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Evaluation of Reduction Factor for concrete coatings of underground structures under blast loading

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ABSTRACT: The reduction factor (R) is one of the most important parameter of loading, analyzing and designing structures subjected to dynamic loading such as earthquake and explosion. This coefficient considers the nonlinear behavior of the structure in linear analysis. Investigations show that the acceptable range for reduction factor of concrete coating of underground structures applied to explosive loading is not determined completely. To find out this factor, the tunnel structure must first be modeled numerically. The interaction between the structure and the soil and their mechanical properties should be modeled so Winkler spring was proposed. In this research, plastic hinges were introduced in the SAP2000 software, and a pushover analysis was carried out.

Outputs of this analysis result in the vertical force-displacement diagrams and their behaviors were plotted for each tunnel performance levels. The Reduction Factor is obtained for a special pattern loading of explosive charge by using the relationships which is developed in this research. It can be noted that the reduction factor for such structures depends on two parameters including ductility and strength factor.

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1- INTRODUCTION

Underground complexes are among the best options for command and control centers, public shelters, weapons depots, equipment and defense industries. The depth of the location of underground structures is determined by the importance of them and determined threat. Due to the location of these structures, reaching greater depths leads to longer access routes but increase construction costs. Accordingly, loading, analyzing and designing these defensive structures are very important. One of the most important features of these structures is their nonlinear behavior when applying dynamic loading such as explosion. The reduction factor actually influences the nonlinear behavior of the structure in linear analysis.

In this paper, the blast loading of underground structures considering the amount of explosives and the blast center distance as fixed parameters. The bed hardness, rock mass continuity and different performance levels affects significantly on determining the structural reduction factor. Complementing this coefficient, linear analysis can be used instead of the conventional time-consuming and complex nonlinear analyzes.

In software SAP2000, Winkler springs are used to model the soil that confined tunnel, which was assumpted spring resistance as soil equivalent parameters. Due to the compressive and shear hardness of the soil, two radial and tangential springs have been used.

For loading of concrete lining, the rock loading method expressed by the Unal΄s relation is based on the RMR rock mass classification. In this study, three types of soils with three different RMRs were applied. Due to the nonlinear aspect of the pushover analysis that lack of summing the effects of the forces, first the load and the weight of the tunnel are applied to the structure and then the explosive load is applied to the structure.

2- NUMERICAL MODELING AND SIMULATION

Similar to "Fig. 1", the intended cross section for the analysis is a horseshoe-shaped tunnel, 40 cm in thickness and 800 cm in width. According to the initial analysis, the concrete cover is fitted with two rows of flexural reinforcements (rebar of 20 mm in diameter with 20 cm in two vertical rows) and the coating of 6 cm. The specification of the concrete used for the concrete coating is also given in "Table 1".

In this part, a numerical simulation of 545 kg TNT explosive caused by the penetration of a bomb to the depth of 6 m in the ground was performed on an underground structure such as "Fig.1". If the explosion center distance is 40 m from the external surface of tunnel, the values of the maximum pressure, impact and duration of the impact are obtained from using TM5-855-1 [1] equations.

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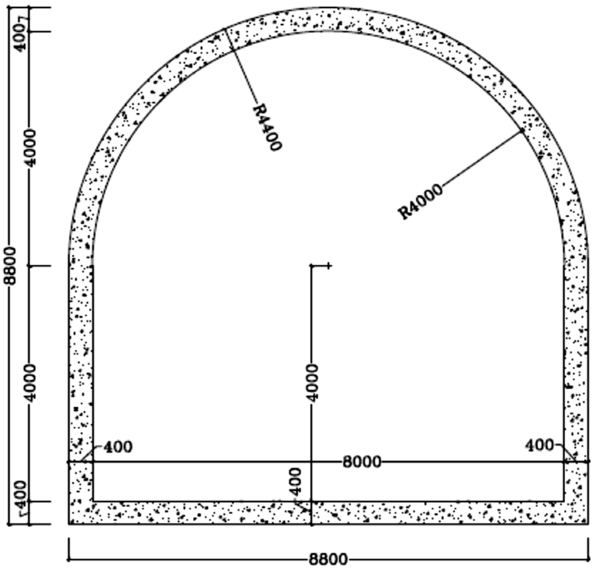

Fig. 1. Scheme of Underground tunnel geometry (dimensions are in mm)

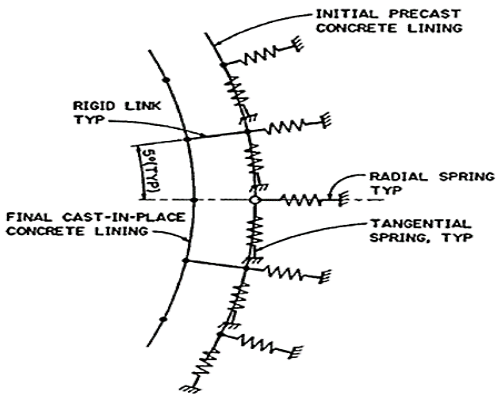

Fig. 2. How to place radial and tangential springs [3]

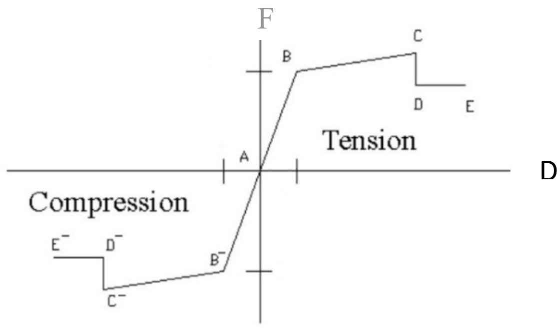

Fig. 3. General-force displacement curve for pushover analysis [4]

Table 1. Properties of concrete

Volumetric mass (kg/m3)	Poisson's ratio -	Modulus of elasticity (GP)
2600	0.2	25.6

Table 2. The values of dead loads on tunnel lining

Soil type	RMR	Vertical load (ton)	Horizontal load (ton)
1	30	30.00	12.30
	50	16.00	6.56
	70	6.88	2.82
2	30	34.00	12.88
	50	18.00	6.80
	70	7.70	3.00
3	30	37.50	12.25
	50	20.00	6.00
	70	8.60	2.60

In nonlinear static analysis the effects of gravity and explosive loads must be considered simultaneously. Explosive loading is applied to the structure by a uniform pattern after the gravity load. The Rock Mass Rating (RMR) [2] method is used to calculate the loading mechanism on the lining section. In the RMR classification, the effective height on the lining system is denoted by h and is calculated from the below "Equation. 1" [3].

$$h = \frac{100 - RMR}{RMR} B \tag{1}$$

In this relation, b is the section width. "Table 2" shows the values of loads on the structure.

"Fig.2" shows the general way of implementing these radial and tangential springs.

"Fig.3" shows the general curve used for pushover analysis. Depending on the coordinates of the characteristic points, this curve can be formulated for any shapes.

Considering three levels of performance (immediate operation (IO), life safety (LS) and collapse prevention (CP)), these three levels were also considered in results. "Fig.4" shows the arrangement of these surfaces for the primary and secondary members.

Finally, Reduction factor is proposed in the ATC-19 "Equation 2".Where R_s is the period-dependent strength factor, Rμ is the period-dependent ductility factor and RR is the redundancy factor [6].

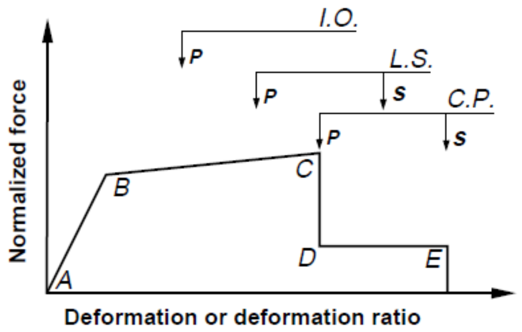

Fig. 4. Three performance levels 5. Reduction factor values with different cases

3- RESULTS AND DISCUSSION

As a result, the value of RR is unit, so the values of Rμ and Rs are multiplied with each other and finally the reduction factor will be obtained. "Fig.5" shows the values of the reduction factor for all the mentioned cases in this study.

4- CONCLUSIONS

In this study, the reduction factor was calculated for the tunnel under blast loading by generalizing the relationships been in the codes to determine coefficient. 27 reduction factors were obtained with different types of boundary condition, soil and performance level. The following conclusion can be drawn based on the numerical results:

– The period of underground structures in this study has an average of 0.03 seconds. The ratio of the dynamic load duration to the average period of the structure is about 12 times, so the structure can deform considerably.

– The average reduction factor of these structures is about 3.19.

– The coefficient of strength of the structure decreases with increasing hardness of the soil and its average amount for the proposed states is 2.44.

– The reduction coefficient due to ductility has a mean value of 1.3 for all cases.

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