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Seismic Analysis of Buildings Resting on Sloping Ground with Soil Structure Interaction

Manjunath H V[1], Sandeep Kumar D S[2]
[1]*M.Tech student,* [2]*Assistant Professor, Department of Civil Engineering, PES College of Engineering, Mandya, Karnataka, India*

Abstract: ***The economic growth and rapid urbanization in hilly region has accelerated the real estate development therefore, population density in the hilly areas has increased. In some hilly areas seismic activity is more serve so buildings in sloping ground should be earthquake resistant to overcome the lateral forces. In the present study, comparative study of buildings resting on sloping ground and plane ground is carried out by using ETABS 2016 under equivalent static analysis and response spectrum analysis. Also comparison of codes is done (IS Code 1983:2002 vs IS Code 1983:2016) by considering displacement, story drift and base shear as outcomes. Sloping angles (0, 10, 20) are taken for G+10 buildings for modelling and analysed. After the analysis is done, a result obtained shows that displacement and story drift has increased in models analysed by IS Code 1983:2016 when compared with Is Code 1983:2002. Also base shear is reduced in models analysed by IS Code 1983:2016 when compared with IS Code 1983:2002.***

Keywords: Sloping ground, Equivalent static analysis, Response spectrum analysis, IS code 1983:2002 and IS code 1983:2016, Displacement, Story drift and Base Shear.

I. INTRODUCTIO

The economic growth & rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has gradually increased. The adobe burnt brick, stone masonry & dressed stone masonry buildings are generally made over level ground in hilly regions. Since level land in hilly regions is very limited, there is a pressing demand to construct buildings on hill slope. Seismic analysis is a method to carry out the response of the building structure during ground motions. It is a part of process in structural design, which includes seismic assessments of the buildings and also the retrofitting measures to strengthen the retaining structure in the seismic regions. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). The objectives of this present study is to do comparative study of IS code 1983:2002 and IS code 1983:2016 and finding out the variation of displacement, story drift and base shear due sloping ground.

II. MODELING DETAILS

A. General Considerations

The models selected for analysis is a symmetrical in plan size 20mX20m and floor to floor height is 3m. Here, 10 story models having different sloping ground such as 0, 10, 20 are analyzed for seismic zone IV and soil type II. Spacing between columns is 5m. Parameters considered are displacement, story drift and base shear. Slab thickness and walls are 150mm and 230mm respectively. Equivalent static analysis and Response spectrum analysis are used for analysis as per IS 1983:2002 and IS 1983:2016.

B. Load Definition

Table. i: Gravity and lateral load considered as per IS 1983:2002

Gravity load	
Dead load	Weight of structure
Live load on floor	2 kN/m^2
Floor finish	1.5 kN/m^2
Seismic load	
Soil condition	Medium soil (Soil type II)
Importance factor	1.2
Response reduction factor	5(SMRF)
Seismic zone	IV

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Table. ii: Gravity and lateral load considered as per IS 1983:2016

Gravity load	
Dead load	Weight of structure
Live load on floor	2 kN/m^2
Floor finish	1.5 kN/m^2
Seismic load	
Soil condition	Medium soil (Soil type II)
Importance factor	1.2
Response reduction factor	5(SMRF)
Seismic zone	IV

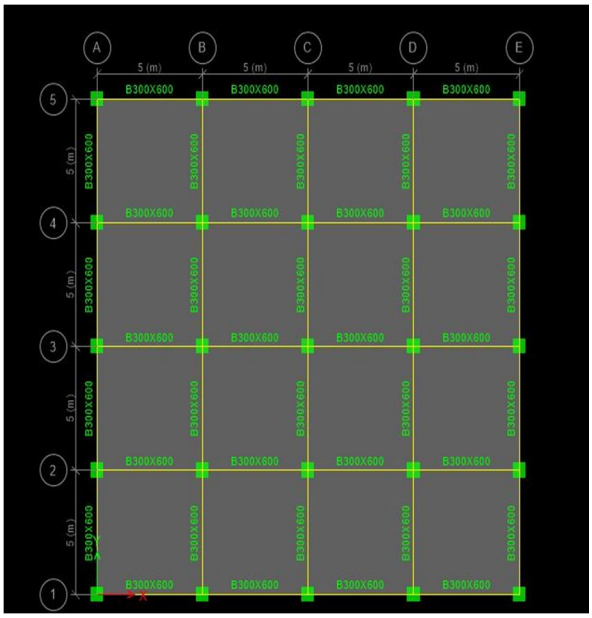
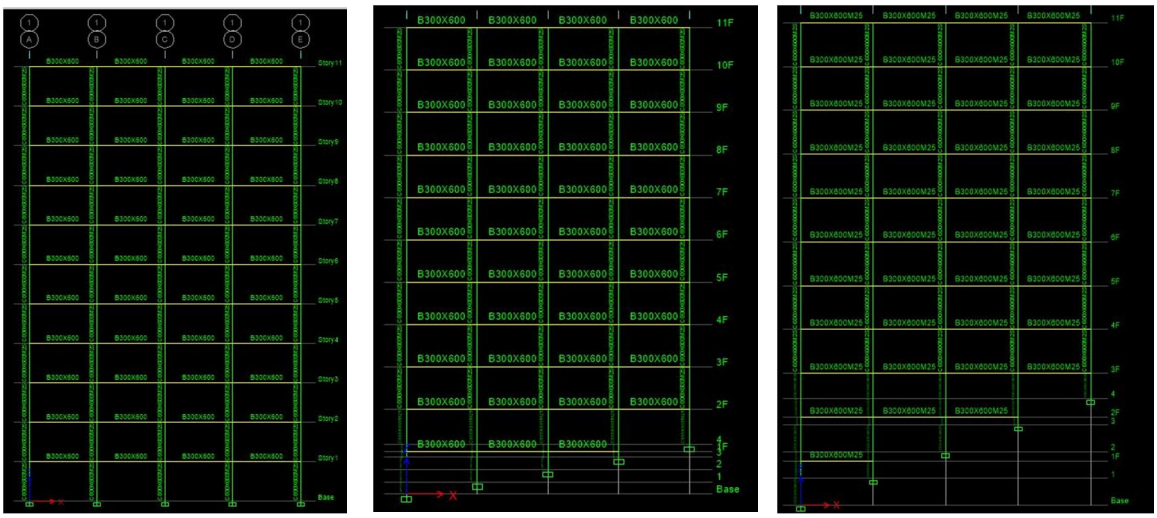


Fig iii: Plan considered for project work.



(a) (b) (c)

Fig iii: Section view for 10 story having sloping angles (a) 0 degree (b) 10 degree (c) 20 degree.

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III. RESULTS AND DISCUSSIONS

A. Plane Ground

Grade of concrete is M25 and of rebar is Fe 500 throughout. The sizes of beam, column are 300mmx600mm and 600mmx600mm respectively.

Table iii: Displacement of buildings on plane ground by ESA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Story11	66.507	121.351	Displacement has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	64.101	116.991	
Story9	60.352	110.322	
Story8	55.362	101.356	
Story7	49.358	90.413	
Story6	42.572	77.873	
Story5	35.213	64.112	
Story4	27.468	49.499	
Story3	19.515	34.453	
Story2	11.582	19.651	
Story1	4.263	6.672	

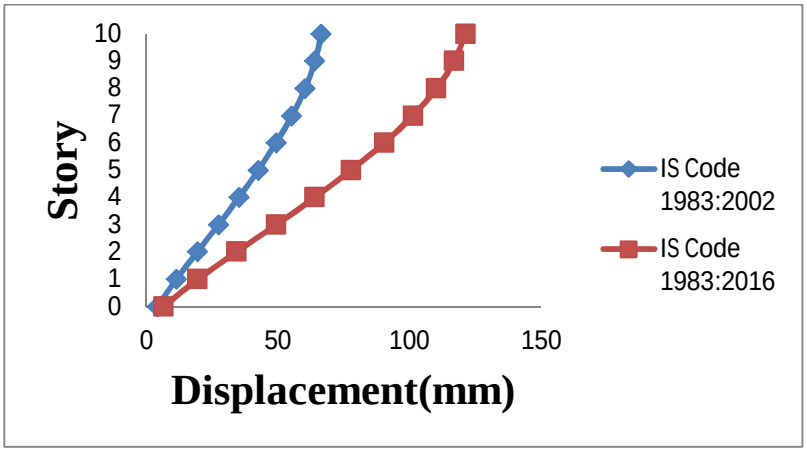

Fig iv: Displacement of buildings on plane ground by ESA.

Table iv : Story drift of buildings on plane ground by ESA.

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	2.406	4.361	Story drift has been increased by 28% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	3.749	6.669	
Story9	4.99	8.966	
Story8	6.004	10.943	
Story7	6.786	12.54	
Story6	7.359	13.761	
Story5	7.744	14.613	
Story4	7.954	15.046	
Story3	7.933	14.802	
Story2	7.32	12.978	
Story1	4.263	6.672	

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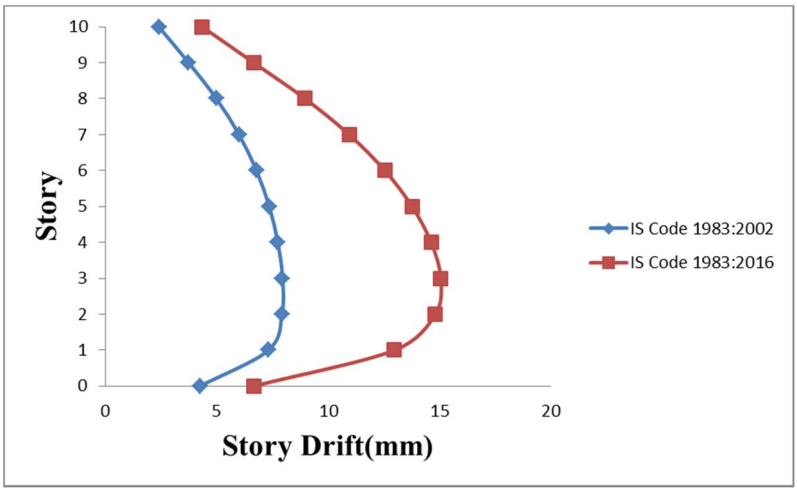

Fig v: Story drift of buildings on plane ground by ESA.

Table v: Story shear of buildings on plane ground by ESA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	1020.19	799.5855	Story shear has been decreased by 12% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	1937.438	1507.351	
Story9	2680.408	2080.642	
Story8	3267.447	2533.612	
Story7	3716.898	2880.417	
Story6	4047.107	3135.213	
Story5	4276.419	3312.154	
Story4	4423.179	3425.397	
Story3	4505.731	3489.096	
Story2	4542.421	3517.406	
Story1	4551.594	3524.484	

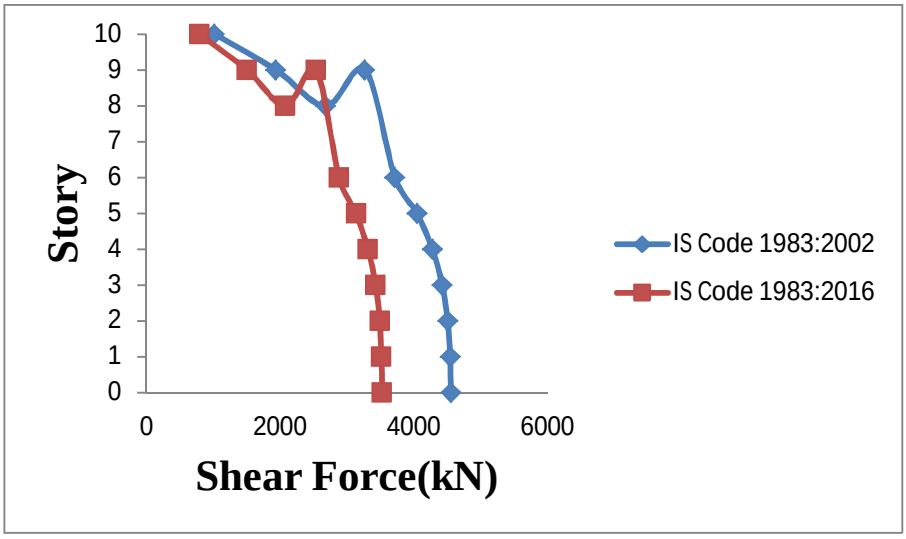

Fig. vi: Story shear of buildings on plane ground by ESA.

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Table vi: Displacement of buildings on plane ground by RSA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Story11	57.352	103.936	Displacement has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	54.746	100.845	
Story9	52.14	96.089	
Story8	48.577	89.595	
Story7	44.14	81.474	
Story6	38.913	71.833	
Story5	32.964	60.74	
Story4	26.353	48.257	
Story3	19.168	34.559	
Story2	11.609	20.221	
Story1	4.336	7.002	

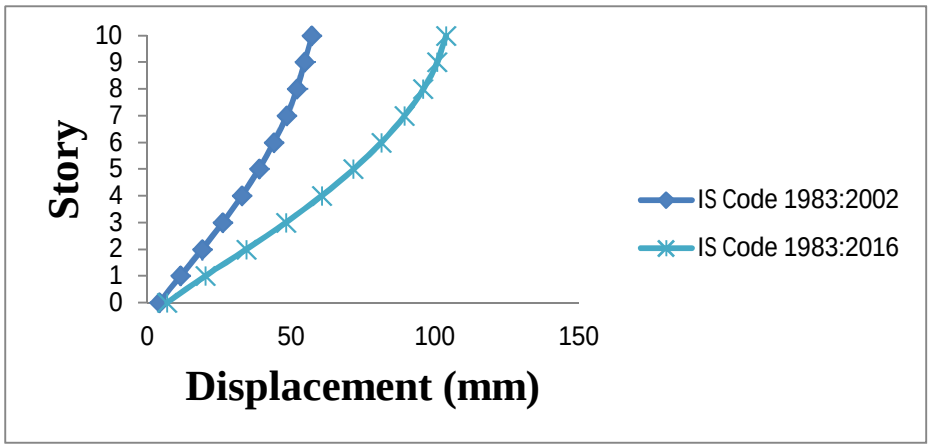

Fig. vii: Displacement of buildings on plane ground by RSA.

Table vii: Story drift of buildings on plane ground by RSA.

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	1.961	4.168	Story drift has been increased by 28% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	3.081	6.236	
Story9	4.101	8.097	
Story8	4.949	9.618	
Story7	5.653	10.876	
Story6	6.256	11.982	
Story5	6.8	13.032	
Story4	7.278	13.963	
Story3	7.587	14.418	
Story2	7.276	13.229	
Story1	4.336	7.002	

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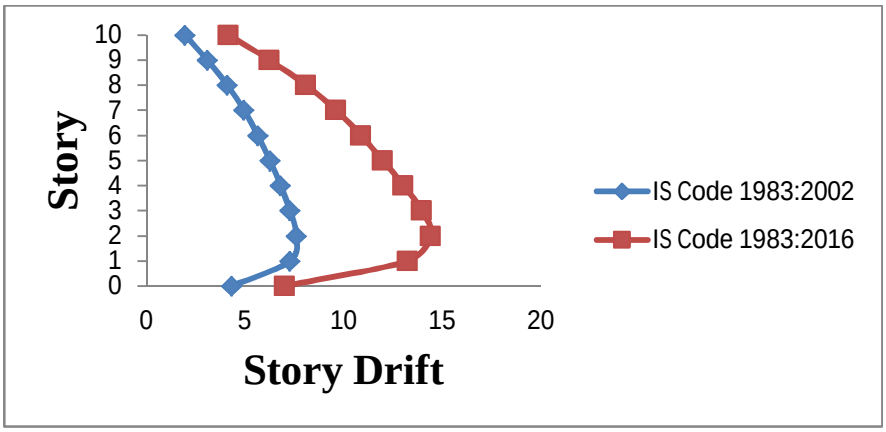

Fig viii: Story drift of buildings on plane ground by RSA.

Table viii: Story shear of buildings on plane ground by RSA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	848.3692	822.992	Story shear has been decreased by 11% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	1606.922	1469.064	
Story9	2195.982	1901.647	
Story8	2670.503	2222.943	
Story7	3061.924	2472.948	
Story6	3398.918	2683.677	
Story5	3715.94	2900.7	
Story4	4015.961	3125.644	
Story3	4289.658	3361.456	
Story2	4511.712	3584.759	
Story1	4616.389	3693.304	

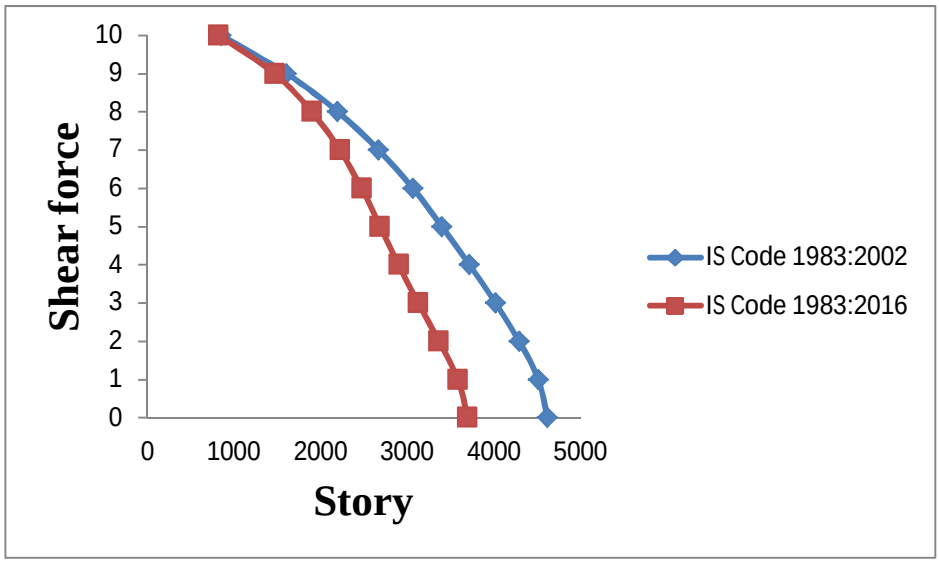

Fig ix: Story shear of buildings on plane ground by RSA.

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B. 10 Degree Slope

Grade of concrete is M25 and of rebar is Fe 500 throughout. The sizes of beam, column are 300mmx600mm and 600mmx600mm respectively.

Table ix: Displacement of buildings on 10 degree slope by ESA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Story11	54.633	103.613	Displacement has been increased by 30% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	52.42	99.397	
Story9	48.95	92.919	
Story8	44.323	84.191	
Story7	38.754	73.528	
Story6	32.458	61.313	
Story5	25.636	47.943	
Story4	18.475	33.865	
Story3	11.212	19.767	
Story2	4.383	7.151	
Story1	0.184	0.232	

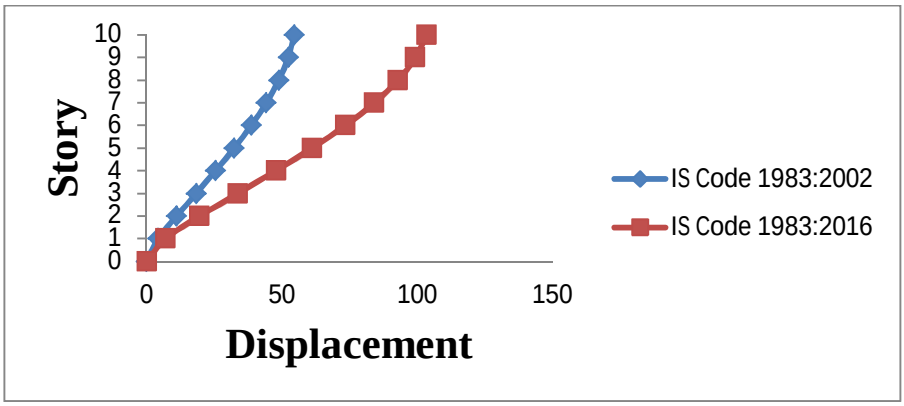

Fig x: Displacement of buildings on 10 degree slope by ESA.

Table x: Story drift of buildings on 10 degree slope by ESA

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	2.213	4.215	Story drift has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	3.47	6.478	
Story9	4.627	8.728	
Story8	5.569	10.663	
Story7	6.296	12.215	
Story6	6.823	13.37	
Story5	7.161	14.078	
Story4	7.262	14.098	
Story3	6.829	12.616	
Story2	4.383	7.151	
Story1	0.184	0.25	

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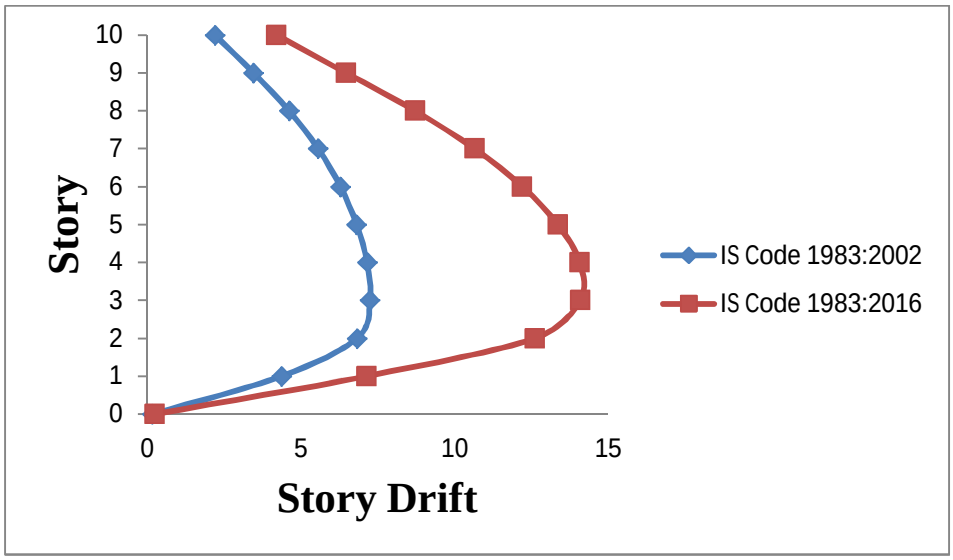

Fig xi: Story drift of buildings on 10 degree slope by ESA.

Table xi: Story shear of buildings on 10 degree slope by ESA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	975.5759	780.4607	Story shear has been decreased by 11% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	1839.395	1471.516	
Story9	2539.089	2031.271	
Story8	3091.933	2473.547	
Story7	3515.205	2812.164	
Story6	3826.18	3060.944	
Story5	4042.134	3233.708	
Story4	4180.345	3344.276	
Story3	4258.089	3406.471	
Story2	4292.238	3433.79	
Story1	2624.952	1845.117	

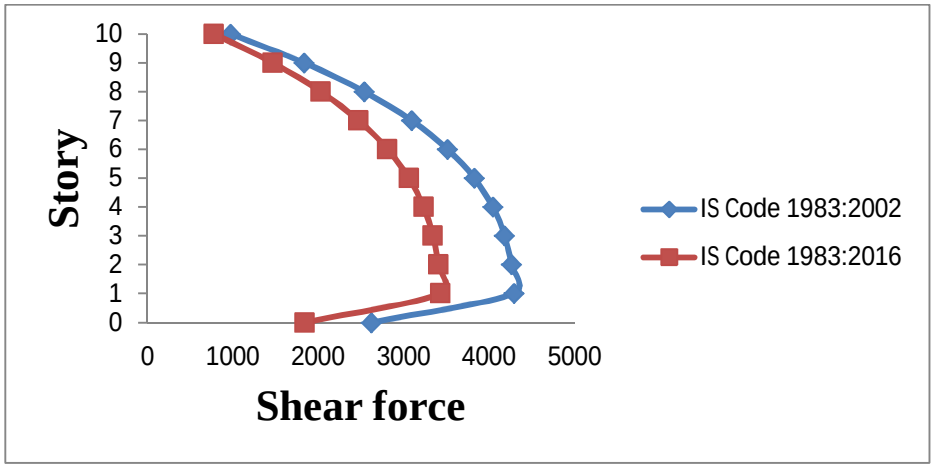

Fig xii: Story shear of buildings on 10 degree slope by ESA.

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Table xii: Displacement of buildings on 10 degree slope by RSA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Story11	57.352	103.936	Displacement has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	54.746	100.845	
Story9	52.14	96.089	
Story8	48.577	89.595	
Story7	44.14	81.474	
Story6	38.913	71.833	
Story5	32.964	60.74	
Story4	26.353	48.257	
Story3	19.168	34.559	
Story2	11.609	20.221	
Story1	4.336	7.002	

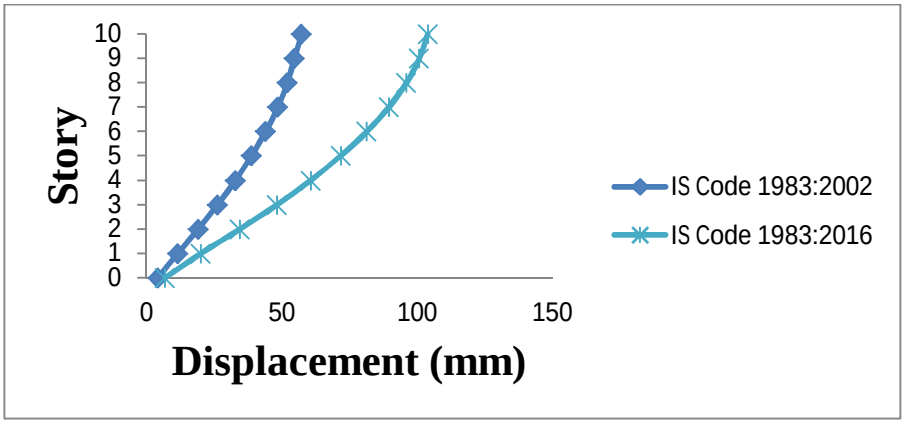

Fig xiii: Displacement of buildings on 10 degree slope by RSA.

Table xiii: Story drift of buildings on 10 degree slope by RSA.

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	1.961	4.168	Story drift has been increased by 28% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	3.081	6.236	
Story9	4.101	8.097	
Story8	4.949	9.618	
Story7	5.653	10.876	
Story6	6.256	11.982	
Story5	6.8	13.032	
Story4	7.278	13.963	
Story3	7.587	14.418	
Story2	7.276	13.229	
Story1	4.336	7.002	

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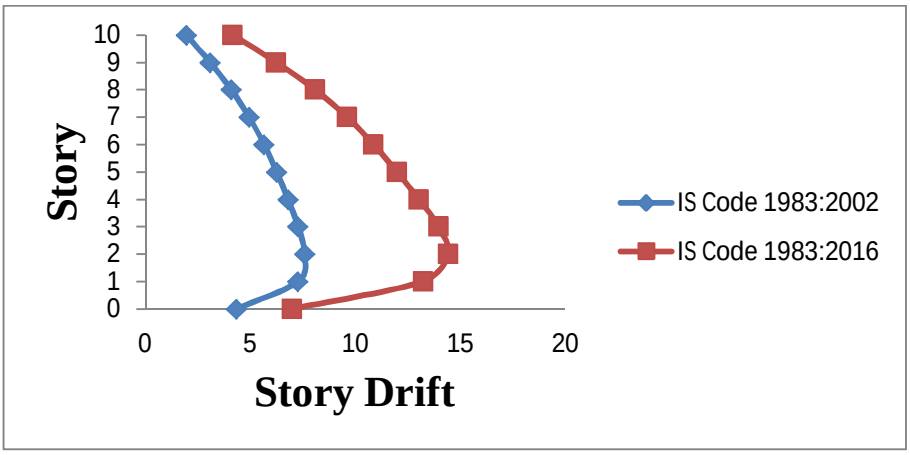

Fig xiv: Story drift of buildings on 10 degree slope by RSA.

Table xiv: Story shear of buildings on 10 degree slope by RSA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	848.3692	822.992	Story shear has been decreased by 11% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	1606.922	1469.064	
Story9	2195.982	1901.647	
Story8	2670.503	2222.943	
Story7	3061.924	2472.948	
Story6	3398.918	2683.677	
Story5	3715.94	2900.7	
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Story1	4616.389	3693.304	

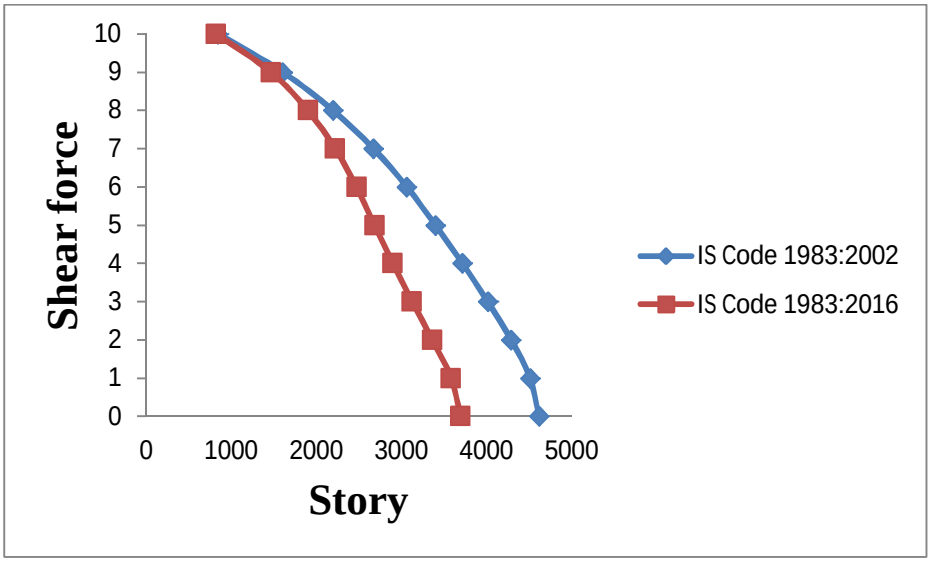

Fig xv: Story shear of buildings on 10 degree slope by RSA.

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C. 20 Degree Slope

Grade of concrete is M25 and of rebar is Fe 500 throughout. The sizes of beam, column are 300mmx600mm and 600mmx600mm respectively.

Table xv: Displacement of buildings on 20 degree slope by ESA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Story11	46.006	84.141	Displacement has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	42.805	80.234	
Story9	39.604	74.204	
Story8	35.319	66.065	
Story7	30.15	56.122	
Story6	24.303	44.757	
Story5	17.976	32.416	
Story4	11.406	19.752	
Story3	5.074	8.101	
Story2	0.695	0.831	
Story1	0.051	0.189	

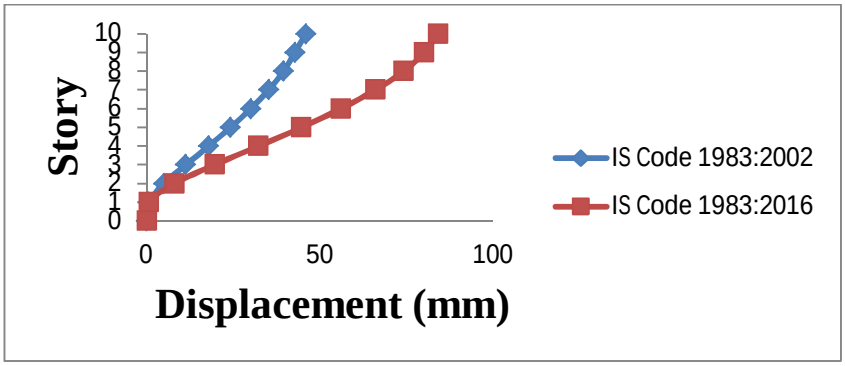

Fig xvi: Displacement of buildings on 20 degree slope by ESA.

Table xvi: Story drift of buildings on 20 degree slope by ESA.

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	2.021	3.897	Story drift has been increased by 30% when compared to IS Code 1983:2002 in IS Code 1983:2016
Story10	3.19	6.019	
Story9	4.274	8.126	
Story8	5.157	9.923	
Story7	5.831	11.323	
Story6	6.297	12.227	
Story5	6.468	12.314	
Story4	5.905	10.554	
Story3	2.869	4.484	
Story2	0.165	0.224	
Story1	0.066	0.055	

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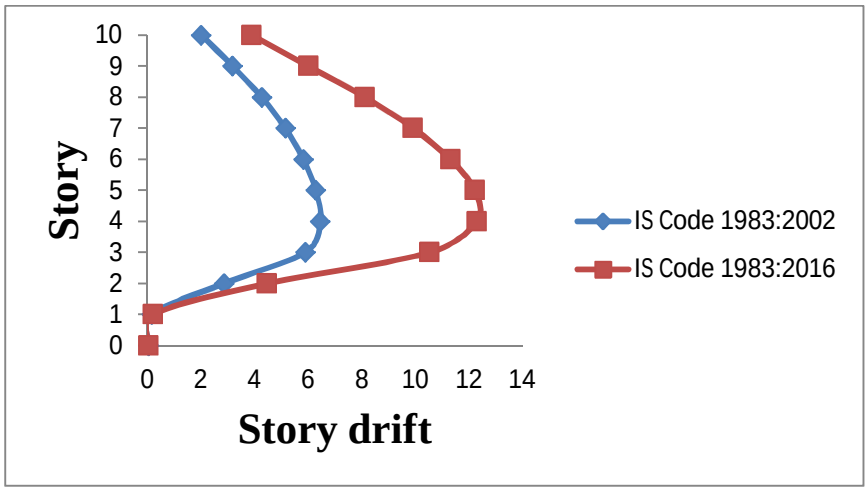

Fig xvii: Story drift of buildings on 20 degree slope by ESA.

Table xvii: Story shear of buildings on 20 degree slope by ESA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	919.9633	735.9706	Story shear has been decreased by 11% when compared to IS Code 1983:2002 in IS Code 1983:2016
St ry10	1734.283	1387.427	
Sto y9	2393.883	1915.106	
Story8	2915.048	2332.038	
Story7	3314.065	2651.252	
Story6	3607.22	2885.776	
Story5	3810.8	3048.64	
Story4	3941.091	3152.873	
Story3	4012.307	3209.846	
Story2	1099.352	361.3143	
Story1	244.7619	273.0511	

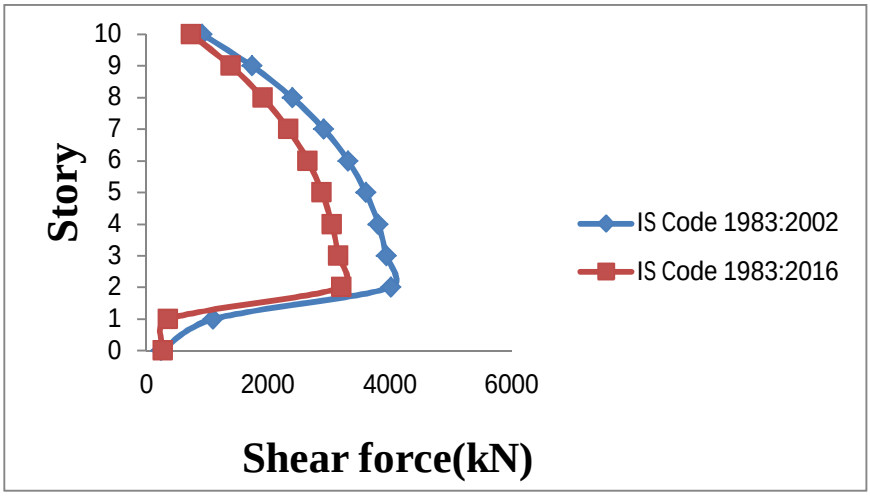

Fig. xviii: Story shear of buildings on 20 degree slope by ESA.

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Table xviii: Displacement of buildings on 20 degree slope by RSA.

STORY	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2002	MAX. DISPLACEMENT(mm) USING IS CODE 1983:2016	REMARKS
Sto y11	38.192	68.944	Displacement has been increased by 29% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story1	36.591	65.83	
Story9	34.008	61.034	
Story8	30.444	54.51	
Story7	25.995	46.384	
Story6	20.773	36.795	
Story5	14.915	25.973	
Story4	8.689	14.562	
Story3	2.862	4.409	
Story2	0.165	0.174	
Story1	0.067	0.126	

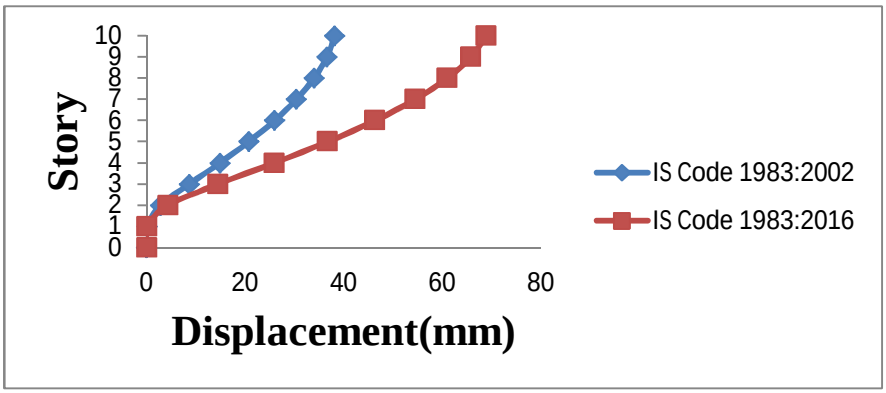

Fig. xxi: Displacement of buildings on 20 degree slope by RSA.

Table xxi: Story drift of buildings on 20 degree slope by RSA.

STORY	MAX. STORY DRIFT(mm) USING IS CODE 1983:2002	MAX. STORY DRIFT(mm) USING IS CODE 1983:2016	REMARKS
Story11	2.002	3.924	Story drift has been increased by 28% when compared to IS Code 1983:2002 in IS Code 1983:2016.
St y10	3.187	5.819	
Story9	4.278	7.515	
Story8	5.21	8.903	
Story7	5.998	10.074	
Story6	6.659	11.054	
Story5	7.121	11.482	
Story4	7.038	10.162	
Story3	3.214	4.409	
Story2	0.357	0.222	
Story1	0.052	0.126	

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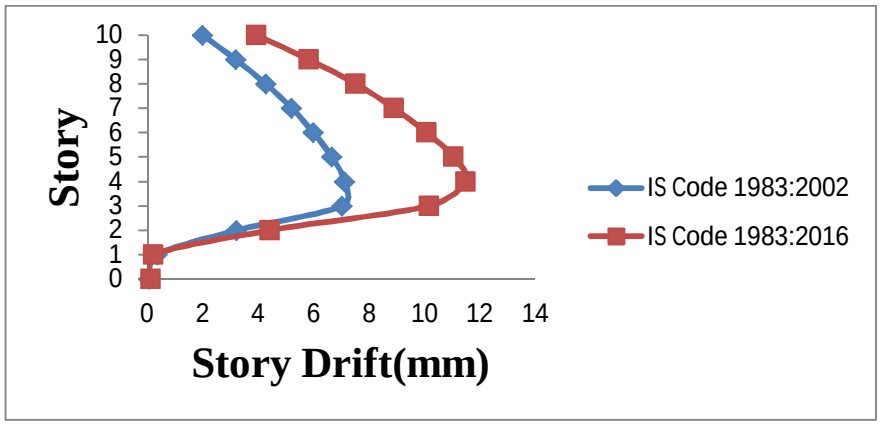

Fig xx: Story drift of buildings on 20 degree slope by RSA.

Table xx: Story shear of buildings on 20 degree slope by RSA.

STORY	STORY SHEAR (kN) USING IS CODE 1983:2002	STORY SHEAR (kN) USING IS CODE 1983:2016	REMARKS
Story11	855.5109	841.0079	Story shear has been decreased by 12% when compared to IS Code 1983:2002 in IS Code 1983:2016.
Story10	1581.293	1439.719	
Story9	2164.836	1847.396	
Story8	2652.308	2149.053	
Story7	3063.163	2395.471	
Story6	3423.14	2649.398	
Story5	3721.641	2901.445	
Story4	3943.581	3127.972	
Story3	4035.806	3228.416	
Story2	1103.228	405.3874	
Story1	243.8984	271.0649	

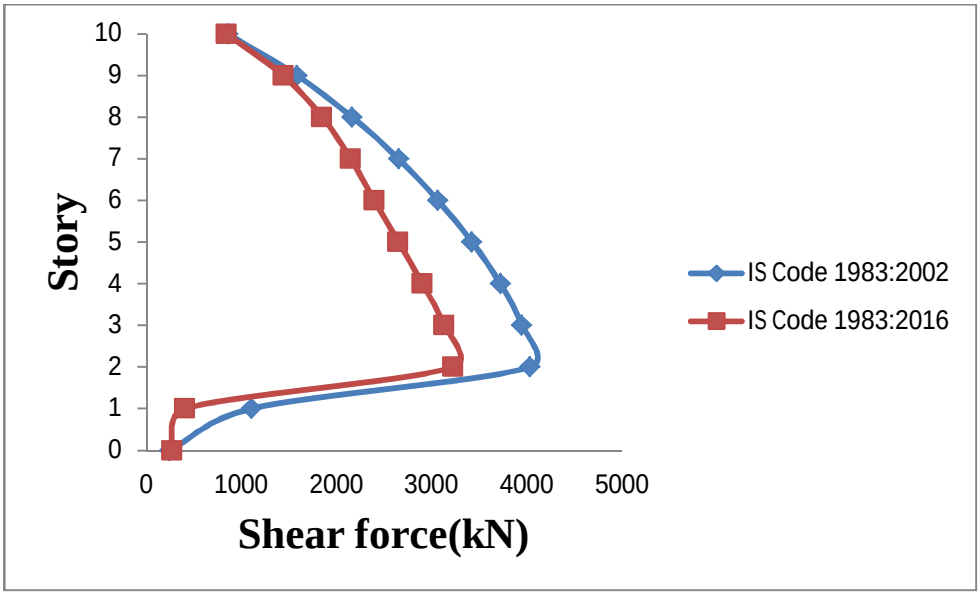

Fig xxi: Story shear of buildings on 20 degree slope by RSA.

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IV. CONCLUSIONS

A. Displacements and Story Drift in all the models analyzed by using IS Code 1983:2016 have been increased when compared to the models analyzed by using IS Code 1983:2002, this is due to change in Important factor (I) in IS Code 1983:2016.

B. Base shear of the models analyzed by using IS Code 1983:2016 have been decreased when compared to the models analyzed by using IS Code 1983:2002 because of change in Important factor (I) in the new code book.

C. The displacements value gets smaller as the slopes increases due to curtailment of column.

D. The story shear value suddenly decreases in sloping ground at base due to curtailment of column.

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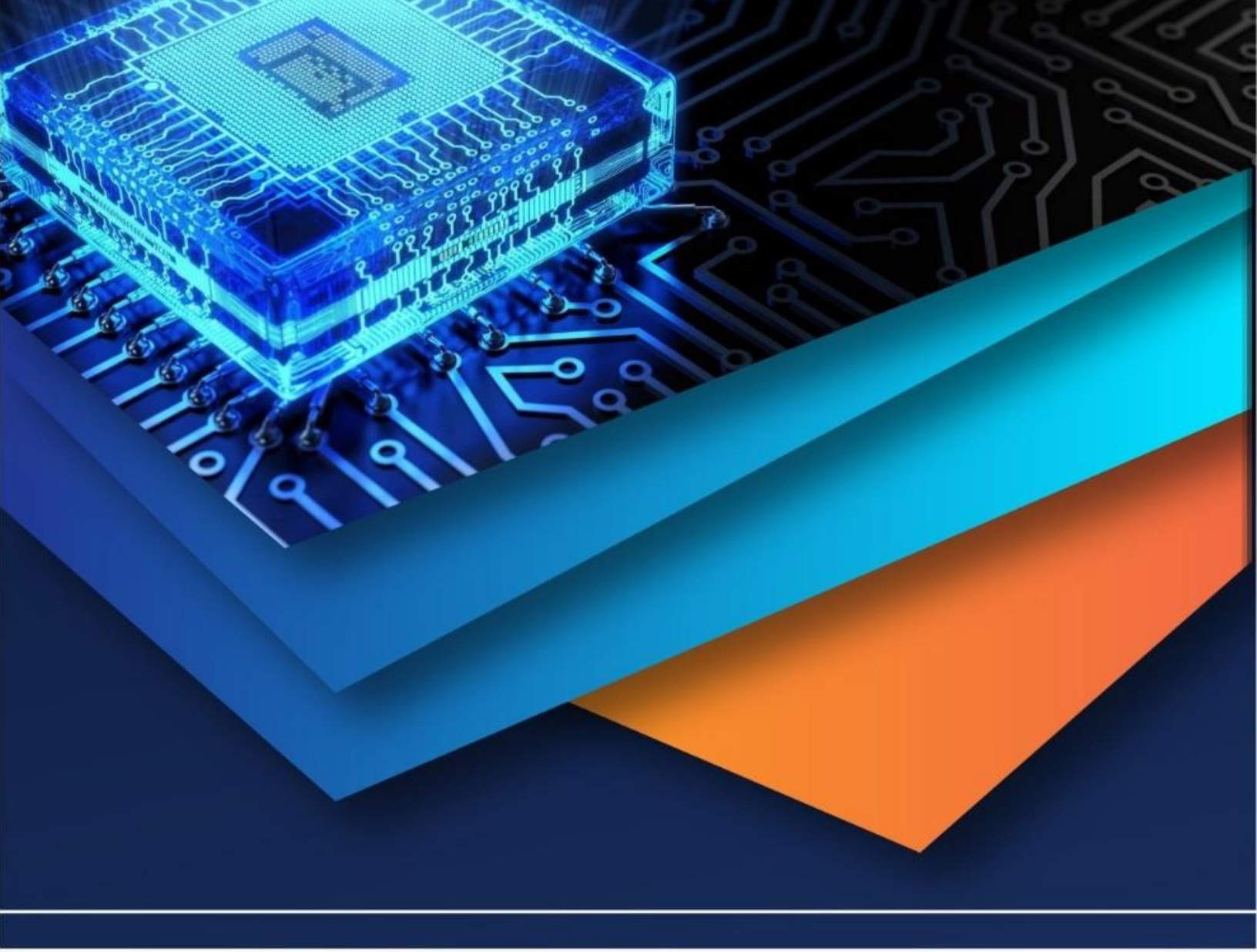

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