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MEASUREMENT OF VIBRATION IN BERTHING STRUCTURE DURING UNDERWATER ROCK BLASTING

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ABSTRACT

Blasting, in particular underwater rock blasting is the most challenging and least understood source of vibration, which may cause considerable damage to the safety of the adjacent buildings and structures and including berthing structures. Though the blast-induced vibration is best controlled by specification of blasting procedures, it is very essential to measure and monitor the blast-induced vibration of the adjacent structures to access its safety. This paper discusses the measurement and monitoring of underwater blast induced vibration on the berthing structure (berth No.8) at Tuticorin in southern part of India. The vibration is recorded using three acceleration transducers mounted on the deck slab of berthing structure and monitored using a data efficiency system consisting of HBM make multi channel carrier frequency amplifier system with digital storage oscilloscope. It is observed that the peak vertical acceleration is much higher than the longitudinal and lateral peak acceleration, because of vibration of deck slab along with frequency of ground excitation. The peak particle velocity (PPV) is obtained from the time history of acceleration by simple integration. From the spectral analysis, the predominant frequency is found as 26 Hz. For this frequency the allowable PPV value is established from various standards as 25mm/sec. The measured PPV values fro all blasts (31 nos) are well below the limit of allowable PPV value, except in few blasts, which shows the berth is safe against underwater blast induced vibration. Pre and post crack survey also proves that there is no considerable damage to the berthing structure.

INTRODUCTION

Soil and rock dredging is the most common and essential operation for the construction and establishment of berthing structures in the ports. The rock dredging is often executed by blasting technique in which the hard bedrock is fragmented for further stages during dredging such as loading and transportation of fragmented rock. Blasting is the most commonly adopted technique for rock dredging.

During blasting, high explosive charges release large amounts of energy in two distinct forms, shock energy and gas energy (Narin van Court and Mitchell 19995). Shock energy results because the rate of reaction in a high explosive is greater than the speed of sound in the explosive material and forms a shock wave, which impact the surrounding ground, which in turn becomes the source of vibration to adjacent structures including coastal structures, which may undergo severe damage.

Most blast design control vibration levels by restricting the amount of explosives detonated at any instant of time (delay). Design must also ensure that enough explosive is detonated within a given volume of rock to fragment it sufficiently for removal. Blast design mainly based on the use of ground vibration propagation equation, which is established by conducting trial blasting. However, it is difficult to measure ground vibration due to underwater rock blasting adjacent to the existing berthing structures. In such cases, monitoring of blast induced vibration is best controlled with a performance specification such as an allowable peak particle velocity at different frequencies rather than a specification of procedures.
Peak particle velocity is the measure of the level of vibration, and it should be measured with the sophisticated instrumentation system. The control of peak particle velocity is by two approaches (Dowding 1996). The first approach is distance related, with no consideration of frequency and requires that each shot to be monitored with a suitable recording system. The second approach requires the monitoring, recording and analysis techniques that provide complete frequency information since maximum peak particle velocity is frequency related.

In the present study, underwater rock blast induced vibration on the newly constructed berthing structure (Berth No.8) of Tuticorin port in the southern part of India is monitored using a data acquisition system consisting of acceleration transducers, digital carrier frequency amplifier system with digital storage oscilloscope. Frequency-based limits for the peak particle velocity is imposed to control the blast induced vibration for the safety of the berthing structure.

SITE PROFILE

The typical site profile near the Berth No. 8 and in the region of blasting is shown in Fig. 1. It is clear from Fig. 1 that, the average water depth is about 8 m. The stratification below the seabed predominantly consists of soft sandy silt/ silty sand of about 1.5 m thickness followed by weathered/hard rock. This rock is brown to mottled, fresh strong limestone / calcarenite to calcirucite. The RQD of the rock varies from 0 to 57 %. The physical and engineering properties of the rock obtained from laboratory tests carried out on intact rock core samples is shown in Table. 1. It is decided to increase the water depth from 8 m to 12 m to accommodate big ships into the berth. Hence, dredging work is planned for excavating the deposit for about 4 m below seabed level. After the soft soil deposit has been scooped out, the weathered and hard rock is to be fragmented for dredging. Hence it is decided to adopt underwater rock blasting technique for fragmentation of weathered/hard rock to enhance the dredging operation.

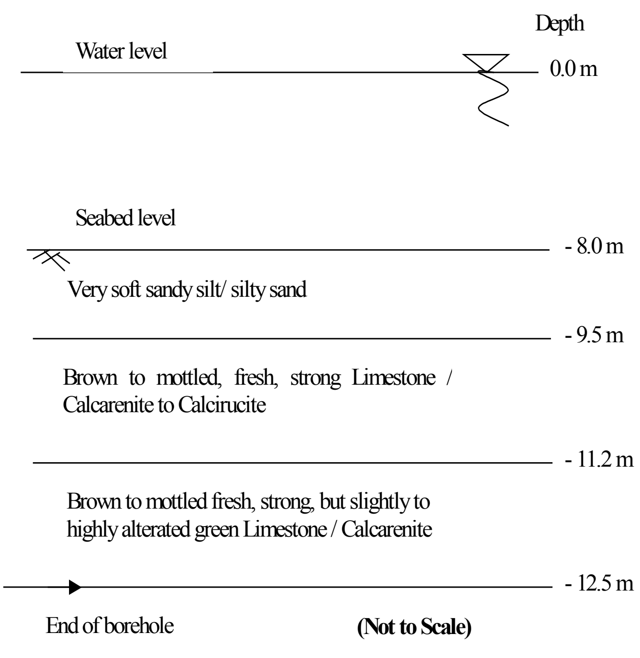


Fig. 1. Typical site profile in the blasting area and near the Berth No. 8

Table 1. Properties of weathered / hard rock

Core No.	Core Length, m	RQD, %	q_u MN/m^2	E_s MN/m^2	ν
C1	1.00	42	74.70	95.24	0.24
C2	1.27	16	34.51	30.00	0.30
C3	1.39	17	20.53	51.35	0.32
C4	0.74	0	21.97	40.00	0.37

BERTHING STRUCTURE

The Berth No. 8 was designed for a live load of 50 kN/m^2. The overall length of the wharf is 325 m and the breadth is 30m. The berthing structure is supported by 275 piles having diameter of 1200 mm. The spacing of piles in longitudinal direction is 5.5 m c/c and in the transverse direction is 6.2 m c/c. The founding level of the pile is - 22 m. A fixity depth of 3 D in rock has been assumed for the calculations. The maximum expected size 'of the vessel is 65,000 DWT. The top level of the deck is + 3.65 m. The location of Berth No. 8 and area of blasting is shown in Fig. 2.

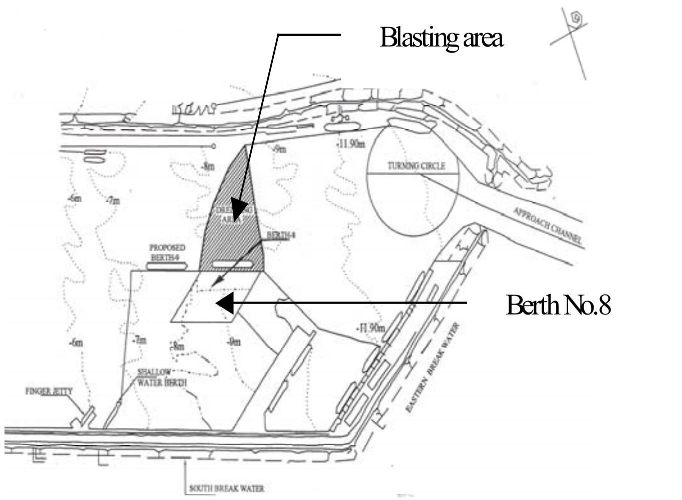


Fig. 2. Layout of Tuticorin port showing location of Berth No. 8 and Dredging / Blasting area

BLAST DESIGN

Based on the trial blasting, the contractors have adopted the following procedure of blast design. It is decided to drill holes of 110 mm diameter up to a depth of 4.5 m into seabed rock. The holes are arranged in a number of rows. There are five types of layout of blasting pattern. The typical blasting pattern for layout no. 5 is shown in Fig. 3, which has a provision for a maximum of 50 holes in five rows.

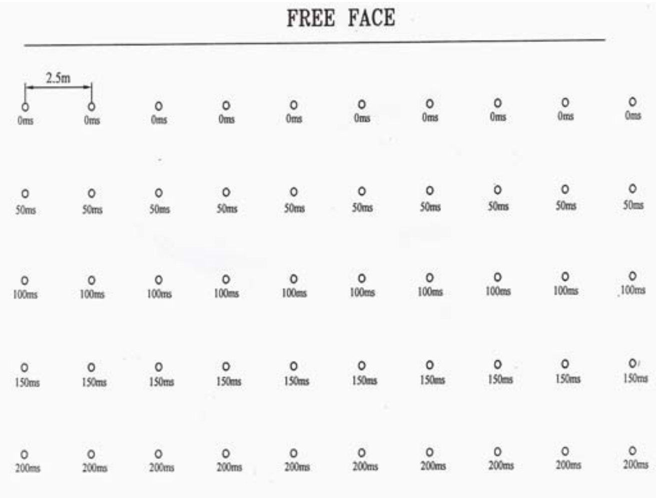


Fig.3. Typical blasting layout no. 5 for rock dredging
(No. of holes / blast – 50)

These holes were filled with 2 kg charge of kelvex-800 CPT type explosives. Excel initiation system is used for detonation. In each row, there is a time delay of 25 m.sec and 50 m.sec. The whole operation of blasting takes place in 800 - 1000 m.sec Blasting is conducted two to three times a day. Normally, on a blasting day, 1 to 5 rows and 8 to 50 holes are detonated .The summary of blast parameters adopted is given below.

- Diameter of the hole : 110 mm
- Depth of the hole : 4.5 m
- Charge per bore hole : 2 kg
- Type of explosive : Kelvex-800 CPT
- Average spacing : 2.75 m
- Delay time : 25 m.sec, 50 m.sec
- Charge / Delay : 2 kg

Pre-Dredge Survey

In order to determine the actual quantum of material to be dredged, a detailed hydrographic survey including sounding and probing is undertaken by Jet probing method, during which, the initial rock profile below the seabed is also established simultaneously. Jet probing method consists of a long metal pipe having nozzle tapered to an orifice of 20 m inner diameter with sufficient length graduated to an accuracy of 5 cm reading fitted at one end. Water is pumped through the pipe so that a minimum water velocity of 20 m / sec is maintained, when the nozzle is at a depth of 17 m below sea water level. A suitable pump with prime mover is provided to maintain continuous uninterrupted supply of 7 litres / sec at a pressure of 7 kg / cm^2 measured at sea level.

DRILLING OF BLAST HOLES

Drilling and blasting operations have been carried out from a floating drilling barge/vessel. It is proposed to install drill machines, which is compressed air operated with drill masts. Details of the installations on the pontoon are given below. With one setting of the Barge, 10 number of blast holes have been drilled. By shifting the barge to next location, another set of 10 holes has been made. It is proposed to repeat the procedure in order to get 50 holes in 5 rows, which will form a round. It is proposed to use confined charges. This has been done by drilling the blast holes of required depth and charging the holes with appropriate quantity of explosives. Slurry explosives available in the form of coup able tubes have been used along with initiating the explosive charges. Simultaneous drilling and charging method has been followed. The following methodology is adopted to make blast holes:

- Initially a casing pipe is lowered to the hard rock bottom, penetrating through the slush.
- Then the drill rod with bit is lowered and drilling has been commenced.
- After completion of drilling, the drill rods are recovered.
- Appropriate quantity of explosive charges is dropped into the hole.
- The casing pipe is withdrawn after charging the holes.

VIBRATION MEASUREMENT

The vibration measurement have been carried out on top deck level of Berth No. 8 along the eastern side of the berth, which is nearest points from the blasting locations. The blasting is carried out at a distance of 50 m to 124 m from the berth. Three HBM make acceleration transducers mounted in orthogonal directions on a wooden plank are fixed on the top of the deck level to measure the vibration of berthing structure in vertical, longitudinal and lateral directions. The acceleration transducers are connected to the Data Acquisition System consisting of HBM make digital carrier frequency amplifier and Agilent make digital storage oscilloscope with storage through floppy to measure the vibration response of Berth No.8 during blasting. The vibration traces were stored in floppy diskettes for further analysis in the laboratory. The vibration of berthing structure is observed and recorded for each shot of blast hole.

ANALYSIS OF VIBRATION DATA

Time Domain Parameters

The vibration data obtained during blasting are acquired and processed. The typical time-histories of vertical, longitudinal and lateral acceleration of berthing structures during blasting are shown in Fig. 4.

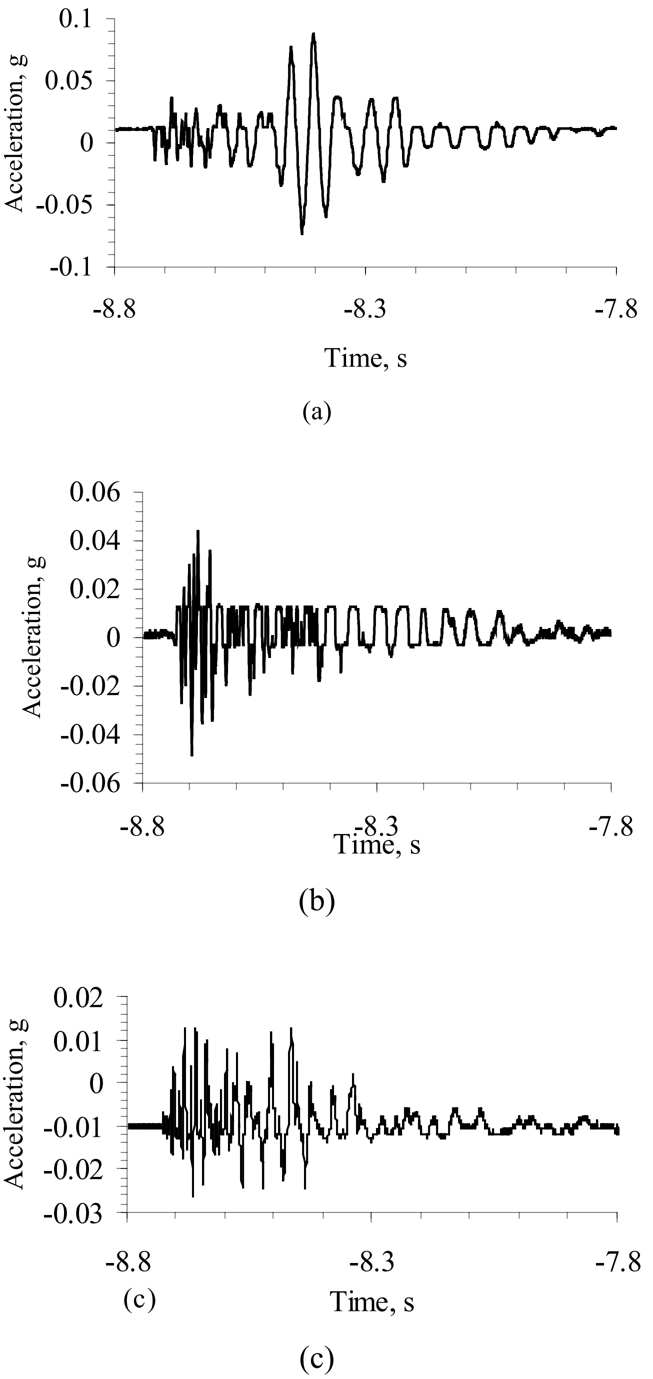


Fig.4. Typical time history of acceleration recorded during Blast No. 10 for (a) Vertical (b) Longitudinal (c) Lateral

It is observed from Fig. 4 that, the total duration of structural response is about 800 m.sec - 1000m.sec. It can also be observed from Fig. 4 (a) that, the vertical component may be divided into two parts: initial P-wave component and remaining part as shown in Fig. 4. It clearly indicates that, the compression wave components in the direction of source to receiver arrived first, and then vertical component reflects back and forth inside. But, from Fig. 4 (b) & (c), it is observed that, the initial part of time history has high frequency content and thereafter just free vibration of deck slab, which indicates that, the berthing structure vibrates along with the frequency of ground excitation initially and then only the deck slab of berthing structure vibrates freely at its natural frequency.

Table. 2. Three components of recorded acceleration

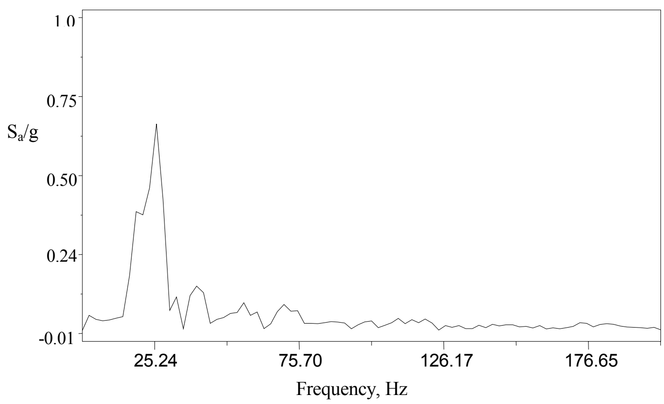
Blast No.	Dist* m	Blasting Details		Peak Particle Acceleration g		
		No. of Holes	No. of Rows	Verti.	Long.	Lat.
1	52	08	01	0.434	0.307	0.062
2	55	27	03	1.080	1.070	0.214
3	64	23	03	0.807	0.324	0.125
4	73	28	04	0.173	0.211	0.045
5	91	29	04	0.108	0.132	0.067
6	104	41	05	0.136	0.137	0.025
7	124	29	03	0.188	0.211	0.045
8	50	22	02	0.225	0.325	0.110
9	117	37	05	0.168	**	**
10	139	27	04	0.009	0.004	0.003
11	179	21	03	0.005	0.001	0.001
12	48	06	01	0.062	0.065	**
13	48	06	01	0.055	0.067	**
14	50	06	01	0.048	0.005	**
15	50	11	01	0.132	0.132	**
16	46	06	01	0.089	0.063	**
17	46	06	01	0.078	0.078	**
18	46	06	01	0.056	0.078	**
19	46	06	01	0.064	0.077	**
20	40	07	01	0.101	0.084	**
21	40	07	01	0.053	0.087	**
22	40	07	01	0.093	0.081	**
23	40	07	01	0.035	0.052	**
24	40	07	01	0.070	0.057	**
25	44	07	01	0.033	0.067	**
26	44	07	01	0.097	0.106	**
27	44	07	01	0.100	0.080	**
28	44	07	01	0.057	0.054	**
29	44	07	01	0.106	0.134	**
30	44	07	01	0.088	0.068	**
31	44	07	01	0.102	0.204	**

* Distance from the Berth No. 8
** Not measured
Charge per hole for blast no.1 to 19 = 2 kg
Charge per hole for blast no.19 to 31 = 3 kg

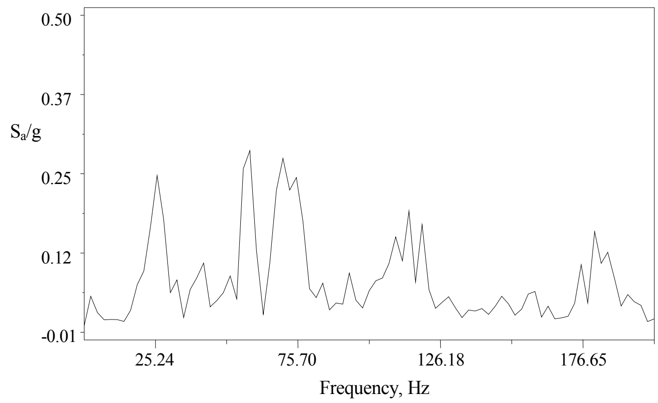
The recorded values of three components of vibration for all blasts are given in Table. 2. It is observed from Table. 2 that, the maximum peak acceleration in the vertical mode of vibration is much higher than the other two modes of vibration. This is due to the fact that, the P-wave travels even in water, which may dissipate its most of the energy associated during blasting. Whereas, S-wave will not travel in water, but travel only through bedrock, in which, energy dissipation is much lower and thereby produces predominantly vertical vibration. The maximum peak vertical acceleration is about 1.08g occurs at a distance of 55 m from the face of Berth. The peak particle velocity and displacement in three orthogonal directions determined from the time history are given in Table. 3. From Table. 3, it can be seen that, vibration displacement in vertical is higher than longitudinal directions and lateral directions, because of high energy content associated with the vertical vibration.

Frequency Domain Parameters

The PC-based DAS and associated software, DASYLAB is used to analyse the time domain parameters and transform into frequency domain parameters using Fourier transform technique. The typical spectral acceleration amplitude versus frequency plot obtained from the analysis time history using the software is shown in Fig. 5.



(a)



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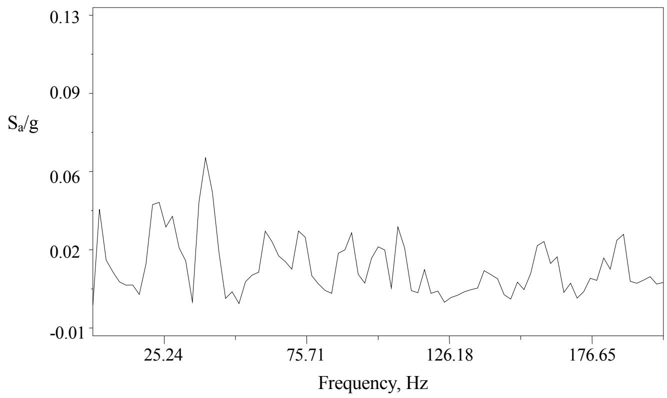


(c)

Fig.5. Typical spectral acceleration amplitude versus frequency plot (a) Vertical (b) Longitudinal (c) Lateral

Table 3. Peak particle velocity

Blast No.	Peak Particle Velocity mm/sec		
	Vertical	Longitudinal	Lateral
1	33.50	13.25	1.58
2	37.60	19.15	3.75
3	28.60	08.50	2.70
4	14.60	04.86	1.20
5	04.26	01.06	0.85
6	05.10	01.90	0.66
7	02.90	01.23	4.40
8	19.90	03.32	0.90
9	3.50	*	*
10	2.60	0.78	0.58
11	0.23	0.11	0.05
12	3.73	3.93	*
13	3.30	4.00	*
14	2.88	0.30	*
15	7.93	7.93	*
16	5.34	3.73	*
17	4.68	4.68	*
18	3.36	4.68	*
19	3.84	4.62	*
20	6.07	5.04	*
21	3.18	5.22	*
22	5.58	4.86	*
23	2.10	3.12	*
24	4.74	3.42	*
25	1.98	4.02	*
26	5.82	6.36	*
27	6.00	4.80	*
28	3.42	3.24	*
29	5.82	8.05	*
30	5.28	4.08	*
31	6.12	12.25	*

* Not measured

From Fig. 5, it is clear that, the spectrum has the high frequency component (25 to 175 Hz) and low frequency component (2 to 25 Hz). The spectrum of vertical acceleration has the predominant frequency of 26 Hz. Fig. 5 (a) indicates that, the energy of the initial P-wave in vertical acceleration is distributed in the narrow frequency band, but the longitudinal and lateral spectral accelerations are distributed in the wide frequency band (Kramer 1996). This indicates that, the energy in the vertical acceleration spectrum is more and concentrated at almost one frequency, wherein; the energy is widely distributed in the spectrum of longitudinal and lateral accelerations. The low – frequency component is probably a complex interaction of the progression of blasting delay intervals, the amplified transverse motion of the wall and possible longitudinal standing waves in the wall. Free vibration analysis of berthing structures is carried out using STAAD/Pro software. The natural frequencies of berth are presented in Table 4. It can be noticed from Table 4 that, the predominant frequency obtained from the vibration data is very close to estimated second modal frequency of 26 Hz.

Table 4. Natural Frequencies of Berth No. 8 using STAADPro

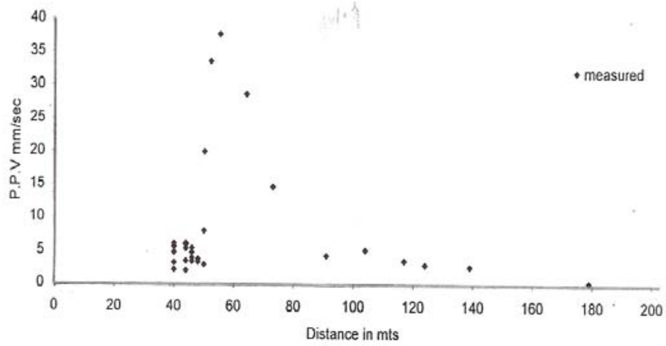
Mode No.	Natural Frequency Hz
1	01.059
2	26.096
3	48.503
4	64.474
5	72.721

CONTROL OF BLAST INDUCED VIBRATION

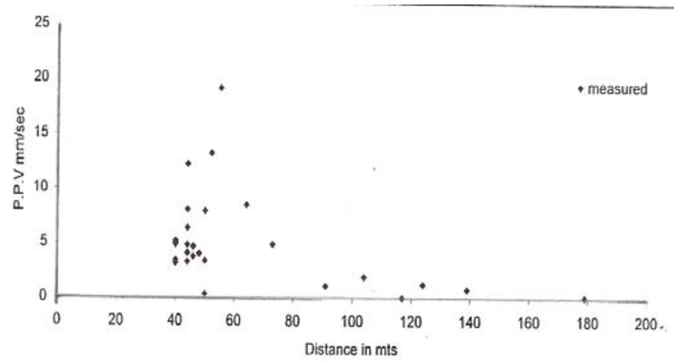
Maximum Peak Particle Velocity

The time history of particle velocity is computed by integration of measured time-history of particle acceleration. The peak particle velocities (PPV) calculated in vertical, longitudinal and lateral directions are given in Table. 3. The peak particle velocity varies from 5.1 mm/s to 37.6 mm/sec in vertical direction, from 1.23 to 19.15 mm/sec in longitudinal direction and from 0.66 to 3.75 mm/s in lateral direction. Table 2 & 3 show the details of the field vibration measurement carried out on the same point of Berth No.8 during 31 blasting. These blasting are carried out with the charge per hole of 2 kg, at various distances from the berth. Table 2 & 3 indicate that, the peak particle acceleration and velocity decrease with the increase of distance of blasting locations. However, the actual level of vibration is also dependent upon the blasting pattern (Number of rows, charge per hole and time delay). The estimated peak particle velocities for two blasting numbers 1 and 2 are practically same, even though the measured peak particle acceleration for blast No.2 is higher than for blast No.1. It is due to the fact that the structure vibrates at low frequency during blast No.1 than blast No.2.

For controlled blasting, PPV shall satisfy one of the following (1) Maximum PPV independent of frequency and (2) Maximum PPV dependent on frequency. In this case the blast control was carried out using the second method. From the spectrum analysis, the predominant vibration frequency is established as 26 Hz. The frequency based limit value of PPV is dependent upon the type of structures, the distance of the structures from the location of blasting. The Swiss standard SN640312 specifies the permissible PPV for reinforced concrete structures and steel structures (Category I) due to blasting for the range of 10 – 60 Hz is 30 mm/s. The German standard DIN 4150 recommends the permissible value for civil engineering structures due to blasting for the frequency of 25Hz is about 25 mm/s. The variation measured peak particle velocity (PPV) values with the distance from the berth is shown in Fig. 6. It is observed from Fig. 6 that, the measured PPV values during 31 blasts are well within the allowable PPV value of 25 mm/sec, except in few blasts. This shows, the established relationship is adequate towards the safety of the berthing structure. This indicates that the vibration level of berthing structure is well within the limit and it is not affected by the underwater blasting. Pre and post crack survey also proves this statement that, there is no damage to the berthing structure.



(a)



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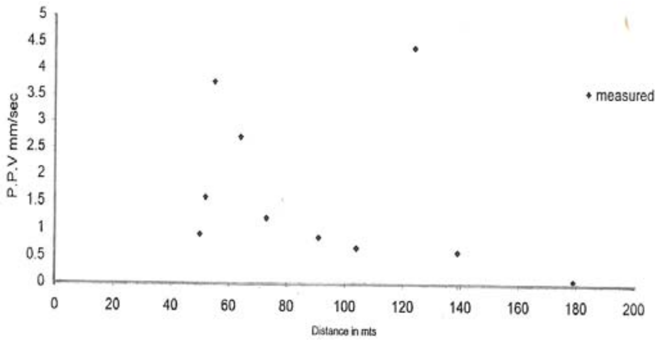

(c)

Fig.6 Recommended and measured peak particle velocity for (a) Vertical (b) Longitudinal (c) Lateral

Establishment of Attenuation Relationships

Using the field structural vibration measurement data the variation of PPV with the scale distance, D is plotted which is given in Fig.24. Based on the vibration data an exponential fit was made to establish the following attenuation equation.

$$V = 16\ e^{-0.0472D} \quad (1)$$

Where,

V = Peak particle vertical velocity (mm/sec) of structure
D = Scaled distance (m /kg)

SUMMARY AND CONCLUSIONS

Underwater blast induced vibration on the newly constructed berthing structure is monitored using a sophisticated data acquisition system consisting of three acceleration transducers and a digital carrier frequency amplifier system with digital storage oscilloscope. The observed and measured time histories of acceleration components are analysed towards the safety of the berthing structure and following conclusions are arrived.

- The whole blasting operation has taken only about 800 to 1000 m.sec. There was a disturbance of water during blasting.
- The peak particle acceleration measured in vertical mode is much higher than the acceleration recorded in other two modes. The maximum peak acceleration is about 1.08g. The maximum peak acceleration for all modes occurs at a distance of 55 m from the face of the berth.
- The spectral analysis of time history shows that, the very narrow frequency band (2 to 25 Hz) for vertical vibration and wide frequency band (25 to 175 Hz) for longitudinal and lateral vibration, which indicate the energy is most concentrated in narrow band for vertical mode.
- The predominant frequency in vertical mode is about 26 Hz is close to the estimated natural frequency of the berthing structure. For this frequency, the allowable PPV is established as 25 mm/sec.
- The measured PPV values during 31 blasts are compared with established allowable PPV values for predominant frequency. Vibration monitoring during blasting show that, except in few blasts, the measured PPV values are well within the allowable PPV value of 25 mm/sec. This shows, the established relationship is adequate towards the safety of the berthing structure.

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