CONSEQUENCES OF POORLY COMPACTED BACKFILL MATERIAL ON CONCRETE RETAINING WALLS

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Abstract- Reinforced concrete retaining walls are extensively used in civic and transport infrastructure. Their integrity plays an important role in ensuring public safety. Despite the advancement in construction techniques and improvement in design codes, retaining wall failures are still common and instigating life and property loss. The quality of backfill material is directly related to the distresses generated in the wall. The classical design techniques used for earth pressure estimation normally consider triangular earth pressure distribution and ignores the soil arching effects. In this research prevalent finite element analysis has been done on concrete retaining walls with different backfill characteristics. Overall 12 cases has been investigated to highlight the consequences of poorly compacted backfill material on concrete retaining walls. This multi-physics approach considers the real effect of the backfill soil on pre-failure distresses generated in the concrete retaining walls. It has been observed that poorly compact backfill material can generate higher stresses in wall at critical sections. The analysis results can be effectively utilized to improve the wall geometric designs and hence, enhance the public safety and furthermore, believed to be helpful for the engineers involve in the design and construction of retaining walls.

Keywords- Concrete retaining walls, Backfill material, Horizontal thrust, Wall stresses.

1. INTRODUCTION

Reinforced Concrete (RC) retaining walls are an essential element of the contemporary infrastructure. They are used to support potentially vulnerable slopes, deep excavations, embankments and basements. Over the years the design and construction of RC retaining walls is greatly improved and many innovative technologies have been adopted. However, retaining wall failure is still a common phenomenon. A 6.1 meter retaining wall failed in 2012 in western India due to poorly selected backfilled properties [1] Several retaining walls collapsed during 2004 Niigata ken earthquake in Japan causing partial blockade of the road network[2]. In May 2006 a concrete retaining wall with a height of 8.9-m failed in Kahramanmaras, Turkey, damaging several buildings. Investigations revealed that, the poor material quality was one of the main failure cause.[3] The poor compaction reduces the stabilizing forces in the wall system, and have high active forces. The back fill material characteristics plays a very vital role in wall stability and any miscalculation and error can lead to a human disaster. Classical wall design practices are still considering linear (triangular) earth pressure distribution for the backfill material and ignoring the soil arching effect. The initial methods to estimate soil arching action were partly based on Rankine theory and later proved inaccurate. The modern studies shows two stage development of arching effect. These findings demonstrates higher lateral earth pressures than classical theory. Moreover, the pressure distribution is nonlinear approximately centered at a height 2/5 times the height of the wall [4]. Utilizing full scale experimental test results and mathematical techniques, the modified earth pressure equations for lateral active forces considering arching effect were also developed. Similar to classical methods, the stress friction angle(Ø) of the soil and the wall friction (δ) angle are the key input parameters for these equations[5].

Because of the non-linear pressure distribution and heterogeneity in the backfill material, FEM analysis can be a very effective tools for the earth pressure estimation in retaining walls. A number of studies have been found in the literature about the application of FEM on earth pressure analysis. For example, finite element modelling was applied to deep excavation analysis for metro station excavation and was found in good comparison with instrument readings[6]. Simplified 2D FEM studies using PLAXIS was conducted on deep excavation and tunneling in soft ground. The study was focused on the effects of mesh, ground conditions and the constitutive soil models. The soil conditions were selected form real field investigation results. The accurate prediction of ground movements was found to be difficult and dependent on parametric selection[7].

Whilst, the earth pressure estimation has been thoroughly studied, the existing literature regarding, retaining rigid walls and backfill characteristics mainly focus on development of lateral pressures and wall instability (movement), the effect of backfill quality on pre-failure distresses developed at the various sections of wall has not been well understood. The peak stresses and strains present along the wall geometry during the life span of the structure, are required to be highlighted for the identification of the critical sections. The Multiphysics FEM analysis has been presented in this study to highlight functional distresses generated by poorly compacted granular backfill material on concrete retaining walls.

2. METHODOLOGY

Backfill material compaction sometimes become challenging due to space requirements. The numerical modeling and simulation technique using Finite Element Method has been designated in this study, to present the effects of inappropriate compaction of backfill material on the reinforced concrete retaining walls. The study cases are designed on the basis of backfill material, having different degree of compaction and external horizontal loading (Thrust). Three soil compaction levels are selected for the modeling. The compaction level varies in terms for relative density ranging from very loose to medium. Each compaction case is then subjected to four different loading conditions. The load is applied as external horizontal thrust. Consequently, overall 12 cases are analyzed, the classification of the studied cases is shown in Table 1.

Table1: Studied Cases Based on Back Fill Compaction and External Loading

Backfill Compaction	**External Horizontal Thrust**			
	10-kPa	**50-kPa**	**100-kPa**	**200-kPa**
Very Loose	Case 1-A	Case 1-B	Case 1-C	Case 1-D
Loose	Case 2-A	Case 2-B	Case 2-C	Case 2-D
Loose to Medium	Case 3-A	Case 3-B	Case 3-C	Case 3-D

3. MODEL AND MATERIALS

The 2-D Finite Element Modeling (FEM) using COMSOL Multiphysics software has been used in this study [8].As compared to the classical geotechnical FEM modules, the COMSOL is capable of analyzing coupled Multiphysics phenomena simultaneously. The structural mechanics module (used in the analysis) of the software, provide freedom to the researchers to designate any material as linear elastic, nonlinear elastic and elastoplastic. The wall system has been characterized by a 3.5-m high tapered reinforced concrete retaining wall. The base width of the wall stem is 1-m, while the crown is 0.5-m wide. The wall foundation is 3-m wide, with a thickness of 0.5-m. The wall is supported on dense granular natural ground. The ground depth of 3-m below foundation is considered in this study (i.e. equal to foundation width). The main area of interest "loose backfill material" is presented by a 3.0 x 3.5 m rectangular block. The geometric details of the wall model system is shown in Figure 1. The load required to be supported is applied on the right corner of the backfill material. The top of the backfill and wall crown were kept free, hence no surcharge load was considered.

Since the main wall is model as reinforced concrete, typical strength and deformation properties of RC are adopted. The concrete density (ρ) is taken as 2300 kg/m^3, and 28 days compressive strength value of 28-MPa is considered. The value of Elastic modulus (E) and poisons ratio (ν) for concrete are assumed to be 25-GPa and 0.20 respectively.

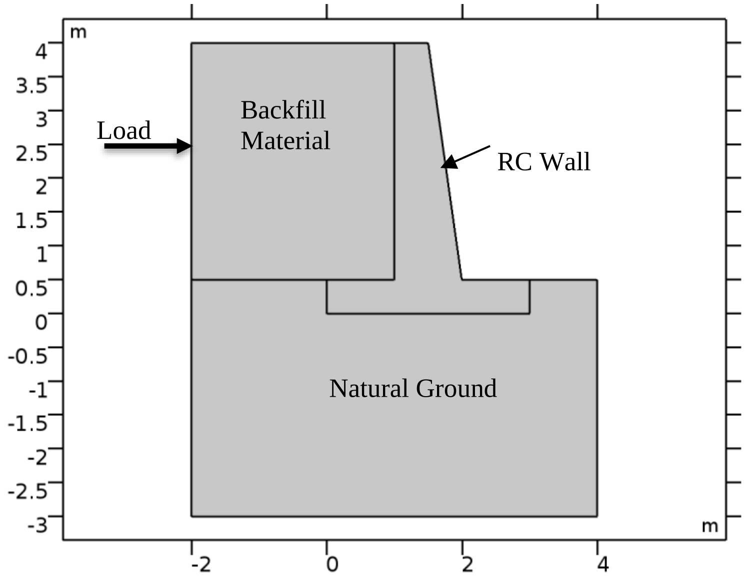


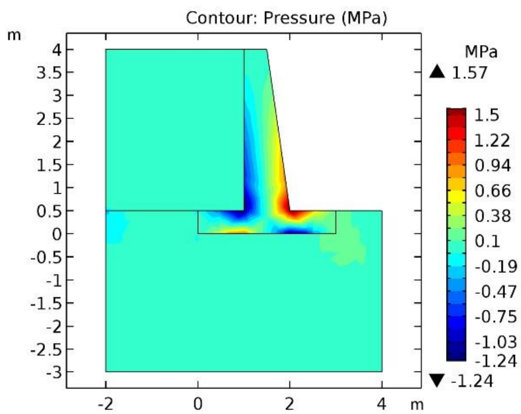
Figure 1: Model Geometry of a Tapered RC Retaining Wall

The foundation supporting natural ground is modeled as dense sand, whereas, the backfill material is represented by three different compaction levels of loose sand. The density of the sand varies from 1400 to 1600 kg/m$^{3.}$ The particulars of the mechanical properties of the geo-material and concrete used in the FEM analysis is presented in Table 2.

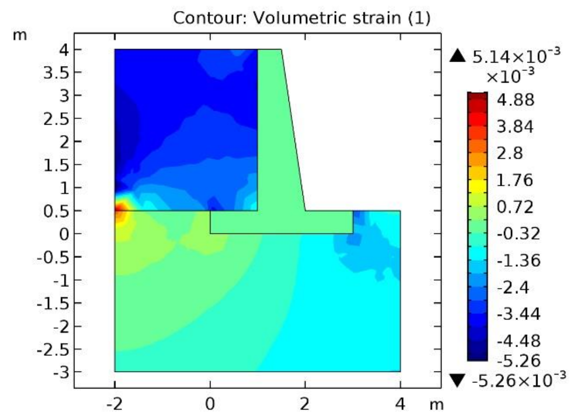
Table 2 Material Properties Used in the Study

Material		**Density (ρ) kg/m^3**	**Elastic Modulus (E) MPa**	**Poisson ratio (ν)**	**Material Specific Parameter(s)**
Wall Concrete		2300	25000	0.20	Compressive Strength (fc') = 28 MPa
Natural Ground		1700	80	0.30	Frication Angle (ϕ) = 38º
Backfill Material	**Very Loose**	1400	15	0.30	Frication Angle (ϕ) = 30º
	Loose	1500	35	0.30	Frication Angle (ϕ) = 32.5º
	Loose to Medium	1600	70	0.30	Frication Angle (ϕ) = 35º

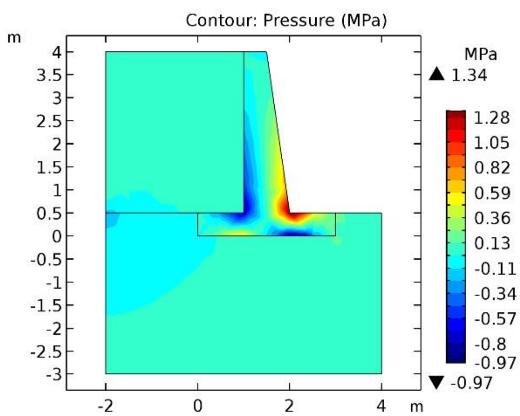
4. RESULTS AND DISCUSSIONS



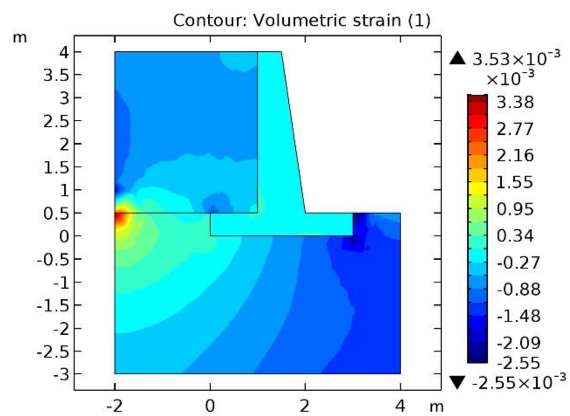
2(a) Stress Distribution for Case 1C



2(b) Volumetric Strain for Case 1C



2(c) Stress Distribution for Case 3C



2(d) Volumetric Strain for Case 3C

Figure 2: Examples of FEM Analysis Results at 100kPa Horizontal Thrust

The key objective of this study is to locate the pre failure distresses in the wall, owing to improper compaction of the backfill material. Therefore, FEM analysis has been carried out at low strain levels. The materials and the overall wall system remains within elastic limit. The analysis results for Case 1C (very loose backfill soil at 100 kPa Horizontal Thrust) and 3C (loose to medium backfill soil at 100 kPa Horizontal Thrust) are shown in Figure 2. Form Figure 2(a) and Figure 2(c) it is clear that most of the stresses in the system are taken by the wall. Under the same external loading and boundary conditions, the very loose backfill material implies 15% more peak stress, in the wall as compared to the medium backfill material. The location of the peak stress remains the same i.e. at the exterior joint of the wall base and stem[8].

The deformation results of the system for the above two cases are shown by Figure 2(b) and Figure 2(d). The very loose granular backfill material deform more than the medium loose material. Since concrete is more rigid than the soil, therefore in both cases almost no deformation is observed in the wall. The location of peak volumetric strain is at the junction of backfill material and the natural ground at the loading side. This may be a limit of FEM model and the real semi-infinite ground may have well distributed strains over the larger area with minimal effects. The peak volumetric strain **(ε_{vol})** for Case 1C is found to be 5.14 $\times 10^{-3}$, and for Case 3C it is 3.53 x 10^{-3}.

The peak wall stresses collected form all the 12 cases are plotted are Figure 3. The backfill material in the loosest state always impose higher stresses on the wall as compared to the other two compaction levels. With the increase in applied horizontal thrust this trend further diversified. These results are in good comparison with the experimental study on Ottawa sand carried out at the University of Washington, based on these experiments, the soil densification decreases the magnitudes of active stresses behind rigid walls.[9] The higher deformations in the loose back fill material may cause cracking which lead to the moisture penetration in case of a rainfall event and can impose a serious threat to the wall safety.

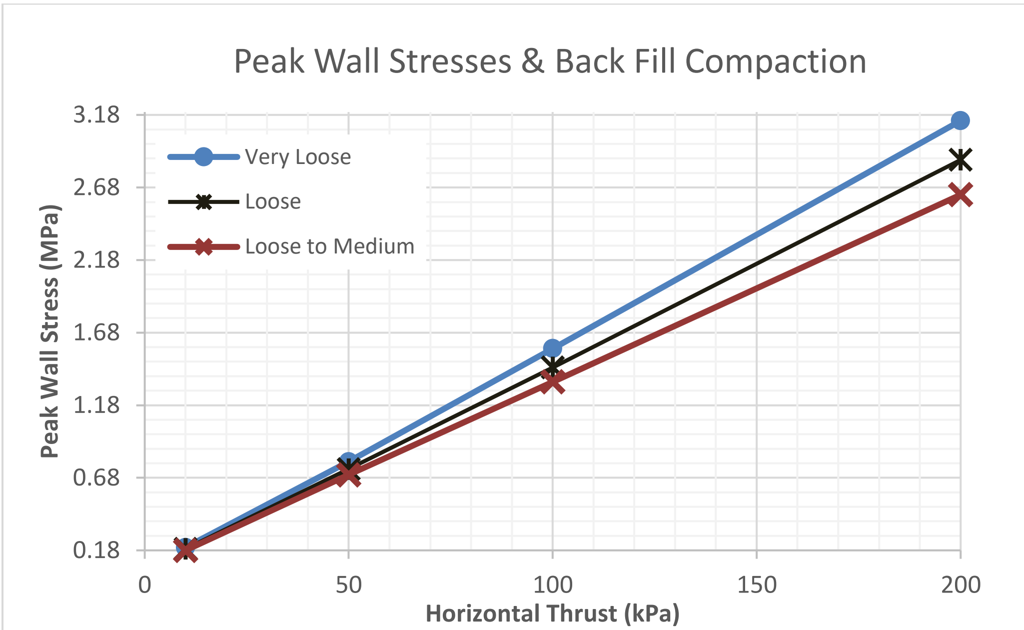


Figure 3: Effect of Backfill Material Quality on the Wall Stresses

5. CONCLUSIONS

COMSOL Multiphysics based FEM analysis conducted on dozen of retaining wall cases reveals that, improperly compacted backfill material imposes higher stresses in the RC retaining walls as compared to the well compacted material. The peak stresses (pre failure) developed on the joint between the wall stem and its base. Therefore, Stem-base joint should be carefully designed. Loose backfill material is further vulnerable in cases where external loading is relatively high.

Most of the stresses in the system are engaged by the wall. However, volumetric deformations development in the backfill material and foundation supporting strata. These deformations may lead to cracking, allowing water infiltration and can effect the overall wall safety. Despite of space issues, the backfill material should be properly compacted for RC shear walls of raft and other shallow foundations to avoid moisture induced settlements.

6. RECOMMENDATIONS

Compaction characteristics of a Backfill martial, plays a significant role in determining wall stability. In case, there is a space limitation, to deploy a mechanical compaction technique. The well-graded, self-compacting course grain geo-material, such as 60-40 grave-sand mixture should be used. If properly dumped the material can gain up to 98% of relative density.

7. ACKNOWLEDGEMENT

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