Numerical Analysis of Effect of Width and Location of Surcharge Load on the Geosynthetic Reinforced Soil Walls

K. N. Manohara

Abstract The geosynthetic reinforced soil techniques have emerged as exciting engineering techniques mainly due to their cost effectiveness, technical simplicity and ease of construction. They are considered superior as compared to other alternatives in the context of their stability even under seismic conditions. This paper aims at understanding the effects of the width and location of surcharge loads on the performance of the geosynthetic reinforced soil walls. The numerical simulations of a geosynthetic reinforced soil wall is analyzed using the finite element software PLAXIS 2D. A very fine mesh was used with water table at great depth for the analysis. A multi-stage construction was simulated and plastic analysis was carried out. Different combinations of surcharge are applied and the stresses developed in the soil, displacements at the top, middle, and toe of the wall and maximum strains developed in the wall for the different surcharge combinations were plotted and analyzed.

Keywords Numerical analysis · Geosynthetic reinforced soil walls · PLAXIS 2D

1 Introduction

Reinforced soil walls are composite structures made up of reinforcement and compacted backfill. The stability of this composite system is imparted by the friction between the reinforcement and backfill and tension in the reinforcement. They have been proven to be a sustainable and cost-effective alternative for the conventional masonry and concrete retaining walls. The flexibility in their design and the ease of construction makes them a desirable option in the field. Various materials ranging from metals, polymers, jute coir, etc., are being used today as reinforcements. Among these, the geosynthetics are gaining popularity as they are available in a variety of sizes, types and strength and have a vast application potential.

The Geosynthetic Reinforced Soil (GRS) walls are flexible and minimum excavation will be required behind the face of the wall. Also, these geosynthetics can be used

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S. Patel et al. (eds.), *Proceedings of the Indian Geotechnical Conference 2019*,
Lecture Notes in Civil Engineering 137,
https://doi.org/10.1007/978-981-33-6466-0_23

effectively even when the backfill material is relatively poor. They are cost effective and are free from corrosion. Numerous experimental studies have been carried out on these GRS walls by various researchers like Juran and Christopher [1], Fishman et al. [2], Porbaha and Goodings [3], Yang et al. [4], Mirmoradi and Ehrlich [5], etc., using instrumented models and monitored field structures. However, construction of these walls, their maintenance, and testing are not simple and requires sophisticated instruments which may not be available to all interested researchers. Therefore, numerical analysis provides a simpler and accurate tool to carry out different types of studies on these structures. Advanced constitutive model for both the reinforcement and soil can be implemented into the analysis. Karpurapu and Bathurst [6], Rowe and Ho [7], Leshchinsky and Vulova [8], Yoo and Song [9] and many other researchers carried out the analysis of the GRS walls by numerical modeling.

The surcharge acting on the soil retained by the GRS walls plays a very important role in the design and performance of the wall. Jewell and Milligan [10], Gomes et al. [11], Bathurst et al. [12], Abu-Hejleh et al. [13], Helwany et al. [14], Abu-Hejleh et al. [15], Xiao et al. [16], etc., have assessed its effects on the serviceability of the GRS walls. Mirmoradi and Ehrlich [5] conducted an experimental study to evaluate the effects of the width and location of the surcharge. The present study evaluates the effects of width and location of the surcharge on the GRS walls using finite element computer program PLAXIS 2D.

2 Finite Element Modeling and Analysis

2.1 Configuration of the Wall

The wall considered in the present study is 6 m high, reinforced with polypropylene geogrid reinforcement of length 4 m. The vertical spacing between the geogrids is 0.5 m and the facing panel of length 0.5 m and thickness 0.15 m is provided. The normal stiffness (EA) of the geogrid is taken as 2500 kN/m. The properties of the backfill and the foundation soil are presented in Table 1.

3 Methodology

The GRS wall was modeled in PLAXIS 2D using 15 node triangular elements as a plain strain model. Plate elements were used to define the facing panels and geogrid to define the reinforcement. The concrete panels of size 0.5 m * 0.5 m and thickness of 0.15 m were considered for the facing panels. The panels were modeled as linear elastic material. The panels were placed one on top of the other so as to allow for their translation and rotation in either directions. The material data set was entered as mentioned above and assigned to its respective part of the model. The properties

Table 1 Properties of the backfill and foundation soil

Parameters	Name	Backfill	Foundation	Units
Material model	Model	Mohr–Coulomb	Mohr–Coulomb	–
Type of material behavior	Type	Drained	Drained	–
Soil unit weight above phreatic level	γ_{unsat}	16	18	kN/m^3
Soil unit weight below phreatic level	γ_{sat}	18	20	kN/m^3
Young's modulus	E_{ref}	100,000	100,000	kN/m^2
Poisson's ratio	ν	0.3	0.3	–
Cohesion	c_{ref}	1	1	kN/m^2
Friction angle	φ	44	36	°
Dilatancy angle	ψ	14	6	°

of the backfill and the foundation soil are assumed. The soil-geogrid and soil-facing interfaces were defined. Standard fixity condition which allowed for vertical movements and restricted the horizontal movements for the side boundaries and restricted movement in both directions at the bottom boundary was used for the boundaries. The wall however was free to move in both horizontal as well as vertical direction. A very fine mesh was used for the analysis and the mesh was refined around the wall and the geogrid for a better accuracy. Figures 1 and 2 shows the model and the mesh generated for the GRS wall.

The surcharge is applied in different combinations so as to analyse the effect of;

- width for the same equivalent magnitude of surcharge with different widths.
- width for the same magnitude of surcharge with different widths.

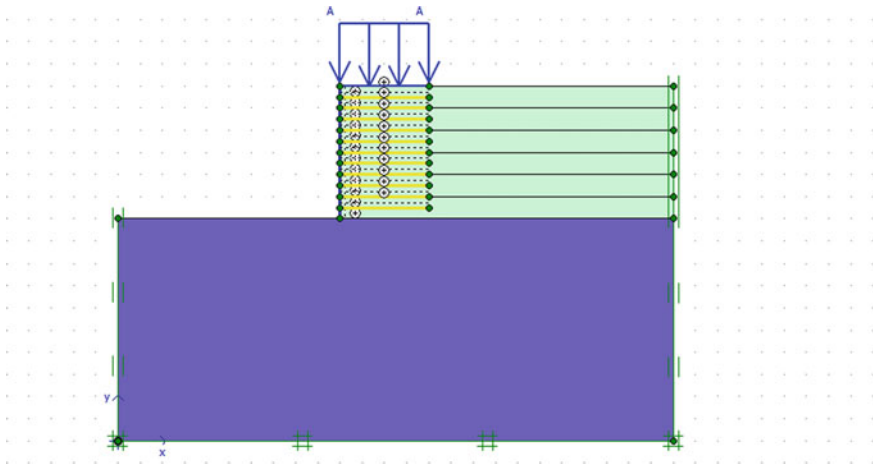

Fig. 1 PLAXIS input model

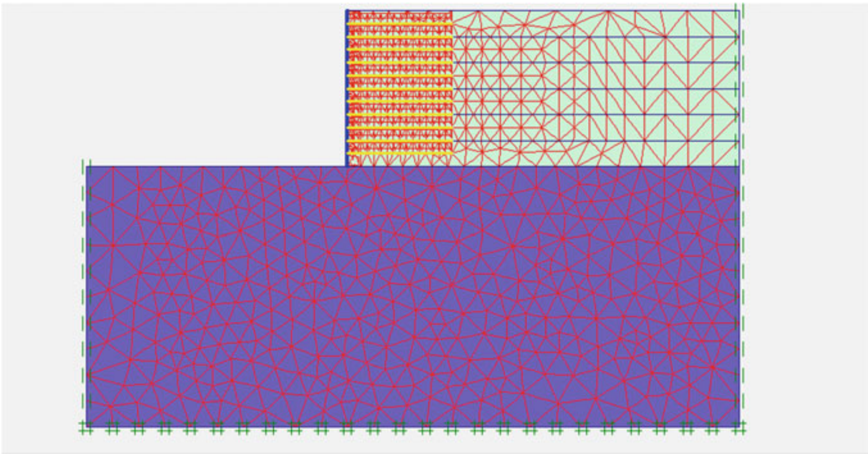

Fig. 2 Mesh of the model

- location for a surcharge of a fixed magnitude and width but located at different distances from the face of the wall.

Plastic analysis is carried out by simulating staged construction involving six stages, each of 1 m lift and corresponding lifts for each phase are activated and the calculation program is run.

4 Results

4.1 Effect of Width of the Surcharge

For the same equivalent magnitude of surcharge with different widths.

Three different combinations of surcharge were applied on the GRS wall to study the effect of width of the surcharge with the same equivalent magnitude of 80 kN/m^2. The combinations used were; 20-4-0, 40-2-0, and 80-1-0, where the first value denotes the magnitude of the uniformly distributed load, the second denotes the width of the load and the last value denotes the distance of the surcharge from the face of the wall. The stresses developed in the soil due to the surcharge, the displacement of the wall at the top, middle, and toe of the wall and maximum strain in the wall for the different surcharge combinations are plotted (Figs. 3, 4 and 5).

The stresses developed in the soil is found to decrease with decrease in the width for the same equivalent magnitude of the surcharge. However, there is an increase for the last combination due to concentration of a greater load at the back of the wall. The displacements at the top and middle portion of the wall increases with decrease in the width of the surcharge because of the increase in stress concentration at the

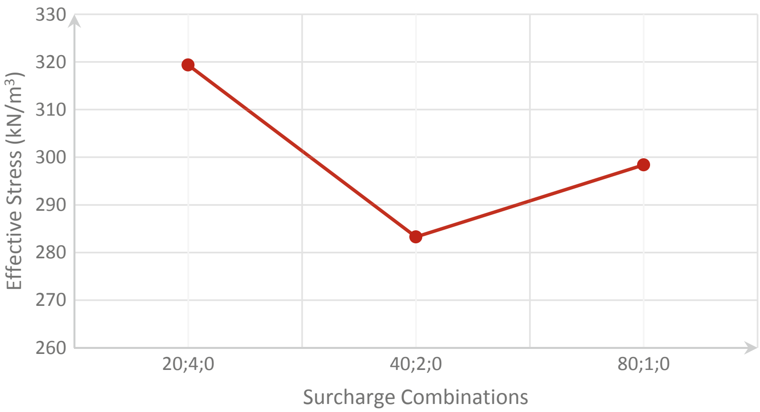

Fig. 3 A plot of effective stresses developed in the soil versus the surcharge combinations

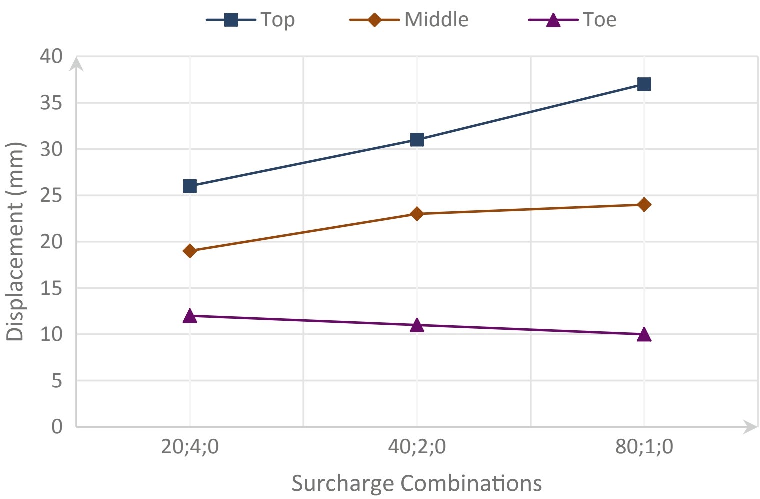

Fig. 4 A plot of displacements in the wall versus the surcharge combinations

back of the wall. However, the displacements show a decreasing trend at the toe of the wall due to the reduction in the soil stresses at lower surcharge widths. The maximum strain follows a similar trend as the stresses developed.

For same magnitude of surcharge with different widths.

In this case, the magnitude of the uniformly distributed loads is kept constant at 40 kN/m^2 and the loads are placed on the immediate back of the wall. The surcharge combinations used are; 40-4-0, 40-2-0, 40-1-0. The stresses developed in the soil due to the surcharge, the displacement of the wall at the top, middle, and toe of the wall and maximum strain in the wall for the different surcharge combinations are plotted (Figs. 6, 7 and 8).

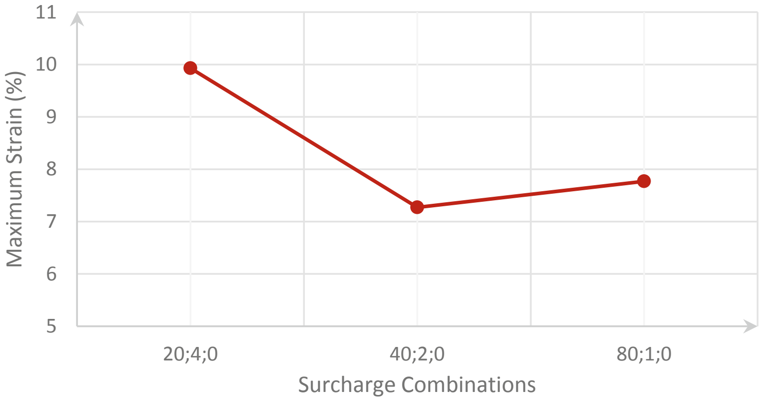

Fig. 5 A plot of maximum strain in the wall versus the surcharge combinations

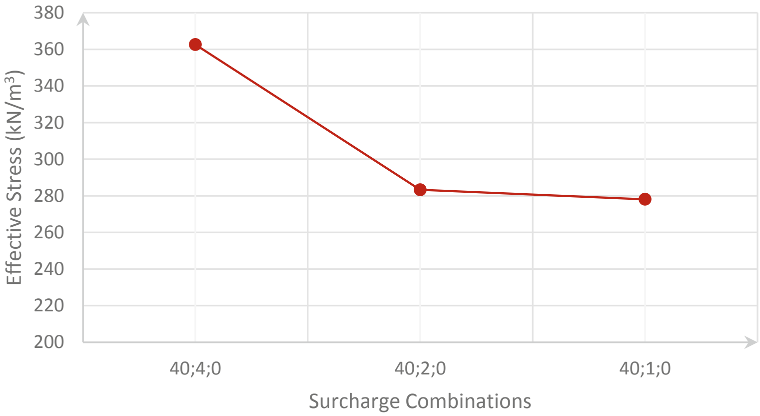

Fig. 6 A plot of effective stresses developed in the soil versus the surcharge combinations

The effective stresses developed in the soil shows a similar trend as before and decreased with decrease in the width. The wall displacements are found to decrease with decrease in the width. With the decrease in the width, for the same surcharge magnitude, the load acting on the soil will decrease leading to a reduction in the displacements of the wall. The strain developed also reduces with width due to reduction in the stresses.

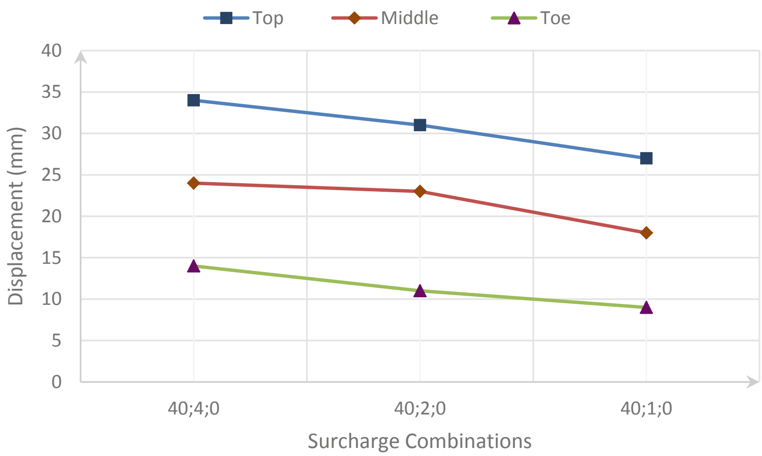

Fig. 7 A plot of displacements in the wall versus the surcharge combinations

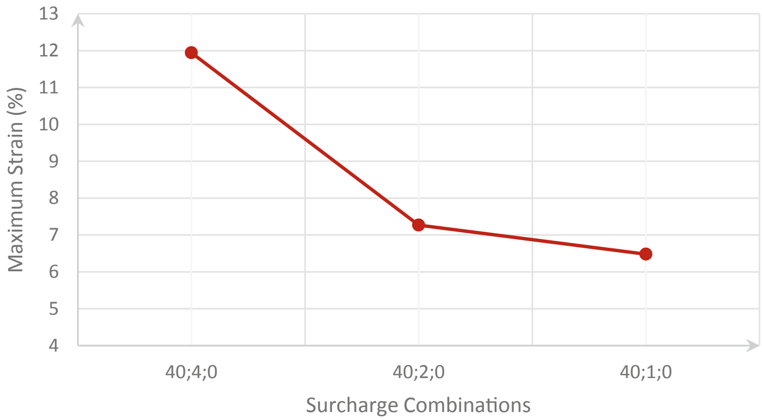

Fig. 8 A plot of maximum strain in the wall versus the surcharge combinations

4.2 Effect of Location of the Surcharge

To study the effect of the location of the surcharge on the GRS walls, the magnitude and the width of the surcharge is kept constant at 40 kN/m^2 and 2 m, respectively, and the surcharge is placed at different distances from the back of the wall. The surcharge combinations used in this case are; 40-2-0, 40-2-1, 40-2-2. The stresses developed in the soil due to the surcharge, the displacement of the wall at the top, middle, and toe of the wall and maximum strain in the wall for the different surcharge combinations are plotted (Figs. 9, 10 and 11).

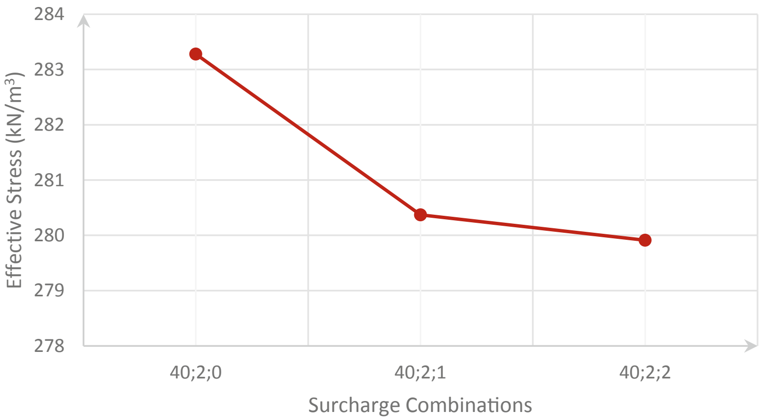

Fig. 9 A plot of effective stresses developed in the soil versus the surcharge combinations

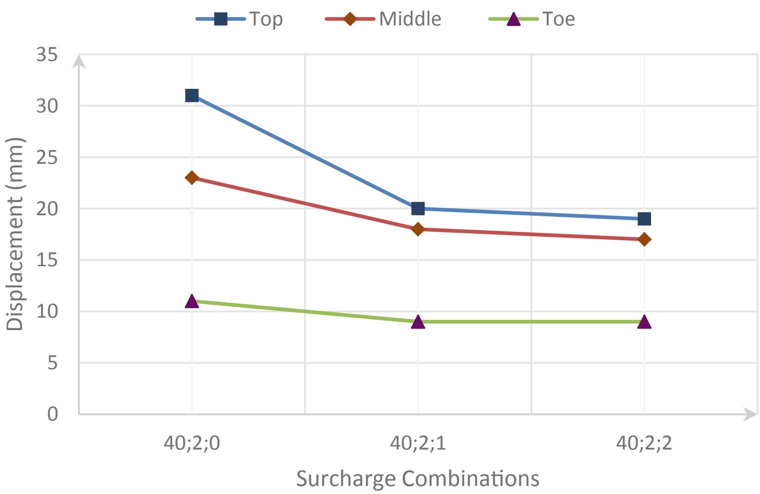

Fig. 10 A plot of displacements in the wall versus the surcharge combinations

The stresses generated within the soil, displacements at the top, middle, and toe of the wall as well as the maximum strain developed is found to decrease as the surcharge moved away from the immediate back of the wall. This is because the influence zone of the load also moves away from the wall along with the surcharge.

5 Conclusions

The following conclusions could be drawn from the present study:

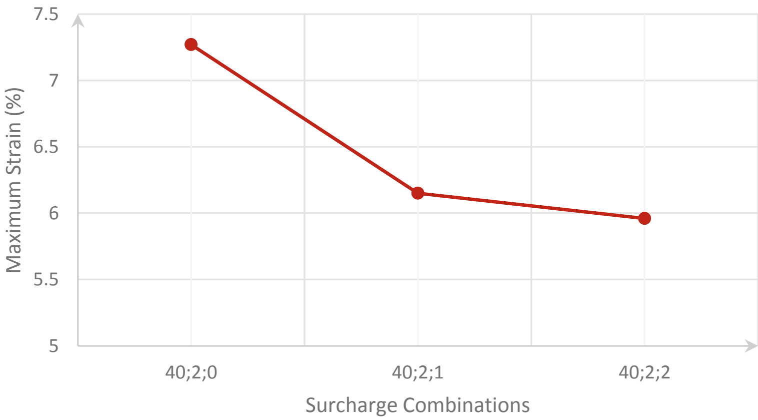

Fig. 11 A plot of maximum strain in the wall versus the surcharge combinations

- For the same equivalent magnitude of the surcharge, it is found that the stresses and strains in the soil was more for a widely distributed load rather than more concentrated load. However, the displacements are greater in case of concentrated loads (loads with a smaller width) than the distributed loads (loads with a greater width).
- Although the displacements increase with increase in the load concentration near the back of the wall at the top and middle, the displacement at the toe of the wall shows a decreasing trend due to the reduction in the soil stresses at lower surcharge widths.
- For the same magnitude of surcharge, greater the distribution width of the surcharge, greater will be the stresses developed and hence the strain. Wall displacement is also found to increase with increase in the width of the load.
- Closer the surcharge to the back of the wall, greater the stresses and strains in the soil. Displacements of the wall are also found to reduce with the increase in distance of the surcharge away from the wall.

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