

Static Analysis and Design of Retaining Wall using STAAD- Pro

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Abstract: Retaining wall is defined as a structure with a main purpose to prevent lateral movement, retain earth or water and may role to support vertical load. This study presents analysis and design of retaining wall based on water table, analytically and using STAAD.Pro software. Structural software in which retaining wall is prepared using plate element. The loading conditions are acted on retaining wall such as lateral load of soil on stem wall, vertical load on heel slab, vertically acted soil bearing pressure etc. are shown in model. In this work include estimation of primary dimensions of the wall and factor of safety against sliding, overturning and bearing were calculated. The shear resistance for the base, the tension stresses in the stem and the base were checked. Calculation of reinforcement for each part of the wall were done. In conclusion, this paper shows application of STADD.Pro software package in design of retainng wall and obtained result is more accurate than analytical method for design of retainng wall.

Keywords: Design of Retaining Wall

I. INTRODUCTION

Retaining walls are structures designed to restrain the soil (or the other material) in a position wherever the bottom level changes suddenly. They are usually employed in areas with steep slopes or wherever the landscape has to be shaped severely for construction or engineering projects. However, retaining walls are found to be an awfully economical answer against landslides. There are numerous ways in which of constructing a retaining wall, the foremost common varieties being: a. Gravity walls: they manage to resist pressure from behind due to their own mass. b. Piling walls: made of steel they are usually used in tight spaces with soft soil having 2/3 of the wall beneath the ground. c. Cantilever walls: they have a large structural footing and convert horizontal pressure from behind the wall into vertical pressure on the ground below. d. Counter fort walls: they are suitable and economical for retaining wall heights 8.0m to 10.0m. e. Anchored walls: they use cables or other stays anchored in the rock or soil behind to increase resistance.

The type of wall that will be used depends on the circumstances of every case. Soil type, slope angle, groundwater characteristics and other specifics will be considered before deciding on the proper solution. The lateral force due to earth pressure is the main force that acts on the retaining wall which has the tendency to bend, slide and overturn it. The present thesis focuses on the stability analysis and designing the counter fort type of wall. The main considerations are the external stability of the section and the adherence to the recommendations of IS 456:2000. 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 unity for the structure to be safe against failure with respect to that particular criteria. Different modes of failure have different factors of safety.

II. STUDY AREA

Aamayizhanjan thodu near Aakulam lake is the study area. Aakulam is a region in Trivandrum city, the capital of kerala state in India. It is about 10 km from Thiruvananthapuram city center. Situated where the Aakulam lake joins the sea.

III. SOFTWARE USED

STAAD Pro full form stands for Structural Analysis and Designing Program. STAAD Pro is a structural analysis & design computer program that was being developed by Research Engineers International (REL) at Yorba Linda, California in 1997. Today, STAAD Pro is one of the popular and widely used software for structural analysis and design across the globe by

Civil engineers. It supports all types of various steel, concrete, and timber design codes. Using STAAD Pro, civil engineers can design any type of structure, and later share the synchronized model data amongst the entire design team. It ensures on-time and budget-friendly completion of structures and designs related to steel, concrete, timber, aluminium, and cold-formed steel projects, irrelevant to the complexities. STAAD Pro helps structural engineers to automate their tasks by removing the tedious and long procedures of the manual methods. Today, many online platforms and apps provide certification in STAAD Pro that gives complete knowledge on this designing software.

IV. METHODOLOGY

The various steps involved in the stability analysis of retaining wall in Aamayizhanjan thodu are as follows:

- Step 1: Site reconnaissance Site reconnaissance mission would facilitate to decide future programme of field investigations, that is, to assess the necessity for preliminary or elaborated investigations.
- Step 2: Material collection. The soil samples was collected in polythene covers and then air-dried.
- Step 3: Determination of properties of soil characteristics were determined using Specific Gravity, Particle size distribution, Atterberg limits, Light compaction, Unconfined Compression Tests etc.
- Step 4: Designing of Retaining wall technically, while designing, all necessary parameters and requirements are considered and all the possible solutions are generated. The design of retaining wall includes the following steps:
 - Fixation of the base width and the other dimensions of the retaining wall.
 - Performing stability checks and computation of maximum and minimum bearing pressure.
 - Design of various parts like stem, toe slab, heel slab.
- Step 5: Stability analysis using STAAD Pro.software. The analysis using STAAD Pro software consists of three different cases:
 - Selection of suitable height of retaining wall.
 - With the selected height as constant, selection of suitable backfill mix.
 - Finally, stability analysis for various water table depths.

V. EXPERIMENTAL SETUP

Basic properties of the collected sample were determined using laboratory tests. Laboratory tests includes

- Moisture content determination test
- Specific gravity test
- Atterbergs limits
- Particle size distribution (sieve analysis and hydrometer analysis)
- Light Compaction test
- Unconfined compression test

5.1 Water Content Determination

Natural water content is set by oven drying methodology as per IS: 2720 (Part II) 1973. This technique covers the determination of water content of soils expressed as a proportion of the oven-dry weight. The soil specimen taken shall the representative of the soil mass. Clean the container with lid, dry and weigh (W_1). Take the desired amount of the soil specimen within the container fragmented and placed loosely, and weigh with lid (W_2). Then keep it in an oven with the lid removed, and maintain the temperature of the oven at $110 \pm 5^\circ\text{C}$. Dry the specimen within the oven for 24 hour. Each time the container is taken out for weighing. Replace the lid on the container and cool the container in a desiccator. Record the ultimate mass (W_3) of the container with lid with dried soil sample. The % of water content (W) shall be calculated as follows:

$$W = ((W_2 - W_3) / (W_3 - W_1)) \times 100$$

Where, W = water content percentage

W_1 = Mass of container with lid in gram

W_2 = Mass of container with lid with wet soil in gram

W_3 = Mass of container with lid with dry soil in gram

5.2 Specific Gravity

The specific gravity of solid particles (soil sample) is determined in a laboratory using density bottle fitted with a stopper having a hole. The density bottle fitted with a stopper having a hole. The density bottle of 50 millilitre unit capacity is employed [IS: 2720 (part2) 1980]. The mass of the bottle, together with that of the stopper is taken about 5-10 g of oven dry sample is taken within the bottle and weighed. Water is then additional to hide the sample. Water is additional till the bottle is full. Additional water is added to the bottle to make it full. The stopper is inserted within the bottle and mass is taken. The bottle is empty, washed and so refilled with distilled water. The bottle should be crammed to the same mark as within the previous case. The mass of the bottle crammed with the water is taken.

When receiving the sample it's dried in oven at a temperature of 105 to 1150C for a period of 16 to 24 hours. After that, dry the pycnometer and weigh it with its cap and take regarding two hundred g to three hundred g of oven dried sample passing through 4.75mm sieve into the pycnometer and weigh once more. Add water to cover the sample and screw on the cap. Shake the pycnometer well to get rid of entrapped air for regarding ten to twenty minutes. When the air has been removed, fill the pycnometer with water and weigh it. Clean the pycnometer by washing totally and fill the cleansed pycnometer fully with water up to its top with cap screw on. Weigh the pycnometer when drying it on the surface completely. The specific gravity of device dirt is decided mistreatment the relation:

$$G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

Where, W_1 = Weight of dry pycnometer

W_2 = Weight of pycnometer and dry sample

W_3 = Weight of pycnometer, soil sample and water

W_4 = Weight of pycnometer and water

5.3 Consistency Limits or Atterberg's Limits

The liquid limit was applied as per IS: 2720 part 5-1985. The Liquid Limit (LL) is the water content comparable to the arbitrary limit between liquid and plastic state of consistency of the soil. It's outlined as the minimum water content at which the soil continues to be in a liquid state, however features a little shearing against flowing which may be measured by normal means that. Flow curve is plot with variety of blows on x axis and water content on y axis. The water akin to twenty five blows is that the liquid limit. The original liquid limit test of Atterberg concerned with intermixture a pat of clay in a very little spherical bell bottom ceramic ware bowl of 10-12cm diameter. A groove was cut across the pat of clay with a spatula, and the bowl was then stricken persistently against the palm of 1 hand. Casagrande later standardized the equipment and also the procedures to form the measurement more repeatable. Soil is placed into the metal cup portion of the device and a groove is created down its center with a homogenous tool of 13.5mm width. The cup is repeatedly dropped 10mm onto a tough rubber base throughout which the groove closes up step by step as a result of the impact. The number of blows for the groove to shut is recorded. The wet content at that it takes 25 drops of the cup to cause the groove to shut over a distance of 13.5mm is defined as the liquid limit. The check is generally run at many moisture contents, and also the wet content which requires twenty five blows to close the groove is interpolated from the check results. The Liquid Limit test is outlined by ASTM standard test technique D 4318. The test methodology additionally permits running the test at one moisture content wherever twenty to thirty blows are needed to close the groove; then a correction factor is applied to get the liquid limit from the moisture content

The plastic limit was applied as per IS: 2720, part 5-1985. The plastic limit (PL) is the water content where soil transitions between brittle and plastic behaviour. A thread of soil is at its plastic limit once it begins to crumble once rolled to a diameter of 3mm. To enhance test result consistency, a 3mm diameter rod is usually used to gauge the thickness of the thread once conducting the test. At this water content, the soil loses its plasticity and passes to the semi-solid state. The shear strength at the plastic limit, is regarding a hundred times that at the liquid limit. The plasticity index (PI) could be a measure of the plasticity of a soil. The plasticity index is that the size of the range of water contents wherever the soil exhibits plastic properties. The PI is the distinction between the liquid limit and also the plastic limit.

The PI is given by the equation

$$PI = LL - PL$$

Where, PI = Plasticity Index

LL = Liquid Limit

PL = Plastic Limit

Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of (non-plastic) tend to own very little or no silt or clay. The importance of the plasticity index is in the incontrovertible fact that the malleability index may be a description of what proportion a soil expands and shrinks. Once a structure is made on a soil with a high plasticity index the structures foundation is much more likely to crack and fail. Thus it's very vital to understand what the plasticity index and in turn the liquid limit and plastic limit are used to find the plastic index. It is also used for classification of soil.

5.4 Sieve Analysis

A sieve analysis is an analytical technique used to determine the particle size distribution of a granular material with macroscopic granular sizes. The sieve analysis technique involves several layers of sieves with different grades of sieve opening sizes. Clean the sieves of sieve shaker using cleaning brush if any particles are struck in the openings. Record the weight of each sieve and receiving pan. Dry the specimen in oven for 3-4 minutes to get the dried specimen (ignore, if the specimen is already dried). Weigh the specimen and record its weight. Arrange the sieves in order as the smaller openings sieve to the last and larger openings sieve to the top. (Simply, arrange them to the ascending order of sieve numbers – No.4 sieve on top and no.200 sieve at bottom)- Sieve numbers and the particle sizes are provided below in a chart for further understanding. Keep the weight recorded specimen on the top sieve and then keep the complete sieve stack on the sieve shaker (Don't forget to keep the lid and receiving pan). Allow the shaker to work 10-5 minutes. Remove the sieve stack from the shaker and record the weight of each sieve and receiving pan separately.

5.5 Hydrometer Analysis

Hydrometer will be used for particle size analysis. A special kind of measuring system with a protracted stem (neck) will be used. The stem is marked from prime to bottom, usually in the range of 0.995 to 1.030. Hydrometer is first tag. Suspension ready is added to 1000ml of jar and water is added to that to bring the level to 1000ml mark. The suspension is mixed thoroughly by inserting a bung on the open end of the jar and turning it the other way up and back many times. The jar is then placed on a table and a stop watch is started. The measuring system is inserted in suspension and also the presentation is taken once ½ minute of the commencement of the geological phenomenon. Any readings area unit taken once one minute, 2 minutes, and 4 minutes of the commencement of geological phenomenon. The hydrometer is then removed from the jar and rinsed with distilled water and floated during a comparison cylinder containing distilled water with the dispersing agent added to a similar concentration as in the soil specimen. Further readings are taken once 8, 15 and 30 minutes and 1, 2, 4, 8 and 24 hours reckoned from the start of the sedimentation. For each of those readings, the hydrometer is inserted regarding 20 seconds before the reading. The hydrometer is taken out after the reading and floated in the comparison cylinder.

5.6 Light Compaction Test

Compaction is the concentration of soil by reduction of air voids. The light compaction technique was administered by as per IS: 2720, part 8-1983. The aim of a laboratory compaction test is to determine, the amount of water to be added for field compaction of soil and resultant density expected. Compactive effort depends on the amount of water the soil contains during soil compaction. The soil is sometimes compacted into the mould to a particular quantity of equal layers, each receiving a number blows from a standard weighted hammer at a specific height. This method is then repeated for varied moisture contents and also the dry densities are determined for each. The graphical relationship of the dry density to moisture content is then plotted to determine the compaction curve. The maximum dry density is finally obtained from the peak point of the compaction curve and its corresponding moisture content, also referred to as the optimal moisture content. Compaction of clay was meted out using standard proctor test with 3 layers on every twenty five blows. The values of optimum moisture content and maximum dry density are obtained in a plot of dry density versus moisture content.

5.7 Unconfined Compression Test

Unconfined compression test was followed by as per IS: 2720, part 10-1991. This check is conducted on undisturbed or remoulded cohesive soils that are ordinarily saturated. This check may be thought-about as a special case of triaxial compression check once the confining pressure is zero and the axial compressive stress solely is applied to the cylindrical specimen. The stress could also be applied and the deformation and the load readings square measure noted till the specimen



fails. The world of cross section of specimen for varied strains is also corrected assuming that the volume of the specimen remains constant and it remains cylindrical. The subsequent equations were used.

$$\text{Axial strain } (e) = L / L_0$$

$$\text{Corrected area of cross section } (A) = A_0 (1 - e)$$

$$\text{Axial stress } (q_u) = P/A \text{ (kg/cm)}$$

Where, A_0 = Initial area of cross section of the sample (cm^2)

L_0 = Initial length of sample (cm)

P = Axial stress (kg)

Graphs are plotted between axial strain (e) Vs axial stress (q_u). The maximum price is the unconfined compression strength of clay sample. Soil sample without water hyacinth fibre were tested to find out the optimum moisture content based on compressive stress. Samples for conducting unconfined compression check were prepared at optimum moisture content using moulds. In this study the stress is applied and the deformation and loading readings are noted until the specimen fails. The maximum axial strain is noted.

VI. RESULTS AND DISCUSSION

6.1 Properties of Soil Sample

Soil characteristics were determined using Specific Gravity test, Hydrometer test, Atterberg's limits, Light compaction test, Unconfined Compression Tests etc. The test results are shown in Table.

Table 1: Properties of Soil Sample

Sl. No	Properties	Values
1	Natural water content	46 %
2	Specific gravity	2.6
3	Particle size distribution Sieve analysis % of sand % of clay and silt Hydrometer analysis % of clay % of silt	61.65% 38.35% 22% 68%
4	Liquid limit	47.8%
5	Plastic limit	12 %
6	Unconfined Compressive strength	0.37 Kg/cm ²
7	Cohesion	0.19 Kg/cm ²
8	Angle of internal friction	0
9	Maximum dry density	1.64 g/cm ³
10	Optimum moisture content	21.9 %
11	IS classification	CI

6.2 Design of Retaining Wall

Table 2: Design Parameters of Retainng Wall

Design parameters		
1	Height of earth to be retained, h (m)	4
2	Surcharge pressure on the backfill, (kN/m ²)	0
3	Angle of internal friction of soil, ϕ (°)	0
4	Slope of backfill, β (°) with the horizonta	20
5	Unit weight of the soil, γ (kN/m ²)	18
6	Concrete density (kN/m ²)	25
Wall Foundation Design		

1	Depth of foundation	2.9
2	Overall height of the wall, H (m)	6.9
3	Bearing capacity of soil, q_0 (kN/m ²)	53
Wall dimensions		
1	Base thickness (mm) (H /12)	0.55
2	Length of heel slab (m) (H/\sqrt{Ka})	4
3	Length of the toe slab (m)	2
4	Total length of base slab (m)	6
5	Thickness of the stem at base (mm)	0.58
6	Thickness of stem at top (mm)	0.2
Earth pressure analysis		
1	Stability against overturning (FOS > 1.4)	1.93
2	Eccentricity of vertical reaction from C.G. of the footing, e (m)	0.97
3	Maximum pressure on soil at the base, Pmax (should be > q_0)	182.89
4	Check for sliding stability, FSs (Should be < 1.4. If not safe, provide shear key)	0.53
Adjustments for safe FSs (Provision of shear key)		
1	Width of shear key (mm)	1.5
2	Depth of shear key (mm)	1.5

Table 3: Bending Moment and AST Values

Parts of retaining wall	Bending moment (KNm/m)	Area of steel(mm ² /m)
Stem	1152.21	1461.6
Toe	447.38	824.76
Heel	870.35	1059.66

6.3 Design of Retaining Wall in STAAD-Pro

Here, the retaining wall is analyzed using Staad-Pro., a structural software in which retaining wall is prepared using plate element. Staad-Pro gives better and accurate results for analysis of retaining wall. The loading conditions are acted on retaining wall such as lateral load of soil on stem wall, vertical load on heel slab, vertically acted soil bearing pressure etc. are shown in model. Fixed support condition has been given to the junction of stem wall and base slab. The results of analysis of retaining wall in Staad-Pro. gives nodal reactions, plate stresses and bending moment.

Step 1:

- Open the STAAD.Pro software. Click on the “New project” option.

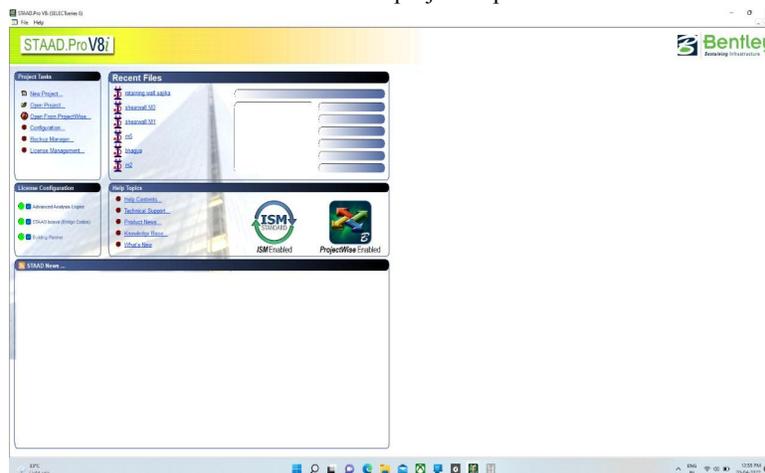


Figure 1: Open window of STAAD Pro

- Give file name, then set units and click next button

Step 2: Modelling

- Click geometry
- Click add beam and then click finish button
- Insert node by joint coordination method and click 'add new point'
- Select add beam and join all the nodes
- Select all beams and insert transitional repeat, give 1m to z axis, thus create 1m retaining beam
- Then create plate

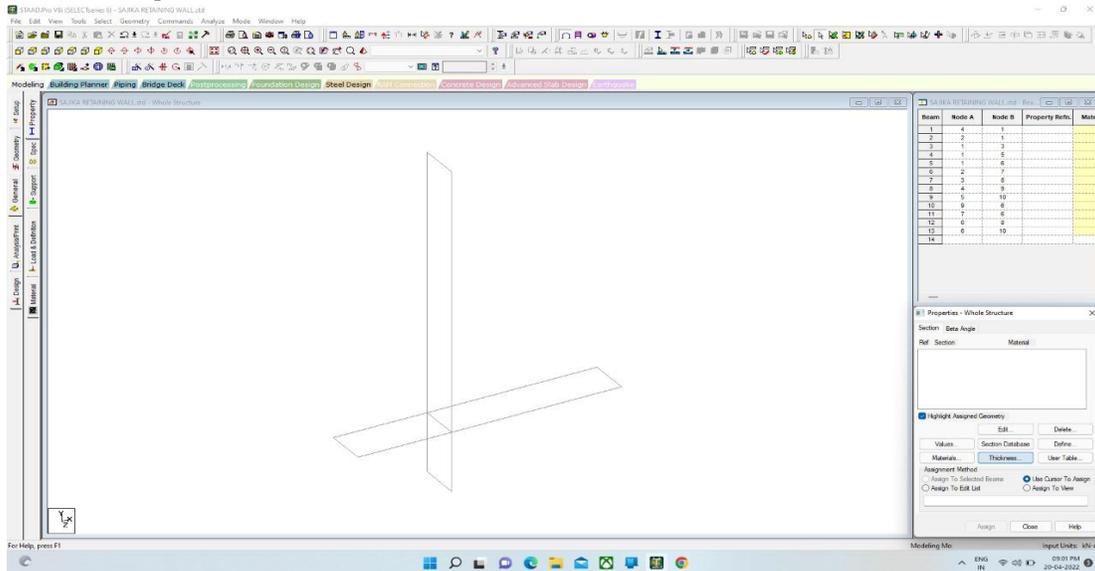


Figure 2: Stage of modelling

Step 3: Properting

- Click 'property' and select thickness
- Select nodes and assign to plate

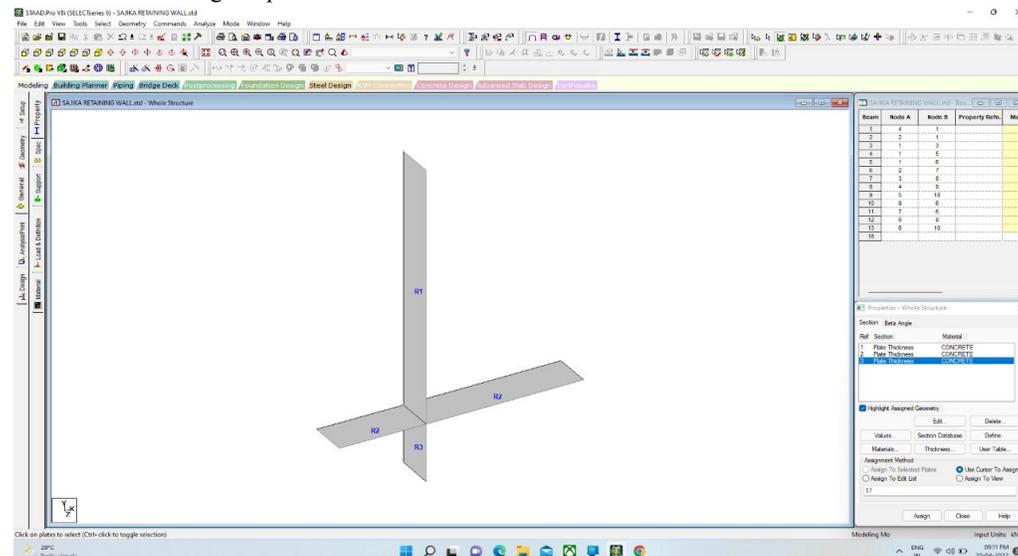


Figure 3: After applying plate thickness

Step 4: Supporting

- Click ‘support’ and create fixed support
- Then assign to bottom nodes

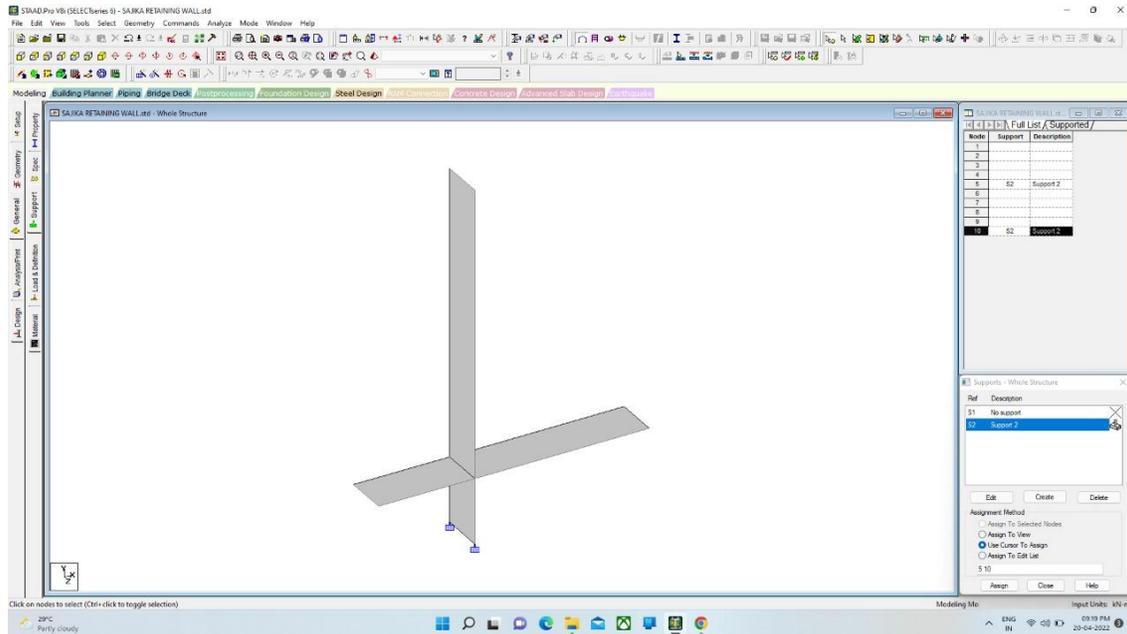


Figure 4: After applying support

Step 5: Apply load

- Click ‘load definition’
- Select load case details and click add
- Click loading type and add loads
- Click plate load and add values on each load condition and select direction for application of load
- Then assign loads to each plates
- Then get analysis print up to this stage

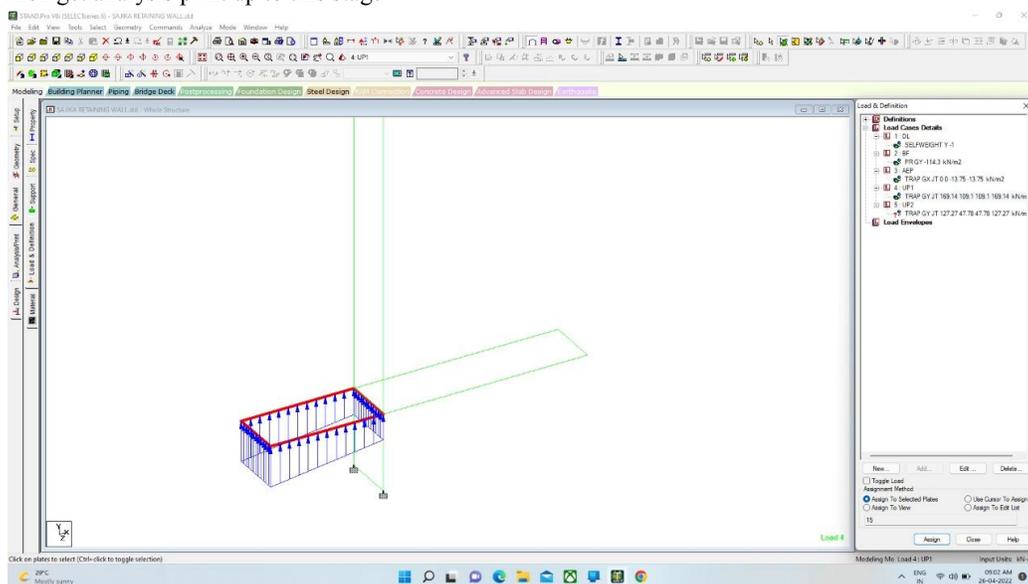


Figure 5: load in toe slab

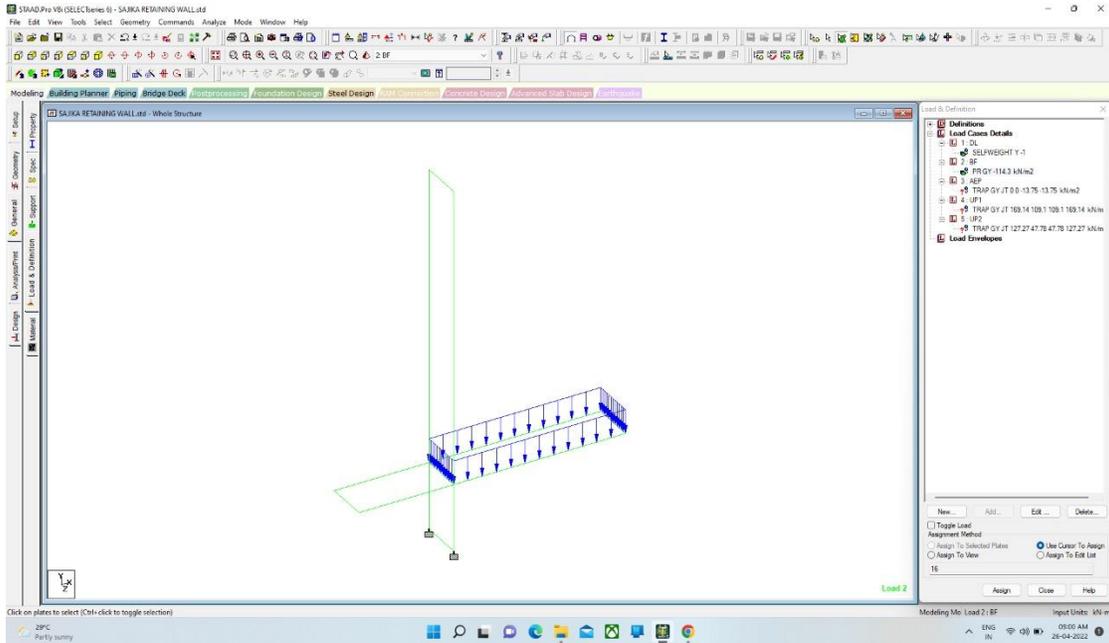


Figure 6: Load on heal slab

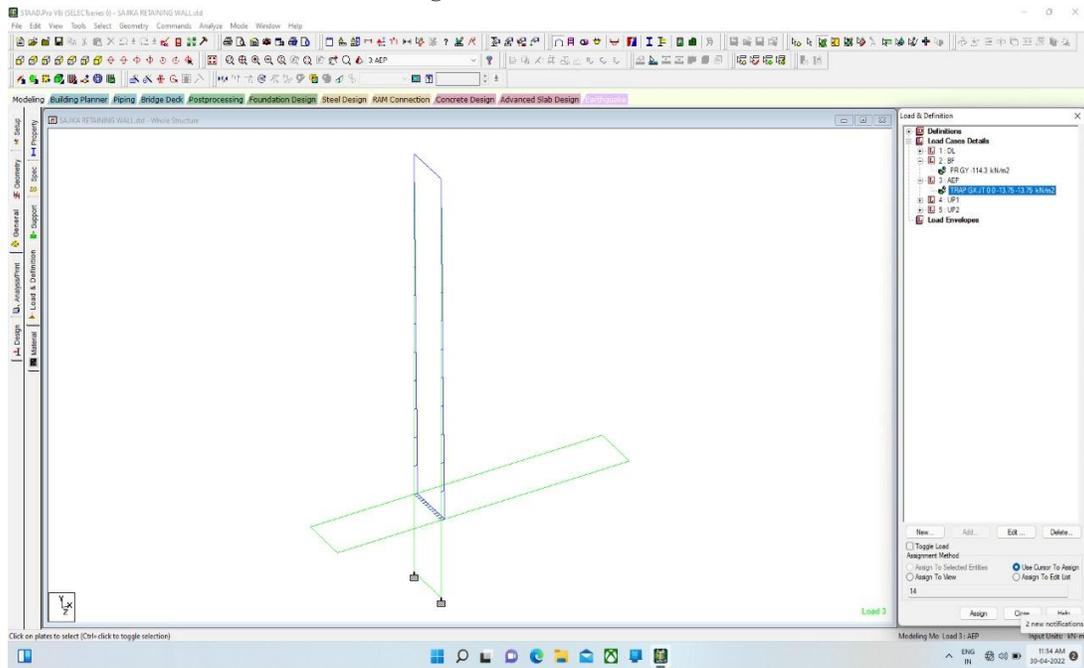


Figure 7: Load on stem

Step 6: Design

- Click "Design"
- Click new envcoop and select slab design
- Click slab menu and select form slab
- Select each slab and select slab from design type
- In slab design brief give cover and reinforcement details
- And get the results of each slabs

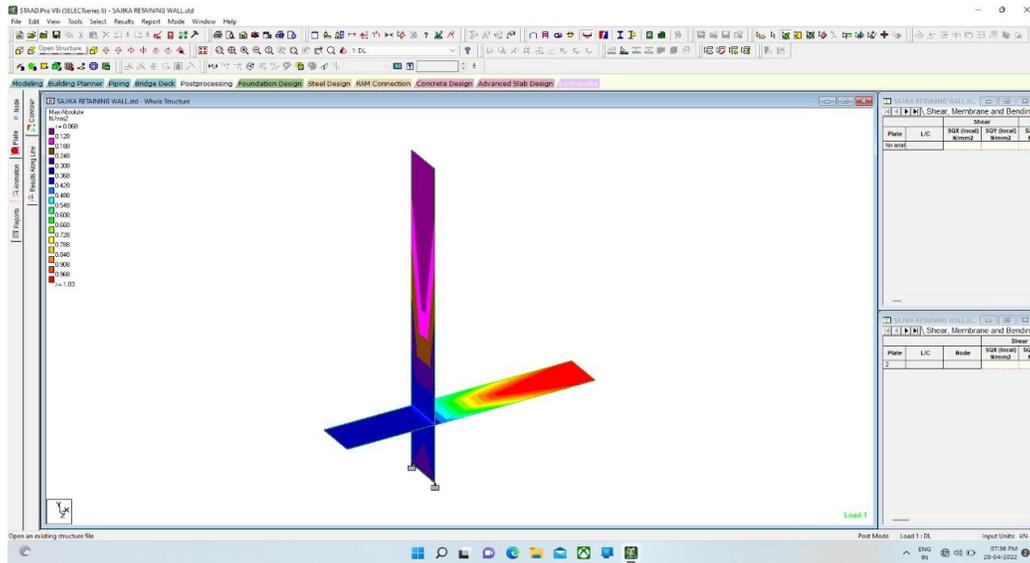


Figure 8: Stress variation

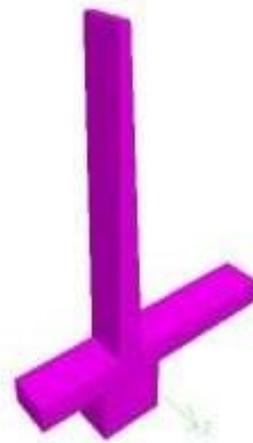


Figure 9: 3d rendering view

Table 4: Bending Moment and Joint Load Values For Various Loading Condition

Loading condition	Joint load reaction (KN)			Bending moment (KNm)		
	Fx	Fy	Fz	Mx	My	Mz
1 (DL)	0	97.118	4.303	12.902	5.562	36.155
2 (LL)	0	228.6	130.465	39.77	71.536	457.2
3 (LL)	22.773	0	0.408	0.336	13.115	84.452
4 (LL)	0	153.032	28.263	22.972	26.955	180.443
5 (LL)	0	175.05	75.131	29.401	46.352	297.107

VII. CONCLUSION

A retaining wall is one of the most important types of retaining structure. It is extensively used in variety of situations such as highway engineering, railway engineering, bridge engineering and irrigation engineering. This research aims more accurate result comparing both manually and using software.

- The bending moment of each part of retaining wall is obtained in manually while in STAAD Pro gives bending moment in all directions.
- The shear force value is obtained from STAAD Pro design.

- The bending moment diagram, shear force diagram and the deflection diagram are obtained using STAAD Pro.
- The 3D rendering image of retaining wall is obtained from STAAD Pro software.
- The amount of steel is obtained from both manual calculation and by using STAAD Pro.
- Moreover more accurate result is obtained from STAAD Pro software.

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