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Underwater Blasting on Mithi River Extension: A Case Study

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Abstract- The Mithi River is confluence of the tail water dischargesof Powai and Virar Lakes, and flows through Sakinaka, Santacruz, Kalina, Vakola, BKC, Dharavai beforemeeting the Arabian sea at Mahim Creek, stretching over17.84 KM. As Mithi river was considered one of the reason for Mumbai flooding in year 2005 that paralysed the city. The Mumbai Metropolitan Regional Development Authority(MMRDA) has undertakendeepening the river bed, to increase discharge capacity ashard rock is encountered for stretch of 2 KM, where it meets Sea. This lead to bed rock blasting by specialized underwater blasting techniques near sensitive structures like flyover, Mahim Causeway, Dharavi Bridge, Railway Track and old Pipeline of water supply. Control of vibrations and fly rock were important objectives of the project along with desired fragmentation. Also,stop special attention has to be given on protecting Marine life. As we were approaching away from sea, tide head was not sufficient to conduct blasting under sufficient water head as chances of fly rock were to greater extent. Special Odex System of drilling was carried out in Overburden filling. Couplable Plastic Tube (CPT) Seismic Explosive used with Specific Charge ranging from 0.49 Kg/M³ to 0.59 kg/ M³ and specific drilling was0.88 to 1 M/M³ to restrict better fragmentation. Theground vibration limit was restricted below 10 MM/S, which was threshold limit given by CIMFR, considering nearby sensitive structures. The desired fragment size below 0.7 M³ was achieved without compromising safety standards. OB Filling and blasted rock can be easily removed throughout high tide by deploying 1 M³ bucketcapacity excavator.

Keywords - Underwater Blasting, Mithi River, Couplable Plastic Tube, ODEX system

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1. Introduction

Underwater blasting includes removal of rock which is fully or partly covered by water. The underwater blasting operation requires greater care and more thorough planning than similar operation above water. Both drilling and charging become more complicated and some faq`2ctors which have to be considered for the successful underwater blasting operation. During flooding of Mumbai in Year July 2005, MMRDA, Mumbai has undertaken deepening and widening of Mithi River. Bed Rock has to be blasted up to the depth of 1-2 m, to the stretch of 2 Km, where the river meets Arabian Sea. As area is covered by sensitive structures with adjoining fisherman colonies, railway track andwater pipeline including traffic which was unable to during blasting hours as shown in Fig.1.Special underwater blast design with due regards to vibrations and elimination of fly rock has to be considered while designing and executing blasting operation. Also, specialODEX drilling was carried out due to water head limitation and considering fly rock.

Although there is no indication of any marine life at the blasting site due to pollution of water as a precautionary measure the standard mitigation measures were adopted to avoid possible environmental impact to flora and fauna. For the purpose of the prevention of death or injury to marine mammals or turtles, the blast exclusion/observation zone was determines and monitored. This paper deals with blast execution, specialized drillingadopted and special care taken for protection of marine life controlling blast induced vibrations.

1.1 Geotechnical Information

The basic rock mass formation of the blasting site is basalt. These rocks consist primarily of a succession of basaltic lava flows with individual flow thickness varying between a few meters to 45 meters, with an average thickness of 10 to 15 meters. The two types of flow consist of compact nonvascular basalt and amygdaloidal basalt with zeolites as cavity filling material. Breccia also forms some intrusions. The compact basalts are relatively more jointed in comparison to amygdaloidal basalts, which generally have one joint set. The strike and dip of the compact basalt joint sets are: 450 – 2150 and 780 due North-West;1300- 3100 and 870 due South-West. The basalt rock is black in color and resistant to weathering because of their hard and compact nature. Flow of ground water through the jointing is more pronounced in the high-tide period. The joints are by and large tight with aperture < mm in general. Some of the random joints are filled with gouge on the wall near the roof. The average joint spacing varies between 0.30 to 0.50 m. The joints are slightly rough, irregular and planer. Since depth is very low and strata is of subsoil type, sometimes clay fillings were noticed in the joints. The core samples were collected from various blast sites and were subjected to laboratory analysis to determine the uniaxial compressive strength (UCS) and modulus of elasticity (E). The digital Schmidt hammer was used to obtain the in-situ strength of the rock mass. The RQD was range was decided based on measurement of joint volume. The uniaxial compressive strength of basalt from Pointload testing was 74 MPa and the strength from Schmidt rebound hammer 51 MPa. The RQD was 80% and the elasticity modulus was 14.5 GPa.

1.2 Drill and Blast Methods

The most common methods presently in use forunderwater blasting are:

- Drilling and blasting through rockfill
- Drilling and blasting from platform
- Drilling and blasting with divers

Blasting with concussion charges Where the water is not too deep, it may be economically advantageous to make a rockfill overthe area to be blasted and drill and charge through the rockfill. The selection of methods can be considered by referring fig.2.

Figure 1. Underwater Blast Site with Important Civil and Sensitive Structures.

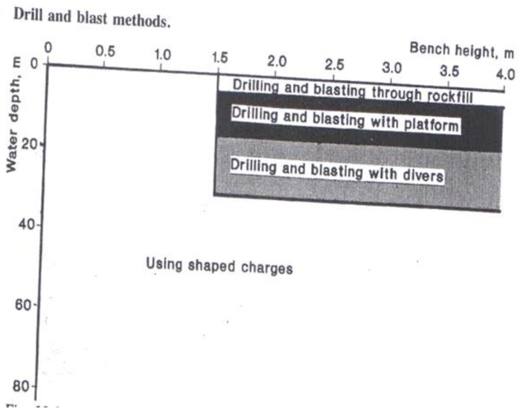

Figure 2. Economic Bench Heights and waterdepths for different methods.

1.3 Overburden Drilling (OD METHOD)

Drilling this so-called topsoil is often problematic as the ground collapses behind the drill bit. This makes it difficult to retrieve the drill string after drilling. In practice, the wellbore is often lost before the casing is used to support it. Other problems are caused by voids or porous bottoms that interfere with the circulation of flushing media and prevent drilling debris from being flushed out of the hole. In areas with mixed overburden or unknown drill ability, it is difficult to determine which tools excavators use to optimize overall results without risking down hole equipment loss. It Is difficult. The best solution to deal withsuch problems is to use ODEX (product of Atlas Copco), commonly referred to as the ODEX method.

With the ODEX equipment, deep holes can besimultaneously drilled and cased in all types of formations, even with large boulders. Casing diameters from 89 mm (ODEX 76) to 273 mm (ODEX 240) are available. The process is based on a pilot drill and an eccentric reamer working together to drill a hole slightly larger than the outer diameter of the casing. This causes the casing to follow the drill bit down the hole. With ODEX, part of theimpact energy is distributed through the shoulder of the guiding device into the casing pipe and strikes a special casing shoe at the lower end of the casing. In both DTH and top hammer drills, the casing is forced into the hole without rotation. Once the casing is in bedrock, pause drilling and slowly reverse to rotate the reamer in place.

Reduce the overall diameter of the drill assembly. Once this is done, the entire drill string can be pulled up from inside the casing, leaving the casing embedded in the rock. You can then continue drilling into the rock bed using a conventional drill string. Commercially availablestandard dimension steel tubes are used for the casing. In applications where the casing is reused, it is usually worth using threaded casing tubes (ODEX-T).

Before retracting casing from hole, PVC pipe of lesser hole diameter is to be inserted, so that it will protect hole during hole collapsing. Generally, in underwater blasting, blasting pattern is square, as Burden was 1.3m, as the same spacing and depth of hole was varying from 2.0 m to 2.25 m with specific Drilling of 0.59 to 0.79 M/M^3. Actual drilling by ODEX System at Mithi Riveris shown in Fig.3 & 4.

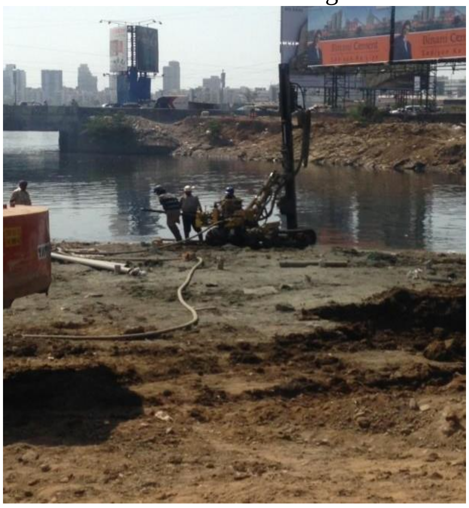

Figure 3. ODEX Drilling at Mithi River near Mahim Bridge

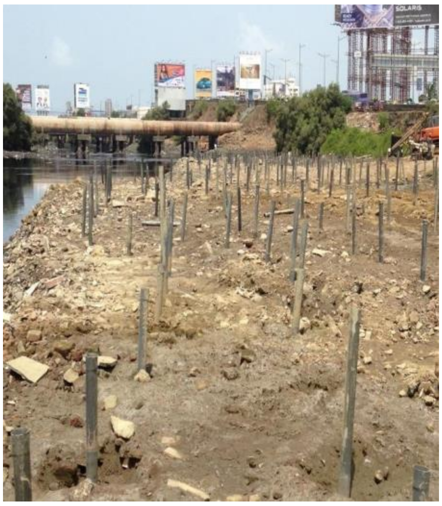

Figure 4. Holes already drilled by ODEX system in OB near water pipeline and busy road, in Mithi River Bed.

1.4 Charge Calculations

The most important factor in underwater blasting is to ensure good fragmentation and avoid stumps above the stipulated bottom. Normal bench blasting requires a specific charge of approximately 0.35kg/cu.m to ensure good fragmentation in quarry blasting. Since misfires can be expected in some blast holes, the specific charge is doubled in the case of underwater blasting to 1.00kg/cu.m. implying that if one of the blast holes does not detonate, but the adjacent holes do,the specific charge remains 0.50kg/cu.m.in this area. In the case of vertical holes, the specific charge shouldbe increased with approx. 10% to 1.10kg/cu.m.

In underwater blasting, the rock movement is obstructed by the water pressure, the weight of the overburden and the weight of the rock itself. To ensure good breakage and displacement of the rock, the specific charge is increased to compensate for these conditions.

The sub drilling should be at least of the same magnitude as the burden, but no less than 0.8 m. The hole depth is the bench height plus the sub drilling. The uncharged section of the hole should be 1/3of the burden.

$h_o = 1/3\ B$ (m) In deeper water, it is recommended that the hole is charged close to the blast hole collar to ensure displacement. If the holes are not charged close to the rock surface, the top of the rock is merely lifted and returns unbroken to its original position due to theweight of the water.

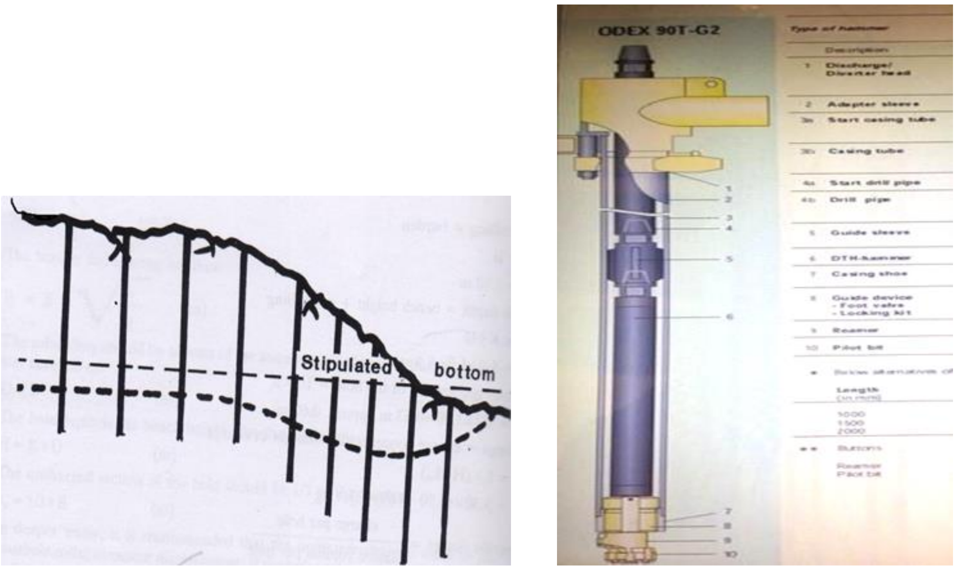

Figure 5. ODEX Drilling System Method with Reamer Collapsible Bit

Figure 6. Odex Drilling step-by-step

1.5 Opening the Cut

The result of the blasting operation depends on a successful opening of the cut, thus drilling and charging must be carried out with utmost carefulness. Often enough there is no free face against which the cut can be opened. Therefore, the first rows have to be drilled with a denser drilling pattern. In the case of inclined holes, the opening of the cut cause less problem than vertical holes, as shown if fig 5.

Fig.5. Opening the Cut for Free Face

1.6 Explosives

Explosives for underwater blasting should have high strength, good water resistance and should retain their sensitivity when subjected to hydrostatic pressure. Superpower Seismic Explosives mfg. by Solar explosives, India meet these requirements having VOD of 5000 M/S, Density of 1.20 g/ml and sleeping time of 30 days. Even though less sophisticated explosives can be used if the water depth does not exceed 10 meters and the time of exposure to water is short.

The explosive must give full detonation even when it has been stored under water for a long time as it must be taken into account that more often than not, unpredictable circumstances in underwater blasting, add time to the operation. Superpower Seismic Explosives are guaranteed to resist water for at least one week. Maximum charge per delay was kept to 3.0kg/hole/delay.

1.7 Blast Initiation

A reliable blast initiation system is required for underwater blasting and for this reason a non-electric millisecond delay detonator system must be used. Theseparation delay between successive explosive chargesmust be 9 milliseconds or more to ensure that reinforcement of detonation shock waves does not occur. Delays of 25 milliseconds or more will ensure that explosive charges will act independently of the preceding and succeeding explosive charges. The nonel imitation system reduces the vibration and air over pressure levels of underwater blasting. The blast hole charging was done with top decking and air curtains were used to reduce the pressure levels. Crushed angular rock will be used as stemming material. The sizing of the aggregate should be approximately 10% of the blast hole diameter. The use of an angular crushed rock in the stemming column instead of watercan have the effect of forcing the explosive gas energyto do more work on the rock mass thereby releasing a slightly lower pressure impulse into the water when thework is completed.

1.8 Blast induced ground vibrations control

According to the United States Bureau of Mines (Devineetal., 1963) established that ground vibration propagation from quarry blasts can be expressed by thefollowing general equation:

$$V = k\,(R/W^{0.5})^{b} \qquad \text{.........(1)}$$

Where:

V = peak particle velocity, in millimeters per second, R = distance from blast to monitoring point, in meters, W = explosive charge weight per delay, in kilograms, and K and b are site constants calculated from a regression analysis of measured data.

The following attenuation equation was derived from the trials conducted in similar rock formations and canbe used to predict peak particle velocity at the test sitefor hard rock conditions:

$$V = 1120\,(R/W^{0.5})^{-1.6} \qquad \text{.........(2)}$$

Maximum charge per delay used was ranging from 1- 3kg. According to the attenuation equation the maximum peak particle velocity (mm/s) at various distances is given in Table 1.

Table 1. Blast induced peak particle velocity (mm/s) at various distances

Distance, m	Peak particle velocity, mm/s
20	9.28
25	6.49
30	4.85
40	4.23
50	3.73
60	3.33
70	3.01
80	1.76
90	1.46
100	1.23
110	1.06
120	0.92
130	0.81

As the vibration limits with a frequency range of 10- 25Hz,are within 10 mm/s up to 20m, it is considered as safe vibration intensity from the structural safety point of view. Fly rock

There was practically no fly rock in all the blasts. This is due to precise blast design as well as sufficient and OB cover of 3.5 m due to which no cases of ejected fly rock. This helped in conducting blasting operations without interrupting the traffic which was about 30 m from the blast site. Therefore, all the blasts were safer to the surrounding public and habitats. Use of nonel initiation system also helped in containing the fly rock.

1.9 Blast Induced Explosion pressure

The ultimate pressure impulse transmitted through water by the detonation of confined explosive charges underwater is an integration of the pressure pulses created by propagation of the seismic shock pulse across the rock water interface, the onset of rock movement, and the expansion of the explosive gases into the water.

The propagation of pressure impulse through thewater is dependent on;

1. The hydrography of the site,
2. The water depth
3. The propagation characteristics of the soundunderwater.

The popular model for the prediction of the pressure impulse from blasting has been referenced below.

The ICI Handbook of Blasting Tables (1987) specified that the following equation may be used to predict the peak pressure for a confined underwater blast:

$$P_c = 21{,}840\ (R/W^{1/3})^{-1.13} \quad \ldots\ldots\ldots(3)$$

where:

P_c = peak pressure, in kilopascals.

W = explosive charge weight, in kilograms.

R = distance from the explosive charge, in meters,

The Australian Standard 2187.2-2006 Explosives – Storage and Use – Use of Explosives states that a peak pressure of 40 kPa is safe to humans and animals. Oriard (2002) demonstrates the typical pressures generated by underwater blasting can bereduced significantly below the level of Equation 3 as the depthof burial of the explosive charge in the rock mass is increased, that is the distance from the top of the explosive charge to the top of the blast hole is increased. Oriard (2002) also demonstrates that the useof air curtains around the underwater blasting operations can further reduce water pressures generated in the surrounding water mass.

The explosion pressures were measured by state of art instruments like hydrophones and charge conditioning amplifier as well as blast pressure monitoring instruments like minimate of Instantel Inc., Canada,. The attenuation equation derived from the experimental data for similar sites is as follows:

$$P_c = 1945\ ((R/W^{1/3})^{-1.13} \quad \ldots\ldots\ldots(4)$$

According to the attenuation equation the peak pressure (kPa) at various distances is given in Table 2.

Table 2. Blast induced peak pressure

Distance, m	Explosion pressure, kPa
10	117.20
15	71.46
20	50.31
25	38.32
30	30.68
35	25.42
40	21.60
45	18.71
50	16.45
55	14.64
60	13.17
65	11.94
70	10.91
75	10.03
80	9.27

According the internationally accepted AustralianStandard (2006) the pressure limits of 40 kPa is considered as the threshold limits although 100 kPa waswas used as the safe limit for fish farms in Hong Kong.From the Table 2, the 40 kPa pressure is occurring within 25m from the blast site. This indicates thatthereis no effect of blasting on marine life beyond 25mdistance from blasting zone. Therefore, plastic wire netsof 1-2mm mesh size were spread at a distance of 25m to screen out the marine life to enter in to the blasting zones. This assured the safety of marine life at the underwater blasting site.

1.10 Mitigations measures for minimizing impacts onmarine life

Although there was no indication of any marine life at the blasting site due to pollution of water. As a precautionary measure the standard mitigation measures were adopted to avoid possible environmentalimpact to flora and fauna. For the purpose of the prevention of death or injury to marine mammals or turtles, the blast exclusion/observation zone was determines and monitored in the following manner:

1. At least one day prior to the commencement of the construction, a temporary blast exclusion /observation zone, nominally 100m in all the directions from blast site was implemented. The temporary exclusion zone was demarcated with marker buoys along the outside (deployedat 100m)and additional buoys was placed at 50m from the proposed area of blasting.
2. Visual monitoring for the presence of marine mammals within 100m radius of the active blasting area was undertaken. Visualmonitoring was commenced at least 60 minutesprior to each blast using binoculars and the naked eye from the boats positioned within 50m of the drill and blast area. Visualmonitoring continued until the blast has been detonated.
3. During blasting, visual observationswithin the 100 m observation zone was maintained continuously to identify if there are any marinefauna present.

Sound pressure was measured at a distance 100-200 m from the blast site with an autonomous hydrophone. Following each blast, the blast sound pressure levelwas measured and recorded to confirm compliancewith the 40kPa threshold.

2. Conclusions

The underwater trial blasts conducted with optimized blast design parameters at Mithi river extension project were fruitful in containing the side effects of blasting i.e., ground vibrations, air overpressure and fly rock. Blast data was generated on fragmentation, ground vibrations and Fly rock analyzed for blast performance assessment. Fragmentation size was within the bucket able range of Excavator and was easily able to lift and load bucket in Dumpers. OB filling also had a added advantage that it acted as a ramp and platform for dumpers, where excavator can directly load. This also eliminated the practice normally practiced of placing excavator on platoons and loading, thus saving lots of cost in rehandling of blasted material. By keeping maximum charge of 3 Kg/Hole/delay also helped us in controlling vibrations below 10mm/sec, which was the threshold limit provided by CIMFR andCWPRS. Also, due care was taken in protecting flora and fauna of river. Sufficient OB cap helped us in containing Fly rock. This also helped us in conducting blasting operations without interrupting the traffic which was about 30m from the blast site. The application of optimized techniqueshelped in enhancement of both safety and productivity of underwater blasting.

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