

ANALYTICAL STUDY OF CANTILEVER RETAINING WALL INCLUDING EFFECT OF SOIL STRUCTURE INTERACTION

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Abstract - In the present study, using numerical 2-D simulation, the influence of the different types of soil on the different heights of the wall is addressed. A cantilever retaining wall is considered and is been modeled for the soil-structure interaction using finite element package SAP2000 Version 14.0.0. Dynamic distress and response of a cantilever retaining wall are studied considering six degrees of freedom system. For the validation purpose of the retaining wall, support conditions are considered to be fixed. For the analysis, the inputs are density of concrete, modulus of elasticity of concrete, density and SBC of soil, modulus of elasticity of soil, angle of internal friction and loading (active and passive earth pressure). The targeted output is maximum lateral displacement. Finally the response spectrum inputs are given to the retaining wall for all the three types of soils (soft, medium, soft rock and hard rock) and three types of seismic zones (III, IV and V). Based on the present studies going on globally on SSI it can be concluded that neglecting the same would sometimes result in unsafe seismic design and can lead to dangerous situations.

After the analysis, it is observed that the percentage variation in the deflection is 900% (avg) towards the fixed end and converges to 1% towards the free end when compared with classical method. As the stiffness of the soil increases that is in soil4 there is a reduction in deflection and as the height of the retaining wall increases there is an increase in the deflection at their free ends. The deflection increases with the increase in seismic zone value.

1. INTRODUCTION

Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquake, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. 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). In general, it lengthens the apparent system period, increases the relative contribution of the rocking component of ground motion to the total response, and usually reduces the maximum

base shear. This reduction results from the scattering of the incident waves from the foundation, and from radiation of the structural vibration energy into the soil. As the soil surrounding the foundation experiences small to moderate level of non-linear response, the soil-structure interaction can lead to significant absorption of the incident wave energy, thus reducing the available energy to excite the structure.

Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soil for example nuclear power plants, high-rise buildings and elevated-highways on soft soil.

1.1 Retaining Wall

The following parameters influence the design of the retaining wall: wall height, soil type, and sloping land below and/or above the retaining wall, loads above and behind the retaining wall. Satisfying the external stability criteria is primarily based on the section giving the required factor of safety. The ratio of resisting forces to the disturbing forces is the factor of safety and this factor of safety should always be greater than 1.5 for the structure to be safe against failure with respect to that particular criteria. Different modes of failure have different factor of safety.

The cantilever wall generally consists of a vertical stem and a base slab, made up of two distinct regions i.e. a heel slab and a toe slab. All three components behave like one way cantilever slabs. The stem acts as a vertical cantilever under the lateral earth pressure, the heel slab and toe slab acts as a horizontal cantilever under the action of the resulting soil pressure.

2. BEHAVIOR OF CANTILEVER RETAINING WALL UNDER STATIC LOADING

After the design of cantilever retaining wall, static analysis is done for the same by classical method (conjugate beam method) to get the deflection. By plotting the bending moment and M/EI values on A0 size graphs manually for all the three retaining walls of 4 m, 6 m and 8 m the deflections of the same has been calculated. The manually plotted graphs which are scanned and adjusted to the page are as shown from Fig -1 to Fig -3. The X-axis

represents the height of the retaining wall (m) and Y-axis represents the deflection (mm).

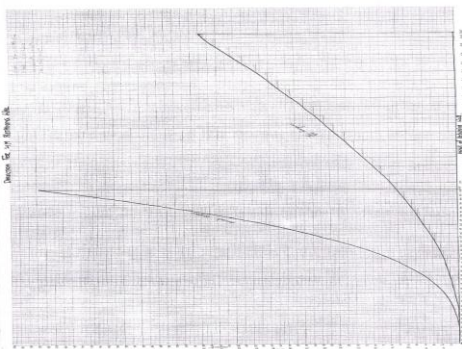


Fig -1: Deflection of 4 m Retaining Wall (Manual)

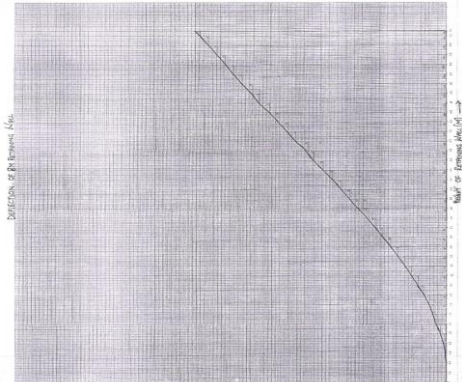


Fig -2: Deflection of 6 m Retaining Wall (Manual)

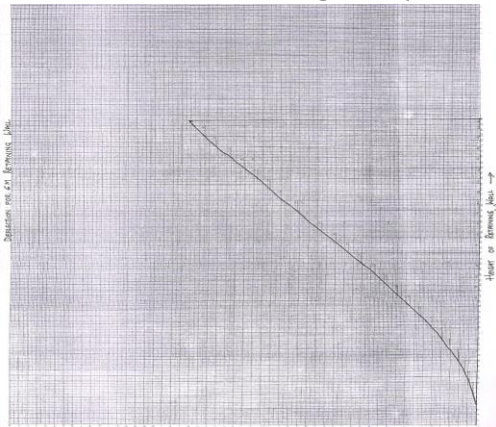


Fig -3: Deflection of 8m Retaining Wall (Manual)

3. ANALYSIS OF RETAINING WALL UNDER DYNAMIC LOADING

In the present study, two-dimensional analysis using finite element approach where ever necessary has been adopted. Only elastic analysis is carried out in this study.

The structure is modeled as a three-dimensional plain strain solid element using software package SAP. The method of analysis used in the present study is Response Spectrum Method (RSM).

3.1 Assumptions made

The material behavior of concrete, reinforcing steel and soil are assumed to be linear. Though the structure is analyzed for factored loads the loads applied on the structure generally don't exceed the working load levels. At working load level the stresses developed can be expected to be within the elastic limit of the material and hence the materials are assumed to be elastic. Full contact is ensured between the retaining wall and the soil in the analysis and no separation case is considered.

3.2 Model of structure

All the structural systems are modeled as plane strain elements using SAP Software package. The modeling of the structural components of the retaining wall and soil in the present analysis is done using 3-D solid elements.

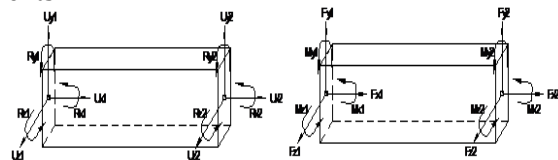


Fig -4: Degree of Freedom for wall and soil element

In the present study the three-dimensional (3D) wall and soil elements are defined from the required type of member property specified as per the cross sectional details. It has 6 Degrees of Freedom ($U_x, U_y, U_z, R_x, R_y,$ and R_z) for each node. It can take up real constants (such as Area, $I_{xx}, I_{yy}, I_{zz},$ etc.) and material constants (like density, modulus of elasticity, Poisson's ratio etc.).

3.3 Link element (gap element)

The Tension/Compression Friction Isolator element is one of the link elements available in the SAP 2000 software program to augment the needs of different structural engineering application. This element is generally used to represent the contact between two structures to transmit the contact forces between them. Both linear and non linear options are available. In this study the weight of the element is considered to be zero. Fig -5 shows the link element and its component, in which i & j are the nodes (extreme ends) of the link element while k is its stiffness.

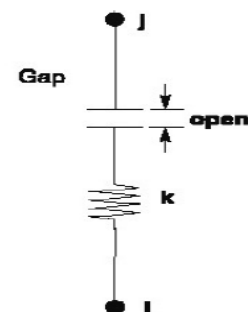


Fig -5: The gap element

3.4 Response Spectrum Method (RSM)

The following steps are required in RSM:

Formulation of an appropriate mathematical model consisting of lumped mass system using 2D/3D beam elements.

Determination of natural frequency and mode shapes following a standard stiffness matrix, transfer matrix or other standard approach.

Determine total response by combining responses in various modes by (i) by mode combination procedure such as SRSS, CQC, etc. or (ii) time-wise superposition of responses using ground motion time history(s). In RS method (iii) Ah shall be computed as per 6.4.2 of IS1893 (Part-1):2002.

3.5 Types of Coordinate Systems

All coordinate systems in the model are defined with respect to a single global coordinate system. Each part of the model (joint, element, or constraint) has its own local coordinate system. All coordinate systems are three- dimensional, right- handed, rectangular (Cartesian) systems.

3.6 Material Properties

There are specified material properties which are used to define the mechanical, thermal, and density properties for the frame, shell, plane, and solid elements. These Material properties may be defined as isotropic, orthotropic or anisotropic. Depending upon the element type, the properties can actually be utilized.

3.7 Degrees of Freedom

In the structural model, deflection is governed by the displacements of the joints and every joint may have up to six displacement components:

- The joint may translate along its three local axes which are denoted as U1, U2, and U3.
- The joint may rotate about its three local axes which are denoted as R1, R2, and R3.

These six displacement components are known as the degrees of freedom of the joint. The joint local degrees of freedom are illustrated in Fig -6.

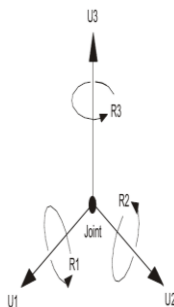


Fig -6: The six (displacement) degrees of freedom in the joint local coordinate System

The model of cantilever retaining wall for fixed base by SAP 2000 Ver. 14.0.0 is as shown below:

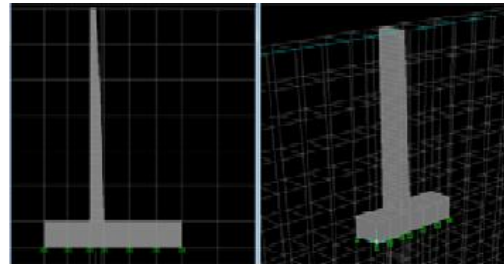


Fig -7: SAP

Model of Cantilever Retaining Wall (Fixed Base)

The model of cantilever retaining wall for actual condition in soil by SAP 2000 Ver. 14.0.0 is as shown below:

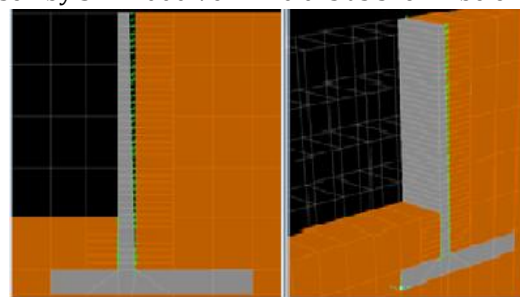


Fig -8:

SAP Model of Cantilever Retaining Wall (Embedded in Soil)

4. RESULTS

The present analytical study carried out comprises primarily of static and dynamic analysis of cantilever retaining wall by classical method (conjugate beam method) and the method of 'Response-Spectrum' presented in IS1893:2000, using SAP2000 Ver14.0.0 software respectively.

The max. Lateral Displacement due to seismic excitation of the cantilever retaining wall for static and dynamic analysis is studied, viz,

The variations in the aforementioned parameter is studied by varying the following parameters, viz,

1. Soil type (soft, medium, soft rock and hard rock)
2. Height of the cantilever retaining wall (4, 6 & 8 m)
3. Structure in Different Zones (III, IV & V)

4.1 Static analysis -Variation in Displacement

The variation in the displacement for three different heights (4 m, 6 m and 8 m) of retaining wall are presented in Table 1 to 3.

Table -1: Horizontal Deflection of 4 m Height Retaining Wall

Distance from fixed end (m)	Deflection (mm)		% Variation	Distance from fixed end (m)	Deflection (mm)		% Variation
	Conjugate beam method	SAP			Conjugate beam method	SAP	
0.2	0.025	0.11	340	2.1	2.43	2.81	16
0.4	0.1	0.26	160	2.3	2.81	3.17	13
0.6	0.24	0.46	92	2.5	3.21	3.54	10
0.8	0.42	0.69	64	2.7	3.61	3.91	8
1	0.65	0.96	48	2.9	4.02	4.27	6
1.2	0.91	1.26	38	3.1	4.43	4.64	5
1.4	1.21	1.58	31	3.3	4.84	4.99	3
1.6	1.53	1.92	25	3.5	5.26	5.36	2
1.8	1.87	2.27	21	3.65	5.67	5.72	1

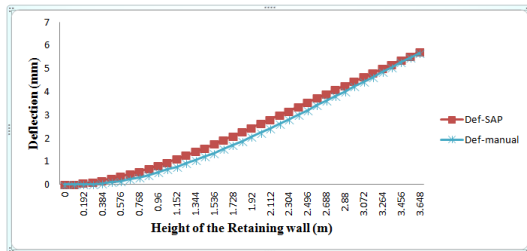


Fig -9: Horizontal Deflection of 4 m Height Retaining wall

Table -2: Horizontal Deflection of 6m Height Retaining wall

Distance from fixed end (m)	Deflection (mm)		% variation	Distance from fixed end (m)	Deflection (mm)		% variation
	Conjugate beam method	SAP			Conjugate beam method	SAP	
0	0	0	0	3	3.67	7.08	93
0.2	2E-04	0.051	25400	3.2	4.56	7.93	74
0.4	5E-04	0.14	27900	3.4	5.19	8.49	64
0.6	0.001	0.46	45900	3.6	6.2	9.34	51
0.8	0.003	0.68	22567	3.8	6.89	9.9	44
1	0.005	0.95	18900	4	7.97	10.75	35
1.2	0.03	1.58	5167	4.2	8.71	11.31	30
1.4	0.032	1.95	5994	4.4	9.84	12.18	24
1.6	0.21	2.55	1114	4.6	10.99	12.96	18
1.8	0.49	3.21	555	4.8	11.76	13.49	15
2	0.77	3.67	377	5	12.93	14.3	11
2.2	1.09	4.16	282	5.2	14.1	15.1	7
2.4	1.67	4.92	195	5.4	14.88	15.63	5
2.6	2.34	5.72	144	5.6	16.07	16.43	2
2.8	2.84	6.26	120	5.7	16.46	16.69	1

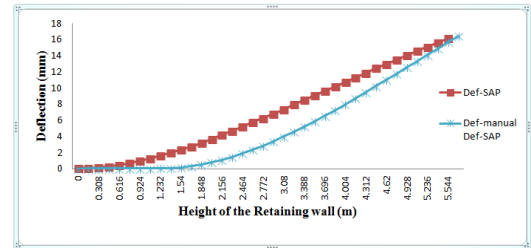


Fig -10: Horizontal Deflection of 6 m Height Retaining wall

Table -3: Horizontal Deflection of 8m Height Retaining wall

Distance from fixed end (m)	Deflection (mm)		% Variation	Distance from fixed end (m)	Deflection (mm)		% Variation
	Conjugate beam method	SAP			Conjugate beam method	SAP	
0	0	0	0	3.8	7.32	9.7	33
0.2	0.005	0.08	1500	4	8.62	10.5	22
0.4	0.086	0.2	133	4.2	9.6	11.3	18
0.6	0.075	0.4	433	4.4	10.4	12.1	16
0.8	0.066	0.7	961	4.6	11.21	12.8	14
1	0.18	1	456	4.8	12.03	13.6	13
1.2	0.35	1.3	271	5	12.87	14.4	12
1.4	0.71	1.9	168	5.2	13.72	15.2	11
1.6	1.01	2.35	133	5.4	14.58	16	10
1.8	1.355	2.85	110	5.6	15.44	16.8	9
2	1.745	3.35	92	5.8	16.31	17.6	8
2.2	2.18	3.9	79	6	17.18	18.4	7
2.4	2.655	4.5	69	6.2	18.49	19.5	5
2.6	3.165	5.15	63	6.4	19.37	20.3	5
2.8	3.72	5.8	56	6.6	20.25	21.1	4
3	4.31	6.45	50	6.8	21.13	21.9	4
3.2	4.925	7.15	45	7	22.01	22.65	3
3.4	5.575	7.9	42	7.2	22.89	23.4	2
3.6	6.6	9	36	7.3	23.33	23.8	2

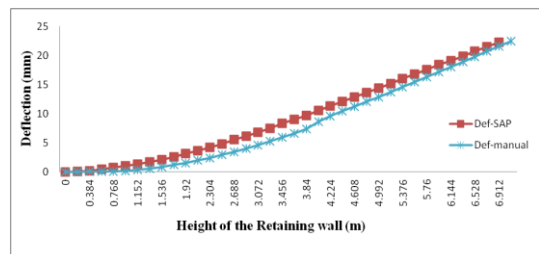


Fig -11: Horizontal Deflection of 8 m Height Retaining wall

4.2 Static analysis

The results of static analysis of the cantilever retaining wall using SAP 2000 VER14.0.0 are tabulated here and to give a clear picture of this graphical presentation of the same is been done.

The variation in the displacements of the three retaining walls with varying soil type are compared with the

Distance from fixed end (m)	fixed base	soil1	% variation	soil2	% variation	soil3	% variation	soil4	% variation
0	0	0	0	0	0	0	0	0	0
0.5	0.35	1.31	274	0.53	51	0.45	29	0.43	23
1	0.96	1.96	104	0.95	-1	0.83	-14	0.81	-16
1.5	1.75	2.67	53	1.40	-20	1.26	-28	1.23	-30
2	2.63	3.41	30	1.88	-29	1.71	-35	1.68	-36
2.5	3.54	4.16	18	2.37	-33	2.17	-39	2.13	-40
3	4.46	4.93	11	2.86	-36	2.63	-41	2.58	-42
3.5	5.36	5.68	6	3.35	-38	3.08	-43	3.04	-43
3.65	5.72	5.98	5	3.55	-38	3.27	-43	3.22	-44

standard retaining wall with fixed base and corresponding values are represented in the graphical form as below.

Table -4: Horizontal Deflection (mm) of 4 m Height Retaining wall considering soil

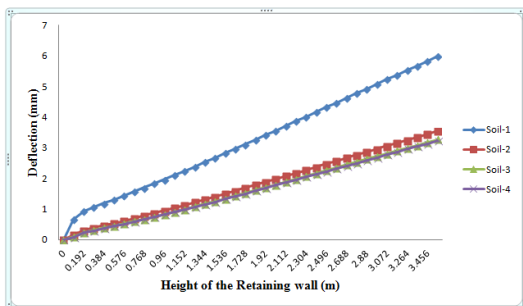


Fig -12: Horizontal Deflection of 4 m Height Retaining wall considering soil

Table -5: Horizontal Deflection (mm) of 6 m Height Retaining wall considering soil

Distance from fixed end	fixed base	soil1	% variation	soil2	% variation	soil3	% variation	soil4	% variation
0	0.09	2.02	211	0.2	20	0.03	21	0.01	5
0.6	0.46	2.94	539	0.47	2	0.23	-50	0.19	-59
1	1.1	3.65	232	0.77	-30	0.48	-56	0.43	-60
1.2	1.58	4.12	161	0.98	-38	0.67	-58	0.61	-61
2	3.67	5.88	60	1.87	-49	1.46	-60	1.38	-62
2.2	4.16	6.27	51	2.07	-50	1.64	-61	1.55	-63
3	7.08	8.47	20	3.26	-54	2.71	-62	2.61	-63
3.2	7.93	9.1	15	3.61	-54	3.02	-62	2.91	-63
4	10.7	11.2	4	4.75	-56	4.05	-62	3.92	-64

4.2	11.3	11.6	3	4.97	-56	4.25	-62	4.12	-64
5	14.3	13.9	-3	6.18	-57	5.35	-63	5.19	-64
5.7	16.69	15.81	-5	7.16	-57	6.23	-63	6.05	-64

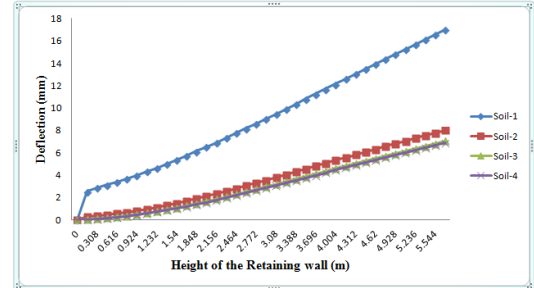


Fig -13: Horizontal Deflection of 6 m Height Retaining wall considering soil

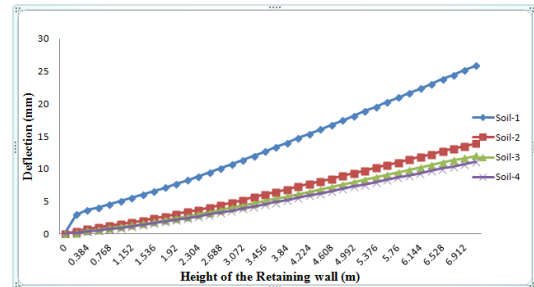


Fig -14: Horizontal Deflection of 8 m Height Retaining wall considering soil

Table -6: Horizontal Deflection (mm) of 8 m Height Retaining wall considering soil

Distance from fixed end	Fixed Base	soil1	% Variation	soil2	% Variation	soil4	% Variation
1	1	7.56	656	2.25	125	1.41	41
1.2	1.3	8.24	534	2.66	105	1.73	33
2	2.85	11.62	308	4.77	68	3.34	17
2.4	3.9	13.25	240	5.78	48	4.23	8
3	5.8	15.83	173	7.45	28	5.59	-4
3.6	9	18.98	111	9.5	6	7.29	-19
4	10.5	20.84	98	10.71	2	8.3	-21
4.8	13.6	24.61	81	13.17	-3	10.36	-24
5	14.4	25.57	78	13.79	-4	10.88	-24
5.2	15.2	26.52	74	14.41	-5	11.4	-25
6	18.4	30.35	65	16.88	-8	13.48	-27
6.4	20.3	32.73	61	18.41	-9	14.76	-27
7	22.65	35.59	57	20.24	-11	16.09	-29
7.3	23.8	37.02	56	21.16	-11	17.07	-28

Table -7: Maximum Horizontal Deflection of 4m Height Retaining wall – Zone III

Soil type	RW in static analysis	RW in dynamic analysis	% variation in deflection
Soil 1(soft)	6	6.2	3.33
Soil 2(medium)	3.5	3.6	2.86
Soil 3(soft rock)	3.3	3.7	12.12
Soil4(hard rock)	3.2	3.8	18.75

Table -8: Maximum Horizontal Deflection of 4m Height Retaining wall – Zone V

Soil type	RW in static analysis	RW in dynamic analysis	% variation in deflection
Soil 1(soft)	6	6.7	11.67
Soil 2(medium)	3.5	3.9	11.43
Soil 3(soft rock)	3.3	3.9	18.18
Soil4(hard rock)	3.2	4	25

Table -9: Maximum Horizontal Deflection of 6m Height Retaining wall – Zone III

Soil type	RW in static analysis	RW in dynamic analysis	% variation in deflection
Soil 1(soft)	17	17.1	0.58
Soil 2(medium)	8	8.2	2.5
Soil 3(soft rock)	7	7.2	2.86
Soil4(hard rock)	6.9	7.0	1.45

Table -10: Maximum Horizontal Deflection of 6m Height Retaining wall – Zone V

Soil type	RW in Static analysis	RW in Dynamic analysis	% variation in deflection
Soil 1(soft)	17	17.3	1.76
Soil 2(medium)	8	8.9	11.25
Soil 3(soft rock)	7	8.2	17.14
Soil4(hard rock)	6.9	7.5	8.7

Table -11: Maximum Horizontal Deflection of 8m Height Retaining wall – Zone III

Soil type	RW in Static analysis	RW in Dynamic analysis	% variation in deflection
Soil 1(soft)	26.5	31.8	20
Soil 2(medium)	14.3	17.7	23.78
Soil 3(soft rock)	12.4	16.2	30.65
Soil4(hard rock)	11.4	14.9	30.7

Table -12: Maximum Horizontal Deflection of 8m Height Retaining wall – Zone V

Soil type	RW in Static analysis	RW in Dynamic analysis	% variation in deflection
Soil 1(soft)	26.5	35.7	34.72
Soil 2(medium)	14.3	20.3	41.96
Soil 3(soft rock)	12.4	17.7	42.74
Soil4(hard rock)	11.4	15.5	35.96

5. SUMMARY AND CONCLUSIONS

In the soils having comparatively less stiffness (modulus of elasticity), the effect of soil-structure interaction is prominent as these could tend to increase or decrease the response as compared to the fixed base.

The static deflection obtained by classical method (conjugate beam method) was compared with that of the SAP modeled retaining wall and was found that it varies linearly. That is the percentage variation in the deflection is 900% (avg) towards the fixed end and converges to 1% towards the free end.

The deflection at the free end of the cantilever retaining wall increases with the increase in the height of the retaining wall that is, 5.98 mm in 4 m, 16.9 mm in 6 m and 23.8 mm in 8 m retaining wall respectively.

The deflection at the free end of the cantilever retaining wall decreases with the increase in the stiffness of the soil. The drop in the deflection in 4 m height retaining wall is within the range, 5.98 mm in soil1 to 3.22 mm in soil4, in 6 m height retaining wall the value ranges from 16.69 mm in soil1 to 6.05 mm in soil4 and in 8 m height retaining wall the value lies within the range 23.8 mm in soil1 to 17.07 mm in soil4.

The deflection at the free end of the cantilever retaining wall increases with the increase in the seismic zone. The increase in the deflection for 4 m height retaining wall ranges from 6.2 mm in zone III to 6.77 mm in zone V, in 6 m height retaining wall the value lies within 17.1 mm in zone III to 17.3 mm in zone V and in 8 m height retaining wall the value ranges from 31.8 mm in zone III to 35.7 mm in zone V.

ACKNOWLEDGEMENT

I express my profound gratitude and indebtedness to Mr. P. M. Ravindra, Associate Professor, Department of Civil Engineering, B.I.T, Bangalore, who with his inspiration, incessant encouragement and support, has rendered meticulous guidance throughout the research work.

I express my deep sense of gratitude to Dr. Pradeep Kumar T V, who has been a guiding beacon of light, who with his constant motivation and support, has rendered meticulous guidance throughout the research work.

REFERENCES

- [1] Rajasankar and Nagesh, (2007), "SSI analysis of a massive concrete structure based on a novel convolution/deconvolution technique", Sadhana, Vol.32, part3, pp 215-234.
- [2] Deepankar and Sanjay, (2006), Geotechnical and Geological Engineering (2006) 24: pp 1103-1113, DOI 10.1007/s10706-005-1134-x.
- [3] B.C.Punmia, (2007),"Limit State Design of Reinforced Concrete Structures", Lakshmi publishers, New Delhi, pp 647- 721.