iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** VI **Month of publication:** June 2026

DOI: https://doi.org/10.22214/ijraset.2026.83888

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

Analysis and Behaviour of Curved Retaining Walls in Black Cotton Soil using PLAXIS 3D

Aditya Raghuwanshi[1], Dr. Raghvendra Singh[2]
[1]M.Tech Scholar [2]Professor, Ujjain Engineering College, Ujjain, M.P., India

***Abstract**: In this research paper, the main focus is understanding the 3D finite element analysis and behaviour of non-circular curved retaining wall when compared to conventional straight retaining wall using black cotton soil. As retaining walls constructed in highly expansive soils, such as Black Cotton soil, frequently suffer from severe lateral displacement and structural instability. This study evaluates the reduction in lateral displacements and bending moments achieved by utilizing an arched geometry. Utilizing PLAXIS 3D software, numerical models were developed by diaphragm walls which help to simulate a 10m deep excavation. A curve-in-plan retaining wall is an alternative design to the traditional straight retaining wall, specifically intended for use in situations involving very deep excavations. It is found that such curved shape helps to reduce displacements when compared to straight retaining walls.*
Keywords: Curved Retaining Wall, Black Cotton Soil, PLAXIS 3D, Finite Element Analysis, Arched Geometry, Diaphragm Wall, Straight Cantilever Retaining Wall, Plate Model.

I. INTRODUCTION

A Retaining wall is a structure designed to retain earth in vertical position at location where abrupt change in ground level occurs. It causes the retained earth to exert lateral earth pressure on the wall which tends to overturn and slide it. Its distribution is typically triangular, least at the top of the wall and increasing towards the bottom. The Lateral pressure behind the wall depends on the angle of internal friction and cohesive strength of Retained material as well as direction and magnitude of movement of stems. They are constructed in various fields of engineering such as roads, harbors, dams, subways, railroads, tunnel, mines, and military fortifications.

A. This research is generally focusing on the following types of retaining wall

1) Cantilever Embedded Retaining wall:

Cantilever embedded retaining walls are those structure that are used to support soil at vertical angle. A cantilever embedded retaining wall resists the overturning moment of supported soil by utilising earth pressures below the supported depth caused by the compression of the soil due to rotation of structure.

Retaining walls are designed for their overall stability, that is to stop the wall failing due to material or soil failures. Designed to minimize the ground movements to prevent damage to surrounding buildings.

The vertical cross-section of a retaining wall is the most critical dimension of a retaining wall as vertical direction is where the most resistance to the movement and failure is obtained.

2) Curved Retaining wall:

Curved retaining walls, which will have a capping beam, use the theory of arches to reduce deflection on the structure. They have been identified to potentially allow for the removal of prop in deep excavations, which could save money, improve production rates, reduce material use and health and safety risk of deep excavations.

Curved retaining walls have been used historically, however these where mainly used to move the centre of gravity of a gravity retaining wall further back so as to save the materials by giving resistance to overturning.

This paper will majorly focus on Diaphragm walls because it has many fewer joints in the plan direction as compared to other forms of walls. These structures consist of reinforced concrete retaining walls made up of connected wall panels that form a continuous barrier, making them well-suited for deep excavations in expansive soil conditions.

II. LITERATURE REVIEW

1) Sandip M Chavan, Dr. Vijay Sharma (2017) find the behaviour of a 4m high straight cantilever retaining wall constructed in highly expansive Black Cotton soil. The authors used the finite element software Plaxis 2D to study the significant differential settlements and lateral movements resulting from the processes of soil shrinking and swelling characteristics of expansive clays in Maharashtra, India. The study evaluated four different structural cases: a standard cantilever wall, a wall with a shifted stem, a wall with front toe-filling, and a wall supported The analysis of pile bearing capacity showed that a standard straight retaining wall constructed in black cotton soil remains significantly unstable.
2) Daniel Gilmore, Dr. Raul Fuentes (2017) explored the concept of non-circular, arched retaining walls to minimize deep excavation displacements. They adapted the trial load method an established analytical limit equilibrium technique originally used for designing arch dams to predict the structural behaviour of curved retaining walls. Their mathematical analysis demonstrated that an arched geometry naturally distributes lateral soil loads outward toward the corners of the excavation. As a result, the curved wall analytically reduced maximum horizontal displacements by 15% to 25% compared to traditional straight walls, offering significant potential to reduce the need for internal structural props.
3) Zhang, Y. P., & Zhang, T. Q. (2001) introduced the cantilever arched retaining structure as an innovative and highly efficient alternative for deep foundation pits. Through a systemic behaviour analysis, they highlighted that curving the retaining wall creates a more reasonable structural shape that inherently leads to smaller deformations and lower overall construction costs compared to traditional straight walls. To calculate these benefits, they developed a mathematical arch-beam method, which analyses the structure by splitting the soil forces between horizontal arches and vertical beams. Their early work established the foundational theory that a curved wall can successfully distribute heavy lateral soil loads through horizontal arching action.
4) H. F. Schweiger, F. Scharinger, & R. Lüftenegger, (2009) compared 2D and 3D finite element models of a deep excavation in soft clayey silt to determine which method best matched actual in-situ measurements. They found that while a basic 2D model could adequately estimate horizontal wall deflection in certain sections, it fundamentally failed to predict the vertical ground settlements surrounding the site. Because the excavation had a complex spatial geometry (roughly square in plan), the researchers concluded that a 2D plane-strain assumption was inadequate. Ultimately, their study proved that a full 3D analysis is absolutely necessary to accurately capture true spatial deformations and surface settlements in soft soils.

III.MODELLING METHODOLOGY AND ANALYSIS

3D Finite Element analysis of Straight & Curved Retaining walls in Black cotton soil using PLAXIS 3D is conducted by the following a systematic methodology. Here's an overview of the steps we will take in PLAXIS 3D software:

A. Soil Mode

In Soil mode, we have to firstly create a 100m x 100m boundary. For this inside Project properties > Model we have to set contours as shown in Table 1.

TABLE 1: SET CONTOURS (IN M)

Contours (in m)	
X_{min}	-50m
X_{max}	50m
Y_{min}	-50m
Y_{max}	50m

Click OK, This creates a 100m x 100m boundary.

1) Now, Place a Borehole

Click Create borehole button on the left hand toolbar and move the cursor to the centre axis on the grid, click exactly at coordinates (0,0,0) to drop the borehole. After this Modify soil layers toolbar will open.
In Modify Soil layers toolbar, Click Add button to add a single soil layer, Set top elevation to 0m and bottom elevation to -50m. This will create a massive clay type block needed for the model.

2) Set Water table

In Modify Soil layers toolbar, Set Head to -50. This will force the water table down to very bottom of the mode, which ensures pore water pressure don't interfere with the wall.

3) Add material for soil layer

Now in the same Modify Soil layers toolbar, Inside Soil Layers tab, in materials click + or New. Input the following properties as shown in Table 2.

TABLE 2: THE PROPERTIES USED FOR BLACK COTTON SOIL

General	Material set	Identification	Black Cotton Soil
		Material model	Mohr-Coulomb
		Drainage type	Drained
	General properties	γ_{unsat} (Unsaturated unit weight)	18.350 KN/m^3
		γ_{sat} (Saturated unit weight)	19.120 KN/m^3
Parameters	Stiffness	E' (Young's modulus)	6525 KN/m^2
		ν' (Poisson's ratio)	0.250
	Strength	c'_{ref} (Cohesion)	30 KN/m^2
		φ' (phi – friction angle)	17^o
Interfaces	Strength	Strength	Rigid
Initial	K_0 settings	K_0 determination	Automatic

Click OK, Now 50m deep soil is fully configured with exact Black cotton soil.

B. Structures mode:

Click Structures tab at top left of blue colour, here we will draw all the physical elements. Now, in the left toolbar navigate the Create line tool. This will draw line for making Straight and Curved retaining walls. Dimensions of the wall are given in Table 3:

TABLE 3: DIMENSIONS OF THE WALL

Length of the wall (L)	30m
Retained Height (H)	10m
Embedded depth (D)	10m
Arch Rise	2m

1) For Straight retaining wall

Draw a line or write the following in command window, and hit Enter
_line (-15 -15 0) (15 -15 0)
This will draw a straight line with the coordinates provided above.

2) For Curved retaining wall:

For making curved retaining wall we have to make a parabolic arch that spans 30m. From x = -15m to x = 15m and bulges outward by 2m at the centre. For this draw a line or write the following in command window, and hit Enter
_line (-15 -15 0) (-12 -15.72 0) (-9 -16.28 0) (-6 -16.68 0) (-3 -16.92 0) (0 -17 0) (3 -16.92 0) (6 -16.68 0) (9 -16.28 0) (12 -15.72 0) (15 -15 0)
By this the curve line is drawn successfully.

3) Turn these lines *into 20m Deep wall (Plate):*

Select the whole line (Straight or Curved) by using Select tool, In the left toolbar click the 4th tool named Extrude object.
Set the extrusion vector as shown in Table 4,

TABLE 4: EXTRUDE THE LINES

Extrusion Vector

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

X	0
Y	0
Z	-20m

This will extrude the line to 20m deep wall. Now select all the surfaces by select surface tool, then Right click on this wall and Create > Create plate

4) Create diaphragm wall as materials and assign to this plate:

Click the Show Materials icon visible at last 2nd of the left toolbar. In Set type select Plates then click New. Input the following properties as shown in Table 5.

TABLE 5: THE PROPERTIES USED FOR DIAPHRAGM WALL

Material set	Identification	Diaphragm Wall
	Material type	Elastic
Properties	d (Thickness)	1m
	γ (Unit weight)	25 KN/m^3
	Isotropic	No
	E_1 (Vertical Stiffness)	$28*10^6$ KN/m^2
	E_2 (Horizontal Stiffness)	$2.8*10^6$ KN/m^2 [10% of vertical]
	ν_{12} (Poisson's ratio)	0.2
	G_{12} (Shear Moduli)	$11.67*10^6$ KN/m^2
	G_{13}	$11.67*10^6$ KN/m^2
	G_{23}	$1.167*10^6$ KN/m^2

After input these properties click OK. Now from Material sets drag and assign this diaphragm wall to the extruded plate in straight retaining wall & to all 10 extruded plates one by one in curved retaining wall. After assigning the grey plates surface will turn into blue.

5) Create the Capping beam and material:

Select the top line in Straight retaining wall & all 10 top lines in Curved retaining wall by using select line tool. Right click on the select lines and click Create Beam. Now thick line will appear on the top of the wall. Click the Show Materials icon visible at last 2nd of the left toolbar. In Set type select Beams then click New. Input the following properties as shown in Table 6.

TABLE 6: THE PROPERTIES USED FOR CAPPING BEAM

Material set	Identification	Capping Beam
	Material type	Elastic
Properties	E	$15*10^6$ KN/m^2
	γ (Unit weight)	25 KN/m^3
	Beam type	User-defined
	A (Cross section area)	$2m^2$
	I_2 (Moment of Inertia)	$0.667m^4$
	I_3	$0.167m^4$

After input these properties click OK. Now from Material sets drag and assign this Capping Beam to the Top beam in straight retaining wall & to all 10 beams one by one in curved retaining wall. After assigning the grey beam will turn into pink.

6) Create a Steel prop

The prop is used to connect straight side walls across the centre of excavation. To do this click to line tool and draw a line or enter the following in the command:

_line (-15 0 0) (15 0 0)

This will create a line at the centre. Right click on this line and click Create Beam.

Click the Show Materials icon visible at last 2nd of the left toolbar. In Set type select Beams then click New. Input the following properties as shown in Table 7.

TABLE 7: THE PROPERTIES USED FOR STEEL PROP

Material set	Identification	Steel Prop
	Material type	Elastic
Properties	E	$210*10^6$ KN/m^2
	γ (Unit weight)	76.5 KN/m^3
	Beam type	User-defined
	A (Cross section area)	1m^2
	I_2 (Moment of Inertia)	0.12m^4
	I_3	0.12m^4

After input these properties click OK. Now from Material sets drag and assign this Steel Prop to this beam in straight retaining wall & curved retaining wall. After assigning the grey beam will turn into pink.

7) Define the Soil Excavation volume:

We need to outline the 30m*30m block of soil that will be dug out. On the left toolbar click Create Surface tool to create top surface for Straight and Curved retaining walls. Draw the surface or create it by using the following command:

_surface (-15 -15 0) (15 -15 0) (15 15 0) (-15 15 0)

A top 30m* 30m square surface is created on ground level. Now, click to this top surface and select Extrude from the left toolbar as per the following Table 8:

TABLE 8: EXTRUDE THE SURFACE

Extrusion Vector	
X	0
Y	0
Z	-10m

This represents the 10m deep block, the dirt excavation will dug out. It is that 3D chunk that we are planning to dug out.

8) Create Soil volumes

For Straight retaining wall create Left surface wall, Right surface wall. But for Curved retaining wall create Left surface wall, Right surface wall and back wall. Since back wall is already present in straight wall so there is not need to create it again. To draw the Left surface wall, Right surface wall, Back surface wall, Use the following command:

Left surface wall:

_surface (-15 15 0) (-15 -15 0) (-15 -15 -20) (-15 15 -20)

Right surface wall:

_surface (15 -15 0) (15 15 0) (15 15 -20) (15 -15 -20)

Back surface wall:

_surface (-15 -15 0) (15 -15 0) (15 -15 -20) (-15 -15 -20) [NOT REQUIRED FOR STRAIGHT RETAINING WALL]

Select the newly created surface walls. Right click on the new walls and Click Create Plate. Now Go to Show materials & Drag and Assign Diaphragm walls to Left surface wall, Right surface wall in straight retaining wall and to Left surface wall, Right surface wall and back surface wall in curved retaining wall.

C. Mesh mode

Go to Mesh tab at the top with green colour. Go to Model Explorer > Click + sign on Geometry > Uncheck Soil Volumes. This will allow us to see the plates or beams and to select them further.

From the left toolbar click 2nd tool named Select multiple objects. In this firstly click Select Beam and select all the beams, then when all the beams are selected. At left side in selection explorer see the coarseness factor which is 0.5 by default. Just make it 0.2.

Similarly, click to Select plate and select all the plates, when all the plates are selected. At left side in selection explorer see the coarseness factor which is 0.5 by default. Just make it 0.2.

Now navigate in the left toolbar 7th tool and click Generate Mesh. Click OK. In command line you will see the no. of elements and nodes generated.

To verify this click on View Mesh which is 8th tool.

D. Staged construction:

In this we need to tell software, that what the natural ground stresses are before any excavators arrive. This process is divided into various stages. Firstly, double click on Initial phase on the left side Phases explorer, we need to set the calculation type to K_0 Procedure which is set by default, then click OK.

Now we have to add phases for the following retaining walls:

1) For Straight retaining wall

In Phases explorer, Click + to Add phase, Phase 1 is created in this, Activate or Check Plates listed in the model explorer. Again Click + to Add phase 2, Phase 2 is created in this, Activate or Check Beams listed in the model explorer. Again Click + to Add phase 3, Phase 3 is created in this select the 30m*30m top surface which is 10m deep and Deactivate this surface which was the chunk of dirt. After deactivation of chunk, click Calculate which is at 8th in the toolbar. During calculation of Phase 1, Phase 2 and Phase 3. If our model and calculation with values are correct All the phases will turn to green tick in the phases explorer. To generate or find the report we can click view calculation results tool.\

2) For Curved retaining wall

In Phases explorer, Click + to Add phase, Phase 1 is created in this check primary panels and side walls, Expand Plates & Activate or Check Plate_1, Plate_4, Plate_7, Plate_10, Plate_11, Plate_12, Plate_13. Again Click + to Add phase 2, Phase 2 is created in this, Keep everything checked from Phase 1. Activate or Check Plate_2, Plate_5, Plate_8. Again Click + to Add phase 3, Phase 3 is created in this, Keep everything checked from Phase 2. Activate or Check Plate_3, Plate_6, Plate_9. Now check that every single plate in your entire model should have a green checkmark next to it. Again Click + to Add phase 4, Phase 4 is created in this, Keep all plates checked from previous phases.

Expand Beams folder from model explorer and Activate or Check all Beams listed in the model explorer. This will install capping beam and central steel strut. Again Click + to Add phase 5, Phase 5 is created in this, Keep all plates and beams checked. In this select the 30m*30m top surface which is 10m deep and Deactivate this surface which was the chunk of dirt. After deactivation of chunk, click Calculate which is at 8th in the toolbar. During calculation of Phase 1, Phase 2, Phase 3, Phase 4 and Phase 5 If our model and calculation with values are correct All the phases will turn to green tick in the phases explorer. To generate or find the report we can click view calculation results tool.

IV. RESULTS AND DISCUSSION

1) *Horizontal Displacement:* To evaluate the performance of retaining walls, the maximum horizontal displacement (U_y) is extracted and compared in Figure 1. The conventional straight retaining wall exhibited a critical maximum displacement of 58.13mm (or 0.05813m). But by altering the geometry to a curve, the maximum displacement reduced to 43.18mm (or 0.04318m).
2) *Bending Moment:* The maximum Bending moment (M_{22}) observed and compared in Figure 2 in straight retaining wall is 344.6 KN-m. But for curved retaining wall it got reduced to 330.2 KN-m. This reduction proves that curved geometries not only limit physical soil movement but also actively relive structural stress from concrete panels.

Parameters	Straight Retaining Wall	Curved Retaining Wall
U_y (Horizontal displacement)	0.05813m	0.04318m
M_{22} (Horizontal bending moment)	344.6 KN-m	330.2 KN-m

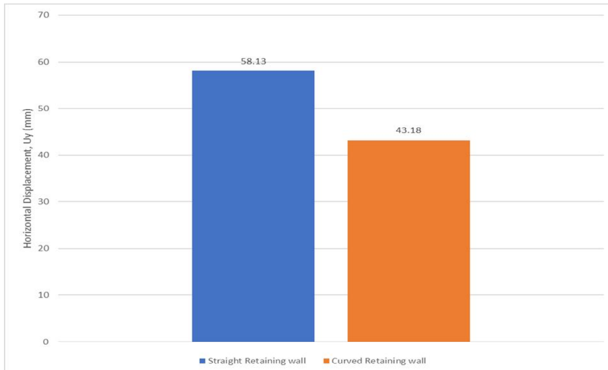

Figure 1: Horizontal Displacement Uy (mm)

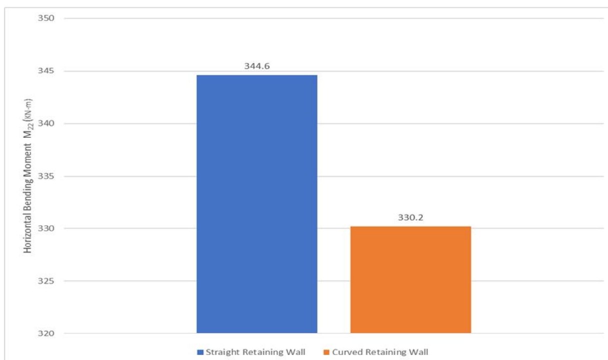

Figure 2: Horizontal Bending Moments M22 (KN-m)

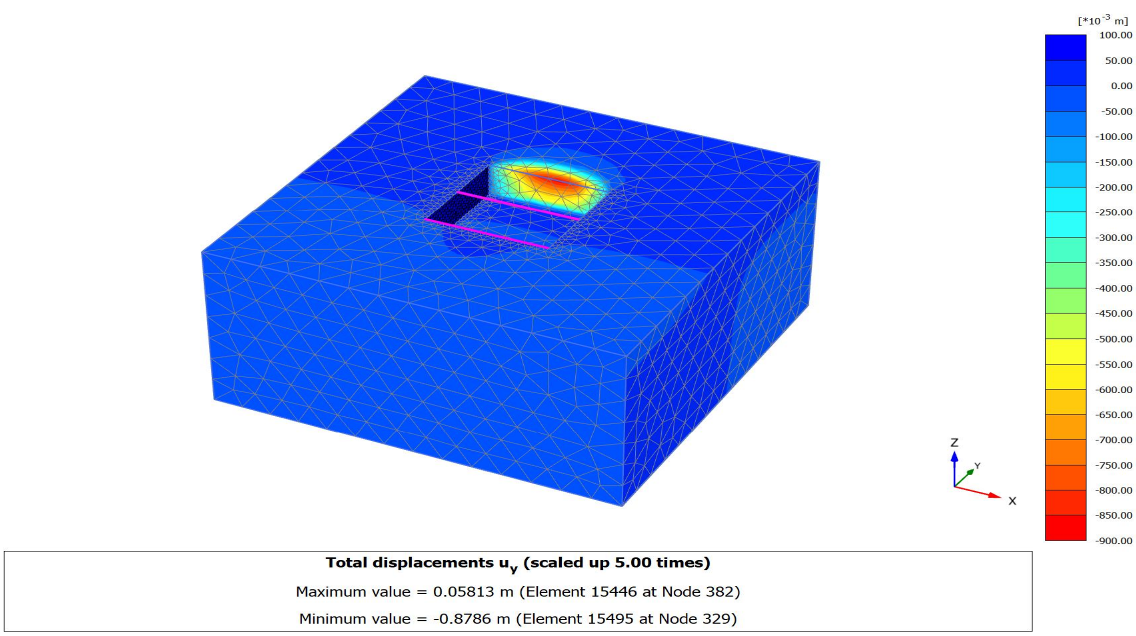

Figure 3: Horizontal displacement profile of Straight Retaining wall using Black cotton soil in PLAXIS 3D

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

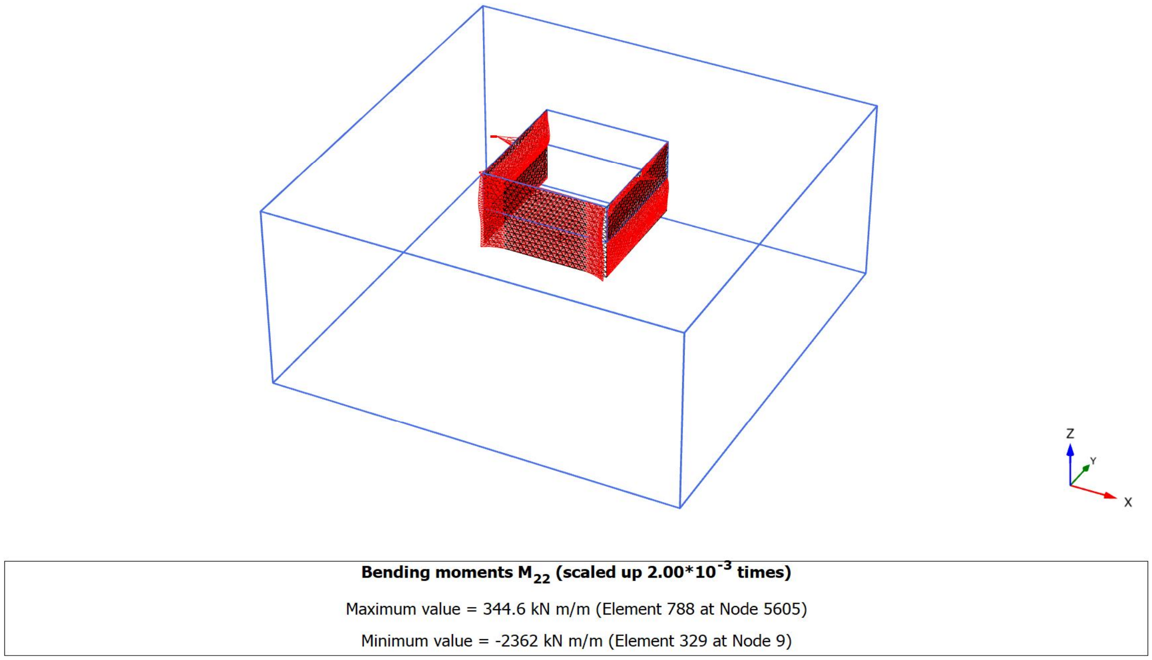

Figure 4: Horizontal Bending moment of Straight Retaining wall using Black cotton soil in PLAXIS 3D

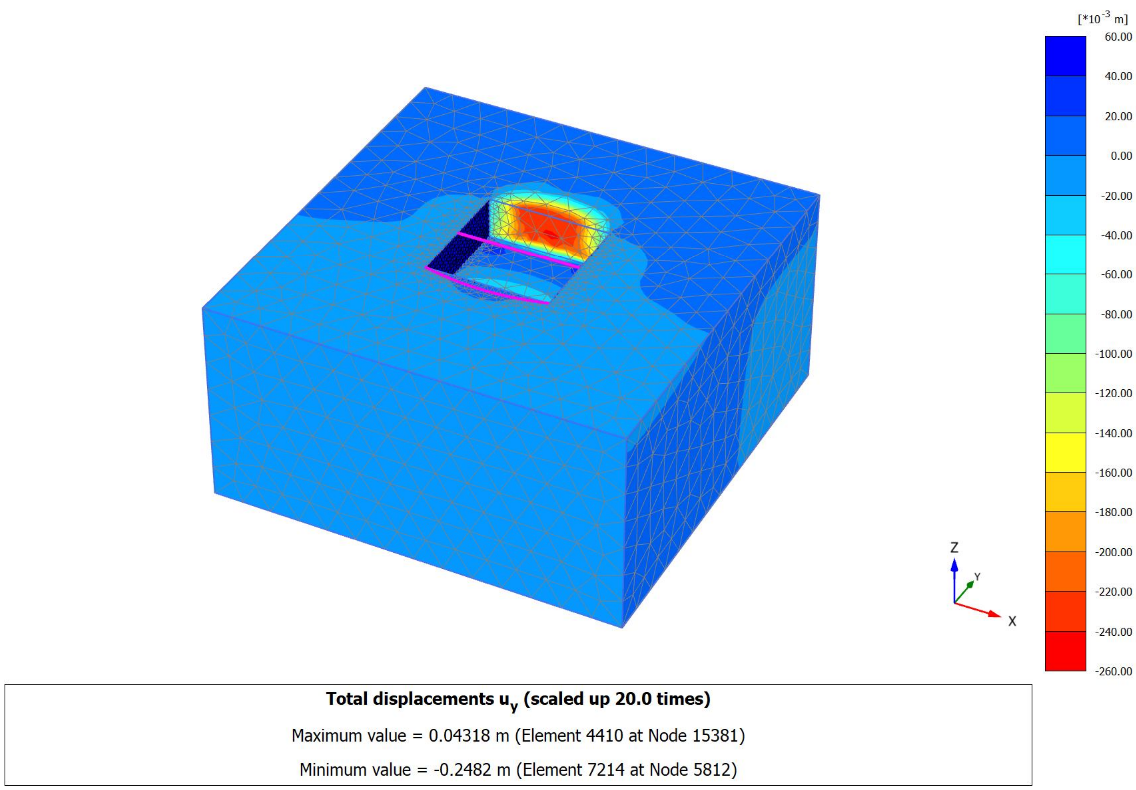

Figure 5: Horizontal displacement profile of Curved Retaining wall using Black cotton soil in PLAXIS 3D

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

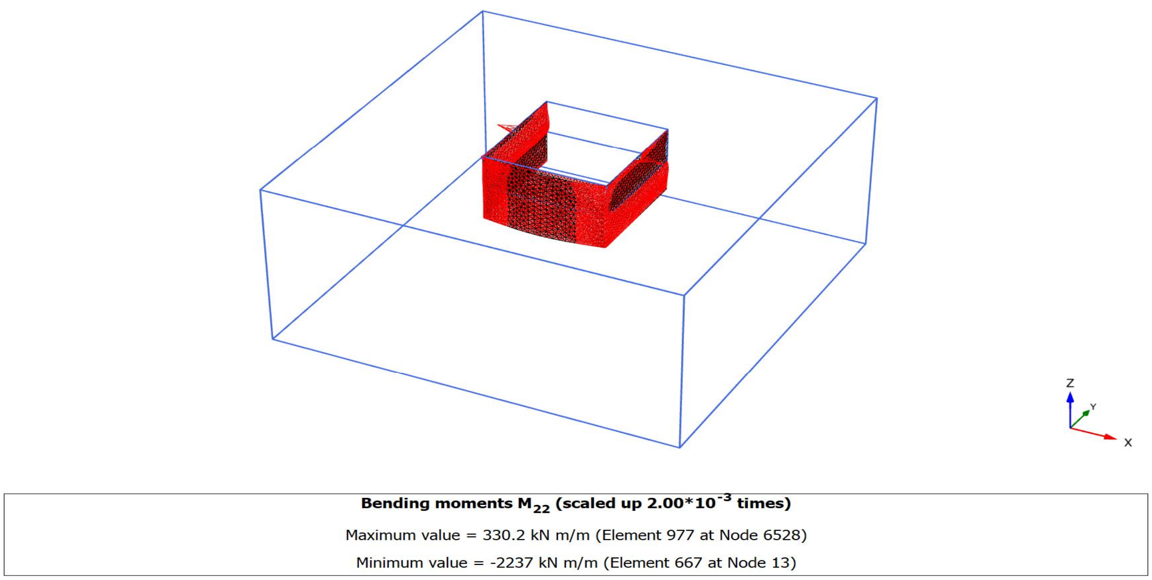

Figure 6: Horizontal Bending moment of Curved Retaining wall using Black cotton soil in PLAXIS 3D

Furthermore, to understand the structural behaviour, a line cross-sectional displacement profile also extracted along the centreline of the walls from ground level (z = 0m) to toe (z = -20m).

Depth Vs Horizontal Displacement Values at centre for Straight retaining walls from (0, -15, 0) to (0, -15, -20) and for Curved retaining walls from (0, -17, 0) to (0, -17, -20):

Straight Retaining Wall		Curved Retaining Wall	
Z [m]	Uy [mm]	Z [m]	Uy [mm]
0	58.129	0	15.81
1.352	57.762	1.429	13.705
2.598	57.407	2.857	13.759
3.912	56.96	3.571	14.116
4.554	56.694	4.286	14.598
5.196	56.382	5.714	15.695
6.451	55.613	6.429	16.263
7.692	54.606	7.857	17.4
8.831	53.459	8.571	17.954
9.415	52.8	9.286	18.495
10	52.108	10.714	19.559
11.176	50.688	11.429	20.085
12.431	49.257	12.857	21.175
13.531	48.15	13.571	21.706
14.804	47.084	14.286	22.259
15.453	46.628	15.714	23.337
16.103	46.228	16.429	23.862
17.402	45.561	17.857	24.665
18.701	45.016	18.571	24.742
19.35	44.768	19.286	24.638
20	44.526	20	24.135

As seen in the profile data above, the curved wall's centreline deflections begins at 15.81mm at ground level and gradually increasing to 24.135mm at the toe. But in straight wall it starts from 58.129mm at ground level o 44.526mm at toe. This indicates parabolic geometry locks effectively soil mass in upper retained heights.

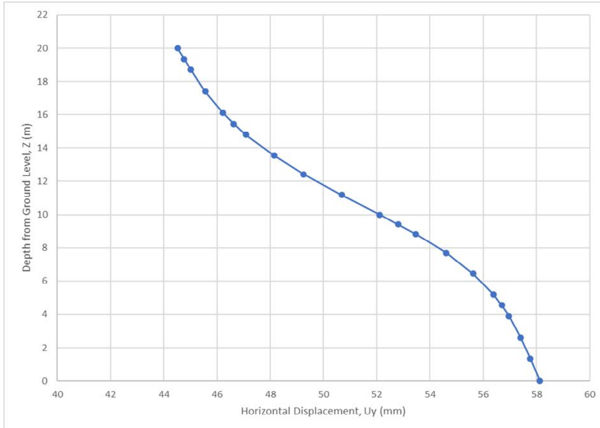

Figure 8: Depth Vs Horizontal Displacement at Centre in Straight Retaining Wall

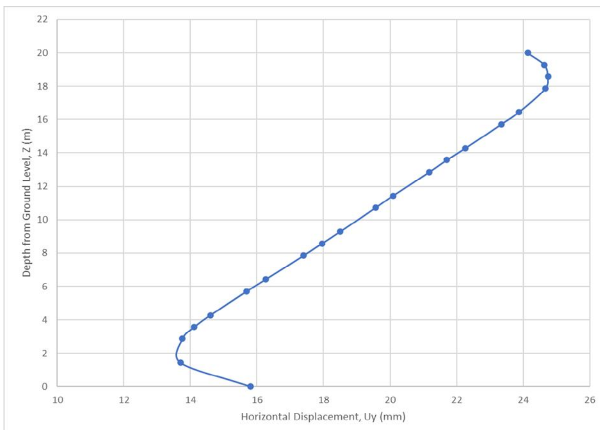

Figure 9: Depth Vs Horizontal Displacement at Centre in Curved Retaining Wall

V. CONCLUSIONS

Based on 3D finite element analysis conducted in PLAXIS 3D, the following conclusion are found regarding the behaviour of retaining walls in expansive Black Cotton Soil.

1) *Inefficiency of Straight Walls:* Straight diaphragm walls are structurally inefficient in highly expansive soil as it suffer from severe displacement (up to 58.13mm). Which in practical applications require massive concrete thickness to prevent failure.
2) *Superiority of Curved Geometry:* After modifying the wall geometry to a non-circular curved or arch drastically improves structural stability and also capitalizes on 3D spatial soil structure interactions.
3) *Displacement Reduction:* The arched geometry successfully reduces the maximum lateral displacement by 25.71% (from 58.13mm to 43.18 mm), And also reduced the maximum bending moment by 4.17% (from 344.6 KN-m to 330.2 KN-m).

VI. ACKNOWLEDGMENT

Special thanks to the Department of Civil Engineering, Ujjain Engineering College, Ujjain M.P. India, for providing the resources and guidance necessary for completing this study.

REFERENCES

[1] Sandip M Chavan, Dr. Vijay Sharma, "Behaviour of Retaining Wall in Black Cotton Soil", International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 07, July 2017, Pp: 780-784.
[2] Daniel Gilmore, Raul Fuentes, "Predicting the behaviour of non-circular, curved-in-plan retaining walls using the trial load method", 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, 2017, Pp: 1987-1990.

[3] Zhang, Y. P., & Zhang, T. Q., Behaviour Analysis of Cantilever Arched Retaining Structures in Foundation Pits," Journal of Zhejiang University (SCIENCE), Volume: 2, No. 3, Pp: 309-312.
[4] H. F. Schweiger, F. Scharinger, & R. Lüftenegger, "3D finite element analysis of a deep excavation and comparison with in situ measurements" Geotechnical Aspects of Underground Construction in Soft Ground, Taylor & Francis Group, Pp: 193-199.
[5] Plaxis 3D Connect Edition V20 | Tutotial Manual
[6] Table 2: The Properties used for Black cotton soil, Source: Sandip M Chavan, Dr. Vijay Sharma, "Behaviour of Retaining Wall in Black Cotton Soil", Pp:781
[7] Table 3: Dimensions of the wall, Source: Daniel Gilmore, Raul Fuentes, "Predicting the behaviour of non-circular, curved-in-plan retaining walls using the trial load method", Pp: 1989
[8] Table 5,6: The Properties used for Diaphragm Wall, Capping Beam, Source: BS EN 1991-1-1:2002, The Concrete Society, [No date], Goh, 1993 and Richards and Powrie, 1994.
[9] Table 7: The Properties used for Steel Prop, Source: EN 1993-1-1:2005, Geocentrix, 2004.