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# Non-Linear Analysis of Transmission Tower on Sloped Ground Subjected to Seismic Forces

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**ABSTRACT:** In this study, an attempt has been made to study the non-linear time history analysis of transmission towers on various sloped ground (13.5 degree and 30 degree) when subjected to seismic forces in seismic zone 5. Two different heights (30m and 40m height) transmission towers with different bracing systems (eccentric bracing, X bracing and inverted V bracing) are modelled and analysed using SAP2000 software. Effect of provision of base isolation (rubber isolator) technique is also dealt. The parameters such as axial force, time period, base reactions are obtained. All these parameters increase as the height increases.

**KEYWORDS:** non-linear time history analysis, base isolation, SAP2000, seismic, transmission tower, sloped ground.

## I. INTRODUCTION

A transmission tower is a tall structure used to carry high voltage AC and DC and they come in different sizes and shapes. The need of electric consumption has been increasing in all parts of the world day by day. Transmission line towers are one of the important life-line structures used to carry electricity. In present situation the power plants have been increasing resulting in the increase of the transmission towers to satisfy the needs. Hence it is necessary to design and analyse the transmission towers to withstand all the odds and prove to be reliable, economical and durable. Transmission towers on hilly areas (zone 5) are more prone to earthquakes and hence it is necessary to carryout seismic design to satisfy the serviceability criteria.

Transmission towers are designed and constructed in wide variety of shapes, types, sizes, configurations and materials. The supporting structure is classified into these types as follows: lattice steel towers, tubular steel pole and guyed towers. Steel lattice towers are generally preferred for supporting structure. Various factors like ground clearance, proper insulation, sufficient cross sections and spacing between the conductors have to be taken care of. Time history examination is the well ordered investigation of the dynamic reaction of a structure to a predetermined loading that may shift with time. Usually under dynamic loading, to find out seismic response for a particular earthquake data we use time history analysis. The major reason to prefer time history analysis is that, basically response spectrum analysis is linear dynamic analysis. Since we are performing non-linear analysis time history analysis is preferred. Also time history analysis will give response of the structure with respect to time during and after the application of load.

## II. RELATED WORK

Parashuram Hadimani and Sachin Kulkarni concluded that as the number of modes increased, natural frequency gradually increased. Also through spectrum analysis they found that, stress increases as the acceleration increases [1]. Transmission towers subjected to wind forces will experience tension at windward side and compression at leeward side when analysed using STAAD PRO software was confirmed by K.N.G. Nandan and Trinath babu [2]. Sourabh Rajoriya, k.k. pathak and vivekanand vyas found that deflection and support reaction is more for 60m tower than 40m and 50m tower. But bending stress was more in case of 50m tower [3]. From the wind analysis Keshav Kr. Sharma, S.K.Duggal, Deepak Kumar Singh and A.K.Sachan found that displacement increases with increase in speed and it was

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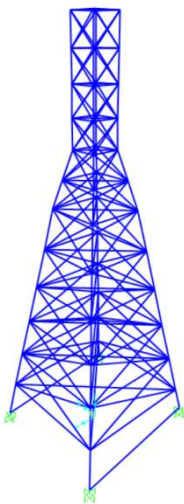
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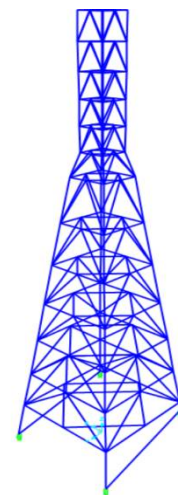
maximum for W bracing and minimum for K bracing. Stress was vice-versa of displacement criteria [4]. Shachindra Kumar Chadhar and Dr. Abhay Sharma carried out static analysis for 15 storeyed building in zone 4 and found that V bracing reduces storey drift, bending moment and shear forces significantly. Also concluded that double angle section gives better result than ISMC and ISMB [5]. By carrying out analysis using SAP2000 software for five storied moment resisting frame with rubber isolation, Prof.R.B.Ghodke and Dr.S.V.Admane concluded that, as the height increases, displacement also increases with increase in time period due to isolation [6]. Alok Dua, Mathias Clobes and Thomas Hobbel conducted dynamic analysis using SAP2000 and found that, the response for a coupled model is different from the response when only wires were considered and also aerodynamic damping is an influential parameter in the response of transmission lines [7]. Provision of base isolation technique result in reduction of base shear, story drift, displacement and time period. This was given by Dr .R .S .Talikoti and Mr. Vinod R thorat [8]. Progressive collapse analysis carried out by Li Tian, Ruisheng Ma, Wenming Wang and Lei Wang found that, compared to scale model test, numerical simulation method was found to be accurate. Longitudinal or transverse collapse path are different under various seismic waves [9].

### III. MODELLING OF TRANSMISSION TOWER:

The steel transmission tower is designed for heights of 30m and 40m. The towers are provided with 3 different types of bracings: eccentric type, X type and inverted V type. Support conditions like fixed support and provision of rubber isolators is included. Base width of 5m is adopted. For 40m transmission towers ISA100\*100\*10 and for 30m transmission towers ISA80\*80\*10 is adopted. The towers are modelled, analysed and designed using SAP2000 software.



30m tower with X bracing on  
13.5 degree sloped ground



40m tower with inverted V bracing  
on 30 degree sloped ground

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### IV. ANALYTICAL RESULTS

Table 1: 30m transmission tower on 13.5 degree sloped ground

Height in m	Support conditions	Bracings	Inclination of ground in degree	Base reaction in N	Joint displacement in mm	Time period in sec	Axial force in N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
30	Fixed	Eccentric	13.5	150	14.650	1.1807	146.4	0.0068	0.05944
		Inverted V	13.5	842	14.668	0.7587	881.6	0.0062	0.05878
		X	13.5	631	14.750	0.8830	966.1	0.0080	0.09305
	Rubber isolator	Eccentric	13.5	142	14.684	1.7532	187.3	0.0156	0.13183
		Inverted V	13.5	231	14.740	1.3750	1452.1	0.0071	0.08739
		X	13.5	401	14.764	1.5515	1895.0	0.0087	0.10230

Table 2: 30m transmission tower on 30 degree sloped ground

Height in m	Support conditions	Bracings	Inclination of ground in degree	Base reaction in N	Joint displacement in mm	Time period in sec	Axial force in N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
30	Fixed	Eccentric	30	185	14.560	1.1010	106.7	0.0075	0.70630
		Inverted V	30	565	14.650	0.6506	392.1	0.0072	0.06976
		X	30	701	14.640	0.2190	421.1	0.0081	0.08771
	Rubber isolator	Eccentric	30	181	14.790	1.3970	143.1	0.0097	0.08562
		Inverted V	30	352	14.865	0.7046	2875	0.0194	0.20718
		X	30	491	15.430	0.3320	2390	0.0153	0.16470

Table 3: 40m transmission tower on 13.5 degree sloped ground

Height in m	Support conditions	Bracings	Inclination of ground in degree	Base reaction in N	Joint displacement in mm	Time period in sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
	Fixed	Eccentric	13.5	285	14.687	1.4313	419.3	0.0081	0.07194
		Inverted V	13.5	994	14.802	1.0326	1624	0.0119	0.16869

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40		X	13.5	947	14.799	1.1823	1045	0.0136	0.18542
	Rubber isolator	Eccentric	13.5	244	14.770	2.3570	437.9	0.0124	0.10506
		Inverted V	13.5	628	15.020	1.8270	2162	0.0212	0.18920
		X	13.5	796	15.191	2.0000	1607	0.0382	0.23152

Table 4: 40m transmission tower on 30 degree sloped ground

Height in m	Support conditions	Bracings	Inclination of ground in degree	Base reaction in N	Joint displacement in mm	Time period in sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in $m/s^2$
40	Fixed	Eccentric	30	342	14.595	1.2976	391.4	0.0078	0.06340
		Inverted V	30	1654	15.040	0.5893	2673	0.0112	0.15691
		X	30	2548	15.051	0.5241	3504	0.0164	0.19255
	Rubber isolator	Eccentric	30	297	14.880	1.6990	438.9	0.0130	0.11131
		Inverted V	30	1168	15.230	0.9220	3561	0.0225	0.23461
		X	30	956	15.195	1.0430	9280	0.0423	0.25310

Table 5: 30m transmission tower with different eccentricity on 13.5 degree sloped ground

Height in m	Support conditions	Inclination of ground in degree	Angular variation in degree	Base reaction, N	Joint displacement, mm	Time period, sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in $m/s^2$
30	Fixed	13.5	5.44	139	14.617	1.4570	147.5	0.0065	0.05814
			8.13	150	14.650	1.1807	146.4	0.0068	0.04944
			10.78	328	14.718	0.9700	277.8	0.0069	0.05501
	Rubber isolator	13.5	5.44	125	14.675	1.9548	205.6	0.0092	0.08549
			8.13	142	16.684	1.7532	187.3	0.0156	0.07536
			10.78	240	14.781	1.6030	434.6	0.0158	0.08023

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Table 6: 30m transmission tower with different eccentricity on 30 degree sloped ground

Height in m	Support conditions	Inclination of ground in degree	Angular variation in degree	Base reaction in N	Joint displacement in mm	Time period in sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
30	Fixed	30	5.44	138	14.530	1.3960	138.2	0.0073	0.07065
			8.13	185	14.560	1.1010	106.7	0.0075	0.07063
			10.78	288	14.693	0.7160	883.5	0.0076	0.07045
	Rubber isolator	30	5.44	110	14.632	1.7450	168.6	0.0083	0.08405
			8.13	181	14.790	1.3970	143.1	0.0097	0.08000
			10.78	481	14.903	0.9220	523.7	0.0099	0.08213

Table 7: 40m transmission tower with different eccentricity on 13.5 degree sloped ground

Height in m	Support conditions	Inclination of ground in degree	Angular variation in degree	Base reaction, N	Joint displacement, mm	Time period, sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
40	Fixed	13.5	5.44	281	14.656	1.7828	462.3	0.0069	0.09709
			8.13	285	14.687	1.4313	419.3	0.0081	0.07194
			10.78	331	14.874	1.3811	624.2	0.0083	0.07477
	Rubber isolator	13.5	5.44	273	14.728	2.4102	607.5	0.0195	0.01904
			8.13	244	14.770	2.3570	437.9	0.0124	0.01050
			10.78	318	14.959	2.1478	1587	0.0125	0.01082

Table 8: 40m transmission tower with different eccentricity on 30 degree sloped ground

Height in m	Support conditions	Inclination of ground in degree	Angular variation in degree	Base reaction, N	Joint displacement, mm	Time period, sec	Axial force, N	Absolute velocity in m/s	Absolute acceleration in m/s <sup>2</sup>
40	Fixed	30	5.44	205	14.587	1.6981	501.9	0.0070	0.09832
			8.13	342	14.595	1.2976	391.4	0.0078	0.06341
			10.78	366	14.782	1.0919	615.6	0.0081	0.09421
	Rubber isolator	30	5.44	165	14.642	2.1280	551.1	0.0126	0.12121
			8.13	297	14.880	1.6990	438.9	0.0130	0.11131
			10.78	314	14.940	1.4619	649.3	0.0131	0.11138

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## V. DISCUSSIONS

From the results following discussions can be done,

**A. Base reaction:** It was found that base reaction for 40m height transmission tower was more than that of 30m height transmission tower. Also we found that transmission tower with eccentric bracing attracts less base reaction.

**B. Different sloping angles:** As the angle of sloping ground increases, base reaction, joint displacement increases. Also axial force increases in majority of the cases.

**C. Rubber isolator:** Provision of rubber isolator decreases the base reactions whereas time period and displacement of the structure increases on providing bracings. Provision of rubber isolator increases the axial forces at the tower legs due to energy dissipation.

**D. Angular variation of eccentric bracings:** Axial forces, joint displacement increases as the eccentric distance increase. With lower eccentricity the upmost parameters can be controlled for safer design.

**E. Axial force:** As the height of the transmission tower increase, axial force also increases. Axial force is less in case of eccentric braced transmission towers compared to transmission towers with inverted V bracing and X bracing.

**F. Joint displacement:** It is clear that 40m height transmission towers will have more lateral displacement compared to 30m height transmission towers. From the results it has been found that, transmission towers with eccentric bracing will have less lateral displacement when compared to that of X bracing and inverted V bracing.

## VI. CONCLUSIONS

1. The provision of non-linear rubber isolator increases the time period, resulting in improvement in the ability of the structure to withstand the earthquake forces.
2. Provision of eccentric bracing system has greater effect against earthquake forces compared to other two (X bracing and inverted V bracing) as it reduces base reaction to greater extent.
3. Thus non-linear analysis prove that, by providing non-linear rubber isolator with eccentric bracing system we can design the structures to withstand the earthquake forces even in severe earthquake zones (zone 5).
4. It can also been concluded that, variation in eccentric distance of eccentric bracings brings out variations in results. So with lower eccentricity the upmost parameters can be controlled for safer design.
5. Use of non linear rubber isolator with eccentric bracing in transmission tower satisfies both serviceability and collapse criteria.
6. From the analysis and above discussions it is clear that, time period and base reactions increase as height of transmission tower increases.
7. From the analysis we found that axial force will be more in taller towers resting on higher elevated ground.
8. Transmission towers with eccentric bracings will have less axial force compared to transmission towers with inverted V bracings and X bracings.
9. Finite non-linear analysis is fast and economical. It covers all important typed of non-linearity of structures, which will help in performing accurate analysis and design.

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