# CONTROLLED DEMOLITION OF STRUCTURES

**DISSERTATION**

*Submitted in partial fulfillment of the*

*Requirement for the award of the degree*

Of

**MASTER OF TECHNOLOGY**

In

**EARTHQUAKE ENGINEERING**

(With specialization in **Structural Dynamics**)

By

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**MAY - 2016**

# CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation report titled **"Controlled Demolition of Structures",** submitted to the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, in partial fulfillment of the requirements for the award of the Degree of Master of Technology, Earthquake Engineering with specialization in Structural Dynamics, is an authentic record of my own work carried out under the supervision of **Dr. Manish Shrikhande**, Department of Earthquake Engineering, IIT Roorkee.

The matter embodied in this project report has not been submitted by me for the award of any other degree.

Place: (**NIHIR KHUNGUR BORO)**

Date:

# CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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# ACKNOWLEDGEMENT

I wish to affirm my profound gratitude and deep regards to my mentor **Dr. Manish Shrikhande,** for his exemplary guidance, monitoring and constant encouragement throughout the course of this dissertation work. The blessing, help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark.

I am grateful to my friends who are actively involved in providing me a vital support and encouragement whenever I need.

Finally, I would like to express my gratitude to my parents for their faith and support, which has been a constant source of inspiration.

Place: (**Nihir Khungur Boro)**

Date:

# ABSTRACT

Controlled demolition of structures is the process of tearing down/bringing down or breaking apart a structure after its useful life period or partly damaged uninhabitable structure with the help of some equipment in a controlled manner so as to have negligible impact on its surrounding environment with minimum effort. For small buildings it is a simple process with the help of light equipment, but in case of larger buildings it may require the use of a wrecking ball, cranes etc.

After a devastating earthquake some structures remain standing but become dangerous and uninhabitable. Such buildings/structures need to be removed quickly and efficiently as it is an imminent threat to life and surrounding structures. Controlled demolition using explosives is the solution.

We describe the planning and analysis for controlled demolition of two multi-storey buildings using explosives. Various steps involved in the demolition process such as preparation of demolition plan, charge calculation, placement of explosives, sequence of detonation, stability report and precautions to be taken are presented in this report. The report also includes brief explanations about the types of explosives, detonators and terminology used in demolition industry.

## TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

## Chapter 1

# INTRODUCTION

### 1.1. Implosion

Controlled demolition using explosives is termed as implosion. It is called implosion though it is not an implosion (process due to variation in internal and external pressure, ext. pressure >> internal pressure) in literal sense because usually in a classic demolition scenario when the building collapses inward into its own footprint it seems as if it had just imploded. The explosives are used only to remove vertical load carrying structural members such that the whole structure is acted upon by gravity and a progressive collapse is initiated leading to crumbling of the structure. The direction of fall that is inward (implosion type) or onto one of its sides is achieved by removing the vertical load carrying components in a particular sequence. With access to structural details of the structure, breaking the structure from bottom to top and from inside to outside will tend to implode the structure. For conducting a typical building implosions numerous small charges needs to be employed, totaling to a modest quantity of explosives. Small cutter/shaped charges (high velocity charges) are very effective at slicing through steel members when properly installed facing them, therefore not requiring a large quantity of explosives to implode a steel skyscraper but, however, it does, require a large number of charges, since, it is necessary to sever all of a building's support columns, with precise timing. The timing of the charges is very critical for a successful implosion, since it is the asymmetries in the charge detonation that tends to make a building lean to the side being destroyed first.

### 1.2. Progressive Collapse

Progressive collapse is a type of collapse in which an initial local failure in a structure spreads from element to element and eventually results in the collapse of the entire structure or disproportionately large part of it.

### 1.3. Explosives & Detonators

Explosives are materials which cause an instantaneous release of energy of destructive nature in the form of light, pressure, heat and sound when subjected to a certain amount of temperature, shock or pressure. Explosives are broadly classified into two categories as high explosives and low explosives depending on their speed of expansion. In high explosives the front of the chemical reaction moves faster than the speed of sound through the material whereas in low explosives the materials deflagrate.

A detonator is a triggering device that is initiated mechanically, chemically or electrically to trigger an explosive device.

## 1.5. BLAST PARAMETERS

Typical blast pressure profile is as shown in Figure 1.3. At the arrival time following the explosion, pressure at the position (the distance considered from the blast) increases suddenly to a peak overpressure, $P_{SO}$ over ambient pressure, $P_O$ and decays to ambient pressure at time $t_A + t_O$, then further decaying to an under pressure, $P_{SO^-}$, before returning to ambient level. Most design case ignore negative phase because of little effect on structure.

**Detonation Pressure** is a measure of the explosive’s shock wave energy which is influenced by the explosive's velocity of detonation (VOD) (rate of energy release) and density (latent energy).

$$P_d = \frac{V_e^2 \times d_e}{3.8} \tag{1.1}$$

Where,

$P_d$ = Detonation Pressure in $N/m^2$

$V_e$ = Detonation velocity in m/s

$d_e$ = Density of explosive in $kg/m^3$

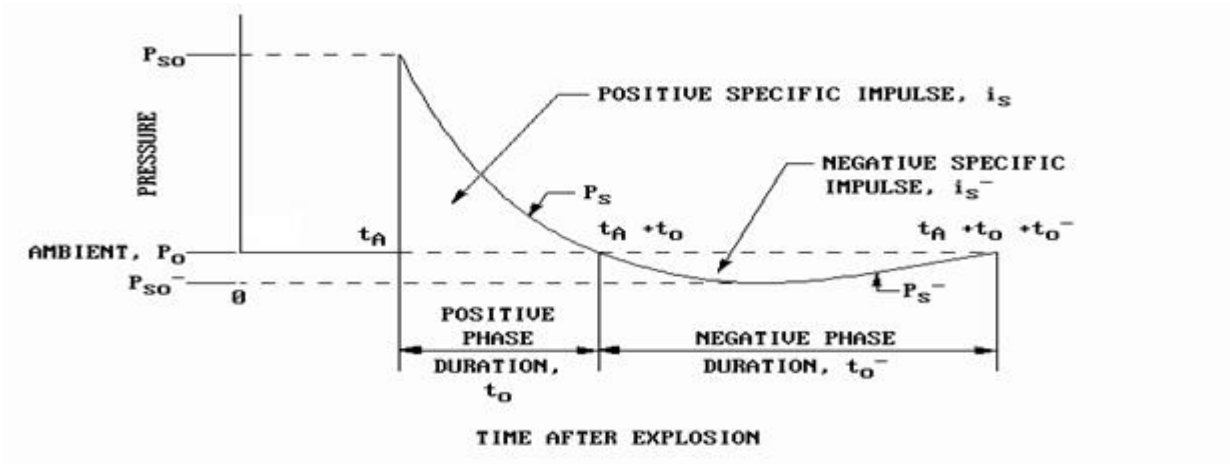



**Fig. 1.1.** Ideal blast wave resulting from explosion in air. [4]

The effect of the blast wave experienced depends on the stand-off distance from the source of the blast. There are also reflected blast waves occurring due to obstruction by some natural features (mountain or large rock) or built up structures which are equally or even more dangerous than the direct waves depending on the location.

In case of controlled demolition, the secondary effect of blasts can be ignored as the charges are confined inside the structural members and are detonated in small quantities spread over a time period with delays. Also, the energy released is consumed in the destruction of the structural elements.

# Chapter 2

# LITERATURE REVIEW

## 2.1 DEMOLITION USING EXPLOSIVES

The term “implosion” was conceived in the late 1950s to describe the process of controlled demolition with minimal use of explosives and minimum cost of structural preparation. The objective is to remove or weaken critical supports so that the building/structure crumbles, being unable to withstand its own weight. This method is best suited for high rise structures (no. of storey > 5) in densely built up urban areas, where the other demolition methods are not feasible. For a safe implosion, each element of the implosion is mapped out ahead of time. The first step is examining the structural/architectural blueprints of the building/structure if it is available to determine the structural system of the building. Thereafter, the demolition crew visits the building for visual inspection and make notes about the supporting elements of the structure on each floor. After collecting all the raw data they need, a plan of attack is figured out. Earlier, the blasters based on their experiences with similar buildings made decisions on, as to the type of explosives to be used, placement in the building and sequence of detonation of explosive. With advent in technology the present generation of demolition crew makes 3-D computer models of structures and run simulations to validate their demolition plan. The building is imploded in such a way that it crumbles straight down into its own footprint. The collapse pattern is achieved by exploding the major supporting columns on the lower floors first and then a few upper stories. For example, in a 20-story building, the blasters might blow the columns on the first and second floor, as well as the 12th and 15th floors [2]. In most cases blowing the supporting members of the structures on the lower floors is sufficient to make a building crumble, but loading the columns on upper floors is necessary to help disintegrate the structural components into smaller parts. This makes for a perfect controlled demolition and easier clean up following the implosion.

## 2.2. EXPLOSIVES USED FOR IMPLOSION

The most common explosives used for demolition purpose are dynamites (straight, ammonia and gelatin), RDX (Cyclotrimethylene-trinitramine) and PETN (penta-erythritol tetra-nitrate), water gels and emulsions.

**(a) Dynamite:** In 1866 Alfred Nobel invented dynamite, a stable product which is safe and easy for handling, by combining nitro-glycerine with an inert filler material. Dynamite is an absorbent stuffing soaked in a highly combustible chemical or mixture of chemicals which burns quickly when ignited, produces a large volume of hot gas in a short amount of time which then expands rapidly creating an explosion, exerting pressure (up to 600 tons per square inch) on whatever is around it. The explosive material cramped into narrow bore holes drilled in the concrete columns sends a powerful shock wave bursting through the column at supersonic speed on its detonation, shattering the concrete into pieces. Blasters use traditional dynamite for concrete column as it has the benefits of having good to excellent water resistance as well as being predictable and reliable. The commercial availability of dynamite ranges from small to medium sized cartridges of varying length.

**(b) Cyclotrimethylenetrinitramine (RDX):** RDX is an acronym for “Research Department Formula X” and is also known as cyclonite or hexogen. Available in powder form, it is a high velocity explosive compound expanding at speeds up to 8,230 m/s. It is used as cutting charge in the form of linear shaped charge. Instead of exploding the target, the concentrated, high-velocity pressure slices right through the steel. Additionally, it may be accompanied by a kicker charge, usually a dynamite on one of the faces of the column to thrust it over in a specific direction. Structural steel is a much denser and stronger material than concrete, therefore it is more difficult to demolish a steel column. To bring down structures with steel supports, shaped charges filled with this specialized explosive is used. RDX is also mixed with plasticizer (5.3% dioctyl sebacate, ‘DOS’ or dioctyl adipate, ‘DOA’), plastic binders (2% polyisobutylene, ‘PIB’) and mineral oil (1.6% process oil) to make plastic explosives like C4.

**(c) Pentaerythritol tetranitrate (PETN):** Chemically it is very similar to nitroglycerin. It is the nitrate ester of pentaerythritol. It is practically insoluble in water. It is a high velocity explosive with detonation velocity ranging from 7420 m/s to 8500 m/s. When mixed with RDX along with some other minor additives it forms a plastic explosive called ‘Semtex’.

**(d) Water Gel and Emulsions:** It is a water-based chemical mixture which is either a water gel or emulsion. Water gel consists of oxidizing salts and fuels that are dissolved in water whereas emulsions are fine droplets of oxidizing salts and water surrounded by a fuel mixture of wax and oil. These explosives, available in several forms and sizes are even more stable. The typical size of cartridges used either individually or in bundles for demolition of concrete and brick structural components is 31mm in diameter and 200mm long [3].

## 2.3. ELECTRONIC DETONATORS

Electronic detonators are electronic devices used to trigger an explosion with more precise control over very short time delay. These are designed for variety of blasting applications to provide the precise control which is essential to produce an accurate and consistent blasting results. A dedicated programming device called the ‘logger’ can be used to program the detonator in 1-millisecond increments from 1 milliseconds to 10,000 milliseconds. The reliability of connections in detonation network can also be verified and ensured. Some examples of commercially available electronic detonators are Smartshot, Uni tronic 600, Digishot plus, I-kon and Daveytronic.

Advantages of Electronic detonators:

- Delay range varies from 1- 14000 milliseconds with an increment of 1 milliseconds.
- They have 0.01% precision of nominal delay time.
- Unique ID in each detonator.
- Reliable and safe initiation capacity of 1600-2400 units per blast per blasting machine.
- Multiple verification of detonators prior to each blast.

**Fig. 2.1.** Electronic detonator
[www.detnet.com, Dated:-10/12/2015]

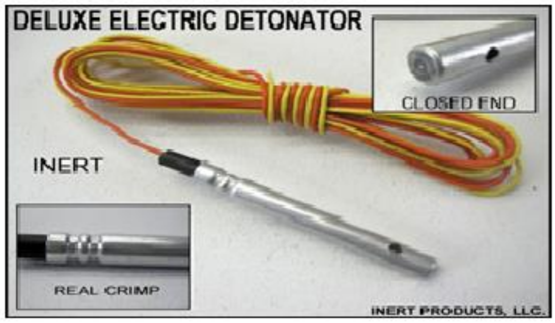



**Fig. 2.2.** Electric detonator
[http://inertproducts.com, Dated:-10/12/2015]


**Fig. 2.3.** System setup of Electronic Detonator
[www.aisystem.com.au, Dated:-10/12/2015]

## 2.4. SCIENCE OF CONTROLLED DEMOLITION

Concept and mechanism as how to initiate a successful progressive collapse:-

- **2.4.1. Type 1: Implosion,** i.e. inward collapse of the structure onto its own foot print

Step 1:

Giving direction to the collapse by blowing off the columns in the sequence as shown in the figure below.

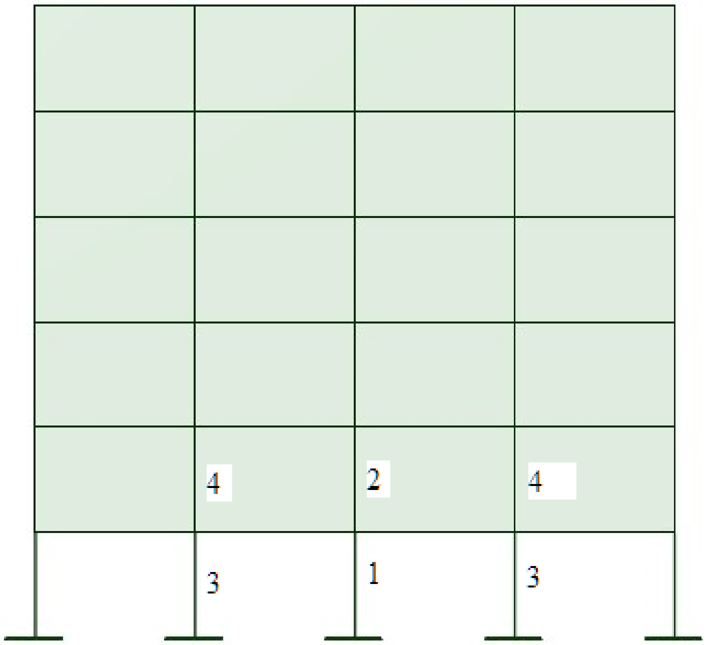



**Fig. 2.4.** Location and sequence of detonation of charges to give direction to collapse

Due to the removal of inside column by blasting the building will start collapsing inward. Time taken by the $1^{st}$ floor slab to hit the bottom will depend on the plastic rotation capacity of the beam and column joint at the ends.

Time taken ∝ Plastic rotation capacity (moment)

Step 2:

Hammer and anvil action

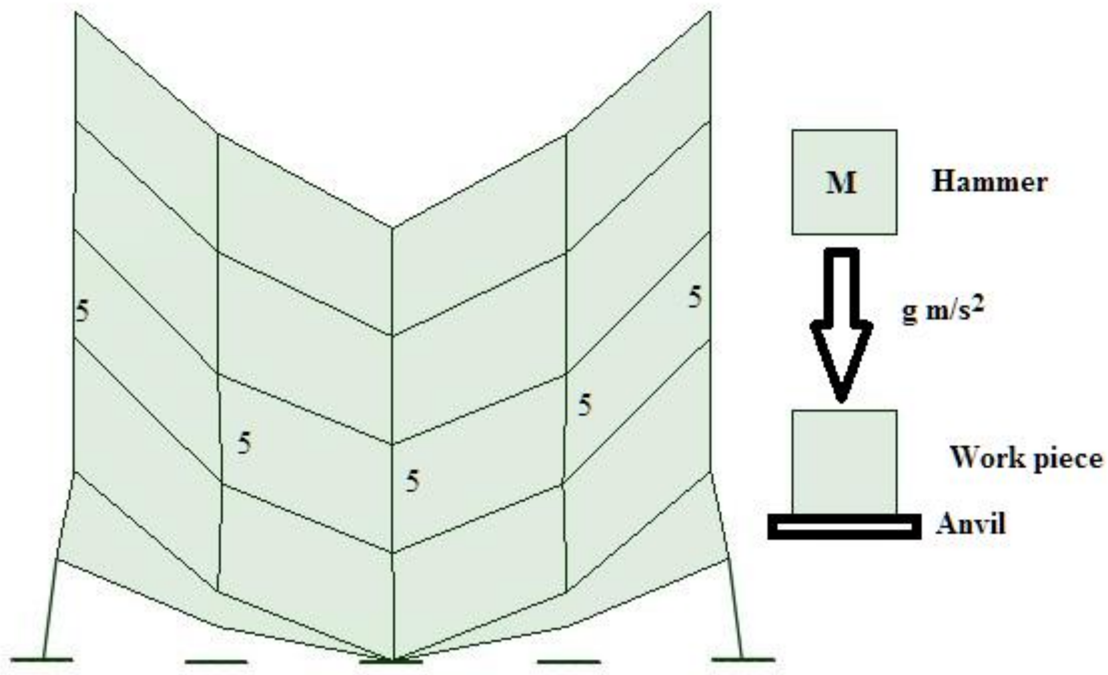



**Fig. 2.5.** Location and Sequence of detonation to provide space for free fall

All columns in $4^{th}$ floor have to be exploded at a single instance of time so that the floors above with mass M can free fall with 1 g acceleration (act like a hammer) and impact the third floor and other debris (assumed as a work piece) with a force equal to Mg and fragment.

The floor to be removed to provide space for acceleration should be so chosen such that the impacting force of the above floors should be very much greater than the resisting force offered by the lower stories

**Force = M** X **g > Resisting Force of Work piece**

Where,

M = mass of the structure acting as hammer

g = acceleration due to gravity.

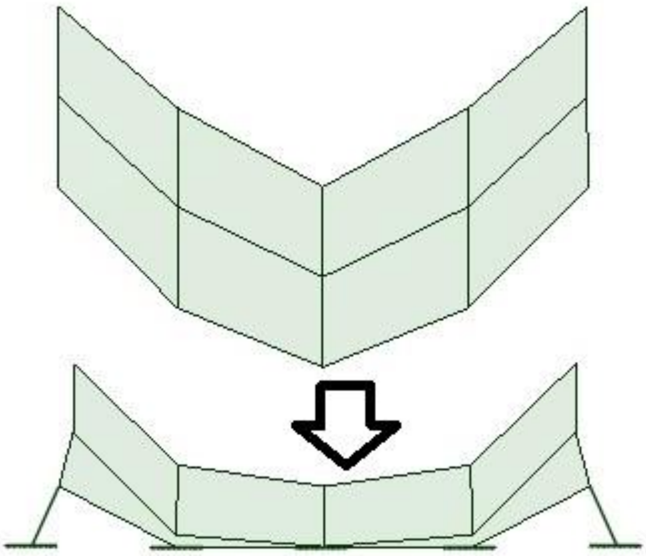


**Fig. 2.6.** Crush down Phase

In terms of energy, the Kinetic energy of the impacting floor should be very greater than the energy absorption capacity of the underlying floor along with the energy dissipated during crushing of the underlying floor.

If **K.E > Energy absorption capacity + Energy dissipated**

the collapse will propagate downward.

For crush up to take place the impacting floor (referring to figure i.e. Hammer) should have enough Kinetic Energy left after crushing the floors underneath on impact with the debris on ground such that the Kinetic energy dissipated is very much greater than the energy absorption capacity plus the energy dissipated during crush up

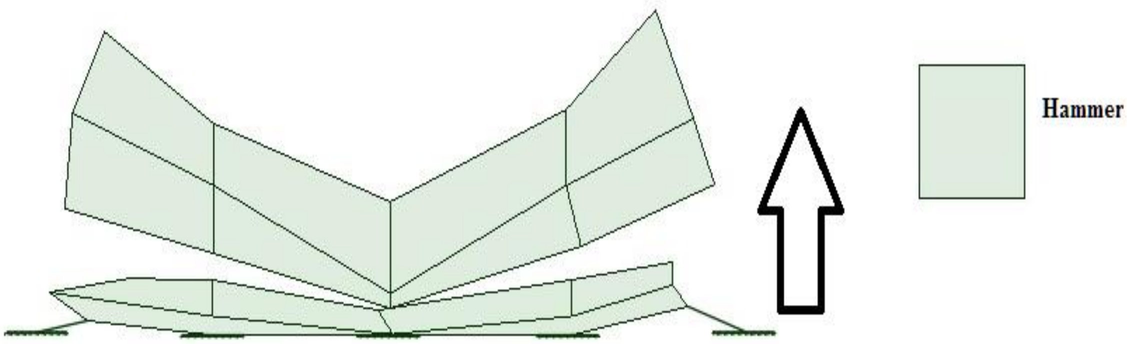



**Fig. 2.7.** Crush up Phase

- **2.4.2. Type 2: Toppling onto one side,** in this type of demolition the building/structure is made to fall on one of its faces/side. We take advantage of the P-Delta affect.

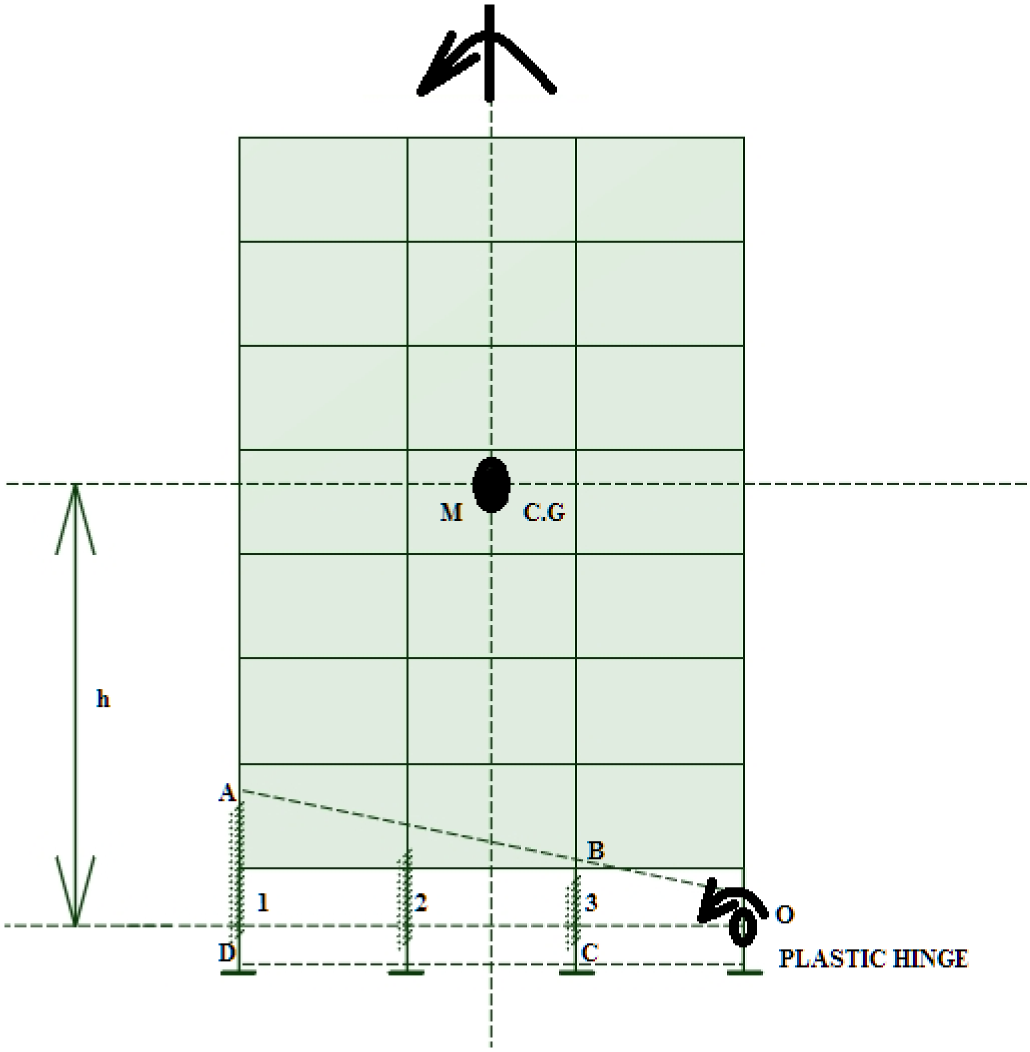



**Fig. 2.8.** 2-D model of **Type 2 demolition**

Step 1:

Remove the columns/support elements in sequence as shown in above figure along the direction of collapse as shown in above figure.

It is like a felling a tree on one of its side. A wedge shape part, 'ABCD', is removed from the vertically supporting elements of the structure as shown in the figure. The structure is made to tilt in the direction decided for the collapse.

Step 2:

Moment, 'Mgh' starts acting on the last vertically supporting element which is very much larger than the plastic moment capacity of the element (column/shear wall) and the building falls on its determined face.

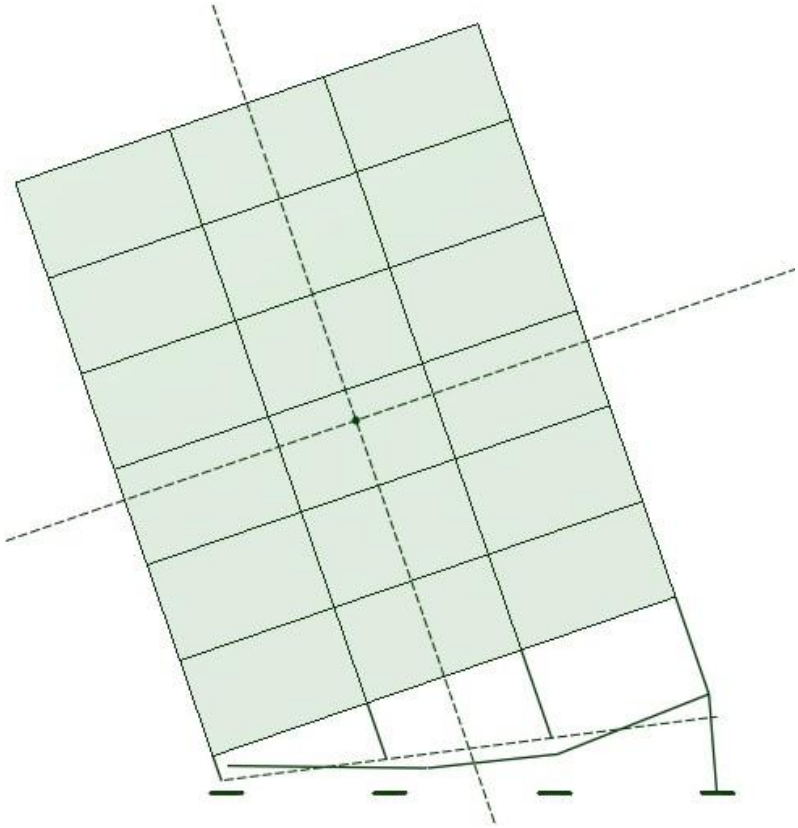


**Fig. 2.9.** Collapse in progress

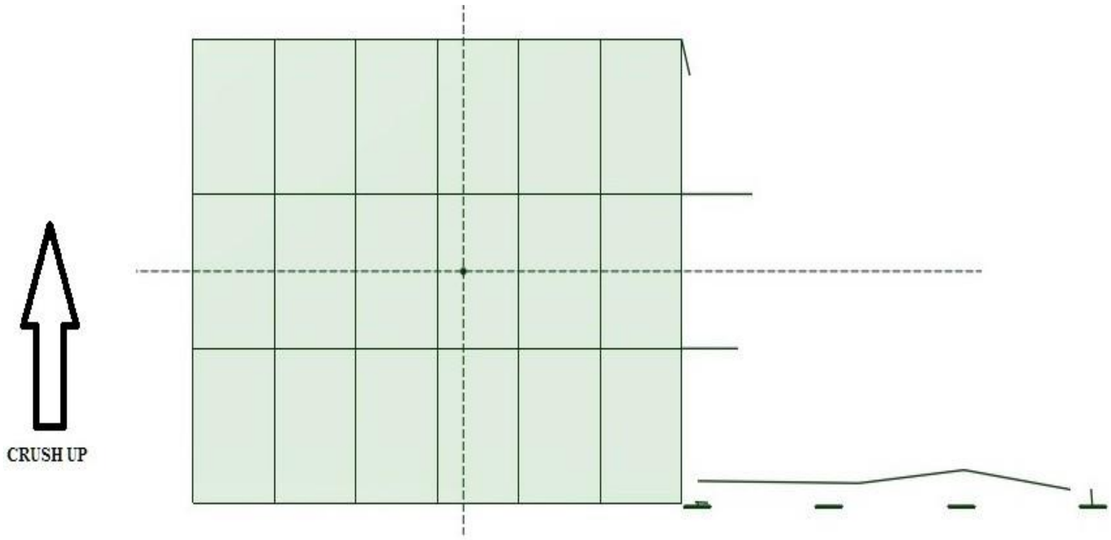



**Fig. 2.10.** Initiation of the 'Crush Up' phase on impact with ground

For crush up to take place the energy criterion is the same as for '**Type 1**' demolition mentioned in section 4.1.1. but in this case the plastic hinge moment-capacity of the last supporting element 'O', in figure 4.5, will govern the amount of Kinetic energy in the falling part of the strucure at the time of impact on ground. The acceleration of the body is less than gravitational acceleration (9.81 m/s$^2$) initially, but aft.er the formation of plastic hinge in element 'O' (figure 4.5), the body will accelerate with acceleration g (9.81 m/s$^2$).

- The sequence of detonation should have sufficient time delay for formation of plastic hinges at joints of structure such that energy demand for Crush up phase is not large.
    - Else the end picture will be somewhat like figure 4.7
- The last supporting element (element O in figure 4.5) where the desired plastic hinge governing the collapse is to be formed, should be such that its axial carrying capacity is more than its plastic moment capacity. (Slender sections)
    - Else the controlled demolition would end up as shown in figure below.

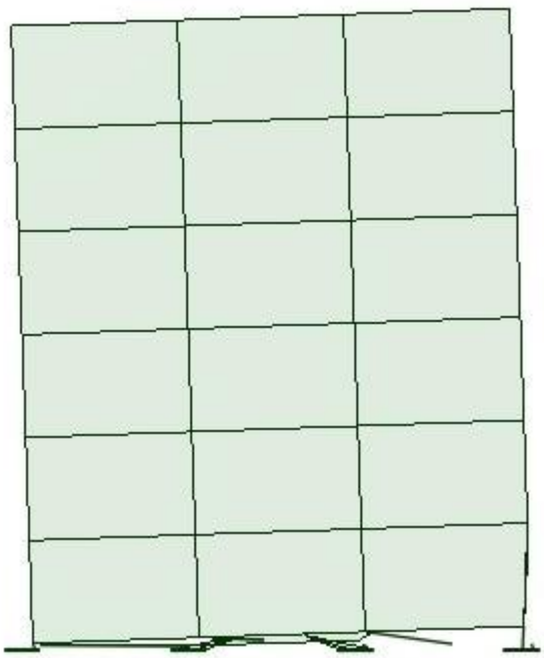


**Fig. 2.11.** Failed demolition

- Also, if the plastic moment capacity is inadequate and the time delay between consecutive detonation is very very small then there is a chance of rolling over of the falling part due to the intactness(still rigid) of the falling part having a high momentum.

## 2.5. STEPS INVOLVED IN CONTROLLED DEMOLITION (IMPLOSION)

### 2.5.1. PRE-PLANNING OF DEMOLITION ACTIVITY

The different steps involved before the start of a demolition process are:

A. Surveying of site and inspection:

1. Structural surveying

   (a) Survey of the structure.

   (b) Record drawings and details.

   (c) Look for hazardous Materials in the site and its surrounding

B. Removal of hazardous materials from the site.

C. Soft stripping of the structure.

D. Preparation of plan along with strategy to implement.

1. Detailed plans showing:

   (a) The location of building to be demolished

   (b) Topographic details of the site with contours and sections of the slopes and ground supporting the building

   (c) Details of ground removal or backfilling

   (d) The clear distances of structures, streets and significant street furniture from the building to be demolished

2. A Detailed plan showing the steps for the demolition.

E. Stability report from local governing authorities.

F. Safety measures to be taken.

### 2.5.2. QUANTITY OF EXPLOSIVES

The quantity of explosives required for the demolition are calculated using empirical formulas. The amount of explosives required are calculated for each similar structural member. The type of explosives required will depend on the type of material that is to be destroyed.

For R.C.C sections

The number of charges required is calculated using the formula,

$$N = \frac{W}{2R} \tag{2.1}$$

Where,

N = number of charges,

W = pier, slab or wall width considered,

R = breaching radius.

The empirical formulas used for charge calculation are:

**a.) Portuguese method :** developed by Gomes

$$Q = R^2 \times K \times L \tag{2.2}$$

Where,

Q = Explosive charge per drill using TNT (Kg.)

R = The shortest distance from the centre of the drilled hole to the exposed face of columns or to half the space between drills in square grids in metres.

K = Coefficient that depends on the confining and resistance characteristics of the section.

L = Blast section length in metres.

**Table 2.1.** Values for K for reinforced concrete columns & walls. [6]

| K – Reinforced concrete columns and walls | | | | |
|---|---|---|---|---|
| % of reinforcement | 1% | 2% | 3% | 4% |
| Hoop | 8mm @ 25-30 cm | 8mm @10-15 | 8mm @10-15 cm | 8mm @10 cm |
| Concrete Quality | Weak - Medium | Medium | Medium – Good | Good - Very |
| K | 2.05 | 4.02 | 6 | 7.97 |
| NOTES: The values for K can be reduced if the element hoops are lower than considered above, i.e. if spacing is greater than indicated. Excluded from this adjustment is the value of K (1%) that should not be optimized but possibly increased if the concrete is of good quality. | | | | |

**b.)** U.S Army formula :

$$P = R^3 \times K \times C \quad (2.3)$$

Where,

P = TNT required (pounds)

R = breaching radius (ft.)

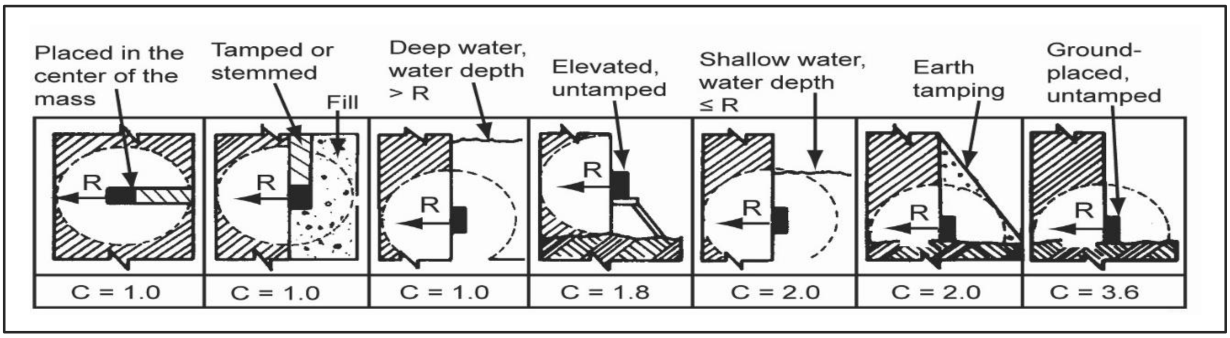
K = material factor, which reflects the strength, hardness, and mass of the material to be demolished which is given in table 2.2.

C = tamping factor, which depends on the tamping and location of the charge given in table 2.3.

**Table 2.2.** Material Factor (K) for Breaching Charges. [7]

| *Material* | *R* | *K* |
|---|---|---|
| Earth | All values | 0.07 |
| Poor masonry,<br>Shale,<br>Hardpan,<br>Good timber &<br>Earth construction | Less than 1.5 m (5 ft.)<br>1.5 m (5 ft.) or more | 0.32<br>0.29 |
| Good masonry,<br>Concrete block,<br>Rock | 0.3 m (1 ft.) or less<br>Over 0.3 m (1 ft.) to less than 0.9 m (3 ft.)<br>0.9 m (3 ft.) to less than 1.5 m (5 ft.)<br>1.5 m (5 ft.) to less than 2.1 m (7 ft.)<br>2.1 m (7 ft.) or more | 0.88<br>0.48<br>0.40<br>0.32<br>0.27 |
| Dense concrete<br>First-class masonry | 0.3 m (1 ft.) or less<br>Over 0.3 m (1 ft.) to less than 0.9 m (3 ft.)<br>0.9 m (3 ft.) to less than 1.5 m (5 ft.)<br>1.5 m (5 ft.) to less than 2.1 m (7 ft.)<br>2.1 m (7 ft.) or more | 1.14<br>0.62<br>0.52<br>0.41<br>0.35 |
| Reinforced concrete (factor does not consider cutting steel) | 0.3 m (1 ft.) or less<br>Over 0.3 m (1 ft.) to less than 0.9 m (3 ft.)<br>0.9 m (3 ft.) to less than 1.5 m (5 ft.)<br>1.5 m (5 ft.) to less than 2.1 m (7 ft.)<br>2.1 m (7 ft.) or more | 1.76<br>0.96<br>0.80<br>0.63<br>0.54 |

**Table 2.3.** Tamping Factor (C) for Breaching Charges [7]



### 2.5.3. PLACEMENT OF EXPLOSIVES

The explosives are placed inside or on the face of columns and load bearing walls. The most suitable place for placing the charges are the columns at the ground/lowest storey level, as it is the place where the stored potential energy of the structure can be released most effectively and efficiently. Generally the lower storey levels are charged to initiate the collapse mechanism with one or more floor level on top fully rigged with explosives depending on the number of stories to create a structural vacuum for proper fragmentation of the debris. The method and type of loading steel columns with explosives is very much different from the ones that are used in reinforced concrete columns. Structural steel is more ductile and tougher than concrete resulting in slender sections. The internal confinement of explosives is not possible in case of thin steel sections (I, channel, angle, box etc.), as compared to that of concrete columns where charges are loaded inside the holes drilled. For steel sections special cutting charge in the form of shaped charges are used. For civilian use chevron shaped copper clad linear shaped charges are available which have RDX packed inside chevron shaped linear copper elements.

The charges in the form of cartridges along with stemming are placed in holes drilled on RCC columns. Stemming in the form of high density foam or typical tubular bags of sand are placed in the balance of the hole to confine the charge. On detonation of the explosives, the concrete in the column fragments and the reinforcing bars are bent, but intact. Excessive reinforcements and closely spaced shear stirrups in concrete columns increases its resistance against explosion and arrests the progressive collapse. Earthquake resistant reinforced concrete structures have good resistance to explosions as they have highly reinforced columns with closely spaced transverse reinforcement bent at $135^{o}$ at ends. Therefore closely spaced stirrups or spirals should be exposed and clipped, while the longitudinal reinforcements notched as per allowance to avoid premature failure of the member. If left uncut, unfractured concrete may remain trapped inside and the column may retain some of its load carrying capacity. To prevent flyrocks, each column should be wrapped with chain-link fencing and geotextile fabric. The fencing prevents the large chunks of concrete from flying out, while the smaller bits are trapped in the fabric. Geotextile fabric is also wrapped around the perimeter of each floor that is charged as second line of defence to contain the flyrocks that passes through tearing the material that is wrapped around each individual column. Neighbouring structures may also be covered to protect it from flyrocks, dust and blast wave.

**Fig. 2.12.** Columns loaded with charge wrapped around by geo-textile.
[http://science.howstuffworks.com/, Dated:-10/12/2015]

**Fig. 2.13.** Structure rigged with explosives, wrapped around by geo-textile.
San Juan, Puerto Rico. Dated: July 25, 2011 [The Loizeaux Group LLC]

### 2.5.4. SEQUENCE OF DETONATIONS

The main idea of implosion is to get an almost fluidic motion in the collapse of the structure resulting in reduced ground vibrations due to restrained impact. A properly designed implosion generates ground vibrations having peak particle velocity less than 25mm/s [2]. The columns located at the lower floor levels have the most amount of potential energy stored, maximum being at the lowest floor level of the building. Therefore to have the maximum amount of potential energy available immediately to initiate the progressive collapse, the charge placed in the columns at the lowest level of the building is detonated first. Also it is this first wave of detonation that decides the direction of fall. Columns on the other floors are detonated with a delay varying from a few milliseconds to seconds for proper fragmentation of the structural members and to control its velocity and trajectory. Earlier the blasting crew decided the sequence of detonation based on their experience, some do to this day. Present generation demolition crew makes 3-D computer models and simulates the implosion and arrive at a sequence of detonation that would impart the desired collapse pattern and fragmentation of debris. If the detonation are timed too close, there is chance of the building getting pancaked and portions of the building being pushed outward in random directions. If the delay time is too large then fluidic motion is arrested, which would lead to use of more explosives to overcome the inertia of the structure between each spill and also more importantly, an interruption in the fluidic motion could lead to causing complete loss of control over the trajectory of the structure due to disengagement of elements. After the detonation of a column, the structure above it is acted upon by gravity. The actual acceleration is less than 9.81 $m/s^2$ as some energy is consumed in overcoming the resistance offered by the connections of the structure as it falls. The downward momentum of the falling part of the structure can be slowed or stopped by naturally occurring alternate load paths in the structure. In a building implosion, the detonations are sequenced in such a way that the adjacent line of columns is detonated before any alternate load path is formed, to allow the propagation of progressive failure. Therefore, assuming freefall, suppose a delay interval of one second in detonation is provided between adjacent lines of columns, the line just detonated would have dropped almost 5.2 m [2] thereby impacting the ground before the next line of column is detonated. This type of scenario is to be avoided as the portion of structure still standing may be redirected into unexpected directions due to an impulsive ground impact by a portion of the structure. Also from the empirical notion, that material motion starts approximately 50-100 milliseconds after the blast [5]. The latest charge is detonated 50 milliseconds after the first one to ensure that falling debris does not interrupt the ignition lines [5]. Making 3-D computer models to simulate the collapse so that the sequence of detonation can be validated is a better option.

## Chapter 3

# DESCRIPTION OF WORK

### 3.1. STAGES OF PROJECT

The project was divided into two parts/stages. First part consisted of designing two structures on which controlled demolition was to be carried out. The design was done using Response Spectra Method for Earthquake Resistant design following the Indian Standards codes of practice namely,

I. IS 1893 (Part 1):2002, "Criteria for Earthquake Resistant Deign of Structures"

II. IS 456:2000, "Plain and Reinforced Concrete - Code of Practice".

The designs were verified in a computer software. After the verification of the designs, the collapse mechanism was decided. A hypothetical case of the structures being located in a heavily built up area inaccessible to heavy and large machineries needed to be demolished was considered which finally led to the selection of demolition using explosives as the solutions. Thereafter the steps involved before the execution of Implosion were carried out and 3-D computer models created to verify the Controlled demolition as predicted.

#### 3.1.1. STAGE 1: Acquiring the Problem

Designing of two buildings, for which a controlled demolition is to be simulated.

- Create the architectural layouts
    - i.e. setting the geometry and dimensions of building.
- Design criteria: Inter-Storey drift.
- Get preliminary cross section details of structural members.
- Use software CSI SAP2000 and complete the design.
- Verify the design.

N.B.: For real world practical demolition project Survey and Analysis of existing building is to be carried out.

#### 3.1.2. STAGE 2: Simulation of Controlled Demolition.

Designing the collapse pattern in which the building is to be demolished.

- Decide the pattern in which the building is to be collapsed.
- Identify the supports that need to be removed.
    - o Make a finite element model of it in Ansys and run simulations subjecting it to blast load for total disintegration so as to optimize the use of charges applied.
- Calculate the quantity of charge required for the demolition
- Make a model of the entire structure and load the supports to be eliminated with the estimated charge and run the simulation. In the simulations the instantaneous removal of members were done to simulate the blast loading to reduce the computational time.

### 3.2. DESIGNING OF THE STRUCTURES

The two structures/buildings are designed to resist earthquakes following the Indian Standard codes of practice, namely:

- IS 1893 (Part 1):2002, "Criteria for Earthquake Resistant Deign of Structures".
- IS 456:2000, "Plain and Reinforced Concrete - Code of Practice".

#### 3.2.1. DESIGN PARAMETERS

- Location of the structures: Seismic Zone V
- Soil type: Rocky
- Importance Factor: 1
- Reduction Factor: 5
- Design criteria: Inter storey Drift, limited to 0.2% of storey height.

#### 3.2.2. BACKGROUND OF DESIGN METHODOLOGY

- Response Spectra method used for design.

From Equation of motion for Undamped Free Vibration and considering Fundamental mode we get,

$$[K]_{n\times n} \{\Phi_1\}_{n\times 1} = \omega_1^2 [M]_{n\times n} \{\Phi_1\}_{n\times 1} \tag{3.1}$$

Where,

$K$= Stiffness matrix of the system.

$M$= Mass matrix, diagonal since considering lumped mass at floor level.

$\omega_1$= Fundamental normal mode.

$\Phi_1$= Mode shape corresponding to fundamental mode.

$n$ = Number of floors.

Assuming $\{u\} \approx \{\Phi_1\}.q$ , where $\{u\}$ = floor displacement, $\{\Phi_1\}$ is known.

On expressing the above equation in terms of K, we get-

$$\{K\}= \omega_1^2 [M] [S]^{-1}\{\Phi_1\} \tag{3.2}$$

Where,

$[S]$= Matrix obtained on expansion of eq. (3.1) and expressing in terms of K.

- Steps involved hereafter are:-

1. Choose $\omega_1$ to get maximum allowable roof displacement. It can be calculated as roof displacement $u_n$ is predetermined, following clause 7.8.4.5 (b) page 26 of IS 1893 (Part1):2002.
2. Solve for $\{K\}$.

3. Find Eigen values and vectors of [K] and [M].
4. Solve for storey drifts and check for permissible drifts considering suitable number of modal participation.
5. If ok calculate the column dimensions from the calculated storey stiffness. Else adjust the storey stiffness vector as per demand (increase/decrease) and repeat from step 3.
6. The beam dimensions were computed following the guidelines in IS 456:2000 based on the l/d ratio.

### 3.3. DRAWINGS AND DETAILS OF THE STRUCTURES

#### 3.3.1. BUILDING 1

- No. of storey = 20
- Total Height of building = 62 m
- Structural system = moment resisting frame

##### 3.3.1.1. PLAN

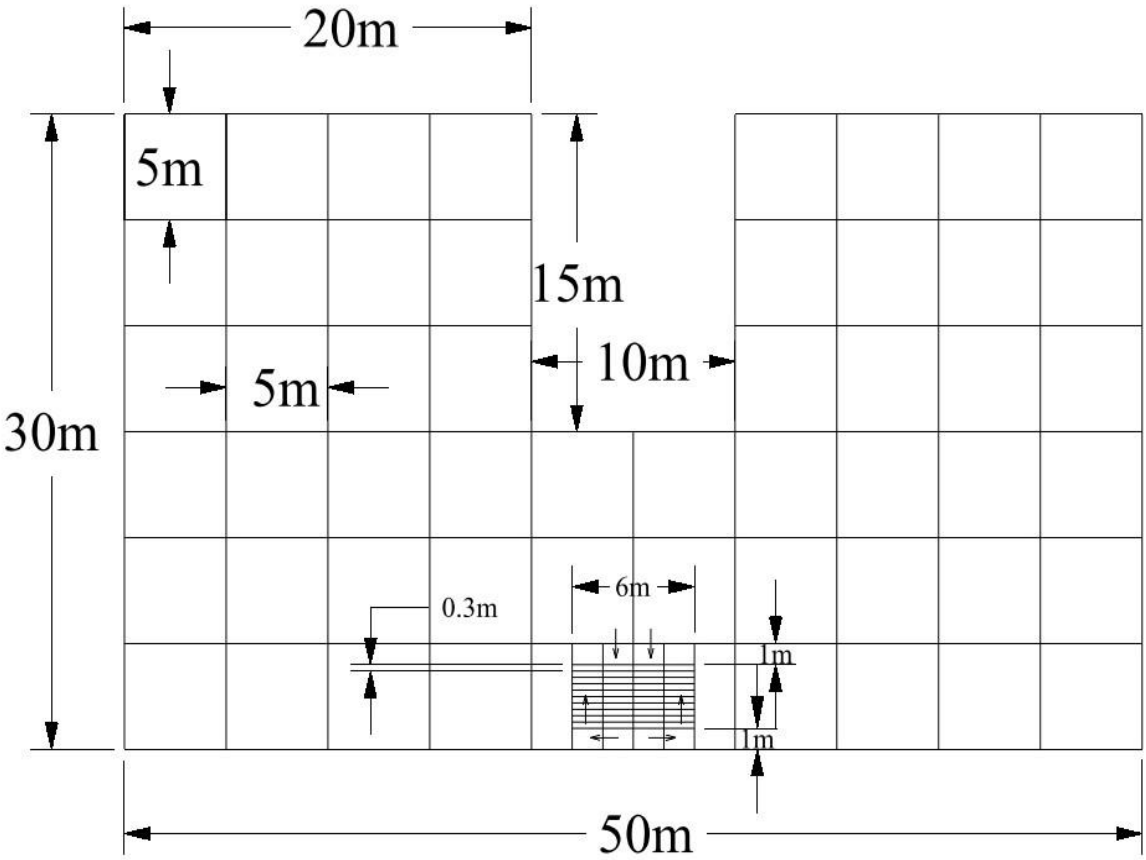



**Fig. 3.1.** Plan of building 1

### 3.3.1.2. ELEVATION

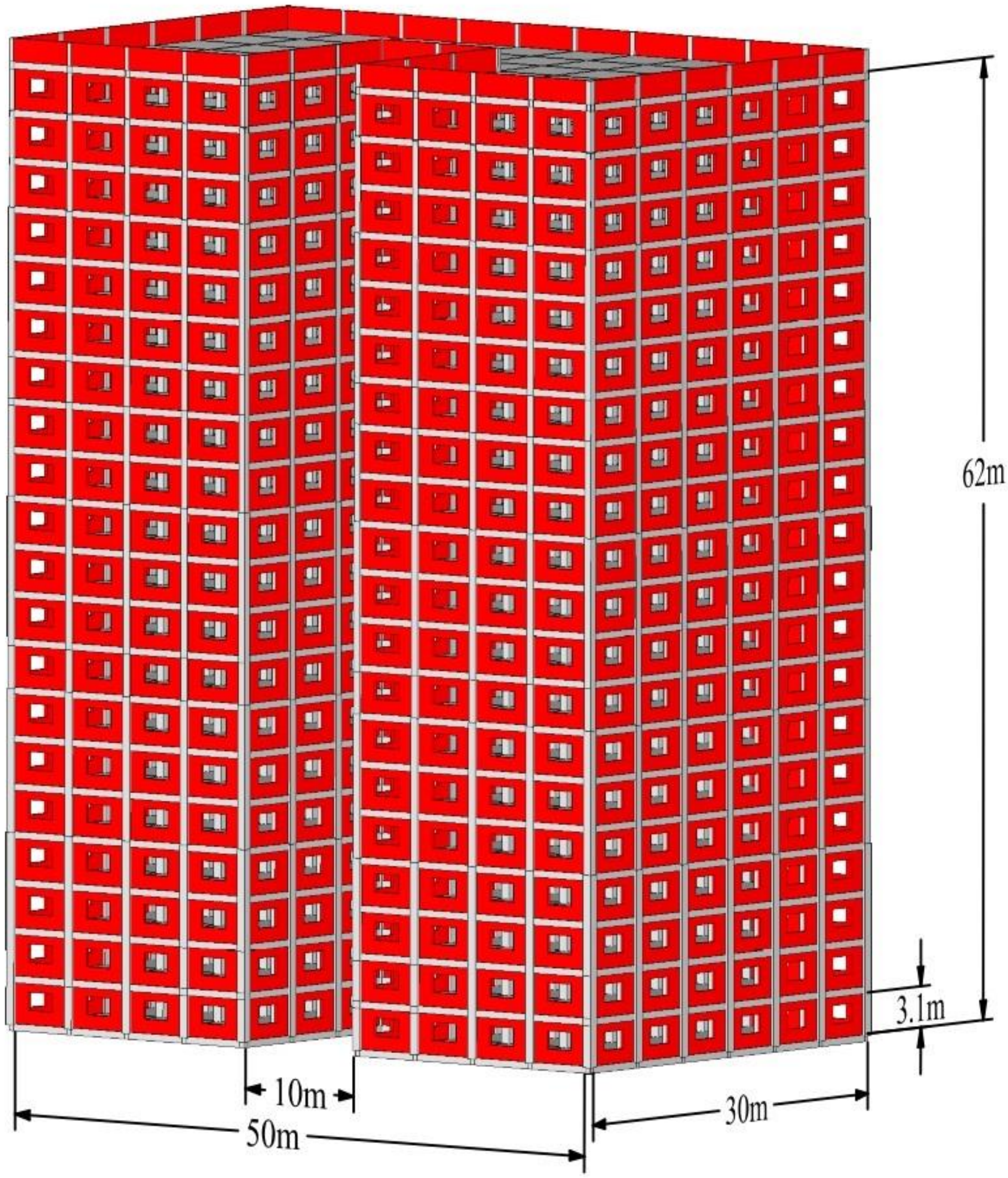



**Fig. 3.2.** Elevation of building 1

### 3.3.1.3. CSI SAP 2000 Analysis Model

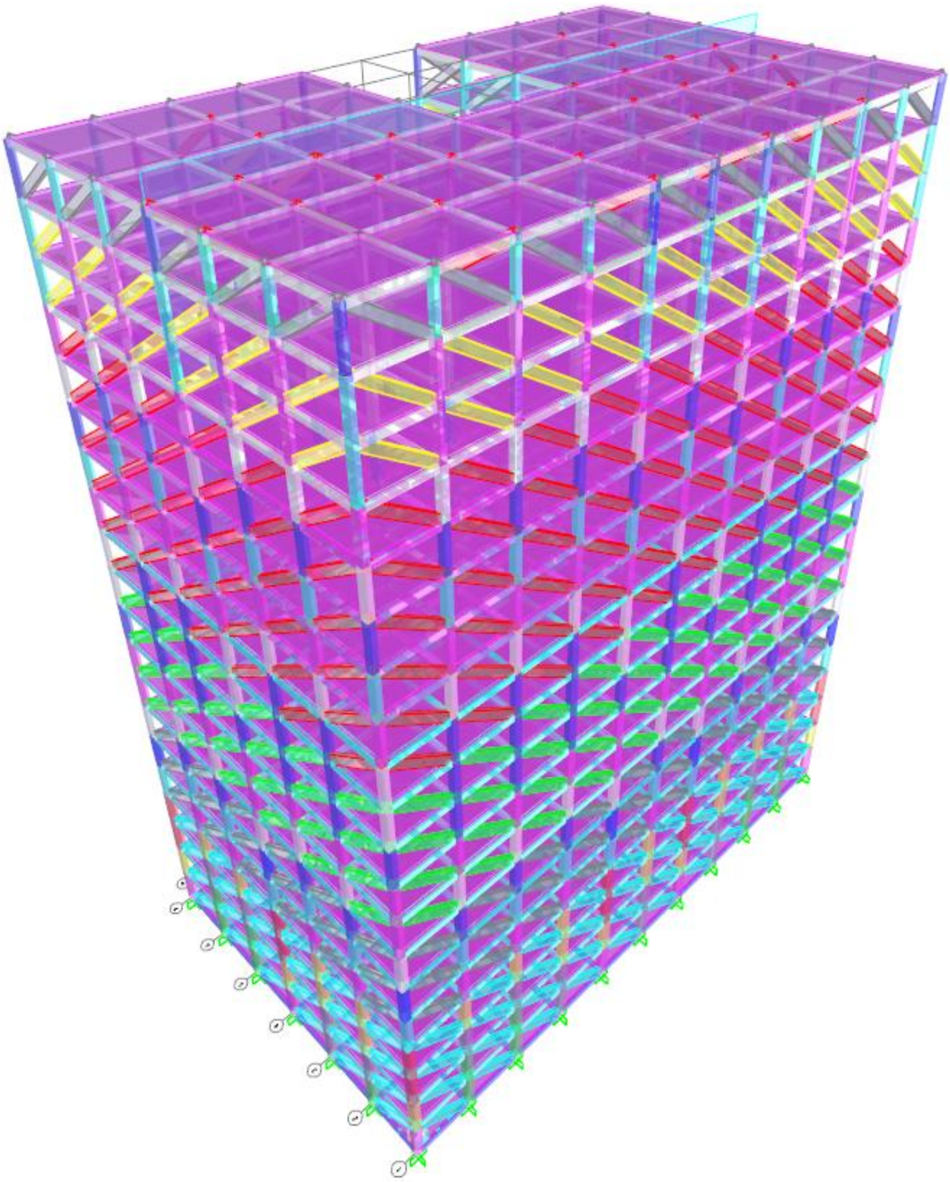


**Fig. 3.3.** Model used for Design of building 1

### 3.3.1.4. STRUCTURAL DETAILS

**Table 3.1.** Summary of Column and Beam Details

| Sl. No. | Storey | Column Dimensions (b = d) mm | Percentage Reinforcement in Columns | Beam Dimension (b X d) mm | Percentage Reinforcement in Beam |
|---|---|---|---|---|---|
| 1 | 1 | 650 | 3.00 – 5.96 | 350 X 450 | 0.448 |
| 2 | 2 | 650 | 2.51 – 5.19 | 350 X 450 | 0.448 |
| 3 | 3 | 650 | 2.51 – 4.00 | 350 X 450 | 0.448 |
| 4 | 4 | 650 | 1.92 – 3.45 | 350 X 450 | 0.448 |
| 5 | 5 | 600 | 2.00 – 4.00 | 350 X 450 | 0.54 |
| 6 | 6 | 600 | 1.70 – 3.15 | 350 X 450 | 0.54 |
| 7 | 7 | 600 | 1.59 – 2.94 | 350 X 450 | 0.54 |
| 8 | 8 | 550 | 1.89 – 3.25 | 350 X 450 | 0.54 |
| 9 | 9 | 550 | 1.66 – 2.9 | 350 X 450 | 0.54 |
| 10 | 10 | 550 | 1.24 – 2.9 | 350 X 450 | 0.54 |
| 11 | 11 | 550 | 0.83 – 2.11 | 350 X 450 | 0.54 |
| 12 | 12 | 500 | 1.00 – 2.55 | 350 X 450 | 0.54 |
| 13 | 13 | 500 | 0.96 – 2.35 | 350 X 450 | 0.59 |
| 14 | 14 | 500 | 0.96 – 2.35 | 350 X 450 | 0.59 |
| 15 | 15 | 500 | 0.96 – 1.57 | 350 X 450 | 0.59 |
| 16 | 16 | 500 | 0.96 – 1.28 | 350 X 450 | 0.59 |
| 17 | 17 | 500 | 0.96 – 1.00 | 350 X 450 | 0.54 |
| 18 | 18 | 450 | 0.84 – 1.24 | 350 X 450 | 0.54 |
| 19 | 19 | 450 | 0.84 – 1.24 | 350 X 450 | 0.54 |
| 20 | 20 | 400 | 0.80 – 1.57 | 350 X 450 | 0.54 |

Column height = 3.1 m

Beam Span = 5 m

Internal wall thickness = 0.150 m

External wall thickness = 0.230 m

1$^{st}$ Natural period = 1.2804 seconds along direction of 30m length.

2$^{nd}$ Natural period =1.2374 seconds along direction of 50m length.

### 3.3.2. BUILDING 2

- No. of storey = 30
- Total Height of building =93m
- Structural system = moment resisting frame

### 3.3.2.1. PLAN

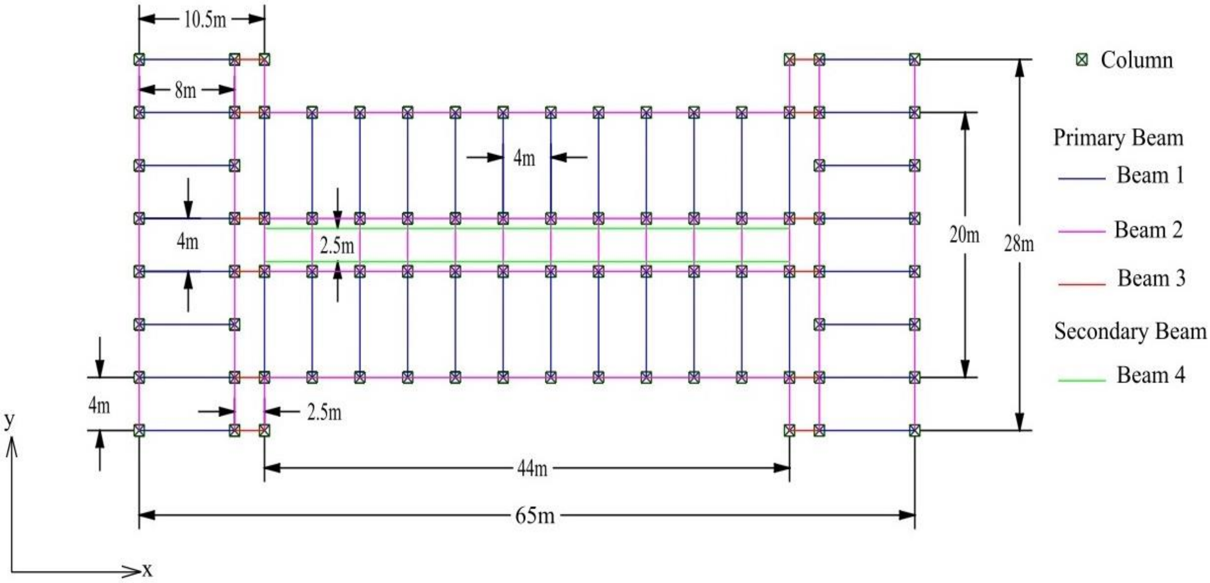



**Fig. 3.4.** Column and Beam Layout of building 2

### 3.3.2.2. ELEVATION

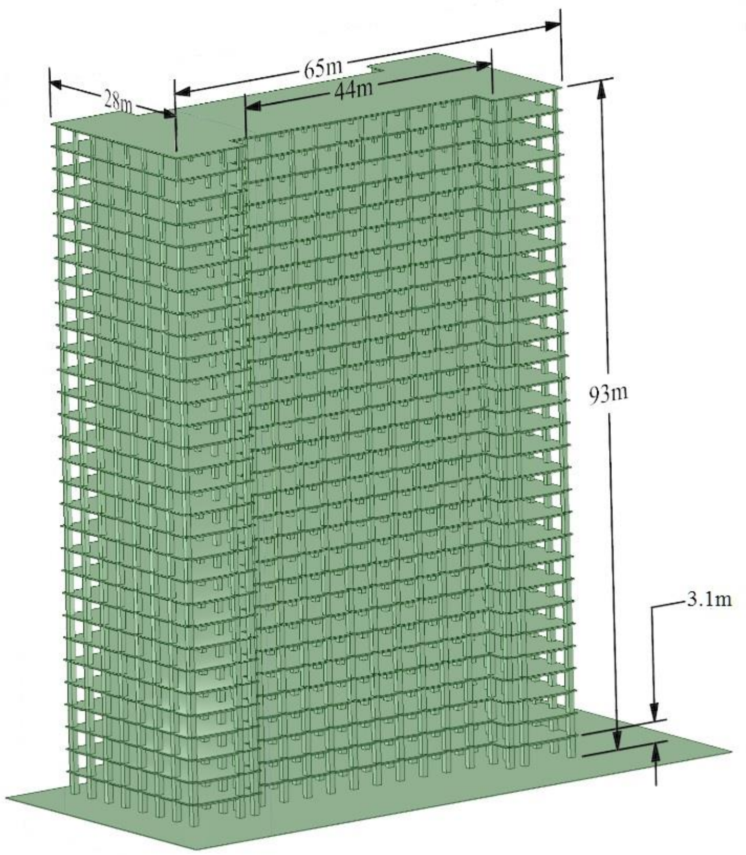



**Fig. 3.5.** Elevation of bare frame of building 2

### 3.3.2.3. CSI SAP 2000 Analysis Model

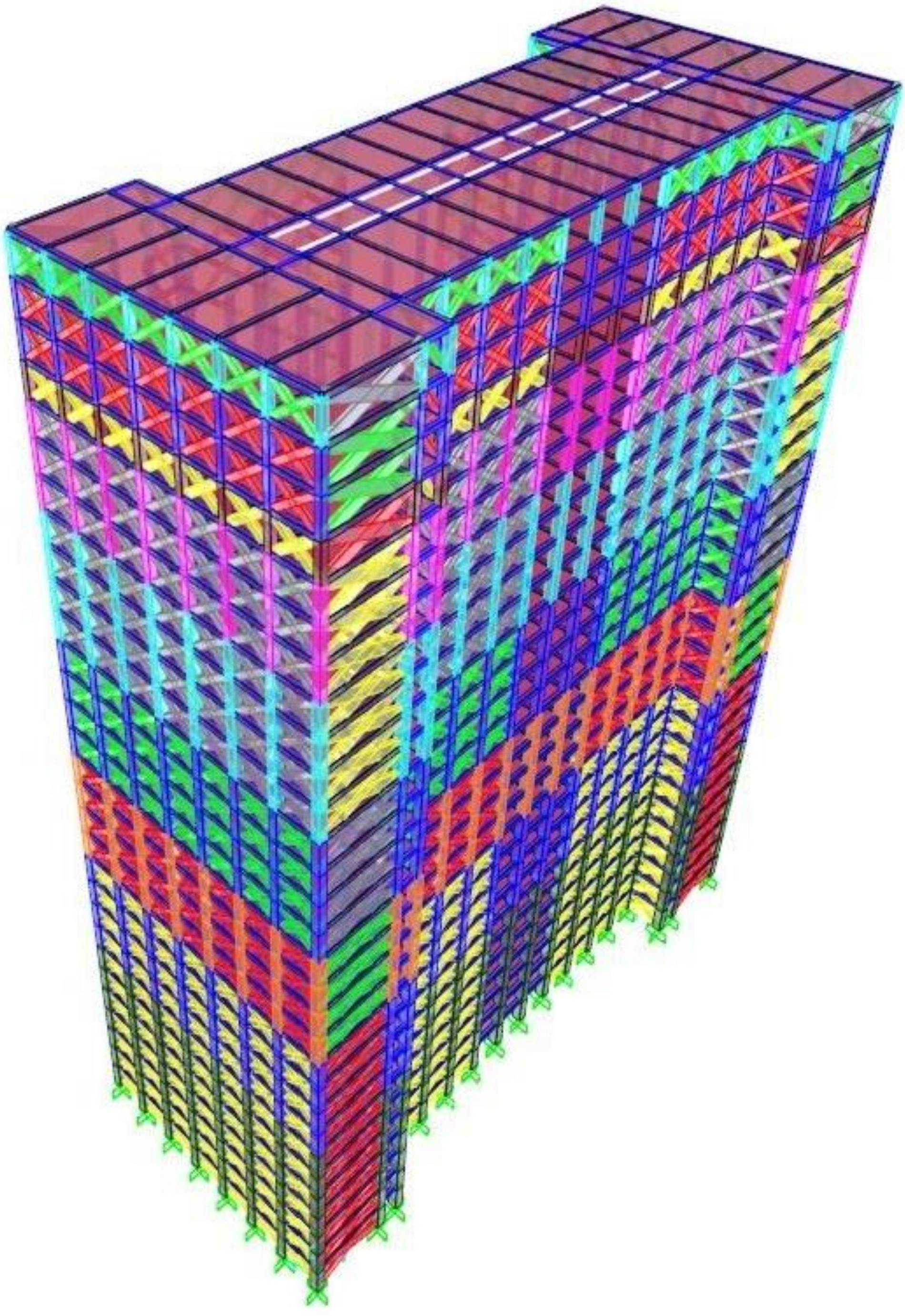


**Fig. 3.6.** Model used for Design of building 2

### 3.3.2.4. STRUCTURAL DETAILS

**Table 3.2.** Summary of Column and Beam Details

| Sl. No. | Storey | Column Details | | Percentage Reinforcement in Beams | | | |
|---|---|---|---|---|---|---|---|
| | | Size (mm) | % Rebar | Beam | | | |
| | | | | Beam 1 | Beam 2 | Beam 3 | Beam 4 |
| 1 | 1 | 850 | 2.50 – 5.65 | 0.26 – 0.52 | 0.26 | 0.26 – 0.52 | 0.36 – 0.94 |
| 2 | 2 | 850 | 1.85 – 4.75 | 0.26 – 0.53 | 0.26 – 0.33 | 0.26 – 0.78 | 0.36 – 0.94 |
| 3 | 3 | 850 | 1.75 – 4.0 | 0.26 – 0.53 | 0.26 – 0.34 | 0.26 – 1.02 | 0.36 – 0.94 |
| 4 | 4 | 850 | 1.60 – 3.50 | 0.26 – 0.53 | 0.26 – 0.42 | 0.26 – 1.14 | 0.36 – 0.94 |
| 5 | 5 | 850 | 1.45 – 3.0 | 0.26 – 0.53 | 0.26 – 0.46 | 0.26 – 1.29 | 0.36 – 0.94 |
| 6 | 6 | 850 | 1.30 – 2.60 | 0.26 – 0.53 | 0.26 – 0.49 | 0.26 – 1.38 | 0.36 – 0.94 |
| 7 | 7 | 850 | 1.10 – 2.30 | 0.26 – 0.53 | 0.26 – 0.50 | 0.26 –1.47 | 0.36 – 0.94 |
| 8 | 8 | 800 | 1.50 – 2.60 | 0.26 – 0.53 | 0.26 – 0.52 | 0.77 – 1.54 | 0.36 – 0.94 |
| 9 | 9 | 800 | 1.30 – 2.25 | 0.26 – 0.53 | 0.26 – 0.53 | 0.26 – 1.61 | 0.36 –0.94 |
| 10 | 10 | 800 | 1.05 – 2.00 | 0.26 – 0.52 | 0.26 – 0.55 | 0.26 – 1.67 | 0.36 – 0.94 |
| 11 | 11 | 800 | 0.90 – 1.80 | 0.26 – 0.52 | 0.26 – 0.55 | 0.26 – 1.72 | 0.36 – 0.94 |
| 12 | 12 | 750 | 1.20 – 2.10 | 0.26 – 0.52 | 0.26 – 0.55 | 0.26 – 1.77 | 0.36 – 0.94 |
| 13 | 13 | 750 | 1.00 – 1.80 | 0.26 – 0.52 | 0.26 – 0.55 | 0.26 – 1.81 | 0.36 – 0.94 |
| 14 | 14 | 750 | 0.80 – 1.60 | 0.26 – 0.52 | 0.26 – 0.56 | 0.26 – 1.85 | 0.36 – 0.94 |
| 15 | 15 | 750 | 0.80 – 1.40 | 0.26 – 0.51 | 0.26 – 0.55 | 0.26 – 1.88 | 0.36 – 0.94 |
| 16 | 16 | 700 | 0.80 – 1.65 | 0.26 – 0.51 | 0.26 – 0.54 | 0.26 – 1.92 | 0.36 – 0.94 |
| 17 | 17 | 700 | 0.80 – 1.45 | 0.26 – 0.51 | 0.26 – 0.54 | 0.26 – 1.96 | 0.36 – 0.94 |
| 18 | 18 | 700 | 0.80 – 1.20 | 0.26 – 0.51 | 0.26 – 0.54 | 0.26 – 2.00 | 0.36 – 0.94 |
| 19 | 19 | 700 | 0.80 – 0.95 | 0.26 – 0.50 | 0.26 – 0.53 | 0.26 –2.03 | 0.36 – 0.94 |
| 20 | 20 | 650 | 0.80 – 1.15 | 0.26 – 0.50 | 0.26 – 0.52 | 0.26 – 2.07 | 0.36 – 0.94 |
| 21 | 21 | 650 | 0.80 – 0.90 | 0.26 – 0.50 | 0.26 – 0.52 | 0.26 – 2.19 | 0.36 – 0.94 |
| 22 | 22 | 650 | 0.80 | 0.26 – 0.49 | 0.26 – 0.51 | 0.26 – 2.23 | 0.36 – 0.94 |
| 23 | 23 | 650 | 0.80 | 0.26 – 0.49 | 0.26 – 0.50 | 0.26 – 2.26 | 0.36 – 0.94 |
| 24 | 24 | 600 | 0.80 – 1.76 | 0.26 – 0.48 | 0.26 – 0.49 | 0.26 – 2.29 | 0.36 – 0.94 |
| 25 | 25 | 600 | 0.80 | 0.26 – 0.48 | 0.26 – 0.48 | 0.26 – 2.32 | 0.36 – 0.94 |
| 26 | 26 | 600 | 0.80 | 0.26 – 0.47 | 0.26 – 0.47 | 0.26 – 2.35 | 0.36 – 0.94 |
| 27 | 27 | 550 | 0.80 | 0.26 – 0.45 | 0.26 – 0.44 | 0.26 – 2.39 | 0.36 – 0.94 |
| 28 | 28 | 500 | 0.80 | 0.26 – 0.44 | 0.26 – 0.43 | 0.26 – 2.43 | 0.36 – 0.94 |
| 29 | 29 | 500 | 0.80 | 0.26 – 0.43 | 0.26 – 0.42 | 0.26 – 2.49 | 0.36 – 0.94 |
| 30 | 30 | 450 | 0.80 – 0.90 | 0.26 – 0.33 | 0.26 – 0.35 | 0.26 – 2.45 | 0.26 |

***Note :-*** *The percentge reinforcement of beams as shown in table 3.2 shows the range of top and bottom reinforcents at both ends and mid-span.*

Beam details

- Beam 1: Primary
  - Span = 8.000 m
  - Breadth = 0.350 m
  - Depth = 0.500 m
- Beam 2: Primary
  - Span = 4.000 m
  - Breadth = 0.350 m
  - Depth = 0.450 m
- Beam 3: Primary
  - Span = 2.000 m
  - Breadth = 0.300 m
  - Depth = 0.350 m
- Beam 4: Secondary
  - Span = 4.000 m
  - Breadth = 0.150
  - Depth = 0.250 m

Column height = 3.1 m

Internal wall thickness = 0.150 m

External wall thickness = 0.230 m

1$^{st}$ Natural period = 2.04253 seconds along direction of 28m length.

2$^{nd}$ Natural period = 1.75863 seconds along direction of 65m length.

## 3.4. DEMOLITION

In this phase of the project, the collapse mechanism of the two structures are decided. The columns required to be removed are identified along with its sequence of removal and the amount of charge required per column is calculated in terms of TNT equivalent. The decided collapse mechanism is simulated in a computer and the results of the simulations are used to optimize the selection of the members and its sequence of removal to get the desired controlled demolition.

### 3.4.1. BUILDING 1

To make the building collapse inwards onto its own foot print and have maximum fragmentations of structural members, loading the columns of 1st, 2nd, 8th and 14th floor is recommended. All internal and external infills are to be removed from the floors that are loaded with explosives. At the ground floor this is done to prevent the building from swaying into unwanted directions while on the upper floor it is done to provide space for gaining inertia. Only 5 lines of column (the centre and two on either side) along the 50 metre length direction of the building on the 1st and 2nd floor is to be destroyed whereas all the 74 columns on the 8th and 12th floor are to be destroyed. The elevator shaft is to be stripped (mechanically or by using explosives) and reinforcements cut. The loading of charge and sequence of delay is as shown in the following figure.

**Floor 1**

| Line No. | Detonation Time (seconds) |
|---|---|
| 1 | 0.000 |
| 2 | 0.100 |
| 3 | 0.200 |
| 4 | 0.100 |
| 5 | 0.200 |

**Floor 2**

| Line No. | Detonation Time (seconds) |
|---|---|
| 1 | 0.050 |
| 2 | 0.150 |
| 3 | 0.250 |
| 4 | 0.150 |
| 5 | 0.250 |

**All columns at 8th floor @ 0.300 seconds**
**All columns at 14th floor @ 0.350 seconds**

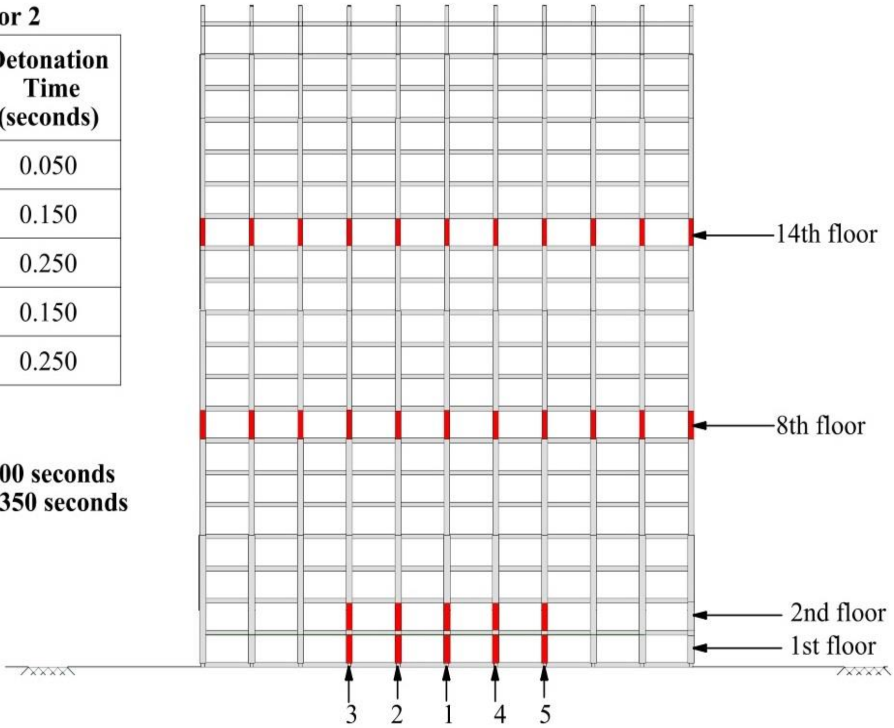



**Fig. 3.7.** Scheme of collapse sequence

The columns coloured in red shows the line of columns loaded with explosives. The amount of explosives required for the demolition job is shown in table 3.3.

#### 3.4.1.1 DETAILS OF CHARGE LOADING

The columns in the floor that are charged need to be prepared before loading it with explosives. The preparatory work involves stripping of concrete cover and exposing the reinforcements. The longitudinal reinforcements need to be notched while the transverse reinforcements can be cut. The details of charge required per column is shown in the following table.

**Table 3.3.** Details of columns and quantity of charge required

| Sl. No. | Storey | Column Details | | % Rebar in Columns | Details of Hole Drilled | | | | Charge per Hole, TNT (gm) |
|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | No. | | No. of holes | Depth (mm) | Diameter (mm) | Spacing (mm) | |
| 1 | 1 | 650 | 21 | 3 | 5 | 325 | 38 | 650 | 412.00 |
| | | | 7 | 4 | 5 | 325 | 38 | 650 | 547.20 |
| | | | 4 | 5.97 | 5 | 325 | 38 | 650 | 800.00 |
| 2 | 2 | 650 | 15 | 2.51 | 5 | 325 | 38 | 650 | 345.32 |
| | | | 13 | 3 | 5 | 325 | 38 | 650 | 412.00 |
| | | | 4 | 5.19 | 5 | 325 | 38 | 650 | 700.00 |
| 3 | 8 | 550 | 31 | 1.89 | 6 | 275 | 38 | 550 | 158.20 |
| | | | 33 | 2.59 | 6 | 275 | 38 | 550 | 215.60 |
| | | | 10 | 3.25 | 6 | 275 | 38 | 550 | 270.05 |
| 4 | 14 | 500 | 33 | 0.96 | 6 | 250 | 38 | 500 | 64.06 |
| | | | 31 | 1.50 | 6 | 250 | 38 | 500 | 94.90 |
| | | | 10 | 2.35 | 6 | 250 | 38 | 500 | 147.30 |

Total Explosives per floor,

1. Floor 1 = 78.412 kg of TNT
2. Floor 2 = 66.679 kg of TNT
3. Floor 8 = 88.317 kg of TNT
4. Floor 14 = 39.173 kg of TNT

The total Explosives required to implode the building in terms of TNT equivalent is 272.581 Kg.

The blasts are grouped into 8 stages at 0.000s, 0.050s, 0.100s, 0.150s, 0.200s, 0.250s, 0.300s and 0.350s.

The quantity of explosives being detonated at each stage is tabulated below.

1. Stage1 = 8.9160 kg @ 0.000 s
2. Stage 2 = 7.2390 kg @ 0.050 s
3. Stage 3 = 39.3040 kg @ 0.100 s
4. Stage 4 = 34.0532 kg @ 0.150 s
5. Stage 5 = 30.1920 kg @ 0.200 s
6. Stage 6 = 25.5060 kg @ 0.250 s
7. Stage 7 = 88.3170 kg @ 0.300 s
8. Stage 8 = 39.1730 kg @ 0.350 s

### 3.4.2. BUILDING 2

To make the building collapse inwards onto its own foot print and have maximum fragmentations of structural members, loading the columns of 1st, 2nd, 13th, 14th and 23rd floor is recommended. All internal and external infills are to be removed from the floors that are loaded with explosives. At the ground floor this is done to prevent the building from swaying into unwanted directions while on the upper floor it is done to provide space for gaining inertia. The elevator shafts are to be stripped completely and reinforcements cut.

Since the building is very long in one direction, for the demolition purpose the building is divided into two equal halves along the length and charged identically with respect to the axis of symmetry. The loading of charge and sequence of delay is as shown in the following figure.

**Floor 1**

| Line No. | Detonation Time (seconds) |
|---|---|
| 1 | 0.000 |
| 2 | 0.000 |
| 3 | 0.100 |
| 4 | 0.200 |
| 5 | 0.300 |
| 6 | 0.400 |
| 7 | 0.500 |
| 8 | 0.600 |
| 9 | 0.100 |
| 10 | 0.200 |
| 11 | 0.300 |
| 12 | 0.400 |
| 13 | 0.500 |
| 14 | 0.600 |

**Floor 2**

| Line No. | Detonation Time (seconds) |
|---|---|
| 1 | 0.060 |
| 2 | 0.060 |
| 3 | 0.160 |
| 4 | 0.260 |
| 5 | 0.360 |
| 6 | 0.460 |
| 7 | 0.560 |
| --- | --- |
| 9 | 0.160 |
| 10 | 0.260 |
| 11 | 0.360 |
| 12 | 0.460 |
| 13 | 0.560 |
| --- | --- |

**All columns at 13th floor @ 0.630 seconds**
**All columns at 14th floor @ 0.640 seconds**
**All columns at 23rd floor @ 0.660 seconds**

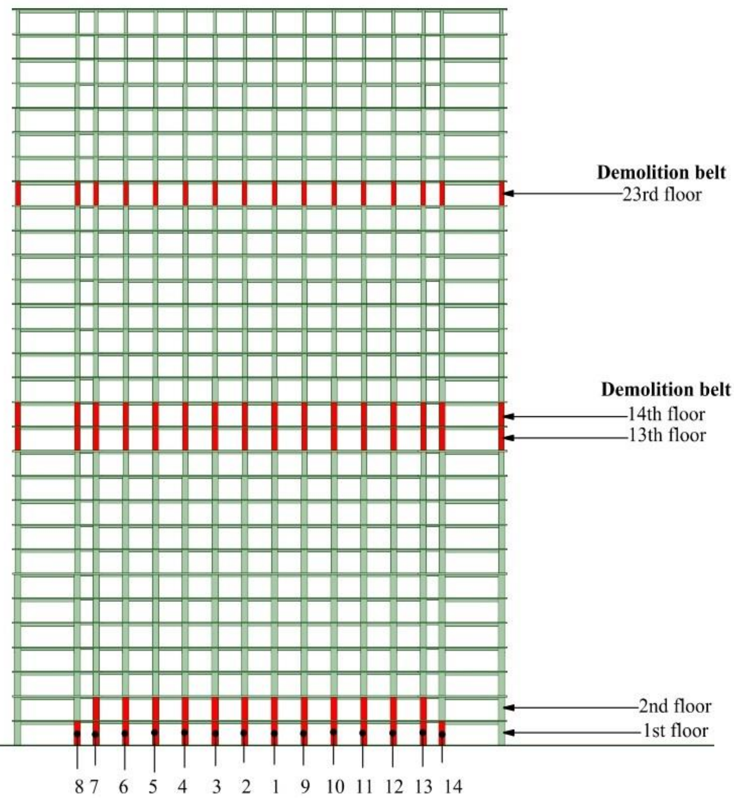



**Fig. 3.8.** Scheme of collapse sequence

The columns coloured in red shows the line of columns loaded with explosives. The amount of explosives required for the demolition job is shown in table 3.4. .

The delay interval per charge varies from 10 to 60 milliseconds. The removal of columns at 1st and 2nd floor follows a pattern whereas all the columns in 13th, 14th and 23rd floor are removed simultaneously at a particular time.

### 3.4.2.1 DETAILS OF CHARGE LOADING

The columns in the floor that are charged need to be prepared before loading it with explosives. The preparatory work involves stripping of concrete cover and exposing the reinforcements. The longitudinal reinforcements need to be notched while the transverse reinforcements can be cut. The details of charge required per column is shown in the following table.

**Table 3.4.** Details of columns and quantity of charge required

| Sl. No. | Storey | Column Details | | Percentage Rebar in columns | Details of Hole Drilled | | | | Charge per Hole, TNT (gm) |
|---|---|---|---|---|---|---|---|---|---|
| | | Size (mm) | No. | | No. of holes | Depth (mm) | Diameter (mm) | Spacing (mm) | |
| 1 | 1 | 850 | 32 | 2.50 | 4 | 425 | 50 | 850 | 769.20 |
| | | | 20 | 3.50 | 4 | 425 | 50 | 850 | 1072.42 |
| | | | 16 | 5.65 | 4 | 425 | 50 | 850 | 1224.00 |
| 2 | 2 | 850 | 32 | 1.85 | 4 | 425 | 50 | 850 | 571.83 |
| | | | 12 | 3.5 | 4 | 425 | 50 | 850 | 1072.42 |
| | | | 8 | 4.75 | 4 | 425 | 50 | 850 | 1224.00 |
| 4 | 13 | 750 | 64 | 1.00 | 4 | 375 | 38 | 750 | 216.25 |
| | | | 20 | 1.80 | 4 | 375 | 38 | 750 | 380.25 |
| 5 | 14 | 750 | 64 | 0.80 | 4 | 375 | 38 | 750 | 216.25 |
| | | | 20 | 1.60 | 4 | 375 | 38 | 750 | 340.90 |
| 6 | 23 | 650 | 84 | 0.80 | 5 | 325 | 38 | 650 | 140.75 |

Total Explosives per floor,

1. Floor 1 = 262.590 kg of TNT
2. Floor 2 = 163.838 kg of TNT
3. Floor 13 = 85.780 kg of TNT
4. Floor 14 = 82.632 kg of TNT
5. Floor 23 = 59.115 kg of TNT

The total Explosives required to implode the building in terms of TNT equivalent is 653.955 Kg.

The blasts are grouped into 16 stages at 0.000s, 0.060s, 0.100s, 0.160s, 0.200s, 0.260s, 0.300s, 0.360s, 0.400s, 0.460, 0.500s, 0.560s, 0.600s, 0.630s, 0.640s, and 0.660s.

The quantity of explosives being detonated at each stage is tabulated below.

1. Stage1 = 29.4660 kg @ 0.000 s
2. Stage 2 = 26.3080 kg @ 0.060 s
3. Stage 3 = 24.6144 kg @ 0.100 s
4. Stage 4 = 18.2990 kg @ 0.160 s
5. Stage 5 = 24.6144 kg @ 0.200 s
6. Stage 6 = 18.2990 kg @ 0.260 s
7. Stage 7 = 24.6144 kg @ 0.300 s
8. Stage 8 = 18.2990 kg @ 0.360 s
9. Stage 9 = 29.4660 kg @ 0.400 s
10. Stage 10 = 26.3080 kg @ 0.460 s
11. Stage 11 = 56.3270 kg @ 0.500 s
12. Stage 12 = 56.3270 kg @ 0.560 s
13. Stage 13 = 73.4850 kg @ 0.600 s
14. Stage 14 = 85.7800 kg @ 0.630 s
15. Stage 15 = 82.6320 kg @ 0.640 s
16. Stage 16 = 59.1150 kg @ 0.660 s

### 3.5. SAFETY ASSESSMENT

For the safety of the people living in the vicinity of the building, the demolition crew and the nearby structures, the minimum standoff distance from the imploding building is to be computed along with the details of maximum overpressure and sound level in decibels. The possibilities of flyrocks are also considered for setting up of the minimum safe standoff distance. A computer software, “Conwep” developed by, “USAE Engineer Research & Development Center, Geotechnical/Structural Laboratory”, which is distributed freely on request to researchers is used for the plotting of pressure versus range curve for a given known quantity of explosives.

From the curve ideal safe standoff distance is chosen and sound pressure/level is calculated corresponding to the peak overpressure at the safe distance.

Formula used for calculation of sound pressure –

$$dB = 20.log_{10}(\frac{P}{P_0}) \tag{3.3}$$

Where,

dB = sound level in decibels

P = Overpressure in psi

$P_0$ = Overpressure of the lowest sound that can be heard = $3x10^{-9}$

The amount of explosives used to determine the safe standoff distance is the maximum amount of explosives that is detonated simultaneously at any one instant of time in the sequence of detonation.

Safe Standoff distance parameters: –

- ±100 Pa ~ 135 dB is the threshold of pain pressure level for sound at which prolonged exposure may lead to hearing loss.
- 1–10 kPa Typical explosion peak overpressure needed to break glass windows (approximate)
- Normal atmospheric pressure is approximately 0.1 MPa
- The threshold for lung damage occurs at about 15 psi = 0.1034 MPa blast overpressure.
- At 5.1 psi = 0.0344 MPa (182.33 dB) blast overpressure potential rupture of eardrums and beyond 14.5 psi = 0.0999 MPa (191.41 dB) rupture is guaranteed.

### 3.5.1. BUILDING 1

The maximum amount of explosives detonating simultaneously is 88.3170 kg at 0.300 s.

The following plot shows the variation of pressure with distance for detonation of 88.3170 kg of TNT.

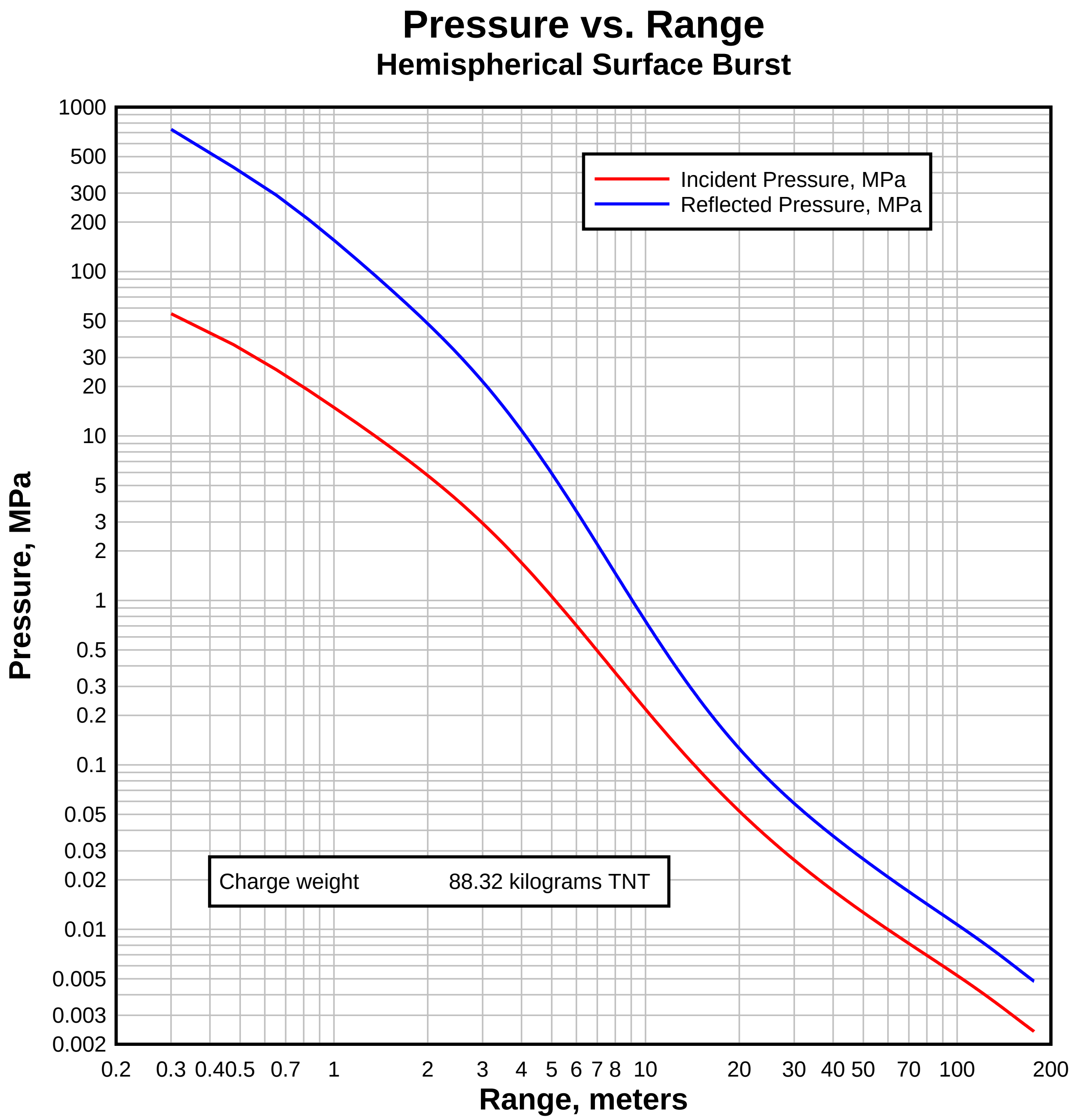



**Fig. 3.9.** Pressure v/s Range

A minimum standoff distance of 30 m is recommended.

At Range = 30 meters

Incident Pressure = 0.02639666 MPa

Sound Level = 182.12 dB

### 3.5.2. BUILDING 2

The maximum amount of explosives detonating simultaneously is 85.780 kg at 0.630 s.

The following plot shows the variation of pressure with distance for detonation of 85.780 kg of TNT.

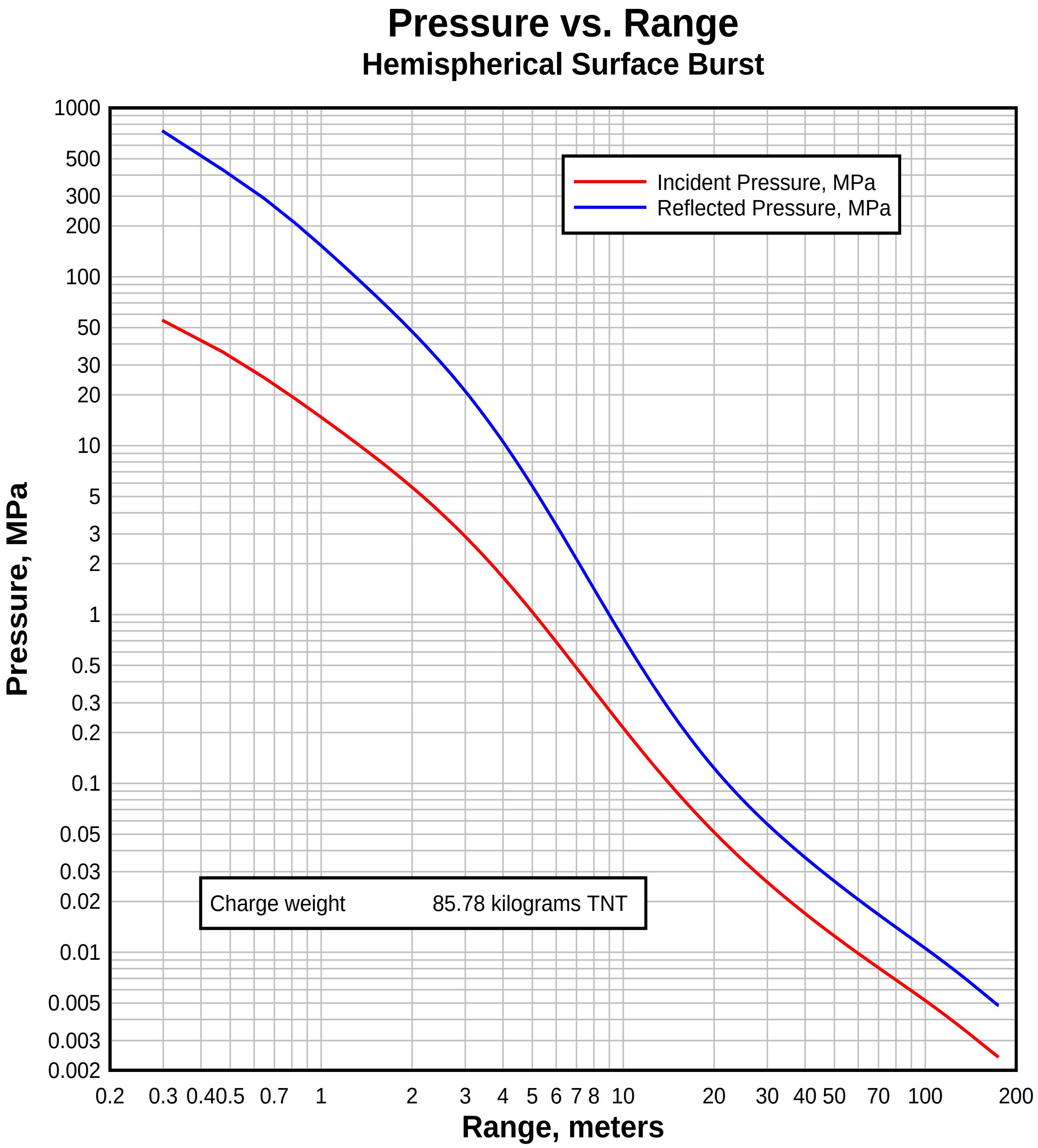



**Fig. 3.10.** Pressure v/s Range

A minimum standoff distance of 30 m is recommended.

At Range = 30 meters

Incident Pressure = 0.02599993 MPa

Sound Level = 181.98 dB

Chapter 4

# VALIDATION AND DISCUSSION

## 4.1. VALIDATION OF QUANTITY OF CHARGE REQUIRED

The quantity of explosives required were calculated using the Portuguese method for calculation of charge, developed by Gomes [6]. To validate the quantity of charges calculated, two columns of different cross section with known percentage of reinforcements were considered and the quantity of charges required calculated simultaneously by two separate parties, one being me and the other the Sappers of the Bengal Engineering Group of the Indian army, and the results compared.

N.B. - *The involvement of the Sappers were unofficial and on good will due to personal relationship*.

The methodology used by the Sappers cannot be illustrated here as it is confidential.

Details of Column,

**Table 4.1.** COMPARISON OF QUANTITY OF CHARGE CALCULATED

| PARAMETER | COLUMN 1 | | COLUMN 2 | |
|---|---|---|---|---|
| | AUTHOR | SAPPER | AUTHOR | SAPPER |
| No. of holes drilled | 5 | 2 | 4 | 2 |
| depth of hole | 325 mm | 325 mm | 375 mm | 375 mm |
| spacing holes centre to centre | 600 - 650 mm | 1000 mm | 600 - 650 mm | 1000 mm |
| density of charge used (kg/m$^3$) | 1640 | 1498 | 1640 | 1498 |
| charge | TNT | PEK-I, PEK-II or LTPE | TNT | PEK-I, PEK-II or LTPE |
| Relative Effectiveness (R.E.) factor | 1 | (PEK) 1.17 | 1 | (PEK) 1.17 |
| Total charge (gm) | 1380.00 | 561.00 | 2120.00 | 637.50 |
| Quantity of charge/hole (gm) | 276.00 | 280.50 | 424.00 | 318.75 |
| Quantity of charge/hole TNT (gm) | 276.00 | 327.60 | 424.00 | 372.94 |
| Total charge required in terms of TNT (gm) | 1380.00 | 656.37 | 2120.00 | 745.90 |

**Table 4.2.** Details of Columns used for validation

| Column | Length (m) | Size (mm) | Longitudinal Reinforcement | Stirrups |
|---|---|---|---|---|
| Column 1 | 3.1 | 650×650 | 12 no. 20 mm dia. | 8mm dia. @ 150mm c/c |
| Column 2 | 3.1 | 750×750 | 12 no. 20 mm dia. | 8mm dia. @ 150 mm c/c |

There are some variations in the quantity of explosives calculated by both parties as different empirical formulas were used. Also there is difference in the type of damage intended. The Sappers intension is to just take out a part of the section and render the member useless, thus reducing the number of charges required which in turn reduces the total quantity of charge required, whereas the damage intended by the author is to take out the whole member, thus involving more number of charges and increasing the overall quantity of explosives required.

The validation holds good as the amount of charges calculated to be placed in one hole is reasonably comparable considering the empirical nature of work.

Also carrying out blast tests is highly recommended to check the effectiveness of explosives being used for demolition purpose for the following reasons,

i.) to optimize the quantity of charges required as the field conditions do not have the ideal condition in which its explosive strength was determined .

ii.) explosives deteriorate with time, so it wise to check its strength by conducting trial blasts.

iii.) conducting trial blasts on members will also give a fair idea of the strength of the material of the member.

From this discussion we can conclude that the quantity of the explosives estimated for the implosion of the two buildings is acceptable.

Simulations were also carried out to check the validity of charge calculated.

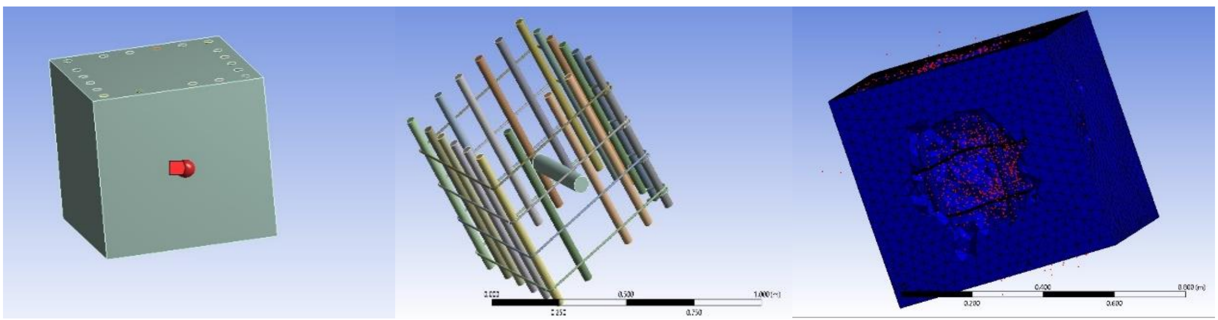


**Fig. 4.1.** Model of Section of Reinforced Column with demolition charges used for simulation

### 4.2. VALIDATION OF SEQUENCE OF DETONATION

The selection of members and its sequence of removal, that is, the sequence of detonation with the required time interval necessary for the intended collapse pattern was arrived on by conducting simulations on smaller models.

The above stated approach gives a reasonably good idea as to how to design the collapse as we get a very good idea about exactly after how many milliseconds the movement of the structure starts after the removal of supporting members. Also after running simulations with varying time delays we get an idea of the variation of collapse pattern with variation in delay interval.

The following figures below shows the collapse pattern at 1second for different time interval.

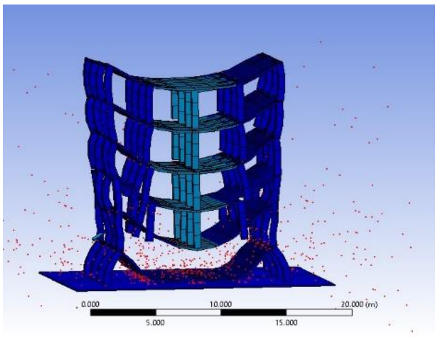


**Fig. 4.2.** Collapse @ 0.040s delay

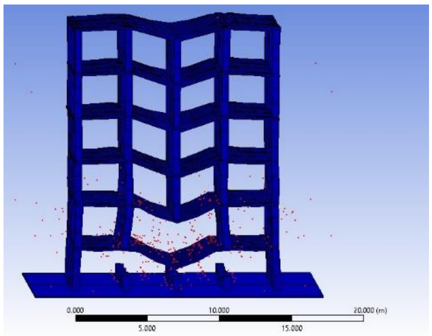


**Fig.4.3.** Collapse @ 0.400s delay

### 4.2. VALIDATION OF SAFETY ASSESSMENT

The over pressure computed was for air blast above ground considering hemispherical surface burst whereas the type of blast that is taking place in the implosion is confined in which the over pressure at the same standoff distance is much lesser, thus over estimating the expected over pressure and fixing the standoff distance is staying on the conservative side. Also dangers from fly rocks is minimised as the members subjected to blasts are wrapped around with geotextile fabric.

### 4.2. MODELLING

In the models the infills and reinforcement were not modelled to save computational time. Infills could be neglected as it is to be removed from all floors that are charged with explosives. Modelling the infill on other floor is not necessary as it is very weak in tension and out of plane action, also there is no chance of infills taking the loads as it would be going down along with the frame being subjected to mostly out of plane forces. With infills modelled, the inertia forces would be larger due to the increased weight. Reinforcement can be neglected as it is exposed and cut wherever permitted and possible, also the reinforcements would not change the collapse pattern but slightly increase the total time of collapse. To mimic the blast loading on column, pressure loading of $10^8$ Pa was applied normal to two opposite faces of the column for a duration of 0.001s to have instantaneous removal of the member. These values were arrived after many trials and error. Erosion control was on for material failure and geometric strain limit of 0.9.

## Chapter 5

# CONCLUSION

The principle concern of the structural engineer in a demolition project is uncontrolled collapse. In a controlled demolition only a planned collapse is acceptable. The factors governing the method of demolition applied to a particular structure are type, site condition, height and age of structure, economy and most importantly its location and its accessibility. Controlled demolition of structure is essential to safeguard the safety of workers along with the people and structures in the neighbourhood, thereby reducing the probability of accidents and injuries. In a matter of seconds a structure crumbles onto itself, with negligible to minimum physical damage to its immediate surroundings without causing public nuisance for a long period like other demolition techniques are capable of.

If the loss of total (internal) energy during the crushing of one story (representing the energy dissipated in the complete crushing and compaction of one story, subtracting the loss of gravity potential while crushing that story) exceeds the impacting kinetic energy to that story, collapse will propagate to the next story. This is the criterion to trigger off a progressive collapse. If this is satisfied, there is no way to deny the inevitability of a progressive collapse driven by gravity alone (irrespective of the exceedance of the combined strength of the columns of one floor may over the weight of the part of the tower above that floor). What matters is energy, not the stiffness, nor strength.

The Advantages of implosion method over conventional methods are:

- Comparatively cheaper for buildings more than 5 storeys,
- Comparatively much quicker,
- Best suited for multi- storeyed buildings, smokestacks, distressed piers, towers etc.

The disadvantages of this method over conventional methods are:

- Dangers from flyrocks,
- No tolerance for error in execution,
- Experienced personnel required for handling explosives.

The advantages of this method make this method more acceptable over the other demolition methods.

The planning and analysis of controlled demolition of two multi-storey building is elaborated in this report which could be referred to for conducting implosion type of controlled demolition.

# REFERENCES


[1].Andrew, E.N, “Progressive Collapse- An Implosion Contractor’s Stock in Trade”, *Journal of Performance of Constructed Facilities*: 391-402, 2006.

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[6].Rodrigues, D.J.B, “Controlled Demolition of Reinforced Concrete Buildings by the Use of Explosives. The Armed Forces Hospital Building C5 case study”, *Tecnico Lisboa*:-----, 2014.

[7].-----, Field Manual 5-250 of the U.S. Army.

# APPENDICES

## A. DESIGN PROGRAM in MATLAB

```
M=seismic weight * diag([1 1…n times… 1 1 1],0); % n is number of stories.
ot=[n^2…..3^2 2^2 1^2]; %for parabolic mode shape or [n…3 2 1] for linear mode shape.
s=zeros(n,n);
% computation of S matrix.
for i=1:n
    if(i<n)
         s(i,i)=ot(1,i)-ot(1,i+1);
         s(i+1,i)=ot(1,i+1)-ot(1,i);
    end
    if(i==n)
        s(i,i)=ot(1,i);
    end
end
w=ω1; %chosen to get maximum permissible drift
k=power(w,2)*inv(s)*M*ot';
b=0;
% formation of K matrix from vector k
for i=1:n
   if(i<n)
       if(i>1)
           b=k(i-1,1);
       end
       K0(i,i)=b+k(i,1);
       K0(i,i+1)=-k(i,1);
       K0(i+1,i)=-k(i,1);
   end
    if(i==n)
        K0(i,i)=k(i,1)+k(i-1,1);
    end

end
[o,w2]=eig(K0,M);
```

```
wn(:,1)=sqrt(diag(w2));
u1=0;
u2=0;
for i=1:n
     for j=1:n
       u1=u1+o(j,i);
       u2=u2+power(o(j,i),2);
     end
      r(i)=u1/u2;
end
for i=1:n
    t(i,1)=(2*pi())/wn(i,1);
end
for i=1:nm % number of modes considered for calculation.
    if(t(i,1)>=.4&&t(i,1)<=4)
        sd(1,i)=1000*((z*9.81*t(i,1))/(8*power(pi(),2))); % for rocky soil only.
    end
    if(t(i,1)>=.1&&t(i,1)<.4)
        sd(1,i)=1000*((2.5*z*9.81*power(t(i,1),2))/(8*power(pi(),2))); % for rocky soil only.
    end


end
for i=1:nm % number of modes considered for calculation.
    for j=1:n
        deltam(j,i)=r(1,i)*sd(1,i)*o(j,i);
    end
end
for i=1:n
    sum=0;
    for j=1:nm
        sum=sum+power(deltam(i,j),2);
    end
    deltasrss(i,1)=sqrt(sum);
end

for i=1:n
```

```
    if(i<n)
        id(i,1)=deltasrss(i,1)-deltasrss(i+1,1);
    end
    if(i==n)
            id(i,1)=deltasrss(i,1);
    end
end
idp=.002*3100; % permissible inter-storey drift.
flag=0;
for i=1:n
    if(id(i,1)<=idp)
        flag=0;
        continue ;
    end
    flag=1;
    break;
end
% iteration part
if(flag==1)
    flag2=1;
    while(flag2==1)
        kf=zeros();
        for i=1:n
         kf(i,1)=(k(i,1)*id(i,1))/idp;
        end
        b=0;
        Kf=zeros(n,n);
        for i=1:n
           if(i<n)
                if(i>1)
                    b=kf(i-1,1);
                end
                Kf(i,i)=b+kf(i,1);
                Kf(i,i+1)=-kf(i,1);
                Kf(i+1,i)=-kf(i,1);
            end
```

```
    if(i==n)
        Kf(i,i)=kf(i,1)+kf(i-1,1);
    end


end
of=zeros();
wf=zeros();
sdf=zeros();
r=zeros();
deltamf=zeros();
deltasrssf=zeros();
idf=zeros();
tf=zeros();
r=zeros();
[of,wf]= eig(Kf,M);
wnf(:,1)=sqrt(diag(wf));
u1=0;
u2=0;
for i=1:n
    for j=1:n
            u1=u1+of(j,i);
            u2=u2+power(of(j,i),2);
    end
    r(i)=u1/u2;
end
for i=1:n
     tf(i,1)=(2*pi())/wnf(i,1);
end
for i=1:8
    if(tf(i,1)>=.4&&tf(i,1)<=4)
             sdf(1,i)=1000*((z*9.81*tf(i,1))/(8*power(pi(),2)));
    end
    if(tf(i,1)>=.1&&tf(i,1)<.4)
            sdf(1,i)=1000*((2.5*z*9.81*power(tf(i,1),2))/(8*power(pi(),2)));
    end
end
```

```
for i=1:nm % number of modes considered for calculation.
   for j=1:n
            deltamf(j,i)=r(1,i)*sdf(1,i)*of(j,i);
   end
end
for i=1:n
sum=0;
for j=1:nm % number of modes considered for calculation.
   sum=sum+power(deltamf(i,j),2);
   end
   deltasrssf(i,1)=sqrt(sum);
end

for i=1:n
    if(i<n)
            idf(i,1)=deltasrssf(i,1)-deltasrssf(i+1,1);
   end
   if(i==n)
            idf(i,1)=deltasrssf(i,1);
   end
end
flag2 = 0;
for i=1:n
   if(idf(i,1)<=idp)
            flag2=0;
            continue ;
   end
   flag2=1;
   break;
end
for i=1:n
   id(i,1)=0;
   k(i,1)=0;
   id(i,1)=idf(i,1);
   k(i,1)=kf(i,1);
```

```
      end
   end
end

% % % calculation of column dimension (square): uncracked section
e=5000*sqrt(grade of concrete); % modulus of elasticity.
l=length of column;
k11=kf/(nc*1000); % nc is number of colums per floor.
cs=sqrt(sqrt((k11*power(l,3))/e));
% cracked section
csc=sqrt(sqrt((k11*power(l,3))/(0.7*e)));
%% code ends
```

N.B.- *more accurate estimate of column dimension can be done considering the stiffness of beams and frame action.*

The above code was used to get the preliminary sizing of columns which were fed in a commercial software CSI SAP2000 for further design and analysis. The beam dimensions were computed following the guidelines in IS 456:2000 based on the l/d ratio.

**B. PROGRAM in MATLAB TO CHECK DESIGN OF BUILDING 1**

*%% the effect of stiffness of beam is taken into account (static condensation of K matrix) not considering infill to compare the period of bare frame with sap results.*

```
csp(:,1)=[400 450 450 500 500 500 500 500 500 550 550 550 550 600 600 600 650 650 650 650];
bb=350;
bd=450;
ib=(350*power(bd,3))/12;
%icsp=.7*power(csp,4)/12;
icsp=power(csp,4)/12;
e=5000*sqrt(30);
h=3100;
l=5000;
for i=1:20
   rt=zeros(2,2);
   st=zeros(2,1);
   sh=zeros(1,2);
```

```
    rt=[((4*icsp(i,1)/h)+((4*ib)/l)) (2*ib)/l ;(2*ib)/l ((4*icsp(i,1)/h)+((4*ib)/l))];
    st(:,1)=[(6*icsp(i,1))/power(h,2) (6*icsp(i,1))/power(h,2)];
    sh=[(6*icsp(i,1))/power(h,2) (6*icsp(i,1))/power(h,2)];
    temp=inv(rt)*st;
    ksp(i,1)=((24*icsp(i,1)*e)/power(h,3))- sh*temp*e;
    kp(i,1)=(ksp(i,1)/2)*(74*1000);
end
 b=0;
for i=1:20
   if(i<20)
       if(i>1)
           b=kp(i-1,1);
       end
       Kp(i,i)=b+kp(i,1);
       Kp(i,i+1)=-kp(i,1);
       Kp(i+1,i)=-kp(i,1);
   end
    if(i==20)
        Kp(i,i)=kp(i,1)+kp(i-1,1);
    end
end
%% Computation of mass matrix
M=zeros(20,20);
g=9.81;
ll=3*1000*(50*30-150);
ds=.15*25*1000*(50*30-150);
dsff=1000*(50*30-150);
drt=1500*(50*30-150);
extwall(:,1)=.23*20*1000*(3.1-.45)*(5-(csp/1000))*38;
intwall(:,1)=.15*20*1000*(3.1-.45)*(5-(csp/1000))*30;
prptwall=.23*20*1000*1.5*(5-(csp(1,1)/1000))*38;
db=25*1000*(bb/1000)*(bd/1000)*(l/1000)*127;
dc(:,1)=25*1000*power((csp/1000),2)*(h/1000)*74;
for i=1:20
     if(i==1)
        M(i,i)=(ds+drt+prptwall+(.5*(extwall(i,1)+intwall(i,1)))+db+(dc(i,1)*0.5))/g;
```

```
    end
    if(i>1)
        M(i,i)=(ds+dsff+(.5*(extwall(i-1,1)+intwall(i-
1,1)))+(.5*(extwall(i,1)+intwall(i,1)))+db+(dc(i-1,1)*0.5)+(dc(i,1)*0.5)+0.25*ll)/g;
    end
end

% %M=2.1e+6*diag([1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 ],0); approximate value used for
comparison of period.

sdp=zeros(1,20);
[op,w2p]=eig(Kp,M);
wnp(:,1)=sqrt(diag(w2p));
u1=0;
u2=0;
for i=1:20
    for j=1:20
      u1=u1+op(j,i);
      u2=u2+power(op(j,i),2);
    end
     r(i)=u1/u2;
end
for i=1:20
   tp(i,1)=(2*pi())/wnp(i,1);
end
for i=1:5
   if(tp(i,1)>=.4&&tp(i,1)<=4)
       sdp(1,i)=1000*((0.36*9.81*tp(i,1))/(8*power(pi(),2)));
   end
   if(tp(i,1)>=.1&&tp(i,1)<.4)
       sdp(1,i)=1000*((2.5*0.36*9.81*power(tp(i,1),2))/(8*power(pi(),2)));
   end
end
for i=1:5
   for j=1:20
       deltamp(j,i)=r(1,i)*sdp(1,i)*op(j,i);
```

```
    end
end
for i=1:20
    sum=0;
    for j=1:5
        sum=sum+power(deltamp(i,j),2);
    end
    deltasrssp(i,1)=sqrt(sum);
end
for i=1:20
    if(i<20)
        idp(i,1)=deltasrssp(i,1)-deltasrssp(i+1,1);
    end
    if(i==20)
            idp(i,1)=deltasrssp(i,1);
    end
end
sum=0;
for i=1:20
sum=sum+idp(i,1);
end
avgidp=sum/20;
%% end of program
```

N.B. - *this code is valid only for the building 1.*