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Precautionary Measures Taken for Protection of Gas Pipeline During Demolition of High Rise Structure by Delayed Detonation Technique

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ABSTRACT: Demolition is usually carried out on structures when it has completed its design life period, undergone deterioration, fire attacks, violation of building rules, etc. Demolition can be executed using various techniques, with controlled implosion gaining global prominence. An implosion is the engineered collapse of a structure using strategically placed explosives to bring it down within its own footprint. This paper deals with a case study of the demolition of Supertech Twin Towers, Noida, India and precautionary measures taken for the protection of buried gas pipeline during demolition by delayed detonation technique. The demolition of the Supertech Twin Towers presented significant engineering and logistical challenges, particularly in ensuring the safe collapse of the 32-storey structures within a densely populated urban environment. A key challenge involved protecting critical infrastructure, such as the location of gas pipeline running at a distance of 16m to 30m from the building at a depth of 4m. The proximity of the gas pipeline raised significant safety concerns due to the risk of damage during the demolition process, which could lead to hazardous leaks or explosions. To address these concerns, a three-layer protection system was implemented, comprising engineered materials such as rubber crumb, rubber pad and geosynthetics in addition to impact cushion berms. These were selected for their ability to absorb and mitigate blast-induced ground vibrations. The effectiveness of each layer were validated through finite element numerical modeling assessing the expected impact of implosion on buried pipeline. The results showed that the three-layer protection system substantially attenuated blast-induced ground vibrations at pipeline depth. The successful implementation of these measures in the field ensured the safe demolition of structure without causing damage to the gas pipeline.

KEYWORDS: Controlled demolition, buried pipeline, ground vibration, finite element modelling

1 INTRODUCTION

Demolition of structures constitutes a critical phase in the lifecycle of built infrastructure, often necessitated by factors such as the expiration of design life, structural deterioration, fire damage, or violation of urban planning norms. In contemporary urban environments, the need for controlled and efficient demolition is further heightened by increasing population density and the prevalence of high-rise developments. Urban implosion is now a routine requirement for city regeneration projects worldwide.

Controlled implosion refers to the strategic use of explosives to collapse a structure within its footprint, thereby minimizing damage to adjacent facilities. Several techniques are employed: simultaneous detonation triggers all charges at once and is suited for isolated sites but may generate high ground vibrations (Yuan et al., 2009); delayed (sequential) detonation, widely adopted in urban environments, staggers charge initiation to induce progressive failure and reduce vibration amplitudes (Stark & Fell, 2008; Joseph et al. 2023); directional folding guides collapse away from sensitive zones; base cutting (or pancake collapse) severs lower columns to initiate a vertical fall; and top-down initiation, though rarely adopted, is used under specific structural or spatial constraints. The selection of an appropriate technique depends on the type and configuration of the structural system, the proximity to critical infrastructure, statutory requirements, and overall site conditions.

Ground vibrations generated during implosions propagate through the soil in the form of body waves compression (P-waves) and shear (S-waves) and surface waves, notably Rayleigh and Love waves. Among these, surface waves tend to dominate near the ground surface and are often responsible for the highest amplitudes and longest durations of motion. Such transient dynamic loading can cause differential settlement, distortion, or resonance in above-ground structures, particularly those with shallow foundations or irregular geometries. For underground utilities, these vibrations can induce ovaling, bending, or axial strains due to the mismatch in stiffness between the structure and surrounding soil, especially when the pipeline is shallow-buried or aligned perpendicular to the direction of wave propagation. The severity of response is further influenced by soil type, damping characteristics, and frequency content of the blast (Zhou & Hao, 2008; Song et al., 2008). Understanding the propagation and attenuation of vibrational energy is therefore essential for ensuring safety especially when infrastructure such as gas pipelines can pose a risk of leaks or explosions if compromised by such effects.

The structural integrity of buried pipelines under blast-induced ground motions has been examined through both experimental studies and numerical simulations, with particular attention to strain localization, deformation modes, and the role of burial conditions. Rajan et al. (2013) demonstrated that pipelines embedded in cohesive soils at shallow depths are prone to high strain concentrations under transient dynamic loading, especially near geometric discontinuities such as joints or bends. Song et al. (2008) highlighted that both burial depth and lateral offset from the blast source are key parameters influencing pipeline vulnerability, with reduced cover resulting in amplified stress response. Zhang et al. (2017) further established that the application of engineered energy-dissipating layers such as geotextiles or granular berms can significantly reduce the transmission of surface wave energy to the pipeline zone. Dhanya et al. (2022) demonstrated that incorporating rubber materials with geosynthetics in engineered vibration isolation layers can enhance damping capacity and substantially attenuate ground-borne vibrations. These insights underscore the necessity of incorporating site-specific vibration mitigation strategies when conducting implosions near critical underground utilities. Despite these valuable contributions, real-world case studies involving large, urban demolitions with close pipeline proximity remain rare, especially with detailed vibration control and monitoring strategies.

This paper presents a comprehensive case study on the protection of a shallow-buried pipeline located within 16m–30 m of the Supertech Twin Towers, large high-rise structures undergoing controlled implosion. Field-measured vibrations were recorded during blasting, and Peak Particle Velocity (PPV) values were analyzed to evaluate vibration levels. A three-layer vibration isolation system comprising a rubber crumb, a geogrid layer, and a surface rubber pad was considered to mitigate the impact of blast-induced ground motions. The effectiveness of the proposed protection system was assessed through dynamic finite element analysis using PLAXIS 2D, with PPV used as the primary parameter to quantify vibration attenuation. The study highlights the use of numerical modelling to support vibration mitigation design for underground utilities in urban demolition scenarios.

2 CONTROLLED DEMOLITION STRATEGY AND UTILITY IMPACT ASSESSMENT

The controlled demolition of the Supertech Twin Towers - Apex (32 storeys, 103 m in height) and Ceyane (29 storeys, 97 m in height) in Noida, India was executed on August 28, 2022, following a Supreme Court directive. The image of the Towers is shown in Figure 1. The site is underlain by medium-density alluvial soil of predominantly sand and silt, underlain by extremely dense silty sand over hard rock, with the groundwater table at approximately 5 m depth. The Supertech Twin Towers, comprising reinforced concrete frame structures with central shear walls, were supported on a piled raft foundation extending beneath two basement levels.

Figure 1. The twin towers located in the urban setting, pre-weakened and prepared for blasting.

The towers were situated within close proximity of several occupied high-rise residential buildings, including Emerald Court, ATS Village, and Aster-2 (Figure 2). The demolition was mandated due to zoning violations and unauthorized vertical expansion beyond approved plans. Located within a densely populated residential zone, the twin high-rise towers required meticulous planning, precise execution, and stringent safety measures. A key hazard identified during planning was a high-pressure compressed natural gas (CNG) pipeline owned by GAIL (Gas Authority of India Limited), situated 16–30 m from the towers and buried at a shallow depth of approximately 4 m. As a major regional supply line, its proximity and shallow cover increased susceptibility to blast-induced ground vibrations, making its protection a primary design constraint that directly influenced the sequencing, charge distribution, and overall execution strategy.

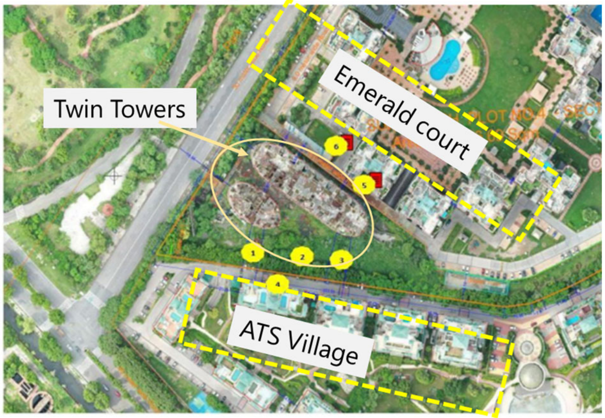

Figure 2. Layout of the Supertech Twin Tower with nearby structures.

2.1 *Demolition strategy*

To achieve a controlled structural collapse within the building footprint and minimize impacts on adjacent structures and buried utilities, a waterfall implosion technique with delayed detonation sequencing was adopted. In this method, explosive charges are initiated in a top-to-bottom sequence, creating a cascading, or "waterfall," collapse effect. This approach was chosen after assessing the risks of simultaneous detonation and mechanical dismantling, both of which were deemed less suitable given the site-specific hazards and the close proximity of sensitive infrastructure. The staged initiation of charges across selected structural elements induced progressive failure, causing the towers to fold inward and directing debris toward the footprint center. This sequencing strategy effectively reduced ground vibration amplitudes while enhancing control over collapse direction and debris confinement. Additionally, to reduce the impact load transmitted to the ground, the structures were pre-weakened and rubble was strategically heaped in the basements to act as a cushioning layer.

Pre-blast vibration predictions were undertaken by Vibrock Ltd., a UK-based specialist in blast vibration analysis, to support the demolition planning process for the Supertech Twin Towers. Vibrock estimated that peak particle velocities (PPV) within a 10 m radius of the towers would range between 22 mm/s and 34 mm/s, while at distances of up to 100 m the PPV would be in the range of 3–5 mm/s, as reported in Joseph and Boominathan (2024). These values were derived from site-specific blast modelling parameters, including the implosion time isochrone, collapse time contour, direction of pull and local soil conditions. According to vibration damage criteria reported by Chi and Zhang (2010), a PPV of up to 35 mm/s is classified as *no damage* and above 115 mm/s will create severe damages for buried pipelines and reinforced concrete structures.

2.2 *Vibration measuring instrumentation and results*

During the blast, detailed vibration measurements were recorded. A set of monitoring points was established along the pipeline corridors and at nearby buildings up to 70 m from the blast source, as shown in Figure 3**.** Each monitoring location on the pipeline was instrumented with a high-sensitivity piezoelectric accelerometer (to measure vertical ground acceleration) and a tri-axial geophone (to measure ground velocity in three directions). The accelerometers were mounted on small concrete footings embedded at shallow depth to ensure good contact with the ground, and they were connected to a multi-channel data acquisition system (HBM QuantumX) with real-time recording via Catman software. 3-D geophones (Manufacturer: Seismic Source, Model: Sigma4) with a natural frequency of 2 Hz were installed to measure the vibration level. These geophones are capable of recording vibration in three perpendicular directions (Vertical, Horizontal-longitudinal, and Horizontal-lateral). Pre-blast calibration with known vibration sources was performed to verify sensor accuracy.

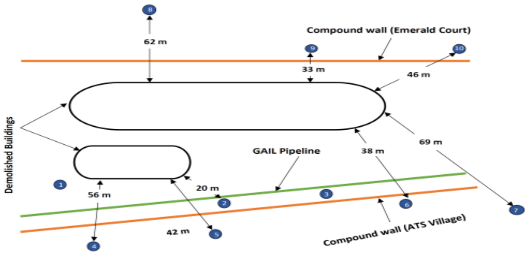

Figure 3. Schematic showing the relative positions of the towers and the vibration measurement location

Figure 4 presents the typical recorded vertical particle velocity time history and its corresponding frequency spectrum at Location 9, situated 33 m from the demolition building. The particle velocity exhibits a distinct peak during the main collapse phase, followed by a rapid decay in amplitude within a short duration. The frequency spectrum (Figure 4b) indicates that the dominant motion is concentrated in the 3–10 Hz range, confirming that the vibration energy was predominantly carried in the low-frequency band most relevant to the dynamic response of large structures and buried pipelines.

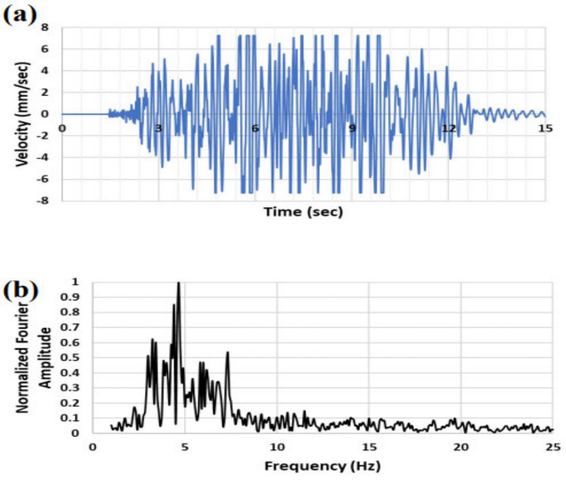

Figure 4. a) Velocity Time History, and b) Frequency Spectrum at location 9 located 33m away from the demolition building

Table 1 summarizes the PPV values and corresponding dominant frequency content measured at the designated monitoring locations during the blast. At the GIAL pipeline location, a maximum vertical PPV of 24.8 mm/s was recorded. Vertical PPV values ranged from 6.42 mm/s (Location 4, 56 m from the building) to 7.27 mm/s (Location 6, 38 m from the building). At Location 9 (33 m), the vertical PPV was 7.25 mm/s, indicating that proximity to the blast generally correlated with slightly higher vertical PPVs.

Table 1. Peak particle acceleration and velocity measured at selected locations during blasting.

Location No	Distance between building and the sensors (m)	Direction	PPV (geophone/accelerometer) (mm/s)	Frequency Content (Hz)
1	20	Vertical	24.8	5-15
2	25	Vertical	20.4	5-15
4	56	Vertical Horizontal 1 Horizontal 2	6.42 3.7 3.33	2-8
5	42	Vertical Horizontal 1 Horizontal 2	7.26 2.89 5.95	3-12
6	38	Vertical Horizontal 1 Horizontal 2	7.27 1.56 3.13	3-13
7	69	Vertical Horizontal 1 Horizontal 2	6.86 1.46 2.13	3-9
9	33	Vertical Horizontal 1 Horizontal 2	7.25 2.99 4.22	3-8

3 NUMERICAL MODELLING OF PIPELINE PROTECTION MEASURES

To protect the pipeline from the impact of blast-induced ground vibrations, a passive vibration isolation system was proposed above the pipeline alignment. This multi-layer system was specifically developed to attenuate transmitted wave energy through mechanisms including material damping, impedance contrast, and mechanical reinforcement, each contributing distinctively to overall vibration reduction. To evaluate the dynamic response of the buried gas pipeline and to verify the effectiveness of this protective barrier, a two-dimensional finite element model was developed in PLAXIS 2D as shown in Figure 5.

The proposed system comprised a surface rubber pad for high-frequency damping, a geogrid interface layer to provide tensile reinforcement and shear redistribution, a rubber crumb layer for energy dissipation through nonlinear deformation, and a base steel plate to ensure uniform stress transfer and partial reflection of downward-propagating waves.

3.1 *Model Geometry and materials*

The finite element model domain was defined as 120 m in width and 30 m in depth to ensure adequate wave propagation and minimize boundary reflection effects. Model boundaries were chosen after convergence testing to ensure all reflected waves

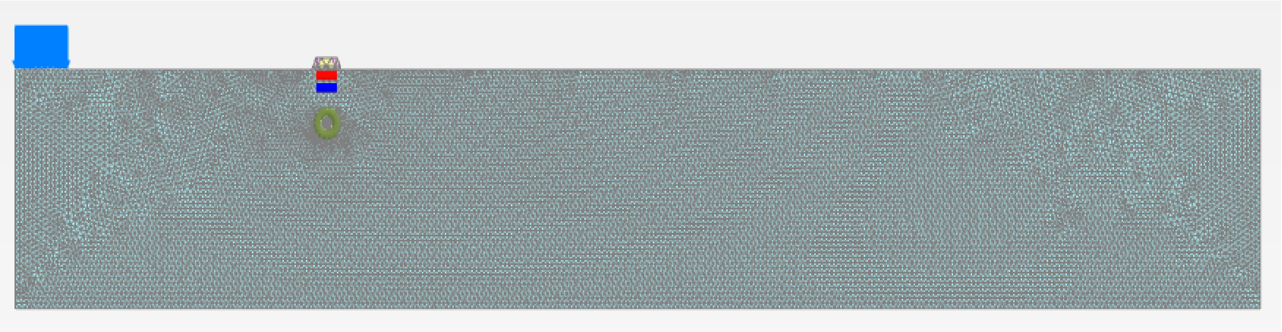

Figure 5. PLAXIS 2D model of buried pipeline system

dissipated before reaching the region of interest. The geometry included the ground surface, the embedded pipeline, and the overlying multi-layer protection system. The buried pipeline was located 20 m horizontally from the assumed vibration source and embedded at a depth of 4.0 m (to pipe crown). Absorbing (viscous) boundaries were applied along the vertical model edges to prevent artificial wave reflections, while the bottom boundary was fixed in both horizontal and vertical directions to simulate a rigid base. These conditions ensured realistic dynamic wave transmission through the soil mass during blast loading.

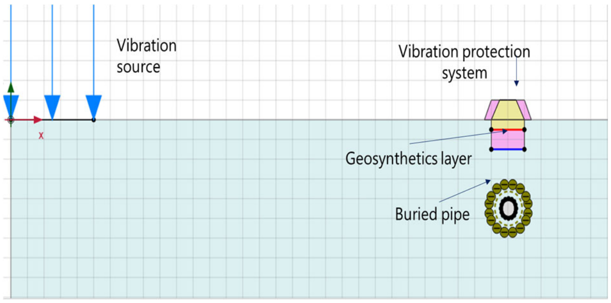

Figure 6. Buried pipeline with passive isolation system subjected to vibration from dynamic loading

3.2 *Model Geometry and materials*

Above the pipeline, a three-layer vibration isolation system was modeled to simulate the actual field layout (Figure 6). The protection system comprised a surface rubber pad, a central rubber crumb layer, and a geogrid interface arranged sequentially. The upper layers act synergistically to attenuate vibrations, absorb transient energy, and redistribute shear stresses from demolition-induced ground motions. Below this, a second rubber pad rests atop a steel plate placed directly above the pipeline crown, serving to uniformly transfer loads and reflect downward-propagating stress waves. Figure 7 illustrates the cross-sectional configuration of the buried pipeline with the multi-layer passive isolation system subjected to dynamic vibration loading

The soil was modeled as silty sand using the Mohr–Coulomb constitutive model, with values of cohesion, friction angle and modulus of elasticity, pertaining to the site. The rubber crumb was modeled using the soft soil model to represent its highly nonlinear compressibility and damping characteristics. The pipeline and steel plate were treated as linear elastic materials. The pipeline was modeled as a hollow circular section using a 16-sided polygonal approximation, with an outer diameter of 1.0 m and a wall thickness of 0.1 m. Linear elastic properties representative of concrete were assigned ($E = 30$ GPa, $\nu = 0.2$, $\gamma = 25$ kN/m^3). Interface elements were provided around the pipeline perimeter to capture soil–structure interaction, with a strength reduction factor of $R_{inter} = 0.70$ to simulate realistic slip and shear transfer. Material parameters assigned to each domain are summarized in Table 2.

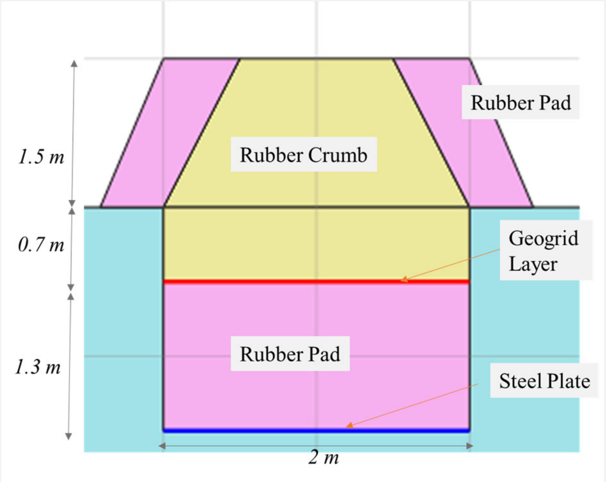

Figure 7. Configuration of the pipeline protection system

Table 2. Details of material models adopted in the FE model

Layer	Material Model	Properties & Function
Rubber Pad	Linear Elastic	$E = 2.5$ MPa, $\nu = 0.42$, $\gamma = 15$ kN/m^3 Rayleigh damping parameters (High damping ratio (~10%), absorbs transient stress waves)
Geogrid Layer	Geogrid Interface	EA = 120 kN/m, Pull-out stiffness = 5MN/m^3
Rubber Crumb	Soft Soil Model	$E_{50} = 1.5$ MPa, $E_u^r = 4.5$ MPa, OCR = 1.2, $\gamma = 10$ kN/m^3, $\nu = 0.4$; Rayleigh damping parameters
Steel Plate	Linear Elastic	$E = 200$ GPa, $\nu = 0.3$, $\gamma = 78.5$ kN/m^3

A non-uniform mesh was used with local refinement around the pipeline and the protective layers to capture stress concentrations and transient vibration response with high fidelity. Fifteen-node triangular elements were adopted throughout the domain, and mesh convergence was checked to ensure no difference in peak response at the pipeline for further refinements..

3.3 *Dynamic Loading*

Blast-induced ground motion in the numerical model was simulated by applying a vertical sinusoidal velocity time history as a dynamic line load across a 20 m-wide surface band, replicating the primary impact zone of the collapsing tower. Based on the vibration prediction study of Vibrock a design PPV of 34 mm/s was adopted as the input for dynamic loading

(Joseph and Boominathan 2024). The total simulation time was set to 2.0 seconds, with a fine time increment of 0.001 seconds to capture detailed transient response. Key output parameters included velocity and acceleration time histories at selected nodes, to evaluate the vibration attenuation effectiveness of the isolation system.

3.4 *Results and Discussion*

The performance of the proposed passive vibration isolation system was evaluated by comparing the predicted peak particle velocity (PPV) and peak particle acceleration (PPA) values at selected monitoring points across and below the protection layers. Table 3 and Figure 8 present comparative results at four critical depths, clearly showing the progressive attenuation of ground vibrations as waves propagate downward through each protective stratum.

At the input surface (Point A), representing an unprotected location near the blast source, PPV reached 28.7 mm/s. As ground motion travelled through the layered barrier system, PPV progressively decreased, reaching 20.97 mm/s at the geogrid–rubber interface (Point B), then 14.64 mm/s just above the pipeline crown (Point C), and further dropping to 7.73 mm/s at the pipeline level (Point D), directly beneath the trench. This corresponds to a total reduction of approximately 73% in PPV, demonstrating the combined damping and scattering effects achieved by the multi-layer design. Similarly, PPA values displayed a downward trend: from 0.320 m/s² at the surface, PPA was reduced to 0.065 m/s² at pipeline depth, representing a reduction of nearly 80%.

The attenuation trend observed was consistent across all barrier layers. For example, at mid-depth (Point B), where the geogrid–rubber interface is located, PPV dropped by approximately 27% (from 26.80 mm/s without protection to 20.97 mm/s with protection), indicating significant partial wave dissipation and redistribution at this layer. At the base of the protection stack (Point C), immediately above the pipeline, a further 31% reduction in PPV was noted reflecting the cumulative effect of energy damping and mechanical isolation provided by the layered configuration.

The greatest performance benefit was observed at the pipeline (Point D), where the layered system consistently reduced transmitted energy to below established safety thresholds for utility lines. In particular, the progressive energy dissipation at each layer demonstrates the complementary functions of the rubber pad (high-frequency damping), geogrid (shear distribution), and rubber crumb (nonlinear energy absorption), while the steel plate further ensures that stress concentrations do not localize at the pipeline interface.

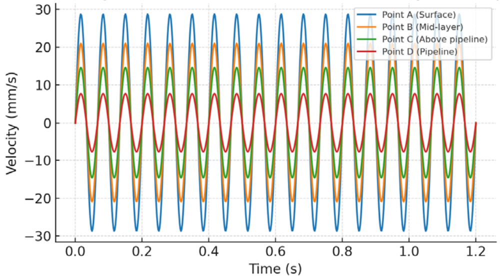

Figure 8. Vertical PPVs at pipeline monitoring points

The results indicate that the system remains highly effective even under conservative blast loading conditions. Overall, these findings validate the effectiveness of the engineered barrier in safeguarding buried pipelines and highlight the critical importance of a properly designed, multi-material protection system for urban demolition scenarios. These outcomes validate the barrier's function as a vibration mitigation strategy for shallow-buried utility lines.

Table 3. Pipeline response with and without protection system

Location Point	Position	PPA (m/s²)		PPV (mm/s)	
		Without protection	With protection	Without protection	With protection
Point A	At ground level	0.320		28.7	
Point B	At mid-layer interface	0.235	0.118	26.80	20.97
Point C	Just above pipeline crown	0.213	0.085	22.55	14.64
Point D	At pipeline	0.162	0.065	18.8	7.73

4 POST DEMOLITION ASSESSMENT

Following the execution of the controlled implosion, a post-demolition inspection was conducted to evaluate the performance of the vibration protection system and confirm the structural integrity of the nearby buried gas pipeline. The assessment protocol included immediate visual surveys and follow-up feedback from the gas utility operator. Visual inspection of the pipeline corridor revealed no signs of surface settlement, ground fissures, or structural distress and no drop in pressure or any damages were the feedback obtained from gas utility operator.

As shown in Figure 9**,** the controlled collapse was successfully directed inward, with debris confined within the designated footprint. No debris encroachment or ground heave was observed near the pipeline alignment, indicating that the delayed detonation method and engineered barrier system performed as designed. Figure 10 illustrates the pre- and post-demolition conditions of the Supertech Twin Towers, highlighting the effectiveness of the delayed detonation technique in achieving the intended collapse mechanism without compromising adjacent infrastructure

Post-event monitoring data and regular patrols conducted by the pipeline operator (GAIL) over the subsequent week confirmed the continued safe operation of the line. No anomalies were reported confirming that the three-layer protective system performed as intended under field conditions. This outcome validated the design assumptions and reinforced the applicability of numerically guided vibration mitigation strategies in urban demolition projects.

Figure 9. Debris fall image after the waterfall implosion of Supertech Twin Tower

Figure 10. Pre- and post-demolition views of the Supertech Twin Towers, demonstrating successful collapse without damage to nearby infrastructure.

5 CONCLUSIONS

This study presented a field-validated approach for protecting shallow-buried pipelines from blast-induced ground motions during controlled demolitions in urban environments. A passive vibration isolation system—comprising a surface rubber pad, geogrid reinforcement, and an underlying rubber crumb layer—was implemented above a high-pressure gas pipeline located near the demolition footprint of two high-rise towers. Finite element simulations using PLAXIS 2D were performed to assess the system's effectiveness under conservative vibration scenarios.

The results demonstrated substantial attenuation of ground vibrations, with peak particle velocities reduced by 73% at the pipeline level. The layered barrier also produced a phase delay and amplitude reduction in vertical motion, indicative of progressive damping. The system was successfully deployed during the Supertech Twin Towers demolition, without any adverse impact on the adjacent gas infrastructure. The findings highlight the applicability of passive, material-based isolation systems for safeguarding buried lifelines in vibration-sensitive demolition or blast contexts, and offer a scalable framework for future urban infrastructure protection strategies. The results support adoption of engineered layered vibration isoaltion barriers as a best-practice standard for pipeline safety in dense urban redevelopment scenarios.

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