Seismic Analysis of RC Framed Structures using ETABS Software

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Abstract— Under seismic loading for the soft storey structure, the columns will fail due to the formation of plastic hinges and thus the mitigation of it is necessary and under heavy vibrations, the structure will experience excessive movements, feeling uncomfortable. Traditionally, the soft storey effect is reduced by shear walls, bracings and excessive movements by isolators and dampers. In the present investigation, a G + 10 storied building subjected to seismic loading was studied for equivalent static, response spectrum, non – linear time history (El Centro) method carried out in ETABS software. The parameters of displacement, storey drifts, base shear, storey stiffness, time period, peak accelerations and velocities to determine the structural performance. The performance of the structure was determined with struts under soft storey effect and vibrational control. Here, these effects are reduced by the shear walls, bracings, cross sectional increase in soft storey columns and TMD, analyzed with struts modelled using Den Hartog for TMD and Mainstone for Struts. The study show the comparison of the parameters, which revel that all the models perform better when compared to conventional frame. The results revealed that maximum displacement, drift and base shear are drastically reduced for TMD, and soft storey and displacements are moderately reduced for shear walls and bracings.

Keywords: Equivalent diagonal strut, IS: 1893-2016, mitigation technique, soft storey, Tuned mass damper

I. Objectives

For analysing the behaviour of the masonry infill frame, ETABS software is used and the effect of infill walls is obtained by analysing the models for the load combinations given in IS: 1893 – 2016 (Part 1) and IS: 456 – 2000. Since the open ground storey is utilized for providing parking and lobby spaces, the mitigation techniques adopted were providing the structural walls and bracing along the frames, Thus, an RC frame is developed having an open ground storey and the various models developed were :

(1) Bare frame with no masonry loads (BF)
(2) Bare frame with masonry loads i.e., conventional frame (CF)
(3) Conventional frame with masonry loads and increased column size until ground storey (CF-IC)
(4) Conventional frame with masonry loads and shear walls at the core (CF-SW C) and corners (CF-SW L), bracings at the corners (CF-B)
(5) Conventional frame with masonry loads and TMD placed at the centre of the building in top storey(CF-T)
(6) RC frame with infills modelled as struts having open ground storey (soft storey) (CFS)
(7) RC frame with infills modelled as struts having open ground storey (soft storey) and increased column size until ground storey (CFS-IC)
(8) RC frame with infills modelled as struts having open ground storey (soft storey) and shear walls at the core (CFS-SW C) and corners (CFS-SW L), bracings at the corners (CFS-B)
(9) RC frame with infills modelled as struts having open ground storey (soft storey) and TMD placed at the centre of the building in top storey (CFS-T)

Static and dynamic analysis are performed and the performance is evaluated by the parameters like displacements, drifts, base shear, stiffness and time period, acceleration and velocity.

II. Literature Survey

On the condition of controlling the structural the vibrations, the importance of using the mitigation techniques have become predominant. The basic studies carried out on the concept of controlling the responses, using the masonry infill and Tuned Mass Damper are discussed under the section of literature review which provided the details of modelling and the responses obtained by them.

A. On Masonry Infill

Diptesh Das, CVR Murty, (2004) provided "Brick masonry infill in seismic design of RC framed building – cost implications and behaviour". A three storied building was analysed under Eurocode 8, Nepal Building code 201 (NBS 201), Indian seismic code (designed, detailed using IS 456 for one model and designed by IS 456, detailed using IS 13920 for another) and Equivalent Braced frame (EBF) method with infills modelled using Equivalent struts. They observed the behaviour, the quantity of concrete and steel used for the models and obtained the quantity required for concrete for all models are comparable but reinforcing steel required when designed by NBS 201 and EBF method are half of the amount required for the other models. Due to the presence of infills during the analysis, the storey drift and ductility of the structure was reduced and increase in strength, stiffness. Buildings designed by EBF method has the maximum ability to sustain deformation during earthquake shaking and the model designed by IS 456 was stiffer and NBC 201 was more flexible.

Shaharban P S, Manju P M, (2014) analysed "Behaviour of Reinforced Concrete frame with infill walls under seismic loads using ETabs". The performance of masonry brick infill for an RCC framed structure under cyclic loading for a 10 storey structure has been studied in ETABS using Struts. A 40% infill arranged at outer Periphery with and without soft storey, at inner core and at lift core with bare frame was considered. They obtained, for the bare frame without infills, the base shear was underestimated which may result in collapse of the structure when actual infills are considered. Masonry infills when provided at the inner core level, structure has got lesser displacement when compared to other models.

Daniele Perrone et.al, (2017) discussed on "Nonlinear behaviour of masonry infilled RC frames: Influence of masonry Mechanical properties". A parametric study on the effect of time period, Young's modulus,

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openings are considered for nonlinear response analysis. It was observed that as height increases, the time period increases, Young's modulus and ductility decreases. Due to the presence of infills, the inter story displacement and the collapse mechanism are uniform. The responses of the structure with openings are the intermediate responses of base and full infilled frame.

B. On Tuned Mass Damper

Rahul Rana, T T Soong, (1998) discussed the “Parametric study and simplified design of tuned mass damper”. They carried out the analysis for two time history earthquakes and determined effect of detuning for a SDOF and MDOF systems. They observed that when mass ratio and structural damping increases, the effect of the detuning and responses of the structure decreases. They provided that the effect of optimal parameter depends on the type of excitations i.e, based on base or main mass excitations. Under harmonic and time history analysis for a 3 DOF structure, they observed that the multiple TMD usage was not effective in the response control due to less difference between second and third mode of TMD.

Jose Luis Almazan et.al, (2012) studied on “Torsional balance of asymmetric structures by means of tuned mass dampers”. The research was carried out by placing one or two TMD in a structure when it is subjected to uni or bi-directional seismic exhortations. It was observed that for the asymmetric structure which can be subjected to torsional effects can be reduced by the implementation of TMD into the structure when it is designed for optimum parameters. When more eccentricity in the asymmetric structure is observed, the TMD has reduced the deformations by 20 to 50% at the edges. Natural frequencies and the position of TMD depend on the torsional stiffness, eccentricity, and lateral stiffness ratio of the structure. The time period of TMD is determined by applying the concept of tuning the structure and TMD in order to reduce the exaltation displacements and torsional effects.

Santhosh HP et.al, (2017) presented “Seismic isolation of RC framed structure with and without infills”. The response of the structure is determined for a G+ 3 storey building using response spectrum method where all the parameters are compared and studied for seismic forces using lead rubber bearing seismic isolator. It was observed that on installing base isolator, the time period, frequency of the structure has been increased which can be inferred as the isolators prevent the resonances. Base shear, inter storey drift and reinforcing Steel are reduced and increase in displacement of the structure was observed at the location of isolator level. Due to the inclusion of infills, increase in rigidity and stiffness has been observed.

III. MODELLING OF MASONRY INFILL WALLS AND PENDULUM TMD

A. Masonry Infill Wall

Masonry infill wall is one of the conditions to increase the vertical stiffness or to reduce the vertical irregularity, so that soft storey effect is eliminated or reduced to some extent.

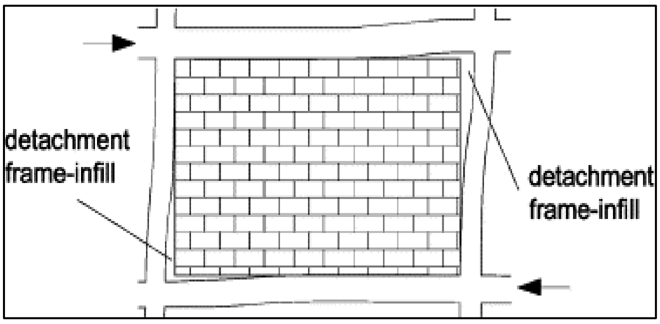

Fig. 1: Behaviour of walls under lateral loading

Experiments and researches carried out on masonry infill showed when a lateral force is applied on the structure, the bare frame will undergo displacement but the walls located between the columns and beams doesn’t experience any movement, instead they fail by diagonal crushing, shear failure, etc. As it is difficult to determine the behaviour of the walls, inclusion of them is considered as placing the wall loads while analysing the structure but the stiffness of them is not considered. When the stiffness of walls is considered, they can be modelled using Finite Element method or Equivalent Diagonal Strut method. The behaviour of the frame with the infill incorporated between columns and beams shows the movement of the frame when subjected to the lateral loads is being showed in the fig.1

B. Modelling Techniques of Masonry Infill

When the frame with walls is considered during analysis, the structural engineers usually prefer a bare frame analysis applying the walls loads on the beams where required due to the difficulty in modelling. Based on the previous research carried out on the masonry infill walls, the walls can be modelled using the equivalent diagonal strut or FEM techniques, as shown in fig. 2 below.

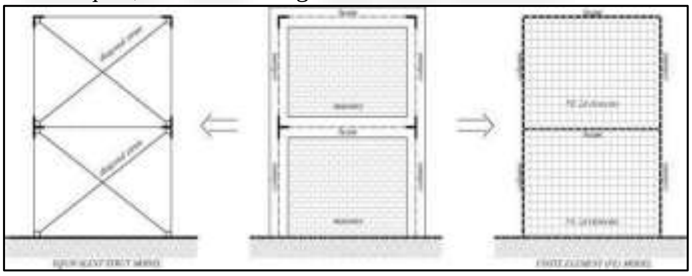

Fig. 2: Modelling of walls

1) Finite Element Method

Finite element method involves discretization of the member into smaller elements and the behaviour of the member was determined. For the infill wall system, the walls are discretized as a 2 Dimensional plate element as the thickness of the wall is negligible and the stress parameters are studied. This discretization of the wall is shown in fig. 2 above.

2) Equivalent Diagonal Strut method

When the frame is subjected to the lateral loads, the diagonal points of the frame will experience compressive force along the wall placed between the columns and beams. This method was first provided by Holmes (1961), later modified by many scientists and developed a formulae. The formulae presented in IS: 1893-2016 (Part 1), was even given by Mainstone and FEMA 306. Width and thickness of

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the strut, height and width of the wall provided between the columns and beams, elastic modulus of the frame and masonry infill are the parameters which depend on the strength and stiffness of the infill frame.

C. Pendulum Tuned Mass Damper

The process of replacing the springs, dampers from translational TMD with the cables, tensioned wires is known as Pendulum TMD. The behaviour is described as the movement of to and fro motion as shown in fig. 3. When a lateral force is acting on the structure, the building moves in the force direction whereas the TMD moves in the opposite direction i.e, out of phase movement, resulting in the less vibration. This condition will be efficiently working when the structure and TMD are along the same frequency i.e, the TMD should be modelled to the frequency of the structure.

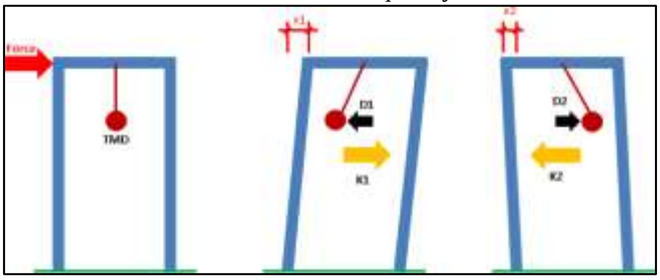

Fig. 3: Movement of TMD under lateral loading

TMD and the structure when combines and works as a single unit, the vibrations gets reduced. This result can be obtained when the stiffness and damper are modelled in such a way that they match the frequency of the structure. The following fig. 4 shows the parameters involved and the schematic diagram of the primary and TMD system.

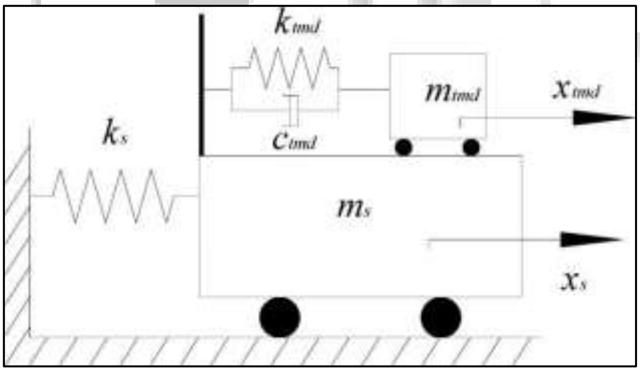

Fig. 4: Schematic diagram of Primary structure and TMD using D'Alembert's principle of equilibrium equation

IV. BUILDING DESCRIPTION AND MODELLING OF TMD

The building considered is asymmetric G+10 storied RC residential building of 28.5 m length and 8.17 m width with a plinth height of 2m and floor height 3.6 m subjected to normal live, wind and seismic loads using ETABS. The below table provides the description of the building considered. The top storey is treated as Head room to place TMD.

Condition	**Values**
Framing type	SMRF
No. of floors	G+10 RC
Plinth height	2 m
Floor height	3.6 m
Seismic zone	V, Z = 0.36
Response reduction factor	5
Importance factor	1.2
Type of soil	Medium, type II
Slab thickness	125 mm
Wall thickness	Main = 230 mm, Partition = 115 mm

Table. 1: Description of building

A. Material and Structural Properties

- Grade of concrete and steel: M40 and Fe 500 (Main), Fe 415 (Stirrups)
- Compressive strength and Young's modulus of masonry = 6 MPa and 3300 MPa
- Size of column: Stairs – 675*675 mm and remaining – 375*675 mm.
- Size of beam: 300*600 mm
- Slab thickness: 125 mm

B. Loads

Live load of 2.0, 3.0 and 1.5 kN/m2 is assigned on slabs for all rooms, corridors and terrace loads respectively and floor finish of 1.0 kN/m2. Wall loads are assigned on beams based on the location of walls. The below fig 5 shows the building plan considered for the static and dynamic analysis (Response spectrum and time history (El Centro).

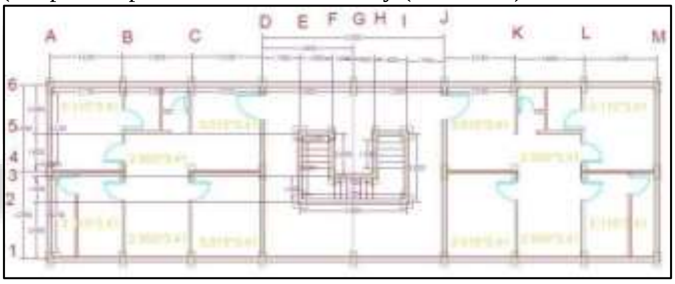

Fig. 5: Residential building plan

C. Time Period

Along X & Y Directions, For 41.6 M Height

D. Models Developed

(1) Bare frame with no masonry loads (BF)
(2) Bare frame with masonry loads i.e, conventional frame (CF)
(3) Conventional frame with increased column size of (CF-IC)
  (i) 375*825 mm, (CF-IC1)
  (ii) 525*675 mm (CF-IC2) and
  (iii) 525*825 mm (CF-IC3) until ground storey
(4) Conventional frame with shear walls at the core (CF-SW C) and corners (CF-SW L), bracings at the corners (CF-B)
(5) Conventional frame, TMD placed at the centre of the building in top storey(CF-T)
(6) RC frame with infills modelled as struts having open ground storey (soft storey) i.e, Strut frame (CFS)
(7) Strut frame with increased column size until ground storey at the core (CFS-IC) i.375*825 mm, (CFS-IC1)
  (i) 525*675 mm (CFS-IC2) and
  (ii) 525*825 mm (CFS-IC3) until ground storey

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(8) Strut frame with shear walls at the core (CFS-SW C) and corners (CFS-SW L), bracings at the corners (CFS-B)

Strut frame with TMD placed at the centre of the building in top storey (CFS-T)

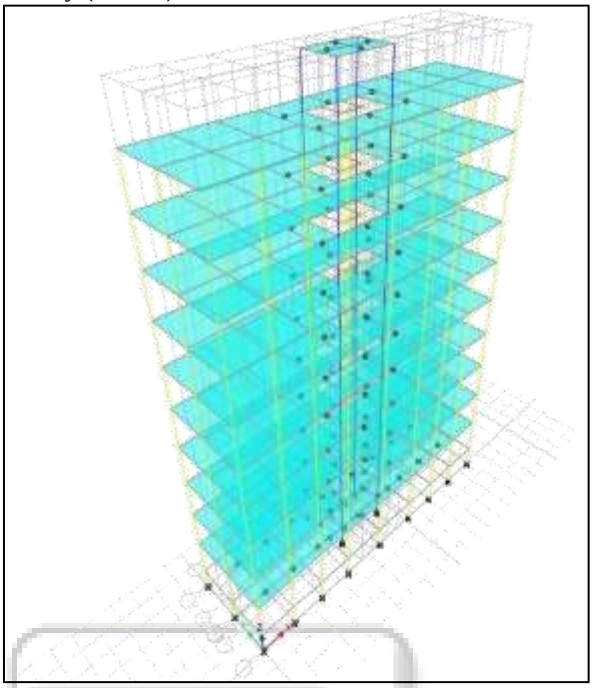

Fig. 6: Conventional frame (CF)

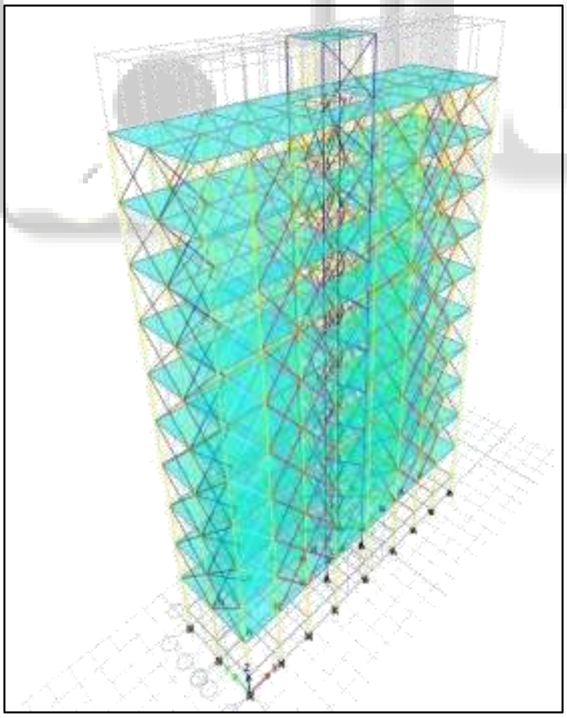

Fig. 7: Strut frame (CFS)

E. Properties of TMD and Piston

Mass, Stiffness and Damping of TMD and Piston is calculated which is given in the following table TMD is placed at the centre of the building in Head room.

Condition	**Value**
Total Mass of the Structure (ms)	2348500 kg
Natural Frequency of the Structure (ws)	4.6 rad/sec
Mass Ratio for TMD	0.03
Mass of TMD ($mtmd$)	70455 kg
Optimum Frequency ratio	0.971
Stiffness of TMD ($ktmd$)	1403.008 kN/m
Frequency of TMD ($wtmd$)	4.46 rad/sec
Optimum Damping ratio	0.1045
Damping Coefficient of TMD ($ctmd$)	65.67 kN-sec/m
Mass of Piston ($mpiston$)	1409 kg
Stiffness of Piston (k_{piston})	28.06 kN/m
Damping Coefficient of Piston ($cpiston$)	1.313 kN-sec/m

Table. 2: Properties of TMD and Piston

Piston is used for connecting the free end of the TMD to the column joints in terrace floor. The method of connecting the TMD to Pistons is necessary because, when the damper experiences more displacements, it should not get into contact with the elements present beside it as well as to hold the TMD and control the deflections.

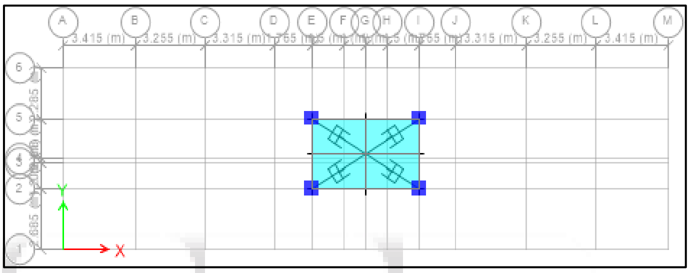

Fig. 8: Plan with TMD at top storey with TMD and Pistons

V. RESULTS AND CONCLUSION

The following conclusions can be drawn from the usage of Masonry infills, mitigating soft storey, TMD involvement in the structure.

(1) The SPD value obtained being 35.5%, Masonry infills should be considered during analysis, to determine the design forces of the structure.

(2) By considering the stiffness and strength of the infills when the structure is subjected to lateral loads, the responses like displacement, drift, velocity and acceleration of the structure were reduced when compared to the conventional frame.

(3) Around 78% and 82% reduction in displacement was observed TMD without infills and 35% and 15% reduction was observed for the Shear walls when placed at core without infills along X and Y axis respectively when compared with Conventional frame (CF).

(4) With the involvement of masonry struts, 50% and 30% reduction in displacement was observed for conventional frame and 32% and 24% reduction was observed for the TMD frame with infills along X and Y axis respectively when compared with Conventional frame (CF).

(5) The drifts were controlled by 54% and 35% for the conventional frame with infills and 60% and 66% reduction when TMD was considered in comparison with conventional frame for two axis respectively.

(6) When TMD was considered, the base shear has reduced by 55% and 33% with reference to conventional frame

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for both the axis respectively whereas increase in base shear was observed when infills were considered.

(7) The soft storey effect was eliminated better by using the shear walls at the core level having a percentage of 112% and no effect was observed when TMD is involved.

(8) When the TMD is involved in the structure, the time period of the structure has been reduced by the effect of tuning the structure and TMD.

(9) The performance of TMD was determined by the graphs plotted for time period against base shear and displacements, velocities and accelerations at top storey which inferred that the structure goes in out – of – phase when TMD is considered.

(10) Under the economy conditions, for a ten storied building, involving TMD results in high cost due to the provision of high tension rods to support TMD mass, 4 Pistons at 4 corners and greater column size is required to carry the TMD mass at the top storey and the soft storey effect cannot be removed.

(11) When shear walls are provided, both displacements and soft storey condition has been greatly reduced for lesser cost of construction.

VI. FUTURE SCOPE

- Determining the performance of TMD for taller structures for different mass ratios.
- Analysis of the effect of optimized parameters for mass and base excitations.
- Dependency of the mass ratio with the energy dissipation of the structure and TMD.

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