Reliability Calculation of Large-scale Complex Initiation Network

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Abstract. A method was proposed to calculate the reliability of bundle-series compound initiation network which was the widely used for large-scale demolition blasting in China. The network was defined reliable only when all the 2nd level Nonel detonator joints outside the blasting holes were initiated. Based on the definition a series of equations were inferred to calculate the reliability of the complex initiation network. A program is written by Matlab to solve the equations. The method showed good performance with much less computations compared to the traditional ones.

1. Introduction
Initiation network of large-scale demolition blasting is considered the most complex among all kinds of blasting. And its reliability calculation is very complicate as well, compared with other blasting. For large-scale demolition blasting, in the past few years electric initiation network is widely used. The electric initiation network has many advantages. In this initiation network every electric detonator could be tested with ohmmeter respectively before the network is connected. After the network is connected the whole network resistance could be tested with ohmmeter, too. However, for the electric initiation network the premature explosion may happen due to its vulnerability to external stray current, static electricity, and lighting. Especially, it mustn’t be used in some conditions, e.g., the electric interference exists nearby or in thunderstorm weather [1]. Moreover, the quantity of the electric detonators is limited, and this constricts the application of the large-scale demolition blasting where thousands of detonators are initiated at the same time. Hence, it is seldom adopted in the large-scale demolition blasting nowadays [2]. In contrast, non-electric initiation network is proof of stray current and there is no limitation of the quantity of electric detonators. All the advantages discussed above led to the wide application of non-electric initiation network in the large-scale structure demolition. However, so far there isn’t a practical test approaches to prevent misfire. In order to reduce the possibilities of misfire, reliability of the initiation network is very important [3].

2. Reliability of initiation network components
Initiation network is mainly composed of primer, detonators, connectors and Nonel tubes which connect all the components. Bundle-series compound initiation network is shown in Figure 1.
In order to simplify the problem, the reliability of primer and Nonel tube are assumed completely reliable. In other words, their reliability is one.

Initiation reliability of plastic reflective four-path connector is denoted by $r_0$. Its reliability is 0.9843[4]. Plastic four-path connector is shown in figure 2. Joint of Nonel detonators and Nonel tube is shown in figure 2. Reliability data of network components is listed in Table 1.
Table 1. Reliability of initiating network components

| Initiating network components | Reliability (%) | Symbol | Degree of confidence |
|------------------------------|-----------------|--------|---------------------|
| Plastic reflective four-path connector | 0.9843 | \( r_0 \) | 0.95 |
| Electric detonator | 0.9975 | \( r_e \) | 0.95 |
| Nonel detonator | 0.9612 | \( r_{Ni} \) | 0.95 |
| Nonel detonator-Nonel tube joint | 0.9943 | \( r_n \) | 0.95 |

3. Calculation of the bundle-series compound initiation network

This paper define the initiation network is reliable when all the detonator joints of level 2 are initiated, because one of detonator joint of level 2 misfire, there will be about 20 blasting holes couldn’t explode, which may lead to a failure of the demolition blasting. So it is reasonable to define the network is reliable only when all the detonator nodes of level 2 are initiated.

To make sure to initiate a level 2 detonator joint, at least one of the two detonators at the joint must initiate and the joints will explode certainly. Detonation transmission must be ensured for four-path joint which is connected to this detonator joint. Detonation wave must be transmitted through at least one of the two four-path at the joint. It means that failure of the \( A_{ij} \) and \( A_{ij} \) won’t occur at the same time. And \( A_{i,j,1} \) and \( A_{i,j,2} \) cannot occur at the same time either. The block diagram of the initiation network reliability is shown in Figure 4 [5]. The network reliability can be calculated out from equation (1) ~ equation (14).

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\begin{align*}
R_1 &= (1 - R_0)R_0 \\
R_2 &= R_0(1 - R_0) \\
R_3 &= R_0^2 \\
P(A_1^{(1)}) &= R_1 \\
P(A_1^{(2)}) &= R_2 \\
P(A_1^{(3)}) &= R_3 \\
P(A_1) &= P(A_1^{(1)}) + P(A_1^{(2)}) + P(A_1^{(3)}) = R_1 + R_2 + R_3 \\
P(A_i^{(1)}) &= [P(A_{i-1}^{(1)}) + P(A_{i-1}^{(2)})]R_1 \\
P(A_i^{(2)}) &= [P(A_{i-1}^{(2)}) + P(A_{i-1}^{(3)})]R_2 \\
P(A_i^{(3)}) &= [P(A_{i-1}^{(1)}) + P(A_{i-1}^{(2)}) + P(A_{i-1}^{(3)})]R_3 \\
P(A_i) &= P(A_i^{(1)}) + P(A_i^{(2)}) + P(A_i^{(3)}) \\
P(B_i) &= 1 - (1 - r_{e_i})^2 \\
P(B_0) &= 1 - (1 - r_e)^2 \\
P(S_2) &= P(B_0)P(C)P(A_m)P(B_2)P(B_3)\cdots P(B_m) \\
&= [1 - (1 - r_e)^2]r_n P(A_m)[1 - (1 - r_{Ni})^2]^n
\end{align*}
\]
C: joint composed with two electric detonators and two detonating tube bounded together by adhesive plaster; B₀₁, B₀₂: the first and the second electric detonator composing of the joint bounded together by adhesive plaster; Aᵢ₁, Aᵢ₂: two four-path composing of i th (i=1,2,3, ...m) four-path connector joint of the two main detonating lines; Bᵢ₁, Bᵢ₂: two Nonel tube detonators connected to the i th (i=1,2,3, ...m) plastic four-path connector joint.

Figure 4. Reliability block diagram of bundle-series compound initiation network
$R_1$ - the reliability that the first four-path connector failed and at the same time the second one exploded; $R_2$ - the reliability that the two four-path connectors failed at the same time; $R_3$ - the reliability that both the four-path connectors exploded. $A_{i}^{(1)}$ - the reliability of the first connector valid and at the same time the second one invalid at $i^{th}$ $(i=2,3,\ldots,m)$ four-path joint; $A_{i}^{(2)}$ - the reliability of the first joint at $i^{th}$ $(i=2,3,\ldots,m)$ joint, failure of the second one and the existence of blasting wave output; $A_{i}^{(3)}$ - the reliability of effectiveness of both the four-path and the existence of blasting wave output; $A_i$ - the reliability of effectiveness of at least one four-path at $i^{th}$ $(i=2,3,\ldots,m)$ four-path connector joint and existence of blasting wave output; $B_i$ - the reliability of effectiveness of at least one detonating tube detonator at $i^{th}$ $(i=2,3,\ldots,m)$ four-path joint; $S_2$ is valid of the blasting network; $B_0$ - at least one detonator at the joint is valid; C - the joint composed with the electric detonators and two detonating tube bound together; $P(A_{i}^{(1)})$, $P(A_{i}^{(2)})$, $P(A_{i}^{(3)})$, $P(A_i)$, $P(B_i)$, $P(S_2)$ - the probability of the event described above.

The reliability of the demolition blasting network could be easily calculated with Matlab according to the above equations [6].

4. Conclusions
The reliability calculation of the large-scale demolition blasting is proposed in this paper. Matlab can be utilized to calculate the reliability of bundle-series compound initiation network. The bundle-series compound initiation network is very reliable, but in practical project, other factors, i.e. construction efficiency, safety and economy should be taken into consideration when comparing the reliability of initiation networks.

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