Response of Coastal Structures against Tsunami Forces and Its Variation When Impact Load is Applied on Exterior and Interior Columns under Different Soil Conditions

AHL Swaroop, Sk.Yazdani, SRK Reddy

Abstract: ***The catastrophic tsunamis generated during Tohoku, Japan (2011), Indonesia (2004) and Alaska (1964) earthquakes caused severe damage to life and coastal structures and warned the coastal community on prepared and constructing safe structures against such events. Since most of the tsunamis are triggered by undersea earthquakes , it is necessary to establish analytical methods for obtaining the variation of response parameters when tsunami waves hit exterior and interior columns when the similar structure rests on different soils. In this paper, a G+9 storey coastal structure is chosen for the analysis and the response parameters like bending moments, shear forces, time periods, displacements and base shears are worked out considering with and without the effect of Soil Structure Interaction (SSI). From the results it is observed that the multi storied structure is more vulnerable when it rests on loose soil compared to when it rests on stiff soil or hard rock and when it is fixed at the base.***

Keywords : ***Tsunami, Hydrodynamic and Impact forces, Soil Structure Interaction, Base shears and Displacements, ending moments and Shear forces in column.***

I. INTRODUCTION

Earthquakes, wind storms, volcanoes, floods, tsunamis etc., are the most common natural disasters that occur all over the world. Geological evidences reveal that these natural hazards will continue in future also and are apparent to be enhanced in size and frequency. India is one of the most disaster prone countries of the world because of its topographical features, climatic environments, population growth, urbanization, ecological deprivation and non-technological development reforms. Whether these are artificial or natural, it is the time to take up defensive measures and implement administrative strategies to minimize the loss against such disaster events.

Revised Manuscript Received on January 15, 2020

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According to present Indian seismic zone map (IS 1893-2016, Part-1), nearly 60% of land area in India is under seismic risk up to certain level. It is a well-known fact that 7500 km long coast line in India comprises of different geological features with different soils or rocks .The east coast belt, predominantly near Kakinada, in East Godavari District, Machilipatnam, in Krishna District, Bapatla and in Guntur District of Andhra Pradesh, is recognized as disaster pronezones. During 2004 Indonesia earthquake followed by tsunamis hit these regions and a part of shoreline was washed away at Machilipatnam and damaged the other shorelines in little sum. The soil profiles in these areas of coastal region mainly consists of silty clay, siltysand and a small portion of soft disintegrated khondalite, hard disintegrated khondalite and hard massive khondalite rocks. So, the impact of soil structure inetraction has a key role in getting the response of the coastal structures against the tsunami forces.

II. APPROACH AND METHODOLOGY

In the analysis, the most predominant tsunami forces hydrodynamic and impact forces are considered to impart on the G+9 multi storied structure and the Harry Yeh equations are applied for various beach slopes and inundation depths to determine tsunami loads that act at different floor levels on this structure. The maximum magnitude of forces obtained from said equations are used while carrying out the analysis when the structure is interacted with different soils like loose soils(S1), Medium sand(S2),Weathered rock(S3),Hard rock(S4) and when the structure is assumed to be Fixed at the base (FB) conditions.

The laboratory tests are carried out to determine the static properties of soils in the study area and then dynamic properties of soils are evaluated in analysis of structure, when soil structure interaction is considered, two additional soil springs one in vertical and the other in rocking modes are introduced and analysis is carried out by using SAP 2000.The tsunami loads thus obtained are applied on the frame at different floor levels, the response parameters like bending moments, shear forces, base shears and displacements are obtained and the results are compared with fixed base condition.

III. PROBLEM CHOSEN FOR STUDY

A G+9 multistoried structure of size 28m x 36 m in plan, 3.5m height of each floor with each column size of 500mm x 500mm , beam size of 230mm x 600mm is adopted and a slab thickness of 150mm as shown in figure is chosen for analysis. Hydrodynamic force obtained are equally applied on all the columns at required run up height and impact force is applied as a single concentrated load separately on the exterior and interior Columns as shown in figure3 & 4 at required run up .The response parameters bending moment, shear force, displacement and base shears are obtained for various load combinations like 1.5(DL+LL)(LC1),1.2(DL+LL+TL)(LC2),1.5(DL+TL)(LC 3),0.9DL+1.5TL(LC4) considering with and without SSI effect.

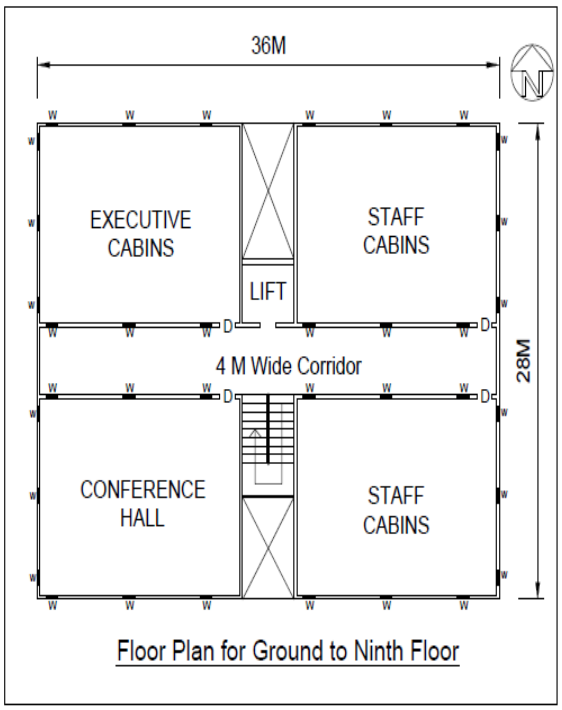

Fig 1: Floor plan of G+9 structure

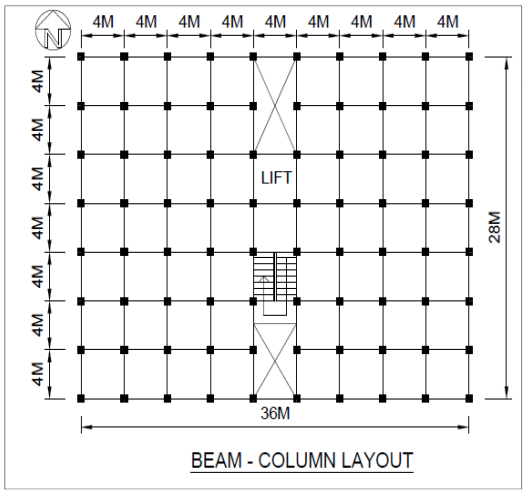

Fig 2:Beam Column Layout

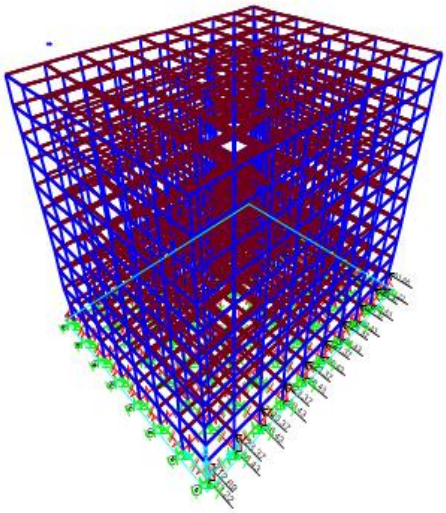

Fig 3:Impact forces applied on Column 1

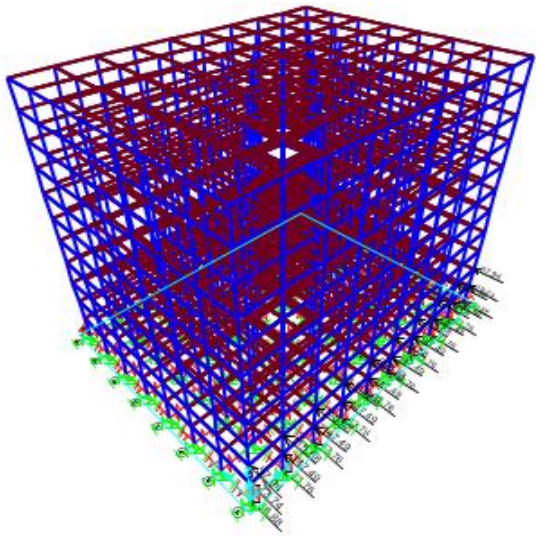

Fig 4:Impact forces applied on Column 5

IV. RESULTS

Table 1: Bending moment values for columns 1 & 5 for Run up Height =3m

Soil type	Bending Moment values(kNm)							
	Exterior column				Interior Column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	86.336	98.952	98.757	98.791	86.336	95.626	96.869	97.891
S2	68.316	55.353	69.546	74.604	68.316	54.581	68.523	72.909
S3	59.423	49.543	45.098	50.4	59.423	47.537	43.129	47.402
S4	57.591	48.923	29.35	38.639	57.591	46.072	26.836	35.061
FB	51.3471	42.8675	28.31	30.517	51.3471	41.077	28.31	30.517

Table 2: Bending moment values for columns 1 & 5 for Run up Height =6m

Soil type	Bending Moment values(kNm)							
	Exterior Column				Interior Column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	86.336	258.87	254.125	275.984	86.336	252.124	251.134	270.435
S2	68.316	248.476	243.121	271.536	68.316	245.274	241.901	269.467
S3	59.423	235.273	237.543	269.762	59.423	232.146	231.417	267.195
S4	57.591	227.156	226.982	256.296	57.591	223.154	223.563	251.168
FB	51.3471	199.542	211.31	249.866	51.3471	206.181	221.168	254.748

Table 3: Bending moment values for columns 1 & 5 for Run up Height =9m

Soil type	Bending Moment values(kNm)							
	Exterior Column				Interior Column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	86.33	293.10	329.185	360.91	86.336	290.167	325.624	354.98
S2	68.31	284.37	319.532	352.98	68.316	281.901	315.745	332.98
S3	59.42	279.41	310.745	341.81	59.423	275.189	305.897	321.95
S4	57.59	267.97	290.956	332.13	57.591	263.901	286.032	310.98
FB	51.34	255.95	283.341	320.44	51.347	222.769	282.555	282.79

Table 4: Bending moment values for columns 1 & 5 for Run up Height =12m

Soil type	Bending Moment values(kNm)							
	Exterior Column				Interior Column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	86.336	252.963	380.342	384.097	86.336	250.876	379.098	381.557
S2	68.316	259.876	376.067	379.98	68.316	254.976	374.123	376.987
S3	59.423	261.975	371.087	371.546	59.423	259.907	368.909	369.021
S4	57.591	268.908	367.908	368.908	57.591	265.786	357.57	365.897
FB	51.3471	279.975	350.462	350.702	51.3471	247.741	310.62	310.962

Table 5: Shear force values for columns 1 & 5 for Run up Height =3m

Soil type	Shear force Values(kN)							
	Exterior Column				Interior Column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	49.876	59.108	23.764	34.67	49.876	48.068	22.284	33.477
S2	41.098	45.089	18.789	27.982	41.098	34.987	17.563	26.182
S3	38.095	39.631	13.786	20.145	38.095	27.067	12.965	19.823
S4	24.784	25.123	10.845	18.093	24.784	24.953	9.086	17.444
FB	23.849	19.079	8.277	13.795	23.849	19.079	8.277	13.795

Table 6: Shear force values for columns 1 & 5 for Run up Height =6m

Soil type	Shear force Values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	49.876	156.12	143.128	179.11	49.876	155.079	142.748	178.145
S2	41.098	150.673	142.723	178.032	41.098	149.025	141.044	177.298
S3	38.095	149.932	141.987	176.715	38.095	148.278	140.549	175.26
S4	24.784	143.107	140.898	175.526	24.784	142.116	140.224	174.098
FB	23.849	139.487	139.782	173.968	23.849	139.487	139.86	173.379

Table 7: Shear force values for columns 1 & 5 for Run up Height =9m

Soil type	Shear force Values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	49.876	90.155	93.784	93.846	49.876	87.803	92.014	92.87
S2	41.098	82.082	91.279	92.057	41.098	77.042	90.878	90.878
S3	38.095	80.128	89.014	89.582	38.095	76.883	88.214	88.672
S4	24.784	70.308	88.154	88.897	24.784	66.855	86.278	87.654
FB	23.849	69.256	86.408	87.156	23.849	68.972	86.189	86.197

Table 8: Shear force values for columns 1 & 5 for Run up Height =12m

Soil type	Shear force Values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	49.876	119.91	133.196	138.148	49.876	118.456	133.017	137.258
S2	41.098	115.369	133.015	135.978	41.098	114.478	132.789	134.015
S3	38.095	110.254	132.312	133.045	38.095	109.654	131.874	132.048
S4	24.784	105.145	131.445	132.145	24.784	104.354	130.215	131.587
FB	23.849	104.726	130.421	130.586	23.849	104.726	129.012	129.145

Table 9: Displacement values for columns 1 & 5 for Run up Height =3m

Soil type	Displacement values(mm)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	54.125	65.21	69.15	70.14	54.125	64.12	67.112	69.29
S2	43.125	64.12	6.48	67.14	43.125	63.015	66.258	68.125
S3	40.189	61.28	65.36	66.51	40.189	60.21	65.128	65.18
S4	37.896	59.34	64.31	65.24	37.896	59.125	64.012	64.189
FB	34.152	58.56	63.14	63.64	34.152	57.125	62.897	63.125

Table 10: Displacement values for columns 1 & 5 for Run up Height =6m

Soil type	Displacement values(mm)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	54.125	74.99	83.46	86.72	54.125	66.85	76.19	81.51
S2	43.125	73.77	82.07	85.27	43.125	65.76	74.92	80.15
S3	40.189	70.42	78.43	81.5	40.189	62.77	71.61	76.61
S4	37.896	68.24	75.95	78.92	37.896	60.83	69.34	74.18
FB	34.152	67.34	74.96	77.88	34.152	60.03	68.43	73.21

Table 11: Displacement values for columns 1 & 5 for Run up Height =9m

Soil type	Displacement values(mm)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	54.125	87.74	95.98	98.86	54.125	72.21	82.68	88.36
S2	43.125	86.31	94.38	97.22	43.125	71.03	81.29	86.88
S3	40.189	82.39	90.19	92.91	40.189	67.8	77.69	83.05
S4	37.896	79.84	87.34	89.97	37.896	65.71	75.24	80.42
FB	34.152	78.79	86.2	88.78	34.152	64.84	74.25	79.36

Table 12: Displacement values for columns 1 & 5 for Run up Height =12m

Soil type	Displacement values(mm)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	54.125	92.24	101.41	105.88	54.125	89.17	100.04	105.15
S2	43.125	90.74	99.72	104.15	43.125	87.71	98.37	103.41
S3	40.189	86.62	95.29	99.51	40.189	83.74	94.11	98.82
S4	37.896	83.94	92.28	96.36	37.896	81.14	91.17	95.69
FB	34.152	82.83	91.07	95.09	34.152	80.07	89.85	94.43

Table 13: Base shear values for columns 1 & 5 for Run up Height =3m

Soil type	Base Shear values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	1132.12	1721.32	1748.21	1836.25	1132.12	1654.12	1678.12	1784.14
S2	1232.152	1887.6	1833.11	1911.45	1232.152	1764.12	1794.12	1897.65
S3	1345.012	1935.7	1915.92	1946.91	1345.012	1891.14	1894.21	1914.19
S4	1542.015	2038.4	2012.81	2121.34	1542.015	1984.12	2010.11	2098.57
FB	1642.96	2190.5	2163.58	2241.25	1642.96	2098.71	2121.65	2198.15

Table 14: Base shear values for columns 1 & 5 for Run up Height =6m

Soil type	Base Shear values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	1132.12	1814.13	1874.62	1901.25	1132.12	1715.26	1753.58	1864.21
S2	1232.152	1925.43	1951.63	1964.23	1232.152	1816.54	1841.54	1914.12
S3	1345.012	2016.52	2146.35	2235.14	1345.012	1942.31	1964.35	2131.51
S4	1542.015	2256.12	2345.58	2401.53	1542.015	2141.27	2357.67	2365.35
FB	1642.96	2321.15	2541.24	2621.23	1642.96	2246.68	2478.29	2495.37

Table 15: Base shear values for columns 1 & 5 for Run up Height =9m

Soil type	Base Shear values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	1132.12	1913.46	1976.24	2041.57	1132.12	1817.91	1861.13	1987.41
S2	1232.15	2013.27	2156.31	2204.12	1232.15	1947.57	2095.24	2184.21
S3	1345.01	2117.16	2213.21	2312.14	1345.01	2067.53	2117.12	2216.54
S4	1542.01	2367.84	2497.61	2567.45	1542.01	2146.53	2397.16	2472.37
FB	1642.96	2489.19	2611.57	2781.21	1642.96	2397.14	2514.17	2615.14

Table 16: Base shear values for columns 1 & 5 for Run up Height =12m

Soil type	Base Shear values(kN)							
	Exterior column				Interior column			
	LC 1	LC 2	LC 3	LC 4	LC 1	LC 2	LC 3	LC 4
S1	1132.12	2097.45	2017.19	2109.15	1132.12	1948.65	1989.56	2101.12
S2	1232.152	2141.57	2211.13	2305.67	1232.152	2017.84	2121.45	2267.54
S3	1345.012	2214.69	2345.67	2415.61	1345.012	2141.27	2221.47	2371.54
S4	1542.015	2514.15	2614.31	2703.14	1542.015	2314.18	2416.68	2678.12
FB	1642.96	2614.65	2813.14	2913.67	1642.96	2478.91	2518.94	2757.16

V. CONCLUSIONS:

- Bending moments, Shear forces, base shears and displacements are high in Exterior column than interior column however the percentage variation lies between 1% to 6%.
- Bending moment values are decreasing from loose soil to hard rock or fixed base with considerable variation between loose soil to medium sand with a variation around 24% and for weathered or hard rock lies around 1% to 6% for all run up heights.
- Shear force values are decreasing from loose soil to fixed base with considerable variation between loose soil to medium sand with a variation around 19 % and for weathered or hard rock lies around 1% to 5% for all run up heights.
- Displacements values are decreasing from loose soil to hard rock or fixed base with a variation of maximum 5% for all run up heights.
- Base shear values are increasing from loose soil to hard rock or fixed base with a variation of maximum 14% for all run up heights.
- It can be concluded that when coastal structures rest on loose soils, soil-structure interaction effect is more and hence to be considered in carrying out earthquake / tsunami analysis.

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