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Investigating the Effects of Remapping Method in Explosion

Patlamada Yeniden Eşleme Yönteminin Etkilerinin Araştırılması

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ABSTRACT

Using real explosives to detect explosion effects is a difficult and impractical method due to its danger and cost. Performing numerical analyses based on previously conducted experimental studies allows for the diversification of studies on this subject. Since the elaboration of numerical analyses causes an increase in the amount of processing, it requires the devices that need to perform these operations to be very advanced. It is an important optimization that the solutions are shorter and closer to reality, and this can be done with the remapping method. With this method, the explosion loads obtained from 1D analysis can be integrated into 2D and 3D analyses with certain methods, and the duration of these analyses is reduced and their accuracy is increased. Within the scope of this study, the methods and approaches for the application of remapping technique are explained. As a result of this study, it will help those who want to perform explosion simulations to obtain more accurate results in a shorter time with less processing power, and it will pave the way for many scientific studies to be carried out.

Key Words

Numerical analysis, AUTODYN, remapping, explosion, blast.

ÖZ

Patlama etkilerinin tespitinde gerçek patlayıcıların kullanılması pek çok açıdan mümkün olmamaktadır. Daha önce yapılmış deneysel çalışmalar temel alınarak sayısal analizlerin yapılması bu konudaki çalışmaların çeşitlenmesine olanak sağlamaktadır. Sayısal analizlerin detaylanması, işlem miktarının artmasına sebep olduğundan, bu işlemleri yapması gereken cihazların çok gelişmiş olmasını gerektirmektedir. Çözümlerin daha kısa sürelerde ve gerçeğe daha yakın olması önemli bir optimizasyondur ve bu remapping (yeniden eşleme) yöntemi ile yapılabilmektir. Bu yöntem ile 1D analizden elde edilen patlama yükleri 2D ve 3D analizlere belirli yöntemlerle entegre edilebilmekte ve bu analizlerin süreleri azalmakta, doğruluğu artmaktadır. Bu çalışma kapsamında, remapping tekniğinin uygulanmasına yönelik yöntem ve yaklaşımlar açıklanmıştır. Bu çalışma neticesinde patlama simülasyonu yapmak isteyenlerin daha az işlem gücü ile daha doğru sonuçlar almasının yardımcı olacak ve pek çok bilimsel çalışmanın yapılabilir olmasın katkı sağlayacaktır.

Anahtar Kelimeler

Sayısal analiz, AUTODYN, remapping, patlama, patlama dalgası.

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INTRODUCTION

When an explosion occurs, some results occur. Detection of the effects resulting from the explosion can be of critical importance for many situations. Because the effects of the explosion can cause high destruction. Conducting tests with real explosives is a method for detecting explosion effects, but such tests are both very costly and subject to many permit procedures. Since such tests are costly and require high-tech products for measurement, it is not possible to verify the same tests by repeating them or to conduct separate tests for different situations. There are some experimental studies conducted from the Second World War to the present [1]. Some of them are state-supported and quite comprehensive. Some are experiments that observe more limited situations for the detection of special situations. These experiments have become even more valuable today because with the advancement of technology, explosion experiments can be simulated in a computer environment, and these numerous analyzes can be verified with these experimental results. With numerical analyzes, many different tests can be performed in a short time and useful outputs are obtained [2]. The verification of the results obtained from these simulations is possible by comparing them with experimental data. In many academic studies, the results obtained from these experiments have been used to verify numerical analyses.

Although simulations provide more practical and faster solutions than explosion experiments, very high-capacity computers and long periods of time may be required to solve some complex analyses. Such delays may disrupt studies or make them inaccessible. For this reason, methods have been developed that can use computers with lower specifications and allow faster analyses. One of these methods is the Remapping method, which can also be used in the AUTODYN program. Remapping application, 1D analysis is created with very small meshes and the resulting situation is integrated into the 2D or 3D Euler environment. The explosion situation that reaches a certain stage in 1D analysis continues in accordance with the new Euler environment to which it is integrated. [3].

When close range explosion cases are examined, the data obtained are seen to be according to spherical or hemispherical explosive shapes and the explosion point is accepted as the most central. This idealized situation should be accepted as the starting point because the explosive shape and the starting point of detonation affect the results a lot and may prevent validation. Within the scope of this study, it is assumed that the hemispherical explosives on the ground explode from their centers[4].

In the literature, it is seen that remapping analyses are performed in many different numerical analysis programs. Various verifications and comparisons of the result data and evaluation of the method have been made. T. C. Chapman et al. described the application of AUTODYN remapping method and verified the analysis results with CONWEB [2]. J. Shin et al. compared the results of remapping methods in AUTODYN and Air3D software in their study [4]. M. Johansson and his colleagues investigated the remapping method for different explosives and compared the values [5]. In the scope of our study, many different semi-empirical methods were included in the evaluation for verification. In order to support the results, numerical analysis was performed with AUTODYN and separate analyses were performed for two different environments. The reliability of the method and the application was tested with double verification. The results are quite consistent.

Methodology of Remapping at AUTODYN

Numerical analyses used as an alternative to experiments with real explosives can be performed with various package programs. One of the most widely used of these is the AUTODYN software. This software has been verified with real experiments in many scientific articles and is an application that has been used for many years. It is suitable for 1D, 2D and 3D analyses and these methods can be used together to speed up analyses and produce more accurate results.

Remapping Method

The remapping method is a widely used method for AUTODYN in the analysis of explosive effects. It is possible to obtain the behavior of the explosive with high precision and low time in 1D analysis. It is known that the mesh size is very important in the correct transfer of behavior [6]. As seen in Figure 1, even if the mesh sizes are taken very small, the total mesh number will be quite low compared to 2D and 3D analyses. And the simulation here takes a very short time to complete. In 2D and 3D analyzes, especially in air modeling, the use of small meshes greatly increases the number of meshes

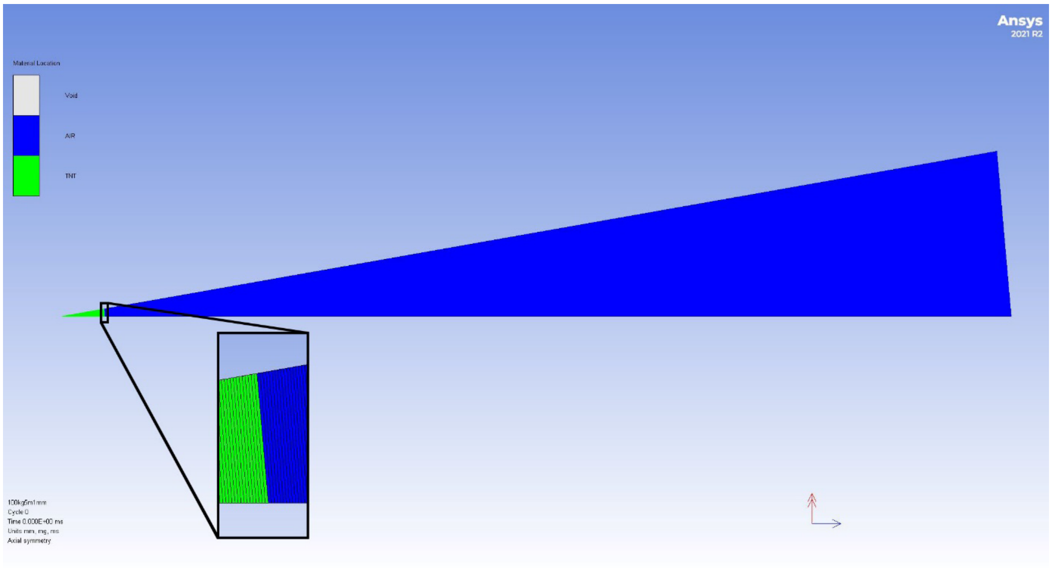

Figure 1. Very fine mesh size at 1D analysis.

and increases the analysis times [7]. The results obtained from 1D analysis are quite useful and can be used directly with remapping in 2D, 3D analyzes. This helps to shorten the duration of the analyzes. The explosion type obtained with the remapping method occurs as a global effect in the open air. In the 2D or 3D explosion environment scenarios to be analyzed, the results obtained from 1D analyzes can be used up to the limit where the explosive will behave globally.

Validation of the Remapping Method

Empirical formulas created with experimental data have different limitations in different methods, but the general approach is the mass scale application. Since the explosive effects and distance are directly related, it is seen that methods based on this relationship are developed. Since the explosive effects depend on many factors, even in repeated experiments with real explosives, the results presented by these experimental semi-empirical formulas are similar and compatible with each other, but they are not completely the same.

The meanings of the symbols used in the formulas given below are as follows:
Z= Scaled Distance
R= Distance to explosion point (m)
W= Weight of explosive TNT equivalent (kg)

Kingery-Bulmash Free Air Blast Peak Pressure Formula and Table of Constants [8,9,10]:
Blast-resistant design is primarily aimed at modeling the effects of the blast. In the United States, the United Kingdom, Australia, and many other countries, this includes the use of empirical charts such as UFC 3-340-02 (DOD 2008) developed by Kingery and Bulmash (1984) [4]. The formulas developed by this method include explosion effects such as explosion pressure amount, explosion effect time, impulse amount, and there are different data for free air explosion and semi-spherical, close-to-earth explosion scenarios. They have also managed to formulate the reflected pressure and reflected impulse values as a result of their studies. The obtained graph is shared as Figure-2. The formulas of this method for open air free explosion is below.

P_{KB}= Pressure value (kPa) resulting from open air explosion obtained by Kingery-Bulmash method

U, K0, K1, K2, C0..C8 values are certain constants and are known to be obtained from experimental data [8].

$$Z = R / W^{\frac{1}{3}} \tag{1}$$

$$U = K_0 + K_1 \times \log Z \tag{2}$$

$$P_{KB} = 10^{\left(C_0 + C_1.U + C_2.U^2 + \ldots + C_N.U^N\right)} \tag{3}$$

Table 1. Kingery-Bulmash Free Air Blast Incident Peak Overpressure Conctants [8].

Incident Peak Overpressure, Ps (Unit: kPa)			
Z	K_o	K_1	K_2
0,05~40 (Unit: $m/kg^{1/3}$)	-0,214342789141	1,35034249993	
	C_0	C_1	C_2
	2,661368669	-1,69012801396	0,00804973591951
	C_3	C_4	C_5
	0,336743114941	-0,00516226351334	-0,0809227619888
	C_6	C_7	C_8
	-0,00478507266747	0,00793030492242	0,00076884469735

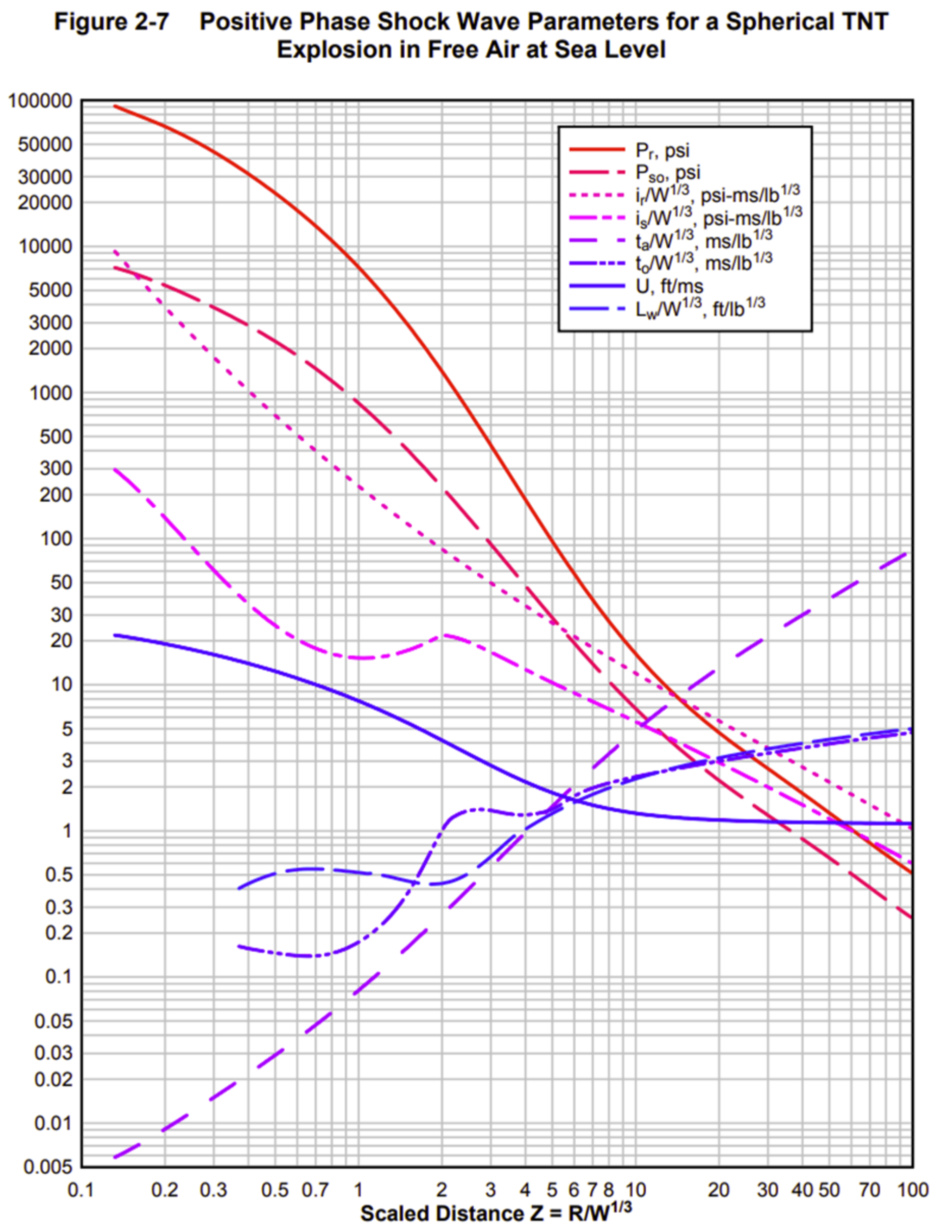

Figure 2. Kingery-Bulmash Positive phase shock wave parameters of free-air burst [11].

Heinrich Free-Field Air Explosion Peak Pressure Formula [12]:

The Henrch method is also widely used, and the data obtained from experimental data has enabled the development of an empirical formula.

P_H= Pressure value (kPa) resulting from open air explosion obtained by Henrch method (Formula 4,5,6)

$$P_H = \frac{1,379}{Z} + \frac{0,543}{Z^2} - \frac{0,035}{Z^3} + \frac{0,006}{Z^4} \qquad (0,05 \le Z \le 0,3) \qquad (4)$$

$$P_H = \frac{0,607}{Z} - \frac{0,032}{Z^2} + \frac{0,209}{Z^3} \qquad (0,3 \le Z \le 1,0) \qquad (5)$$

$$P_H = \frac{0,065}{Z} + \frac{0,397}{Z^2} + \frac{0,322}{Z^3} \qquad (1,0 \le Z \le 10,0) \qquad (6)$$

Brode Open Air Explosion Peak Pressure Formula [13]:

Brode adapted the formula for the shock wave overpressure of an infinite ideal gas by numerical simulation as follows:

P_B= Pressure value (kPa) resulting from open air explosion obtained by Brode method (Formula 7,8)

$$P_B = \frac{0,096}{Z} + \frac{0,143}{Z^2} + \frac{0,573}{Z^3} - 0,0019 \qquad (0,0098 \le Z \le 0,98) \qquad (7)$$

$$P_B = \frac{0,657}{Z^3} + 0,098 \qquad (Z \ge 0,98) \qquad (8)$$

Ruce Wang Sphere Explosive Peak Pressure Formula in Open Air [14]:

Ruce Wang's method is again based on mass scaling and has formulated the pressure of a spherical explosive open-air explosion through experiments.

PRW= Pressure value (kPa) resulting from open air explosion obtained by Ruce Wang method

$$P_{RW} = \frac{0,082}{Z} + \frac{0,26}{Z^2} + \frac{0,69}{Z^3} \qquad (Z > 0,5) \qquad (9)$$

The data obtained from the simulation is also expected to be compatible with semi-empirical experimental methods. The analyses were made for the effects of 10 kg and 100 kg TNT explosives. The purpose of verifying the two different explosive loads with semi-empirical results is to make double verification. TNT and Air material parameters from the AUTODYN library were used.

Table 2. Material Properties of TNT [15].

Material	TNT
Equation of State	JWL
Reference Density	1.630 [g/cm^3]
Parameter A	3.7377E+08 [kPa]
Parameter B	3747100E+06 [kPa]
Parameter R1	4.15
Parameter R2	0.9
Parameter W	0.35
C-J Detonation Velocity	6.9300E+03 [m/s]
C-J Energy / Unit Volume	6E+06 [kJ/m^3]
C-J Pressure	2.1E+07 [kPa]

Table 3. Material Properties of Air [15].

Material	Air
Equation of State	Ideal Gas
Reference Density	1.225E-03[g/cm^3]
Gamma	1.4
Adiabatic Constant	0
Pressure Shift	0 [kPa]
Reference Temperature	288.2 [K]
Specific Heat	717.6 [J/kgK]
Thermal Conductivity	0 [J/mKs]

Comparison Of The Results Of 1D Analyses For Remapping With Experimental Data

The analysis data are compared with the results obtained from the experimental semi-empirical methods mentioned above. These methods are Kingery-Bulmash, Henrch, Brode and Ruce Wang. The average of the results obtained from these methods is taken because the results of these methods are close to each other and have the same behavioral tendency. The reason for taking the average is to make the display of the results more understandable. The results are shared as Figure 3 and Figure 4.

The results shown in figure-3 give the peak pressure values of 10 kg explosive in the range of 1m to 6m. Since the values decrease significantly after the distance of 6m, the display of the result has been determined up to this point. The values seen in figure-4 give the values of 100 kg explosive in the range of 3m to 13m. Since there was a very close explosion before 3m for 100kg TNT, it was started with 3m since it was challenging the working boundary conditions of both semi-empirical methods and the analysis was ended with 13m since it approached the environment limit. The results obtained with smaller mesh sizes show a trend compatible with each other and with semi-empirical methods.

It is clearly seen that the results are compatible with the experimental data. It is seen that these results give different results for different mesh sizes, and it is understood that the most sensitive results are provided with 1 mm mesh. It can be said that 1 mm mesh size is sufficient for these quantities in 1D analysis.

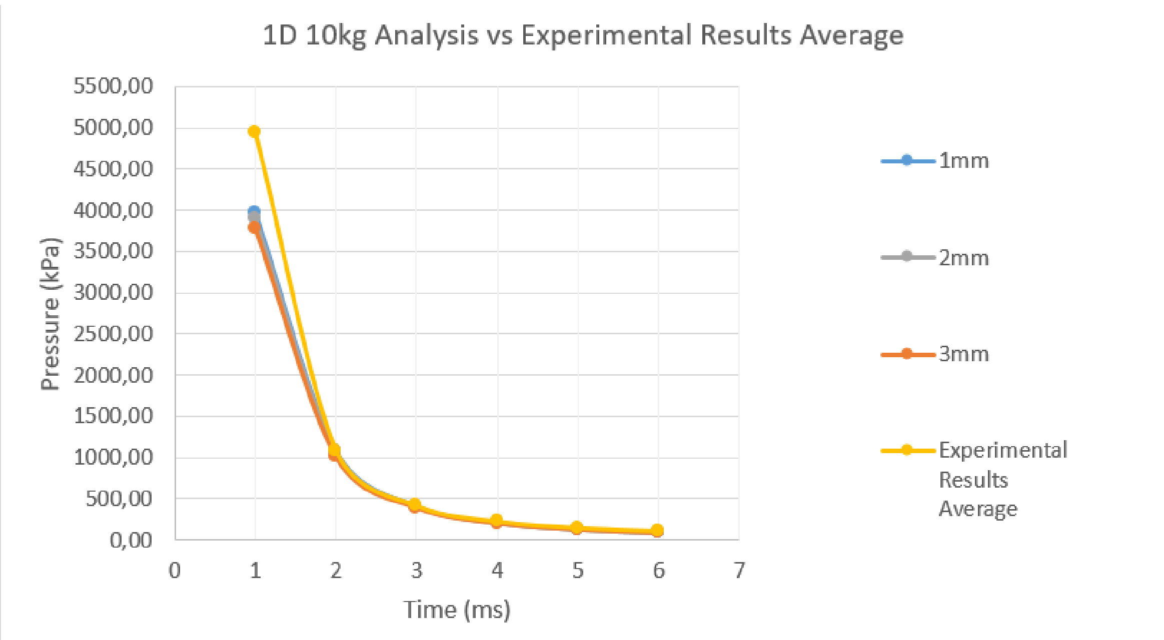

Figure 3. 1D Pressure – Time Result from 1m to 6m to 10 kg TNT.

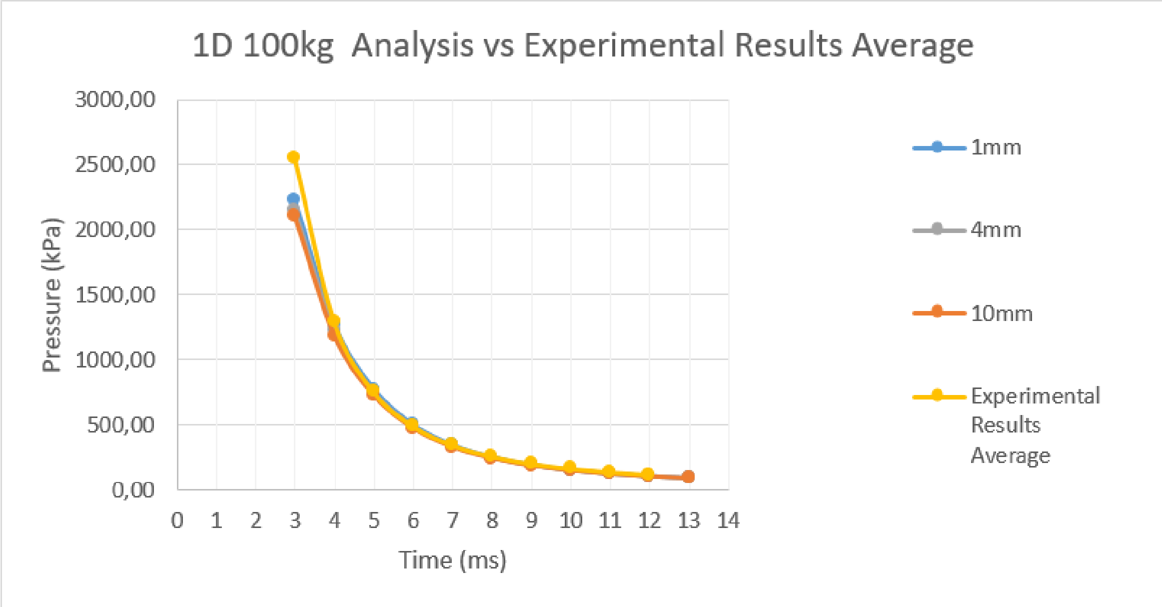

Figure 4. 1D Pressure – Time Result from 3m to 13m to 100kg TNT.

Utilizing 1D analysis in 2D analysis with the remapping method

Simulating the explosive can be done with the remapping method, as well as by modeling the geometry of the explosive itself and detonating it. Images of these two different environments are shared in Figure 5.

In case the analysis is done by directly modeling the real dimensions of the explosive, the explosive mesh size will be the same as the mesh size of the environment and will prevent the explosive, which is quite small in size compared to the environment, from having a realistic geometry. In the graph shown in Figure 6, the explosive modeled with 1 mm mesh size in 1D analysis using the Remapping method is transferred to the 20 mm mesh size environment, as well as the results of the environment where the explosive is directly modeled with 20 mm mesh sizes and the average of the experimental data. As can be seen from the data, the values are close to each other and it can be understood that the analysis using the data obtained in the remapping method is more approximate at distances close to the experimental data. It can be determined that the remapping method gives faster results as well as more accurate results.

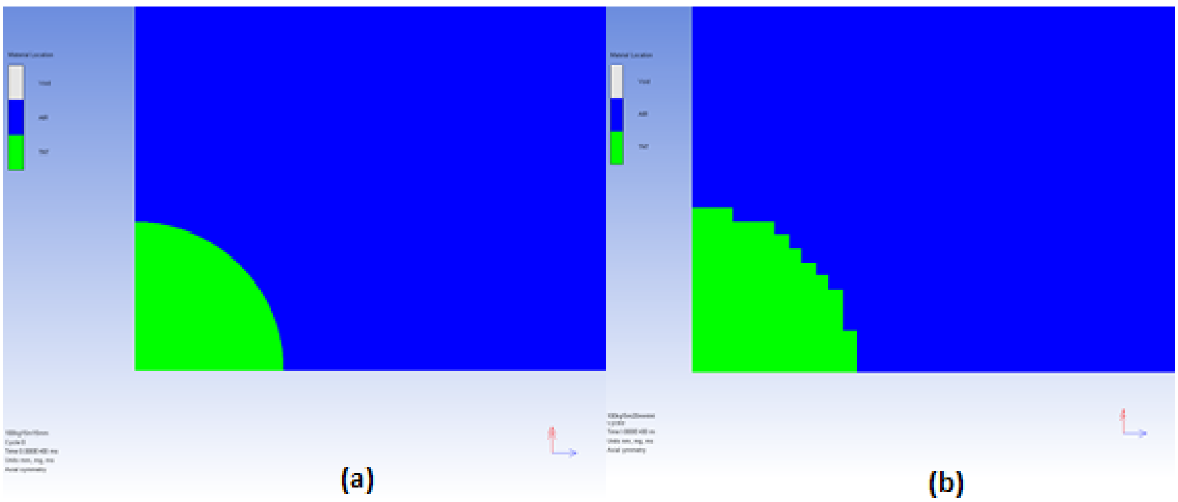

Figure 5. Appearance of explosives depending on mesh size (a) 1mm mesh from remapping, (b) 20mm mesh from air domain.

The data in the graphs are named as follows:
The graphs shown as “20mm” show the values resulting from transferring the 1mm mesh size domain in the 1D analysis to the 20mm mesh size 2D domain with the remapping method (for example: 20mm, 15mm, 10mm).

The results named as like “20mmtnt” show the analysis results where the explosive is modeled with its real dimensions within the 2D domain and both the explosive. That domain are divided into meshes with these dimensions, and the remapping method is not used (for example 20mmtnt, 10mmtnt)

In 2D analyses, the values resulting from modeling the explosion environment with 20 mm mesh were examined, and a significant increase in analysis times was observed when the explosive was modeled without using the remapping method. This analysis shows that if the mesh size used for direct modeling of the explosive in the environment was taken as 10 mm, the times increased even more. The analysis data obtained and the data obtained from the remapping method are shown in Figure 7.

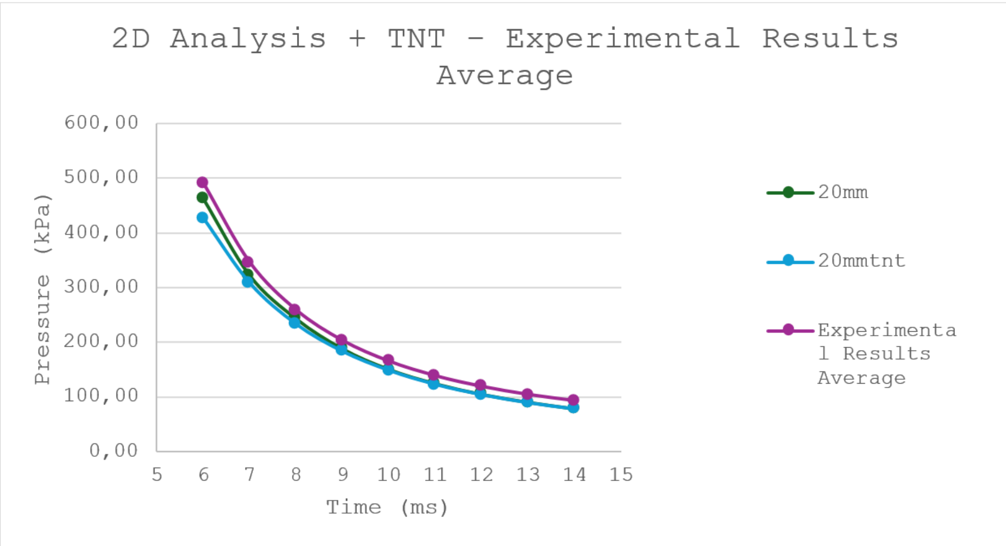

Figure 6. Pressure-time relationship as a result of the numerical analysis where remapping and direct explosive modeling were performed in 20 mm mesh air environment.

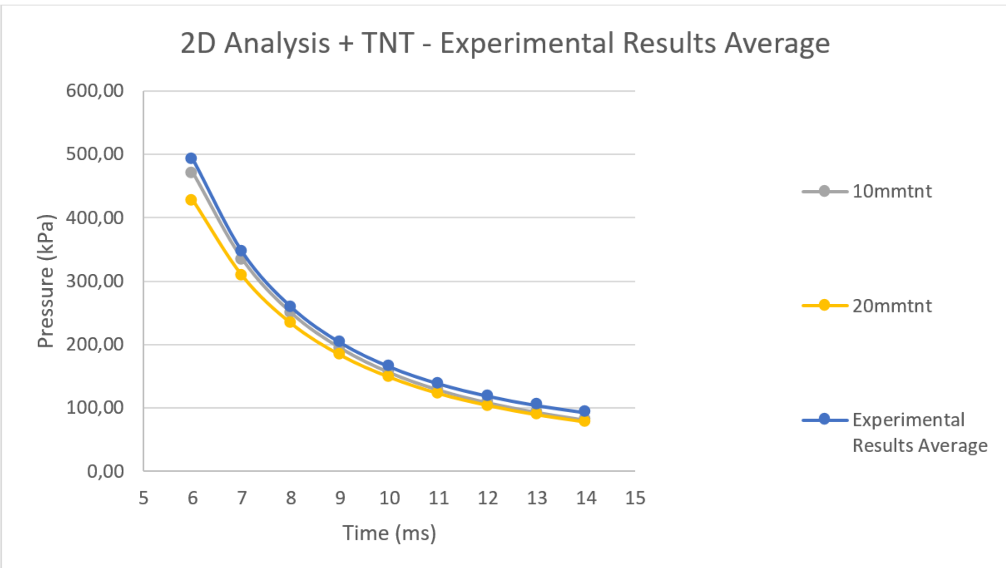

Figure 7. Pressure-time relationship as a result of the experiment carried out in 10 mm and 20 mm mesh air environment, where the explosive was directly modeled for both.

All the results obtained with the remapping method and the results obtained from the studies where the explosive was modeled in the same environment are shared in Figure 8 together with the mesh size information. The effect of using small mesh and applying the remapping method can be understood from the graph.

The main purpose of using 1D analyses with remapping is to shorten analysis times in 2D and 3D real-like environments and to ensure that the results are closer to the truth. When the obtained results are compared with the data obtained by modeling the explosive itself without remapping, it can be seen that the time and accuracy change.

For example, if the effect of an explosive on a structure such as a wall is to be examined in 2D analyses, a part of the distance between the explosive and the wall can be solved with the remapping method and the relationship between the explosive and the wall can be examined. The aim should be for the domain distance of the 1D analysis used in the remapping method to be shorter than the place where the interaction will be provided and for the interaction to occur after the analysis starts. When the analysis is designed in this way, the interaction of the explosive close to the ground with the ground is seen as seen in Figure 9. As seen in Figure 10, the explosion analysis obtained with the remapping method cannot be performed with the interaction of a barricade-like wall-like structure. As seen in Figure 11, the analysis of reflection effects on walls in closed spaces and indoor explosions can be performed in this way. Similar analyses can also be performed in 3D using the remapping method. 2D and 3D analyses have the same features in terms of the techniques and approaches used.

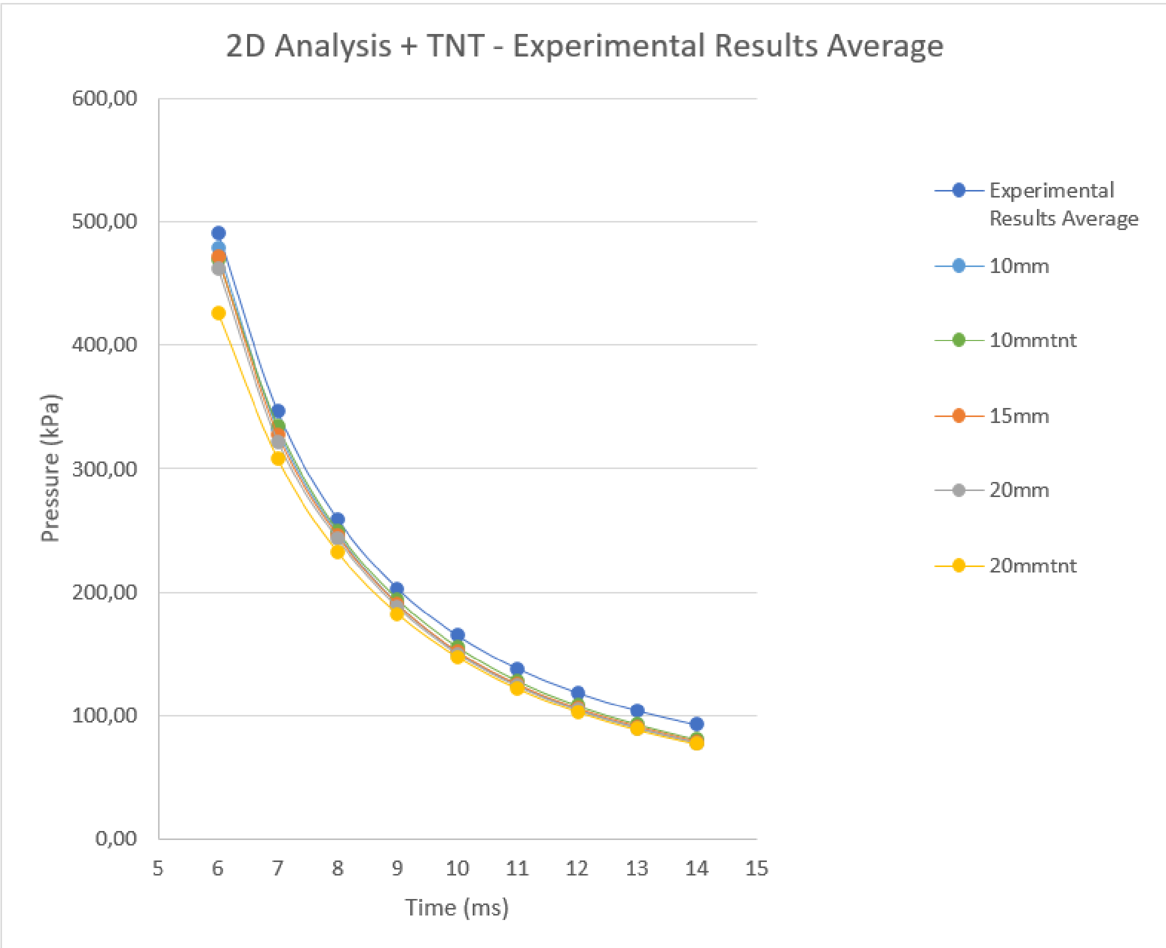

Figure 8. Pressure time graph for domains with different mesh sizes where explosives are modeled with remapping and real dimensions.

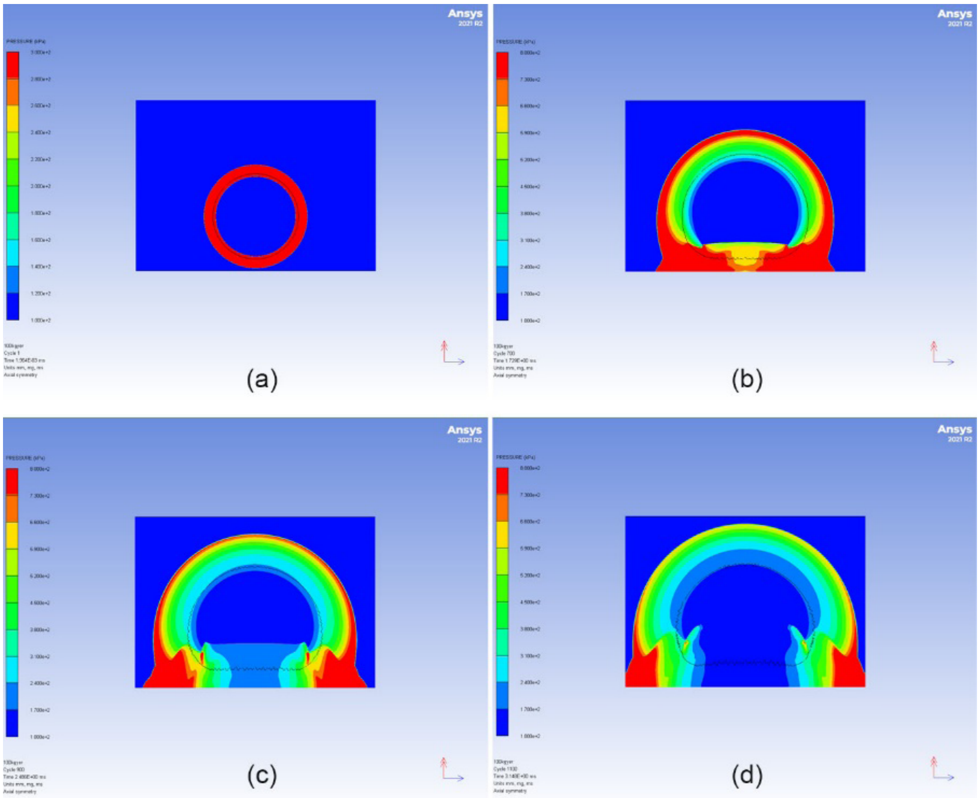

Figure 9. Sample images of near-ground explosion simulations using the remapping method.

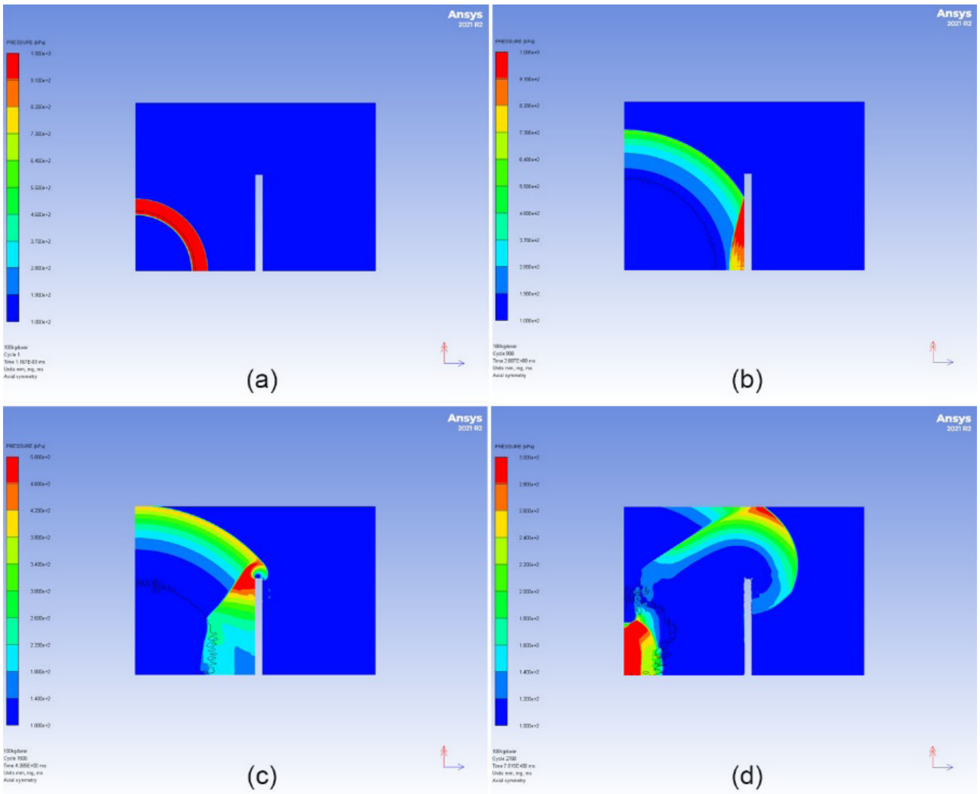

Figure 10. Sample images of the pressure wave interaction with the wall using the remapping method.

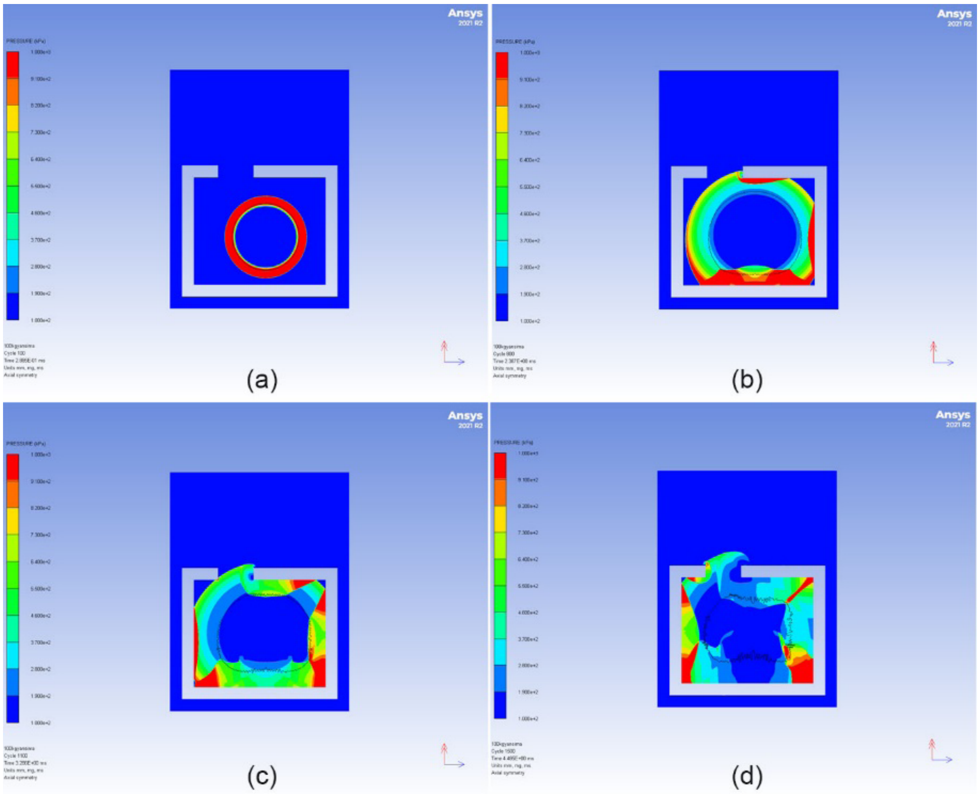

Figure 11. Sample images of the indoor explosion, multiple reflections of blast waves using remapping method.

Conclusion

Explosion experiments are quite difficult to perform using real explosives due to both occupational safety risks and procedural obstacles. For this reason, explosion analyses and behavior determination using numerical analysis methods are widely used. One application where these analyses are performed is the AUTODYN program. In order for these and similar analysis programs to provide the required accuracy, the modeled environment is expected to be close to reality. This needs to be presented in the most optimum way. As details increase, processing times increase and more advanced devices are needed. For this reason, the use of the Remapping method, which is both more realistic and requires less processing power, appears as a very useful solution. The aim of this study is to facilitate the examination of explosion effects, to help obtain effective working environments and times, and to contribute to the presentation of accurate studies. In the light of this study, it is aimed to enable other researchers to conduct studies where opportunities were previously insufficient, by obtaining results that are quite close to the truth.

In the study, different analyses were performed using different amounts of explosives. These analyses were repeated with and without the remapping method. The results obtained were compared with the averages of the data obtained from different semi-empirical methods. It was concluded that the results obtained with the remapping method gave more accurate results than those obtained with semi-empirical methods for two different experimental environments.

References

1. A. Tya, J. Warren, T. Bennett, S. Fay, Prediction of clearing effects in far-field blast loading of finite targets. Shock Waves., 21. (2011) 111-119.
2. T.C. Chapman, T.A. Rose, P.D. Smith, Blast wave simulation using AUTODYN2D: A Parametric Study, International Journal of Impact Engineering, Volume 16, Issues 5–6, (1995) 777-787, ISSN 0734-743X, https://doi.org/10.1016/0734-743X(95)00012-Y.
3. D. Si, Z. Pan, H. Zhang, Determination method of mesh size for numerical simulation of blast load in near-ground detonation, Defence Technology, Volume 38 (2024) 111-125, ISSN 2214-9147, https://doi.org/10.1016/j.dt.2023.08.004.
4. J. Shin, A. Whittaker, A. Aref, D. Cormie, Air-blast effects on civil structures. Multidisciplinary Center for Earthquake Engineering Research, State University of New York, Buffalo, New York, (2014).

5. M. Johansson, O. Larsen, L. Laine, Explosion at an intersection in an Urban Environment–Experiments and analyses. SAVIAC 78th Shock and Vibration Symposium, Philadelphia, PA, (2007).
6. Z. Xue, S. Li, C. Xin, L.Shi, H. Wu, Modeling of the whole process of shock wave overpressure of free-field air explosion, Defence Technology, Volume 15, Issue 5, (2019) 815-820, ISSN 2214-9147, https://doi.org/10.1016/j.dt.2019.04.014.
7. A. Karla, F. Zhu, K. H. Yang, A. I. King, Key Parameters in Blast Modeling Using 2D to 3D ALE Mapping Technique, 13th International LS-DYNA Users Conference, Wayne State University, Detroit, MI USA (2014).
8. D. Jeon, K. Kim, S. Han, Modified Equation of Shock Wave Parameters. Computation. 5. 41. (2017).
9. C.N. Kingery, G. Bulmash, Airblast parameters from TNT spherical air burst and hemispherical surface burst. U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, (1984).
10. International Ammunition Technical Guideline. Formulae for Ammunition Management 01.80. (2017).
11. United States Department of Defense (U.S DoD). Structures to Resist the Effects of Accidental Explosions; Report to Army Armament Research and Development Command; United States Department of Defense: Arlington County, VA, USA, (2008) Volume 4
12. J. Henrych, The Dynamics of explosion and its use. Amsterdam and New York: Elsevier Scientific Publishing Company, (1979).
13. H. Brode, Numerical solutions of spherical blast wave. J Appl Phys (1955) 26(6): 766e75.
14. W. Ruce, G. Zhao, Terminal effect of projectile. Bei Jing: Bei Jing Institute of Technology Press (1993).
15. AUTODYN®, software for non-linear dynamics, proprietary to Century Dynamics. (1985-2006).
16. W. E. Baker, Explosions in air. Austin: University of Texas Press (1973).
17. G.F. Kinney, K.J. Graham, Explosive Shocks in the Air, Second edition. Springer-Verlag, Berlin. 1985.
18. J. Hetherington, P. Smith, Blast and Ballistic Loading of Structures (1st ed.). CRC Press. 1994.