OPTIMUM EARTHQUAKE RESPONSE OF TALL BUILDINGS

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Abstract

The present study discusses the optimum earthquake response of tall buildings. The possibility of design approach is based on 'expendable top storey' for the tall buildings. If such a behaviour is feasible one can conceive of a structure whose top storey is permitted and designed to undergo large inelastic deformations while reducing damage in the lower storey. The concept was first proposed in an earlier research (Jagadish and Raghu Prasad). Such a concept juxtaposes the often-mentioned 'soft first storey' concept. The question is how to design a tall building so as to cause yielding of the uppermost floor or a few upper flowers, thus leaving the lower floor to be within the elastic limit? Recently observed that if a building has members size are derived for buildings designed for different values of R, it may be possible to optimize the energy absorption.

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1. INTRODUCTION

In the present days, tall buildings are designed for earthquake resistance according to the earthquake zone they are in. They are designed for a known R value. The base shear increases as the R value decreases. So the zones where the Earth Quake is expected to be stronger, the building is designed for lesser R value, so as to allow for inelastic deformation (which is anyway inevitable) with provision of ductile detailing.

If the value of R is chosen to be small then the design base shear is larger and thus probability of the building yielding is less. In fact, it need not be provided with ductile detailing.

On the other hand if the value of R is higher, the design base shear is lower and thus the chances of the building getting into inelastic regime are higher thus requiring ductile detailing. In the present work, structural size and reinforcement required for different base shears or in other words different values of R are combined in one frame in such a way that yielding can take place in upper stories thus absorbing energy. The lower stories obviously will remain elastic. Such a building is found to consist of optimum sized members. Thus it can be called as optimum design. In other words the inelastic response can be termed optimum.

R -Value

With the "R" value located in the denominator of the calculation for the lateral load on the building, higher "R" value reduces the total load on the building. "R" values range from 1.5 for unreinforced concrete and masonry shear walls to 8 for properly detailed shear walls, braced frames and moment frames.

High "R" value -> lower design lateral loads -> more ductile detailing expense.

low "R" value -> higher design lateral loads -> less ductile detailing expense.

2. STRUCTURAL MODEL

For this study, a nine storey building is considered. The dimensions in plan of the building are 48mX20m. The structural models have the same story height of 3m. and have a uniform mass distribution over their height. Building plan is shown is below fig.2.2 a

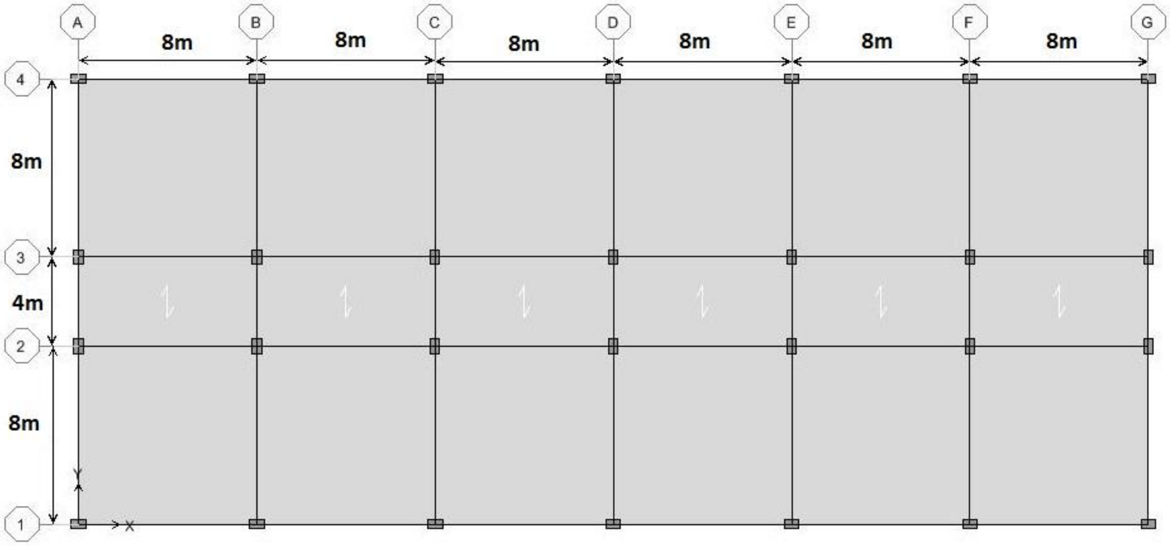


Fig 2.2 a: Building plan

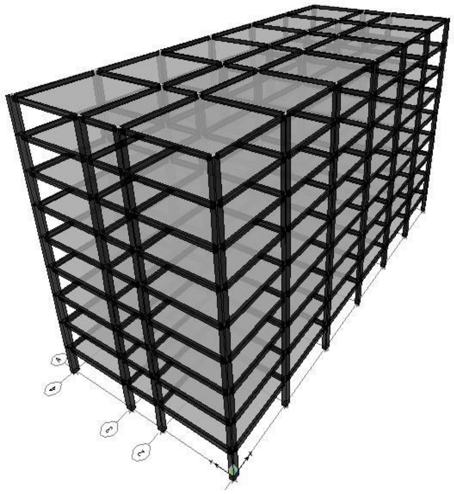


Fig 2.2.b: 3D view

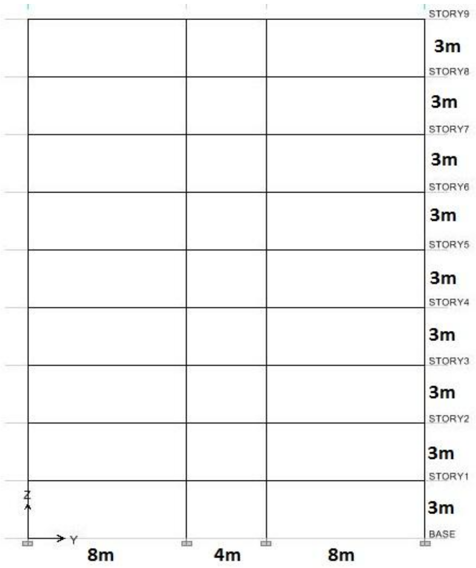


Fig 2.2.c: Building Elevation

In this thesis, there are two types of models, namely Basic model and combined model

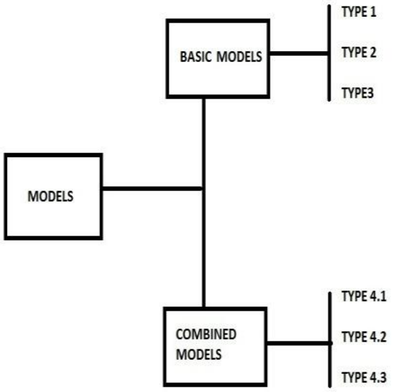
Basic model(BM) is a model in which, for chosen value of R different optimized sizes of beams are obtained over the height. The beam sizes decreases over the height. The Basic models are type 1,type 2 and type3.

- optimized frame for R=3 is Type 1 model.
- optimized frame for R=4 is Type 2 model.
- optimized frame for R=5 is Type 3 model..

Combined model (CM) is a model in which, the optimized beam sizes obtained from various R values are combined in a single model. The lower one third is taken from TYPE1 ,the middle third from TYPE2 and upper third from TYPE3 . Combined models is also analysed by response spectrum for R=3,4 and 5 respectively and the results are identified as Type 4.1,4.2 and 4.3 respectively.

The combined model is designed for different base shear obtained from R=3, 4 and 5 respectively.

3. TYPES OF MODELS



The steps for creating the types of optimum models
Two types of combined models have been employed in the present study. In one type, the optimized beam of the basic models are combined and that is called Type4. In the other type called Type8,the columns which are optimized in the basic models Type1,2&3 are combined.

3.1 Type4-Combination of Optimized Beams

STEP1- A 9-Storey building is designed for different value of R, They are R=3,4&5 and analysed by response spectrum method .In the analysis the dimension of the beams have been reduced gradually till they fail. The dimensions of the beams one step before they failed have been assumed to be the optimum dimension. The column dimensions have been kept constant. The frames for R=3,4 & 5 have been named TYPE -1,TYPE-2 AND TYPE3.

STEP2-A combined model where the dimensions of 1/3rd bottom storey are given the dimensions of TYPE1, the next three stories are given the dimensions of TYPE2 and the last three (upper) stories are given the dimension of TYPE 3.

STEP3- The combined model is named as TYPE 4

STEP4-The type 4 is again analyzed for R=3, 4 & 5 respectively by the Response spectrum method. They are named as TYPE 4.1,TYPE 4.2 AND TYPE 4.3 respectively.

3.2 Type8-Combination of Optimized Columns

STEP1- A 9-Storey building is designed for different value of R, They are R=3,4&5 and analysed by response spectrum method .In the analysis the dimension of the beams have been reduced gradually till they fail. The dimensions of the columns one step before they failed have been assumed to be the optimum dimension. The column dimension have been kept constant. The frames for R=3,4 & 5 have been named TYPE -5,TYPE-6AND TYPE7.

STEP2-A combined model where the dimensions of 1/3rd bottom storey are given the dimensions of TYPE5, the next three stories are given the dimension of TYPE6 and last three (upper) stories are given the dimension of TYPE 7 is termed.

STEP3- The combined model is named as TYPE 8

STEP4-The type 8 is again analyzed for R=3, 4 & 5 respectively by the Response spectrum method. They are named as TYPE 8.1,TYPE 8.2 AND TYPE 8.3 respectively.

4. RESPONSE SPECTRUM ANALYSIS

4.1 Analysis Input

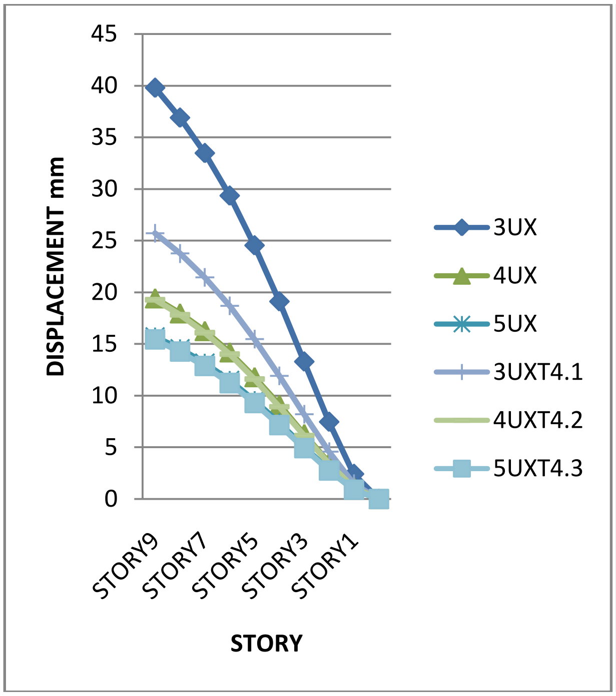
Table below shows input for response spectra analysis for various types of models

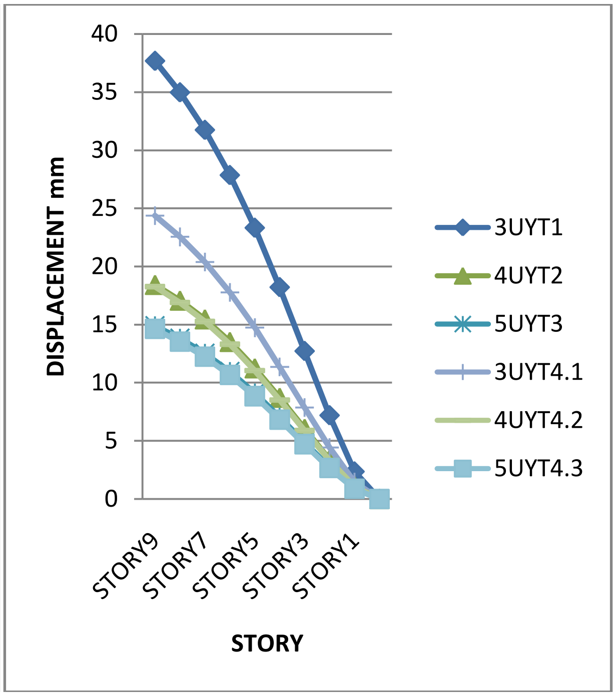
Table 3.1.1 Response spectrum data

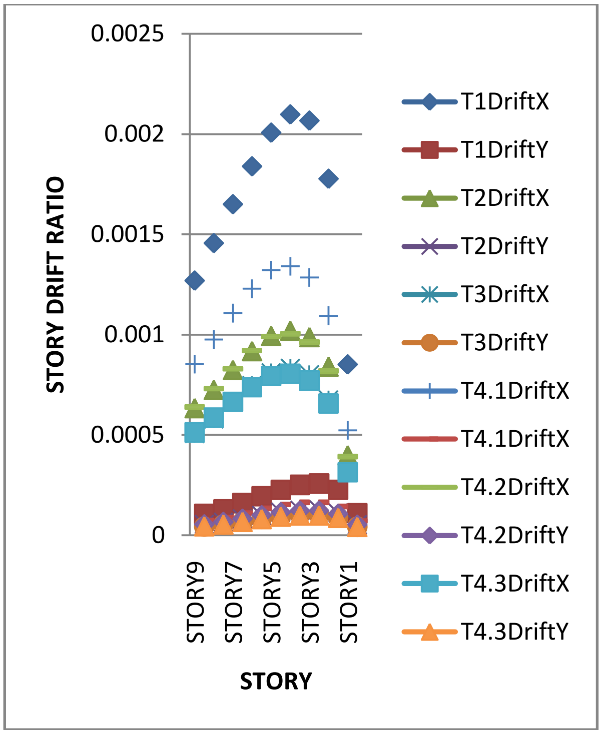
	BASIC MODELS			COMBINED MODELS		
TYPES	T1	T2	T3	T4.1	T4.2	T4.3
R VALUE	R=3	R=4	R=5	R=3	R=4	R=5
Function input	0.1	0.1	0.1	0.1	0.1	0.1
spectrum case name	spec1	spec1	spec1	spec1	spec1	spec1
structural and function damping	0.05	0.05	0.05	0.05	0.05	0.05
model combination	CQC	CQC	CQC	CQC	CQC	CQC
directional combination	SRSS	SRSS	SRSS	SRSS	SRSS	SRSS
input response spectra	9.81/2*3	9.81/2*4	9.81/2*5	9.81/2*3	9.81/2*4	9.81/2*5
eccentricity ratio	0.05	0.05	0.05	0.05	0.05	0.05

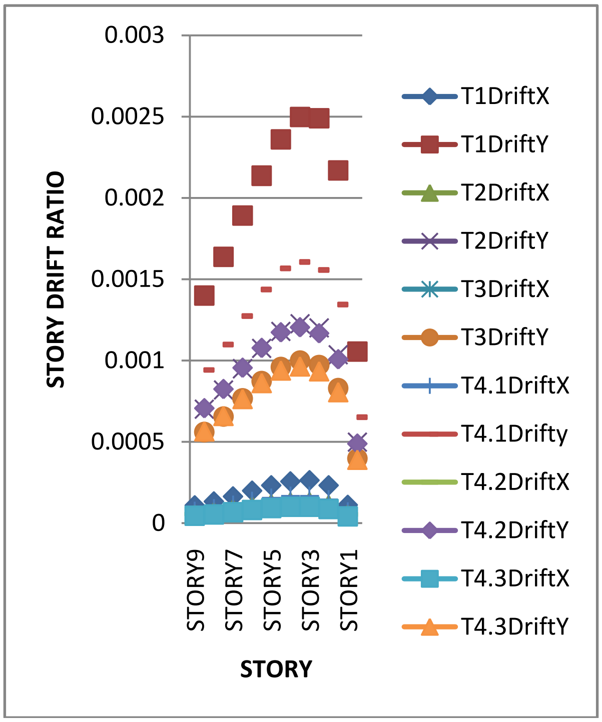
4.2 Results

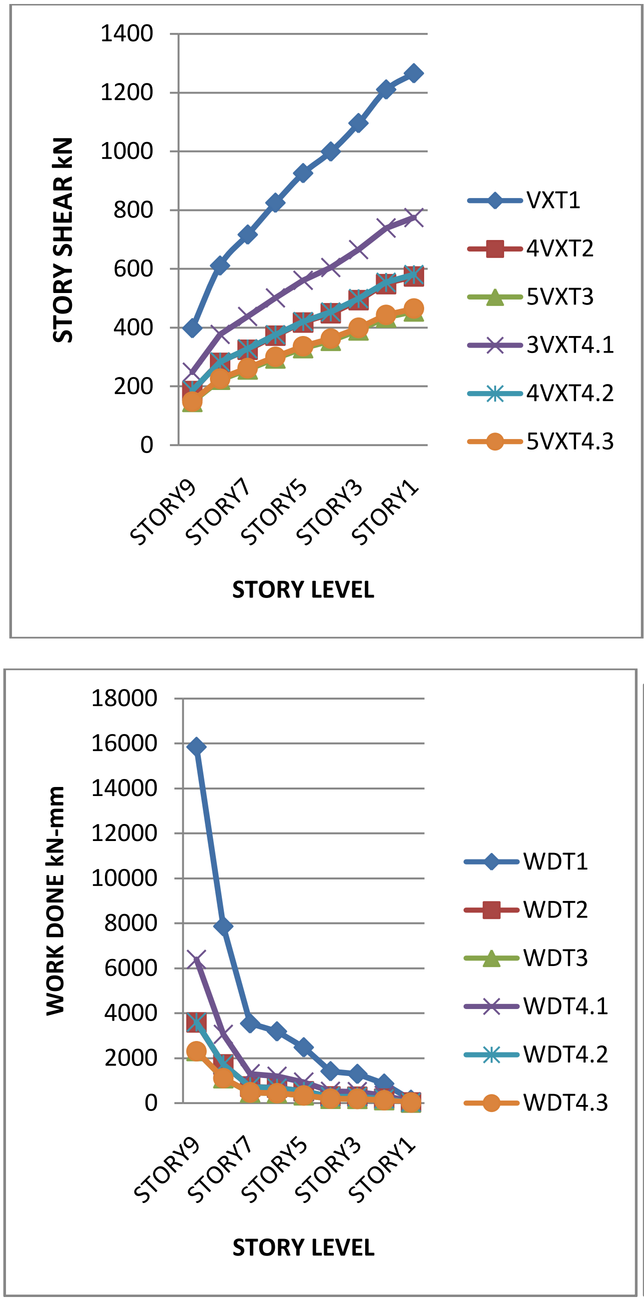
4.2.1 Comparison of Basic Model with Combined Model -Type4











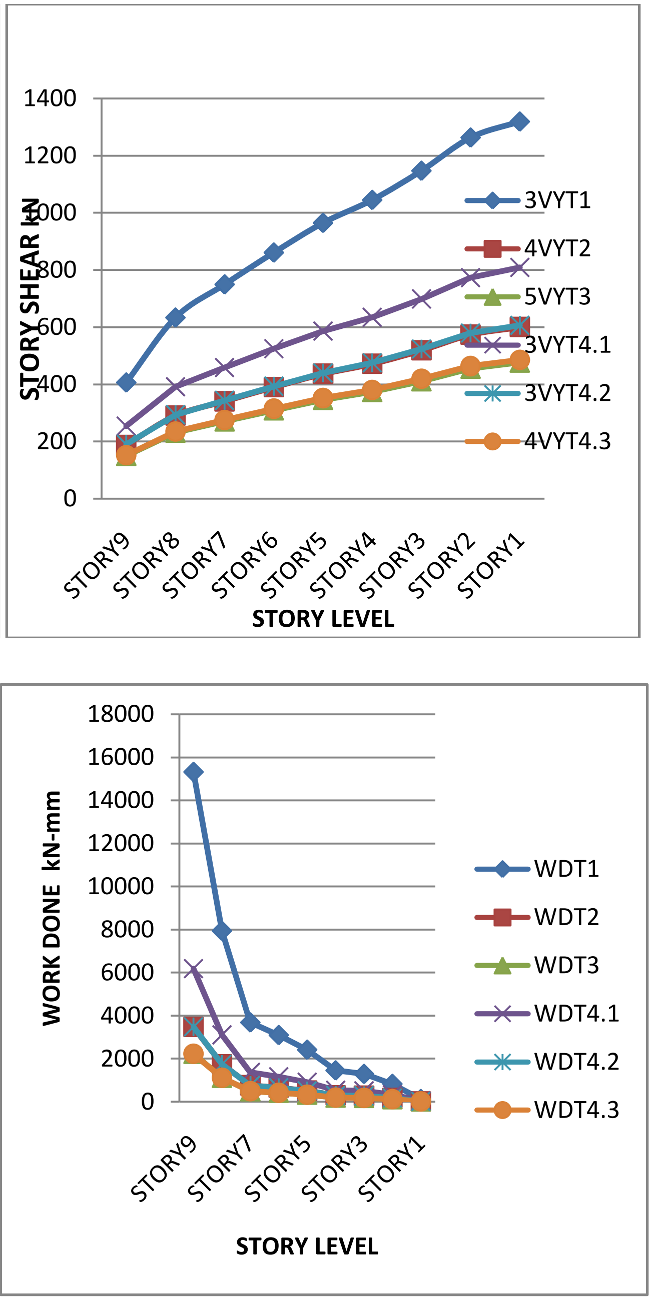


Chart 1- EARTQUAKE IN X-DIRECTION

Chart 2- EARTQUAKE IN Y-DIRECTION

4.2.1.1 Base Shear, Displacement and Work done

Table 3.2.1 Base shear, displacement and work done

KIND OF RESPONSE OF STRUCTURE IN X DIRECTION	R VALUUE	BASIC MODEL	COMBINED MODEL	REDUCTION(%)
	3	39.7957	25.6995	35.42141488
DISPLACEMENT(MM)	4	19.4271	19.2747	0.784471177
	5	15.6773	15.4197	1.643140082

	3	15836.3	6384.013	59.6874711
Work Done KN/mm2	4	3582.163	3591.069	-0.00248
	5	2306.915	2298.152	-0.00379
KIND OF RESPONSE OF STRUCTURE IN Y-DIRECTION	R VALUUE	BASIC MODEL	COMBINED MODEL	AVEARGE REDUCTION
	3	37.6768	24.3573	35.3519938
DISPLACEMENT(MM)	4	18.4339	18.268	0.008
	5	14.8885	14.6144	0.018
	3	15315.24	6186.511	59.6055236
Work Done KN/mm2	4	3474.421	3479.871	-0.001566
	5	2239.379	2227.088	-0.00379

4.2.1.2 Base Shear

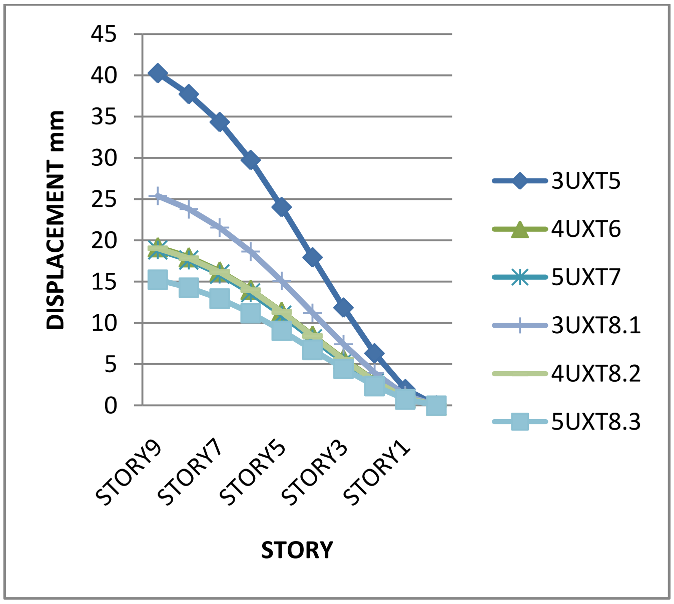
X-Direction

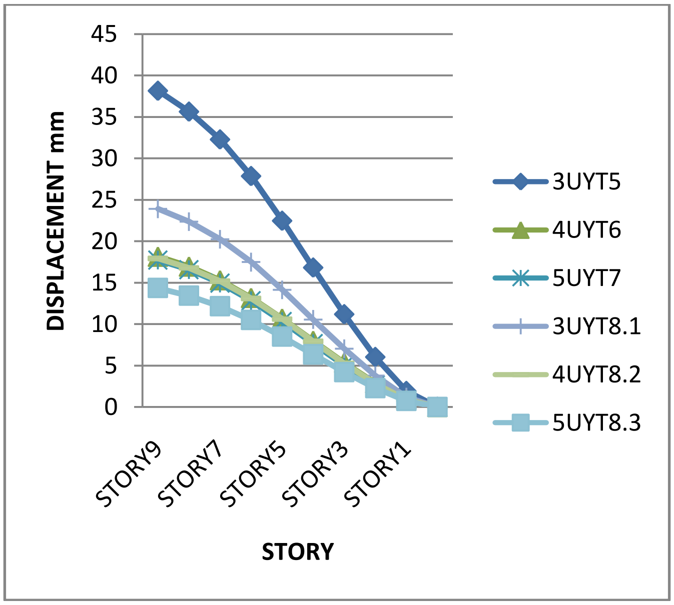
NO	R VALUE	Vs(KN)BASICMODEL	Vs(KN)COMBINED MODEL	REDUCTION(%)
1	3	1264.84	774.34	38.77973113
2	4	574.04	580.76	-1.16855154
3	5	455.15	464.61	-2.077565979

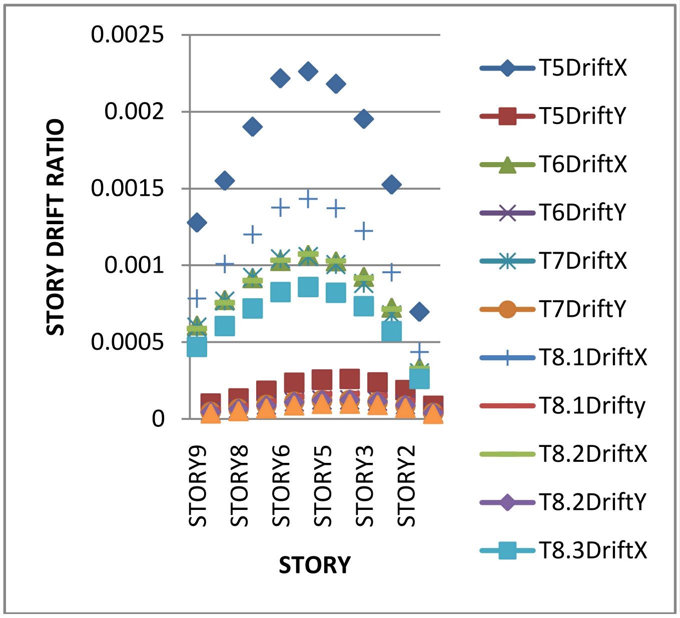
Y-Direction

NO	R VALUE	Vs(KN) BASICMODEL	Vs(KN)COMBINED MODEL	REDUCTION(%)
1	3	1319.41	809.32	38.66
2	4	600.34	606.99	-1.09
3	5	476.31	485.59	-1.91

4.2.2 Type 8



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0.0005
0
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STORY8
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STORY2
STORY
T5DriftX
T5DriftY
T6DriftX
T6DriftY
T7DriftX
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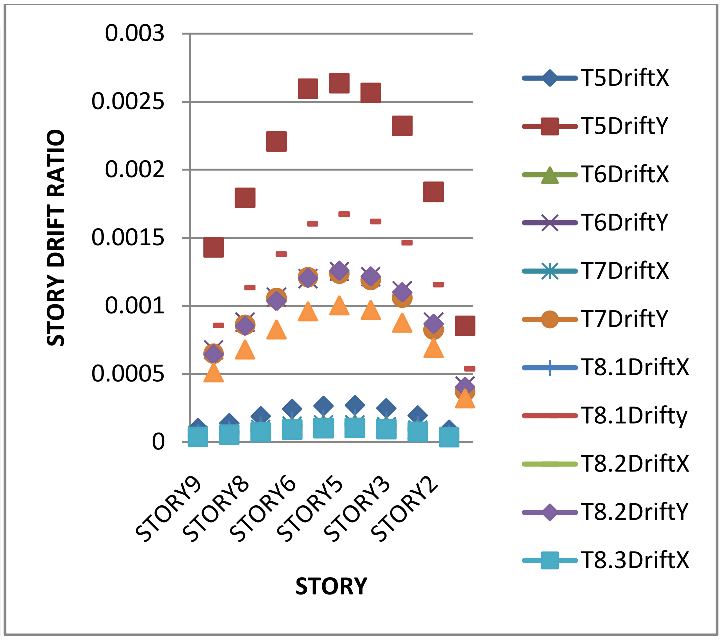
T8.2DriftX
T8.2DriftY
T8.3DriftX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STORY2
STORY
T5DriftX
T5DriftY
T6DriftX
T6DriftY
T7DriftX
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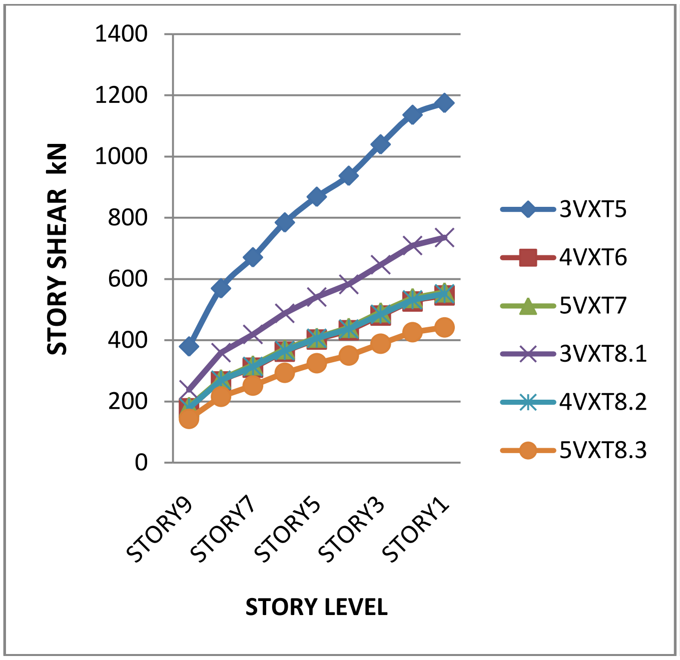
T8.2DriftX
T8.2DriftY
T8.3DriftX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STORY5
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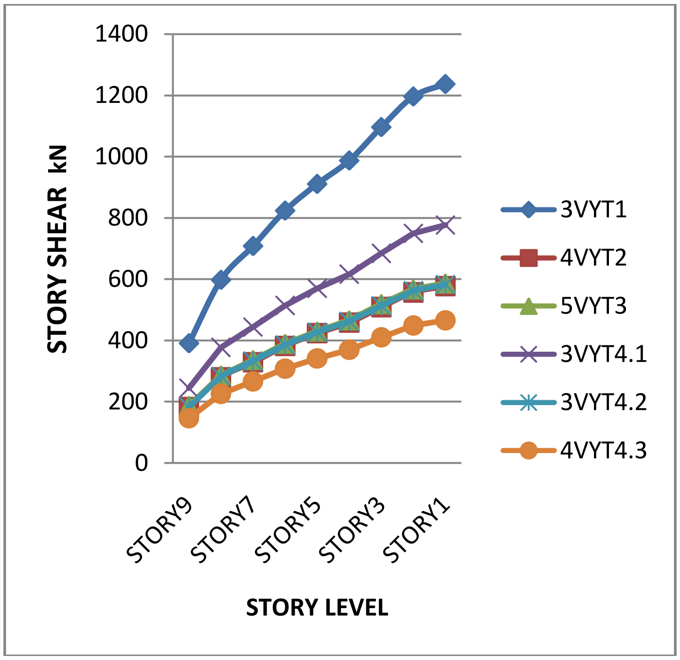
3VXT8.1
4VXT8.2
5VXT8.3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4VYT2
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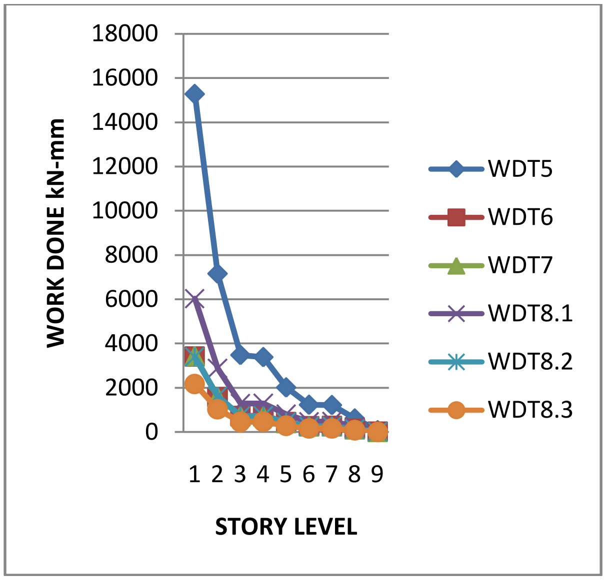
4VYT4.3



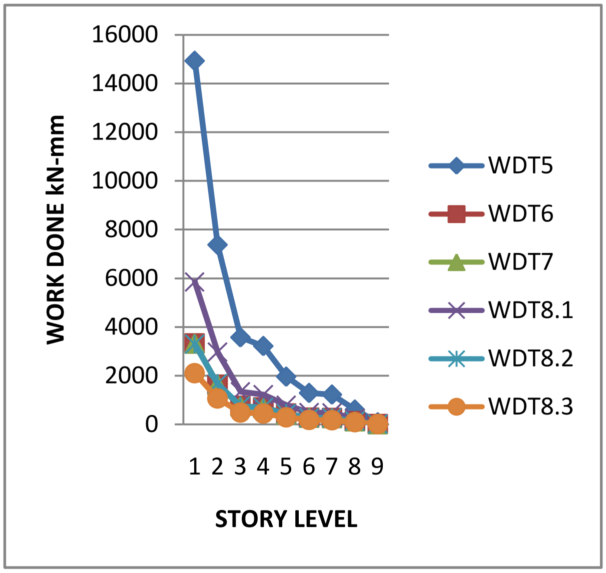


Chart 1.1- EARTQUAKE IN X-DIRECTION

Chart 2.1 - EARTQUAKE IN Y-DIRECTION

4.2.2.1 Base Shear, Displacement and Workdone

Table 3.2.3 Base shear, displacement and workdone

KIND OF RESPONSE OF STRUCTURE IN X DIRECTION	R VALUUE	BASIC MODEL	COMBINED MODEL	AVEARGE REDUCTION
	3	40.252	25.3722	36.966
DISPLACEMENT(MM)	4	19.1996	19.0292	0.008875
	5	18.8359	15.2233	19.1733
	3	15269.6	6030.464	60.50
Work Done KN/mm2	4	3411.193	3392.145	0.00558
	5	3436.987	2170.995	36.83
KIND OF RESPONSE OF STRUCTURE IN Y-DIRECTION	R VALUUE	BASIC MODEL	COMBINED MODEL	AVEARGE REDUCTION
	3	38.1533	23.9095	37.3333
DISPLACEMENT(MM)	4	18.134	17.9321	0.0111
	5	17.7251	14.3457	19.065
	3	14920.61	5853.046	60.77202
Work Done KN/mm2	4	3327.226	3292.334	0.01
	5	3319.734	2107.096	36.52816

4.2.2.2 Base Shear

X-Direction

NO	R VALUE	Vs(KN) BASICMODEL	Vs(KN)COMBINED MODEL	REDUCTION(%)
1	3	1174.46	735.37	37.3865
2	4	546.3	551.53	-0.00948
3	5	556.84	441.22	20.763

Y-Direction

NO	R VALUE	Vs(KN) BASICMODEL	Vs(KN)COMBINED MODEL	REDUCTION(%)
1	3	1236.67	776.62	37.200
2	4	577.09	582.46	-0.00921
3	5	586.54	465.97	20.5561

5. PUSH OVER ANALYSIS

5.1 Types of Models

The models which are used in response spectrum analysis are also used in pushover analysis. The sizes of columns and beams are same as of that models.(3.2.2-3a)

In case of beams optimization, the basic models are named as
- optimized frame for R=3 is Type 1model.
- optimized frame for R=4 is Type 2 model.
- optimized frame for R=5 is Type 3 model.

And combined model is named as
-combined optimized frame for R=3 is Type 4 model.

In case of column optimization, the basic models named as
- optimized frame for R=3 is Type 5 model.
- optimized frame for R=4 is Type 6 model.
- optimized frame for R=5 is Type 7 model.

And combined model is named as
-combined optimized frame for R=3 is Type 8 model.

The steps for creating the types of optimum models are same as explained in 3.

The loads considered are
Dead Load, Live Load, Floor Finish, and Earth Quake Load
All models consist of these loads. They are explained in detail in chapter 3(3.2.3).Along with this pushover is also considered.
Pushover Analysis Data

Hinge assignment
For beam default M3 hinges and for column default P-M-M hinges are assign the default hinge properties available with the software. Default hinge properties are as per ATC-40 and FEMA 273.
Beams > default M3=0
default M3=1
Columns> default P-M-M =0
default P-M-M =1

Static non linear data for PUSH1
DL=Dead load factor 1
LL=Live load factor 0.5
FF=Floor finish factor 1
Static non linear data for PUSH2
EQX= -1

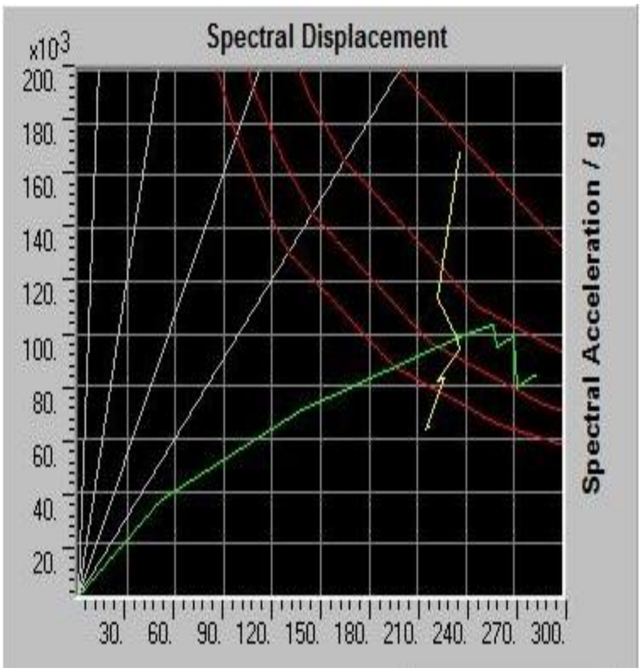
6. STATIC LOAD ASSIGNMENT

RESULTS

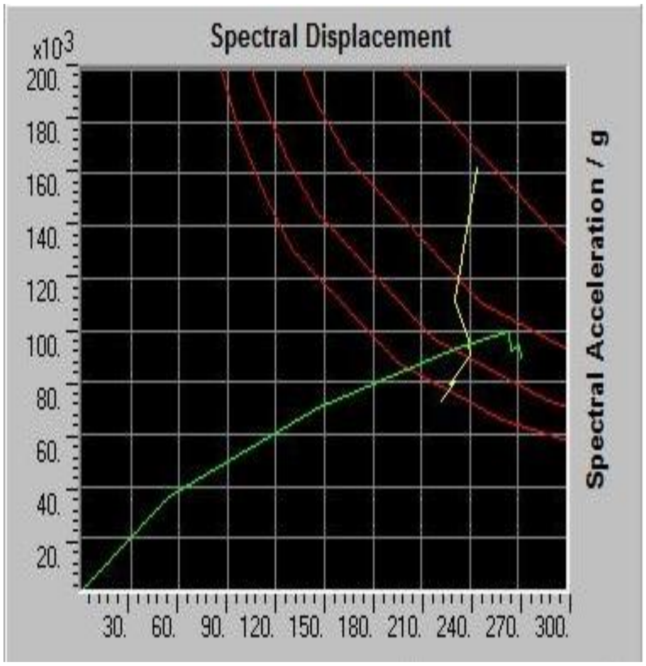
COMPARISION OF BASIC MODEL WITH COMBINED MODEL

-TYPE-4

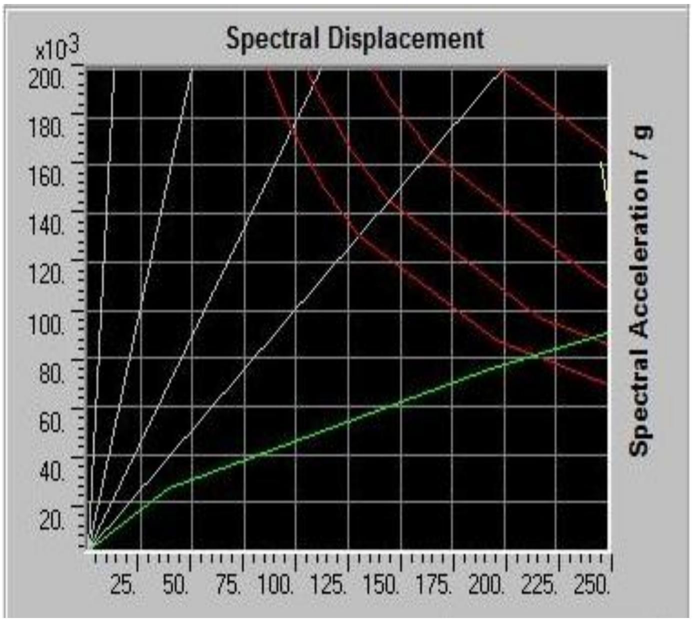
CAPACITY SPECTRUM



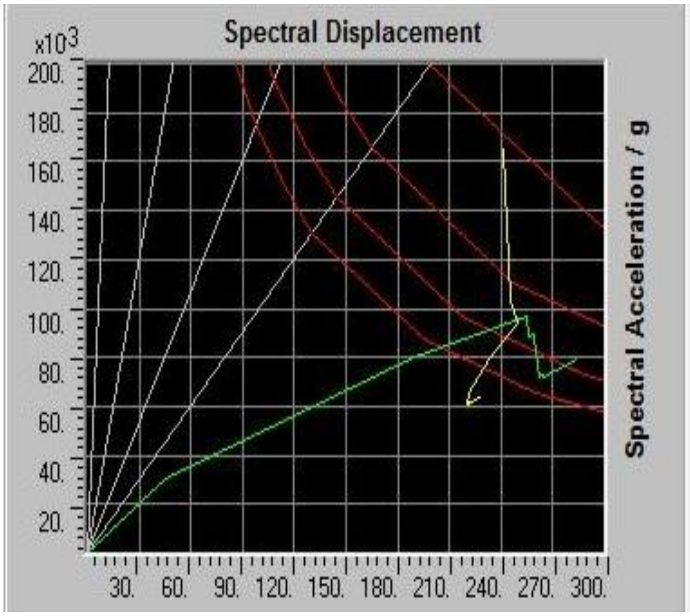
TYPE-1 MODEL



TYPE-2 MODEL

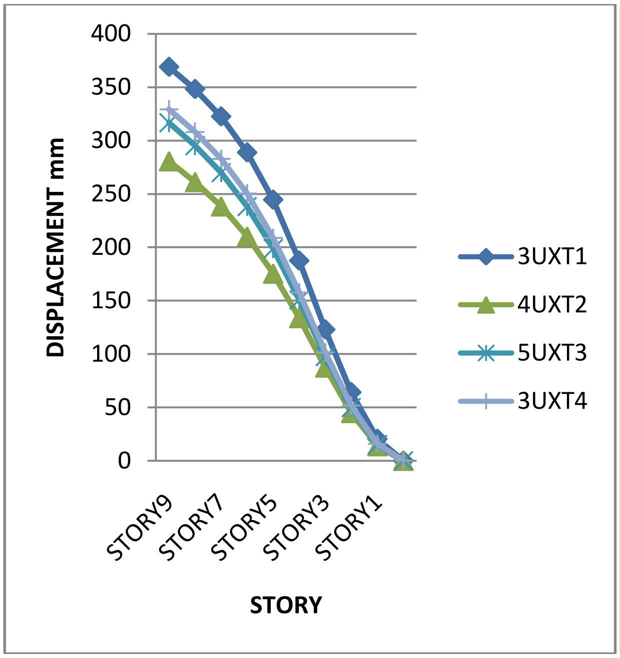


TYPE-3 MODEL



TYPE-4 MODEL

Displacements, Story drift ratio, Story shear & Work done



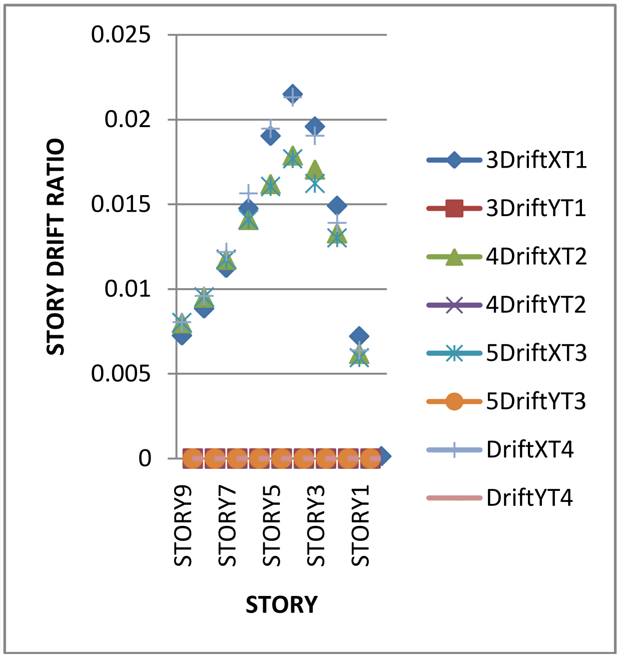
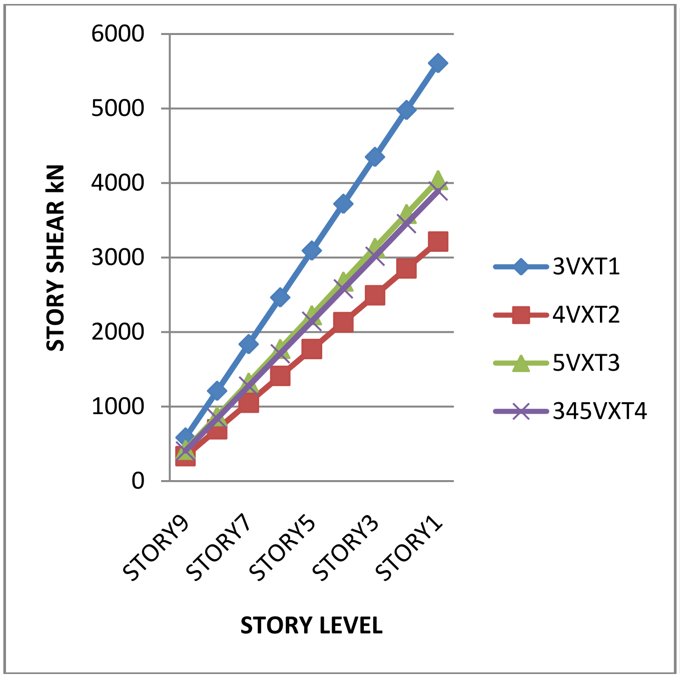


Chart 4.1

Chart 4.2



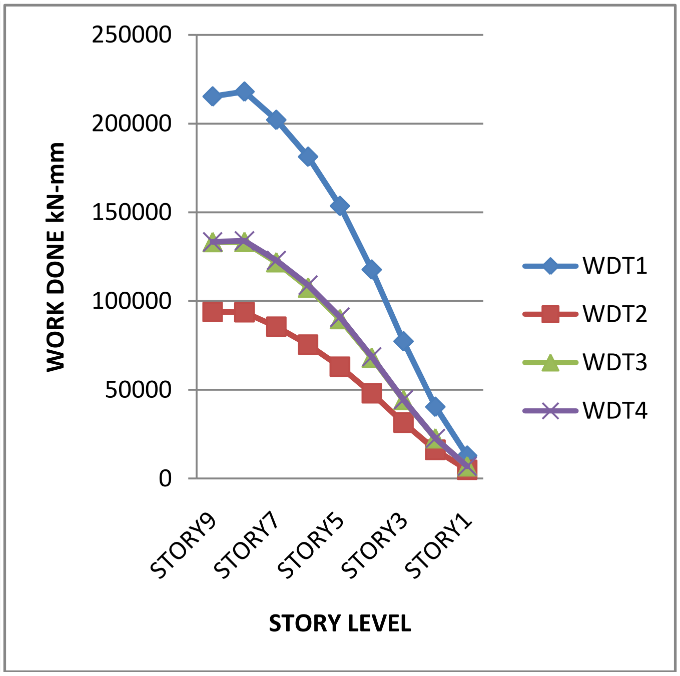
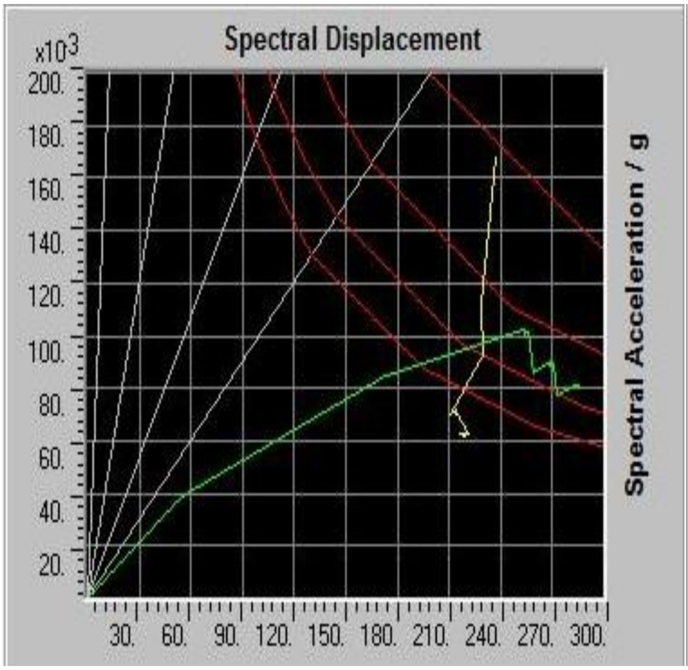


Chart 4.3

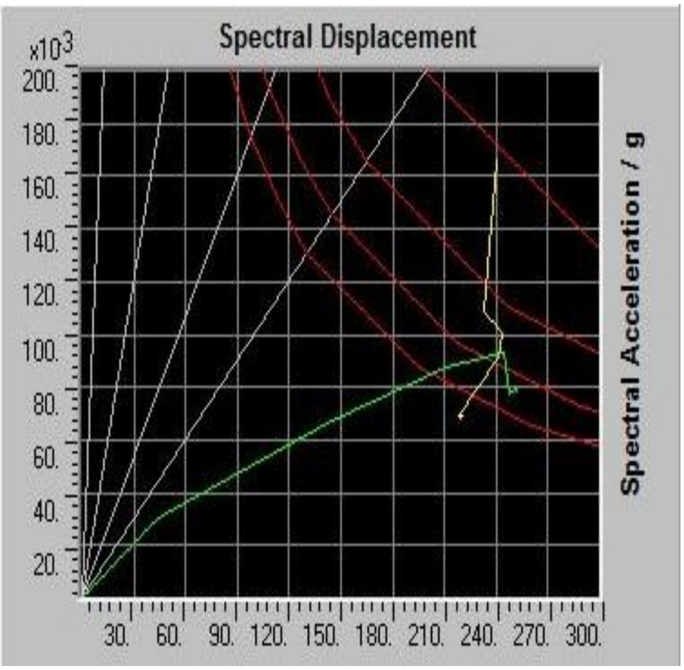
Chart 4.4

-TYPE8

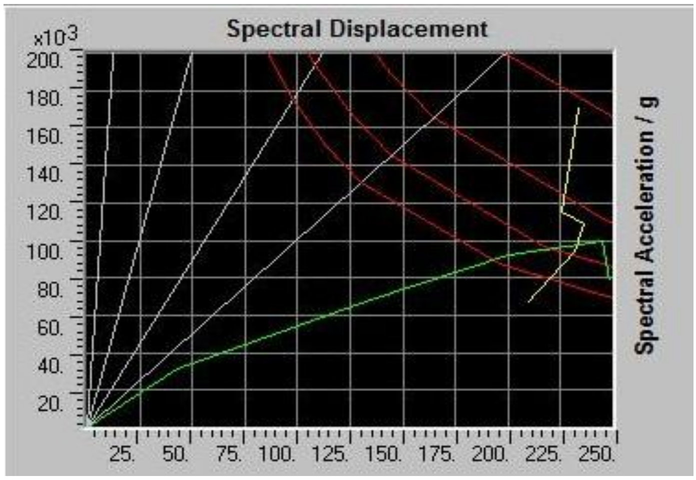
CAPACITY SPECTRUM



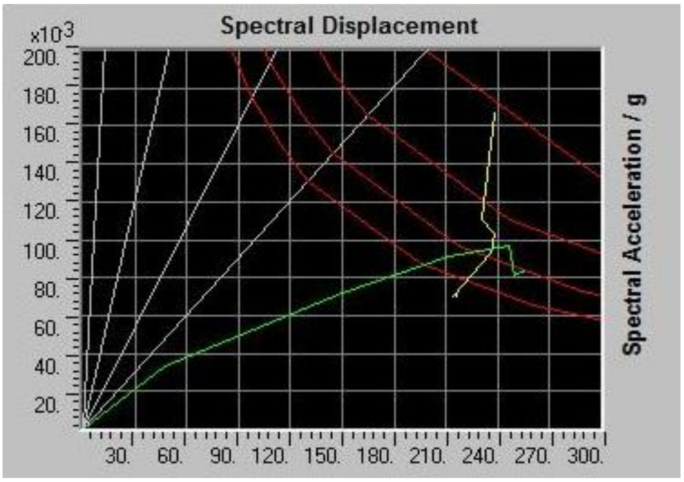
TYPE-1 MODEL



TYPE-2 MODEL



TYPE-3 MODEL



TYPE-4 MODEL

Displacements, Story drift ratio, Story shear & Work done

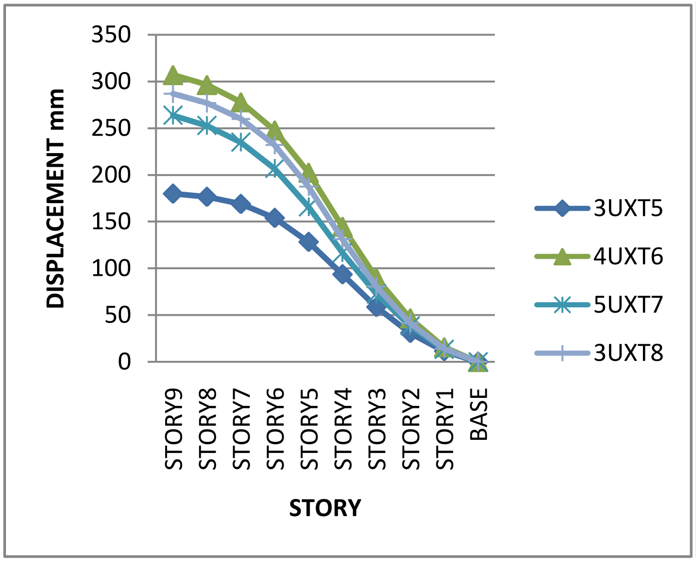


Chart 4.5

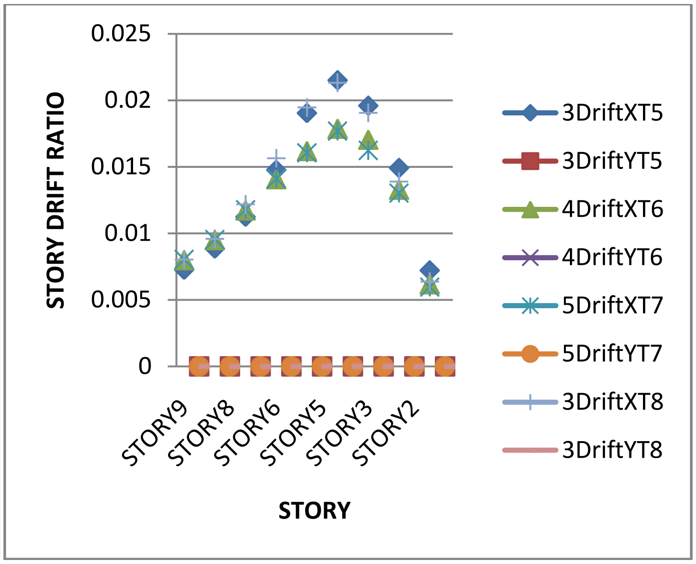


Chart 4.6

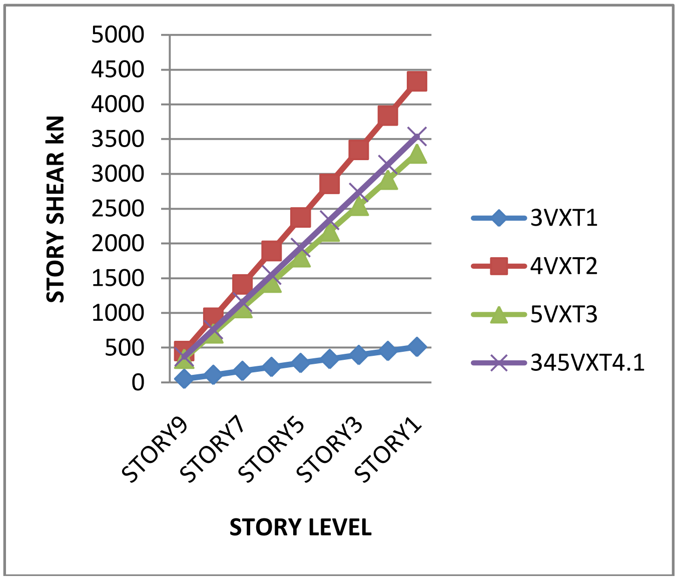


Chart 4.7

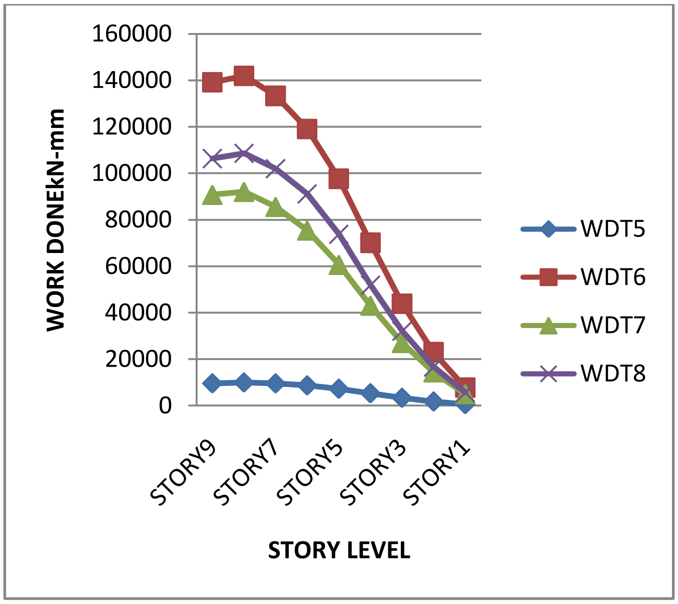


Chart 4.8

5 EXPENDABLE TOP STOREY (ETS)

As we know that, most of the structures undergo yielding during strong ground motions. This means that structures undergo nonlinear deformations during earthquakes. In this paper, the possibilities of absorber behavior have been explored for yielding structures subjected to earthquake ground motions. A nine-storeyed, structure has been chosen for the purposes of this study. The objective of the investigation is to find the circumstances under which the storey of the structure could absorb a major portion of the energy input, thus reducing the response levels of the lower storey. If such a behavior is feasible, one can conceive of a structure whose top storey is permitted and designed to undergo large inelastic deformations, while reducing damage in the lower stories. Such a design approach may well be termed as the 'expendable top storey'(ETS) concept. It may well be remarked that such a concept juxtaposes the often mentioned 'soft first-storey' concept. The soft first-storey approach has been commented upon widely for the questions it poses about the stability and safety of the design. It looks as though the 'expendable top storey' concept is more favourably placed regarding the overall stability and safety of the structure. The top storey would then behave like a mechanical fuse undergoing large deformations. However, the problem of designing the top storey to withstand the large ductility demand placed on it needs to be looked into. The fact that the absorber system has a lower mass compared to that of the main structure probably favours the practical design of the top storey. The concept was first proposed in an earlier research (Jagadish and Raghu Prasad).

In general, the top mass experiences much larger ductilities than the lower mass. It is also seen that as the strength of the upper storey is reduced, its maximum displacement increases in proportion. That is completely in contrast with the response characteristics of the lower stories.

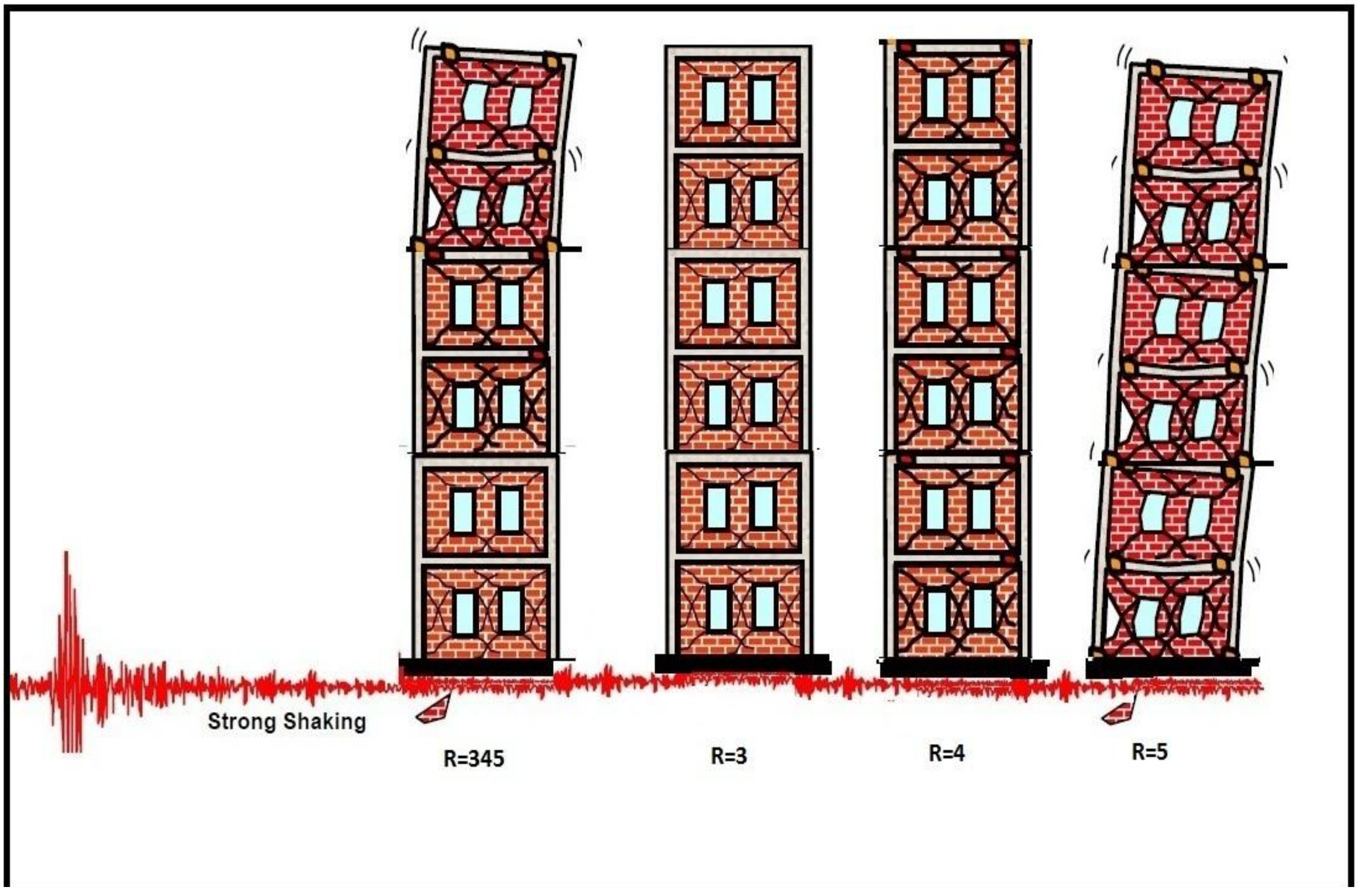


Fig 5.1 Expendable top storey

STRUCTURAL MODEL

For this study, building with nine storey is considered. The dimension in plan of the building are 48mX20m. The structural models have the same story height of 3m. and have a uniform mass distribution over their height.Building plan is shown is 3.2a

The 3D model shown in fig 3.2b and fig 3.2c shows the building elevation. The same optimized sections obtained in Response Spectrum analysis are also used here. The steps for creating optimum models are the same as explained in 3.2.1.

The sizes for bottom 4 stories are obtained from type1(R=3) model, next 4 stories are obtained from type 2(R=4) and top most storey is from the type 3(R=5). Now this structure is subjected to response spectrum analysis and designed. The failing beams and columns are optimized. This model is used for push over analysis.

STATIC LOAD ASSIGNMENT

The loads considered are

Dead Load, Live Load, Floor Finish, and Earth Quake Load. All models consist of these loads. They are explained in detail in chapter 3(3.2.3).Along with this pushover is also considered.

Pushover Analysis Data

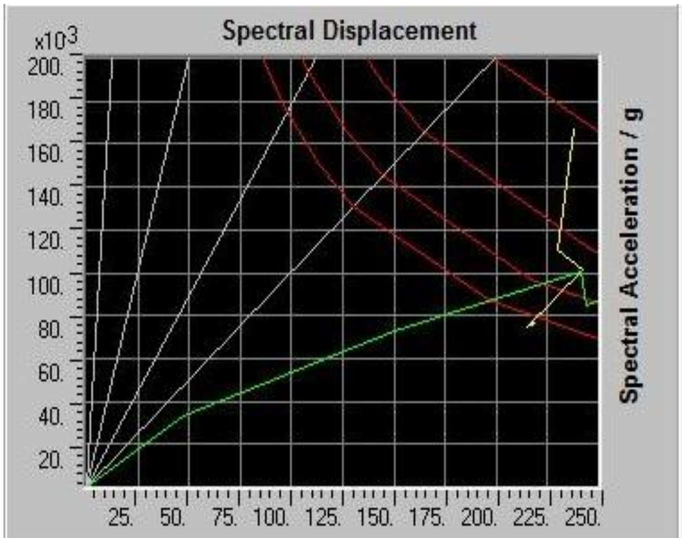
Hinge assignment

For beam default M3 hinges and for column default P-M-M hinges are assign the default hinge properties available with the software. Default hinge properties are as per ATC-40 and FEMA 273.

Beams > default M3=0
default M3=1
Columns> default P-M-M =0
default P-M-M =1
Static non linear data for PUSH1

RESULTS

DL=Dead load factor 1
LL=Live load factor 0.5
FF=Floor finish factor 1
Static non linear data for PUSH2
EQX= -1



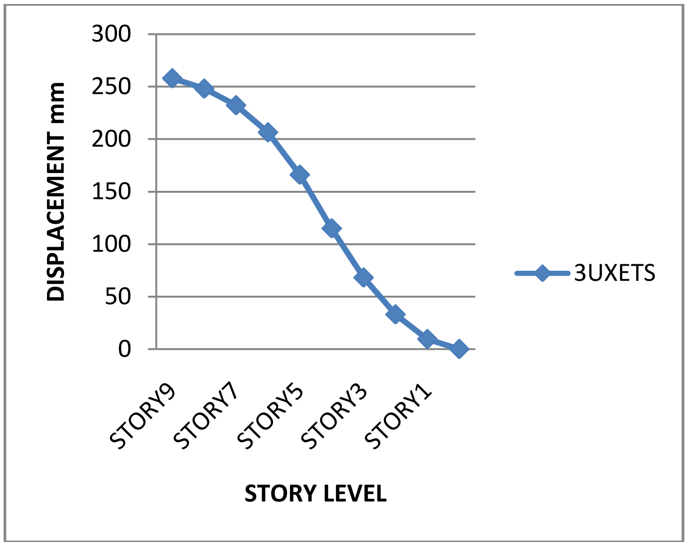
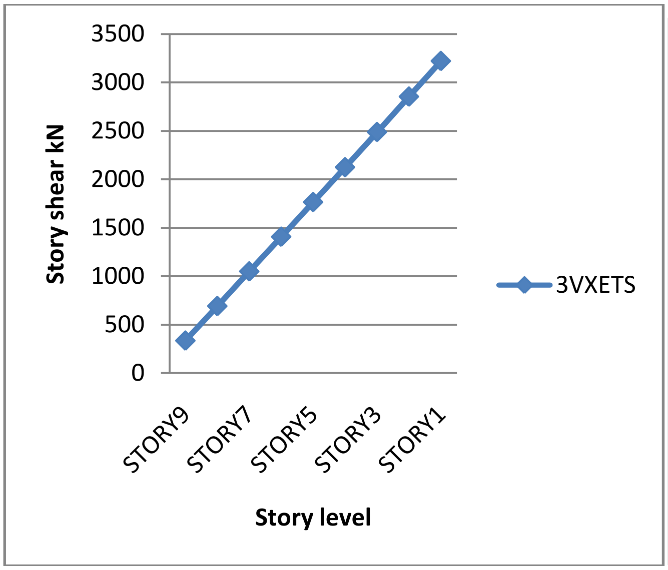


CHART 6.1



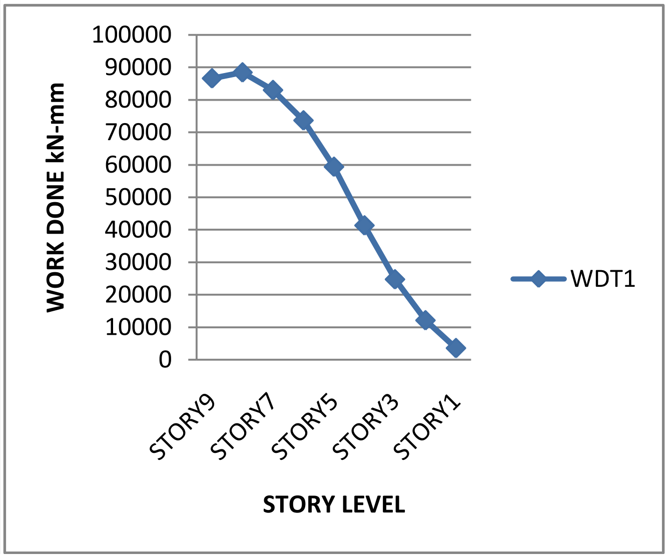


Chart 6.2

Chart 6.3

DISCUSSIONS

Capacity spectrum

The capacity spectrum curve of the models are shown in Fig. Red curve in Fig shows the response spectrum curve for various damping values. The pushover analysis was including number of steps. It has been observed that, on subsequent push to building, hinges started forming in beams first. Initially hinges were in B-IO stage and subsequently proceeding to IO-LS , LS-CP, CP-C, C-D,and D-E stage.

Displacement (mm)

As it can be seen from figures, the displacement of the stories of structures is reduced by developing a combined model. Furthermore the graph shows that there has been steady increase in the amount of displacement of stories over the height.

According to this concept, the reduction of displacement of stories is due to increase of stiffness of structure as well as decrease of velocity and acceleration of structure. In other words by creating the combined model, the response of structure such as velocity and acceleration can be reduced and it is the cause of reduction of displacement.

Story Drift Ratio

It is the displacement of one level relative to the other level above or below.
The building may collapse due to different response quantities. For eg., at local levels such as strains, curvatures, rotations and at global levels such as interior story drifts.

Individual stories may exhibit excessive lateral displacement. Therefore it can be concluded that by decreasing the story drifts of structure, the probability of collapse of the building can be reduced. To do that, as it is mentioned, combined model can play a significant rule to reduce response of structure

Story Shear (kN)

It is the sum of design lateral forces at all levels above the storey under consideration.
As it can be seen from figures, the maximum top story shear and minimum top story shear. Furthermore the graph shows that there has been steady decreasing in the amount of story shear over the height. In all models, the story shear at the base is more and at the top stories shear is less.

Work Done (kN-mm)

Work done is obtained as a product of lateral force of each storey and the corresponding displacement.
In the figures, the maximum workdone and minimum workdone is shown. The curves shown in figure , fallows the patterns of mode shape. It is seen that the workdone is maximum at the top 3 stories and has much higher value when compared to bottom stories. This is due to the higher R value at these stories. This implies that there is increased energy absorption at the top stories.

6 RECOMMENDATION AND CONCLUSIONS

Overview

The present study was designed to determine the optimum earthquake response of tall building by combining the different structural element sections obtained from different values of R. The main objectives of the study are stated in the chapter one. The purpose of the study is to investigate whether the combined model provides adequate energy dissipation.

Conclusions

The following conclusions are drawn from the present study
RESPONSE SPECTRUM ANALYSIS

The results show that the combined model with beams selected from the frames designed for R=3,4 & 5 for lower, middle & upper stories respectively exhibit a very stiff response for R=3, while for R=4 & 5, the decrease in the displacements is not significant.

Even the drift ratios are relatively less in the combined model for R=3.

In the combined models with columns chosen from the basic models designed for R=3,4&5 for the lower, middle & upper stories respectively much lower displacements and storey drifts for R=3, again are observed and not so much for R=4&5.

Therefore in general, it can be said that the combined models defined in present work can be considered as optimum in lower zones where we consider R=3 and not so much for higher zones where R=4&5

PUSHOVER ANALYSIS
Pushover analysis has given an idea how the combined model behaves in the inelastic regime. It is seen that the ductility demand is reduced in the combined model.

EXPENDABLE TOP STORY
It is seen that by a proper design of the top storey, it is possible to absorb the energy in the top storey, thus leaving the bottom stories to be within the elastic limits.

Recommendations for further work

It is recommended that further research be undertaken in following areas

1. Determining the optimum earthquake response of tall building structures by combining both optimized columns and beams.
2. Determining the optimum earthquake response of tall building structures by doing non linear dynamic analysis to assess the exact performance of combined model.
3. The ductilities obtained in the present work are the global values and thus may not help much in designing the members. Therefore a detailed analysis has to be performed to obtain the members ductilities.

Application

The method of combining the various structural elements from the basic models designed with different values of R is a simple method to obtain a frame which could be optimum, resulting in lower displacement and storey shears.

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