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Impact of Vibrations on A High Rise RCC Structure Due to Blast Induced Demolition of Adjacent Building

Akhil Anil [1], S.S. Chandrasekaran [2] and A Boominathan [3]

[1] Junior Engineer, Geostructurals Pvt Ltd, Pullepaddy, Cochin 682018, Kerala
E-mail: akhil.cecons@gmail.com
[2] Professor, Department of Structural and Geotechnical Engineering, School of Civil Engineering, Vellore Institute of Technology (VIT)
E-mail: chandrasekaran.ss@vit.ac.in
[3] Professor, Department of Civil Engineering, Indian Institute of Technology Madras
E-mail: boomi@iitm.ac.in

Abstract. The demolition of high rise structures is a very challenging task especially in urban areas. Controlled explosion using delayed detonation techniques can be used effectively for demolition of high rise structures to reduce the time required and for cost control. The technology was successfully used for the demolition of five high rise structures situated in Maradu municipality, Cochin for violating the costal regulation zone norms in January 2020. Vibration generated during the demolition process was studied by the team of IIT Chennai by instrumentation at strategic locations and an attenuation relationship was formulated to infer damage potential of surrounding buildings. Among the structures demolished was 17 storeyed Golden Kayaloram apartment which was just 10 meters away from 20 storeyed Heera Windfaire apartments. It was apprehended that the blast induced vibration will induce considerable damages on the adjacent structure. Based on the site specific acceleration measured at the property of Heera apartments the blast induced impact on the structure was analyzed using STAAD PRO V8i and is compared with dead load, live load and earthquake load combinations. From the studies carried out it can be concluded that the forces induced due to the blast induced vibration is lesser than the earthquake forces and since the structure was designed for taking care of earthquake forces, the building was capable to withstand blast induced loading without any damages other than minor cracks due to impact of flying debris.

Keywords: Demolition, Costal regulation norms, Attenuation relationship, Site specific acceleration, Blast induced Vibration

1 Introduction

Rapid economic growth and the cost of increase of land has led to development of high rise residential and commercial building across urban India. When the buildings are constructed not much importance is given regarding the planning for deconstruction of the structure. As the high rise buildings are developed in prime location areas such as marine bays, water front properties etc. the density of building will be very high and demolition of structures will be a major challenge. Demolition of structures is generally carried out when the life span of the building is over, or it has undergone

severe damages due to corrosion, fire etc. or due to change of utility need in the locality or for removal of building which has legal violations.
Demolition can be defined as dismantling, razing, destroying or wracking any building or structure or any part thereof by pre-planned and controlled manner. The demolition method is selected after pre-demolition works such as surveying, removal of hazardous material and stability analysis report. Implosion or explosion deconstruction is an effective and efficient method of deconstruction, and can reduce both cost and time to bring dangerous multistorey structures to ground in comparison to conventional demolition methods. Implosion is the strategic placing of explosive material and timing of its detonation so that a structure collapses on itself in a matter of seconds, minimizing the physical damage to its immediate surroundings. The technique weakens or removes critical supports so that the building can no longer withstand the force of gravity and falls under its own weight.

During the demolition by blasting techniques it is to be ensured that the impact of vibration induced by the touchdown of the collapsing structure does not adversely affect the safety of the buildings nearby and delayed detonation techniques is adopted for the same. In order to ensure that the execution happens as planned, vibration analysis studies are carried out. From the recorded time history of acceleration, the peak vertical acceleration and the duration of the ground vibrations can be determined. From the data collected the impact of the blast induced vibration on the neighboring structure can be studied. Peak particle velocity (PPV) measured on the ground has been widely used to evaluate the ground motion caused by blasting demolition. Referring to the Sadov's Formula of blasting vibration and depend on observed data of chimney blasting demolition, several similar semi-theoretical formulas with empirical coefficients were developed Zhou (2009) [1] in order to predict the ground motion with vertical PPV. Response spectra, which is frequently used in earthquake engineering to evaluate strong ground motion Wang et al. (2010) [2] and Wang and Li (2012) [3], caused by earthquakes, were also introduced to analyze the ground motion of blasting, but its application was still limited in the analysis of vibration caused by building collapse Chen et al. (2017) [4].

2 Project Description

The Secretary, Maradu Municipality, requested the Department of Civil Engineering Indian Institute of Technology, Madras to carry out vibration measurements during the controlled demolition of apartment building as per the direction of the Honorable Supreme Court of India. Consequently, a team from IIT Madras carried out vibration measurement during the execution of controlled demolition of the buildings on 11th and 12th of January 2020.The Golden Kayaloram building was demolished in the afternoon of 12th January 2020. The vibration measurement was carried out at selected locations, and was monitored at two stations. The data collected by the instruments were analyzed and interpreted in terms of Peak Particle Acceleration and Peak Particle Velocity. A model for the structure Heera windfaire was developed on STAAD PRO V8i and a comparative study was done subjecting it to the lateral loads generated due to the touchdown vibration, the lateral loads of earthquake as defined by IS1893 part 1 [5] and the model under the dead and live load condition.

2.1. Area studied

Maradu is located just 7km from Cochin Corporation. The Gram Panchayat, formed in 1953, was upgraded to a Municipality in 2011. The google map of the location is shown in Figure 1.

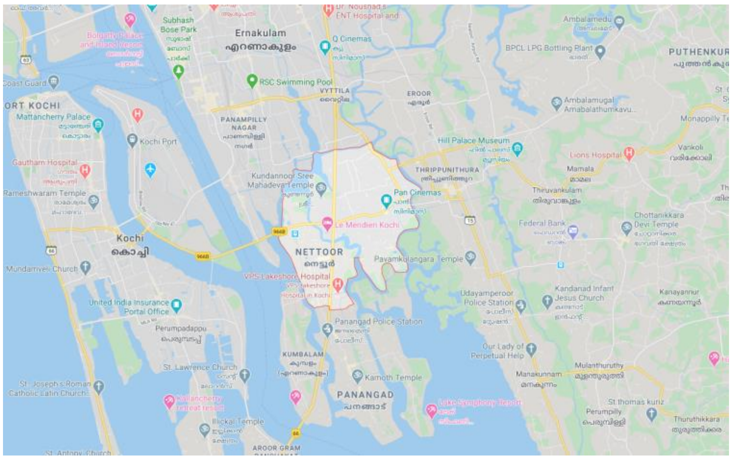

Fig.1. The google map image of the location

2.2. Typical soil profile of the area

The soil profile in the area comprise of top very loose sand followed by very soft marine clay extending up to a depth of 26m with SPT value of 1 to 6. Below this, medium stiff laterite strata is noted up to 36m followed by dense sand, medium stiff clay and very dense sand strata up to a depth of 58m. Since the top soil consist of very soft marine clay extending up to 26m, for the high rise structures in this locality bored cast in-situ piles of end bearing type are adopted. The piles are constructed by DMC method and they are terminated at a depth of 40 to 48m below the ground surface where very dense sandy strata were encountered.

2.3. Structures studied

2.3.1. Golden Kayaloram Apartments

The Golden Kayaloram Apartment was a 17 storey apartment with a height of 54m. Supreme court had ordered the demolition of the building due to violation of coastal regulation zone. The Demolition of Golden Kayaloram apartments took place on 12th of January 2020 at 2pm. This was the last building that underwent the controlled implosion with regards to the demolition order which was passed.

Fig. 2. Image of Golden kayaloram apartment between heera windfaire and backwaters

The aspects that made the controlled implosion at this site challenging, was the vicinity of an Anganvadi which was situated just 5m away from the building boundary, Heera Windfaire apartments which is a 20 storeyed building located just 10m away from Golden Kayaloram plot and the backwaters which was at a vicinity of 9m to Golden Kayaloram. The relative locations of the structures are as shown in figure 2.

2.3.2 Heera Windfaire apartment

Heera windfaire apartment is a 20 storeyed building with a floor area of 20000 Sq.m and a height of 60 meters. It was apprehended that since the space between the Golden Kayaloram Apartment and Heera Windfaire was very low, the touch down vibration induced during delayed detonation technology in controlled demolition process will impart serious damages to the structure. The apartment was evacuated before the demolition took place and instrumentations were carried out to understand the impact.

3 Technical Specification and Design Approach

3.1. Peak particle velocity

Computing formula of vibration caused by dynamic compaction and heavy punching on earth advanced by Chi and Zhang(2010) [6]:

$$v = K\left(\frac{\sqrt[3]{MgHC^2}}{R}\right)^a$$

where, C is the velocity of longitudinal wave of Strata media; K, a are modulus, decided by dynamic compaction experiment. The formula can be applied to predict the vibration velocity caused by the collapsed building part. M is the mass quantity of the collapsed body; H is the height of the mass centre. Table 1 shows the relation between the damage level of the buildings and vibration velocity Chi and Zhang (2010) [6]:

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

Damage Level	Maximum Velocity of mass point (mm/s)
None	35
Slight Cracking/desquamation	55
Cracking	80
Severe Cracking	115

3.2. Surveying and measurement of ground vibration

A proper surveying of the blast location, Golden kayaloram was done and the position to place the equipment's were decided based on the wire length availability. The control station was fixed under a cover so that there won't be any direct debris fall contact. Vibrations generated due to the demolition of buildings were measured with a help of piezoelectric type accelerometers fixed directly on the concrete blocks embedded in the grounds as shown in Figure 3(a). In addition, inductive type acceleration transducers were fixed on to beams and columns of Heera windfaire apartments as shown in Figure 3(b). The vibration signals received from the accelerometers is connected to a multi-channel Digital carrier frequency amplifier system to amplify the received signals. Two data acquisition systems consisting of multi- channel digital carrier frequency amplifier system of Hottinger Baldwin Messtechnik (HBM) make (model: MGC plus and QuantumX), and a CATMAN Easy program installed on to a Laptop were used to monitor and record the vibrations as digital data as presented in Figures 3 (c) and (d).

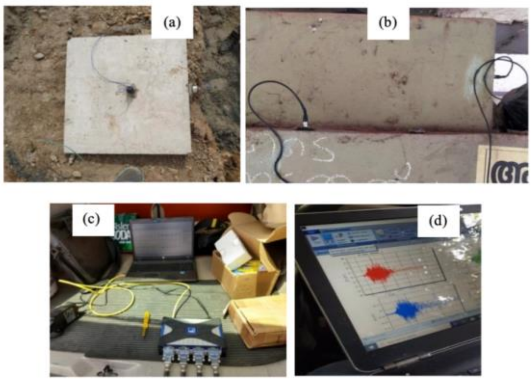

Fig. 3. Placement of accelerometers and measurement of vibrations

The time history of vertical acceleration during the controlled demolition operations was continuously recorded and stored. The recorded vibration data are processed using Catman AP software to arrive at peak particle acceleration (PPA), Peak particle velocity (PPV), frequency content and duration of ground vibration. The accelerometers were placed between 45m to 150m from the building, PPV ranges from 0.93 to 105.43mm/s and PPA ranges from 0.27 m/s^2 to 3.65 m/s^2. For the purpose of analysis of model of Heera Windfaire apartment the PPA value selected at the accelerometers positioned within the premises and building was taken. The Acceleration time history recorded is shown in figure 4 and velocity time plot is indicated in figure 5.

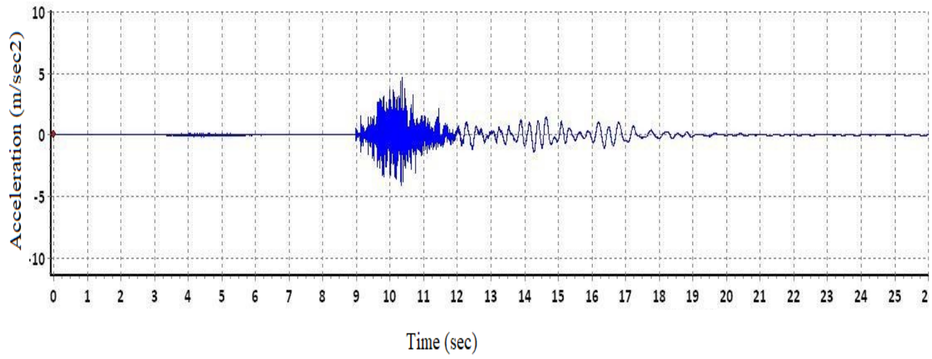

Fig. 4. Acceleration-time history recorded during the demolition of Golden Kayaloram at Heera Windfaire

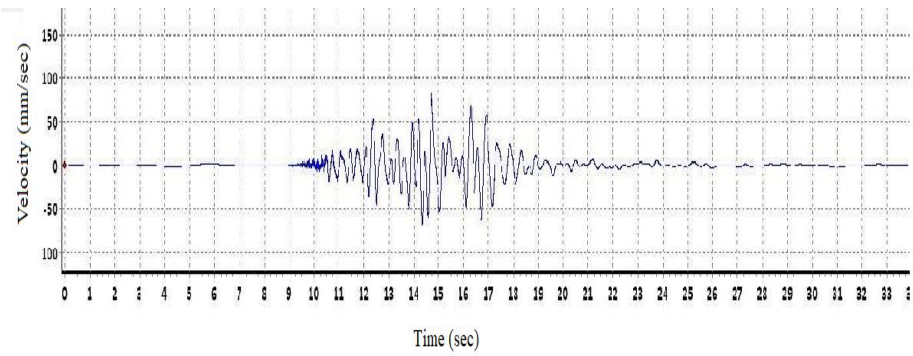

Fig. 5. Velocity-time plot recorded during the demolition of Golden Kayaloram at Heera Windfaire

The frequency content of the ground vibrations was determined from the Fourier Spectra obtained from the measured time history of acceleration using Seismosignal 2020 software. The frequency content of the motion was found to consist of both low frequency (2-10Hz) and high frequency (50-150 Hz) components likely due to blasting and sequential collapse of buildings.

3.3 Development of Heera Windfaire Model

Heera windfaire apartment was considered for the study, since being a high rise building and very close to the demolished building site the touch down vibration was expected to create considerable damages on the structure. The Framed structure of the building with columns, beams, slabs and shear walls were developed using STAAD software. The loads were assigned to the building based on the relevant Indian Standard codes IS 875-1987 Part 1 and 2 [7] and IS1893 part 1 [5] and the blast induced loads were provided based on site measurement data. Figure 6 (a) shows the image of Heera windfaire apartment during the demolition of Golden Kayaloram Apartments and figure 6 (b) shows the STADD Model of the structure.

Fig .6 (a) . Image showing Heera windfaire apartment during demolition of Golden Kayaloram

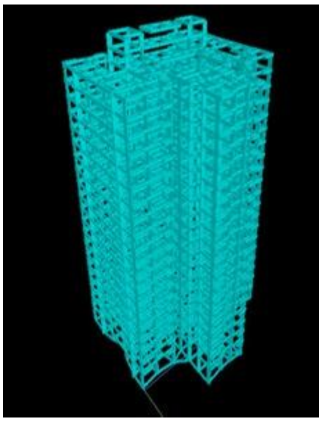

Fig. 6 (b). STADD Model of the Structure

3.4 Parameters defined for the study process

The model that was developed has been analyzed and studied based on selected parameters. The parameters used were (i) comparison of the A_h , S_a/g values for X and Z direction induced by both Touchdown vibration(TDV), Earthquake vibration(EQV) seismic activities (ii)Exemplification of the maximum displacement when both X and Z transitional loads have been applied under TDV ,EQV and DL (Dead + Live) conditions (iii) A comparative study of the storey drift in EQV and TDV in X and Z direction lateral loads were studied (iv)base shear caused by the lateral load of EQV and TDV were studied.

4 Results And Discussions

4.1 Results from vibration studies conducted

From the recorded time history of acceleration, the peak vertical acceleration was identified and it varies from 0.27 m/s^2 to 3.65 m/s^2. The duration of the ground vibrations recorded was 38s. In the present case, the bracketed duration of ground vibration is considerably short and was varying from 0.91s to 8.28s, with widely varying frequency content and hence its damage potential may not be significant.

4.2 Results from structural analysis and design of Heera Windfaire Apartments

After completing of the study of the model under 3 condition that Model under (i)Dead load and live load alone (ii) Touchdown vibration(TDV) and (iii) Under Earthquake vibration(EQV) as defined by Indian Standard code 1893 [5], Comparisons of various parameters were taken into consideration and results were drawn.

Comparison of time period and horizontal seismic coefficient. From the output result obtained the Time period for X for earthquake and vibration was found to be 3.62s and Time period of Z axis is found to be 3.46s. The Sa/g value obtained for the seismic activities were 0.372 and 0.376 for touchdown vibration and earthquake vibration respectively along X direction. The Sa/g value obtained for the seismic activities were 0.372 and 0.396 for touchdown vibration and earthquake vibration respectively along Z direction. The A_h values for seismic activities were 0.0069 and 0.0116 for touchdown vibration and earthquake vibration respectively along X direction. The A_h value obtained for the seismic activities were 0.0069 and 0.0122 for touchdown vibration and earthquake vibration respectively along Z direction. From the results it can be noted that the design horizontal seismic coefficient(A_h) for a TDV induced lateral load is much lesser than compared to the lateral load imposed by EQV and the average response acceleration coefficient (S_a/g) is higher for EQV induced than TDV induced lateral load. The critical impact is noted in the Z direction.

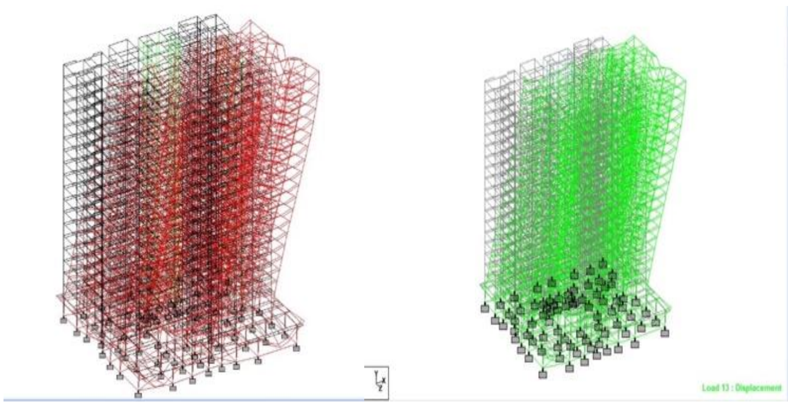

Fig. 7. 3D deflection Image of structure under TDV and EQV

Maximum deflections. The Maximum deflection for X transitional load observed in the case of dead load and live load alone is 20.786 mm, with TDV load added to it is 71.780 mm and when the EQV was applied it is found to be106.613 mm. The Maximum deflection for Z transitional observed in the case of dead load and live load alone is 25.109 mm, with TDV load added to it is 72.147 mm and when the EQV was applied it is found to be 108.523 mm. The maximum permissible deflection under seismic loading as per the coded provisions is 256 mm and the deflection of the structure is within the permissible limits. Figure 7 shows the 3D deflected image of structure under TDV & EQV.

Comparative study of storey drift of the building in TDV and EQV. Storey drift is the lateral displacement of one level relative to the level above or below. Storey drift ratio is the storey drift divided by the storey height and the according to IS1893 [5] the storey drift ratio is 0.004. The storey drift of the structural model is studied and a graph is plotted.

Storey drift in X- direction .As the height of the building increases the storey drift is found to increase and as it reaches 30m it starts decreasing. The storey drift of the TDV in both cases X and Z is found to be comparatively lesser than the storey drift due to the EQV in X and Z direction and the variation with height is shown in figures 8 and 9. Maximum value of storey drift of 3.547 mm and 5.652 mm was noted in X direction and 3.228 mm and 5.286 mm was noted in Z direction for TDV and EQV loadings respectively. The permissible storey drift as per coded provision is 11.6 mm.

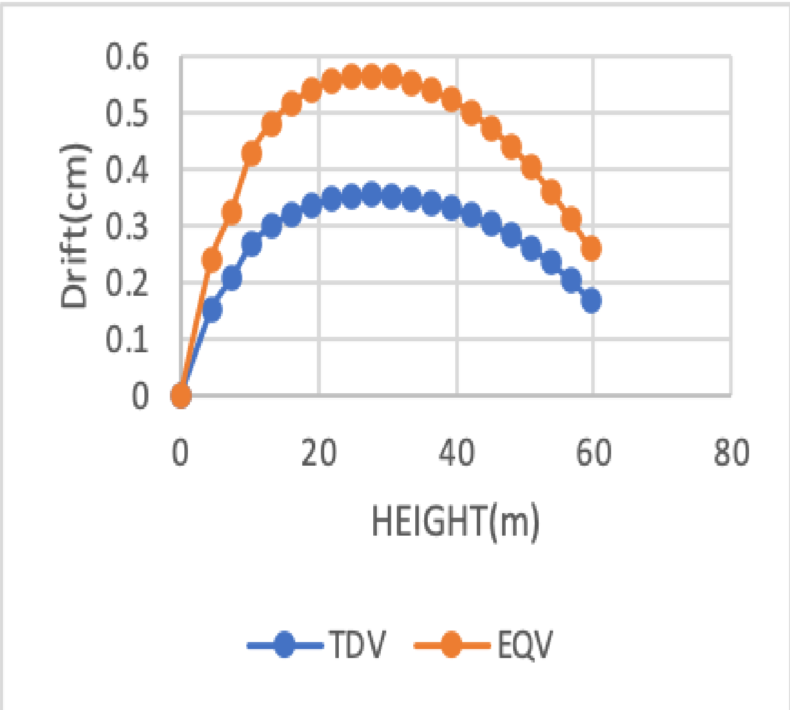

Fig .8. Variation of Storey drift in X direction between TDV and EQV

Storey drift in Z-direction

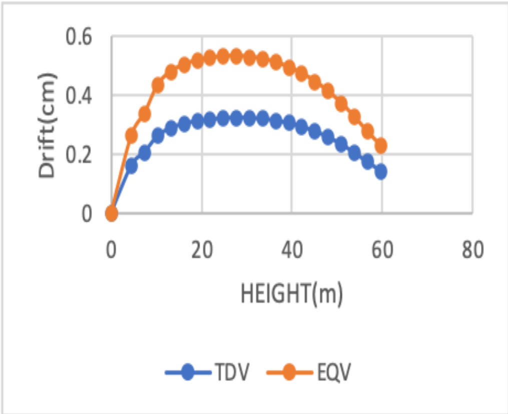

Fig. 9. Variation of Storey drift in Z direction between TDV and EQV

Comparative study of storey shear variation of the building in EQV and TDV
Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. The seismic activities in this situation that is applied to the model are EQV and TDV. From the data given in table 2 and from figure 10, it was observed that the storey shear is found to increase as the height increases, the dip in the graph at a 60m height and in the value of the force in both EQV and TDV cases is due to the presence of the elevator shaft extending to the top of terrace of the building .The storey shear values along the height of the building for EQV under the IS1893 [5] conditions is found to be more than the storey shear values along the height of the building for TDV. The total base shear found in TDV is 1632.854 KN and EQV is 2748.186 KN.

Table 2. Storey shear variation due to TDV and EQV

HEIGHT	TDV	EQV
4.5	2.619	4.409
7.4	3.574	6.016
10.3	6.914	11.637
13.2	11.356	19.113
16.1	16.894	28.433
19	23.528	39.599
21.9	31.258	52.61
24.8	40.085	67.465
27.7	50.008	84.166
30.6	61.027	102.412
33.5	73.142	123.103
36.4	86.354	145.339
39.3	100.662	169.419
42.2	116.066	195.345
45.1	132.566	223.116
48	150.163	252.732
50.9	168.855	284.193
53.8	188.645	317.499
56.7	209.53	352.65
59.6	159.608	268.63
TOTAL=	1632.854	2747.886

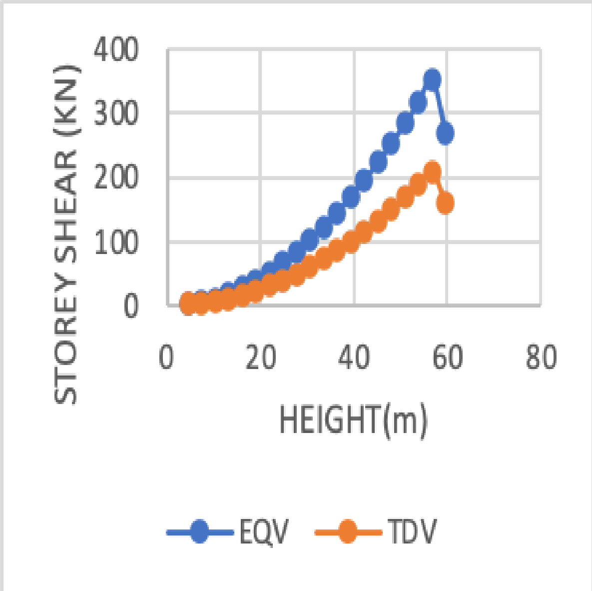

Fig. 10. Comparison of Base shear with height between TDV and EQV

5 Conclusions

From the study conducted about various type of demolition and from the field application it is found that controlled implosion with delayed detonation technique can be successfully used for demolition of high rise structures in urban area with considerable speed and cost efficiency without damaging the adjacent structures. It is noted that the forces induced due to the blast induced vibration is lesser than the earthquake forces and since the structure was designed for taking care of earthquake, the building was capable to withstand blast induced loading without any damages other than minor cracks due to impact of flying debris.

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