Abstract: - The optimum design of reinforced concrete (RC) structures with the minimum weight is not an easy task due to concrete and steel reinforcement bars have extremely different mechanical behavior, i.e. compressive strength, tensile strength, and material cost. Thus, the optimum design of RC structures may not be provided by the conventional approaches. In this paper, the optimum design of RC cantilever retaining walls is investigated. RC design is made according to the requirements of the American Concrete Institute (ACI 318-05) Building code requirements for structural concrete). Recently developed metaheuristic algorithm teaching learning based optimization (TLBO) algorithm is employed for optimization process and in order to strengths and weaknesses of the algorithms results are compared with previous proposed methods, including particle swarm optimization (PSO), big bang big crunch (BBBC) and improved harmony search (IHS) algorithms. By using proposed methods various analyses have been done and according to results, the proposed method is more successful in sense of standard deviation, average cost, and computational cost. Consequently, the proposed method seems suitable and robust for optimum design of RC cantilever retaining walls.

Key-Words: - meta-heuristic methods; teaching learning based optimization; optimum weight; optimum design; reinforced concrete structures; cantilever retaining walls.
must be taken into account during the design process. For that reason, the studies on this subject have been limited. But, after the first metaheuristic algorithm application on optimum design of retaining wall, the subject has become popular [17-31].

2 Methodology

In 2011, Rao et al. [8] developed teaching learning based optimization (TLBO) algorithm from the inspiration of teaching-learning process in a classroom. In this process, the main aim is to increase the level of knowledge of class. Teacher and learner (student) are both making an effort for this purpose. Teacher is the person who has a higher level in class and duty of teacher is to educate learners in order to improve the information of them about the subjects. Learners can also gain information by interaction, searching, discussing the matters. For that reason, TLBO algorithm is used two partitions “teacher and learner phase” during finding optimum results.

Optimization process of TLBO algorithm can be summarized in five steps.

1st step: Design constants and ranges for design variables are determined in this step. These constants are height of stem, yield strength of reinforcement bars, compressive strength of concrete, elasticity modulus, specific gravity of steel and concrete, backfill slope angle, internal friction angles, cohesion of soil, safety factors for overturning, sliding and bearing, range of stem, heel projection and base thickness, range of diameter of reinforcement bars. Also, population size of class and maximum iteration number (stopping criteria) is defined.

2nd step: Initial solution matrix (class) is constructed by using vectors as much as population size. This vectors contain randomly generated values of design variables. In addition to design variables related with cross sectional dimension of retaining wall (see Fig. 1), there are also variables related with RC design (diameter and spacing of reinforcing bars of stem, toe and heel).

During the design there are 29 design constraints that must be provided by each solution vector. Some of these constraints are related with safety (overturning stability, sliding stability and bearing capacity) of retaining wall and the other ones are related with RC design (minimum bearing stress, flexural strength capacity of sections, shear strength capacity, minimum and maximum reinforcement areas, minimum and maximum bar spacing and development length of reinforcement bars) described in ACI 318-05 code.

Fig 1. Design variables of a cantilever retaining wall model

Fig 1. Cross section and forces acting on a typical cantilever retaining wall can be seen in Fig. 1.

3rd step: Then, the step named teacher phase is begun. After assigning the best vector in mean of minimum objective (weight) as teacher (see Eq. 1), new solution vectors (from i=1 to population size) are created according to Eq. (2)

\[ X_{\text{teacher}} = X_{\text{min},i} \] (1)

\[ X_{\text{new},i} = X_{\text{old},i} + \text{rnd} \cdot (X_{\text{teacher}} - T \cdot X_{\text{mean}}) \] (2)
in which \( rnd \) is random number between \((0, 1)\), \( T_F \) is teaching factor (Eq. 3), \( X_{\text{mean}} \) is mean of the design variables, \( X_{\text{old},i} \) is previous value of design variable and \( X_{\text{new},i} \) is the new value of variable.

\[
T_F = \text{round} \left[ 1 + \text{rnd} \left( 0.1 \right) \right] \rightarrow \{ 1 - 2 \} \quad (3)
\]

If the new solution is better than the old one, the new solution is accepted.

4th step: After updating vector in teacher phase, learner phase rules (see Eq. 4) is applied to solution vectors.

\[
X_{\text{new},i} = \begin{cases} 
X_{\text{old},i} + r_i (X_i - X_j); & f(X_i) > f(X_j) \\
X_{\text{old},i} + r_i (X_i - X_j); & f(X_i) < f(X_j)
\end{cases} \quad (4)
\]

In Eq. 4, \( X_i \) and \( X_j \) are randomly selected learners. In this selection the learner must be different from each other. As it done teacher phase, new and old solution is compared and better one is accepted.

5th step: Maximum iteration number is controlled. If it is satisfied the process is stopped if not the process is continue from 3rd step.

Whole optimization process can be seen in flowchart given in Fig. 3.

### 3 Numerical Examples

As numerical example, TLBO algorithm is performed on a retaining wall example and the results are compared with BBBC, PSO and IHS approaches. In the numerical example height of stem is 3 m, yield strength of steel is 400 MPa, compressive strength of concrete is 25 MPa, Elasticity modulus of steel is 200 GPa, specific
gravity of steel and concrete are 7.85 t/m$^3$ and 23.5 kN/m$^3$, respectively, unit material costs are 40 $/m^3$ and 400 $/t$ for concrete and steel, respectively, backfill slope angle is 10°, internal friction angle is 30°, cohesion of base soil is 125 kPa, safety factors for overturning and sliding is 1.5 and for bearing is 3, range of stem and slab thickness is between 0.2 - 3 m, range of heel and toe projection is between is 0.2 - 10 m, range of all diameter of reinforcement bars is between 16 - 50 mm.

The comparative analyses results for internal friction angle (from 18° to 35°) and surcharge load (0 kN to 50 kN) is given in Figs. 4-7. In figures, both average weight and minimum weight values for retaining wall is presented.

4 Conclusion

In this paper, optimum design of cantilever RC retaining wall is presented. In order to investigate strengths and weaknesses of the proposed method analyses results are compared with PSO, BBBC and IHS algorithms.

According to analyses results although approximately the same minimum weight values are obtained for all approaches, the best average weight values are obtained with present approach. Especially, in some analyses of other approaches average weight value is more than two times of minimum weight. This means, robustness of the TLBO algorithm is better than other approaches. The same conclusion can be also observed from Fig. 8 that correspond standard deviation value for 100 independent run given. Consequently, TLBO algorithm seems effective, robust and powerful method for optimum design of cantilever RC retaining walls.
Fig 8. Standard deviation vs. surcharge load plot

References:


