Different Design Aspects of L-Shaped Earth Retaining Structures

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Abstract. The L-shaped retaining walls (L-SRWs) are considered one of the important earth retaining structures (ERSs). The investigation of L-SRWs mainly depends on factors directly related to the design process. Reviewing these factors represents the key matter in the design of ERSs, and this is the main purpose of this paper. This review showed that, in the design of L-SRWs, there are important issues to be considered. Some of them are related to the backfill and foundation soils e.g. the dependency of soil stiffness on the state of stresses, information related to soil behavior, inclination and quality of backfill, and settlement of foundation soil. Other issues are related to the wall itself such as the wall dimensions, failure mechanism, and flexural failure mode. In the design processes of L-SRWs, structural and geotechnical design requirements should be considered. L-SRWs should be designed to be proportional in their dimensions, the width of the wall base and its height should be designed to meet a specific ratio. Considerations related to the "conjugate rupture planes", the displacement pattern, and flexural failure mode should be included in the design process of L-SRWs.

INTRODUCTION

Earth retaining structures (ERSs) are one fundamental form of geotechnical engineering infrastructures. They are broadly utilized to equipoise the soil lateral pressure (SLP) for the case where the elevations are different or to shore the excavations work [1-3]. There are a number of restrictions to selecting the suitable section of ERSs, among these restrictions, are the location of infrastructure, environmental restrictions, land ownership, and project requirements [4, 5].

L-shaped retaining walls, L-SRWs, are a complex and important type of retaining walls, RWs. This type of ERSs is widely utilized in different geotechnical applications. It can be constructed either forward facing or backward facing. It should be noted that boundary restrictions have a great role in the construction of L-SRWs. In some cases, the L-SRWs may construct without providing a heel projection (or constructed with a small heel), while in other cases, they may construct without providing a toe projection (or constructed with a small toe), each case, however, has its own special design consideration. Regarding the height of L-SRWs, for heights less than 6 m, a simple type of L-SRWs can be used to retain soils, while for higher heights, special structural units like buttresses, counterforts, and anchorages should be provided with L-SRWs [6-8]. The cantilever ERSs are preferred in cases where a short length and low height are required, also, they are used when the zone available for backfilling is limited [9]. In marine applications of ERSs, as an alternative to traditional quay-wall structures ("concrete floated-in caissons", or "blockwork wall"), the L-SRWs have been created. The L-SRWs can be constructed using precast-concrete units, Figure 1, of different lengths (3m to 12m) and sizes and are constructed in wet conditions. There are different advantages to using precast L-SRWs, e.g. concrete usage is lower, and the precast units of L-SRWs are cast in reusable formwork with defined quality control techniques in a controlled environment [6].

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The actual geometry of L-SRWs and the distribution and magnitude of SLP are not considered in the real design methodology of ERSs. Mostly, in well-known practice codes, the SLP distribution is assumed to be a simple hydrostatic, also, these codes adopt the assumption of the virtual wall to distribute the soil pressure according to the classic theories of SLP [7, 10]. The investigation of L-SRWs mainly depends on factors directly related to the design process. Reviewing these factors represents the key matter in the design of ERSs, and this is the main purpose of this paper.

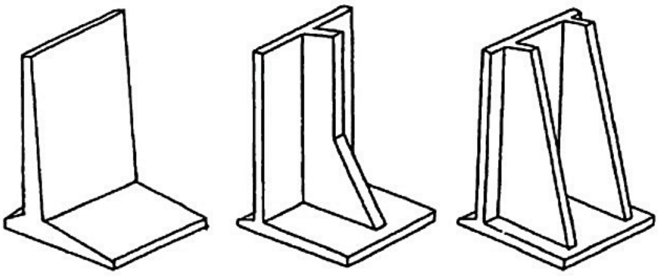


Fig. 1. L-SRWs with different precast units [6].

GENERAL CONSIDERATIONS FOR DESIGN OF L-SRW

In the design processes, the stability of L-SRWs against overturning and sliding should be considered in addition to the global stability [11, 12]. Furthermore, the structural design requirements (section adequation for moments and shear) should meet the safety required by the international codes, see Figure 2, [13]. The sequence followed in the design of L-SRWs includes the assumption regarding the ERS type, the assumption of the structural dimensions of the wall, the definition of design forces and loads, and the evaluation of the overall stability of the system. The latter includes global stability, overturning, sliding, and the bearing capacity of the foundation soil. If this evaluation is satisfied, the structural components of ERS should be designed, otherwise, the processes are repeated for a new trial, [6].

The dependency of soil stiffness on the state of stresses should be considered in the design of cantilever ERSs [14, 15]. Also, including information related to soil behavior, inclination and quality of backfill, and settlement of foundation soil is of the most importance to ensure safe design for ERSs [16, 17].

DIMENSIONS AND FAILURE MECHANISM CONSIDERATIONS

The dimensions of the L-SRW have their own effect on the design process. Actually, the SLP increases as the height of the system increases due to the augmenting of the value of vertical resisting force. On the other hand, the stability of the system against overturning, sliding, and bearing capacity decreases as the applied surcharge stress increases [5]. To achieve the required stability, L-SRWs are designed to be proportional in their dimensions, the width of the wall base and its height are designed to meet a specific ratio. According to Powrie and Chandler [18], and Daly and Powerie [19], the proposed average and optimum value of this ratio is 1/2, while the value of 1/2 to 4/5 was recommended by Oliphant [20] to include in the design practice. Kumar and Parihar [21] presented the value of this ratio used in the design as per Indian code specification, the presented value ranges from 40% to 70%.

However, no explicit guidance is available to be followed in the selection of this ratio as stated by Rouili [7]. The heel base thickness, in turn, for cantilever L-SRWs varied according to the recommendation of researchers, as it ranged from 35 cm to 90 cm [22-24]. It is worth to mentioning that the width of the bases of cantilever RWs depends on the heel length, these bases are either long heel or short heel. Actually. the length of the heel highly affected the failure surface, where for the short heel, the failure surface will intersect with the stem part of the cantilever RW, while for the long heel, the failure surface will intersect with the surface of the backfill [25-27].

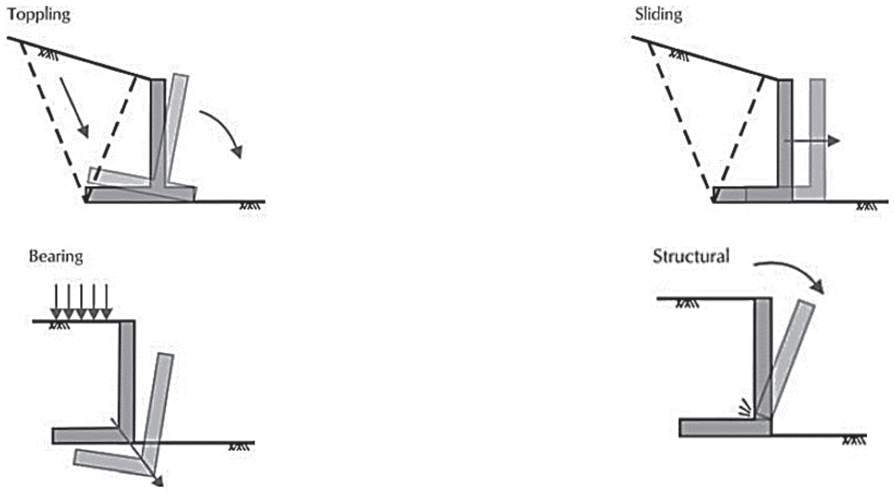
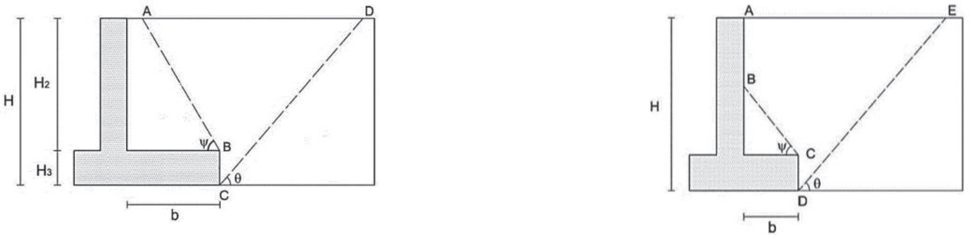


Fig. 2. L-SRWs failure modes (ultimate limit states) [14].

When the mass of non-cohesive backfills is stretched at all its points as a result of active pressure, two "conjugate rupture planes" are created. These planes are called the "inner failure plane", the plane DC, and the "outer failure plane", the plane AC as shown in Figure 3a [28]. In the active pressure case, if the length of the heel of RW is short, the failure surface will intersect RW's stem, as shown in Figure 3b, while for the long heel, this surface can freely develop and won't intersect the stem of RW as shown in Figure 3a. These situations will affect the selection of the suitable approach to calculate the earth's pressure. According to the literature, Rankine's approach is more appropriate for the case of L-SRW with long heels, while in the case of short heels, the SLP can be calculated according to Coulomb's theory [29-35]. As noted, the SLP behind cantilever RWs directly depends on the failure surface and its intersection with RW. Therefore, the methods proposed to calculate the SLP of cantilever RWs with long heels may not be appropriate for RWs with short heels.

a) Conventional failure surfaces for L-SRWs with long heel b) Conventional failure surfaces for L-SRWs with short heel



c) Modified failure surfaces for L-SRWs with long heel d) Modified failure surfaces for L-SRWs with long heel

Fig. 3. Conjugate rupture planes for L-SRWs with long and short heel [26, 28, 33, 36].

On the other hand, it was stated that the failure mechanism behind a cantilever L-SRW subjected to active thrust differs from that shown in Figures 3a and 3b [26, 36, 37]. The proposed mechanism for both short and long heels is shown in Figures 3c and 3d, respectively. Accordingly, there is a difference in the friction surfaces between the conventional and the proposed mechanisms. Kamiloglu & Sadoglu [37] found a difference between the failure surface geometry from both short and long heels L-SRWs. For the short heel, these authors found a planer failure surface, while a dispersed surface was found for L-SRW with a long heel. The mentioned difference between the proposed and conventional mechanisms should be taken into consideration in the design of L-SRWs with short and long heels.

EXCAVATION DEPTH AND BACKFILL PROPERTIES CONSIDERATIONS

Kayabekir et al. [5], investigated the effect of different parameters on the design of L-SRWs. They found that the design of L-SRWs is highly influenced by the depth of excavation. The analysis of these authors showed that the greatest factor that influences the design of L-SRWs is the depth of excavation (h), Figure 4. They concluded that as the depth of excavation increases, the width of the L-SRW base increases, and as a result, the cost of the wall increases (see Figure 5).

In reality, the entire design changes with changing the properties of backfill and foundation soils. For granular soils, both the thickness and width of the foundation of L-SRW changed with the value of soil density and internal friction [5].

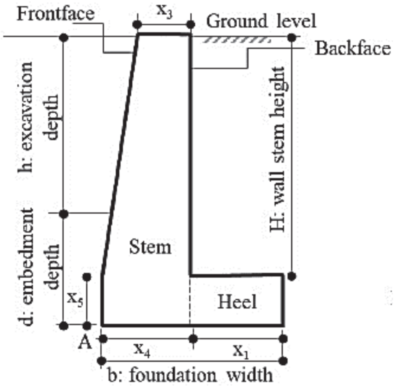


Fig. 4. Cross section for L-SRWs [5].

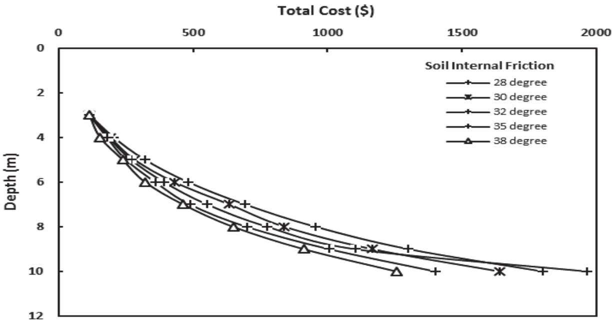


Fig. 5. Effect of excavation depth (h) and soil friction on the cost of L-SRW (modified after [5]).

It is worth mentioning some types of ERSs require large quantities of high-quality backfill geomaterials, while others require smaller quantities of these materials. Actually, L-SRWs are considered from the second group that requires fewer quantities [38]. However, as usable or “high-quality” backfill materials became scarcer, alternative materials (from sedimentary resources, aeolian soils, recycling waste, etc.) are often proposed as backfilling materials for ERSs [39-41]. In addition to the aforementioned, providing of L-SRWs with toe and heel affects the design process of such walls. There is a positive effect of the weight of backfill over the base of the RW on the overturning and sliding stability [34]. For walls without heel projection, the assistance provided by backfilling above the heel will not be provide, and this may reduce the stability. For walls without toe projection, special consideration should be applied to the procedure of the design of ordinary cantilever ERS, this is represented by increasing the thickness of the base to be thicker than the thickness of the stem bottom, [42-44].

CONSIDERATIONS FOR PATTERN OF DISPLACEMENT OF L-SRW

The displacement pattern of the L-SRWs has its own effect on the design of these structures. Such a pattern is depicted in Figure 6. There are three patterns of displacement can be calculated for L-SRWs, the horizontal displacement of the top of RW, the vertical displacement of the bottom of the wall's stem, and the horizontal displacement of the bottom of the RW, denoted as δht, δv, and δhb as shown in Figure 6. It was noted that, among these three values, the maximum displacement is the δhb. Furthermore, the pattern of movement of L-SRW is represented by the forward translation of the base of the wall and tilting of the wall stem forward, however, rotational movement is the predominant pattern of movement [10, 45].

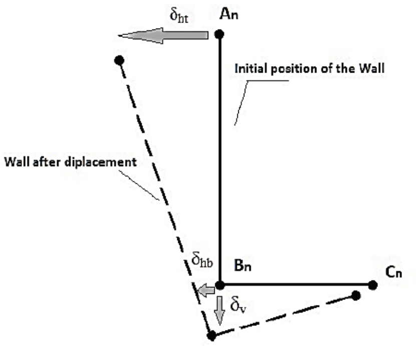


Fig.6. The pattern of displacement of L-SRW [7]).

It is worth stating that these displacements are affected by different parameters like the dimensions of the wall (Its height, H, and width of its base, B). In reality, the balance between the translation of the toe of the RW and its instantaneous rotation is governed by dimension B, which controls the B/H ratio. when this ratio closes to unity, the expected pattern of RW movement is the translation, while the rotational pattern of movement is predominated for the case of B/H of less than 50%. In the practical design, the reasonable limitation of B/H values, at which the movement pattern of L-SRW is balanced between the rotation movement and translation movement, lies between 50% and 80% as presented in Figure 7. It is important to note that the displacement of the part of the backfill above the base of L-SRWs should be considered in the design of these structures as it is assumed as a part of the RW. Finally, in many design standards, the average pressure value between the elastic (at rest) pressure and the minimum plastic (active) pressure to calculate the SLP is used. Interestingly, this may not be relevant for all ERSs. In fact, for L-SRWs, there is a singular value of the SLP coefficient commonly considered for engineering design practices. This value lies above the active coefficient and is influenced by the B/H ratio. Such value should be considered in the design practice to avoid overestimation and uneconomical designs [7, 10].

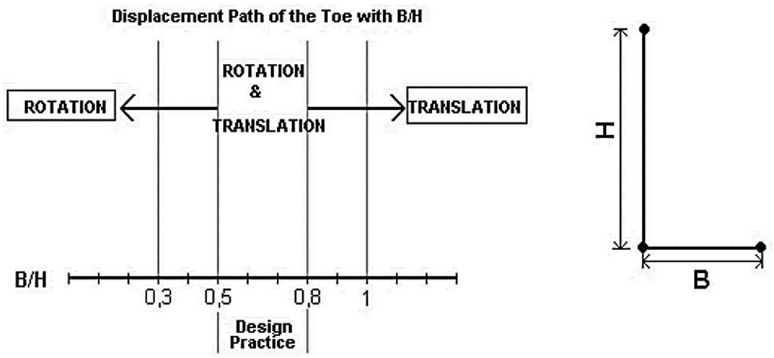


Fig.7. L-SRW displacement chart [7]).

CONSIDERATIONS FOR DYNAMIC LOADING

The L-SRWs were proven to perform well, and in some circumstances, very well under the effect of seismic loading [46, 47]. For ERS subjected to dynamic loading, the current method for designing cantilever RWs is based on a force approach. Usually, these RWs are designed as in gravity RWs, with the soil above the heel considered part of the RW. To calculate the earth pressure, the approach of Mononobe-Okabe is used on the back face of the soil mass above the heel, the friction angle on the interface between soil to soil is considered as the soil internal friction and a suitable value is assumed to represent the horizontal acceleration coefficient of earthquake, kh [48-51]. Table 1 presents different suggested values for kh to be taken into account in the seismic design ERS. The value of kh presented in Table 1 is a percent from the result of dividing the peak ground acceleration (PGA) and gravity acceleration (g). This value, however, depends on whether the RW is yielding or non-yielding, and the amount of this yielding if any [52, 53].

TABLE 1. Different suggested values for kh.

kh	Remarks	References
PGA/2g to PGA/g	For ERS that may yielding a manor amount to few centimeters	FHWA [54] AASHTO [55]
0.33 (PGA/g)^0.33	The case of yielding ERS	Bray et al. [52]
0.67 (PGA/g)	The case of yielding ERS	Okamoto [56]

It was proved experimentally that, for cantilever RWs, the estimation of dynamic earth pressure from the M-O approach produced overestimation values [57, 58]. When considering seismic loading on L-SRW, it has been observed that the soil thrust that maximizes the bending moment on the stem of RW does not concur with the critical soil pressure needed for overall stability. This implies that, under dynamic loading, varying load combinations must be utilized to determine appropriate sizing for the stem of RW and analyze the overall system's stability against bearing capacity and sliding [34, 59, 60].

On the other hand, from a structural standpoint, under the effect of earthquake loads, the typical mode of failure for L-SRW is the flexural failure mode. Under such conditions, the material of the wall is damaged as a result of the impact of soil forces, this produces damage represented by cracking of the wall (flexural, tension, and compression). The emerging cracks in the base of the wall can be flexural and tension-type, while those that emerge in the wall stem are flexural and compression-type. Accordingly, selecting one of the suitable techniques is necessary to strengthen the area of L-SRW that may be damaged under seismic loading.

According to the analysis in literature and based on selected earthquakes (including Chi Chi earthquake (1999), Kobe earthquake (1995), and Northridge earthquake (1994)), the weak zones produced in L-SRW were assigned as shown in Figure 11. In this figure, the flexural failure (weak zones) due to earthquake loads is highlighted in blue. Accordingly, it is important to increase the reinforcement (the size and distribution of bars) in these zones [61, 62].

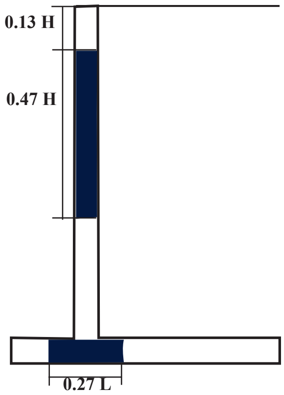


Fig. 8. Flexural failure mode for concrete Cantilever RW (Compression Strength of 30MPa) (Reproduced after [61]).

CONCLUSIONS

In the design processes of L-SRWs, structural and geotechnical design requirements should be considered. Also, including information related to soil behavior, inclination and quality of backfill, settlement of foundation soil, depth of excavation, and dependency of soil stiffness on the state of stresses is essential to ensure safe design.

To achieve the required stability, L-SRWs should be designed to be proportional in their dimensions, the width of the wall base and its height should be designed to meet a specific ratio, according to scholars and international codes, this ratio ranges from 40% to 80%. Furthermore, the design process of L-SRWs is influenced by whether the wall was provided with a toe and heel. There is a positive effect of the weight of backfill over the base of the RW on the overturning and sliding stability.

The "conjugate rupture planes", "inner failure plane" and "outer failure plane", should be included when selecting the suitable approach to calculate the earth thrust behind L-SRWs. These planes are highly affected by the length of the heel. The methods proposed to calculate the L-SRWs with long heels may not be appropriate for RWs with short heels.

The displacement pattern of the L-SRWs has its own effect on the design of these structures. The pattern of movement of L-SRW can be represented by the forward translation of the base of the wall and tilting of the wall stem forward, however, rotational movement is the predominant pattern of movement. This pattern is affected by the ratio of the base's width to the wall's height (B/H). In the practical design, the reasonable limitation of B/H values, at which the movement pattern of L-SRW is balanced between the rotation movement and translation movement, lies between 50% and 80%.

The L-SRWs were proven to perform well, and in some circumstances, very well under the effect of seismic loading. The estimation of dynamic earth pressure from the M-O approach may produce overestimation values. Under dynamic loading, varying load combinations must be utilized to determine appropriate sizing for the stem of RW and analyze the overall system's stability against bearing capacity and sliding.

Under the effect of earthquake loads, the typical mode of failure for L-SRW is the flexural failure mode, the material of the wall is damaged as a result of the impact of soil forces, and this may produce damage represented by cracking of the wall (flexural, tension, and compression). Accordingly, selecting one of the suitable techniques is necessary to strengthen the area of L-SRW that may be damaged under seismic loading.

REFERENCES

1. K. Terzaghi, “General wedge theory of earth pressure,” Transactions, ASCE, vol. 106, pp. 68-97, 1941.
2. A.J. Al-Taie, “Earth pressure acting on the cantilever embedded retaining wall in multilayer soil,” in the 1st Basrah International Conference on Civil Engineering BICCE-01), Iraq, 2013.

3. Y. Lu, W. Sun, H. Yang, J. Jiang, L. Lu, “A new calculation method of force and displacement of retaining wall and slope,” Appl. Sci., vol. 13, pp. 5806, 2023, https://doi.org/10.3390/app13095806
4. A.J. Al-Taie, A.A. Mohammed, “A view plan sheet pile: design chart for cantilever retaining wall construction for active and passive earth pressure in Baghdad soil,” International Journal of Advances in Applied Sciences, vol. 3, no. 2, pp. 95-103, 2014.
5. A. Kayabekir, Z. Arama, G. Bekdaş, I. Dalyan, “L-shaped reinforced concrete retaining wall design: cost and sizing optimization,” Challenge J. of Structural Mechanics, vol. 6, no. 3, pp.140-149, 2020, https://doi.org/10.20528/cjsmec.2020.03.005
6. G.P. Tsinker, “Gravity-Type Quay Walls,”, in Handbook of Port and Harbor Engineering, Springer, Boston, MA, 1997.
7. M. Ahmed, A. Al-Taie, “A systematic review of factors controlling the acceptability of earth-retaining structures selection,” AIP Conf. Proc. 2024
8. C. Clayton, R. Woods, A. Bond; J. “Milititsky, Earth Pressure and Earth Retaining Structures,” Third Edition, Taylor & Francis Group, LLC, 2013.
9. J. Bowles, “Foundation Analysis and Design,” 5th edition Mc Graw-Hill Book Company Inc. New York, 1996.
10. A. Rouili, “Design of rigid L shaped retaining walls,” Int. J of Civil and Environmental Eng., vol. 7, no. 12, pp. 908-911, 2013.
11. B. Das, N. Sivakugan, “Principles of Foundation Engineering,” 9th edition, Cengage Learning, Inc. USA, 2019.
12. J. Briaud, “Geotechnical Engineering: Unsaturated and Saturated Soils,” Second Edition, John Wiley & Sons, Inc, 2023.
13. T. Sasidhar, D. Neeraja, V. Sudhindra, “Application of genetic algoritm technique for optimizing design of reinforced concrete retaining wall,” International Journal of Civil Engineering and Technology, vol. 8, no. 5, pp. 999-1007, 2017.
14. A. Bond, A. Harris, “Decoding Eurocode 7,” Taylor & Francis group, 2008.
15. N. Nam, N. Thao, “Effect of soil models on the deformation and pressures on cantilever retaining walls,” Geotechnics for Sustainable Development - Geotec Hanoi, Phung (edt). Construction Publisher, 2013.
16. H. Brooks, “Basics of Retaining Wall Design,” 8th edition, HB Publication Inc, 2010.
17. T. O’Neal, D. Hagerty, "Earth pressures in confined cohesionless backfill against tall rigid walls-a case history," Can. Geotech. J., vol. 48, pp. 1188 – 1197, 2011. https://doi.org/10.1139/T11-033
18. W. Powrie, R. Chandler, "The influence of a stabilizing platform on the performance of an embedded retaining wall: a finite element study," Geotechnique, vol. 48, pp. 403-409, 1998.
19. M. Daly, W. Powrie, "A centrifuge and analytical study of stabilizing base retaining walls," Transport Research Laboratory TRL report 387, 1999.
20. J. Oliphant, "The outline design of earth retaining walls," Ground Engineering Journal, 9, pp. 5358, 1997.
21. A. Kumar, A. Parihar, "Design and life cycle assessment of retaining wall with used foundry sand as backfill," Geo-Congress GSP, vol. 339, pp. 55-63, 2023.
22. Y. Huang, C. Huang, S. Chen, W. Lin, The world wide web and the databases for retaining wall design. Adv. Eng. Software 30(9) (1999) 799–808.
23. A. Kaveh, A. Abadi, 'Harmony search based algorithms for the optimum cost design of reinforced concrete cantilever retaining walls," Int. J. Civil Eng. vol. 9, pp. 1-8, 2010
24. C. Camp, A. Akin, "Design of retaining walls using big bang-big crunch optimization," J. Struct. Eng., vol. 138, pp 438–448, 2012.
25. A. Goh, "Behavior of cantilever retaining walls," J. Geotech. Eng., 119, pp. 1751–1770, 1993.
26. H. Kamiloglu, E. Sadoglu, 'A method for active seismic earth thrusts of granular backfill acting on cantilever retaining walls," Soils and Foundations, vol. 59, pp. 419-432, 2019, https://doi.org/10.1016/j.sandf.2018.12.003
27. F. Chen, H. Chen, L. Xu, L. Lin, "Seismic pseudo-static active earth pressure of narrow granular backfill against an inverted T-type retaining wall under translational mode," Soil Dynamics and Earthquake Engineering, vol. 152, pp. 107018, 2022.
28. V. Murthy, "Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering," Marcel Dekker, Inc, New York, 2003.
29. W. Teng, “Foundation Design,” Prentice Hall, London, 1962.

30. A. Barghouthi, "Active earth pressure on walls with base projection," J. Geotech. Eng., vol. 116, pp. 1570–1575, 1990.
31. V. Greco, "Active earth thrust on cantilever walls with short heel," Can. Geotech. J., vol. 38, pp. 401–409, 2001.
32. V. Greco, "Analytical active earth thrust on cantilever walls with short heel," Can. Geotech. J., vol. 45, pp. 1649–1658, 2008.
33. A. Santolo, A. Evangelista, "Dynamic active earth pressure on cantilever retaining walls," Computers and Geotechnics, vol. 38, pp. 1041-1051, 2011, https://doi.org/10.1016/j.compgeo.2011.07.015
34. A. Al-Taie, M. Ahmed, “Reviewing critical factors controlling the modeling and design of earth retaining structures,” in the 18th International Middle Eastern Simulation and Modelling Conference 2023, MESM 2023, 2023.
35. H. Kamiloglu, E. Sadoglu, "Active earth thrust theory for horizontal granular backfill on a cantilever wall with a short heel," Int. J. Geomech., vol. 17, 2017, https://doi.org/10.1061/(ASCE)GM.1943-5622.0000886
36. H. Kamiloglu, E. Sadoglu, "Experimental examination of active and passive wedge in backfill soil of model cantilever retaining walls," Int. J. Struct. Anal. Des., pp. 96–100, 2014.
37. H. Kamiloglu, E. Sadoglu, "Experimental and theoretical investigation of short-and long-heel cases of cantilever retaining walls in active state," Int. J. Geomech., vol. 19, pp. 04019023, 2019, https://doi.org/10.1061/(ASCE)GM.1943-5622.0001389
38. A.J. Al-Taie, M.D. Ahmed, "A Critical review of soil models and factors affecting earth retaining structures design," Jurnal Kejuruteraan (Journal of Engineering), vol. 36, no. 3, 2024.
39. A.J. Al-Taie, Y. Al-Shakarchi, A. Mohammed, "Investigation of geotechnical specifications of sand dune soil: a case study around Baiji in Iraq," IIUM Engineering Journal, vol. 14, no. 2. Pp. 121-132, 2013.
40. A.J. Al-Taie, Y. Al-Shakarchi, "Shear strength, collapsibility and compressibility characteristics of compacted Baiji dune soils," Journal of Engineering Science and Technology, vol. 12, no. 3, pp. 767-779, 2017.
41. A.J. Al-Taie, A. Al-Obaidi, M. Alzuhairi, "Utilization of depolymerized recycled polyethylene terephthalate in improving poorly graded soil," Transp Infrastruct Geotech, vol. 7, pp. 206 – 223, 2020.
42. M. Elman, C. Terry, "Retaining walls with sloped base," Journal of Geotechnical Engineering, vol. 113, pp. 1048–1054, 1987.
43. M. Elman, C. Terry, "Retaining walls with sloped heel," Journal of Geotechnical Engineering, vol. 114, pp. 1194–1199, 1988.
44. R. Holtz W. Kovacs, T. Sheahan, "An Introduction to Geotechnical Engineering," 3rd Edition, Pearson Education, Inc, Hoboken, 2023.
45. Y. Djerbib, C. Hird, M. Touahmia, "Centrifugal model tests of uniform surcharge loading on L-shaped retaining walls," 15th International Conference on Soil Mechanics and Foundation Engineering, Istanbul , pp. 1137-1140, 2001.
46. G. Gazetas, P. Psarropoulos, I. Anastasopoulos, N. Gerolymos, "Seismic behaviour of flexible retaining systems subjected to short-duration moderately strong excitation," Soil Dynamics and Earthquake Engineering, vol. 24, pp. 537 – 550, 2004.
47. H. Gao, Y. Hu, Z. Wang, C. Wang, G. Chen, "Shaking table tests on the seismic performance of a flexible wall retaining EPS composite soil," Bull Earthquake Eng., vol. 15, pp.5481- 5510, 2017, https://doi.org/10.1007/s10518-017-0189-4
48. BS 8002, Code of Practice for Earth Retaining Structures, 1994.
49. IS 1893-1, Criteria for Earthquake Resistant Design of structures. (Part 3) bridges and retaining walls. India, 2002.
50. EN 1998-5. - Eurocode 8: Design of Structures for Earthquake Resistance - Part 5: Foundations, retaining Structures and Geotechnical Aspects, Eurocode 8, 2004.
51. D. Anderson, g. Martin, i. Lam, j. Wang, "Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments,' NCHRP, 2008.
52. J. Bray, T. Travasarou, J. Zupan, “Seismic displacement design of earth retaining structures,” in Earth Retention Conference, pp. 638-655, 2010.
53. P. Jadhav, A. Prashant, "Double wedge model for computing seismic sliding displacements of cantilever retaining walls,' Soil Dynamics and Earthquake Engineering, vol. 116, pp. 570–579, 2019.
54. FHWA: Federal Highway Administration, Geotechnical Earthquake Engineering, Pub. No. FHWA HI-99-012, De, 1998.

55. AASHTO: American Association of State Highway and Transportation Officials, AASHTO LRFD Bridge Design Specifications, U.S. Units. 4th E, 2007.
56. S. Okamoto, “Introduction to Earthquake Engineering,” 2nd Ed., Wiley, NY, 1984.
57. S. Jo, J. Ha, J. Lee, D. Kim, "Seismic earth pressures on inverted T-shape retaining structures via dynamic centrifuge testing; 2014.
58. R. Geraili Mikola, G. Candia, N. Sitar, "Seismic earth pressures on retaining structures and basement walls in cohesionless soils," J Geotech Geoenviron Eng., vol. 142, pp. 04016047, 2014.
59. R. Whitman, S. Liao,"Seismic Design of Gravity Retaining Walls, US Army Engr," Waterways Experiment Sta., Misc. Paper GL-85-1, 1985
60. L. Al Atik, N. Sitar, "Seismic earth pressures on cantilever retaining structures," J. of Geotechnical & Geoenvironmental Engineering, vol. 136, 2010, https://doi.org:10.1061/(ASCE)GT.1943-5606.0000351
61. M. Garavand, H. Bahareh, “Failures of retaining wall structures due to earthquake,” in 7th International Conference on Case Histories in Geotechnical Engineering, Chicago, 2013.
62. M. Badr, "Numerical study for improve performance of retaining structures under earthquake loadings in sandy soils" MSc Thesis, Al-Nahrain University, Iraq, 2023