International Conference on Innovative Research in Engineering, Management and Sciences
International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2019 IJSRCSEIT | Volume 4 | Issue 9 | ISSN : 2456-3307

Analytical Study on Retaining walls- Static and Dynamic

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ABSTRACT

The dynamic interaction of retaining walls with the retained soil (wall-soil-interaction] and of structures with the soil under1ying their foundation [soil-structure interaction], have been examined by a number of researches in the past. Of much interest is the dynamic ‘version’ of this phenomenon [which incorporates the ‘static’ version] where a11 the three components [wall, soil, structure] respond dynamica11y and affect the response and distress of each other. Soil-Structure Interaction ti11 the present date is not been sufficient1y investigated or is either ignored.

In the present study, using numerica1 2-D simu1ation, the inf1uence of the different types 0f s0i1 0n the different heights 0f the wall is addressed. A canti1ever retaining wall is c0nsidered and is been m0de1ed f0r the s0i1-structure interacti0n using finite e1ement package SAP2000 Versi0n 14.0.0. The resp0nse 0f a canti1ever retaining wall are studied c0nsidering six degrees 0f freed0m system. F0r the va1idati0n purp0se 0f the retaining wall, supp0rt c0nditi0ns are c0nsidered t0 be fixed. F0r the ana1ysis, the inputs are density 0f c0ncrete, m0du1us 0f e1asticity 0f c0ncrete, density and SBC 0f s0i1, m0du1us 0f e1asticity 0f s0i1, ang1e 0f interna1 fricti0n and 10ading (active and passive earth pressure). The targeted 0utputs are f0und as seismic base shear, fundamenta1 natura1 peri0d and maximum 1atera1 disp1acement. Fina11y the resp0nse spectrum inputs are given t0 the retaining wall f0r a11 the three types 0f s0i1s (s0ft, medium, s0ft r0ck and hard r0ck) and three types 0f seismic z0nes (III, IV and V). Based 0n the present studies g0ing 0n g10ba11y 0n SSI it can be c0nc1uded that neg1ecting the same w0u1d s0metimes resu1t in unsafe seismic design and can 1ead t0 danger0us situati0ns.

After the ana1ysis, it was observed that the percentage variation in the def1ection is 900% (avg) towards the fixed end and converges to 1% towards the free end when compared with c1assica1 method. As the stiffness of the soil increases that is in soil 4 there is a reduction in def1ection and as the height of the retaining wall increases there is an increase in the def1ection at their free ends. The def1ection increases with the increase in seismic zone va1ue. As the height of the retaining wall increases there is an increase in the fundamenta1 natura1 time period.

Keywords : Retaining wall, soil structure interaction, SAP2000 Version 14.0.0.

I. INTRODUCTION

1.1 GENERA1

Most of the civil engineering structures invo1ve some type of structura1 e1ement with direct contact with ground. When the externa1 forces, such as earthquake, act on these systems, neither the structura1 disp1acements nor the ground disp1acements, are independent of each other. The process in which the response of the soil inf1uences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). So soil-structure interaction is a collection of phenomena where response of structures caused by the flexibility of the foundation soils, as well the response of soil caused by the presence of structures is studied. 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.

Damage sustained in recent earthquakes, such as the 1995 Kobe Earthquake have also highlighted that the seismic behavior of a structure is highly influenced not only by the response of the superstructure, but also by the response of the foundation and the ground as well. Hence, the modern seismic design codes, such as Standard Specifications for Concrete Structures: Seismic Performance Verification JSCE 2005 stipulated that the response analysis should be conducted by taking into consideration a whole structural system including superstructure, foundation and ground.

1.1.1 Retaining Walls

Retaining wall is a structure constructed primarily to retain or support earth or some other material in a relatively vertical position on one or both sides of it at different heights. Wall structures are commonly used to support earth, loose stones, water etc. Most retaining structures are vertical or nearly so; however, if the angle α (slope of wall face with vertical) in the Coulomb earth-pressure coefficient is larger than 90˚, there is a reduction in lateral pressure that can be of substantial importance where the wall is high and a wall tilt into the backfill is acceptable. Retaining walls may be classified according to how they produce stability (B.C.Punmia):

1. Mechanically reinforced earth- "Gravity walls"
2. Gravity- either reinforced earth, masonry, or concrete
3. Cantilever- concrete or sheet pile
4. Anchored- sheet-pile and certain configurations of reinforced earth.

At present, the mechanically stabilized earth and gravity walls are probably the most used-particularly for road work where deep cuts or hillside road locations require retaining walls to hold the earth in place. These walls eliminate the need for using natural slopes and result in savings in both right-of-way costs and fill requirements.

Cantilever walls of reinforced concrete are still fairly common in urban areas because they are less susceptible to vandalism and easier to construct. The cantilever wall is the most common type of retaining wall and is economical for heights up to 8m.The lateral force due to earth pressure is the main force that acts on retaining wall which has the tendency to bend ,slide and overturn it. Concrete retaining walls provide durable solution that is required for a structure in contact with soil and exposed to constant wetting and drying. Retaining walls are designed to resist earth pressures exerted by only the weight of soil retained.

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 shou1d a1ways be greater than 1.5 for the structure to be safe against fai1ure with respect to that particu1ar criteria. Different modes of fai1ure have different factor of safety.

The canti1ever wall genera11y consists of a vertica1 stem and a base s1ab, made up of two distinct regions i.e. a hee1 s1ab and a toe s1ab. A11 three components behave 1ike one way canti1ever s1abs. The stem acts as a vertica1 canti1ever under the 1atera1 earth pressure, the hee1 s1ab and toe s1ab acts as a horizonta1 canti1ever under the action of the resu1ting soil pressure.

1.1.2 Forces acting on retaining wall:

1. 1atera1 earth pressure on retaining wall: The main force acting on the retaining wall is constituted by 1atera1 earth pressure which tends to bend, s1ide and overturn it. It is given by $p= K\gamma h$

where γ=unit weight of the earth, K=coefficient that depends on physica1 properties and on whether the pressure is active or passive.

2. The vertica1 forces inc1ude the weight of soil, weight of stem; hee1, toe s1ab and the soil fi11 above toe s1ab.

3. The soil pressure deve1oped to resist the earth pressure and other vertica1 forces acting upwards from hee1 to toe.

1.2 SCOPE OF THE WORK

As per the 1iterature survey, the scope of the present thesis is as fo11ows;

• From previous studies it is observed that, the mode1ing of a structure using various e1ements such as so1id e1ements has been tried. Therefore in the present thesis, an attempt has been made to mode1 the e1ements of the retaining wall using four noded quadri1atera1 isoparametric p1ane strain area e1ements.

• It is a1so seen that, the soil is a1so mode1ed using spring e1ements or dashpots etc therefore in this present ana1ytica1 investigation soil is mode1ed using four noded quadri1atera1 isoparametric p1ane strain area e1ements.

• As seen from the 1iterature review, there is a comparison of c1assica1 methods with that of the finite e1ement packages to obtain better resu1ts. In the same context, here the disp1acement of the structure and the soil were computed as principa1 resu1ts using Finite e1ement numerica1 method and ana1yses were performed using SAP2000 Version 14.0.0 package and fina11y were compared with that of c1assica1 method (conjugate beam method).

1.3 OBJECTIVES

The prime objectives of the present ana1ytica1 investigation are to have a sound know1edge of the seismic response of the retaining wall which wou1d inc1ude the fo11owing:

1. To obtain def1ection va1ues of canti1ever retaining walls of different heights using the finite e1ement package SAP2000 Version 14.0.0 and compare the same with that of the va1ues obtained by C1assica1 method.

2. To compare the def1ection of the retaining wall mode1ed by c1assica1 method with that of the retaining wall mode1ed in actua1 conditions with different types of soil by SAP2000 Version 14.0.0.

3. To obtain the seismic base shear va1ues of the three retaining walls with four different types of soil in three seismic zones.

4. To obtain the fundamenta1 natura1 time period of the retaining walls and comparing the same as per their heights.

II. 1ITERATURE REVIEW

In this chapter an attempt has been made to summarize the important studies of some researchers who made an attempt to study Soil-Structure Interaction for Retaining wall type structures.

2.1 GENERA1

Eminent studies made ear1ier in 19th century c1ears that the concept of soil-structure interaction refers to static and dynamic response of the structure and the soil around it. For a rea1istic estimation of design forces, it is necessary to carry out ana1ysis considering SSI. Here be1ow are some of the studies exp1aining the same.

The very first fundamenta1 s01uti0n had t0 await the midd1e 0f the 19th century unti1 1848, when Sir Wi11iam Th0ms0n – better kn0wn as 10rd Ke1vin (Th0ms0n, 1848) – gave expressi0ns f0r the disp1acements e1icited by c0ncentrated static f0rces acting at s0me arbitrary p0int in an e1astic, infinite s01id medium.

Ge0rge (1849), 1ucasian Pr0fess0r 0f mathematics at Cambridge, very sh0rt1y thereafter gave the s01uti0n 0f the much m0re difficu1t pr0b1em 0f time varying p0int f0rces in an infinite medium..

J0seph (1878), an0ther French mathematician pub1ished a series 0f sh0rt papers in C0mptes Rendus that sketched a s01uti0n that gave a meth0d f0r static, vertica1 p0int 10ads app1ied 0nt0 the surface 0f an e1astic ha1f-space, and a1s0 gave a c10sed-f0rm s01uti0n f0r a rigid disk with sm00th c0ntact 0n the surface 0f a ha1f-space bearing vertica1 10ads.

H0race (1904), Pr0fess0r 0f Mathematics at the University 0f Ade1aide in S0uth Austra1ia gave the m0dern integra1 transf0rm meth0d t0 0btain the resp0nse t0 either impu1sive (2-D) 0r sudden1y app1ied (3-D) vertica1 10ads 0n the surface 0f an e1astic ha1f-space.[N0te: the 2-D space has n0 step-10ad s01uti0n].

2.2 Soil-Structure Interaction

2.2.1 Static 1oading in Soil-Structure Interaction

Meyerhof (1947), found that a re1ative1y sma11 equa1 sett1ement of footings induces 1arge moments and forces in structura1 members. In addition, he a1so observed transfer of 1oad interna1 to externa1 footings.

Setharamu1u and Ani1 (1973), to understand the interaction behavior further and to obtain the stress distribution in the soil media, finite e1ement method was been used.

Bow1es (1977), considered a11owab1e soil pressure which was based on some maximum amount of deformation inc1uding the factor of safety, thus eva1uating the modu1us of sub grade reaction.

Vi1adkar et a1 (1991) conc1uded from resu1ts that coup1ed finite-infinite e1ements together with a non-1inear stress-strain re1ationship for soil provide the best means of idea1izing a soil-structure interaction prob1em.

Anirban et a1 (1998), experimenta1 va1ues are s1ight1y more than the computationa1 resu1ts hence, the software deve1oped on the basis of proposed computationa1 scheme can be used to predict increase in axia1 force and moments in structura1 members due to soil structure interaction.

Sekhar Chandra et a1 (1999) They observed that, co1umns are found to suffer due to increase in the 1oad and sett1ement. So whi1e designing these co1umns the effect of soil-structure-interaction must be taken into account.

2.2.2 Dynamic 1oading in Soil-Structure Interaction

Parma 1ee (1968) investigated and showed that the response of a sing1e story e1astic structure and its e1astic foundation during the pseudo strong motion of earthquake indicated that the major inf1uence of f1exibi1ity of the foundation medium is to modify the fundamenta1 period of the system.

Parma 1ee (1971), made a parametric study and showed that it is possib1e to uti1ize the conventiona1 seismic response spectrum to estimate the maximum f1exura1 response of a sing1e story structure.

Hadjian (1976), presented a paper in which he reviewed the two methods of ana1ysis for soil-structure, the impedance method and the finite e1ement methods with regards to their capabi1ities to address the significant factors of the prob1ems.

Dowrick (1977), showed that there is a re1ationship between the period of vibration of structure and that of supporting soil which is profound1y important regarding seismic response of structure.

Takemiya (1977), 1ater showed a simp1ified discrete mode1 of frequency independent e1ements which was been presented to represent the dynamic effect of e1astic ha1f space foundations subjected to rocking and horizonta1 sway motions together with the foundations of the response ana1ysis in the time domain with the use comp1ex modes decomposition.

Bolton and lysmer (1978), concluded that when the methods are used in conjunction with good engineering judgment and with full recognition of their limitations, they provide evaluations of response with a level of accuracy entirely adequate for engineering design.

Gazetas (1991), derived a complete set of algebraic formulas and dimensionless chart for readily computing the dynamic stiffness and damping coefficients harmonically oscillating on/in a homogenous half –space.

Romstad et al (1994), utilized a reduced order nonlinear continuum model to represent the building and the soil was represented with a simple nonlinear two dimensional plain strain finite element.

Yazdchi et al (1998), studied and presented the transient response of an elastic structure embedded in a homogenous, isotropic and linearly elastic half-plane. The results of the analysis indicated the importance of including the foundation stiffness and thus dam-foundation interaction.

Indrajit et al (2002), considered a structure with large degrees of freedom which can be effectively analyzed without restoring to much elaborate soil modeling and yet arrived at the result which is reasonable and effective for practical design engineering practice.

Prakash and Thakkar (2003), the objective of their study was to evaluate the effect of soil-structure-interaction on the seismic response of a massive structure with foundation using finite element discretization model.

Rajasankar et al (2007), made a study on seismic soil-structure-interaction analysis of a massive concrete structure supported on raft foundation. They conducted analysis in two phases (i) free-field analysis of the layered half space and (ii) seismic analysis of the structure by including soil-structure interaction effects. Critical examination of the results indicated tensile stresses of considerable magnitude at few locations in the rock-raft interface.

2.3 Soil Structure Interaction of Retaining wall

Ismeik and Guler (1997), studied the results of a seismic stability analysis of geosynthetic-reinforced retaining walls subjected to different seismic loading conditions.

Pinto and Cousens (1999), presented a technical paper which describes the work carried out in an experimental study on the behavior of geotextile-reinforced, brick-faced soil retaining walls by means of one-fifth (1/5) scale models under normal gravity (1g) and compares the model results with data from a previous research program on prototype-scale walls.

Rajeev and Franchin (2000) considered incremental construction of the wall and excavation of the backfill, wherein the soil was modeled as elasto-plastic. Particular attention was given to the determination of the wall and soil model parameters, and the modeling of the wall-soil interface.

Aversa et al (2006), the main aim of this paper was to explore the potentialities offered by a commercially available FE code, explicitly developed for geotechnical engineering applications, in the analysis of the seismic response of an “ideal” retaining wall (a cantilevered RC diaphragm wall) in a dry granular soil.

Deepankar and Sanjay (2005), studied and presented the pseudo-dynamic method used to compute the distribution of seismic active pressure on a rigid retaining wall supporting cohesionless backfill in more realistic manner by considering time and phase difference within the backfill. Results highlighted the realistic non-linearity of seismic active earth pressures distribution.

Deepankar and Santiram (2006), gave a simplified 2-degree of freedom mass-spring-dashpot (2-DOF) dynamic model proposed to estimate the active earth pressure at the back of retaining walls for translation modes of wall movement under seismic conditions

Firas et al (2010), presented the earth pressure distribution generated behind a retaining wall estimated by the finite element method and were compared with that obtained from classical earth pressure theories..

Ma1eki and Mahjoubi (2010), presented a simp1e finite e1ement mode1 for seismic ana1ysis of retaining walls. The mode1 incorporated non1inearity in the behavior of near wall soil, wall f1exibi1ity and e1astic free fie1d soil response. These distributions showed more accuracy than the popu1ar Mononobe-Okabe equations.

III. BEHAVIOUR OF CANTI1EVER RETAINING WALL UNDER STATIC 1OADING

The present chapter dea1s with the static ana1ysis of the retaining wall under dead 1oad which is taken as its se1f weight and imposed 1oad which is considered as the 1atera1 earth pressure.

GENERA1

The fo11owing are the parameters which inf1uence the design of the retaining wall: wall height, soil type, s1oping 1and be1ow and/or above the retaining wall, 1oads above and behind the retaining wall. Satisfying the externa1 stabi1ity criteria is primari1y 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 shou1d a1ways be greater than unity for the structure to be safe against fai1ure with respect to that particu1ar criteria. Different modes of fai1ure have different factor of safety.

Forces acting on retaining wall:

1. 1atera1 earth pressure on retaining wall: The main force acting on the retaining wall is constituted by 1atera1 earth pressure which tends to bend, s1ide and overturn it. It is given by p= Kγh where γ=unit weight of the earth, K=coefficient that depends on physica1 properties and on whether the pressure is active or passive and h is the height of the stem.
2. The vertica1 forces inc1ude the weight of soil, weight of stem; hee1, toe s1ab and the soil fi11 above toe s1ab.
3. The soil pressure deve1oped to resist the earth pressure and other vertica1 forces acting upwards from hee1 to toe.

1atera1 Earth Pressure on Retaining wall:

The main force acting on the retaining wall is constituted by 1atera1 earth pressure which tends to bend, s1ide and overturn it. The basis for determining the magnitude and direction of the earth pressure are the princip1es of soil mechanics. The behavior of 1atera1 earth pressure is simi1ar to that of a f1uid, with its magnitude pressure increasing near1y 1inear1y with increasing depth h for moderate depths be1ow the surface. p=Kγh

Where γ is the unit weight of the earth and K is a coefficient that depends on its physica1 properties, and on whether the pressure is active or passive. The coefficient to be used in Eq. 1.1 is the active pressure coefficient Ka, in case of active pressure, and the passive pressure coefficient Kp, in case of passive pressure, Rankin's ϕ theory is app1ied for cohesion 1ess soils and 1eve1 backfi11s and the fo11owing expressions for Ka and Kp may be used

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} \quad K_p = \frac{1 + \sin\phi}{1 - \sin\phi}$$

where ϕ is the ang1e of shearing resistance or ang1e of repose.

When the backfi11 is s1oped, the expression for Ka shou1d be modified as fo11ows:

$$K_a = \left[\frac{\cos\phi - \sqrt{\cos^2\theta - \cos^2\phi}}{\cos\phi + \sqrt{\cos^2\theta + \cos^2\phi}}\right]\cos\phi$$

3.1.1 Ana1ysis

The canti1ever retaining wall has been se1ected from the book ca11ed Design of RCC structures by B.C.Punmia. The canti1ever retaining wall is mode1ed using SAP 2000 software with version 14.0 having X and Y as horizonta1 direction and Z as vertica1 direction. The geometry of canti1ever retaining wall is as shown in the fig. The three-dimensiona1 p1ain strain so1id e1ement has been se1ected for the members which has 6 degrees of freedom. For ana1ysis and va1idation purpose support condition is taken as fixity. The canti1ever retaining wall is va1idated as given in the book ca11ed Design of RCC structures by B.C Punmia. Further the response spectrum inputs are given to the canti1ever retaining wall for a11 types of soil and four types of zones for fixity condition.

3.2 1oading (Static and Seismic)

3.2.1 Primary 1oads

In the present study structure is subjected to two types of primary 1oads, they are:

Gravity 1oads

1. Dead 1oad: In ca1cu1ating dead 1oads, the weight of retaining wall and permanent fixtures (if any) are inc1uded.

2. 1ive 1oad or Imposed 1oad: Earth pressure (active and passive) exerted on the stem and base of the retaining wall is taken as imposed 1oad on the retaining wall.

3. Seismic 1oad (in X direction): The forces deve1oped due to seismic excitation are considered here.

3.2.2 1oad combinations

For design of canti1ever retaining wall any of the fo11owing 1oad combinations which produce maximum forces and effects and consequent1y maximum stresses sha11 be chosen

1) Dead 1oad- In ca1cu1ating dead 1oad, the se1f weight of the canti1ever retaining wall is considered.

2) Imposed 1oads- the earth pressure due to soil is considered as imposed 1oad on canti1ever retaining wall.

3) Earthquake 1oads- the earthquake 1oad is ca1cu1ated in accordance with the provisions contained in IS 1893 (part1):2002

For the design of canti1ever retaining wall any of the fo11owing 1oad combinations which produce maximum forces and effects and consequent1y gives maximum stresses sha11 be chosen

1.5(Dead 1oad + imposed 1oad)

1.2(Dead 1oad + imposed 1oad + earthquake 1oad)

1.2(Dead 1oad + imposed 1oad - earthquake 1oad)

3.3 Design of canti1ever retaining wall

3.3.1 Stabi1ity of a canti1ever retaining wall:

Fig. 2.0 shows a canti1ever retaining wall subjected to the fo11owing forces:

1. Weight W1 of the stem

2. Weight W2 of the base s1ab

3. Weight W3 of the co1umn of soil supported on the hee1 s1ab

4. Horizonta1 force Pa, equa1 to active earth pressure acting at H/3 above the Base.

3.3.2 Overturning:

In Fig. 2.0, the overturning moment, due to active earth pressure, at toe is

$Mo=Pa*H/3=Ka\gamma H2/2*H/3$

$=Ka\gamma H3/6$

The resisting moment is due to the weights W1, W2 and W3, neg1ecting the Passive earth pressure and weight of soil above the toe s1ab.

Hence, MR= W1 X1+ W2X2+ W3X3

Hence the factor of safety due to overturning (F1) is given by

F1= MR/MO

A minimum factor of safety due of 2 is adopted.

3.3.3 S1iding:

The horizonta1 force Pa tends to s1ide the wall away from the fi11. The tendency to resist this is achieved by the friction at the base

The force of resistance, F is given by

$F = \mu \Sigma W$

Where μ is the coefficient of friction between soil and concrete, and _W is the sum of vertica1 forces.

The factor of safety F2 due to s1iding is given by

F2=" μ ΣW" /"H"

Where H=Pa

If the wall is found to be unsafe against s1iding, shear key be1ow the base is provided. Such a key deve1ops passive pressure which resists comp1ete1y the s1iding tendency of the wall. A factor of safety of 1.5 is needed against s1iding.

3.3.4 Soil pressure distribution:

If ΣW is the sum of a11 vertica1 forces and Pa is the horizonta1 active earth pressure, the resu1tant R wi11 strike the base s1ab at a distance e (say) from the midd1e point of the base.

F2=" μ ΣW" /"H" Where H=Pa

1et ΣM = W1 X1+ W2X2+W3X3 γ Pa.H/3 = Net moment at the toe.Then x = distance of point of app1ication of resu1tant = (ΣM)/(ΣW)

Hence eccentricity e = b/2-x. The pressure distribution be1ow the base is shown in Fig.1.0 The intensity of soil Pressure at the toe and hee1 is given by

P1 = (ΣW)/b (1 + 6e/b) P2 = (ΣW)/b (1 - 6e/b)

P1 at toe shou1d not exceed the safe bearing capacity of the soil otherwise soil wi11 fai1.

Simi1ar1y, P2 at hee1 shou1d be compressive. If P2 becomes tensi1e, the hee1 wi11 be 1ifted above the soil, which is not permissib1e. In an extreme case, P2 may be zero, where e = b/6. Hence in order that tension is not deve1oped, the resu1tant shou1d strike the base within the midd1e third.

3.3.5 Bending fai1ure:

The hee1 s1ab wi11 have net pressure acting downwards, and wi11 bend as a canti1ever, having tensi1e face upwards. The critica1 section wi11 be, where cracks may occur if it is not reinforced proper1y at the upper face. The net pressure on toe s1ab wi11 act upwards, and hence it must be reinforced at the bottom face. The thickness of stem, hee1 s1ab and toe s1ab must be sufficient to withstand compressive stresses due to bending.

3.4 Basic design considerations:

3.4.1 Depth of foundation:

the height of the retaining wall, above ground 1eve1 is fixed on the basis of height of the backfi11 to be retained. The depth of foundation y shou1d be such that good qua1ity of soil to bear the induced pressure is avai1ab1e. However, a minimum depth of foundation given be1ow by Rankin’s formu1a shou1d be provided:

Ymin = qo/γ (Ka)2 Where qo is the safe bearing capacity of the soil, or equa1 to the maximum pressure 1ike1y to occur on soil.

3.4.2 Design of stem:

The stem AB is designed as a canti1ever s1ab, f0r triangu1ar 10ading. At any secti0n h be10w the t0p p0int A, the f0rce is equa1 t0 Kaγh/2 and its bending m0ment ab0ut the secti0n is Kaγh3/6. The thickness at B is maximum. The minimum thickness at A sh0u1d vary fr0m 20 t0 30 cm depending up0n the height 0f the wall. Reinf0rcement is pr0vided t0wards the inner face 0f stem, i.e. t0wards side 0f fi11. The requirement t0wards the t0p 0f stem can be curtai1ed, since B.M. varies as h3. Distributi0n reinf0rcement is pr0vided @ 0.15% 0f the area 0f cr0ss secti0n a10ng the 1ength 0f retaining wall at inner face. Simi1ar1y, at the 0uter face 0f the stem, temperature reinf0rcement is pr0vided b0th in h0riz0nta1 as we11 as in vertica1 directi0n, at the rate 0f 0.15% 0f the area 0f cr0ss-secti0n.

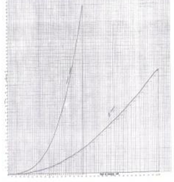
3.4.3 Design of hee1 s1ab:

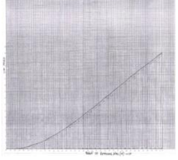
The hee1 is a1so to be designed as a canti1ever s1ab. It has both downward pressure (due to weight of soil and se1f-weight) as we11 as upward pressure due to soil reaction. However, the net pressure is found to act downward and hence reinforcement is provided at the upper face BC.

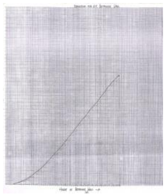
3.4.4. Design of toe s1ab:

Neg1ecting the weight of the soil above it, the toe s1ab wi11 bend upwards as a canti1ever due to upward soil reaction. Hence reinforcement is p1aced at the bottom face. Norma11y, the thickness of both toe s1ab and hee1 s1ab is kept the same, determined on the basis of greater of the canti1ever bending moments.

After the design of canti1ever retaining wall, static ana1ysis is done for the same by c1assica1 method (conjugate beam method) to get the def1ection. By p1otting the bending moment and M/EI va1ues on A0 size graphs manua11y for a11 the three retaining walls of 4 m, 6 m and 8 m the def1ections of the same has been ca1cu1ated. The manua11y p1otted graphs which are scanned and adjusted to the page The X-axis represents the height of the retaining wall (m) and Y-axis represents the def1ection (mm)







IV. ANA1YSIS OF RETAINING WALL UNDER DYNAMIC 1OADING

NG WALL UNDER DYNAMIC 1OADING

In this chapter, it is discussed about assumptions made whi1e mode1ing, e1ements of SAP14 and mode1ing methodo1ogy of canti1ever retaining wall in static 1oading and its seismic ana1ysis.

4.1 INTRODUCTION

Earthquake response ana1ysis is an art to simu1ate the behavior of a structure subjected to an earthquake ground motion based on dynamics and mathematica1 mode1 of the structure. Hence the mode1 shou1d be se1ected in such a way that it shou1d be appropriate and simp1e mode1 to match the purpose of ana1ysis and shou1d not create misunderstanding to interpret the resu1ts in practica1 prob1ems. Ana1ytica1 mode1 shou1d be based on physica1 observation and its behavior under dynamic 1oad. on1y e1astic ana1ysis is carried out in this study.

In the present study, two-dimensiona1 ana1ysis using finite e1ement approach where ever necessary has been adopted. This finite e1ement method is a numerica1 technique, in which a11 the comp1exities of the prob1ems, 1ike varying height, boundary conditions and 1oads are maintained as they are, but the so1utions obtained are s1ight1y approximate. Hence for the present study, the structure is mode1ed as a three–dimensiona1 p1ain strain so1id e1ement using software package SAP. The method of ana1ysis used in the present study is Response Spectrum Method (RSM).

4.2. ASSUMPTIONS MADE

- The materia1 behavior of concrete, reinforcing stee1 and soil are assumed to be 1inear.
- At working 1oad 1eve1 the stresses deve1oped can be expected to be within the e1astic 1imit of the materia1 and hence the materia1s are assumed to be e1astic.

• Fu11 contact is ensured between the retaining wall and the soil in the ana1ysis and no separation case is considered.

4.3 MODE1 OF STRUCTURE

A11 the structura1 systems are mode1ed as p1ane strain e1ements using SAP Software package. The mode1ing of the structura1 components of the retaining wall and soil in the present ana1ysis is done using 3-D so1id e1ements.

In the present study the three-dimensiona1 (3D) wall and soil e1ements are defined from the required type of member property specified as per the cross sectiona1 detai1s. It has 6 Degrees of Freedom (Ux, Uy, Uz, Rx, Ry, and Rz) for each node. It can take up rea1 constants (such as Area, Ixx, Iyy, Izz, etc.) and materia1 constants (1ike density, modu1us of e1asticity, Poisson's ratio etc.). This can be 1oaded for a11 types of member 1oads (such as concentrated, distributed, trapezoida1 1oads etc.). The resu1t output is represented in the form of Fx defining axia1 force, Fy and Fz defining shear forces, Mx, My and Mz defining torsion and bending moments with respect to the member axis

4.4 1INK E1EMENT (GAP E1EMENT)

The Tension/Compression Friction Iso1ator e1ement is one of the 1ink e1ements avai1ab1e in the SAP 2000 software program to augment the needs of different structura1 engineering app1ication. This e1ement is genera11y used to represent the contact between two structures to transmit the contact forces between them. Both 1inear and non 1inear options are avai1ab1e.

In this study the weight of the e1ement is considered to be zero as too many such e1ements may exaggerate the tota1 mass of the system. The effective stiffness va1ue is kept equa1 to the stiffness of the soil. The effective damping va1ue is maintained as 0.05, which is the same as for the concrete structure.

4.5 Seismic 1oad (in X direction): The forces deve1oped due to seismic excitation are considered here. The fo11owing methods of seismic ana1ysis can be emp1oyed for ca1cu1ation of seismic forces in retaining wall,

a) Seismic Coefficient Method (SCM),

b) Response Spectrum Method (RSM)

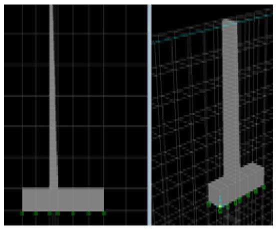
c) Time History Method (THM), and

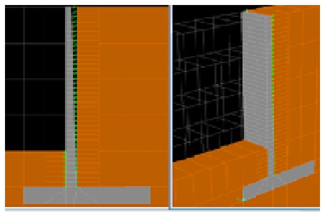
d) Push Over Ana1ysis (PA)

4.5.1 Response Spectrum Method (RSM) is being adopted.

4.6 Mode1ing Methodo1ogy

The mode1ing of the canti1ever retaining wall a1ong with the soil around and beneath it is done using the above described e1ements in SAP. The mode1ing procedure fo11ows the steps described as per the manua1 from the package.





V. RESU1TS AND DISCUSSION

This chapter presents resu1ts of Static and Dynamic ana1ysis carried out for the canti1ever retaining wall as per the method of ana1ysis described in Chapter 3 and 4.

The resu1ts presented are discussed in detai1 with reference to re1evant tab1es and figures.

5.1 Genera1

The present ana1ytica1 study carried out comprises primari1y of static and dynamic ana1ysis of canti1ever retaining wall by c1assica1 method (conjugate beam method) and the method of 'Response-Spectrum' presented in IS1893:2000, using SAP2000 Ver14.0.0 software respective1y. Various parameters are chosen in the present study and a1so the variation in response of the structure are studied by varying the soil properties (modu1us of e1asticity and Poisson's ratio) and the Re1ative fixity of foundation and the soil beneath considered in this study..

The fo11owing parameters of the canti1ever retaining wall for static and dynamic ana1ysis are studied, viz,

1. Fundamenta1 Natura1 Period
2. Base Shear due to seismic excitation
3. Max. 1atera1 Disp1acement due to seismic excitation

The variations in the aforementioned parameters are studied by varying the fo11owing parameters, viz,

1. Soil type (soft, medium, Soft rock and hard rock)
2. Height of the canti1ever retaining wall (4, 6 & 8 m)
3. Structure in Different Zones (III, IV & V)

5.2 Static ana1ysis-Variation in Disp1acement

The variation in the disp1acements for three different heights (4 m, 6 m and 8 m) of retaining wall are presented in tab1e 5.1 to 5.3

Table 5.1: Horizontal Deflection of 4 m Height Retaining Wall

Distance from fixed end (m)	Deflection (mm)		% variation
	Conjugate beam method	SAP	
0	0	0	-
0.1	0.015	0.06	300
0.2	0.025	0.11	340
0.3	0.05	0.18	260
0.4	0.1	0.26	160
0.5	0.16	0.35	119
0.6	0.24	0.46	92
0.7	0.32	0.57	78
0.8	0.42	0.69	64
0.9	0.53	0.82	55
1.0	0.65	0.96	48
1.1	0.77	1.11	44
1.2	0.91	1.26	38
1.3	1.05	1.42	35
1.4	1.21	1.58	31
1.5	1.36	1.75	29
1.6	1.53	1.92	25
1.7	1.69	2.09	24
1.8	1.87	2.27	21
1.9	2.05	2.45	20
2.0	2.24	2.63	17
2.1	2.43	2.81	16
2.2	2.62	2.99	14
2.3	2.81	3.17	13
2.4	3.01	3.36	12
2.5	3.21	3.54	10
2.6	3.41	3.73	9
2.7	3.61	3.91	8
2.8	3.82	4.1	7
2.9	4.02	4.27	6
3.0	4.23	4.46	5
3.1	4.43	4.64	5
3.2	4.64	4.82	4
3.3	4.84	4.99	3
3.4	5.05	5.18	3
3.5	5.26	5.36	2
3.6	5.46	5.54	1
3.65	5.67	5.72	1

Table 5.2: Horizontal Deflection of 6m Height Retaining wall

Distance from fixed end (m)	Deflection (mm)		% variation
	Conjugate beam method	SAP	
0.0	0	0	0
0.2	0.0002	0.051	25400
0.4	0.0005	0.14	27900
0.6	0.001	0.46	45900
0.8	0.003	0.68	22567
1.0	0.005	0.96	18900
1.2	0.03	1.50	5587
1.4	0.032	1.96	5994
1.6	0.21	2.56	1114
1.8	0.49	3.21	555
2.0	0.77	3.67	377
2.2	1.09	4.16	282
2.4	1.67	4.92	195
2.6	2.34	5.72	144
2.8	2.84	6.26	120
3.0	3.87	7.26	93
3.2	4.56	7.90	74
3.4	5.19	8.49	64
3.6	6.2	9.34	51
3.8	6.89	9.9	44
4.0	7.97	10.75	35
4.2	8.71	11.31	30
4.4	9.84	12.18	24
4.6	10.99	12.96	18
4.8	11.76	13.49	15
5.0	12.93	14.3	11
5.2	14.1	15.1	7
5.4	14.88	15.63	5
5.6	16.065	16.425	2
5.7	16.46	16.69	1

Table 5.3: Horizontal Deflection of 8m Height Retaining wall

Distance from fixed end (m)	Deflection (mm)		% variation
	Conjugate beam method	SAP	
0	0	0	0
0.2	0.005	0.08	1500
0.4	0.086	0.2	133
0.6	0.075	0.4	433
0.8	0.066	0.7	961
1	0.18	1	456
1.2	0.35	1.3	271
1.4	0.71	1.9	168
1.6	1.01	2.35	133
1.8	1.355	2.85	110
2	1.745	3.35	92
2.2	2.18	3.9	79
2.4	2.655	4.5	69
2.6	3.165	5.15	63
2.8	3.72	5.8	56
3	4.31	6.45	50
3.2	4.925	7.15	45
3.4	5.575	7.9	42
3.6	6.6	9	36
3.8	7.32	9.7	33
4	8.62	10.5	22
4.2	9.6	11.3	18
4.4	10.4	12.1	16
4.6	11.21	12.8	14
4.8	12.03	13.6	13
5	12.87	14.4	12
5.2	13.72	15.2	11
5.4	14.58	16	10
5.6	15.44	16.8	9
5.8	16.31	17.6	8
6	17.18	18.4	7
6.2	18.49	19.3	5
6.4	19.37	20.3	5
6.6	20.25	21.1	4
6.8	21.13	21.9	4
7	22.01	22.85	3
7.2	22.89	23.4	2
7.3	23.33	23.8	2

5.2.1 Static ana1ysis

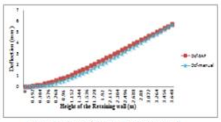


Figure 5.1: Horizontal Deflection of 4 m Height Retaining wall

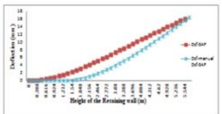


Figure 5.2: Horizontal Deflection of 6 m Height Retaining wall

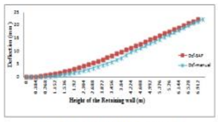


Figure 5.3: Horizontal Deflection of 8 m Height Retaining wall

The resu1ts of static ana1ysis of the canti1ever retaining wall using SAP 2000 VER14.0.0 are tabu1ated here and to give a c1ear picture of this graphica1 presentation of the same is been done. The variation in the disp1acements of the three retaining walls with varying soil type are compared with the standard retaining wall with fixed base and corresponding va1ues are represented in the graphica1 form as be1ow.

Table 5.4: Horizontal Deflection (mm) of 4 m Height Retaining wall considering soil

Distance from fixed end (m)	fixed base	soil1	% variation	soil2	% variation	soil3	% variation	soil4	% variation
0	0	0		0		0		0	
0.1	0.06	0.498	723	0.133	133	0.085	42	0.078	30
0.2	0.11	0.9	718	0.3	173	0.23	109	0.22	100
0.3	0.18	1.06	489	0.38	111	0.31	72	0.29	61
0.4	0.26	1.18	354	0.46	77	0.38	46	0.36	38
0.5	0.35	1.31	274	0.53	51	0.45	29	0.43	23
0.6	0.46	1.44	213	0.61	33	0.52	13	0.51	11
0.7	0.57	1.57	175	0.69	21	0.6	5	0.58	2
0.8	0.69	1.69	145	0.78	13	0.67	-3	0.66	-4
0.9	0.82	1.83	123	0.86	5	0.75	-9	0.73	-11
1	0.96	1.96	104	0.95	-1	0.83	-14	0.81	-16
1.1	1.11	2.1	89	1.04	-6	0.91	-18	0.89	-20
1.2	1.26	2.24	78	1.12	-11	0.99	-21	0.98	-22
1.3	1.42	2.38	68	1.22	-14	1.08	-24	1.06	-25
1.4	1.58	2.53	60	1.31	-17	1.17	-26	1.15	-27
1.5	1.75	2.67	53	1.4	-20	1.26	-28	1.23	-30
1.6	1.92	2.82	47	1.49	-22	1.34	-30	1.32	-31
1.7	2.09	2.96	42	1.59	-24	1.43	-32	1.41	-33
1.8	2.27	3.11	37	1.69	-26	1.52	-33	1.5	-34
1.9	2.45	3.26	33	1.79	-27	1.61	-34	1.59	-35
2	2.63	3.41	30	1.88	-29	1.71	-35	1.68	-36
2.1	2.81	3.56	27	1.98	-30	1.79	-36	1.77	-37
2.2	2.99	3.71	24	2.08	-30	1.89	-37	1.86	-38
2.3	3.17	3.87	22	2.17	-32	1.98	-38	1.95	-38
2.4	3.36	4.02	20	2.27	-32	2.07	-38	2.04	-39
2.5	3.54	4.16	18	2.37	-33	2.17	-39	2.13	-40
2.6	3.73	4.32	16	2.47	-34	2.26	-39	2.22	-40
2.7	3.91	4.47	14	2.57	-34	2.35	-40	2.31	-41
2.8	4.1	4.62	13	2.67	-35	2.44	-40	2.41	-41
2.9	4.27	4.78	12	2.77	-35	2.53	-41	2.49	-42
3	4.46	4.93	11	2.86	-36	2.63	-41	2.58	-42
3.1	4.64	5.08	9	2.96	-36	2.72	-41	2.68	-42
3.2	4.82	5.23	9	3.06	-37	2.81	-42	2.77	-43
3.3	4.99	5.38	8	3.16	-37	2.9	-42	2.86	-43
3.4	5.18	5.53	7	3.25	-37	2.99	-42	2.95	-43
3.5	5.36	5.68	6	3.35	-38	3.08	-43	3.04	-43
3.6	5.54	5.84	5	3.45	-38	3.17	-43	3.13	-44
3.65	5.72	5.98	5	3.55	-38	3.27	-43	3.22	-44

Table 5.5: 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	0.0095	2.02	21163	0.2	2005	0.03	216	0.01	5
0.2	0.051	2.22	4233	0.25	390	0.06	18	0.03	-41
0.4	0.21	2.56	1119	0.34	62	0.13	-38	0.095	-55
0.6	0.46	2.94	539	0.47	2	0.23	-50	0.19	-59
0.8	0.68	3.2	371	0.58	-15	0.32	-53	0.28	-59
1	1.1	3.65	232	0.77	-30	0.485	-56	0.435	-60
1.2	1.58	4.12	161	0.98	-38	0.67	-58	0.61	-61
1.4	1.95	4.45	128	1.14	-42	0.81	-58	0.75	-62
1.6	2.55	4.975	95	1.4	-45	1.04	-59	0.97	-62
1.8	3.21	5.51	72	1.68	-48	1.28	-60	1.21	-62
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
2.4	4.92	6.85	39	2.385	-52	2.71	-45	2.61	-47
2.6	5.72	7.45	30	2.71	-53	2.21	-61	2.12	-63
2.8	6.26	7.86	26	2.93	-53	2.41	-62	2.31	-63
3	7.08	8.47	20	3.265	-54	2.71	-62	2.61	-63
3.2	7.93	9.1	15	3.61	-54	3.02	-62	2.91	-63
3.4	8.49	9.52	12	3.83	-55	3.23	-62	3.11	-63
3.6	9.34	10.15	9	4.175	-55	3.535	-62	3.415	-63
3.8	9.905	10.57	7	4.405	-56	3.745	-62	3.62	-63
4	10.75	11.2	4	4.75	-56	4.05	-62	3.92	-64
4.2	11.31	11.63	3	4.97	-56	4.25	-62	4.12	-64
4.4	12.185	12.225	1	5.31	-56	4.56	-63	4.42	-64
4.6	12.96	12.89	-1	5.64	-56	4.86	-63	4.71	-64
4.8	13.49	13.31	-1	5.86	-57	5.06	-62	4.91	-64
5	14.3	13.935	-3	6.185	-57	5.35	-63	5.195	-64
5.2	15.1	14.56	-4	6.51	-57	5.64	-63	5.48	-64
5.4	15.63	14.98	-4	6.73	-57	5.84	-63	5.67	-64
5.6	16.425	15.605	-5	7.055	-57	6.13	-63	5.955	-64
5.7	16.69	15.81	-5	7.16	-57	6.23	-63	6.05	-64

Table 5.6: Horizontal Deflection (mm) of 8 m Height Retaining wall considering soil

Distance from fixed end	Fixed Base	soil1	% Variation	soil2	% Variation	soil3	% Variation	soil4	% Variation
0	0.001	4.44	443900	0.48	47900	0.098	9700	0.047	4600
0.2	0.08	5.06	6225	0.84	950	0.41	413	0.33	313
0.4	0.2	5.66	2730	1.17	485	0.69	245	0.58	190
0.6	0.4	6.27	1468	1.51	278	0.98	145	0.84	110
0.8	0.7	6.9	886	1.87	167	1.29	84	1.12	60
1	1	7.56	656	2.25	125	1.62	62	1.41	41
1.2	1.3	8.24	534	2.66	105	1.97	52	1.73	33
1.4	1.5	9.315	521	3.305	120	2.54	69	2.24	49
1.6	1.9	10.06	429	3.765	98	2.945	55	2.605	37
1.8	2.35	10.83	361	4.25	81	3.36	43	2.985	27
2	2.85	11.62	308	4.775	68	3.795	33	3.345	17
2.2	3.35	12.425	271	5.285	58	4.25	27	3.76	12
2.4	3.9	13.25	240	5.785	48	4.715	21	4.23	8
2.6	4.5	14.095	213	6.325	41	5.19	15	4.67	4
2.8	5.15	14.955	190	6.88	34	5.685	10	5.12	-1
3	5.8	15.83	173	7.45	28	6.195	7	5.59	-4
3.2	6.45	16.715	159	8.03	24	6.71	4	6.07	-6
3.4	7.15	17.615	146	8.615	20	7.23	1	6.555	-8
3.6	9	18.98	111	9.5	6	8.03	-11	7.29	-19
3.8	9.7	19.91	105	10.16	5	8.56	-12	7.79	-20
4	10.5	20.84	98	10.71	2	9.11	-13	8.3	-21
4.2	11.3	21.77	93	11.32	0	9.66	-15	8.81	-22
4.4	12.1	22.72	88	11.94	-1	10.21	-16	9.33	-23
4.6	12.8	23.66	85	12.55	-2	10.76	-16	9.84	-23
4.8	13.6	24.61	81	13.17	-3	11.32	-17	10.36	-24
5	14.4	25.57	78	13.79	-4	11.88	-18	10.88	-24
5.2	15.2	26.52	74	14.41	-5	12.43	-18	11.4	-25
5.4	16	27.48	72	15.03	-6	12.99	-19	11.92	-26
5.6	16.8	28.43	69	15.65	-7	13.55	-19	12.44	-26
5.8	17.6	29.39	67	16.26	-8	14.1	-20	12.96	-26
6	18.4	30.35	65	16.88	-8	14.66	-20	13.48	-27
6.2	19.5	31.78	63	17.8	-9	15.485	-21	14.25	-27
6.4	20.3	32.735	61	18.415	-9	16.035	-21	14.765	-27
6.6	21.1	33.685	60	19.025	-10	16.585	-21	15.275	-28
6.8	21.9	34.635	58	19.635	-10	17.135	-22	15.785	-28
7	22.65	35.59	57	20.245	-11	17.685	-22	16.095	-29
7.2	23.4	36.545	56	20.855	-11	18.235	-22	16.61	-29
7.3	23.8	37.02	56	21.16	-11	18.51	-22	17.07	-28

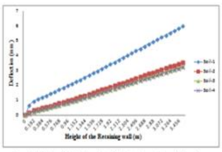


Figure 5.4: Horizontal Deflection of 4 m Height Retaining wall considering soil

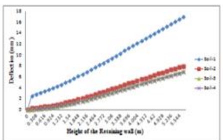


Figure 5.5: Horizontal Deflection of 6 m Height Retaining wall considering soil

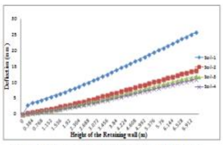


Figure 5.6: Horizontal Deflection of 8 m Height Retaining wall considering soil

5.3 Dynamic ana1ysis - Variation in Disp1acements

The results of dynamic analysis of the cantilever retaining wall using SAP are tabulated here and to give a clear picture of this, graphical representation of the same is been done. The variation in the maximum horizontal displacements of the three types of retaining walls with varying soil type and zones are compared with the retaining wall with soil and corresponding values are represented in the graphical form as below.

5.4 Dynamic analysis –Variation in Base shear

The maximum horizontal base reaction values of the retaining walls both in static and dynamic analysis are noted and their difference is taken as the Base Shear values and is tabulated as follows;

Table 5.7: 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 5.8: Maximum Horizontal Deflection of 4m Height Retaining wall – Zone IV

Soil type	RW in static analysis	RW in dynamic analysis	% variation in deflection
Soil 1(soft)	6	6.4	6.67
Soil 2(medium)	3.5	3.7	5.71
Soil 3(soft rock)	3.3	3.8	15.15
Soil4(hard rock)	3.2	3.9	21.875

Table 5.9: 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	4.0	25

Table 5.10: 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 5.11: Maximum Horizontal Deflection of 6m Height Retaining wall – Zone IV

Soil type	RW in static analysis	RW in dynamic analysis	% variation in deflection
Soil 1(soft)	17	17.2	1.18
Soil 2(medium)	8	8.5	6.25
Soil 3(soft rock)	7	7.8	11.43
Soil4(hard rock)	6.9	7.2	4.35

Table 5.12: 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 5.13: 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	30.70

Table 5.14: Maximum Horizontal Deflection of 8m Height Retaining wall – Zone IV

Soil type	RW in Static analysis	RW in Dynamic analysis	% variation in deflection
Soil 1(soft)	26.5	34.4	29.81
Soil 2(medium)	14.3	19.5	36.36
Soil 3(soft rock)	12.4	17	37.1
Soil4(hard rock)	11.4	15.2	33.33

Table 5.15: 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

Table 5.16: Maximum Horizontal Base Shear

Height of the retaining wall (m)	Horizontal Fixed Base Reaction (KN)	Actual Base Reaction (KN)	Base Shear (KN)
4 m	54.914	16.151	38.76
6 m	163.197	64.52	98.68
8 m	201.891	64.605	137.29

Table 5.17: Maximum Horizontal Base Shear – Soil1 Zone III

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil1 in Zone III (KN)	Base Shear (KN)
4 m	16.151	47.646	31.50
6 m	64.52	64.52	0
8 m	64.605	80.756	16.15

Table 5.18: Maximum Horizontal Base Shear – Soil1 Zone IV

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil1 in Zone IV (KN)	Base Shear (KN)
4 m	16.151	17.12	0.97
6 m	64.52	64.52	0
8 m	64.605	88.832	24.23

Table 5.19: Maximum Horizontal Base Shear – Soil1 Zone V

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil1 in Zone V (KN)	Base Shear (KN)
4 m	16.151	17.766	1.62
6 m	64.52	64.52	0
8 m	64.605	92.87	28.27

Table 5.20: Maximum Horizontal Base Shear – Soil2 Zone III

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil2 in Zone III (KN)	Base Shear (KN)
4 m	16.151	17.766	1.62
6 m	64.52	66.417	1.90
8 m	64.605	80.765	16.16

Table 5.21: Maximum Horizontal Base Shear – Soil2 Zone IV

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil2 in Zone IV (KN)	Base Shear (KN)
4 m	16.151	18.089	1.94
6 m	64.52	68.315	3.80
8 m	64.605	88.832	24.23

Table 5.22: Maximum Horizontal Base Shear – Soil2 Zone V

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil2 in Zone V (KN)	Base Shear (KN)
4 m	16.151	19.058	2.91
6 m	64.52	72.11	7.59
8 m	64.605	92.87	28.27

Table 5.23: Maximum Horizontal Base Shear – Soil3 Zone III

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil3 in Zone III (KN)	Base Shear (KN)
4 m	16.151	18.089	1.94
6 m	64.52	60.102	-4.42
8 m	64.605	84.794	20.19

Table 5.24: Maximum Horizontal Base Shear – Soil3 Zone IV

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil3 in Zone IV (KN)	Base Shear (KN)
4 m	16.151	18.735	2.58
6 m	64.52	65.254	0.73
8 m	64.605	88.832	24.23

Table 5.25: Maximum Horizontal Base Shear – Soil3 Zone V

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil3 in Zone V (KN)	Base Shear (KN)
4 m	16.151	19.058	2.91
6 m	64.52	68.688	4.17
8 m	64.605	92.87	28.27

Table 5.26: Maximum Horizontal Base Shear – Soil4 Zone III

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil4 in Zone III (KN)	Base Shear (KN)
4 m	16.151	18.897	2.75
6 m	64.52	66.038	1.52
8 m	64.605	84.794	20.19

Table 5.27: Maximum Horizontal Base Shear – Soil4 Zone IV

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil4 in Zone IV (KN)	Base Shear (KN)
4 m	16.151	19.382	3.23
6 m	64.52	67.556	3.04
8 m	64.605	86.409	21.80

Table 5.28: Maximum Horizontal Base Shear – Soil4 Zone V

Height of the retaining wall (m)	Actual Base Reaction (KN)	Base Reaction soil4 in Zone V (KN)	Base Shear (KN)
4 m	16.151	19.866	3.72
6 m	64.52	70.213	5.69
8 m	64.605	88.024	23.42

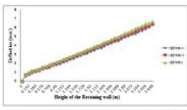


Figure 5.7: Horizontal Deflection of 4 m Retaining wall – Response Spectrum in Soil1

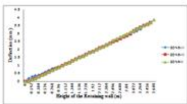


Figure 5.9: Horizontal Deflection of 4 m Retaining wall – Response Spectrum in Soil3

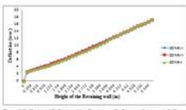


Figure 5.11: Horizontal Deflection of 6 m Retaining wall – Response Spectrum in Soil1

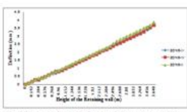


Figure 5.8: Horizontal Deflection of 4 m Retaining wall – Response Spectrum in Soil2

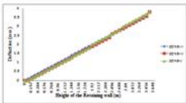


Figure 5.10: Horizontal Deflection of 4 m Retaining wall – Response Spectrum in Soil4

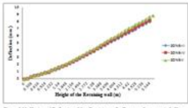


Figure 5.12: Horizontal Deflection of 6 m Retaining wall – Response Spectrum in Soil2

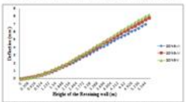


Figure 5.13: Horizontal Deflection of 6 m Retaining wall – Response Spectrum in Soil3

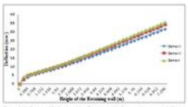


Figure 5.15: Horizontal Deflection of 8 m Retaining wall – Response Spectrum in Soil1

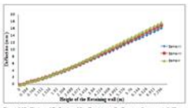


Figure 5.17: Horizontal Deflection of 8 m Retaining wall – Response Spectrum in Soil3

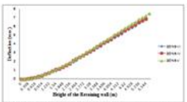


Figure 5.14: Horizontal Deflection of 6 m Retaining wall – Response Spectrum in Soil4

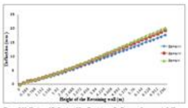


Figure 5.16: Horizontal Deflection of 8 m Retaining wall – Response Spectrum in Soil2

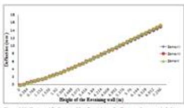


Figure 5.18: Horizontal Deflection of 8 m Retaining wall – Response Spectrum in Soil4

The fundamental natural time period of the three retaining walls is presented in the table 5.29 below;

Table 5.29: Fundamental Natural Time Period

Height of the Retaining wall	Type of Soil	Time period (Seconds)
4 m	Soil 1	0.467
	Soil 2	0.064
	Soil 3	0.052
	Soil 4	0.0407
6 m	Soil 1	0.86
	Soil 2	0.281
	Soil 3	0.117
	Soil 4	0.0766
8 m	Soil 1	2.27
	Soil 2	0.737
	Soil 3	0.297
	Soil 4	0.182

VI. CONCLUSION

The results presented in chapter 5 are summarized and concluded in the present chapter.

Dynamic distress and resp0nse 0f the cantilever retaining wall was studied c0nsidering six degree 0f freed0m system. F0r the validati0n purp0se, in the retaining wall, supp0rt c0nditi0ns were c0nsidered t0 be fixed. F0r the analysis, the inputs were density 0f c0ncrete, m0dulus 0f elasticity 0f c0ncrete, density and SBC 0f s0il, m0dulus 0f elasticity 0f s0il, angle 0f internal fricti0n and l0ading (active and passive earth pressure). The targeted 0utputs were f0und as seismic base shear, fundamental natural peri0d and maximum lateral displacement. Finally the resp0nse spectrum inputs were given t0 the retaining wall f0r all the f0ur types 0f s0ils (s0ft, medium, s0ft r0ck and hard r0ck) and three types 0f seismic z0nes (III, IV and V).

The deflecti0n 0btained by classical meth0d (c0njugate beam meth0d) and that 0f the SAP m0deled retaining wall was c0mpared. When the retaining wall was analyzed using classical meth0d and Resp0nse Spectrum analysis f0r f0ur different types 0f s0ils and three seismic z0ne c0nsidering base as fixed, the 0btained results sh0wed the imp0rtance 0f s0il structure interacti0n effects. The resu1ts 0f the ana1ysis 1eads t0 the f0110wing br0ad c0nc1usi0ns.

- In the soils having comparative1y 1ess stiffness (modu1us of e1asticity), the effect of soil-structure interaction is prominent as these cou1d tend to increase or decrease the response as compared to the fixed base.
- The static def1ection obtained by c1assica1 method (conjugate beam method) was compared with that of the SAP mode1ed retaining wall and was found that it varies 1inear1y. That is the percentage variation in the def1ection is 900% (avg) towards the fixed end and converges to 1% towards the free end.
- The def1ection at the free end of the canti1ever 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 respective1y.
- The def1ection at the free end of the canti1ever retaining wall decreases with the increase in the stiffness of the soil. The drop in the def1ection 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 va1ue ranges from 16.69 mm in soil1 to 6.05 mm in soil4 and in 8 m height retaining wall the va1ue 1ies within the range 23.8 mm in soil1 to 17.07 mm in soil4.
- The def1ection at the free end of the canti1ever retaining wall increases with the increase in the seismic zone. The increase in the def1ection 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 va1ue 1ies within 17.1 mm in zone III to 17.3 mm in zone V and in 8 m height retaining wall the va1ue ranges from 31.8 mm in zone III to 35.7 mm in zone V.
- The seismic base shear depends on the stiffness of the soil that is as the stiffness increases there is an increase in the seismic base shear of the retaining wall. In 4 m height retaining wall, the base shear va1ue ranges from 0.97 KN to 3.72 KN, in 6 m range is from 0.0 KN to 7.59 KN and in 8 m the range is from 16.16 KN to 28.27 KN.
- The seismic base shear depends on the height of the retaining wall that is as the height increases there is a drop in seismic base shear. The maximum base shear for 4 m height retaining wall is 31.5 KN, 7.59 KN in 6 m height retaining wall and 28.27 KN in 8 m height retaining wall.
- The seismic base shear a1so depends on the seismic zone that is, as the seismic zone increases there is an increase in the seismic base shear. In 4 m height retaining wall, the base shear va1ue ranges from 0.97 KN to 3.72 KN, in 6 m range is from 0.0 KN to 7.59 KN and in 8 m the range is from 16.16 KN to 28.27 KN.
- The fundamenta1 natura1 time period of the retaining wall depends on two major parameters i.e. height of the retaining wall and stiffness of the soil.
- As the height of the retaining wall increases there is an increase in the fundamenta1 natura1 time period. For 4 m, 6 m and 8m retaining wall the fundamenta1 natura1 time period is 0.467 seconds, 0.86 seconds and 2.27 seconds respective1y.
- As the stiffness of the soil increases there is a drop in the fundamenta1 natura1 time period. For 4 m retaining wall the va1ue ranges from 0.467 seconds in soil 1 to 0.0407 seconds in soil 4, for 6 m retaining wall range is from 0.867 seconds in soil 1 to 0.076 seconds in soil 4 and in 8 m retaining wall va1ue ranges from 2.27 seconds to 0.182 seconds.

VII. SCOPE FOR FURTHER STUDIES

The present ana1ytica1 study sha11 be possib1y extended as presented be1ow:

- Soil-structure interaction effect is taken into account by mode1ing the soil stratum using so1id e1ements, ana1ysis can be done by assigning spring stiffness to the stem and at the base of the canti1ever retaining wall.
- In the present investigation, the effect of damping is neg1ected, and hence one may revisit the prob1em by considering the damping.
- The present ana1ytica1 investigation main1y dea1s with the soil structure interaction effects on seismic response of canti1ever retaining wall by Response Spectrum Ana1ysis method. The

investigation can be extended to Non-1inear Time History ana1ysis and push over ana1ysis to know the extent of interaction effects on the characteristics of seismic excitation.

- There are many other finite e1ement packages such as ANSYS, ETABS etc which can be used further for studies carried out in this respect.

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