Critical Evaluation of Blast- Induced Structural Damage Criteria for Buildings around Metal Quarries at Thudugala, Kaluthara

Hettiarachchi MM, Priyasanka IDP, Herath HMWD, Mohanaruban G, *Dharmaratne PGR and Hemalal PVA

Department of Earth Resources Engineering, University of Moratuwa
*Corresponding author - dharme27@yahoo.com

Abstract: Quarrying can generate a number of on-site and off-site environmental effects as a result of blasting, excavation, crushing, screening, stockpiling and transport activities. Blasting is necessary for recovery of ore and production of aggregates in most underground and open cut mines, as well as in quarries. However, blasting can cause noise and ground vibration, which can have an impact upon nearby structures and people living close by. Hence, proper control of blasting practices is necessary to ensure both the safety of employees and the protection of the community from adverse effects. In Thudugala, in Kaluthura district, people those who are living close to quarries are highly subjected to these effects due to quarry blasting. In these circumstances, it was decided to conduct a research into the ground vibration impact in the area. Due to complexity of structures ranging from wattle-and-daub structures which do not have proper foundations to those built with good foundations, the applicability of single criteria of 5 mm/sec PPV level of vibration which is currently being used in Sri Lanka is inadequate. It is also noted that the above vibration criteria has been adopted in Sri Lanka without a proper theoretical foundation. In this research program, the propagation of cracks due to the blasting was assessed at the initial stage of the project. At the final stage, the optimum PPV values will have to be found for different types of structures by constructing them. In this area soil overburden is less. Therefore most of the structures have been constructed on rock. When blasting takes place, rock tends to vibrate and the intensity perceived is very high. Therefore crack propagation is high in these particular structures. It is also noticed that the cracks have further developed between the period between pre-blast crack survey and post-blast crack survey. It is due to large number of un-monitored blasts that have been conducted during that period. Therefore to solve this problem, it is recommended to carry out continuous monitoring of blasts.

Keywords: Peak Particle Velocity (PPV), Ground Vibration (GV), Air Blast Over Pressure (ABOP), Crack Survey

1. Introduction

Blasting is carried out to fragment intact rock enabling the earth moving equipment to excavate and haul the raw material at a minimum cost [1]. Blasting is still considered as the most economically viable large-scale rock breakage technique, which is inevitably utilized by mining and construction industries. Blasting dissipates a large amount of energy to the environment as well as to the ground [2].

Blast-induced damage in rock is a significant yet poorly understood area in the rock excavation industries. The prediction and control of blast damage has been traditionally done by approximate methods mostly based on experience rather than on understanding of the physical phenomenon. Perhaps the difficulties of experimentation and modelling in blasting, added to the significant imperfections of natural rock masses at every scale, the limited knowledge on material behaviour at very large stresses and loading rates have significantly limited the research in this area and therefore its understanding has been poor [3 and 4]. This study intends to fill this knowledge gap by providing a method to be applied to predict and control blast-induced damage in rock [5].

Thudugala area in Kalutara district was selected for this project due to the concentration of number of quarries and many complaints received from the people in the area regarding blast-induced structural damages. Other than that, the threshold PPV value which is used in Sri Lanka is not appropriate for Sri Lankan civil structures as they vary from poorly built wattle-and-daub structures to well-built civil structures. Therefore, the main task is to find the optimum PPV threshold values for Sri Lankan structures, giving due regard to constructional aspects.

2. Methodology

2.1. Awareness programs and discussions with relevant stakeholders

A discussion was held to obtain the views of the Divisional Secretary, Grama Niladari, representatives of the quarries and area representatives regarding the problem at hand. The views of both government officers and quarry owners regarding blast induced damages could be understood from these discussions. Areas with most of the damages incurred to civil structures could be identified through this discussion.

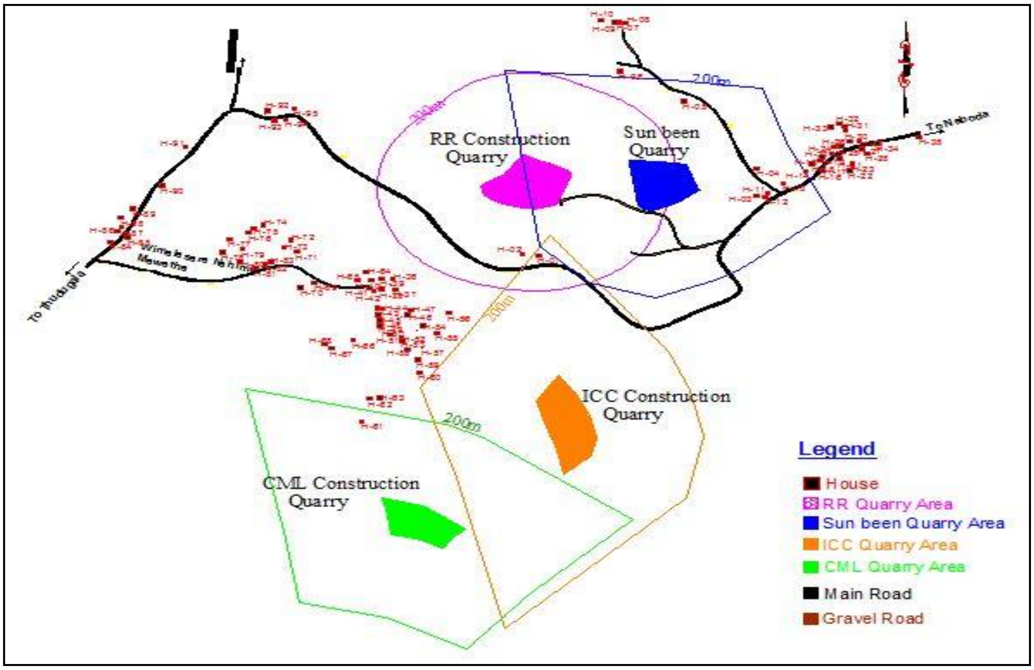

Figure 1: Location of houses within 200 m radius around the quarries

2.2. Identification of the structures which are mostly affected by the quarry-blasting

Initially, locations of the quarries and the mostly affected area from quarrying activities are to be identified. Then the civil structures in the area are to be categorized according to their foundation conditions and the distance from the relevant quarries.

2.3. Ground Vibration (GV) and Air Blast Over Pressure (ABOP) measurements at the nearest structures of quarries

Test blasts were carried out at ICC and CML-MTD quarries in Thudugala area and the GV and ABOP were measured. These readings were taken by means of a number of blast vibration monitors of "Blastmate III" series.

Table 1: The summary of measured blasts

Quarry	Number of blasts
ICC	150
CML- MTD	145
RR	95
Sunbeen	142
Total	532

2.4. Conducting crack surveys

Crack surveys were conducted to identify the extent of cracks and damages in identified structures. In relation to CML-MTD and ICC quarries, nine houses were found within the 200 m radius and in relation to the RR and SUNBEEN quarries, another nine houses were found within the 200 m radius. For convenience of the survey, cracks were classified.

To evaluate blast induced damage criteria for buildings, two types of crack surveys were conducted namely pre- crack survey and post-crack survey. Post-crack survey was carried out after three months lapse of pre-crack survey to assess the propagation of the noted cracks.

Table 2: Classification of blast-induced cracks

Crack width W(mm)	Classification
W < 1	Minor
1 < W < 3	Medium
W > 3	Major

3. Results and Discussion

3.1. Summary of the discussion with quarry stakeholders

Exchange of views and creating awareness among the stakeholders about this study was made during the discussion. A presentation was made to the audience by the study team regarding blasting and blast-induced-damage to the civil structures. Finally, the future strategic action was planned and a tentative time table was set for the project.

3.2. Results of measured GV and ABOP of test blasts

Table 3: Results of test blasts

Blast Monitoring Results						
11/13/2015						
Blast locations			Monitoring points			
			Location 1 (511m)		Location 2 (341m)	
Blast No	GPS Coordinates	Time	GV (mm/s)	ABOP (dB)	GV (mm/s)	ABOP (dB)
CM L #1	151290N 121151E	02:13 pm	0.095	110.9	1.310	106.0

03/16/2016						
Blast locations			Monitoring points			
			Location 1 (H-60)		Location 2 (H-63)	
Blast No	GPS Coordinates	Time	GV (mm/s)	ABOP (dB)	GV (mm/s)	ABOP (dB)
CM L #1	6.55957N 80.06029 E	11:48 am	0.25	101.9	0.12	104.1

03/16/2016						
Blast locations			Monitoring points			
			Location 1 (H-60)		Location 2 (H-63)	
Blast No	GPS Coordinates	Time	GV (mm/s)	ABOP (dB)	GV (mm/s)	ABOP (dB)
CM L #2	6.55957N 80.06029 E	12:04 pm	0.25	104.9	0.13	107.0
CM L #3	6.55957N 80.06029 E	12:12 pm	0.25	107.0	0.13	110.6
ICC #1	6.56305N 80.06219 E	12:49 pm	0.25	101.9	0.11	101.9

Table 4: Number of blasts within time duration (04/01/2016-24/03/2016)

Number of days spent for taking readings	84
Total number of Blasts	532

3.3. Results of the post-crack survey

Table 5: The summary of propagation of cracks in structures

Cracks type	% Propagation rate	
	Length	Width
Major	2.80	0.00
Medium	33.99	8.93
Minor	8.96	-

According to the results, when the major cracks are considered, their lengths have increased by 2.8% for the period of 84 days, but widths have not increased during this period. This has been the least compared to other crack types.

Medium crack lengths have increased by 33.99%. It is a considerable value compared to other propagation values. Crack widths also have increased by 8.93%. Minor crack propagation is negligible.

When a crack develops into a major crack, its propagation rate is low. However, in medium and minor cracks, propagation rate is very high. Firstly, a small crack forms as a minor crack. Then it develops into a medium crack and finally to a major crack [6].

Some cracks could not be identified, because of the modification of the structures. Propagation rates of cracks per blast for 20 holes are summarized in Table 6.

Table 6: Propagation rate per blast

Cracks	% Propagation rate	
	Length	Width
Major	0.005	0.000
Medium	0.064	0.017
Minor	0.017	-

4. Conclusions and Recommendations

4.1. Conclusions

In Thudugala area, cracks are propagated throughout the period. According to the results of this study, cracks propagated as shown below:

- Propagation of major crack length per blast = 0.53%
- Propagation of major crack width per blast = 0.00%
- Propagation of medium crack length per blast = 6.39%
- Propagation of medium crack width per blast = 1.68%
- Propagation of minor crack length per blast = 1.68%

As per the results, propagation rate of the cracks are in the following order:

Major Crack < Minor Crack < Medium Crack

During the time period, new cracks have formed in addition to the previous cracks. House No.H–04 is a special case because it has been constructed on the rock. Therefore the ground vibration intensity of that place is quite large compared to other places. Hence there were many cracks appeared in that house.

According to the data obtained during blast monitoring, PPV value and Air Blast Over Pressure have not exceeded the values specified in the Central Environmental Authority (CEA) guide lines. There have been no complaints during the project period of monitored blasts. However, people informed the project team that they felt very high vibrations and were strongly critical of the effects during the unmonitored blasting period.

In this area soil overburden is less. Therefore most of the structures have been constructed on rock. When blasting takes place, rock tends to vibrate and the intensity perceived was very high. Therefore crack propagation is high in these particular structures. It is also noticed that the cracks have further developed between the period of pre-blast crack survey and post-blast crack survey. It is due to large number of un-monitored blasts that have been conducted during that period.

4.2. Recommendations

To solve the problem of noise and ground vibration, it is recommended to carry out continuous monitoring of blasts. This project needs to be continued in the future by constructing houses with different foundations and building materials as planned, as the effect of blasting may be different on differently built structures.

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