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INVESTIGATION ON EFFECT OF DYNAMIC LOADS ON MULTISTORIED CAR PARKING STRUCTURE AND PARKED VEHICLES

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ABSTRACT

In a typical developing country like India where urbanization is taking place at a rapid pace, multistory parking structures have started mushrooming in almost every city landscape. Firstly, the structure has to be made earthquake resistant. Secondly, the parked vehicles have also to be protected from damage during an earthquake. The safety of parked vehicles is seldom factored into the design. During extreme lateral loading the vehicles themselves will be subjected to excessive displacements which will make them collide with each other leading to considerable damage especially to sensitive electronic / digital controls. Normally the parked vehicles are modelled as mass objects in a structure. However, if one has to understand the behaviour of parked vehicles, the same have to be modelled as dynamic objects with mass and stiffness. This work has precisely considered this important aspect, which is rarely addressed, and herein lies the uniqueness of this research work. This work envisages analysis of a G+11 car parking structure with moment resistant frame as the structural system. The analyses consisted of essentially two procedures; one to model the parked cars as mass objects, treating them as point loads; second, to treat them as dynamic objects, treating each car as single storey portal frame with mass, stiffness and supports. In order to model the car as dynamic object, a typical automobile was considered and its mass and stiffness were found out and from these values, an equivalent frame model was arrived at. Further the analyses included considering mass regularities vertically across the floors as well as horizontally within the floors. Overall 11 models were analyzed five with cars as mass objects and five with cars as dynamic objects. The results studied were base shear, time period, displacement of structure as a whole and displacement of individual cars. It is seen that modelling of the parked vehicles as dynamic objects increases the rigidity of the structure resulting in higher base shear with the percentage difference ranging from 4.58% to 4.75% in comparison with the structures in which parked objects are treated as mass objects. Therefore, from safety point of view modelling of parked vehicles as dynamic objects is required. Car displacement varies from 3.48 mm in ground floor for model Ms2 to 24.74 mm in 11th floor for model Ms5 whereas corresponding floor displacements varies from 2.81 mm to 23.84 mm, indicating the cars do not collide during an earthquake.

Keywords: car parking structure, response spectrum analysis, dynamic loads, stiffness, spring supports, car.

1. INTRODUCTION

The increase in the density of the traffic has an adverse effect on the parking of the vehicles. Transport demand in India has increased by almost eight times since 1980s as a result of rapid economic development [1]. This demand of transport has led to higher vehicle ownership. Traffic congestion is one of the distresses faced by the public. In order to avoid the parking issues and distresses faced by the public due to lack of space for parking, multistoried car parking structures play an important role. The multistoried car parking structure will providea systematic and organized form of parking without any traffic mess. Unsystematic parking causes a lot of traffic nuisance. In today's scenario there is high need of parking structures, due to less availability of land and high vehicle ownership. So, to study the behaviour of the multistoried car parking structure especially during seismic forces is of much importance for future scope. Multistoried car parking structures have high live loadacting on it which primarily consists of vehicle loads thus these structures are heavily loaded and at the same time the loading can be evenly distributed or unevenly distributed along the floor or along the height of the building hence the study of the behaviour of multistoried car parking structures for earthquake forces is of much importance. The main aim of this work is to study the behaviour of the multistoried car parking structure during seismic forces when the structure is having (i) vehicle loads as mass objects i.e. point loads and second (ii) when vehicles are loaded as dynamic objects with mass and stiffness. In first case the vehicle loads will be represented as the concentrated point load while as in second case that is dynamic loading the loading will be more realistic in nature and will be represented as equivalent to half car model [3], [4] used by the department of automobile engineers so that we can get the accurate behaviour of the structure and parked vehicles during lateral forces. In both the types of cases the structure will be further analyzed for various variable loading conditions along the height and floors of the building. Parametric study for variable loading i.e. uneven loading will also be carried out. Response spectrum analysis [2] will be performed. Analysis will be carried out for Zone IV having zone factor of 0.24 using commercial software. In both the cases (i) mass objects (ii) dynamic objects five models of structures will be created in each case having variable vehicular occupancies i.e. different loading conditions, in addition to these models another model will be created having no vehicular load. Thus total 11 models will be analysed and their behaviour will be studied. In addition to the study of the behaviour of the

building it will be investigated that when the design of structure will be preferred from safety point of view and when the design of building will be preferred from serviceability point of view. In addition to the study of the behaviour of the building the behaviour of the parked objects is also studied for dynamic loading when the vehicles are modelled as half car model with mass and stiffness. The maximum vehicle displacement is obtained and the corresponding maximum floor displacement is also obtained. Hence the building displacement, car displacement in case of dynamic loading and corresponding floor displacement will also be investigated.

1.1

- Number of floors - G+11
- Floor height - 4m
- Slab thickness - 220 mm
- Type of structure - RC
- Column dimensions - 1m × 1m
- Beam dimensions - 0.8m × 0.3m
- Plinth beam dimensions - 0.45m × 0.30m
- Grade of concrete - M30
- Grade of stee - Fe415 (HYSD)

1.2 Specifications of the Building

- Maximun No. of cars that can be parked on a floor at a time are 56
- Maximun number of cars that can be parked in the full building are 672
- 8 no. of columns along length at 7m c/c spacing i.e. 7 bays.
- 7 no. of columns along breadth at 5.80m, 8.50m, 6.30m, 6.30m, 8.50m, 5.80m c/c spacing i.e. 6 bays

2. LITERATURE REVIEW

- Nirbhay A. Gajbhiye *et al* (2018) presented the analysis and design of pre-engineered parking plaza. The parking plaza was designed in the areas of Railway station, near Khandesh central mall and Phule market in Jalgon, keeping in view the traffic rush of around 100 to 150 vehicles/hour. To eliminate this problem, pre-engineered parking plaza was designed.

- Pramod Kr *et al* (2018), presented the paper entitled as "Analysis and design of multistoried parking building proposed at Jalahalli cross, Bengaluru". The research work is aimed to design an efficient parking system. Parking was provided for more than 277 cars and the building was designed for G+3 floors.

- Abdul Qayyum *et al* (2017) presented the paper on "Review of multi-storey car parking building". This research presented the design of a multi-storey car parking for the mitigation of traffic challenges in public areas using various case studies. Various design aspects were that of ramp, deck, aisle width and lift provisions.

- Irina Duvanova *et al*, (2016) presented the paper titled as "Efficiency of use underground multilevel parking in conditions of cramped housing development". It was studied that due to high growth rate of motorization storage of personal vehicles is one of the major current problems.

- Tadahisa Muramatsu and Takashi Oguchi (2016) presented the Methodology for measuring the performance of parking area. Research focused to describe the vehicle drop-by behavior so that the performance of an expressway parking area can be understood, based on the data of vehicles entering and exiting the parking area.

- Dr. MD. Subhan, Performed the analysis and design of a multi-storied car park complex. The architectural model was created using Autodesk Revit and the basic model was successfully broken down and outlined on Autodesk Robot structural examination programming.

- Upendra Singh Dandotia et al (2016), analysis and design of multilevel parking building using concept of framed structure. Multilevel parking is og G+2+2 basement having 13 shops on ground floor and its design is based on framed structure at Hazaratganj at lucknow (U.P) India. Design was done using STAAD. Pro.

2.1 Summary of Literature Review

Based on the above literature review the following results were obtained and a critical summary based on above literature is summarized below:

- Growing need for the car parking structures keeping in view the growth in vehicle ownership.
- Dynamic analysis is carried out for multistorey buildings.
- In all cases, vehicles are modelled as mass objects only.
- Literature survey did not indicate any work done wherein the parked vehicles are treated as dynamic objects as being done under this work.

3. PLANNING

The plan for the building was prepared according to the requirements of functionality. The ground floor plan of the building for parking of vehicles is shown in Figure-1.

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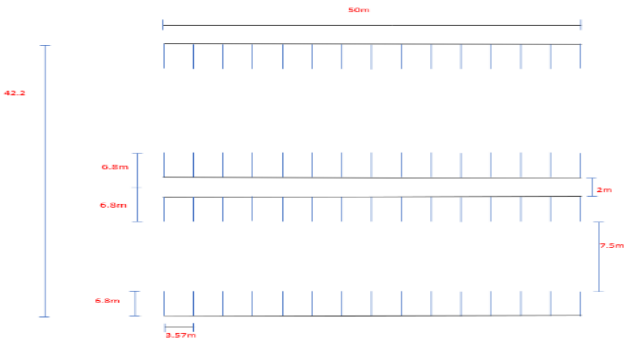

Figure-1. Parking plan of the building.

The distances are measured from external column to external column.14 cars can be parked along the length of the building and 4 cars can be parked along the breadth of the building thus total of 56 vehicles can be parked in a single floor at a time.

Figure-2 depicts the plan of the building with location of columns. The distances are measured centre to centre between the columns.

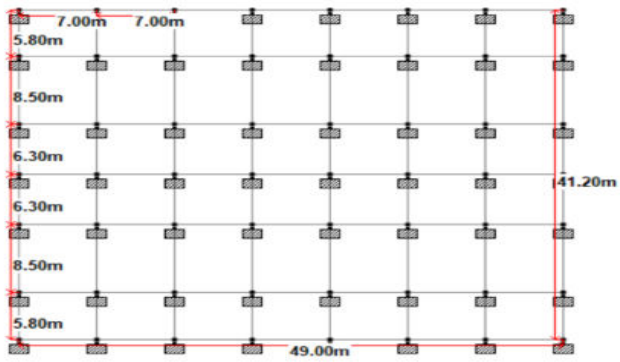

Figure-2. Plan of the building (centre to centre).

Figure-3 shows the elevation of the structure.

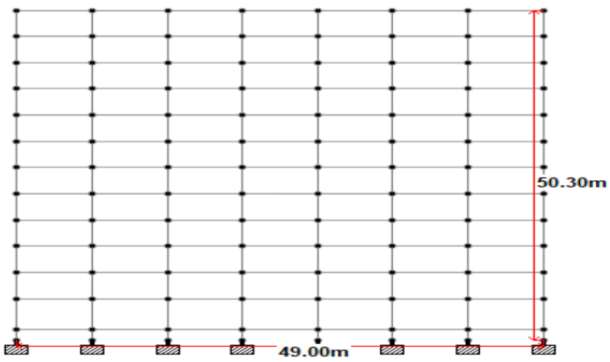

Figure-3. Elevation of the building.

3.1 Modelling of Car as Dynamic Objects

In the field of automobile engineering there are three ways to model a vehicle (a) Quarter car model (b) Half car model (c) Full car model as Shown in Figure-4.

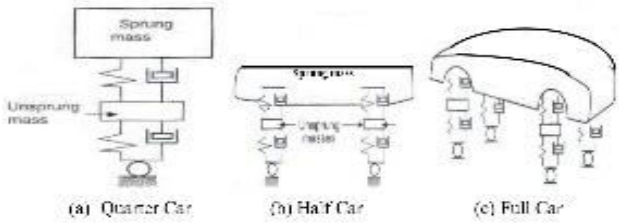

Figure-4. Car models.

In this research work equivalent of Half car model has been adopted for convenience. The car model has been created treating each car as a single storey steel portal frame with mass, stiffness and spring supports. In STAAD. Pro. under "Support" option "Fixed But" option was used to define the spring supports. The spring supports consists of vertical stiffness (FY) and lateral stiffness (FX, FZ). The tyre stiffness which is usually the maximum in the car being even more then suspension stiffness is being represented by vertical stiffness (FY). The frictional value between the tyre and the surface is being represented by the lateral stiffness (FX and FZ). The value of vertical stiffness (FY) was attained through literature review, journals and through discussion with the concerned people of automobile engineering. As STADD. Pro. is inadequate for assigning direct frictional value hence lateral stiffness (FX and FZ) were assigned to define the frictional value between the tyre and the surface and was given a very less value considering very high force acting on the structure during earthquake. Modelling of the car done in this work is represented in Figure-5.

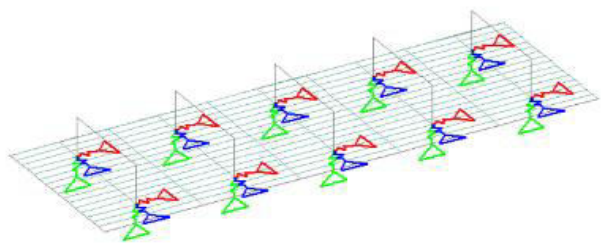

Figure-5. Cars modelled on the slab.

4. RESULTS AND DISCUSSIONS

Analysis of the models was done using commercial software, 11 models were analysed. "Add Surface" command was used for modelling of slabs for the models in which vehicles were modelled as mass objects i.e. Model Mm1, Model Mm2, Model Mm3, Model Mm4, Model Mm5 and for model with no vehicular load i.e. Model M0. "Generate Surface Meshing" command was used for modelling of slabs for the models in which vehicles were modelled as dynamic objects with mass and stiffness i.e. Model Ms1, Model Ms2, Model Ms3, Model Ms4, Model Ms5. In models Ms1, Ms2, Ms3, Ms4, Ms5 vehicles are modelled as equivalent of half car model used by the department of automobile engineering.

4.1 Zone IV Analysis of Model M0 (Building with Standard Live Load But No Car Load)

The model M0 consists only of dead load and standard live load but does not have vehicular load acting on it. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m (walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Load combination = 1.2DL + 0.3LL + 1.2EQ

Figure-6 shows the front view of the model M0 with no vehicular load acting on it

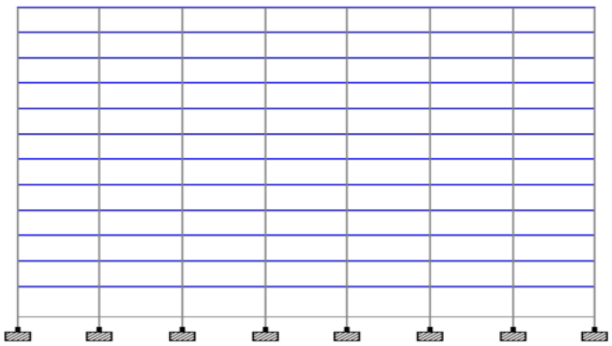

Figure-6. Model M0 - Building with standard live load but no car load (+ Z direction front view).

Figure-7 shows the side view of the model M0 with no vehicular load acting on it

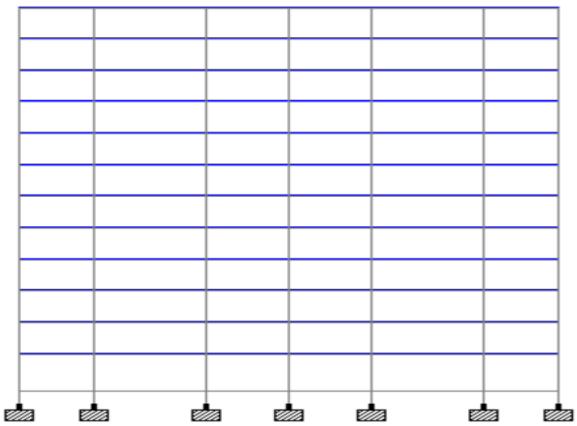

Figure-7. Model M0 - Building with standard live load but no car load (+X direction side view).

Considering the response spectrum analysis, the top story displacements for model M0 are shown in Table-1.

Table-1. Top story displacements for model M0.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.198
Max Z	DL + LL + EQ	23.493

Frequency and time period for model M0 under response spectrum analysis is shown in Table-2.

Table-2. Frequency and time period for model M0.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.545	1.83614
2	0.548	1.82634
3	0.580	1.72503
4	1.722	0.58064
5	1.727	0.57892
6	1.824	0.54831

BASE SHEAR SRSS = 4829.39 kN

4.2 Zone IV Analysis of Model Mm1(Full Occupancy i.e. All Floors are Fully Occupied by Vehicles Modelled as MASS OBJECTS)

The model Mm1 consists of dead load and standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6 kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m (walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

The building is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked and in complete building 672 vehicles are parked. The front view of the model Mm1 is shown in Figure-8.

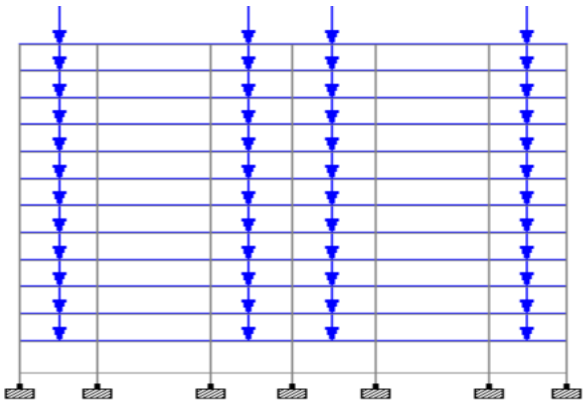

Figure-8. Model Mm1 - full occupancy i.e. all floors are fully occupied by vehicles modelled as MASS OBJECTS (+ Z direction front view).

Side view of the model Mm1 is shown in Figure-9.

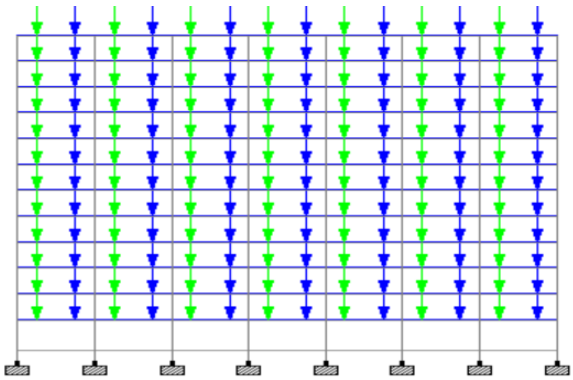

Figure-9. Model Mm1 - Full Occupancy i.e. all floors are fully occupied by vehicles modelled as MASS OBJECTS (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm1 are shown on Table-3.

Table-3. Top story displacements for model Mm1.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	24.256
Max Z	DL + LL + EQ	24.492

Frequency and time period for model Mm1 under response spectrum analysis is shown in Table-4.

Table-4. Frequency and time period for model Mm1.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.522	1.91528
2	0.525	1.90502
3	0.558	1.79054
4	1.651	0.60571
5	1.656	0.60391
6	1.757	0.56920

BASE SHEAR SRSS = 5034.69 kN

4.3 Zone IV Analysis of Model Mm2 (50% Occupancy from GF i.e. GF To 5th Floor are Fully Occupied by Vehicles Modelled as MASS OBJECTS)

The model Mm2 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6 kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m(walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

GF to 5th floor is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 336.

The side view of the model Mm2 is shown in Figure-10.

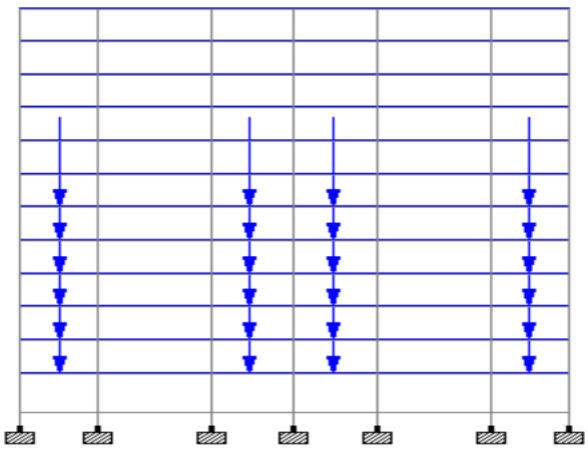

Figure-10. Model Mm2 - 50% 0ccupancy from GF i.e. GF to 5th floor are fully occupied by vehicles modelled as MASS OBJECTS (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm2 are shown on Table-5.

Table-5. Top story displacements for model Mm2.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.791
Max Z	DL + LL + EQ	24.072

Frequency and time period for model Mm2 under response spectrum analysis is shown in Table-6.

Table-6. Frequency and time period for model Mm2.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.534	1.87159
2	0.537	1.86178
3	0.570	1.75443
4	1.670	0.59886
5	1.675	0.59706
6	1.775	0.56339

BASE SHEAR SRSS = 5001.05 kN

4.4 Zone IV Analysis of Model Mm3 (50% 0ccupancy from 6th Floor i.e. 6th Floor to Top Floor are Fully Occupied by Vehicles Modelled as MASS OBJECTS)

The model Mm3 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m (walls on plinth beam)
e) Live load=1.5kN/m^2
f) Vehicle load
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

6th floor to top floor is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 336.

The side view of the model Mm3 is shown in Figure-11.

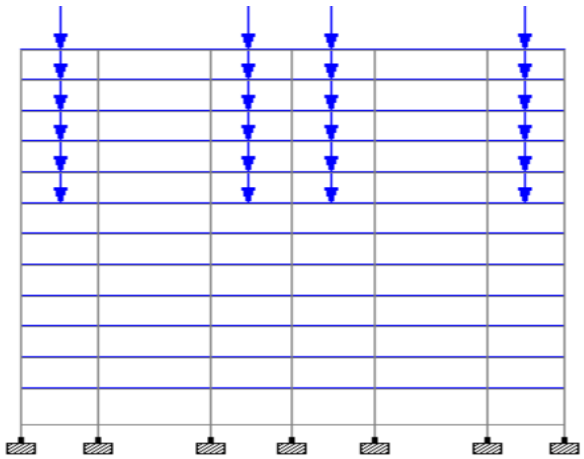

Figure-11. Model Mm3 - 50% Occupancy from 6th floor i.e. 6th floor to top floor are fully occupied by vehicles modelled as MASS OBJECTS (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm3 are shown on Table-7.

Table-7. Top story displacements for model Mm3.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.985
Max Z	DL + LL + EQ	24.238

Frequency and time period for model Mm3 under response spectrum analysis is shown in Table-8.

Table-8. Frequency and time period for model Mm3.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.525	1.90536
2	0.528	1.89497
3	0.561	1.78211
4	1.679	0.59544
5	1.684	0.59368
6	1.783	0.56070

BASE SHEAR SRSS = 4929.93 kN

4.5 Zone IV Analysis of Model Mm4 (Top Two Floors Fully Occupied by Vehicles Modelled as MASS OBJECTS)

The model Mm4 consists of dead load, standard live and vehicular load. The loads acting are as follows: -

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)

iii. 17.71kN/m (walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

The side view of the model Mm4 is shown in Figure-12.

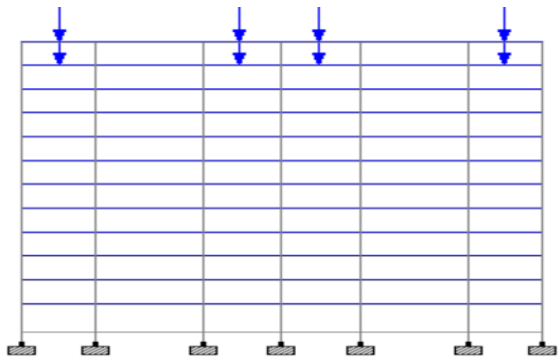

Figure-12. Model Mm4 - Top two floors fully Occupied by vehicles modelled as MASS OBJECTS (+X direction side view).

Top two floors are fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 112.

Considering the response spectrum analysis, the top story displacements for model Mm4 are shown on Table-9.

Table-9. Top story displacements for model Mm4.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.71
Max Z	DL + LL + EQ	23.989

Frequency and time period for model Mm4 under response spectrum analysis is shown in Table-10.

Table-10. Frequency and time period for model Mm4.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.532	1.87924
2	0.535	1.86895
3	0.568	1.76037
4	1.684	0.59366
5	1.689	0.59190
6	1.788	0.55919

BASE SHEAR SRSS = 4897.14

4.6 Zone IV Analysis of Model Mm5 (Floor Increases Occupancy Decreases I.e. Gradual Decrease in Vehicles Modelled as MASS OBJECTS from GF to Top Floor)

The model Mm5 consists of dead load, standard live and vehicular load. The loads acting are as follows: -

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m (walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

No. of vehicles parked in the structure decreases as the floor increases. Total no. of vehicles parked is 365. As we go from 1F to top floor the occupancy decreases. GF is fully occupied by the vehicles having total of 56 vehicles parked while as top floor i.e. 11F has only three vehicles parked on it

GF = 56 vehicles (full occupancy)
1F = 53 vehicles
2F = 50 vehicles
3F = 45 vehicles
4F = 40 vehicles
5F = 34 vehicles
6F = 28 vehicles
7F = 22 vehicles
8F = 17 vehicles
9F = 11 vehicles
10F = 6 vehicles
11F = 3 vehicles

The side view of the model Mm5 is shown in Figure-13.

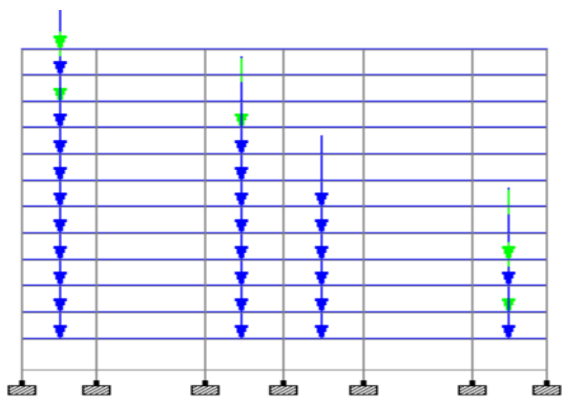

Figure-13. Model Mm5 - floor increases occupancy decreases i.e. gradual decrease in vehicles modelled as MASS OBJECTS from GF to top floor (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm5 are shown on Table-11.

Table-11. Top story displacements for model Mm5.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	24.967
Max Z	DL + LL + EQ	25.661

Frequency and time period for model Mm5 under response spectrum analysis is shown in Table-12.

Table-12. Frequency and time period for model Mm5.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.532	1.87890
2	0.535	1.86964
3	0.568	1.76100
4	1.673	0.59775
5	1.678	0.59608
6	1.779	0.56203

BASE SHEAR SRSS = 4964.64kN

4.7 Zone IV Analysis of Model Ms1 (Full Occupancy i.e. All Floors Are Fully Occupied by Vehicles Modelled as DYNAMIC OBJECTS with Mass and Stiffness)

The model Ms1 consists of dead load and standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m (walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load (included in the self-weight)
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

Vehicle modelling is done using structural elements that is beam and columns of steel property with spring supports defining vertical stiffness (tyre stiffness) and lateral stiffness (friction). The vehicle modelling details are below:

- Beam property = Steel
- Column property = Steel
- Beam size = 0.52m × 0.1m
- Beam length
  - 3.62m(for car having weight 26.25 kN)
  - 3.78m (for car having weight 26.88 kN)
- Column size = 0.22m × 0.22m
- Column length = 1.5m
- Vertical stiffness (FY)= 150 kN/m
- Lateral stiffness (FX, FZ) = 0.2 kN/m

The building is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked and in complete building 672 vehicles are parked. Here all the vehicles are modelled as dynamic objects with mass and stiffness, representing the half car model as is used by the department of automobile engineering. Vertical stiffness represents the tyre stiffness while as lateral stiffness represents the friction between the tyre and surface.

The front view of the model Ms1 is shown in Figure-14.

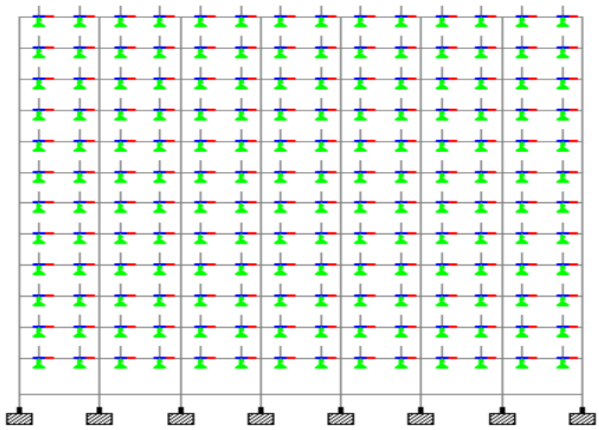

Figure-14. Model Ms1 - Full occupancy i.e. all floors are fully occupied by vehicles modelled as DYNAMIC OBJECTS with mass and stiffness (+Z direction front view).

The side view of the model Ms1 is shown in Figure-15.

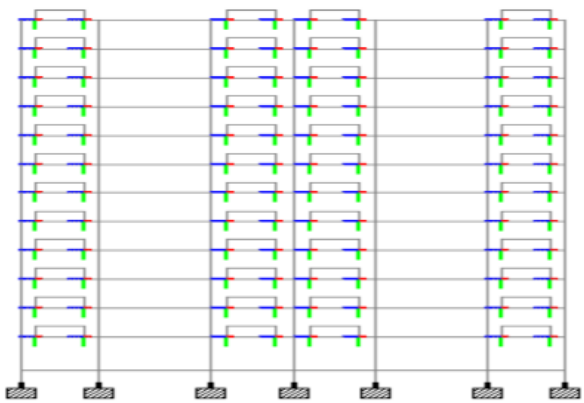

Figure-15. Model Ms1 - Full occupancy i.e. all floors are fully occupied by vehicles modelled as DYNAMIC OBJECTS with mass and stiffness (+X direction side view).

Considering the response spectrum analysis, the top story displacements for model Ms1 are shown on Table-13.

Table-13. Top story displacements for model Ms1.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.028
Max Z	DL + LL + EQ	23.338

Frequency and time period for model Ms1 under response spectrum analysis is shown in Table-14.

Table-14. Frequency and time period for model Ms1.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.548	1.82457
2	0.551	1.81463
3	0.583	1.71668
4	1.726	0.57948
5	1.730	0.57792
6	1.830	0.54657

BASE SHEAR SRSS = 5286.22 kN

Vehicle displacement and corresponding floor displacement for model Ms1 is shown in Table-15.

Table-15. Model Ms1 vehicle displacement and corresponding floor displacement.

FLOOR	DISPLACEMENT (mm)	CAR DISPLACEMENT (mm)
11F	23.028	24.035
10F	22.377	23.46
9F	21.549	22.61
8F	20.41	21.442
7F	18.981	19.983
6F	17.291	18.257
5F	15.358	16.284
4F	13.196	14.078
3F	10.818	11.651
2F	8.252	9.03
1F	5.551	6.271
GF	2.834	3.513

4.8 Zone IV Response Spectrum Analysis of Model Ms2 (50% Occupancy FromGF I.E. GF To 5th Floor are Fully Occupied by Vehicles Modelled as DYNAMIC OBJECTS with Mass and Stiffness)

The model Ms2 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m(walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load (included in the self-weight)
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

The vehicle modelling details are below:

- Beam property = Steel
- Column property = Steel
- Beam size = 0.52m × 0.1m
- Beam length
  - 3.62m (for car having weight 26.25 kN)
  - 3.78m (for car having weight 26.88 kN)
- Column size = 0.22m × 0.22m
- Column length = 1.5m
- Vertical stiffness (FY)= 150 kN/m
- Lateral stiffness (FX, FZ) = 0.2 kN/m

GF to 5th floor is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 336.

The side view of the model Ms2 is shown in Figure-16.

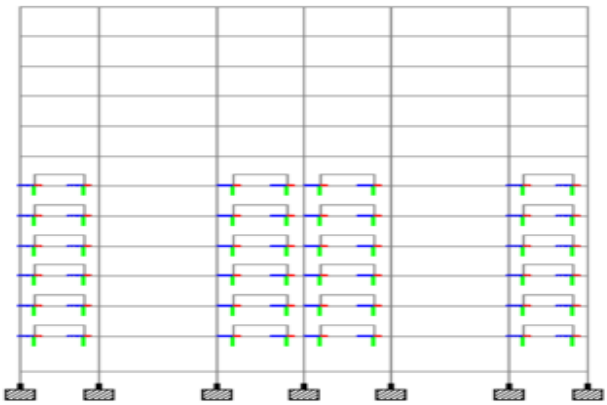

Figure-16. Model Ms2 - 50% Occupancy from GF i.e. GF to 5th floor are fully occupied by vehicles modelled as DYNAMIC OBJECTS with mass and stiffness (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Ms2 are shown on Table-16.

Table-16. Top story displacements for model Ms1.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	22.654
Max Z	DL + LL + EQ	22.966

Frequency and time period for model Ms2 under response spectrum analysis is shown in Table-17.

Table-17. Frequency and time period for model Ms2.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.561	1.78380
2	0.563	1.77470
3	0.594	1.68253
4	1.744	0.57339
5	1.748	0.57206
6	1.847	0.54138

BASE SHEAR SRSS = 5247.12 kN

Vehicle displacement and corresponding floor displacement for model Ms2 is shown in Table-18.

Table-18. Model Ms2 vehicle displacement and corresponding floor displacement.

FLOOR	FLOOR DISPLACEMENT (mm)	CAR DISPLACEMENT (mm)
5F	15.163	16.073
4F	13.043	13.912
3F	10.706	11.528
2F	8.174	8.944
1F	5.503	6.217
GF	2.811	3.487

4.9 Zone IV Response Spectrum Analysis of Model Ms3 (50% Occupancy from 6th Floor I.E. 6th Floor to Top Floor are fully Occupied by Vehicles Modelled as DYNAMIC OBJECTS with Mass and Stiffness)

The model Mm3 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
   i. 4.6kN/m (outer beams top floor)
   ii. 14.72kN/m (outer beams GF to 10 floor)
   iii. 17.71kN/m(walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load (included in the self-weight)
   i. 26.25 kN
   ii. 26.88 kN

1. Load combination = 1.2DL + 0.3LL + 1.2EQ

The vehicle modelling details are below:

- Beam property = Steel
- Column property = Steel
- Beam size = 0.52m × 0.1m
- Beam length
  - 3.62m (for car having weight 26.25 kN)
  - 3.78m (for car having weight 26.88 kN)
- Column size = 0.22m × 0.22m
- Column length = 1.5m
- Vertical stiffness (FY)= 150 kN/m
- Lateral stiffness (FX, FZ) = 0.2 kN/m

6th floor to top floor is fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 336. GF to 5th floor does not have any vehicle parked on it. All the vehicles are parked from 6th floor to the top floor i.e. 11F. The vehicles are modelled as dynamic objects having mass and stiffness. Mass equal to the mass of car and stiffness representing vertical stiffness (FY) i.e. tyre stiffness and lateral stiffness (FX and FZ) representing friction between tyre and surface.

The side view of the model Ms3 is shown in Figure-17.

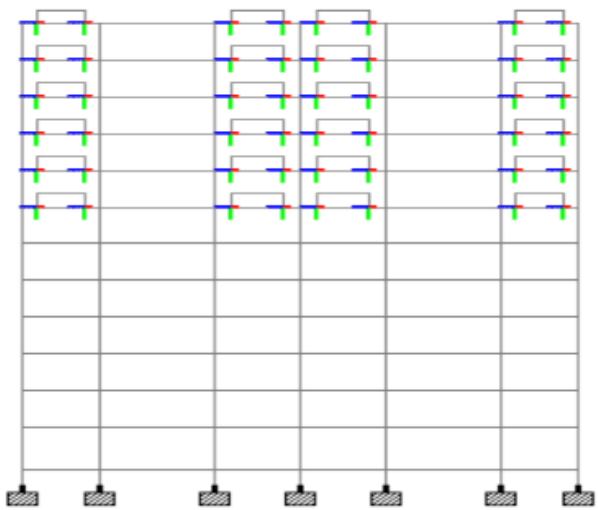

Figure-17. Model Ms3 - 50% Occupancy from 6th floor i.e. 6th floor to top floor are fully occupied by vehicles modelled as DYNAMIC OBJECTS with mass and stiffness (+X direction side view).

Considering the response spectrum analysis, the top story displacements for model Ms3 are shown in Table-19.

Table-19. Top story displacement for model Ms3.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	22.806
Max Z	DL + LL + EQ	23.109

Frequency and time period for model Ms3 under response spectrum analysis is shown in Table-20.

Table-20. Frequency and time period for model Ms3.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.550	1.81737
2	0.553	1.80773
3	0.585	1.71040
4	1.754	0.57002
5	1.759	0.56842
6	1.857	0.53857

BASE SHEAR SRSS = 5169.55kN

Vehicle displacement and corresponding floor displacement for model Ms3 is shown in Table-21.

Table-21. Model Ms3 vehicle displacement and corresponding floor displacement.

FLOOR	FLOOR DISPLACEMENT	CAR DISPLACEMENT
11F	22.806	23.803
10F	22.16	23.232
9F	21.335	22.386
8F	20.202	21.224
7F	18.779	19.77
6F	17.093	18.049

4.10 Zone IV Response Spectrum Analysis of Model Ms4 (Top wo Floors Fully Occupied by Vehicles Modelled as MASS OBJECTS)

The model Ms4 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m(walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load (included in self-weight)
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

The vehicle modelling details are below:

- Beam property = Steel
- Column property = Steel
- Beam size = 0.52m × 0.1m
- Beam length
  - 3.62m (for car having weight 26.25 kN)
  - 3.78m (for car having weight 26.88 kN)
- Column size = 0.22m × 0.22m
- Column length = 1.5m
- Vertical stiffness (FY)= 150 kN/m
- Lateral stiffness (FX, FZ) = 0.2 kN/m

Top two floors are fully occupied by the vehicles according to the plan of the building. In one floor 56 vehicles are parked making total no. of vehicles parked in the building equal to 112.

The side view of the model Ms4 is shown in Figure-18.

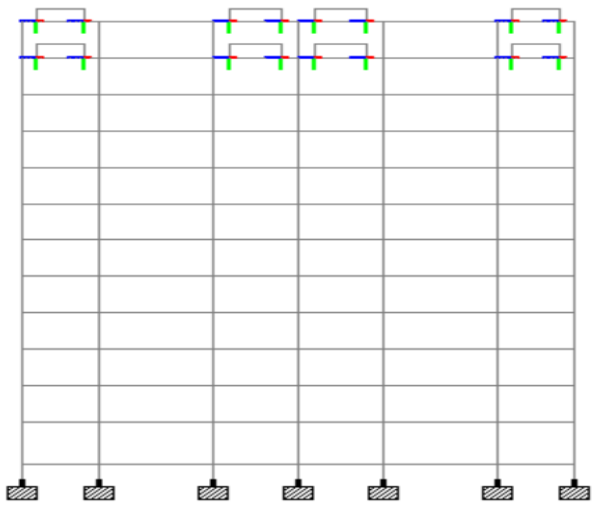

Figure-18. Model Ms4 - Top two floors fully occupied by vehicles modelled as DYNAMIC OBJECTS with mass and stiffness (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm4 are shown in Table-22.

Table 22 Top story displacement for model Ms4.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	22.591
Max Z	DL + LL + EQ	22.887

Frequency and time period for model Ms4 under response spectrum analysis is shown in Table-23.

Table-23. Frequency and time period for model Ms4.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.558	1.79313
2	0.561	1.78388
3	0.592	1.68996
4	1.758	0.56876
5	1.763	0.56726
6	1.861	0.53749

BASE SHEAR SRSS = 5132.25 kN

Vehicle displacement and corresponding floor displacement for model Ms4 is shown in Table-24.

Table-24. Model Ms4 vehicle displacement and corresponding floor displacement.

FLOOR	FLOOR DISPLACEMENT (mm)	CAR DIAPLACEMENT (mm)
11F	22.591	23.572
10F	21.939	22.997

4.11 Zone IV Response Spectrum Analysis of Model Ms5 (Floor Increases Occupancy Decreases I.E Gradual Decrease in Vehicles Modelled as DYNAMIC OBJECTS with Mass and Stiffness from GF to Top Floor)

The model Ms5 consists of dead load, standard live and vehicular load. The loads acting are as follows:

a) Earthquake load
b) Self-weight
c) Floor finish = 0.96kN/m^2
d) Masonry wall load
i. 4.6kN/m (outer beams top floor)
ii. 14.72kN/m (outer beams GF to 10 floor)
iii. 17.71kN/m(walls on plinth beam)
e) Live load = 1.5kN/m^2
f) Vehicle load (included in self weight)
i. 26.25 kN
ii. 26.88 kN
g) Load combination = 1.2DL + 0.3LL + 1.2EQ

The vehicle modelling details are below:

- Beam property = Steel
- Column property = Steel
- Beam size = 0.52m × 0.1m
- Beam length
  - 3.62m (for car having weight 26.25 kN)
  - 3.78m (for car having weight 26.88 kN)
- Column size = 0.22m × 0.22m
- Column length = 1.5m
- Vertical stiffness (FY)= 150 kN/m
- Lateral stiffness (FX, FZ) = 0.2 kN/m

No. of vehicles parked in the structure decreases as the floor increases. Total no. of vehicles parked is 365

GF = 56 vehicles (full occupancy)
1F = 53 vehicles
2F = 50 vehicles
3F = 45 vehicles
4F = 40 vehicles
5F = 34 vehicles
6F = 28 vehicles
7F = 22 vehicles
8F = 17 vehicles
9F = 11 vehicles
10F = 6 vehicles
11F = 3 vehicles

The side view of the model Ms5 is shown in Figure-19.

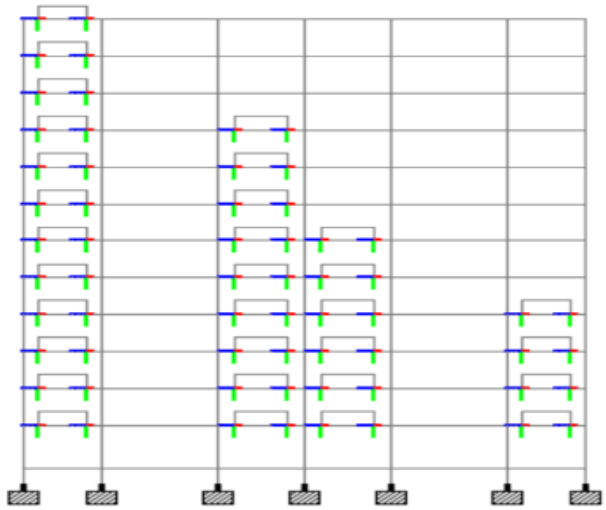

Figure-19. Model Mm5 - floor increases occupancy decreases i.e. gradual decrease in vehicles modelled as MASS OBJECTS from GF to top floor (+ X direction side view).

Considering the response spectrum analysis, the top story displacements for model Mm5 are shown in Table-25.

Table-25. Top story displacements for Model Ms5.

Max	Load combination	Displacement (mm)
Max X	DL + LL + EQ	23.843
Max Z	DL + LL + EQ	24.553

Frequency and time period for model Ms5 under response spectrum analysis is shown in Table-26.

Table-26. Frequency and time period for model Ms5.

MODE	FREQUENCY (cycles/s)	PERIOD(s)
1	0.558	1.79085
2	0.561	1.78217
3	0.592	1.68902
4	1.747	0.57226
5	1.751	0.57095
6	1.852	0.53998

BASE SHEAR SRSS = 5207.79 kN

Vehicle displacement and corresponding floor displacement for model Ms5 is shown in Table-27.

Table-27. Model Ms5 vehicle displacement and corresponding floor displacement.

FLOOR	FLOOR DISPLACEMENT (mm)	CAR DISPLACEMENT (mm)
11F	23.843	24.748
10F	23.186	24.169
9F	22.341	23.306
8F	21.174	22.116
7F	19.704	20.626
6F	17.96	18.852
5F	15.959	16.821
4F	13.716	14.544
3F	11.247	12.037
2F	8.579	9.327
1F	5.772	6.473
GF	2.947	3.621

5. COMPARITIVE STUDIES

The models were studied under response spectrum analysis for its different behaviour in seismic Zone IV. The comparative studies were carried out based on time period, base shear, building displacement, car and corresponding floor displacement for Models Ms1, Ms2, Ms3, Ms4, Ms5.

Figure-20 shows the comparison between the time period for different models.

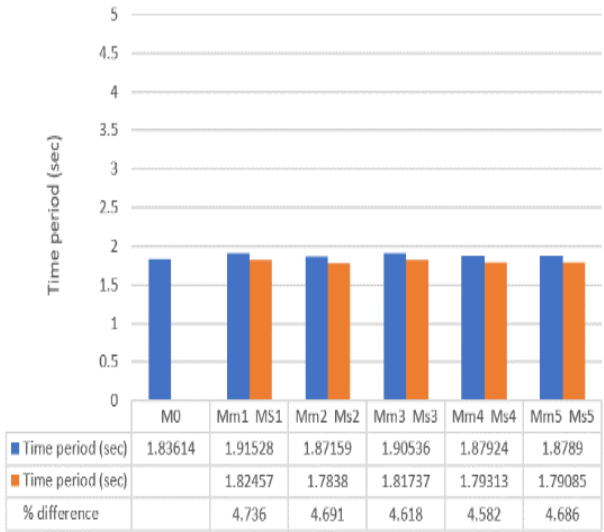

Figure-20. Comparison of time period.

Comparison between the base shear for different models is shown in Figure-21.

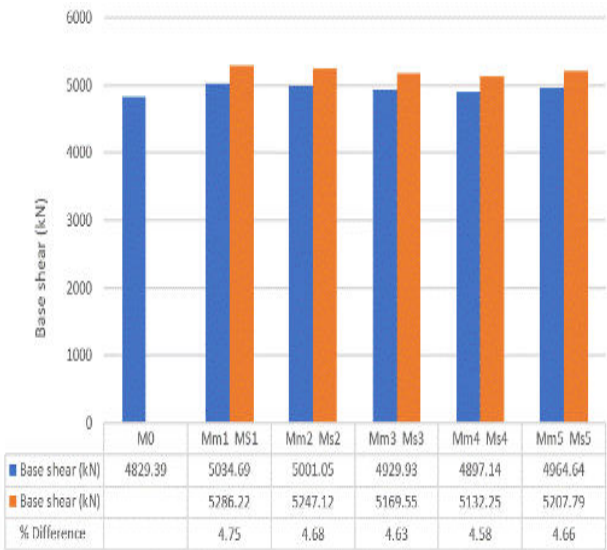

Figure-21. Comparison of base shear.

The graph 20 and 21 indicates that structure with parked vehicles as dynamic objects (with mass and stiffness) have less time period as compared to the structures in which the parked vehicles are treated as mass objects. This indicates that modelling the vehicles as dynamic objects increase the rigidity of the structure which results in higher base shear than the structures with cars modelled as mass objects ranging from 4.58% to 4.75%. This also brings out that design of parking structures treating parked vehicles as dynamic objects leads to safer structure.

Figure-22 shows the displacements of all the models in X direction with comparison.

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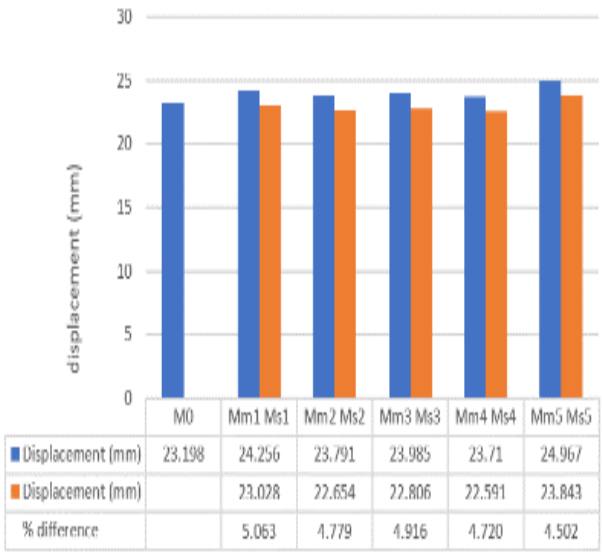

Figure-22. Comparison of displacement for X direction.

Figure-23 shows the displacements of all the models in Z direction with comparison.

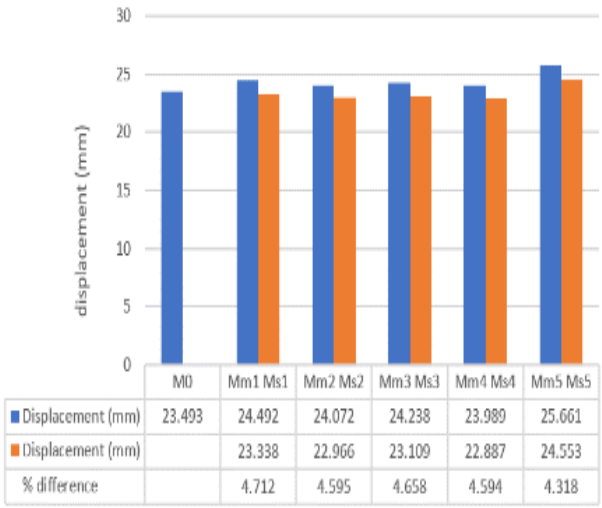

Figure-23. Comparison of displacement for Z direction.

The results from graph 22 and 23 indicate that the structures with mass objects undergo a higher top story deflection varying from 4.31% to 5.06%. This indicates that while designing the structure from serviceability point of view we have to consider the structure with parked vehicles as mass objects. The maximum top story displacement are within the limit prescribed by IS 1893.

Vehicle displacement and corresponding floor displacement for model Ms1 under response spectrum analysis is shown in Figure-24.

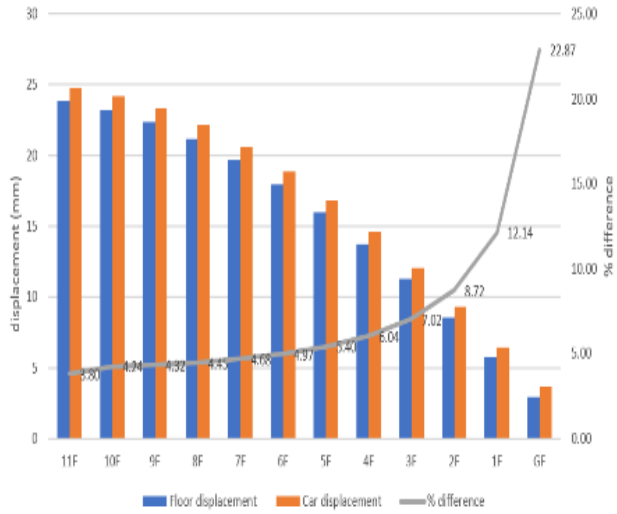

Figure-24. Vehicle displacement and corresponding floor displacement for model Ms1.

The graph 24 indicates that the parked objects (vehicles) undergo higher displacement than the floors where they are parked. The % increase in deflection observed in the parked cars ranges from 4.37% to 23.95%, however the increase is very nominal. It is interesting to note that the vehicles parked in the lower floors are subjected to higher displacements as compared to the vehicles parked in the upper floors. However, since the displacements are very small in the lower stories which does not affect the stability of the cars.

Vehicle displacement and corresponding floor displacement for model Ms2 under response spectrum analysis is shown in Figure-25.

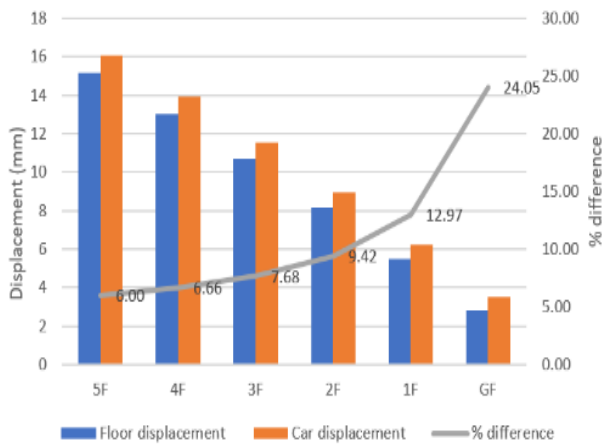

Figure-25. Vehicle displacement and corresponding floor displacement for model Ms2.

The graph 5.28 indicates that the parked objects (vehicles) undergo higher displacement than the floors where they are parked. The % increase in deflection observed in the parked cars ranges from 6.00% to 24.05%. It can be seen that the vehicles parked in the lower floors are subjected to higher displacements as compared to the vehicles parked in the upper floors. However, since the

displacements are very small in the lower stories which does not affect the stability of the cars. The percentage difference from 5th floor to GF considerably increases and is minimum at 5th floor equal to 6.00% and maximum at GF equal to 24.05%. There is high shift in the difference of percentage from 1F to GF because of high difference in displacement between the two floors

Vehicle displacement and corresponding floor displacement for model Ms3 under response spectrum analysis is shown in Figure-26.

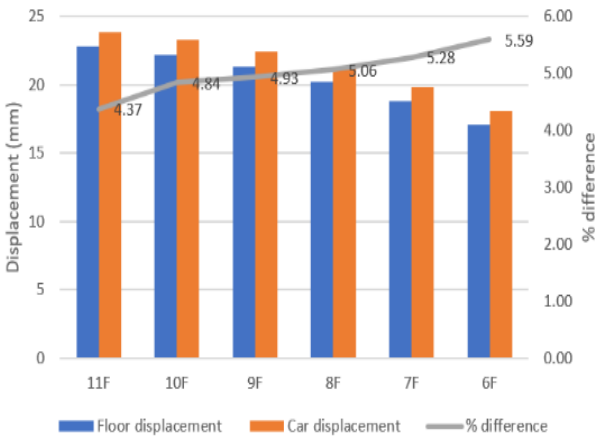

Figure-26. Vehicle displacement and corresponding floor displacement for model Ms3.

The graph 26indicates that the parked objects (vehicles) undergo higher displacement than the floors where they are parked. The % increase in deflection observed in the parked cars ranges from 4.37% to 5.59%.

Vehicle displacement and corresponding floor displacement for model Ms4 under response spectrum analysis is shown in Figure-27.

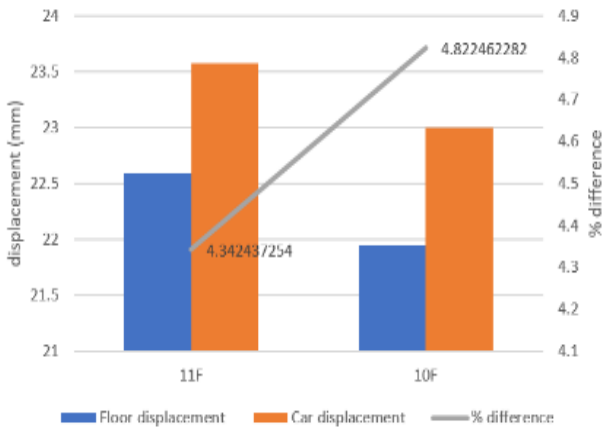

Figure-27. Vehicle displacement and corresponding floor displacement for model Ms4.

The graph 5.30 indicates that the parked objects (vehicles) undergo higher displacement than the floors where they are parked. The % increase in deflection observed in the parked cars ranges from 4.34% to 4.82%.

Vehicle displacement and corresponding floor displacement for model Ms5 under response spectrum analysis is shown in Figure-28.

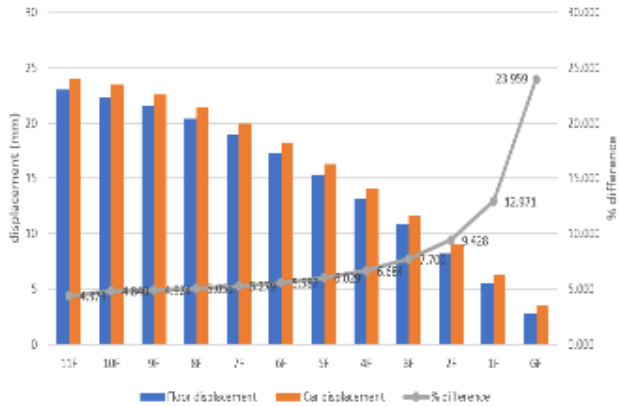

Figure-28. Vehicle displacement and corresponding floor displacement for model Ms5.

The graph 28 indicates that the parked objects (vehicles) undergo higher displacement than the floors where they are parked. The % increase in deflection observed in the parked cars ranges from 3.80% to 22.87%, however the increase is very nominal. It is interesting to note that the vehicles parked in the lower floors are subjected to higher displacements as compared to the vehicles parked in the upper floors. However, since the displacements are very small in the lower stories which does not affect the stability of the cars.

6. CONCLUSIONS

- Under this research work modelling of the parked cars as dynamic objects has been done which is very unique in nature. Further stiffness, support conditions and the structural properties of car model has been found out.
- Modelling of the parked vehicles as dynamic objects increases the rigidity of the structure resulting in higher base shear with the percentage difference ranging from 4.58% to 4.75% in comparison with the structures in which parked objects are treated as mass objects therefore it is concluded that from safety point of view this modelling is required.
- Structures having parked vehicles as mass objects undergo higher top story deflection varying from 4.3% to 5.06% as compared to the structures having parked vehicles as dynamic objects, thus it indicates that while designing the structure from serviceability point of view we have to consider the structure with parked vehicles treated as mass objects also.
- The maximum deflection is in model Mm5 equal to 25 mm which is less than the permissible value equal to 140mm as per codal provision. It is concluded that the relative difference between vehicles and corresponding story where they are parked is mostly less, which indicates that the stability of the parked

vehicles are not very much affected due to lateral dynamic loads

- The high percentage of displacement in lower stories gets offset by the small absolute values.
- Model Mm5 and Model Ms5 are having maximum displacement and are thus more unstable due to highly variable loading from GF to top floor
- It is found that the car displacement in models Ms1, Ms2, Ms3, Ms4, Ms5 is more than their corresponding floors in each building ranging from 3.80% to 24.05%

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