ISSN: 2710-0723

Research on Protective Effect of Lead Buffer Device under Explosion Load

Zhongkang Zhao, Xiaosheng Song

Frontiers in Sustainable Development, North China University of Technology, Tangshan 063210, China

Abstract

In modern society, the frequency of explosion accidents is gradually increasing, which brings a great threat to the safety of people's lives and property and social stability. Explosive loads are extremely destructive, with huge energy and powerful impact force released in an instant, capable of causing serious damage to buildings and infrastructure. Therefore, it is of great practical significance to study explosion protection measures in depth and improve the damage resistance of buildings and infrastructure under explosion loads. The traditional underground dispersed layer can reduce the impact of blast load on the structure to a certain extent, but with the continuous improvement of protection requirements, its limitations are gradually revealed. For example, the protection of underground dispersed layers may be less than ideal in some complex explosion situations, and their performance is susceptible to environmental factors such as salinity, consolidation, precipitation and ice, resulting in reduced protection effectiveness. In order to find a more effective solution for explosion protection, the idea of replacing the underground dispersion layer with lead dampers was proposed. As a new type of protective device, lead damper has unique advantages. Lead has good plastic deformation ability, and can absorb a large amount of energy through its own deformation under the action of explosion load, so as to effectively reduce the impact of explosion on the structure. In addition, lead dampers can be customized to meet specific engineering needs, allowing them to better adapt to different explosion scenarios and structural types. The purpose of this study is to further investigate the protective effect of lead dampers instead of underground dispersed layers under blast loads. Through a combination of theoretical analysis, numerical simulation and experimental research, the performance of the lead damper is comprehensively evaluated, and its response mechanism under blast load is analyzed, as well as the advantages and disadvantages compared with the underground dispersed layer. At the same time, the influence of the design parameters of the lead damper on the protection effect will be studied, so as to provide scientific basis and guidance for its application in practical engineering. Through this study, it is expected to provide a new and more effective means of protection for explosion protection engineering, and improve the safety and reliability of buildings and infrastructure under explosion loads. This will not only help reduce the losses caused by explosion accidents and ensure the safety of people's lives and property, but also contribute to the stability and sustainable development of society.

Keywords

Explosion Load; Protective Effect; Lead Buffer Device; Underground Dispersed Layer; Layered Protection Structure; Supporting Structure.

ISSN: 2710-0723

1. Significance of Topic Selection:

Explosive loads are highly destructive and can cause serious damage to buildings and infrastructure, even endangering people's lives. Therefore, it is of vital practical significance to conduct in-depth research on explosion protection measures to mitigate their hazards.

Although the traditional underground dispersed layer has a certain role in explosion protection, it has many limitations. For example, its protective effect is unstable and susceptible to environmental factors such as salinity, consolidation, precipitation and ice, resulting in a decrease in protective performance. In addition, the underground dispersed layer may not be able to effectively disperse and absorb the explosion energy in some complex explosion situations, and it is difficult to meet the higher requirements of modern engineering for explosion protection.

As a new type of protective device, lead dampers show unique advantages and potential. Lead has excellent plastic deformation ability, and can effectively absorb and dissipate a large amount of energy through its own plastic deformation under the action of explosion load, so as to significantly reduce the impact of explosion on the structure. Compared with the underground dispersed layer, the protection effect of lead dampers is more stable and reliable, and can better adapt to different strengths and types of explosion loads.

It is of great significance to carry out the research on this topic as follows:

Improving the effectiveness of explosion protection: Through in-depth research on the protective effect of lead dampers under explosion loads, it can provide a more effective means of protection for engineering practice, significantly improve the reliability and stability of explosion protection, and ensure that buildings and infrastructure can maintain good structural integrity in the event of an explosion.

Enhance the anti-explosion ability of the structure: The lead damper can effectively absorb and disperse the explosion energy, reduce the vibration and response of the structure, thereby reducing the risk of damage to the structure under the explosion load, greatly enhancing the anti-explosion ability of the structure, and providing a safer protective environment for people.

Promoting the innovation and development of protection technology: This study introduces a new technology option in the field of explosion protection, which is conducive to the continuous innovation and development of explosion protection technology. Through the research and application of lead dampers, technological progress in related fields can be promoted, and more advanced solutions can be provided for future explosion protection projects.

Ensure the safety of people's lives and property: Effective explosion protection measures are an important barrier to ensure the safety of people's lives and property. Through this study, it is possible to improve the explosion resistance of buildings and infrastructure, reduce casualties and property losses caused by explosion accidents, and maintain social stability and harmony.

Promote scientific research in related fields: This topic involves multiple disciplines such as explosion mechanics, structural dynamics, and materials science, and through in-depth research, it can promote the cross-integration of these disciplines, promote the continuous development of scientific research in related fields, and provide a solid theoretical foundation for solving practical engineering problems.

ISSN: 2710-0723

2. Research Background of Layered Protection Structure

2.1. Layered Protection Structure

The supporting structure of the layered protection structure is an important part of the whole protection system, which plays a key role in carrying and transferring the load to ensure the stability and safety of the protection structure.

The support structure is usually located inside the protective structure and is used to support parts such as camouflage, masking and dispersion layers on the upper layer and transfer these loads to the foundation or ground. Its key features include:

Load-bearing load: The supporting structure needs to withstand the self-weight from the superstructure as well as external actions such as explosion loads and impact loads. It must have sufficient strength and stiffness to ensure that excessive deformation or failure does not occur under these loads.

Transfer load: The load from the superstructure is evenly transferred to the foundation or ground to avoid local concentrated loads, which leads to the instability of the structure.

Maintain the stability of the structure: The supporting structure forms a stable whole through reasonable layout and connection, which can resist the impact of external forces such as explosion and prevent the structure from overturning or collapsing.

Adaptation to deformation: Under the action of explosive load, the protective structure will produce a certain deformation. The supporting structure needs to have a certain deformation capacity to adapt to this deformation, and at the same time ensure the safety of the structure after deformation.

There are various forms and materials of supporting structures, such as reinforced concrete structures, steel structures, masonry structures, etc. When designing a support structure, a variety of factors need to be considered, such as the type, size and distribution of loads, the functional and environmental conditions of the structure, the performance and cost of materials, etc. The reinforced concrete support structure has the advantages of high strength, high stiffness and good durability, and is suitable for bearing large loads. The steel structure support structure has the advantages of light weight, convenient construction and reusability, and is suitable for situations with high requirements for construction speed and flexibility. Masonry supporting structures are less costly, but have relatively low strength and stiffness, and are suitable for some minor protective structures.

In addition, the connecting nodes of the support structure are also very important, which directly affects the integrity and stability of the structure. The connection joints should be strong and reliable enough to transfer loads effectively, and should be easy to construct and maintain.

In a word, the supporting structure of the layered protective structure is one of the key factors to ensure the protection effect, and its design and construction quality is directly related to the safety and reliability of the whole protective structure. In the actual project, it is necessary to select the appropriate form and material of the supporting structure according to the specific situation, and carry out careful design and construction to ensure that the protective structure can effectively resist the impact of external forces such as explosion.

2.2. Application Cases of Layered Protection Structure

Military fortifications: Many military bases and fortifications have a layered protective structure. For example, some underground military bunkers often have multiple layers of protection, including camouflage, bomb masking, dispersion, and support structures. These protective structures can effectively resist threats such as missile attacks and bomb explosions, and protect the safety of internal personnel and equipment.

ISSN: 2710-0723

Nuclear power plants: The safety of nuclear power plants is paramount, so a layered guard structure is often used to prevent nuclear leaks. For example, the reactor building of a nuclear power plant usually has a solid concrete structure as a support structure, with a bomb shield and a dispersion layer on the outside to reduce the impact of external shocks on the reactor.

Significant Buildings: Some important government buildings, financial institutions, or cultural heritage buildings may also have layered protective structures. For example, presidential administrations or embassies in some countries may use enhanced protective structures, including bulletproof glass, blast doors, reinforced walls, and support structures, to improve security.

Underground parking lots: Some underground parking lots will use layered protective structures to protect the safety of vehicles and personnel. For example, a bullet shield may be placed on the top of a parking lot to prevent objects from falling or exploding to cause damage to vehicles, while the support structure will also be reinforced to ensure the stability of the parking lot.

Tunneling: Layered protective structures are also considered during the construction of tunnels. For example, the lining structure of a tunnel can act as support and protection, while protective doors or other protective facilities may be installed at the tunnel entrance to reduce the impact of external threats on the interior of the tunnel.

These cases show that layered protective structures have a wide range of applications in various fields, and can effectively improve the safety and protection capabilities of buildings and infrastructure. Of course, the specific design of the protective structure will be adjusted and optimized according to different needs and situations

2.3. Research Status at Home and Abroad

(1) The current research status of the dispersed layer in the layered protective structure in China

In 2011, Gao Guangfa et al. took the design of the distribution layer in the protection project as the research object, summarized the research status and existing problems of the distribution layer, and discussed the problems and development trends that need to be solved in the design of the distribution layer.

In 2015, Ren Xinjian et al. [3] studied the anti-explosion performance of a layered protective structure with foam ceramic hollow balls as the distribution layer through large-scale group charge standard experiments, comparative experiments and secondary explosion experiments.

In 2017, Ye Zhongbao [5] et al. carried out a simulation test of the chemical explosion of the large-scale group charge against the background of the layered civil air defense project, and studied the anti-explosion performance of the layered protective structure with a new hollow shell particle composite material as the distribution layer.

In 2019, Huang Xu et al. [2] studied the impact resistance of the layered protective structure of the civil air defense engineering with the added buffer layer, and discussed the influence of the air buffer layer and the polyethylene PEF buffer layer on the load reduction effect and protective performance of the layered protective structure through theoretical analysis, explosion impact test, numerical simulation and falling impact test, and analyzed the application of the buffer layer in the civil air defense engineering of the existing civil air defense project and the civil air defense project of urban underground space.

In 2022, Zhou Hui [1] reviewed the research on the dispersed layer in the layered protective structure, introduced the protective efficiency of different dispersed layer materials (sand, soil, lightweight concrete, air interlayer, foam ceramics, polymer materials, metal matrix, metamaterials), and analyzed the protective efficiency of dispersed layers with different structural types (multi-layer superposition of different materials, thin-walled column shell

ISSN: 2710-0723

filled with energy-absorbing materials, sandwich core, gradient composed of the same material, negative Poisson's ratio). The main factors affecting the protection efficiency of the dispersed layer (material physical parameters, wave impedance mismatch, thickness, moisture content, element shape and specification) are discussed, the selection and design principles of the dispersed layer are proposed, and the existing problems are discussed and prospected.

Research status of layered protection structure in foreign countries.

In 2000 S Guruprasad described the behavior of a layered sacrificial cladding under blast loads. The cladding structure made of thin mild steel plate was constructed, and the blast load was modeled as an equivalent triangular pulse, experimental and numerical analyses were carried out, a simple analytical model was proposed to capture the overall behavior of the sacrificial cladding, and the results were compared with the finite element analysis. The article concludes that the layered sacrificial cladding is highly effective in energy absorption under blast loads and has predictable behavior, so it can be used to design reliable anti-explosion structures. The highlight of this paper is that an effective sacrificial cladding structure is proposed, and its effectiveness is verified by the analysis of the finite element model and the simple model. The disadvantage is that some factors are ignored in the analysis, such as the strain rate effect, which may affect the accuracy of the results.

In 2000 S Guruprasad discussed the performance of sacrificial layers under explosive loads. A series of explosion experiments were carried out to verify the effectiveness of the analytical model as a reliable design tool. Specimens, experimental setups, instrumentation protocols, and data acquisition and processing systems are described in detail, as well as protocols and challenges. The experimental results show that the layered sacrificial cladding is effective in the design of blast-resistant structures, which verifies the design and basic observations obtained through the analytical research, but the analysis slightly overestimates the deformation and underestimates the collapse time, which is due to the lack of some dissipative factors in the analytical model. In addition, when the blast charge distance is small, the reflected overpressure can be very high, and the first cover plate may tear, but the inner layer will not.

In 2005, G.W. Ma proposed an analytical load-cladding-structure (LCS) model to study the explosion mitigation behavior of sacrificial foam cladding. Based on the shock wave propagation theory, the deformation of the foam under explosive load is derived, and the coupled global response of the protected main structure is considered. The dimensionless parameters of the two foam cladding layers are introduced, and the conclusion is drawn that the maximum deflection of the protected structure under a specific blast load is related to the two dimensionless parameters of the foam cladding. Based on the LCS model, the appropriate design of the foam cladding can be explored to mitigate specific blast loads and the maximum blast loads for specific foam cladding and protected structures can be predicted. The highlight of the paper is that the LCS model and related dimensionless parameters are proposed, which provide guidance for the design and evaluation of foam cladding. The disadvantage is that the idealized RPPL foam model and the equivalent SDOF structure model are used, which may deviate from the actual situation.

In 2005, G.W. Ma proposed a double-layer foam coating to meet different structural protection purposes, based on the rigid-fully plastic-locking foam model, the energy absorption capacity of the double-layer foam coating under the explosion load was analyzed and derived, the layered foam coating with different configurations was studied, the maximum absorbed energy and the maximum explosion pulse that can be resisted were calculated, and the numerical simulation was carried out by the finite element method to verify the accuracy of the analysis results. The highlight of this paper is that the concept of double-layer foam cladding is proposed, and the analysis solution of its energy absorption capacity is given, which provides effective theoretical support for the design of sacrificial foam cladding. The disadvantage is that the ideal

ISSN: 2710-0723

R-P-P-L foam model is used in the analysis, ignoring the elastic behavior of the foam, which may deviate from the actual situation.

In 2012, Chengqing Wu investigated the ability to use foam cladding to mitigate the impact of explosions on reinforced concrete slabs. By establishing an interaction model of the cladding structure based on finite element technology, the interaction between the cladding layer and the reinforced concrete slab under blast load was quantified. The model divides the RC plate into hinged and non-hinged zones, and the foam cladding is simulated with a lumped mass spring system and the progressive densification of the foam is simulated with a nonlinear stiffness spring. At the same time, a series of explosion tests were carried out to verify the model. The highlight of this paper is that a coupling cladding structure interaction model considering multiple factors is proposed, which is verified by experimental data. The downside is that the modeling of foam materials may not be accurate enough and does not take into account the influence of more practical factors.

In 2022, Kostopoulos V studied the explosion-proof protection effect of a composite foam core sacrificial cladding on reinforced concrete (RC) structures through explicit finite element analysis. The fluid-structure interaction (FSI) method was used to analyze the deformation and damage of the RC column under blast impact, and the response of the RC column with or without the cladding layer was compared. The study shows that the proposed foam cone array configuration can reduce the peak force acting on the concrete structure by 50% and be 71% lighter than the protective configuration using a uniform foam layer of the same thickness. The highlight of the paper is that an effective explosion-proof cladding structure is proposed, and its performance is verified by numerical simulation. The disadvantage is that the shape of the conical array structure is not optimized, and the strain rate effect of the Kevlar composite surface layer is not considered in the study.

In 2024, Pengfei Huang et al. proposed a new seismic method for civil engineering buildings, that is, using seismic metamaterials to set up regional seismic barriers around underground structures, and the attenuation efficiency of the seismic barriers to Rayleigh waves and the seismic control performance of underground structures were studied through numerical simulation.

2.4. Research on the Mechanical Properties of Steel Pipe Grouting Sleeve

In 1985, Wang Nianqiao established the differential equation of the coupling motion of the elastic shield layer and the supporting structure, and gave the determination method and the expression of the analytical solution of the layered structure under the action of the ground shock wave sudden constant pressure, and discussed the influence of various parameters on the dynamic load of the supporting structure. The disadvantage is that the analytical solution adopts the linear elastic assumption of medium deformation and ignores the influence of structural deformation on interaction, which may not be suitable for solving and describing the vibration process in the later stage of the structure.

In 2003, Shi Peng et al. designed a new composite bomb shield layer structure, and carried out experiments and numerical simulations.

In 2003, Wang Mingyang et al. studied the deformation and failure of rocks under blast loads, introduced the basic experimental results of rock deformation and failure under blast loads, and expounded the research status of rock deformation and failure under blast loads.

In 2004, Liu Tianyun mainly studied the relevant contents of shallow buried underground protective structures, and studied the effect of buffer separators on the anti-explosion performance of protective structures through static load tests and chemical explosion field tests of composite sandwich panels, as well as on-site chemical explosion tests and finite element simulations of buffer separators set in the overlying soil.

In 2005, Yi Changping mainly studied the effects of blasting vibration on underground caverns, including the effects on adjacent unlined caverns, adjacent cavern linings, caverns and mortar anchors.

In 2006, Zhao Jing mainly studied the anti-explosion performance of shallow underground protective structures, and analyzed the effect of explosion load on the protective structure and the effect of the energy dissipation layer on improving the anti-explosion performance of the protective structure through on-site chemical explosion test and finite element simulation of the protective structural components.

In 2007, Zhao Kai et al. [4] studied the attenuation and diffusion effect of the layered protective layer on the explosion wave, discussed the propagation law of the stress wave in the layered medium through a combination of theoretical analysis, experiment and numerical simulation, analyzed the impact resistance of several commonly used engineering materials, carried out the explosion simulation test and numerical simulation of the layered civil air defense structure, and studied the protection effect of the layered protection structure on the explosion wave.

In 2009, Li Yanzhao et al. [7] conducted a large-scale-like simulated field chemical explosion test on the protective effect of the distribution layer layer layer on the nuclear explosion load.

In 2017, Sun Xiaowang et al. developed a new type of hollow shell particle material as a distribution layer for civil air defense structures, and studied its performance under explosion load through large-scale chemical explosion experiments.

In 2020, Chaoshen Wang et al. established an explosion effect analysis model for underground roadways based on the SPH-FEM coupling method, and compared the performance of different distribution layer structures under blast loads.

In 2021, Sun Jie et al. took the 155mm grenade as an example to study the thickness of the dispersed layer of the layered protective layer of field fortifications, analyzed the ballistic principle of different types of bomb shielding layers and the influencing factors of explosion loads, calculated the internal forces of the fortification structure through the dynamic finite element program LS-DYNA, and estimated the reasonable thickness of the dispersed layer under different bullet shielding layers.

In 2023, Wu Chunyao et al. [8] studied the explosion and tamponade effect of the layered protective structure through numerical simulation, established the geometric model and finite element model of the layered structure, and analyzed the variation law of the explosion crater, stress peak, stress and deformation of the supporting structure layer under different thickness of the bomb shielding layer.

2.5. Summary

These publications study the protective structures under blast loads from different perspectives, and propose a variety of effective protective structures and analysis methods. Future research can further optimize the design of the protective structure, considering the influence of more practical factors, so as to improve the safety and reliability of the structure under blast load.

References

[1] Zhou Hui, Ren Huiqi, Wu Xiangyun, et al. Explosion & Impact,2022,42(11):3-28.

[2] Huang Xu. Research on impact resistance of layered protective structure of civil air defense engineering with buffer layer[D].Southeast University,2019.DOI:10.27014/d.cnki.gdnau.2019.001422.

[3] Ren Xinjian, Zhang Qingming, Liu Ruichao. Experimental study on anti-explosion performance of foam hollow ball distribution layer in layered structure[J].Vibration and Shock,2015,34(21):100-104.DOI:10.13465/j.cnki.jvs.2015.21.018.

ISSN: 2710-0723

[4] Zhao Kai. Research on attenuation and diffusion effect of layered protective layer on blast wave[D].University of Science and Technology of China,2007.

[5] Ye Zhongbao, Li Yongchi, Zhao Kai, et al. Experimental Mechanics,2017,32(03):377-384.

[6] Zhao Yuetang, Yu Xiaocun. Effect of distribution layer thickness on dynamic response of layered structure[J].Chinese Journal of Rock Mechanics and Engineering,2007,(S1):3540-3545.

[7] Li Yanzhao, Wang Xiaojun, Wu Xiangyun, et al. Experimental study on the protective effect of distribution layer hierarchical structure on nuclear explosion load[J].Journal of University of Science and Technology of China,2009,39(09):931-935.

[8] Wu Chunyao, Song Chunming, Wu Huajie. Research on explosion tamponade effect of layered protective structure[J].Protection Engineering,2023,45(05):41-47.

[9] Liu Zheng, Cheng Yihao, Qiu Yanyu, et al. Numerical analysis of layered protective structure against ultra-high velocity penetration[J].Explosion & Impact,2018,38(06):1317-1324.

[10] Ren Xinjian, Zhang Lei. Experimental study on anti-explosion performance of layered protective structure with foam ceramic hollow ball as distribution layer[J].Protection Engineering,2015, 37(01):12-16.