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Numerical Analysis of Density Rate by Trihedral Roller in Embankment Dams

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ABSTRACT

Impact rollers are used in different parts of the world such as Australia and South Africa to improve soil properties. Due to the high depth impact of this roller compared with vibratory rollers, this type of roller is used in dam construction to compress and reduce the permeability of soil and create an impermeable layer, reduced water losses. Given the importance of constructing embankment dams, using this technology can be an effective way to increase storage efficiency. In this study, numerical analysis of density rate was done using a trihedral impact roller. ABAQUS software in a two-dimensional model and the plane strain were selected as the proper model due to responses closer to the experimental results. The results showed that the distribution of cavity pressure at the impact area of the roller has many changes, and these changes reduce in the soil depth, reaching to an almost constant rate.

INTRODUCTION

The density of thick layers of soil in the embankment dams could lead to improved treatment of these dams. Experimental results have shown that the depth effect of vibratory rollers is less than 1 m, and the improved depth by them occurs in the range of 0.5 meter. Therefore, using the impact mechanism in the roller rather than vibration can achieve a higher depth effect. One of the newest tools to perform impact compression is the impact roller that has different types, including three, four, six and eight-sided or octagon rollers. One of the special applications of impact roller is to compact industrial waste such as cement dust, waste, disposable coal waste of the coal mines and industrial wastes (Scott and Suto, 2007). Figure 1 shows an example of such an application.

Because of the small size and ease of movement of the roller with conventional tractors, the roller is capable of covering a larger area in low time. In 1949, for the deep compaction issues that the ministry of roads faced with at that time, Clegg and Brinjes developed the first 7-ton impact roller, and patented the invention in 1959. In the mid-1970s, the first tetrahedron roller similar to its modern form was produced (Avaleh and Carter, 2005). In 1998, Humphries et al. described the 3-, 4- and pentahedron rollers as right tools to improve rice fields with high permeability through field experiments. They described the soil moisture rate as a significant factor at the time of compressing with the roller, and examined the effect of soil structure in the field impact compression as well. They reported that in some cases, even after 3 to 6 passages of the roller, the leak in the soil has been stopped. In 2004, Avaleh investigated the effect of tetrahedron (tetragonal) impact roller on reducing the leakage of water tanks in Australian cotton fields and reducing soil permeability of silty clay dikes based on leakage control experiments, and described the roller very effective. In 2014, Nohani and Mirzaee studied the effective stress distribution in the compaction of embankment dams caused by trihedral impact rollers and concluded that the maximum stress occurs at the roller impact site. In this study, we performed the numerical analysis of compression (density) rate by trihedral impact rollers in embankment dams.

MATERIALS AND METHODS

Application of the finite element method in analysis of the structures enables the designer to find the stress, vibrations and temperature change problems during the designing process and evaluate the changes needed in the design before making the first experimental prototype.

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Thus, assured, ensuring the acceptance of the first laboratory prototype will be achieved in this way. There are two general computing methods of problems solving by finite element method. One of these methods is the use of huge commercial applications that many of them have been simplified to run on personal computers. These multi-purpose programs are used to solve various problems. Alternatively, short programs with specific purposes have been developed to solve the relevant problems. The ABAQUS software was used in this study. The ABAQUS software was first presented in 1978 for solving complex and nonlinear engineering problems in applications of nuclear energy and drilling engineering. The latest provided version of the software, version 6.12, is now known as the world’s strongest and most complete package of finite element analysis in most branches of science and engineering, and is widely used. The equations of the model are given so that through familiarity with the variables affecting the relations, the effects of the variables and the effect of simplifying on equations can be considered.

Governing equations for the modeling roller impact on soil:

$$M \ddot{u} + C(\alpha, \beta) \dot{u} + Ku = F(t)$$  \hspace{1cm} (1)

That in this equation, M is soil mass; C the soil amortization; $K$ soil hardness; $u$ soil shift, $\dot{u}$ soil velocity, $\ddot{u}$ soil acceleration and $F(t)$ loading exerted by the roller on the soils and variable with time.

The boundary conditions of this equation are also as follows:

$\alpha = 0.1; \beta = 0$ that are riley attenuation coefficients. M is obtained by multiplying the density of the soil in the soil volume. $K$ is obtained by integrating the matrix $B$ so that:

$$K = \int B^T DB.$$
RESULTS AND DISCUSSION

After simulation of the impact roller by software through applying different conditions, the outputs were presented and analyzed. Figure 4 shows the strain distribution in the soil.

![Figure 4: Distribution of strain in the soil](image)

As seen in Figure 4, the greatest strain occurs in the roller impact site, and the strain decreases in the soil depth. Figure 5 shows the distribution of cavity pressure.

![Figure 5: Distribution of cavity pressure in soil depth obtained from the numerical model](image)

As seen in Figure 5, the distribution of cavity pressure at the roller impact area has great changes, and the changes reduce in the depth of soil and reach an almost constant value.

To ensure the accuracy of two-dimensional modeling, the trigonal and tetragonal rollers were also modeled both in the three-dimensional mode. The results of three-dimensional models were similar to the two-dimensional case regarding soil subsidence and the effect depth. Therefore, the results in three-dimensional states were not again mentioned. Figures 6 and 7 show the 3D models of these rollers.

![Figure 6: Three-dimensional model of trihedral roller](image)

![Figure 7: Three-dimensional model of tetrahedron roller](image)

For further identification of the trihedral roller behavior and its effects on soil under the roller compaction, the high-changed parameters were studied:

1. Lower soil density
2. Roller weight
3. Impact speed
4. Roller and soil interaction

To study the effect of lower soil density on the response of the model, the soil density was changed in three states of 1000, 1400 and 1800 kg per cubic meter, while other parameters were kept constant. The results of these changes are given in Figure 8 based on the improvement depth.

![Figure 8: Effect of lower soil density of the lower on improved depth](image)
As can be seen in Figure 8, with increasing soil density, the improved depth has reduced. This indicates that the effect of impact roller on loose soils is much more than the hard soils. Soil density increased from 1000 to 1400 kg per cubic meter caused a 35% reduction in improved depth, and increased soil density from 1400 to 1800 kilograms per cubic meter led to a 28% reduction in improved depth. This result indicates that with larger increase in soil density, the descending changes of improved will also decrease and tend to a constant value. To investigate the effect of roller weight on the model response, the weight of roller was changed in three cases of 8 tons, 10 tons and 12 tons, while other parameters were kept fixed. These changes are given in Figure 9 based on the improved depth.

CONCLUSION

The numerical ABAQUS model was used in this study to simulate the trihedral roller to determine the density rate. The results showed good capabilities of ABAQUS software for modeling the movement and compaction of soil by the roller. Also, with increased roller weight, the improved depth highly increased. Increased roller weight from 8 tons to 10 tons caused a 61% increase in the improved depth, and increased roller weight from 10 tons to 12 tons of weight caused a 22% increase in the improved depth. Soil density increased from 1000 to 1400 kg per cubic meter caused a 35% reduction in improved depth, and increased soil density from 1400 to 1800 kilograms per cubic meter led to a 28% reduction in improved depth. The highest strain occurs at the roller impact site, and the strain decreases in the soil depth.

REFERENCES


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