A Case Study on Influence of Subgrade Slope Blasting on Existing Bridge Safety

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Abstract: With the rapid development of China highway, the road network is constantly encrypted, which brought more and more construction projects that have affected the structure and running safety of existing highway facilities. In this paper, the safety of existing bridge under the influence of roadbed slope blasting is analyzed according to the project case. According to the characteristics of blasting vibration, the safety evaluation standard of bridge structure are compared and analyzed, by which a more reasonable safety standard for bridge vibration is put forward. Based on the kinetic principle, the propagation and attenuation of blasting seismic wave and its influence are analyzed by theoretical analysis and numerical simulation. Then the corresponding construction control measures are established with the result, which ensure the safety of the existing bridge during construction. The experience presented in this article may provide a useful reference for other projects when a similar situation is encountered.

Keywords: Blasting Construction, Bridge Structure, Blasting Vibration, Control Standard, Risk Control.

1. INTRODUCTION

In recent years, the rapid development of China's transportation infrastructure has led to an increase in the number of cross-constructions between multiple roads, and blasting construction around the existing roads has also occurred from time to time. Because Chinese law stipulates that blasting shall not be carried out within a hundred meters on both sides of the operating road, the establishment of a warning zone on the road during blasting construction will make it impossible for vehicles to pass, which also reduces its impact on traffic safety. However, the impact of blasting on the safety of existing highway structures is still not negligible, and the impact on bridge engineering is of great concern.

Scholars have conducted studies on the safety assessment of bridges under blast loading. A.Islam[1] evaluated the safety of the bridge under blast load using the design method based on the probability specified by AASHTO. A.R.Al-Wazeer[2] conducted a risk assessment of the bridge and gave a risk-based bridge maintenance strategy. K.N.Suthar[3] analyzed the force conditions under the blast load and the structural damage was divided into three levels: immediate occupancy (IO), life safety/LS, and collapse prevention/CP. With regard to the study of blasting vibration safety standards, as early as the 1920s, the United States and the former Soviet Union[4-5] carried out work on the structural explosion safety criteria. Zhi Zhixin[6] studied the blasting vibration test and the method of determining the safety standards for building structures; Zhao Mingsheng[7] studied the safety standards of buildings (structures) under the action of blasting earthquake; Luo Yi[8] integrated The study has summarized and summarized the safety criteria for blasting vibration. As the shock wave generated by explosion has a high degree of non-linearity, and the action time is very short, it is extremely difficult to obtain accurate calculation and analysis results. Therefore, the experience presented in this article may provide a useful reference for other projects when a similar situation is encountered.

2. PROJECT BACKGROUND

A new expressway crosses the built at an interchange location. Ramp C of the new expressway is a turning lane, which underpasses the existing expressway bridge. One side of the ramp is blasted for excavation. Cross construction site is shown in Figure 1 and Figure 2. The gully and slopes of the project site are covered with the Quaternary Holocene alluvium (Q_4^{al+pl}) and the upper Pleistocene floodplain (Q_3^{pl+dl}). The surface of the reservoir is partially filled with topsoil, and the underlying bedrock lithology is Yanshan early intrusive granite (γ_5^2). For the built expressway has not yet been opened to traffic, the safety impact of blasting construction on the bridge structure is mainly considered.

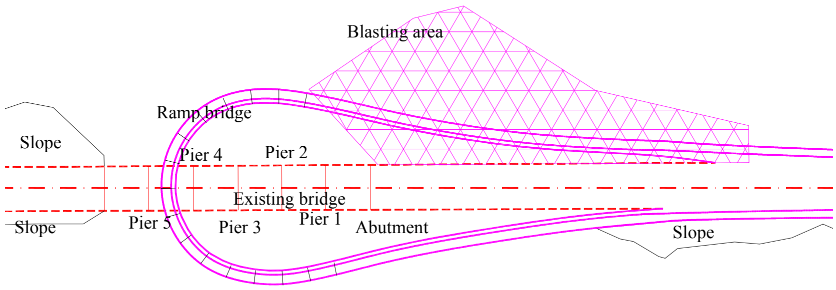

Figure 1: Project Plan

Figure 2: The Situation of The Built Bridge

3. VIBRATION SAFETY STANDARD OF BRIDGE

The damage characteristics of bridge structure under blasting seismic waves are mainly as follows:

(1) Direct damage to the bridge structure: The damage to the bridge structure is caused by the dynamic response caused by blasting vibration.
(2) Indirectly causing damage to the bridge structure: Blasting vibrations cause large ground displacement or instability (such as softening or liquefaction of saturated soil, collapse of the slope, etc.), which in turn causes damage to the bridge structure.
(3) Increase the degree of damage to the bridge structure: For old bridges or damaged bridges, the dynamic response caused by blasting vibration will increase the damage degree of the bridge.
(4) Multiple blasts cause cumulative damage to the bridge structure.

The damage of the bridge under the blasting seismic wave may have:

(1) The impact damage of the upper structure with the abutment caused by the longitudinal displacement;
(2) The ductile damage caused by excessive displacement of the bridge superstructure;
(3) Damage caused by excessive vertical force of the bridge superstructure;
(4) Bearing damage due to excessive bearing shear and bearing slippage;
(5) The damage of the piers caused by lack of bending strength, insufficient ductility and so on.

The ground vibration caused by blasting is a very complex random variable. Its amplitude, vibration period, or frequency changes with time and space. The influence of vibration on the bridge is also a complex process, and it is difficult to obtain accurate answers through theoretical analysis. At present, there are two specific methods for the safety criteria of blasting vibration, which are the peak velocity evaluation method and the seismic intensity method of blasting. The former Soviet Union has always used the ground peak vibration speed as a criterion, and used the safety distance as a control standard to guide the blasting project. European and American countries have experienced safety criteria such as blasting vibration speed, vibration acceleration, and vibration energy ratio. The USMB and the OSMRE used peak tremor as a safety control standard to guide the blasting project. China's "Blasting Safety Regulations" uses the maximum particle velocity at different frequencies as a safety criterion. At present, the vibration control standards given by various countries are mostly the standards of reinforced concrete or building, and the vibration standard of bridge are not clearly given.

According to China's "Blasting Safety Regulations," the allowable vibration velocity for large-volume cast-in-place concrete is in the range of 7 to 12 cm/s, which is larger than the foreign control standards. Combining similar engineering experience and considering certain safety reserves, this project takes 6cm/s as the allowable vibration speed value of the bridge.

4. IMPACT OF BLASTING ON EXISTING BRIDGES

4.1. Theoretical Analysis

Blasting vibration propagates in the form of waves. The attenuation of blasting vibration is closely related to such factors as the amount of explosives, the distance from the blasting source, the nature of the rock and soil, and the site conditions. At present, empirical formulas are mostly used in theory to analyze the law of vibration attenuation. The empirical formula establishes a quantitative relationship between the blasting vibration velocity and its influencing factors.

Sodev's formula gives the relationship between the velocity and the distance and the amount of explosives:

$$R=\left(K/V\right)^{1/\alpha}\bullet Q^{1/3} \tag{1}$$

In the formula,
R—blasting vibration safety allowable distance, m;
Q—the maximum single dose, kg;
V—allowable vibration speed, cm/s;
K,α—Coefficients related to topography and geological conditions, which shall be determined by field tests. Under conditions without test data, reference may be made to Table 1 for selection.

Table 1: Value of K and α

Rock properties	K	α
Hard Rock	50~150	1.3~1.5
Medium Hard Rock	150~250	1.5~1.8
Soft Rock	250~350	1.8~2.0

According to Sodev's formula, when the charge amount and distance are constant, the larger the K value, the smaller the vibration velocity. The roadbed slope adopts open-pit and deep-hole bench blasting using the technology of millisecond minute difference explosive, which can effectively control the blasting vibration and the generation of flying rocks. The maximum single shot dose is controlled within 29.4kg. According to the geological conditions of the project, take K=140, a=2. Whith the formula calculation, it can be known that the safety allowable distance of existing bridges during blasting is 15m.

4.2. Numerical Analysis

When the dynamic calculation is going on, we should load the blasting load by the means of equivalent stress on the nodes of FEM mesh that simulating the blasting hole. In this paper the calculation model of blasting load can be written as [9]:

$$P(t) = P_b f(t) \tag{2}$$

where P_b is pulse peak. In the condition of non-coupling continuous charge, the peak value of initial stress is as follows:

$$P_b = \frac{1}{8}\rho_0 D^2 \left(\frac{R_c}{R_b}\right)^6 \eta \tag{3}$$

Where ρ_0 is dynamite density, D is Detonation Velocity, R_c is equivalent radius of dynamite, R_b is the radius of blast-hole, η is pressure increase multiple when explosion products impact the hole wall which is usually valued 8～11. When the dynamite is non-coupling air-deck charge, we can calculate R_c by the principle of volume equivalent。

$f(t)$ is exponential time lag function, which can be written as:

$$f(t) = P_0\left(e^{-nwt\sqrt{2}} - e^{-mwt\sqrt{2}}\right) \tag{4}$$

where n and m are dimensionless damp parameters related to distance, the value of which determine starting point and pulse wave form of blasting pulse. P_0 is a constant that can make $f(t)$ take the maximum value 1.0 as t=t_R . t_R is usually called starting time of blasting pulse. w is a constant related to P-wave velocity c_p and the diameter of blasting hole:

$$w = \frac{2\sqrt{2c_p}}{3a} \tag{5}$$

t_R can be calculated by n, m and w:

$$t_R = \frac{\sqrt{2}\ln(n/m)}{(n-m)w} \tag{6}$$

P_0 is written as:

$$P_0 = 1/\left(e^{-nwt_R\sqrt{2}} - e^{-mwt_R\sqrt{2}}\right) \tag{7}$$

For each specific project, we can firstly give initial values of m and n, and then correct the two parameters by comparing measuring value and theoretical value to make the pulse wave form close to the measuring result.

According to the blasting design scheme, the blasting parameters selected during the calculation are shown in Table 2. The calculation method uses the equivalent load method to apply the blasting load to the model. The physical layer is simulated by the physical unit, and the relevant mechanical parameters can be seen in the calculation of the slope. The sides and bottom of the model are set as fixed boundaries without reflection, while the displacement boundary condition ux = uy = uz = 0 is satisfied; the top surface and the tunnel excavation perimeter are set as free boundaries. The model grid is shown in Figure 3.

Table 2: Blasting Parameters

Blast hole radius /m	**Detonation Velocity /($km \cdot s^{-1}$)**	**P-wave velocity /($km \cdot s^{-1}$)**	**m**	**n**	**Dynamite Density /($kg \cdot m^{-3}$)**
0.09	4.0	4.5	0.39	0.52	0.47

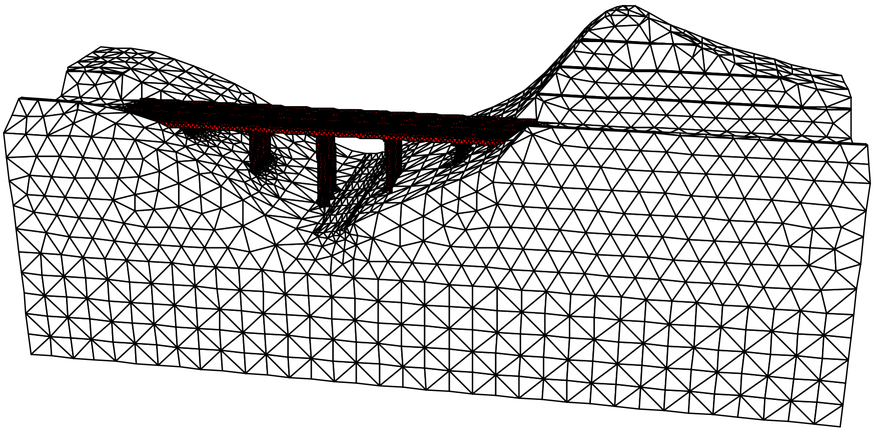

Figure 3: Numerical Model Grid

We calculate the bridge vibration taking the roadbed blasting point away from the bridge abutment 5m and 15m respectively. The calculated time-history curves of the abutment and each bridge pier vibration velocity (vector sum of vibration velocity in each direction) are shown in Figure 4 and Figure 5. The vibration of each point appears hysteresis with increasing distance from the blast point, and the maximum vibration speed of the abutment closest to the blasting point is obviously greater than that of other bridge piers. The maximum vibration speed is 5 cm/s at a distance of 5 m from the bridge, and 15 m from the bridge, the maximum vibration velocity is 7.8 cm/s, which are both greater than the theoretical analysis value and allowable vibration speed.

Therefore, in order to ensure the safety of the bridge as much as possible, according to the result of numerical analysis, it is considered that the blasting construction beyond 20 meters away from the bridge according to the existing scheme can ensure the safety of the bridge. For a distance of 7 to 10 meters, the maximum single-shot dose should not exceed 3 kg; for a distance of 10 to 15 meters, the maximum single-shot dose should not exceed 9.5 kg; for a distance of 15 to 20 meters, the maximum single-shot dose should not exceed. 15 kg. When the blasting point is within 7 meters of the bridge, mechanical excavation should be used for construction.

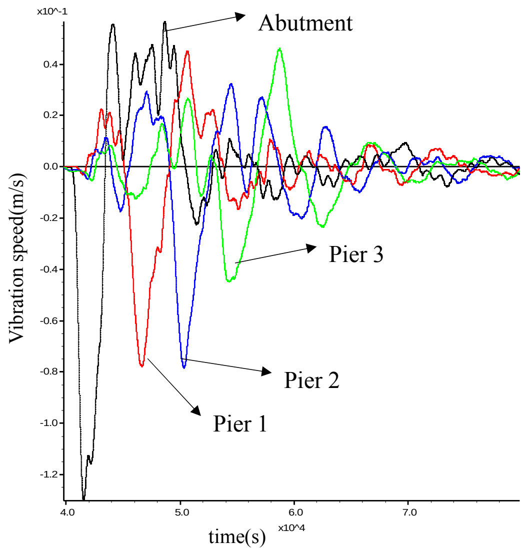

Figure 4: Curve of Vibration Velocity Vs. Time When Blasting Point is 5m Away From Bridge

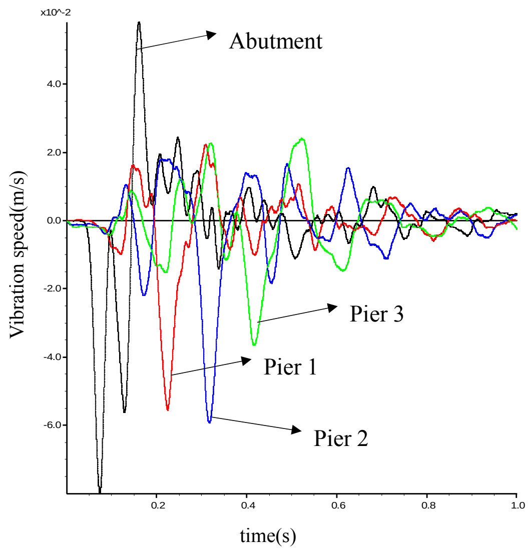

Figure 5: Curve of Vibration Velocity Vs. Time When Blasting Point is 15m Away From Bridge

5. CONSTRUCTION CONTROL MEASURES

5.1. Blasting Control Measures

(1) Slope blasting uses the technology of millisecond minute difference explosive. The maximum allowable single-shot dose is 29.4kg and the allowable distance for the existing bridge is 20m. When the distance is 7~10m, the maximum single-shot dose is 3kg; when the distance is 10m~15m, the maximum single-shot dose is 9.5kg; when the distance is 15~20m, the maximum single-shot dose is 15kg. Mechanical excavation is used within 7m from the bridge.

(2) Within 200m from the blasting point in the blasting time, it is a warning area. It is forbidden for people and vehicles to enter during blasting.

(3) Slope excavation is recommended to use sub-zone construction with blasting from far to near and the free surface orienting away from the bridge, using the barrier effect of the unexploded section to reduce the impact of blasting construction.

(4) Protective devices are installed between the roadbed and the bridge to reduce the impact of blasting flying stones on the bridge; pre-construction will be preceded by the use of pre-perforated crushing of the lone stones in order to prevent the larger rocks from falling and causing damage to the bridge piers.

5.2. Information Feedback During Construction

Considering the uncertainty of geological conditions, the bridge vibration speed should be monitored during construction, and the values of K and α parameters should be analyzed based on the corrected data of vibration velocity. According to the measured parameters, the vibration analysis should be carried out in time to guide the next blasting construction. If the vibration control requirements are not met, the blasting program optimization is needed.

5.3. Monitoring And Early Warning

During the construction period, monitoring points shall be set up to monitor the deformation and vibration speed of the bridge, and special personnel shall be assigned to inspect the external appearance of the bridge.

Risk management with three levels is set up according to the allowable vibration speed, using 2/3 of the allowable value as the warning value and 1/3 as the reference value. The warning rang is between the allowable value and the warning value and the attention range between the warning value and the reference value. When the actual measurement value is within the warning rang, warnings should be given and construction countermeasures should be taken to reduce the maximum single dose and the frequency of blasting; when in attention range, it should pay close attention; if the measured value is less than the reference value, construction can be continued.

The above construction measures are adopted during construction. The maximum vibration speed of the bridge during the entire blasting period does not exceed 1.5 cm/s, which effectively ensures the safety of existing bridge.

6. CONCLUSION

Characteristics of bridge failure under blasting vibration are analyzed through this case study. According to the vibration control standards of buildings in different countries and engineering analogy we give the allowance value of bridge vibration speed for this project. Through theoretical analysis and numerical analysis, the dynamic response of the bridge under the existing blasting scheme is calculated. It is believed that the construction can not meet the requirement of the bridge vibration speed control when the blasting distance is less than 20m. Based on this, we give the maximum explosive charge for different sections. Then the construction control measures of blasting near the existing bridge are proposed from the aspects of blasting control, information feedback during construction, monitoring and early warning and so on, which ensure the safety of the bridge structure during construction.

Acknowledgements

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References

[1] Slam A. Performance of AASHTO girder bridges under blast loading[D]. USA: Florida State University, 2005.
[2] Al-Wazeer A R. Risk-based bridge maintenance strategies[D]. Maryland: University of Maryland, College Park, 2007.
[3] Suthar K N. The effect of dead load, live and blast loads on a suspension bridge[D]. Maryland: University of Maryland, 2007.
[4] Mcanuff A L. Environmental guidelines for maring blasting[C]// The Second International Conference on Engineering Blasting Technique. Kunming：[s.n.], 1995：498－501.
[5] Dowding C H. Suggested method for blast vibration monitoring[J]. International Journal of Rock Mechanics and Mining Sciences, 1992, 29(2)：143－156.
[6] Yan Zhixin, WANG Yonghe, JIANG Ping, et al. Study on measurement of blast-induced seism and building safety criteria[J]. Chinese Journal of Rock Mechanics and Engineering, 2003, 22(11): 1907－1911.(inChinese)
[7] ZHAO Mingsheng, LIANG Kaishui, CAO Yue, et al. Discussion on the security criteria of construction(structure) of building under blasting vibration[J]. Blasting, 2008, 25(4): 24－27.(in Chinese)
[8] LUO Yi, LU Wenbo, CHEN Ming, et al. View of research on safety criterion of blasting vibratio[J]. Blasting, 2010, 27(1): 24－27.(in Chinese)
[9] LI Liang, ZHANG Bingqiang, YANG Xiaoli. Analysis of dynamic response of large cross-section tunnel under vibrating load induced by high speed train[J]. Chinese Journal of Rock Mechanics and Engineering, 2005, 24(23), 4259－4265.(in Chinese)