations :

The following observations were made in light of the observed data's correlation with the reference's specifications for hardened concrete. Ultrasonic pulse velocity (USPV) statistics show that the core concrete is of questionable quality, or unsound in nature. Reduced surface strength is indicated by the rebound hammer test.

The results of the pH and potential research indicate that the concrete is alkaline both at and beyond the level of the reinforcement.

The vibration measurement indicates higher amplitude of vibration observe beyond the limiting value i.e excessive vibrations

Based on the aforementioned observed data, it is necessary to restore the RCC structure of Turbine – Generator set using an appropriate strengthening method.

7.0 Recommendations :

The RCC structure of the turbine generator set should be strengthened utilizing new techniques and high-strength materials.

The following method adopted for structural rehabilitation of TG deck foundation.

7.1 **Restoration of RCC Pedestals**

High strength microconcrete concrete was used to replace the fractured GP-2 concrete. Low viscosity injection epoxy grouting was done for bearing pedestals. Surface treatment

Bearing pedestal surface treatment was done with epoxy mortar.

7.2 **Restoration of RCC Columns**

using high strength epoxy mortar to fill gaps and seal honeycombed patches in RCC columns with injection low viscosity epoxy grouting.

7.3 **Restoration of RCC Beams & Deck slab**

Injection low viscosity epoxy grouting in RCC beams & deck slab and sealing of cracks & honeycombed patches with high strength epoxy mortar. Application of epoxy mortar on all sides of beams.

8.0 Post treatment analysis and observation ;

After the RCC Structure underwent post-treatment, the turbine vibrations as determined by control room recordable data significantly decreased. The observation showing a decrease in the amplitude of vibration's , it was recorded as 5.3 mm/s.

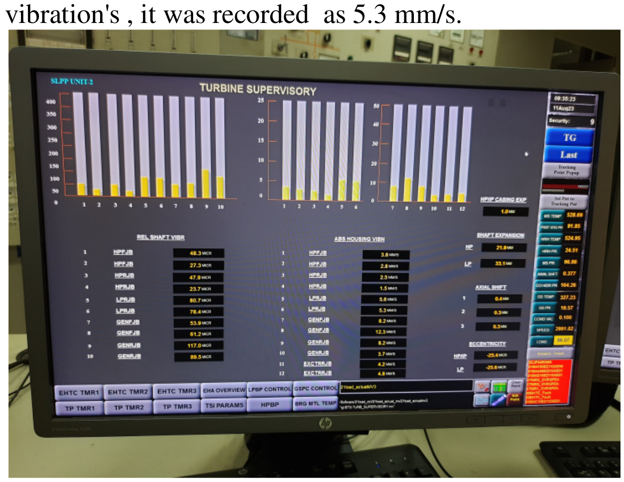

Figure 11: TG deck Vibration data after restoration

9.0 Conclusions:

The present RCC structure identified for structural assessment found to have internal pores, honeycombing and internal cracks and voids in its RCC columns, RCC beams and RCC Bearing pedestals, all of which contribute to unsound hardened concrete. The density of the concrete is increased after the successful implementation of restoration of existing structure.

Ultimatly , amplitude of vibration was significantly reduced.

10.0 Acknowledgement :

The Author expresses gratitude to the management for their support, guidance and permission to complete this work and submit this article for presentation.

The author expects that, this work will be beneficial to the researchers and will provide important information for structural assessment and rehabilitation of the RCC structure of turbine-generator set.

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