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Numerical Simulation Of Radial Decoupling Charge With Ansys-Autodyn

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ABSTRACT

Numerical Simulation With Ansys-Autodyn Is Employed To Study How Radial Decoupling Charge Influences The Blasting Effect. As Expected, The Initial Bore Hole Pressure Is Significantly Decreased Compared With The Fully Coupling Scenario. It Can Be Explained That The Wave Impedance Of Air Is Much Lower Than That Of Explosives. And Another Reason Is That Some Part Of Energy Is Consumed To Compress The Air Medium In The Bore Hole. It Offers A Potential For The Higher Energy Transferring Efficiency With Water Medium Due To Its Special Physical Feature. It Is Concluded That The Method Is A Flexible Tool For Investigating The Influences Of Radial Decoupling Charge.

1. INTRODUCTION

The Excessive Fragmentation In The Crushed Zone Is Associated With Energy Dissipation At A Very High Rate [ ]. In Order To Elevate The Drill Efficiencies And Try To Avoid The Second Blasting, The Excessive Crushing Zone Should Be Minimized Wherever Elimination And Avoidance Is Absolutely Impossible For The Traditional Fully Coupling Charge. And It Is Estimated That More Than 35% Percent Is Consumed For The Crushing Zone. In Order To Make More Explosive Energy Used For Crack Propagation, Decoupling Charges Are Adopted In Actual Blasting Trail. Usually, There Are Two Decoupling Charges, Axial Decoupling Charge (Also Called Air-Decking Charge) And Radial Decoupling Charge. Sometimes, Combination Of These Two Decoupling Charges Is Used To Realize The Specific Objectives. In Present Paper, Only The Radial Decoupling Structure Is Taken Into Consideration. Attempts Have Been Made To Try To Know The Mechanics And Effects Of This Decoupling Charge Both Experimentally And Numerically [-]. However, Some Aspects Still Need To Be Further Explored.

Simulation Is An Effective Approach To Do Some Research. It Can Offer Better Opportunity To Observe The Evolution Process Of Damage In Detail. And Sometimes It Can Cover Some Field That Cannot Be Achieved Through Experiments. There Are Many Approaches For The Simulation With Rock And Concrete Fragment. Ansys-Autodyn, As A Kind Of Commercial Software, Is A Hydro Code Based On Explicit Finite Difference Method (Fdm).

More Than Twenty Factors Are Involved For The Fragmentation In Blasting, I.E. Decoupling Coefficient, Decoupling Medium, Stemming Materials, Boundary Conditions, Initiation Locations As Well As Explosive Types. In This Present Paper, More Concern Is On The Influences Of The Factors On The Bole Hole Pressure As Well As The Fragmentation, Such As Decoupling Coefficient, Decoupling Medium. In Addition, The Damage Of Concrete In The Different Scenarios Is Also Studied. Comparisons Are Performed To Investigate The Corresponding Effects Based On The Simulation Results

2. Calculation Model And Materials Description

2.1 Calculation Model

Fig.1 Shows Calculation Model With Geometry Of 2000mm×2000mm. The Diameter And Height Of Explosives Are 100mm And 500 Mm. The Height Of Stemming Is 500mm. There Are Three Non-Reflecting Faces (Left, Bottom And Right) And One Free Face (Top). Free Face Allows The Reflected Compressive Stress Wave Backward To Produce A Tensile Stress Wave. If The Reflected Tensile Wave Is Sufficiently Strong (Higher Than The Dynamic Tensile Strength Of The Rock), "Spalling" Occurs Progressively From The Free Face Back Towards The Borehole. Non-Reflecting Faces Are Also Called The Transmitting Boundary Condition. It Means The Infinite Dimension Of The Concrete. In This Scenario, None Reflected Compressive Stress Wave Will Be Produced.

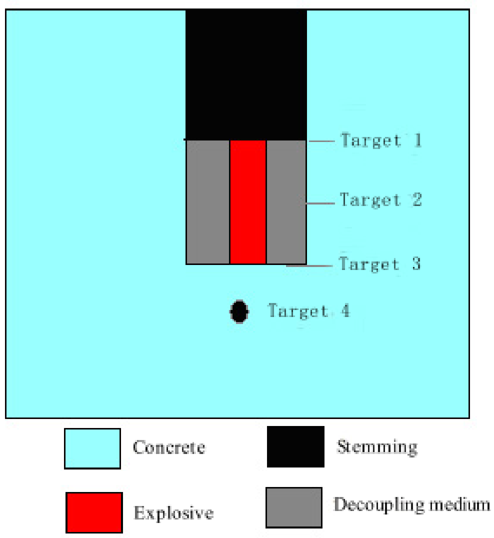


Fig.1 Calculation Model

In Present Paper, Four Decoupling Coefficients Are Designed For The Simulation, 1.6, 2, 2.8, And 3. For These Four Scenarios, The Diameters Of Explosives Are Kept The Same, And The Diameters Of Bore Hole Are Changed. The Decoupling Coefficient Is Defined As:

$$K = \frac{D_b}{D_e} \quad (1)$$

Where, K Is The Decoupling Coefficient, D_b And D_e Are Diameter Of Bore Hole And Explosives Respectively.

2.2 Jwl Equation Of State (Eos) For Explosives

So Far, Several Equations Of State For Explosives Have Been Proposed. Among Them, Jwl Equation Of State Is Proved To Effectively Describe The Relationship Between The Pressure P
And The Relative Specific Volume V Of Detonation Gas Products. And It Is Widely Applied To Various Numerical Simulations. It Has The Following General Form:

$$p = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} \quad (4)$$

Where, A, B, R_1, R_2 And Ω Are Constants. The Terms A And B Relate The Pressure Coefficients; R_1 And R_2 Are The Principal And Secondary Eigenvalues Respectively; Ω Refers To The Fractional Part Of The Normal Tait Equation Adiabatic Exponent; P, V And E Mean The Pressure, Relative Volume And Specific Internal Energy, Respectively. Jwl Parameters For Three Explosives Used In Present Paper Are Summarized In Table 1, Where The Parameters Of Emxs Are Cited From The Ref. [i].

Table1 Parameters Of State Equation For Explosives.

Explosives	A/Gpa	B/Gpa	R_1/Gpa	$R2$/Gpa	Ω	P/Kg·M^{-3}	D/M·S^{-1}	P_{c-J}/Gpa	E/Gj·M^{-3}
Tnt	373.77	3.7471	4.15	0.90	0.35	1630	6930	21	6

2.3 Polynomial Equation Of State For Water

The Polynomial Equation Of State (Eos) And Cut-Off Pressure Of 0 Pa Were Adopted For Water. The Polynomial Equation Of State Is Given As:

$$\mu > 0 \quad p = A_1\mu + A_2\mu^2 + A_3\mu^3 + (B_0 + B_1\mu)\rho_0 e \quad (2)$$

$$\mu < 0 \quad p = T_1\mu + T_2\mu^2 + B_0\rho_0 e \quad (3)$$

$$\mu = \frac{\rho_{\text{current}}}{\rho_{\text{initial}}} - 1 \quad (5)$$

$$e = \frac{\rho g h + \rho_0}{\rho B_0} \quad (6)$$

Where, A_1, A_2, A_3, B_0, B_1, T_1, T_2 Are Constants; E Is The Specific Internal Energy; P And H Are Density And Depth Of Water; ρ_{current} And ρ_{initial} Are Current And Initial Density Of Water; G And P_0 Are Acceleration Caused By Gravity And Atmosphere Pressure, Respectively. The Values Of These Constants Are Listed In Table 2.

Table 2 Parameters Of Polynomial Eos For Water

Parameters	A_1/Gpa	A_2/Gpa	A_3/Gpa	B_0	B_1	T_1/Gpa	T_2/Gpa	P/ Kg·M^{-3}
Water	2.2	9.54	14.57	0.28	0.28	2.2	0	1000

2.4 Polynomial Eos For Air

Polynomial Eos Can Also Be Employed For Air. It Is Written As:

$$p = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)e \quad (7)$$

Where, C_0,C_1,C_2,C_3,C_4,C_5,C_6 Are Constant. In Fact, Air Is Always Taken As Ideal Gas, Where C0= C1=C2=C3=C6=0 And C4 =C5=0.4. The Initial Density And Initial Internal Energy Are 1255 Kg·M^{-3} And 0.25 J·Cm^{-3}, Respectively. The Equation (7) Can Be Rewritten As:

$$p = 0.4\rho e \quad (8)$$

2.5 Rht Model For Concrete

The Rht Damage Constitutive Model In Autodyn Is Used For Concrete, Which Can Capture Realistically The Behaviour Of Concrete In Compression, Where The Pressure Dependency And Strain-Rate Effects Are Considered [ii]. The Parameters For The Concrete Used In Present Paper Can Be Seen In Ref. [iii].

2.6 Compaction Of Sand.

In Present Paper, Sand Is Adopted As The Stemming Material For All Simulation. Compaction Eos Is Applied For This Porous Material. The Density Of Sand Used Is 2641 Kg·M^{-3}.

3. Numerical Results And Discussion

Detonation Of Explosives Induced By The Chemical Interaction Of The Components Will Cause Significant Increase Of Pressure And Temperature Coupled With Sudden Energy Release Within Millisecond Order. This Kind Of Effects Will Be Enhanced Especially In The Confined Space. The Pressure Amplitude Far Exceeds The Strength Of Rock, So The Fragmentation Is Formed.

When The Explosives Are First Initiated At The Top Of Explosives Column, Detonation Will Continuously Propagates Downwards Along The Explosives Column. And The Borehole Pressure Increases With Its Propagation. Pressure-Time Histories Of The Selected Point Are Depicted In Fig.2. It Can Be Observed There Is Small Oscillation When The Detonation Wave Arrives At The Bottom Of The Borehole, And It May Be Connected With The Interaction Of Detonation Wave And The Concrete Adjunction To The Borehole. It Can Also Be Seen That, The Largest Borehole Pressure Will Be Obtained When The Detonation Wave Go Through To The End Of The Explosives Column

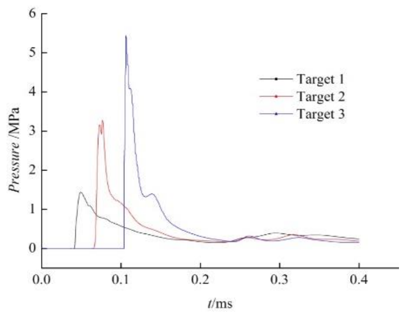


Fig.2 Comparison Between Borehole Pressures At Selected Point (*K*=2)

In Order To Study The Changes Of Stress With Distance, 7 Specific Points Are Selected. They Are At The Bottom Of The Bore Hole From 200 Mm To 700 Mm With The Increment Of 100mm. As Shown In Fig.3, The Stress Of Concrete Induced By The Explosives Detonation Can Be Dissipated Significantly With Distance, And Exhibit A Function Of Exponent Attenuation With The Distance. However, The Action Duration Will Be Prolonged. Therefore The Energy Use Efficiency Will Be Enhanced.

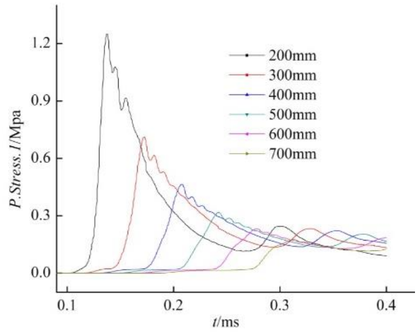


Fig.3 Comparison Between Stresses At Different Distance (*K*=2)

3.1 Decoupling Coefficient

Decoupling Coefficient Is Most Key Parameter In Blasting Practice. It Relates To The Following Aspects, I.E. Peak Pressure Of Bole Hole, Action Duration Of Static Detonation Gas Pressure As Well As The Cracks Control. In General, The Density, Size And Even Shape Of The Radial Cracks Are Also Notably Changed With Increasing Decoupling Ratios. The Previous Research Showed That A Decoupling Of 3.0 Gives A Minimum Amount Of Larger Radial Cracks And A Noticeable Reduction Of The Number And Dimension Of Smaller Cracks.

For Decoupling Scenario, Energy Transferred Mainly Depends On The Wave Impedance Of Explosives. Similarly, Energy Transferred Is Determined By The Wave Impedance Of Mediums. However, The Wave Impedance Of Air Is Far Less Than That Of Explosives. So, Compared With The Scenario Of Decoupling, Less Energy Will Be Transferred Into The Concrete. At The Same Time, Air Medium Will Be Compressed To The Same Order Of Pressure And Heated To The Same Order Of The Temperature Of The Detonation Products. During This Process, Part Of Energy Will Be Consumed. This Is Another Reason For The Energy Reduction. With An Increase Of The Decoupling Coefficient, More Energy Would Be Consumed And Less And Less Energy Is Transferred, Which Can Be Seen In Fig.4.

However, The Lower Amplitude Of Shock Wave Has Significance In Some Specific Blasting. The Undersize Rock Is Reduced Which Is Required For The Certain Blasting Purpose. Some Research Revealed That Energy Will Be Redistributed Through Decoupling Charge. It Means That Some Part Of Shock Wave Energy Will Be Stored In The Air Layer And Will Be Released Later To Act The Surrounding Concrete With Detonation Products. It Is What Some Special Blasting Required

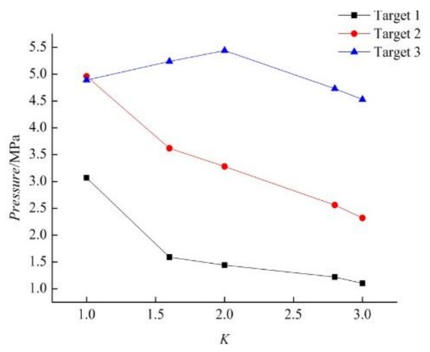


Fig. 4 Comparison Between Borehole Pressures For Decoupling Coefficient

As Present In Fig. 5, The Stress In Decoupling Scenario Is Obviously Lower Than That Of Fully Coupling Case. It Indicates That Undersize Medium Near The Bottom Bore Hole Will Be Largely Reduced Due To Reduction Of Peak Pressure When Decoupling Charges Are Adopted. There Is No Significant Advantage For One Over Another Among These Different Decoupling Coefficients.

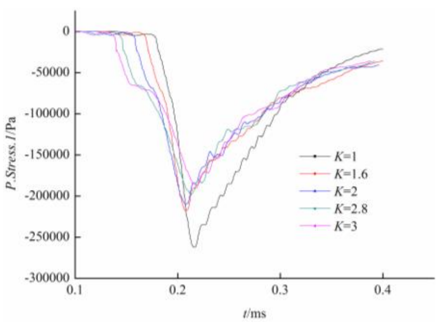


Fig.5 Comparison Between Stresses For Different Decoupling Coefficient (Target 4)

3.2 Decoupling Medium

Usually There Are Two Common Decoupling Mediums In Blasting, Air And Water. The Previous Research Revealed The Different Blasting Effects When Adopting These Two Mediums And Also Showed The Higher Detonation Energy Transferring Efficiency Could Be Obtained When Water Was Used. Actually, The Mechanics For These Two Scenarios Are Different.

When Explosives Explode In The Water, Detonation Products With The High Temperature And High Pressure Exceed The Static Pressure Of Wave. Shock Wave In Water Will Be Formed. The Attenuation Rate Of Shock Wave Is Relatively Slower Because It Is Hard To Compress The Water. As Shown In Fig.6, Higher Pressure Can Be Seen In Case Of Water Medium. However, The Expansion Rate Of Detonation Gas Product In Water Is Much Slower Than That In Air Because Of Higher Density Of Water. Additionally, Sound Velocity Of Shock Wave In Water Is Much Higher Than That In Air. This Leads To The Distinct Arrive Time Of Shock Wave And Detonation Products In This Two Scenarios. It Is Also Called "Time Differences". In Case Of Water, Higher Shock Wave Propagation Velocity And Lower Expansion Of Detonation Products Will Give Birth To Longer Action Duration. Therefore Higher Energy Transferring Efficiency Can Be Obtained In This Case. Basically, The Differences Are Caused Due To Distinct Physical Features Of These Two Mediums.

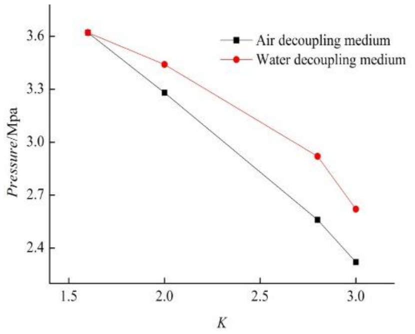
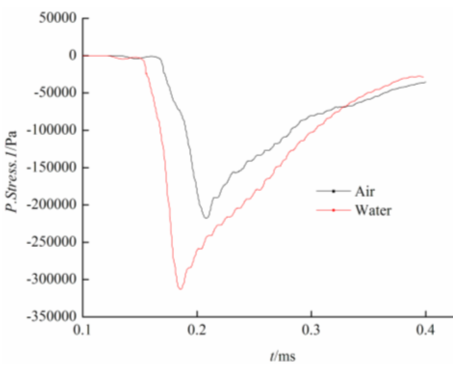


Fig.6 Comparison Between Bore Hole Pressures With Different Coupling Mediums

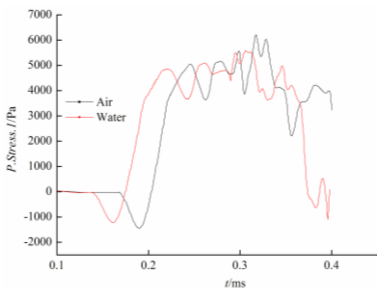
Usually, There Are Two Intensive Damage Zones. One Is Located Near The Bottom Of Bore Hole, Formed By The High Tangential Tensile Stress Surrounding The Borehole, Shown In Fig. 7a. The Other Is Mainly Positioned At The Upper Domain, I. E. Near The Ground Surface, Shown In Fig.7b. It Is Caused By The Reflected Stress Waves From The Free Face.

What Can Be Found From Fig.7a Is That Not Only The Higher Peak Stress Can Be Obtained With Water Medium, But The Longer Action Duration Can Be Realized In This Case. It Can Be Explained The Expansion Rate Of Detonation Gas Product In Water Will Be Much Slower In Water Due To The High Density Compared With Air. From Fig.7a And 7b, It Can Be Clearly Seen That Stress Peak Values At Target 4 Vary With The Mediums And Peak Wave Of Water Medium Is Obvious Less Than That Of Water Scenario. However, In Fig.7b, It Is Almost The Same For The Two Scenarios. No Significant Different Differences Are Observed For Target 5. It Seems That The Effects Of Decoupling Mediums On Near Field Are More Dominant Than That Of Far Field. This Numerical Result Goes Well With The Conclusion Of Jiang Pen-Fei, Et Al[iv].

In Addition, Many Experimental Results Showed That Stress Can Be Buttered And Distributed Evenly Via Water Medium, Which Makes The Pressure Can Be Applied To The Surrounding Rock Gently. In This Scenario, It Offers The Chance For Improvement Of Even Broken Fragmentation, And Great Reducing Of Harmful Shave Effects And Noise.



A-Target 4



B-Target 5

Fig.7 Comparison Between Stresses For Different Decoupling Mediums

3.3 Explosives Types

The Final Blasting Effects Are Also Dependent Upon Explosive Properties, Explosive Density, And Explosive Reaction Rates. It Relates On The Explosives Strength As Well As The Energy Release Processes. Traditionally, Tnt And Anfo Are Usually Used For Blasting. Actually In Some Quarries Where Water Is Present, It Is Necessary To Resort To Waterproof Explosives. And Emulsion Explosive Is The Ideal Water Resistant Blasting Agent.

As We All Know That Tnt Is Kind Of The High Industry Explosive. And It Is Also Typical Ideal Explosives. However, Anfo And Emxs Are Medium Power Explosives. Compared With Tnt, Anfo And Emxs Are Non-Ideal Explosives, And The Wider Detonation Reaction Zone Is The Obvious Feature. In Present Study, Tnt, Anfo, Emxs Are Adopted To Compare The Corresponding Blasting Effects.

From Fig. 8, It Proves That The Bore Hole Pressure Is Mainly Dependent On The Explosives Strength. As It Is Expected, Higher Explosives Strength Will Lead To Higher Bore Hole Pressure, And Thus Offers Fierce Blasting Effects. In General, Based On The Theory Analysis, The Expected Trends Are Followed: For A Specific Material Property And Explosive Type, As The Borehole Diameter Increases The Crushing Zone Radius Increases; Similarly, The Explosive With The Capacity To Generate Higher Borehole Pressures Has The Potential To Increase Crushing For The Same Borehole Diameter. So Emulsion Explosives Are The Preferred Selection In Some Case Of The Lower Borehole Pressure Desired.

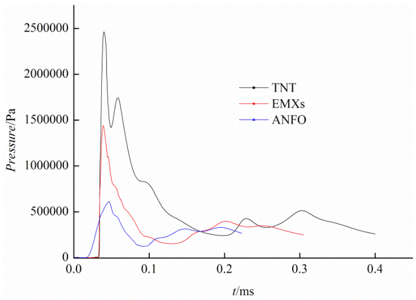


Fig.8 Comparison Between Bore Hole Pressures For Different Kinds Of Explosives (K=2)

4. Conclusions

The Radial Decoupling Charge Is Simulated In Present Paper. The Following Factors Are Taken Into Consideration, Decoupling Coefficient, Decoupling Medium And Explosives Types. And The Comparisons Are Performed To Investigate The Corresponding Influences. The Numerical Results Show That The Radial Decoupling Charge Dramatically Decreases The Initial Borehole Pressure. It Is Connected With The Fact That Wave Impedance Reduction Of Decoupling Medium Compared With The Scenario Of Fully Coupling. Based On The Results Between Air And Water Medium, It Indicates That It Has A Higher Energy Transferring Efficiency When Water Is Adopted As The Medium. Therefore, Appropriate Explosives Should Be Chosen In Specific Blasting.

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