International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Assessment of Rectangular Cavity in Concrete Gravity Retaining Wall using Finite Element Method

P. P. Tapkire, Bilavari Karkare

Abstract*: *The design of the Gravity retaining wall (GRW) is a trial and error process. Prevailing conditions of backfill are used to determine the profile of GRW, which proceeds with the selection of provisional dimensions. The optimum section is having factors of safety of stability higher than the allowable values and stresses in the cross-section smaller than permissible. The cross-section is designed to fulfill conditions of stability, subjected to very low stresses. The strength of the material, which is provided in the cross-section remains unutilized. A computer program is developed to find stresses at various locations on the cross-section of GRW using the Finite Element Method (FEM). A discontinuity in the form of a rectangular cavity is introduced in the cross-section of GRW to optimize it. The rectangular cavity is introduced in the cross-section of GRW at different locations. An attempt is made in this paper to find the stress distribution in the gravity retaining wall cross-section and to study the effect of the rectangular cavity on the stress distribution.

***Two cases representing different locations are considered to study the effect of the cavity. The location of the cavity is distinguished by the parameter λ_w*, the effects of *cases with varied λ_w*as *0.2305 (Case-I) and 0.1385 (Case-II) are observed. The cavity, which is provided not only makes the wall structurally efficient but also economically feasible*.**

***Keywords* : Cavity, *Finite Element Method, Gravity Retaining Wall, Rectangular Cavity, Stress Distribution,*.**

I. INTRODUCTION

Gravity retaining structures extensively used in construction railways highways, bridges, canals, and many other engineering works.

The design of a gravity retaining wall is a trial and error process, which proceeds with the selection of provisional dimensions. In general, the gravity retaining wall designed to satisfy stability criteria. The optimal section is one that gives factors of safety (FoS i.e FoS of overturning, FoS of sliding) higher than the permissible value and stresses induced lower than the permissible limit. As FoS of sliding reaches to the permissible value, FoS of overturning increases the required. The stresses developed in the wall cross-section are very low as compared to permissible stresses due to which the material strength of the cross-section remains unutilized.

To utilize the cross-section effectively and to enrich the structural performance of the gravity retaining wall profile, a concept is introduced to provide a discontinuity in the form of the cavity along the length of the retaining wall.

Thus, the cross-section satisfying the prescribed conditions can effectively utilize by introducing a cavity in it. The profile of GRW with cavity leads to directly saving in the material, also a proportionate reduction in the material handling and labor expenses. The cavity not only makes GRW structurally efficient but also economically feasible. Hence GRW optimization can be achieved by introducing cavity in it. Providing a cavity in a GRW may cause instability in the cross-section. The particular difficulty can overcome by providing the shear key to increase passive resistance.

It becomes interesting to study the effect of various parameters like shape, size, aspect ratio and, the position of the cavity. The stress patterns are affected due to the parameters it also affects maximum and minimum value, and respective positions of stresses induced in cross-section of GRW.

The present study is aimed to optimize the cross-section of GRW by introducing a cavity in it, which makes the wall a structurally efficient form. An attempt is made in this paper, to find the stress distribution along the cross-section of GRW and, to study the effect of the rectangular cavity on the stress distribution.

II. LITERATURE REVIEW

The contribution has been done by the researchers to optimize the design of earth retaining structures and also in the direction to develop an earth retaining system using different innovative concepts. The researchers applied different optimization techniques and adopted a non-conventional system for different types of retaining walls like reinforced concrete structure wall, a gravity wall, etc. Some of these research contributions of researchers are presented as follows. Erol Sadoglu [12] examined symmetrical gravity retaining walls of different heights for optimization. Researchers have shown that safety and stability were interconnected concepts and also the design of a gravity retaining wall is considered as an optimization problem. He considered cost-rela ted function as objective function and constraints were derived from stability verifications.

Manuscript published on November 30, 2019.

* Correspondence Author

P. P. Tapkire*, is research Scholar of Department of Civil Engineering of Sinhgad College of Engineering, Pune, Maharashtra, India (e-mail: pptapkire.nbnscoe@gmail.com).

Dr Bilawari Karkare, she is Director Vishwakarma Institute of Information Technology, Pune, Maharashtra, India (e-mail: bkarkare@gmail.com).

This optimization problem was chosen as the thickness of the gravity retaining wall at regular intervals from the base. A computer program was developed based interior point method to solve the problem. The check of sliding was an active constraint for external stability and bending in the stem verification was an active constraint of internal stability. The outline of optimum cross-sections wider, lower parts and slender stems having a minimum thickness which satisfying the bending verifications. The areas of optimum cross-sections were lesser compared with conventional plain concrete gravity retaining walls. The concluding remark which was drawn that the use of these optimum cross-sections will reduce the costs substantially.

Victor Yepes, Julian Alcala, Cristian Perea, and Fernando Gonz´alez-Vidosa [11] examined reinforced concrete earth-retaining walls in connection with road construction for economic optimization. The optimization of walls was proposed by using a simulated annealing algorithm method. The problem was formulated by considering 20 different design variables. Four variables related to geometrical properties like the thickness of the kerb and the footing, the toe, and the heel lengths. Also, four variables related to material categories and the remaining twelves were related to reinforcement systems. The parametric investigation was carried for walls heights ranging from 4 to 10m in different fills and the bearing conditions. The suggested optimization of cantilever earth retaining walls using the simulated annealing algorithm was proved to be an effective procedure. Optimum walls showed a parabolic variation with the height of the wall. The expressions relating to the cost, the total volume of concrete, the thickness of the kerb and the footing, as well as the lengths of footing and the heel, were derived.

Munwar Basha and G. L. Sivakumar Babu [10] computed optimization of Gravity Retaining Walls carried using a reliability design approach. In this computation, the reliability-based optimum design been used for the reinforced gravity retaining wall with the application of probability theory. Advanced first-order second-moment method (AFOSM) was used to conduct a parametric study that was developed by Hasofer-Lind and Rackwitz-Fiessler (HL-RF). The method was selected to find the effect of uncertainties in design variables on the probability of failure of reinforced gravity retaining wall. All together 8 failure modes considered were listed as follows i) overturning ii) sliding iii) eccentricity iv) bearing capacity failure, v) shear failure in the toe slab vi) moment failure in the toe slab vii) shear failure in heel slab and viii) moment failure in the heel slab. Properties related to backfill soil, foundation soil, the geometry of the wall, reinforcement of provided and concrete were treated as random variables. Optimum wall proportions were found as targeted in a particular study for different coefficients of variation and system reliability index.

.M.Asghar Bhatti [9], demonstrated optimization using the latest tools such as Microsoft Excel for reinforced concrete retaining wall. Worksheets were prepared for analysis and design computations. These worksheets have been further modified into formal design optimization tools. The particular conversion was carried by a simple selection of cells of worksheets corresponding to design variables, objective functions, and suitable constraint functions. And an optimum design was obtained systematically without resorting to trial and error process. A sensitivity analysis was carried out to demonstrate the usefulness of these worksheets. It showed that the optimum cost was affected by different parameters such as wall height, surcharge pressure, permissible soil pressure, and internal soil friction angle.

Claxton, Mary, Robert A. Hart, Paul F. McCombie, and Peter J. Walker [8] studied the instability of dry-stone masonry retaining walls using distinct-element numerical model. These models of a simplified rigid block which was used to investigate the walls in-plane strain. The study was initially concentrated on modeling and experimental data of wall behavior which was reported. The influence of parametric variation on stability was assessed. Experimental and numerical model results were compared with a limit equilibrium analysis

Raj Jalla [7] described the multiple levels of retaining walls and their design. As proposed in the research paper, it was the necessity to use multiple levels of retaining walls for the greater heights. Particularly multiple levels retaining walls were effective and economical when heights of the backfill soil greater than it can be retained by a single-tier retaining wall. The research work also committed that each level of multiple retaining walls should be safe against stability failure criteria. In the research study details of the design of multiple levels of retaining walls were presented which were used in residential construction. Multiple levels of retaining walls become necessary and economical when the height of the backfill was more than a certain height.

Certain points are observed from studying the literature and contributions presented by the researchers. Optimization of GRW as well as RCC retaining wall were considered by various contributors and they adopted the different technique to optimize them. Various parameters such as factors of safety, cost of retaining wall, multiple level analysis, and sensitivity analysis were considered as problems and solutions were mentioned accordingly. In the analysis of GRW utilization of material, the efficiency of the structural form is undetected issues. Alternatively, stress distribution along with the cross-section of GRW which resists driving force and moments with by its weight is not perceived. Considering this as problem stresses induced in the GRW is found out using FEM. After finding stress pattern the rectangular cavity is introduced in the wall appropriately.

III. OBJECTIVE

The work is presented in this paper is based on the following objectives

1. To study the stress distribution along the cross-section in GRW.
2. To study stress distribution along with the cross-section of GRW section by introducing a rectangular cavity.
3. To study the effect of cavity position on maximum-minimum stress magnitude and its location.

IV. PROBLEM FORMULATION

The cross-section of concrete gravity retaining wall under consideration is subjected to gravity loads and lateral earth pressure which produce combined direct and bending stresses [1]. These stresses increase with the distance of the fiber from the top of the wall.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

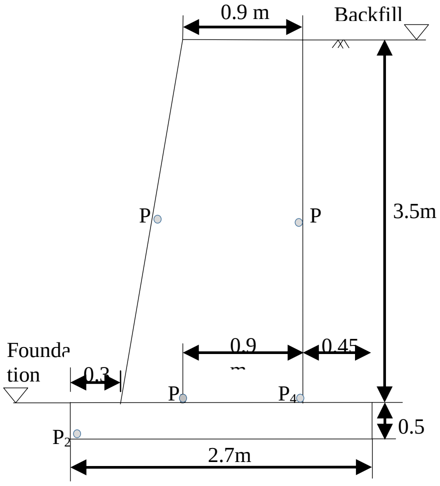


Fig 1. Retaining Wall of Cross-Section

A gravity retaining wall with a vertical face retaining horizontal backfill is considered in this study. Backfill soil having a density of 18kN/m^3, angle of friction of 30^0 and, cohesion=16kN/m^2 is considered along with M20 grade of concrete for gravity retaining wall for analysis. The cross-section of GRW under consideration is shown in Fig 1. The stresses induced in cross-section of GRW are found using the conventional method as well as FEM. A computer program [6] is developed for FEM using three principal steps:

1. Preprocessing: A separate subroutine is written for mesh generation using wall geometry. Four noded iso-parametric elements and constant strain triangle elements are used to discretize the cross-section. The mesh is generated in such a way that the aspect ratio of the elements in any portion of the wall remains close to one. Displacement boundary conditions and prescribed loads are the taken as input applied it to the desired nodes using separate subroutine.
2. Analysis: The dataset prepared by the preprocessor is used as input to the finite element code. Analysis of GRW is considered as plane strain problem. FEM computer code [4], constructs and solves a system of linear algebraic equations,

   $$Kij\ uj = fi \tag{1}$$

   Where u and f are the displacements and externally applied forces at the nodal points respectively. The stiffness matrix is generated according to the selected elements [5].
3. Post-processing: Desired outputs like displacements and stresses at different nodes are generated. After calculating nodal stresses, global stress smoothening is carried [2]-[3]. In the global smoothening method [2], firstly the stresses at nodes are found using interpolation from the stresses at sampling points (Gaussian points). The average nodal stresses of all elements meeting at a common node are considered to smoothen the stress at that particular node. Finally, the principal stresses are calculated and a postprocessor outcome as contours representing stress levels are drawn along the wall cross-section.

The stresses obtained by conventional method and FEM approach are compared at Gaussian point P_1 to P_5 which are shown in Fig 1 and results are given in I. Compressive stresses are considered as positive and tensile stresses are considered as negative.

In the analysis involving numerically integrated elements such as 4 noded iso-parametric elements, the integration points are the best stress sampling points, but the nodes which are the most suitable output location for stresses are the worst sampling points [3]. To decide the appropriate mesh which gives a desirable outcome, the number of grids with a varying number of elements are tried to discretize the cross-section of gravity retaining wall. For this purpose, two parameters are chosen. The first parameter is the horizontal stress σ_x variation against the height of the wall along the vertical face of the stem and face of base slab facing the soil. The second parameter is the variation of vertical stress σ_y at top of the base slab along the width of the wall at the stem-base junction. The cross-section is analyzed with different element sizes.

Table I. Comparison of Stresses

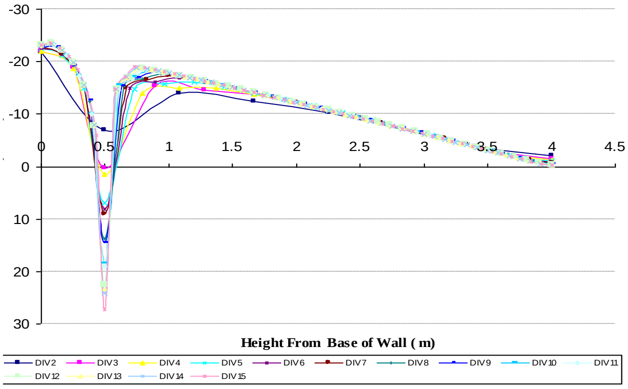
Position	Stress in kN/m^2		Percentage Difference
	By Conventional Approach	By FEM Approach	
P_1	-42.81	-39.13	8.60
P_2	-84.84	-84.08	0.89
P_3	-68.65	-63.58	7.32
P_4	-35.75	-32.85	8.11
P_5	-37.13	-33.44	9.95

Graph G_1 shows a variation of stress σ_x and graph G_2 shows a variation of stress σ_y. It is observed that both graphs follow a stress pattern similar to that of the conventional method.

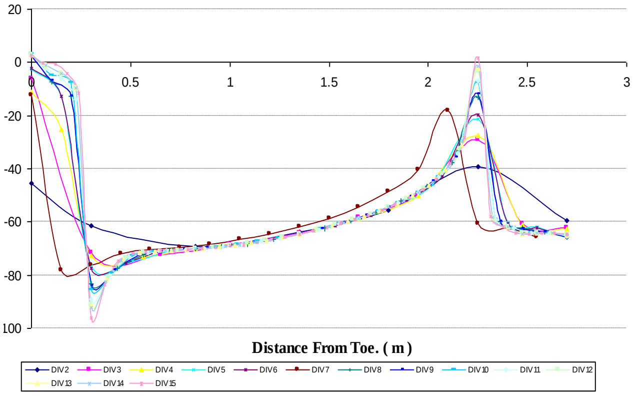
It is found from the graph G_1 that for grid having 12 divisions in the batter gives stress values which are closer to active lateral soil pressure. Graph G_2 shows trapezoidal variation. Toe projection is found to carry negligibly small stresses for fine grids and heel projection is found to carry almost uniform stress which is very close to the overburden due to soil retained above the heel. Therefore, the same grid that yielded the results closer to the desired parameters is finally accepted. Stress distribution for the GRW cross-section is as shown in Fig 2. In Fig 2 Contour values representing stress are in kN/m^2. From Fig 2 it is noted that compressive stresses are concentrated near the stem-toe junction and on the contrary negligible tensile stresses are developed at the stem-heel junction. The stresses induced are very small as compared to permissible stresses for compression and tension according to [14]. It is also noted that very negligible stresses are developed near the top corner on the free side up to the mid-height of the wall on the batter side.

A. Introduction of Cavity

An attempt is made to optimize the cross-section of GRW by removing material in the form of a rectangular cavity. Various positions of the rectangular cavity are tried along with variation in its aspect ratio. Effect of such variations on the largest tensile stress magnitude, its location, maximum displacement, and deformed shape of GRW cross-section with the cavity is studied. During the analysis, it is noticed that the stability criteria for sliding are dissatisfied. It is, therefore, necessary to provide a shear key.



Graph G_1. Variation of σ_{xy} (kN/m^2) against Width of GRW at Stem-Base Junction (m) [15]



Graph G_2. Variation of σ_y (kN/m^2) against Width of GRW at Stem-Base Junction (m) [15]

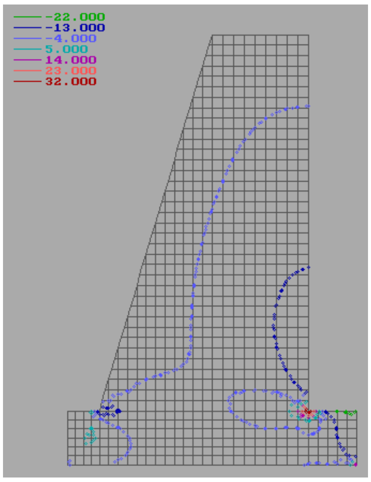


Fig 2. Stress Distribution along Cross-Section of GRW

V. RESULTS AND OBSERVATIONS

A. Assessment of Cavity in Retaining Wall

A large number of trials are taken by incorporating a rectangular cavity with a change in ratio λ_b and ratio C_a. λ_b is defined as the ratio of base width of the rectangular cavity to that of the width of stem at the stem-base junction and C_a, the aspect ratio is defined as the ratio of the height of cavity to its base width. Further, the position of the cavity is also changed using the parameters λ_h and λ_w. λ_h is defined as the percentage of the height of the base of the cavity from top of the wall to the height of stem and λ_w is defined as the ratio of horizontal distance of the vertical face of cavity near the stem to the width of stem at the stem-base junction. The position of the cavity is restricted in the area bounded by edge distance of 0.27m from all the boundaries of retaining wall to avoid slender wall-like element being developed by the side of the cavity in the portion of the wall.

Program outputs for the above parameters are studied. Two representative cases are listed to understand actual variation and trends. In the cases considered lb is kept constant as 0.1385 and the value of λ_w is varied as 0.2305 (Case-I) and 0.1385 (Case-II). The effect of variation of λ_w on the stresses along the cross-section of the wall is studied. For this purpose, stress ratios σ_1 and σ_2 are used. ψ_1 is defined as the ratio of the maximum tensile stress developed to the permissible stress and ψ_2 is defined as maximum compressive stress developed to the permissible stress.

The variation of ψ_1 is plotted in graph G_3 and G_4 by changing λ_h and C_a for Case-I and Case-II respectively. Similarly, a variation of ψ_2 is also plotted in graph G_5 and G_6 for Case I and II respectively.

B. Variation of Tensile Stress Ratio ψ_1 for Case-I and Case-II

Case-I (λ_b= 0.1385, λ_w = 0.2305)

For C_a less than 8.6418 ψ_1 ranges from 0.0281 to 0.0475 which means the maximum tensile stress is less than 5 % of the permissible tensile stress. For C_a greater than 8.6418 the values of ψ_1 increase to 0.1149 which means the maximum tensile stress in this case is less than 11.5 % of the permissible tensile stress.

Case-II (λ_b= 0.1385, λ_w = 0.1385)

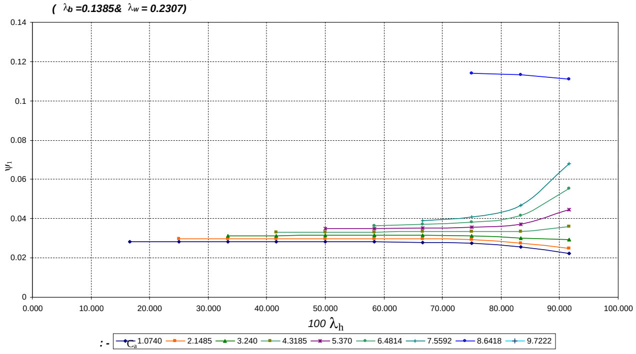
For C_a less than 4.3185 the tensile stresses developed are very small and remain practically constant and less than 5% of permissible stress. For Ca greater than 4.3185 the values ψ_1 increase to 0.3236 which means the maximum tensile stress, in this case, is less than 33% of the permissible tensile stress. As the base of the cavity moves towards base-stem junction which is the region of maximum stress, stress distribution changes and stresses get distributed over the entire cross-section of the wall. From graph G_3 and G_4, it is observed that the response of retaining wall with cavity depends on the position of the cavity from the vertical face of the stem. It is seen that the point of maximum tensile stress slowly shifts from its original position i.e. the junction of the vertical face of stem and base of GRW to right bottom corner of the cavity and then to nearly right top corner of the cavity as C_a increases

C. Variation of Compressive Stress Ratio ψ_2 for Case I and II

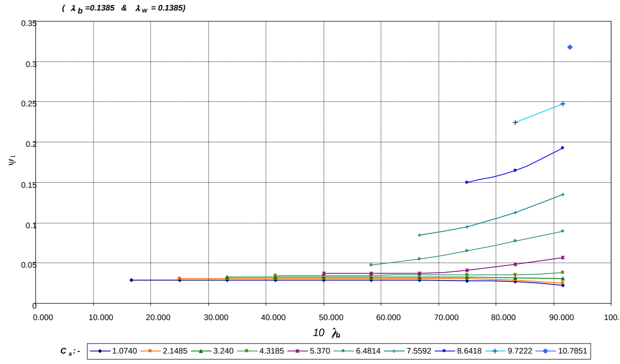
Graph G_5 and G_6 indicate that the maximum compressive stress induced in the section of GRW varies with λ_h depends on C_a. For C_a less than 4.3185 the largest compressive stress is practically constant and less than 2% of permissible stress. For increasing C_a ratio ψ_2 also increases with increasing λ_h. It is found that the position of the cavity affects the maximum compressive stress induced in the section are insignificant.

It is also noticed that the point of maximum compression slowly shifts from its original position i.e. at the junction of batter and base as in GRW to right bottom corner of the cavity to lower the mid-height of the cavity as C_a increases. Stress distribution for the wall cross-section with a cavity is shown in Fig 3 for Case-I and Case-II.

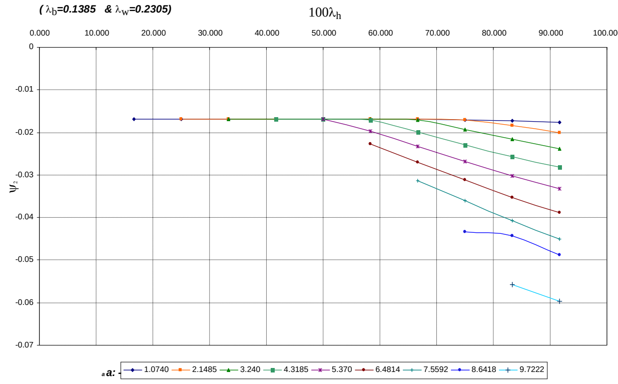
From Fig 3 it is noted that compressive stresses are concentrated near the top corner on the batter side of the cavity and tensile stresses are developed at mid-height of the cavity and stem-heel junction. The stresses induced are higher for both cases as compared to stress in the wall without the cavity.



Graph G$_3$. Variation of ψ_1 (kN/m^2) Vs λ_h for Case-I



Graph G$_4$. Variation of ψ_1 (kN/m^2) Vs λ_h for Case-II



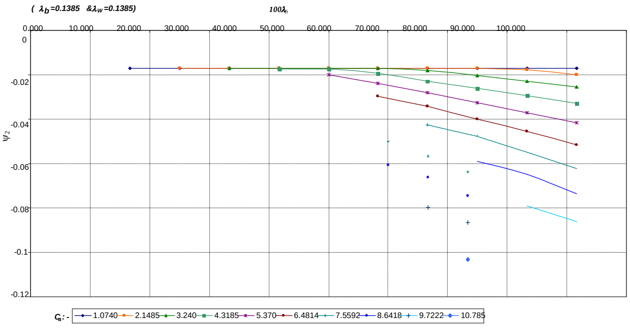
Graph G$_5$. Variation of ψ_2 (kN/m^2) Vs λ_h for Case-I

VI. CONCLUSION

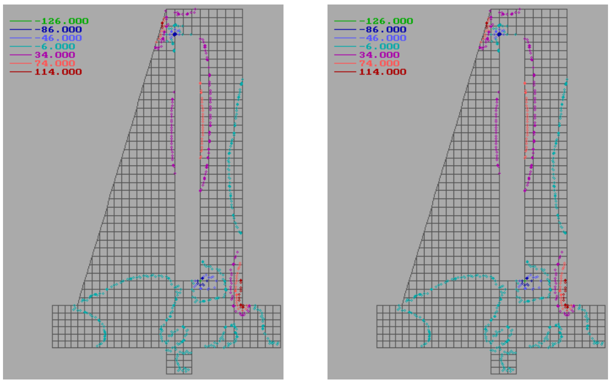
According to the results obtained and observations interpreted some concluding remarks are given below;

i. Cross-section of GRW can be optimized by introducing a rectangular cavity in the section.

ii. A rectangular cavity in the GRW cross-section utilizes material capacity in a better fashion.



Graph G$_6$. Variation of ψ_2 (kN/m^2) Vs λ_h for Case-II



a. Case-I (λ_w = 0.2305) b. Case-II (λ_w =0.1385)

Fig 3. Stress Distribution along Cross-Section of GRW with Rectangular Cavity

iii. The position and aspect ratio of cavity influence stresses induced along the cross-section of GRW.

iv. The location of maximum compressive stress is found to shift from its original position i.e. junction of batter face and base of gravity retaining wall, to backfill side bottom corner of the cavity. Compressive stresses are also developed at the batter side top corner of the cavity.

v. The location of maximum tensile stress is found to shift to mid-height of the cavity from its original position i.e. the junction of the vertical face of stem and base of the gravity retaining wall. Tensile stresses are also developed on the top side of retaining wall above the cavity.

REFERENCES

1. W.C. Huntington "*Earth pressure and Retaining wall"*, John Wiley and sons Inc., New York. 1959, pp 4-32.
2. Hinton, E., and J. S. Campbell. "Local and global smoothing of discontinuous finite element functions using a least squares method." *International Journal for Numerical Methods in Engineering* 8, no. 3 1974: 461-480.
3. Barlow, John. "Optimal stress locations in finite element models." *International Journal for Numerical Methods in Engineering* 10, no. 2 1976: 243-251.
4. IM. Smith "Programming the Finite element method" great Britain and printed at pitman press Ltd, Bath, Avon John Wiely and Sons Ltd. 1979 pp 32-35.
5. Cook, Robert D. *Concepts and applications of Finite element method.* John Wiley & Sons, 2007.
6. Lafore, Robert. *Object-oriented programming in Turbo C++*. Galgotia publications, 2001.

7. Jalla, Raj. "Design of multiple level retaining walls." *Journal of architectural engineering* 5, no. 3 1999: 82-88.
8. Claxton, Mary, Robert A. Hart, Paul F. McCombie, and Peter J. Walker. "Rigid block distinct-element modeling of dry-stone retaining walls in plane strain." *Journal of geotechnical and geoenvironmental engineering* 131, no. 3 2005: 381-389.
9. Bhatti, M. Asghar. "Retaining wall design optimization with MS excel solver." In *Structures Congress 2006: 17th Analysis and Computation Specialty Conference*, pp. 1-15. 2006.
10. Basha, B. Munwar, and GL Sivakumar Babu. "Reliability based design optimization of gravity retaining walls." In *Probabilistic Applications in Geotechnical Engineering*, pp. 1-10. 2007.
11. Yepes, Víctor, Julian Alcala, Cristian Perea, and Fernando González-Vidosa. "A parametric study of optimum earth-retaining walls by simulated annealing." *Engineering Structures* 30, no. 3 2008: 821-830.
12. Sadoğlu, Erol. "Design optimization for symmetrical gravity retaining walls." *Acta Geotechnica Slovenica* 11, no. 2 2014: 71-79.
13. Bowles Joseph E, Foundation Analysis and Design 5th Edition, Mc-Graw Hill International Company 2017.
14. Indian standard IS 456:2000 Plain and Reinforced concrete for practice.
15. P. P. Tapkire, and Dr Bilavari Karkare "Evaluation of Stress Distribution in Gravity Retaining Wall Cross-Section Using Finite Element Method," *Conf ICEITEMS 2019, Hyderabad.*, to be published

AUTHORS PROFILE

P. P. Tapkire Registered as Research Scholar, Department of Civil Engineering, Sinhgad College of Engineering, Pune, and working as Head of Department, Civil Engineering, NBN Sinhgad College of Engineering, Solapur, Maharashtra, India. Graduated in civil engineering and did masters in structure from Shivaji University and having experience of more than 14years in teaching as well as in industry. PG recognized teacher of Solapur University guided 8 PG students and 6 are working under the guidance Handled IITM C band installation project as structural and execution expert. Nominated as member for distance learning syllabus formation committee IGNOU, Delhi. Also worked as committee member to identify centres for IGNOU for distance learning courses. Received appreciation award from ULTRATECH, Cement Solapur for contribution in M-sand Project.

Dr. Bilavari Karkare Director, Vishwakarma Institute of Information Technology, Pune, Maharashtra, India, Having more than 36 years of experience in teaching as well as in Industry. Gold medallist of COEP, Pune at UG. Completed masters in structure from the University of Alberta, Canada and PhD from University of Pune. Recognized Ph. D. guide and P.G. Teacher of University of Pune. Curranty guiding Six PhD students. Handled 7 different research project funded by different agency. 19 Research papers were published in International and National Journals and International Conferences. Nominated on Research Committee for National and International Collaboration of SP Pune University. Awarded as Super Achiever's Award for Promoting Research in the field of Civil and Structural Engineering' by WISE, at ICWES 17 in October 2017 at New Delhi. Also received award as Lady Engineer - 1994' by the Institution of Engineers (India), Nasik Chapter.