Prediction of Behaviour of Adjacent Building Due to Blast Induced Demolition of a High-Rise Structure in Delhi, India

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Abstract: This study focuses on controlled implosion, a novel demolition technique to raze large structures at a reasonable cost and short time duration. Implosion is the controlled placement of explosives and timing of their detonation to cause a structure to quickly collapse in on itself with the least amount of physical harm to its immediate surroundings. This demolition technique was used for the deconstruction of the unlawful Supertech Twin Towers in Noida, India as per the Supreme Court verdict. The UK company Vibrock estimated the intensity of vibrations likely to be created when the building hit the ground based on the blast implosion plan details and the type of soil. Aster-2, a B+G+12 storey, neighbouring structure just 9m away from the tower to be demolished was analysed to ensure its safety due to touchdown vibrations resulting from demolition. Aster-2 was modelled in ETABS software and subjected to different loading conditions including blast-induced vibration and earth quake loadings. The comparison between behaviour of structure under blast loading and seismic loadings is presented, and the safety of the structure is evaluated as per codal provisions. The findings indicate that the structure is safe under the blast loading induced. Crack meters were installed to monitor the variation if any after the blast and it was found that structure didn't had any additional damages due to the implosion. The vibration was monitored using geophones at the basement level of Aster 2 and the peak particle velocity noted was well within the permissible limits.

Keywords: Demolition, Peak particle velocity, Blast induced vibration, Seismic loadings

1 Introduction

As the world keeps developing and lifestyles changing, in addition with economic growth, evolution of technology and subsiding availability of land has led to construction and raising of a plethora of multi-storey and high-rise buildings. Few of these structures do not adhere to the building byelaws, regulations and codal provisions which ultimately leads to the buildings being removed using methods like demolition, deconstruction, or dismantling. Demolition can be defined as wrecking or taking out of any load supporting structural element of a building (houses, commercial establishments, and office buildings) or non-building (highway, streets, and other non-inhabitable construction projects) [1]. Many demolition projects are concentrated in the areas, where both the surrounding building and underground structures are densely distributed. The collapse touchdown of these buildings when they are demolished will inevitably have a large impact on the surrounding buildings and underground structures [2]. The ground vibrations caused by blasting and piling are characterized by short intensive pulses. Though their intensity is much lower relative to earthquake shakings, they may cause developing cracks in the walls and floors [3]. Numerous works has been reported about the application of controlled implosion with delayed detonation technique that can be successfully used for demolition of high rise structures in urban area with considerable speed and cost efficiency without damaging the adjacent structures [4,5,6].

This paper presents the details of prediction and measurement of vibration during the controlled demolition of a High Storey building at Noida and also the results of response of a nearby building due to earthquake and blast induced ground motion.

2 Project Description

Noida Authority decided to demolish Supertech Twin Towers Apex and Ceyane in August 2021 as per the Supreme Court verdict. These towers are near the Noida-Greater Noida Expressway in Sector 93A, Noida. The demolition task of Twin Towers were entrusted to Edifice Engineering and Jet Demolitions. Edifice Engineering engaged Geo Structurals Pvt Ltd, Cochin with pre and post blast structural integrity testing, estimating damage to neighboring structures, and measuring vibration during the demolition. The prediction of touchdown vibration due to the controlled implosion was done by Vibrock, UK. The actual vibration measurement during the blast was carried out by the team led by IIT Chennai. Based on the predicted vibration the safety of Aster 2 was analysed using ETABS model and the results of the behavior of structure during earthquake and blast induced vibration are compared and presented in this paper.

The first tower named Apex had a height of 103 meters, the other named Ceyane had a height of around 97 meters. Both towers together have a built-up area of around 7.5 lakh square feet. Aster-2 is a framed structure just 9 meters away from the Supertech twin towers. It has a basement, a ground floor, 12 stories, and a terrace. In Fig.1.a the proximity of the Supertech twin towers to the structure Aster-2 is shown and the Satellite view of the structures in the demolition site is given in Fig.1.b. The soil profile in the area comprise of medium dense alluvium soil, made up predominantly of sand, and silt with nominal clay component. These alluviums are underlain by very dense silty sand formations followed by hard rock strata. Water table was encountered at depth of 5m below the existing ground level. The foundation provided for Supertech twin tower is pile raft foundation and that of Aster-2 is raft foundation.

Fig.1.a Image showing proximity of structures **Fig 1.b.** Satellite view of the site

3 Prediction of Peak Particle Velocity (PPV)

Peak particle velocity (PPV) is used to measure the ground motion caused by blasting demolition. Several semi-theoretical formulas with empirical coefficients were developed to estimate ground motion with PPP, using Sadov's Formula of Blasting Vibration and chimney blasting demolition observations. Response spectra, which are employed in earthquake engineering to measure forceful ground motion, were also developed to analyze blasting ground motion, but their usage was mostly limited to building collapse vibration studies. Table 1 shows the relation between the expected damage level of the buildings and vibration velocity [7].

Table 1. The relation between the damage level of buildings and vibration velocity

Maximum Velocity of mas point (mm/s)	Damage Level
35	None
55	Very finest plastering cracking
80	Cracking
115	Severe Cracking

The demolition mechanism proposed by Jet Demolition Ltd. has been considered and the predictions are given in terms of most likely and maximum likely vibration level for a distance of 10m to 100m as given in Table 2. The weight and height of each building has been provided along with details regarding adjacent vibration sensitive receptors and the geological condition for the area. A typical ground vibration record for demolished buildings will include a complex waveform sequence. The implosion of explosives creates the first event. The second and subsequent events of the structure hitting the ground have the biggest magnitudes, although they attenuate swiftly with distance. The largest potential energy available upon collision is calculated using each building's weight and height, however due to the structure's progressive collapse, the true impact energy is always far lower.

Table 2. Predicted Peak Particle Velocity

Distance from structure Impact Area (m)	**Peak Particle Velocity (mm/s)**	
	Most Likely	**Maximum Likely**
10	22.0	34
20	16.0	24
30	11.0	17
40	8.0	14
50	6.5	11
60	5.2	9
70	4.6	7.5
80	4.0	6.6
90	3.5	5.8
100	3.0	5

Aster 2 tower was located 9 metres north of Supertech Twin Towers and buried GAIL gas pipe line of 450 mm was located 16 meters away from the Tower building within the plot area buried 4m from ground level in the southern side towards ATS Village. At 10 metres, predicted ground vibration levels vary from 22mm/s most likely to 34 mm/s as maximum likely and at 100 meters, predicted ground vibration level varies from 3mm/s most likely to 5 mm/s most likely. Depending on vibration frequency, the British Standards recommends 15 to 50 mm/s to prevent hairline plaster cracking and when the values exceed 15 mm/s, cosmetic damage is possible. However, the estimated vibration levels are below the threshold for structural damage.

4 Response of the Building due to Blast and Earthquake Ground Motions

4.1 Building Considered

One of the High Stored buildings namely Aster 2 is considered in the present study. Aster 2 is a RCC framed structure. It has a basement, a ground floor, 12 stories, and a terrace. Parking is located on the basement floor. Typical floors have four apartments each from the ground floor to the 12th storey. The building is a framed structure with raft foundation, columns, beams and slabs. Aster-2 was located only 9m away from the twin towers and was expected to have the maximum impact due to the demolition of the Supertech Twin Towers. Aster-2 was studied to assess how the Supertech twin tower's demolition may damage neighbouring structures due to touch down vibrations. Vibrock's study estimates that the peak particle velocity within a 10m radius after the blast will be 34mm/s. Analysis considered peak particle velocity's acceleration-time history curve. Using Seismosignal 2020, Fourier Spectra from the predicted acceleration time historey were used to estimate ground vibration frequencies. The motion had low and high frequency (0.049–150 Hz) components, likely from blasting and building collapses.

4.2. *Properties of Materials*

Non Destructive tests such as Ultrasonic Pulse Velocity test and Rebound Hammer test were carried out to assess the strength characteristics of structural elements of Aster-2. It was found that the minimum grade of concrete noted was above M20. M20 grade was chosen for the columns, beams and slabs and Fe 415 grade steel were considered in the proposed structural designs. The dead loads and live loads were taken as per IS 875[8] and the seismic forces are determined from IS 1893[9] and the blast loads were derived from the reports of Vibrock, UK.

4.3. *Structural Model*

The layout of typical floor, 3D ETABS Model of Aster-2 and the 3D Rendered view of Aster-2 is shown in figures 2 to 4. The structure was subjected to various load combinations as per the guidance given in IS 456[10]. The maximum peak particle velocity likely to happen within a radius of 9m after the blast is 36mm/s and the acceleration time history corresponding to this peak particle velocity was taken in the model to perform time history analysis for blast loading as shown in Figure.5.

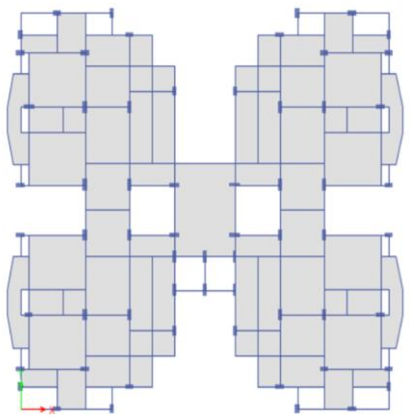

Fig. 2. Layout of typical floor of Aster-2 in ETABS

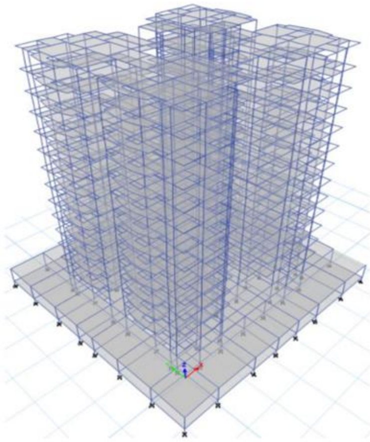

Fig. 3. 3D ETABS Model of Aster-2

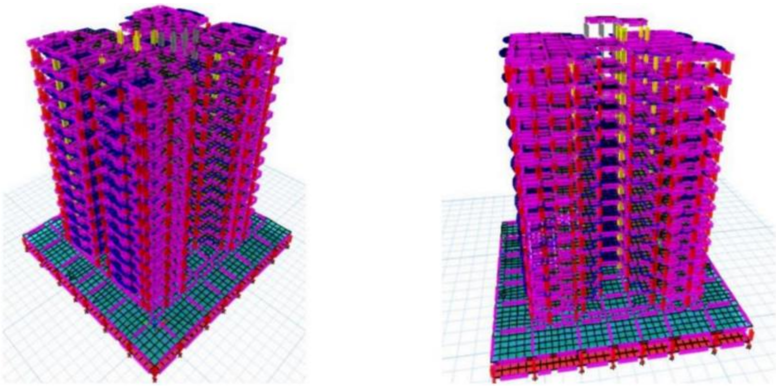

Fig. 4. 3D Rendered view of Aster-2

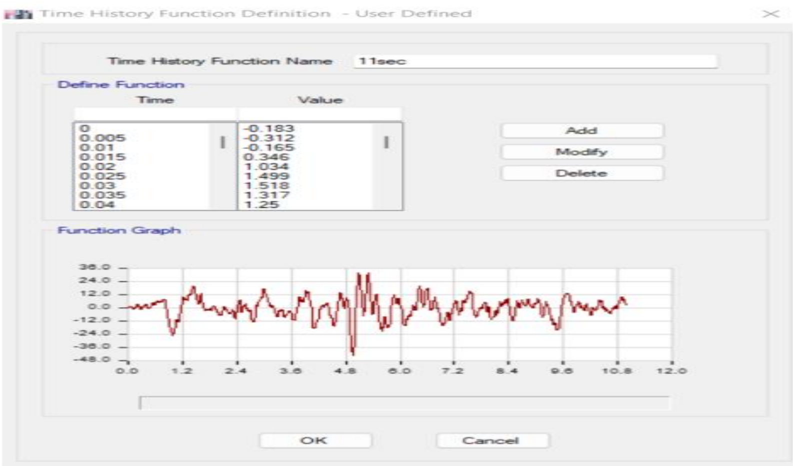

Fig. 5. Time history of acceleration used for the analysis of blast loading

4.4. Storey Drift and Displacement

From the structural analysis, the maximum storey drift along X direction for Blast vibration is found to be about $720x10^{-6}$ and the the same for Earthquake vibration is found to be $2700x10^{-6}$. The maximum storey drift along Y direction for Blast vibration is found to be $690x10^{-6}$ and the same for Earthquake vibration is $2030x10^{-6}$ as shown in Figure 6 and 7.

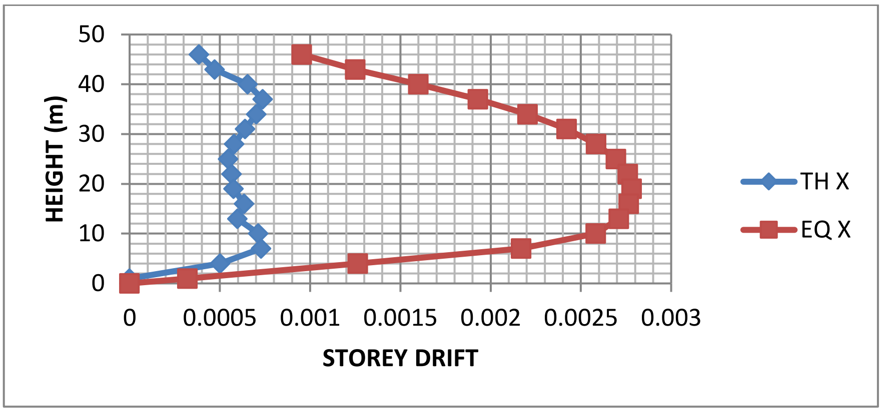

Fig. 6. Maximum storey drift along X direction for Blast vibration and Earthquake vibration

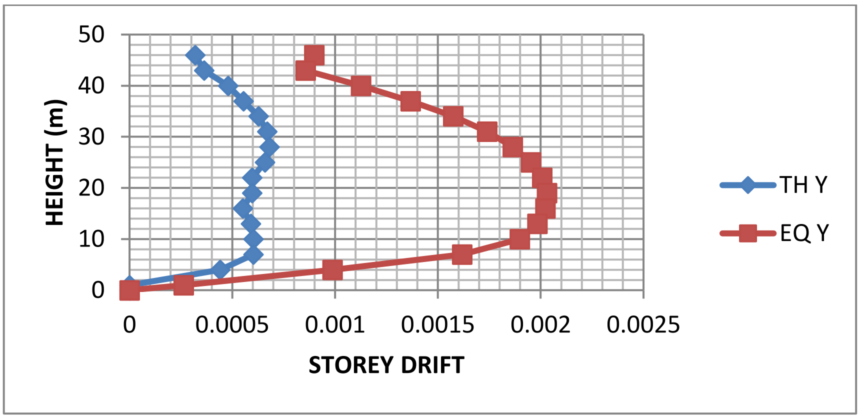

Fig. 7. Maximum storey drift along Y direction for Blast vibration and Earthquake

The maximum storey displacement along X direction for the Blast vibration is 12.5 mm and the same for earthquake vibration is found to be 95 mm. The maximum storey displacement along Y direction for the Blast vibration is 16.5 mm and the same for earthquake vibration if found to be 71 mm. The graphs for the same are shown in Figures 8 and 9. As per IS 1893 part1 2016, Maximum permissible storey displacement is h/250 and the permissible displacement of Aster-2 with a height of 48m is 192 mm. It is noted that the storey displacement and drift are well within the permissible limit as per the codal provisions.

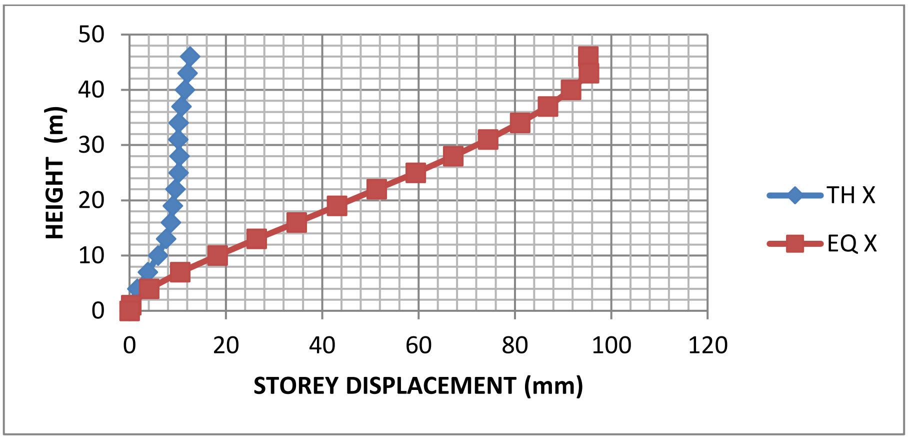

Fig. 8. Max. storey displacement along X direction for Blast vibration and Earthquake vibration

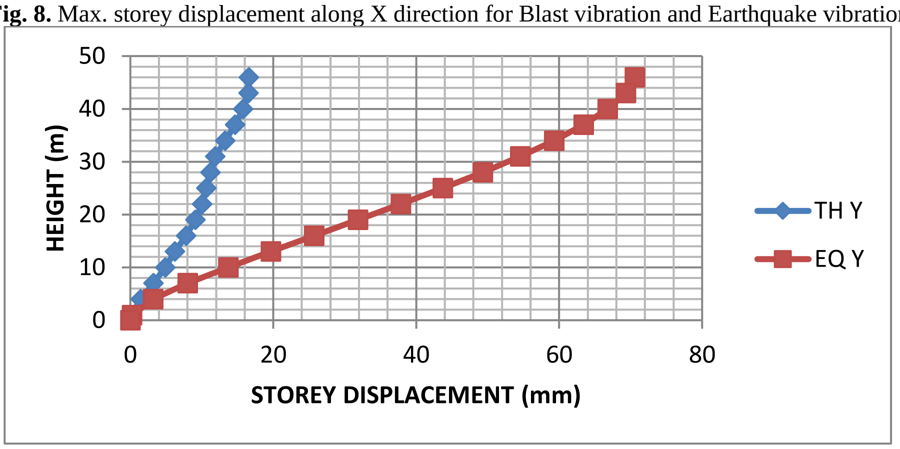

Fig. 9. Max. storey displacement along Y direction for Blast vibration and Earthquake vibration

4.5. Safety assessment of Columns under blast vibrations

The safety assessment of all columns subjected to different load conditions were done and the structure was found to be safe to withstand the blast vibrations. The comparison of reinforcement provided and that required for selected columns (columns C1 to C6) as shown in Fig.10 is given in Table 3.

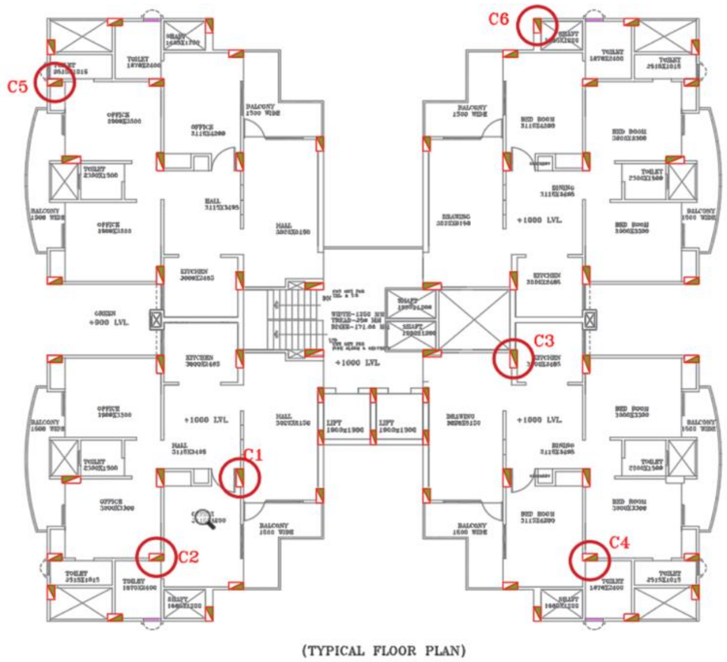

Fig. 10. Column layout of Aster-2

Table 3. Comparison of provided column reinforcement with requirement for Blast loadings

Label	Storey	Section	Provided Rebar%	Blast Loading	
				Load Combination	Rebar %
C1	BF	300X750 M20	4.10	1.5(DL+LL)	2.89
C1	5	300X750 M20	2.70	1.5(DL+BLX)	1.17
C1	10	300X750 M20	1.29	0.9DL+1.5BLY	0.80
C2	BF	300X600 M20	2.95	1.5(DL+LL)	2.85
C2	5	300X600 M22.5	2.01	1.5(DL+BLY)	1.19
C2	10	300X600 M20	2.01	1.5(DL+BLY)	1.34
C3	BF	300X750 M20	4.10	1.5(DL+LL)	2.66

C3	5	300X750 M20	2.70	1.5(DL+BLX)	0.88
C3	10	300X750 M20	1.29	0.9DL+1.5BLY	0.80
C4	BF	300X600 M20	2.95	1.5(DL+LL)	2.99
C4	5	300X600 M20	1.36	1.5(DL+BLY)	1.21
C4	10	300X600 M20	1.11	0.9DL+1.5BLY	0.80
C5	BF	300X600 M20	2.40	0.9DL+1.5BLY	1.92
C5	5	300X600 M20	2.01	0.9DL+1.5BLY	0.80
C5	10	300X600 M20	1.10	0.9DL+1.5BLY	0.80
C6	BF	300X600 M20	2.40	1.5(DL+BLX)	2.26
C6	5	300X600 M20	2.01	1.5(DL+BLY)	1.00
C6	10	300X600 M20	1.10	1.5(DL+BLY)	0.81

5 Measurement of Vibration During the Controlled Demolition of the building

The demolition of the structure was carried out on 28th of August 2022 at 2.30PM. The crack meters were installed wherever minor cracks were noted in the Aster-2 structure as shown in Fig.11.The vibrations were measured using 3-D geophones (Manufacturer: Seismic Source, Model: Sigma4) with a natural frequency of 2 Hz. The geophones are placed at 33 m from the plinth edge of the twin tower buildings and at a depth of 3m from the ground level in the basement. The geophones placed in the structure (Aster-2) for the measurement of vibration is shown in Fig.12. The Peak Particle Velocity (PPV) at Aster-2 location was found to be 7.25 mm/s. The PPV value in the two mutually perpendicular horizontal directions (longitudinal – 2.99 mm/s and lateral – 4.22 mm/s) are also measured along with the vertical direction. No variations have been noted in the cracks after the demolition. The time history velocity obtained from the geophone located at the basement floor of Aster-2 and the corresponding Fourier spectra is . shown in Fig.14.The photograph taken at Aster-2 after the demolition of the Supertech Twin tower is shown in Fig.14.

Fig.11. Placing of crack meter for monitoring crack variations after blast

Fig.12. Placing geophones for vibration measurement in Aster-2

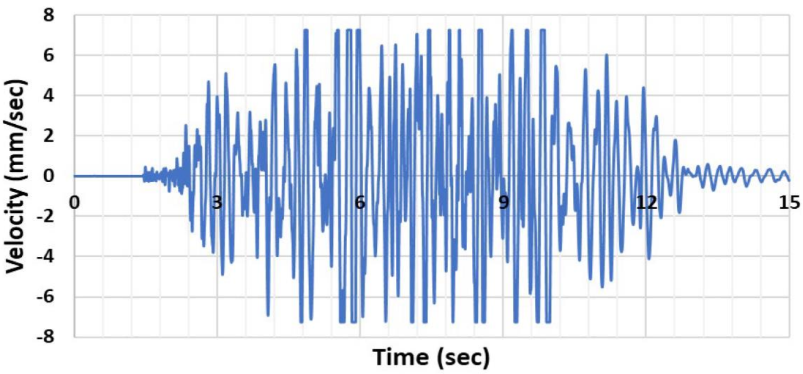

Fig.13.a. Velocity - Time History of Vibration

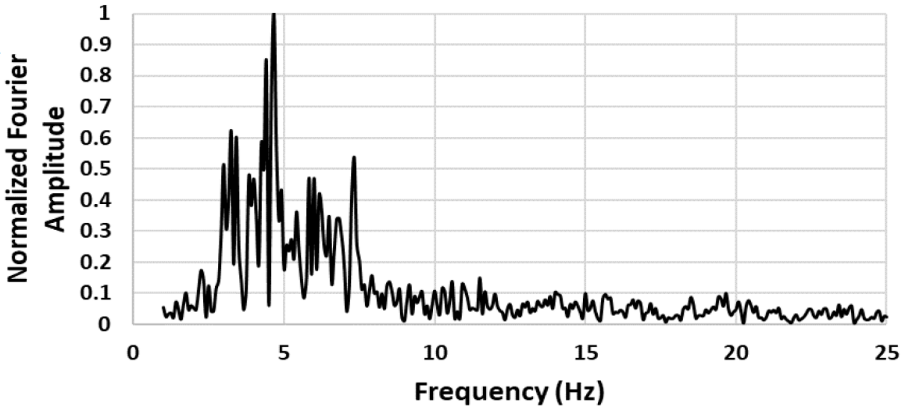

Fig.13.b. Frequency Spectrum of Vibration

Fig.14. The photograph of Aster-2 after the demolition of the Supertech Twin tower

6 Conclusions

From the study carried out, it is noted that if the impact of the vibration during the implosion is as per the prediction made by Jet Demolition and Vibrock, the structure is safe to withstand the blast loading. The effect caused by controlled demolition is considerably lower than the force induced during the earthquake loading. The maximum storey displacement caused by blast induced vibration is only 16.5mm whereas, that caused by earthquake is 95mm. The maximum permissible storey displacement for this structure as per IS 1893 part1 2016 is 192mm. The maximum storey drift caused by the blast loading is 7.2 x10^{-4} which is well within the limit of permissible storey drift of 0.004H, as per IS 1893 part I 2016. From the comparison study of provided reinforcement with the required column reinforcement for blast loading, it is noted that the structure is safe to withstand the blast loading. Observations from Crack meters indicated that the structure didn't had any additional damages due to the implosion. The vibration was monitored using geophones at the basement level of Aster 2 and the peak particle velocity noted was well within the permissible limits. The analysis of the behaviour of the structures with in the critical zone is very essential to ensure the safety of the surrounding built environment when the demolition of high rise structures is carried out by implosion using delayed detonation techniques.

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