

STUDIES ON EFFECTS OF EARTHQUAKE FORCES ON
POWER INSTALLATIONS IN THE UNDERGROUND AND
SURFACE POWER HOUSES IN EPICENTRAL TRACTS

by

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SUMMARY

Effects of earthquake forces on power installations in the underground and surface power houses in the epicentral tracts of four medium sized shallow focus earthquakes which occurred in the Indian Peninsula during last one decade or so have been discussed in this paper. Subsequent dynamic tests on some of the electrical equipments under laboratory conditions have corroborated field observations and revealed that these equipments could withstand efficiently high ground accelerations in the expected frequency range of earthquake vibrations.

INTRODUCTION

Four medium sized shallow focus earthquakes occurred in the Indian Peninsula during last one decade or so and provided an opportunity of studying the effects of earthquake forces on the underground and surface power installations. Three of these shocks which occurred on September 13, 1967 (M = 5.8), December 10, 1967 (M = 7.0) and October 17, 1973 (M = 5.2) had their epicentres in the Koyna region (Lat.17°24' N; Long. 73°45' E) in the close vicinity of the underground hydroelectric power station at Pophali housing eight generators with total installed capacity of 540 MW. The fourth shock occurred on April 13, 1969 (M = 5.7) whose epicentre (Lat.17°55' N; Long. 80°36' E) was close to the surface Thermal Power Station at Kothagudem with an installed capacity of 240 MW. Subsequently in order to verify the observed dynamic behaviour of various electrical equipments during the above earthquakes laboratory experiments on some of these equipments with vibration table test techniques were conducted.

DAMAGE SURVEY OF ELECTRICAL INSTALLATIONS

During the main Koyna earthquake of December 10, 1967 surface area of the underground hydroelectric power station at Pophali was enclosed within isoseismal VI (III) with recorded maximum acceleration of 0.60 'g' close to the epicentre. All

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the eight generator units and other electrical installations in the underground power house and in the surface switchyard escaped with very minor damages. Hydraulic system did not suffer any noticeable damage and no appreciable change was observed in the alignment of machines. All the generators tripped due to effect of vibrations on relays. Condition of all electrical installations in the emergency valve house and at intake tower point was generally satisfactory and no structural damage other than loosening of foundation bolts was observed. Minor damages to porcelain insulators of current and potential transformers in the surface switchyard were noticed. Remaining two shocks in the Koyna region did not produce any damage of significance to surface and underground installations owing to low surface intensity which was V (MM) at Pophali. Recorded maximum acceleration on strong motion accelerograph inside the power house at Pophali during the Koyna earthquake of October 17, 1973 was 5% 'g'. Area surrounding surface Thermal Power Station at Kothagudem was enclosed within isoseismal VI (MM) during April 13, 1969 earthquake. All generators in the Power House tripped due to effect of vibrations on relays but none of the electrical machines founded on well designed heavily reinforced frame type concrete foundations suffered any damage of significance.

Electrical power installations in the underground power house at Pophali have been subjected to several earthquakes of magnitude 4.0 and above which occurred in the Koyna region during the decade following the main shock of December 10, 1967. The power installations here have not shown any signs of distress and thus have demonstrated the threshold levels of safe ground accelerations for these installations. Machines in the Pophali underground power house are founded on confined hard basaltic rock mass and the minor damages observed during the main Koyna earthquake could be attributed to attenuation of surface accelerations with depth (300 m) together with the higher natural frequency of generator foundations (~ 40 Hz).

ASEISMIC TESTS ON ELECTRICAL EQUIPMENTS

Laboratory aseismic tests were conducted on electrical relays, 120 and 198 KV lightning arresters, 220 KV disconnecting switch and minimum oil circuit breaker to estimate their frequency response and assess their capability of sustaining simulated earthquake motions with the help of vibration table test techniques. In view of the observed dynamic characteristics of the main Koyna earthquake aseismic tests were confined to the significant earthquake frequency range of 3 to 15 Hz for 0.50 'g' (horizontal) and 0.25 'g' (vertical) accelerations for testing of above electrical equipments, except for minimum oil circuit breaker which was tested only for 0.60 'g' horizontal acceleration. As there is no standard code of practice prescribing aseismic test procedure, Chilean practice was broadly adopted (1). Fig.1 shows minimum oil circuit breaker under tests on

electro-mechanical vibration table.

Frequency responses of the abovementioned electrical equipments were first estimated by exciting them on the vibration table at appropriate vibration amplitudes. The same were then subjected to the specified horizontal and vertical accelerations in the frequency range of 3 to 15 Hz. Frequency response curves were plotted as dynamic magnification, X (ratio of vibration amplitude at the top of equipment to that at the table) against corresponding frequency. Fig.2 shows a typical frequency response curve for minimum oil circuit breaker for horizontal (Transverse) vibrations. Fundamental natural frequencies and damping coefficients were estimated from the frequency response curves for each equipment and are given in Table-I for various experimental conditions.

The fundamental natural frequencies for all the electrical relays, 120 KV lightning arrester and 220 KV disconnecting switch are found to be within the earthquake frequency range of 3 to 15 Hz thus showing possibility of resonance in the epicentral region (vide Table-I). The electrical relays tripped/operated/showed tendency to trip etc. at or around the resonant frequency when subjected to respective horizontal and vertical accelerations (2) and the same was also experienced during the main Koyna earthquake. Further all other equipments withstood very efficiently simulated earthquake forces produced on the vibration table and showed no failure or distress in any form. Frequency response of 220 KV disconnecting switch was also estimated under prototype conditions at Pophali switchyard which was found to be beyond earthquake frequency range (vide Table-I), indicating that the structure as a whole was highly rigid against the earthquake forces - a fact which was confirmed by its safe dynamic behaviour during the main Koyna earthquake.

Maximum acceleration response spectra of the main Koyna earthquake of Dec. 10, 1967 show large values of acceleration at low periods (0.1 to 0.3 sec) diminishing rapidly with increase of period and thus provide valuable design criteria for structures in the epicentral tracts.

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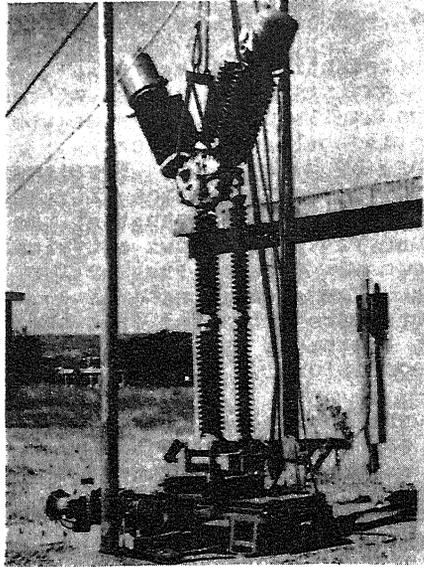


FIG. 1. MINIMUM OIL CIRCUIT BREAKER (TYPE: HLR 245/250-B) UNDER ASEISMIC TESTS ON ELECTRO-MECHANICAL VIBRATION TABLE

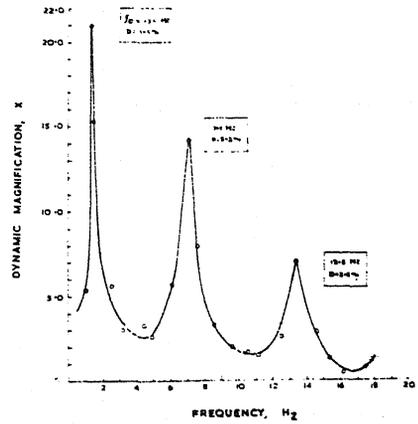


FIG. 2. FREQUENCY RESPONSE CURVE FOR MINIMUM OIL CIRCUIT BREAKER WITH HIGH STRENGTH SOLID CORE SUPPORT INSULATORS

TABLE I
Typical Dynamic Characteristics of Electrical Equipments Estimated from Laboratory and In-situ Prototype Aseismic Tests

Sr. No.	Electrical Equipment	Component of Vibration	Fundamental Natural Frequency (f_0), Hz	Damping (D), % of Critical Damping	Condition of Test	Means of Excitation	
1.	Electrical Relays (Mounted on panels)	Longitudinal (I)	7.5 - 9.0	-	Relays working under prototype conditions	Simusoidal Vibration	
		Transverse (II)	6.4 - 6.7	-		"	
		Vertical	> 15.0	-		"	
2.	120 KV Lightning Arrester	Horizontal	3.8	3.9	Grading ring attached	Simusoidal Vibration	
		Vertical	> 15.0	-		"	
3.	198 KV Lightning Arrester	Horizontal	1.8	3.6	Grading ring attached	Simusoidal Vibration	
		Vertical	> 15.0	-		"	
4.	220 KV Disconnecting Switch (Laboratory)	Longitudinal	3.8	3.4	Closed arm	Simusoidal Vibration	
		Longitudinal	3.6	3.3		Open arm	
		Transverse	3.3	3.0		Closed arm	
		Transverse	3.4	3.3		Open arm	
		Vertical	> 15.0	-		Open arm	
5.	220 KV Disconnecting Switch (In-situ)	Longitudinal	21.0	2.4	Closed arm	Simusoidal Vibration	
		Transverse	19.5	2.0		Closed arm	
6.	Minimum Oil Circuit Breaker - type HLR 245/250-3 with	i) High strength solid core support insulator (2 Pieces)	Transverse	1.35	5.5	As in Fig.1	Simusoidal Vibration
			Transverse	1.25	5.1		Rope test or Snap back test
		ii) Polycone type support insulator (Single)	Transverse	1.60	4.2	"	Simusoidal Vibration
			Transverse	1.53	5.9		Rope test or Snap back test
			Longitudinal	2.10	3.2		"
		iii) Standard solid core support insulator (2 Pieces)	Transverse	1.50	4.6	"	Simusoidal Vibration
			Transverse	1.43	5.6		Rope test or Snap back test
			Longitudinal	1.72	4.2		"

I Longitudinal : Plane of Relay/arm of disconnecting switch/plane of interrupter parallel to direction of force

II Transverse : Plane of Relay/arm of disconnecting switch/plane of interrupter perpendicular to direction of force.