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Analysis of the Effect of Buried Explosive Loading on Underground Reinforced Concrete Structures

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ABSTRACT: Nowdays, for the designing of underground structures in addition to common loads such as earthquakes, explosives loading is considered. Most of these structures around the world are constructed in a safe depth in the soil. The depth of earth where underground structure under explosive forces does not receive damage, called "safe". The depth in design and construction of underground structures for use more of the anchor properties of the soil around the structure and minimize the structural weight and also using the damping properties of the soil to reduce the shock wave caused by the explosion of the exact penetrating weapons. Usually explosive loading of these structures is based on the relations and procedures from theoretical and experimental research. Also the numerical methods and using finite element softwares to calculate the explosion load of these structures has been prevalent. In this study the effects of buried explosion on a reinforced concrete underground structure is investigated numerically and analytically. The numerical simulation was carried out using finite element software AUTODYN. In order to analyze the how to explosive loading and underground structure response, the effect of weight of explosive and buried depth of structures was investigated. Additionally, numerical results with relations that presented in reliable scientific resources and US instructions for designing this type of structures were compared. Finally, according to the results of research, in order to improve the designing of these structures under explosion loading in soil, it's suggested that the incremental factor doesn't apply to such loads.

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1- Introduction

Today, due to the increasing military and terrorist threats in the world, explosions loading is also considered for designing underground structures in addition to common loads such as earthquakes.

Most underground structures around the world are built at a safe depth within the soil. Depth of soil that is not affected by underground structures under the influence of explosive forces is referred to safely depth.

The reason for using depth of soil in designing and constructing underground structures is to get more and more benefits from the soil retention properties around the structure and minimize the weight of the structure, as well as the use of soil damping property to reduce the amplitude of the shock wave resulting from the explosion of accurate penetrating weaponry. Explosion loading of this kind of structures is usually based on the relationship between theoretical and empirical research.

At present, the most important explosion loading available reference for engineers are the United States patent application (TM5-1300) for explosion loading of all structures and (TM5-855-1) in underground structures loading. In the present study, the results of the numerical analysis have been compared with the experimental relations of the handbook (TM5-855-1) [1]. Also, in this research, the results of the research by Smith and Hetherington have been used to obtain ground shock parameters [2].

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2- Definitions

In this section, an explosion loading of an underground structure and its governing relationships are presented. Some of the important relations of ground shock parameters that identified by Smith are listed in Table 1.

Table 1. Ground shock parameters [2]

Parameters	Relation	
Pressure	$P_o = \rho \times C \times u_o$	(1)
PV	$u_o = 48.8 f \left(\frac{2.52R}{W^{1/3}} \right)^{-n}$	(2)
pressure-time function	$P(t) = P_0 e^{-t/t_a}$	(3)

3- Numerical modeling

The underground structure studied under the effect of the explosion inside the soil was a 3D simulation by AUTODYN which is a workbench of ANSYS finite element software that used specially for explosion and affection phenomenon [3]. Figure 1 is the reinforced concrete underground structure modeled on AUTODYN.

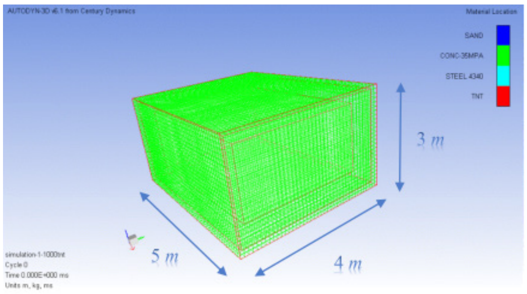

Figure 1. The reinforced concrete underground structure modeled on AUTODYN

The geometric model includes reinforced concrete underground structure, soil sand as an explosion-wave propagation environment, and TNT as an unprotected explosive charge. Some characteristics of the behavioral equations of materials in modeling are presented in Table 2.

Table 2. Characteristics of the behavioral equations of modeling materials

Model components	Type of Materials	Density (kg/m^3)	EOS	Resistance Model
Structure	Conc35	27500	P-Alpha	RHT-Concrete
	Steel 4340	78300	Linear	Johnson-Cook
Soil	Sand	2641	Compaction	MO-Granular
Explosive	TNT	16300	JWL	-

4- Verification check

In this section, in order to verify the validity of the numerical results obtained from AUTODYN, the peak of pressure (Po) and particle velocity (PPV) values obtained from software with the results (TM5-855-1) and Smith's relations are investigated.

According to a parametric analysis, between numerical outputs and Smith and (TM5-855-1) results, AUTODYN results is acceptable in analyzing the effects of shock ground of explosion.

5- Simulation and analysis

This section explains the results of numerical models, the explosion loading on reinforced concrete underground structure (RCUS) modeled under buried explosion was investigated. For this purpose, the results of numerical modeling of a RCUS in 10 to 40 meters' depths from the surface, are affected by 500 kg of TNT explosive that penetrates all models to a constant depth of 6 meters, with the results of (TM5-855-1).

The Table 3 relates to the results of the numerical method of the RCUS in which ceiling and walls that receive the highest load values like what you see in Figure 2.

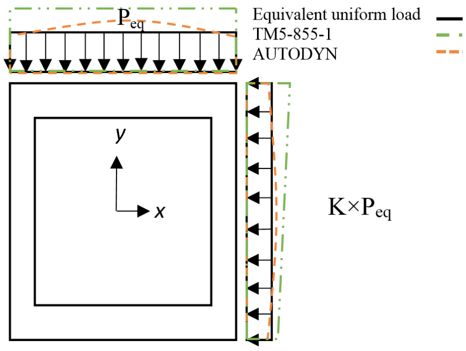

Figure 2. Comparison of explosion loading of RCUS in numerical method and (TM5-855-1)

Table 3. The Results of loading underground structures under buried explosion with 500 kg TNT

Numerical Model	Structural burial depth (m)	AUTODYN Loading (N)		TM5-855-1 Loading (N)	
		funds	Ceiling	funds	Ceiling
1	10	1600	2600	1772	4200
2	20	94	145	100	225
3	30	25.9	36.5	27.5	52
4	40	11.9	15.2	12.6	22

According to the results, it can be clearly seen that the results of the (TM5-855-1) for loading on this structure are conservative. Consequently, the results of loading on the ceiling without applying the coefficient factor (1.5P) of (TM5-855-1) were corrected and according to Table 4, the results have a better match with the numerical study.

Table 4. The Results of loading underground structures under buried explosion without coefficient factor

Numerical Model	Structural burial depth (m)	AUTODYN Loading (N)	TM5-855-1 Loading (N)
		Ceiling	Ceiling
1	10	2600	2800
2	20	145	150
3	30	36.5	35
4	40	15.2	15

6- Results and Discussion

According to the results obtained for the loading on the roof of RCUS, it was observed that the values of the regulation are conservative in comparison to the other two methods, so it is suggested in the designs in accordance with the instruction (TM5-855-1) the incremental factor is not applied to explosion loading this structures.

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