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PROJECTION EFFECT ON SEISMIC RESPONSE OF SQUARE SYMMETRIC STRUCTURE (Using waffle slab system)

Suvradeep Saha

M Tech scholar, Dept of CIVIL & STRUCTURAL Engineering, NIT JIS Group (MAKAUT WB), formerly known as WBUT , West Bengal, INDIA

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Abstract - *The behaviour of a building during earthquake depends critically on the geometry of the structure. Structures with large hanging or projection parts are very vulnerable to seismic effects. In practical problem the prediction of such effects is difficult to represent because of the various parameters involved which can affected the behaviour of a structure individually or as a whole .This research work attempts to create an similar virtual environment with the help of ETABS software & verify the effects of different forces on three different projection type models keeping the projection area on each floor same but distribution & geometric orientation of projection different. Initially a square symmetric five-storey structure with waffle slab system is modeled ,then three different types of projection is applied on each sides and the models are analyzed in ETABS .Post analysis of the results are compared and the difference in the response parameters & the behaviour of three different specimens have been shown graphically*

***Key Words*: Dynamic analysis, Storey Deflection, Storey Shear, Base Shear, Response Spectrum Analysis, Modal Analysis, Time period, Projection, Waffle slab.**

INTRODUCTION

During earthquakes structures with large projections or hanging floors can face severe damage due to the ground vibrations & lateral seismic forces. Even if the area of projection is same the geometric orientation of its mass distribution can influence the dynamic response of the structure in different ways. Generally it is difficult to predict the behaviour of structure accurately because of the tedious mathematical calculations involved. Under different conditions various parameters like geographical locations, soil profiles, seismic zone factors can affect the structure in different ways, combining them together is not always easy. In modern days different computer aided analysis and design software are used for artificial modeling of structures and analysis is performed on the basis of assumed force parameters and load cases according to the native codal provisions. With the help of inbuilt programs various related parameters are combined together to obtain the analysis results much faster and more accurately. This is not only time saving but also helps us understand the nature of seismic response and it's probable effect on structure virtually. In the present paper an attempt has been made to create such a virtual situation with the help of ETABS software & the response of the structure is computed and compared for three different types of projection having same area but different geometric orientation of projection .Initially a square symmetric structural model is developed which contains a waffle slab system with circular column on which different projection combinations are applied to predict the difference in their behavior due to their individual geometry. In the current study response spectrum analysis and equivalent static force analysis is used for finding the results.

Objectives

Virtual or prototype modeling of a square symmetric structure with an waffle slab system containing circular columns

* Applying 3 different types of projection [H, Plus, H-plus] combinations on the four sides of square symmetric structure.

*Perform Dynamic & Modal analysis and to obtain Seismic performances of different shape of structures and to evaluate lateral forces, overturning moment, deflections and storey drift.

Definitions & Keywords

Storey:

When the multi-story building or the residential building is constructed in that when the floor to floor gap will be there that is the story.

Storey Shear:

We will calculate all the lateral loads at each floor of the Building.

Story Drift:

Defined as the difference in lateral deflection between two adjacent stories. During an earthquake, large lateral forces can be imposed on structures; Lateral deflection and drift have three primary effects on a structure; the movement can affect the structural elements (such as beams and columns);

the movements can affect non-structural elements (such as the windows and cladding); and the movements can affect adjacent structures. Without proper consideration during the design process, large deflections and drifts can have adverse effects on structural elements, nonstructural elements, and adjacent structures

Center of mass

It is the unique point at the center of a distribution of mass in space that has the property that the weighted position vectors relative to this point sum to zero. In analogy to statistics, the center of mass is the mean location of a distribution of mass in space. According to IS: 1893-2002, center of mass is the point through which resultant of the masses of a system acts. This point corresponds to center of gravity of masses of system. Earthquake induced lateral force on the floor is proportional to mass. Hence, resultant of this force passes through the center of mass of the floor.

Center of rigidity

It is the stiffness centroid within a floor-diaphragm plan. When the center of rigidity is subjected to lateral loading, the floor diaphragm will experience only translational displacement. Other levels are free to translate and rotate since behavior is coupled both in plan and along height. As a function of structural properties, center of rigidity is independent of loading. According to IS1893-2002, Centre of stiffness, for a one story building can be defined as the point on the floor through which lateral force should pass in order that floor undergoes only rigid body translation, with no rigid body rotation.

ANALYSIS METHOD

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. There are different types of earthquake analysis methods. Some of them used in the project are:

Response Spectrum Analysis

This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except for very simple or very complex structures. The structural response can be defined as a combination of many modes. Computer analysis can be used to determine these modes for a structure. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and the modal mass, and then they are combined to estimate the total response of the structure. In this the magnitude of forces in all directions is calculated and then effects on the building are observed.

Equivalent static force analysis:

The equivalent static force analysis for an earthquake is a exceptional concept which is used in earthquake resistant design of structure. This concept is useful since it converts a dynamic analysis into a partly static & dynamic analysis to evaluate the maximum displacements produced in the structure because of earthquake due to ground motion. For earthquake resistant design of structures, only these maximum displacements are of interest, but not the time history of stresses. Equivalent lateral force for an earthquake is defined as a set of static lateral forces which produces the similar peak responses of the structure as that have been produced in the dynamic analysis of the building under the similar ground motion. This concept has drawback since it uses only a single mode of vibration of the structure.

Methodology

The method of analysis used for the present study is

1. Response spectrum method
2 Modal analysis

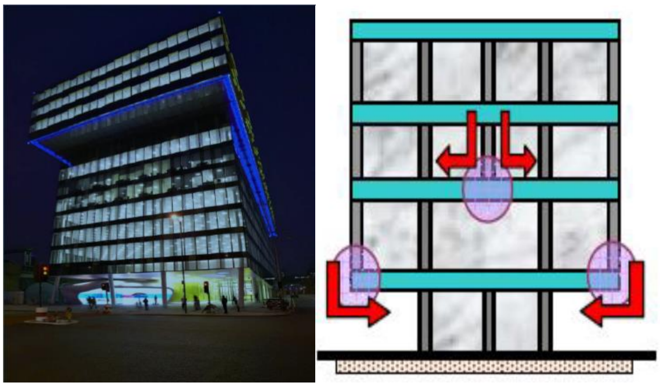
Concept of Projection or floating structures

As the name indicates they are structures with hanging or projection parts which do not transfer the loads to the ground linearly. These kinds of structures comprises of floating floors, beams and columns. In case of heavy load carrying structures of large span structures special type of Load transfer mechanism can be used which provides better stability to the structure.

Plus shape projection building **H-shape projection building**

H-shape projection building

In conventional ways cantilever beams are used to transfer the slab loads, but in modern days flat slab or waffle slab are also used to resists heavy loads. In this study two such slab system have been used to optimize the load carrying capacity and compare the result of the two systems. These are flat slab and waffle system.



Floating or hanging structure

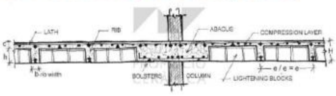
Floating or hanging structure

Flat slab/plate is most widely used systems in reinforced concrete construction in offices, residential and industrial buildings in many parts of the world. This system having advantages that it reduces cost of form work and construction time, easy installation and requires the least story height. The flat plate system, in which columns directly support floor slabs without beams. Shear walls are relatively thin, vertically deep reinforced column used in structure which provide stability to structures from lateral loads like wind, seismic loads

Waffle system

A waffle slab is a type of building material that has two-directional reinforcement on the outside of the material, giving it the shape of the pockets on a waffle. This type of reinforcement is common on concrete, wood and metal construction. A waffle slab gives a substance significantly more structural stability without using a lot of additional material. This makes a waffle slab perfect for large flat areas like foundations or floors.

Waffle slab system



MATERIAL SPECIFICATIONS & PROBLEM FORMULATION

MATERIAL SPECIFICATIONS

Grade of Concrete, M30 f_{ck}= 30N/mm^2
Grade of Steel fy= 415N/mm2
Density of Concrete ϒc= 25kN/m3
Density of Brick walls considered ϒ brick= 20kN/m3

MATERIAL SPECIFICATIONS

Slab Waffle shell type

Drop panel 250 mm

Columns circular 400 mm at top

Columns circular 500 mm at the base

Grade of steel: Fe415

Seismic Load: The different seismic parameters are taken as follows, IS 1893(Part-1):2002.

Seismic zone: II

Soil type: II.

Importance factor: 1.

Response reduction factor: 5.

Damping: 5%.

Z: 0.36

All the structures taken for study are symmetric along X & Y axis thus the response obtained for X direction is assumed to be identical in nature

SOFTWARE USED

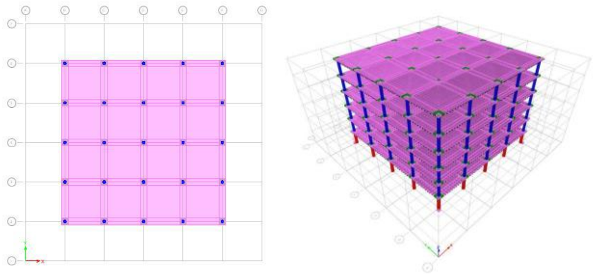
- ETABS 2016

PROBLEM FORMULATON

A square symmetric 5 storey structure is taken as an initial model on which three types of projection has been applied separately .The three structures are named as PLUS , H & H-PLUS on the basis of their projection type. All the models have been generated with the help of ETABS 2016 software and later Response spectrum analysis is performed. In the initial square model 400 mm thick circular columns have used .On the outer part only 500 mm thick circular columns have been used because the outer linings have to bear the extra projection loads along with the interior loads. Dead load of 2kN & Live load of 4 KN has been applied along with earthquake load as Ex & Ey along the X & Y coordinate direction in ETABS software. Loads considered are taken in accordance with the IS-875(Part1, Part2), IS-1893(2002) code and combinations are acc. to IS-875(Part5).

Post analysis of the structure, maximum storey drift, storey overturning moment, storey shear and maximum storey displacement are computed and then compared for all the analyzed cases. Modal analysis is done for 12 preset modes in ETABS.The dimension of the initial square structure is 24m x 24m on 6m x6m grid in E4ABS. The columns are placed at 6m intervals on the grid along with slab drops of 2mx2m on their top with thickness of drop 250mm. The dimension of the waffle slab taken is 100mm thick and overall depth of 350 mm .The lower portion of the slab is made up of waffle pods, which are shell type. The projection in the respective models is highlighted with red & yellow colours .The plus type projection is marked with red colour

& H type with yellow. The inner slab portion is marked with magenta colour.

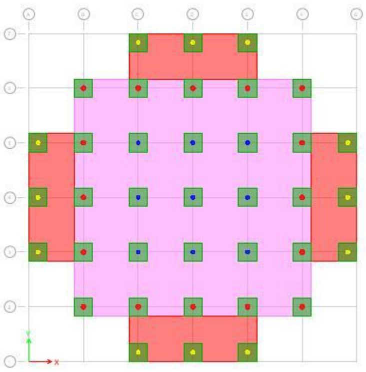


Plan & 3D view of initial square structure without any projection

The three type of projections are explained below:

Plus type projection:

The projection is applied on the middle faces of the square on each of the four sides with dimension of 12m x 6m starting from 1st to 5th storey. On each sides of the square structure there is 1 projection element of 12m x 6m. The projection is equally distributed on each of the four sides of the square structure. The projection on each storey is highlighted by red colour. The projection is uniform throughout the vertical axis and consecutive floors are connected by columns on the same point. Due to this reason vertical load transfer is uniform up to the first floor.



PLAN VIEW OF PLUS TYPE PROJECTION

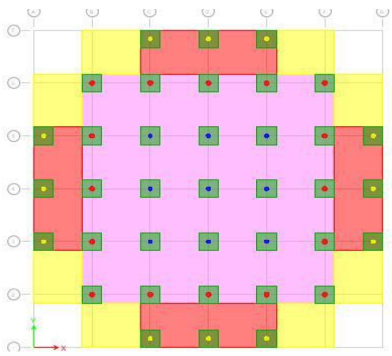
H type projection:

The projection is applied on the corners of the square structure .The dimension of the projection is 6m x 6m on four sides of the square structure. On each sides of the square structure there are 2 projection elements of 6m x 6m. In this type there are total 8 projection units of dimension 6m x 6m distributed on the four sides of the structure. In each face of the square projection units are kept at the corner ends far apart from each other. The projection is uniform throughout the vertical axis. The projection on each storey is highlighted by yellow colour. The projection is uniform throughout the vertical axis and consecutive floors are connected by columns on the same point. Due to this reason vertical load transfer is uniform up to the first floor.

PLAN VIEW OF H TYPE PROJECTION

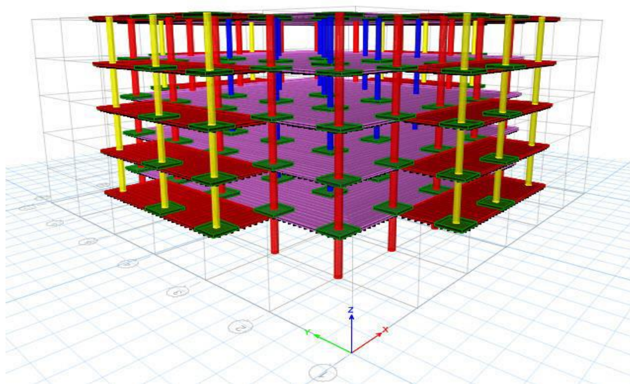
H –I Combined type projection

The vertical projections are alternate i.e.-type in one floor & Plus type on the next. This is a combined type alternate projection where the projection is not uniform on consecutive floors. Due to this projection type loads are not vertically uniform and thus they are not transferred to the lower floors uniformly. The loads on the hanging part are transferred to the adjacent columns

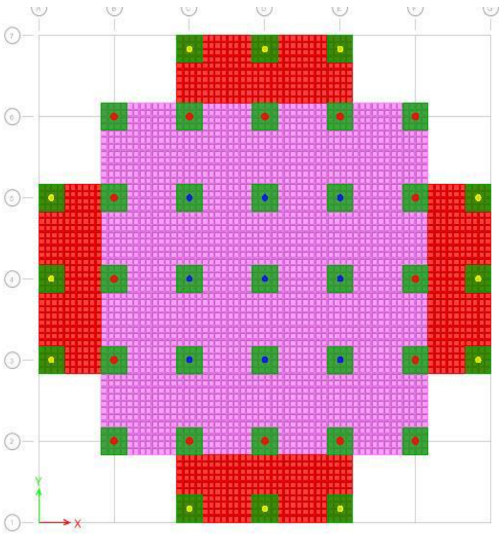


PLAN VIEW OF H-PLUS TYPE PROJECTION

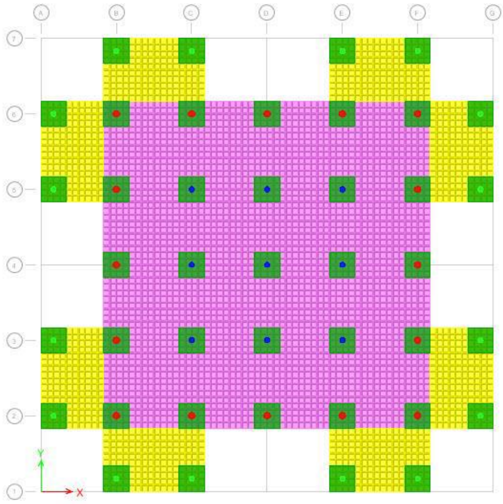
Modeling and Result:
PLUS SHAPE PROJECTED STRUCTURE



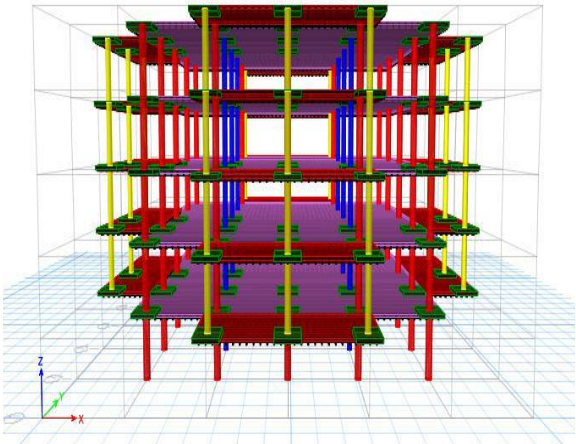
3D view of plus shape structure



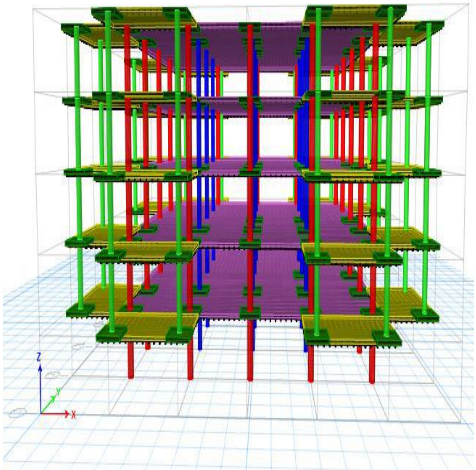
Top view of plus shape structure



Top view of H shape structure

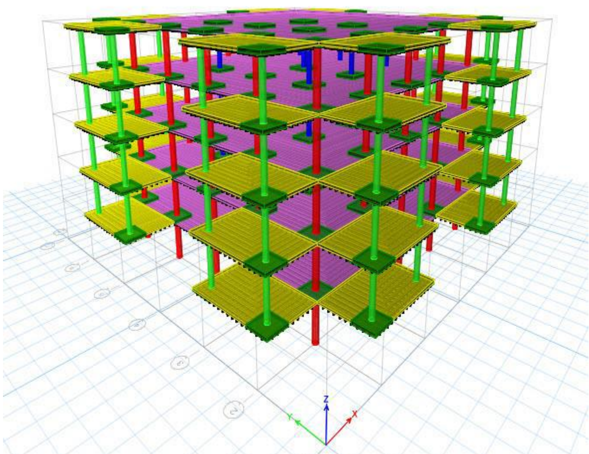


Elevation view of plus shape structure



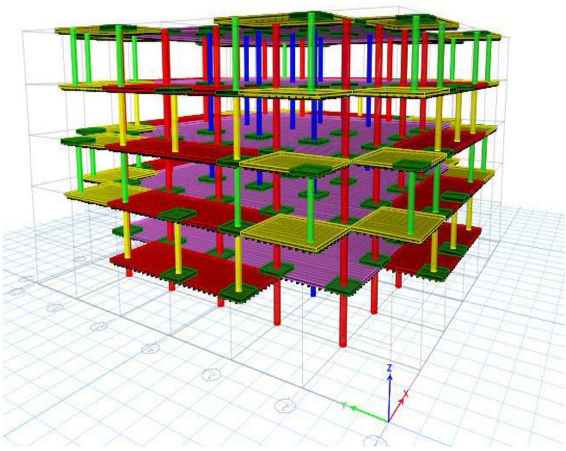
Elevation view of H shape structure

H- SHAPE PROJECTED STRUCTURE

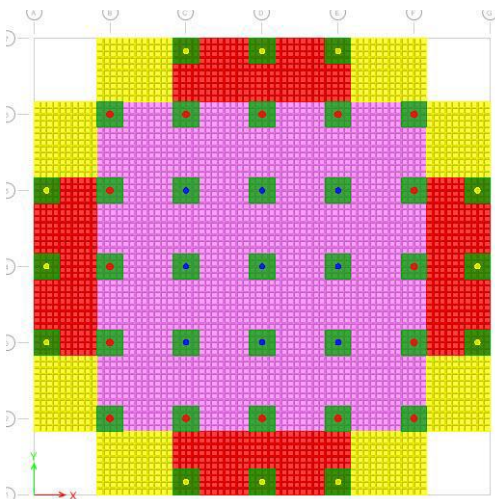


3D view of H shape structure

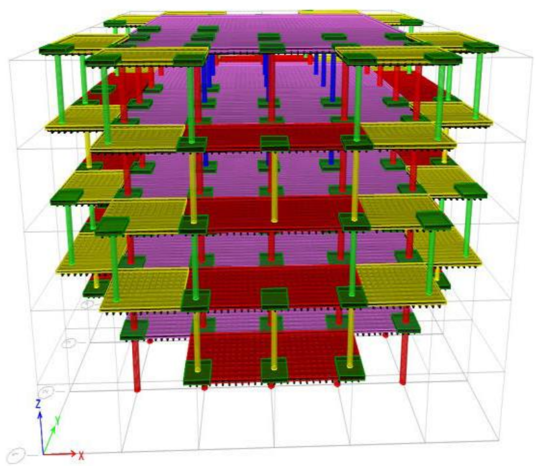
H-PLUS SHAPE PROJECTED STRUCTURE



3D view of H plus shape structure

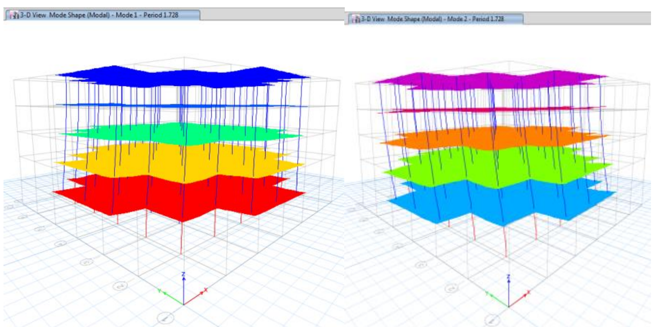


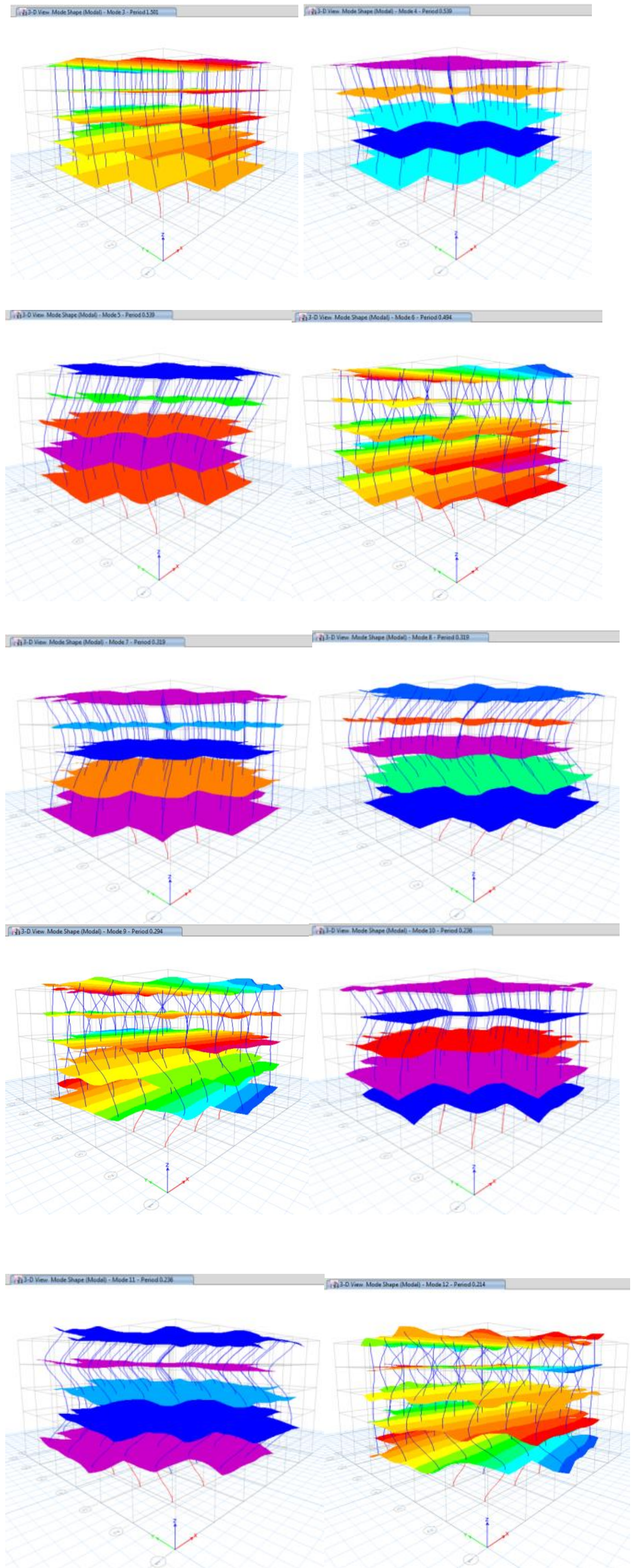
Top view of H-plus shape structure



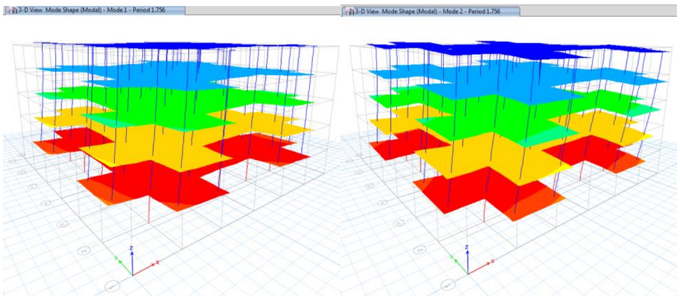
Elevation view of H- plus shape structure

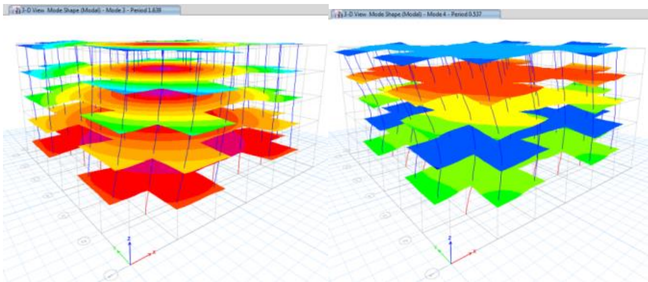
Modal displacement & deformation for PLUS shape structure

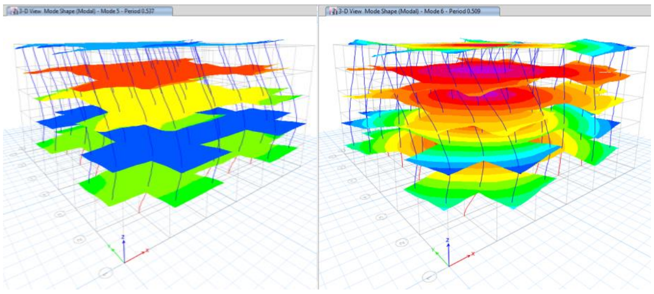


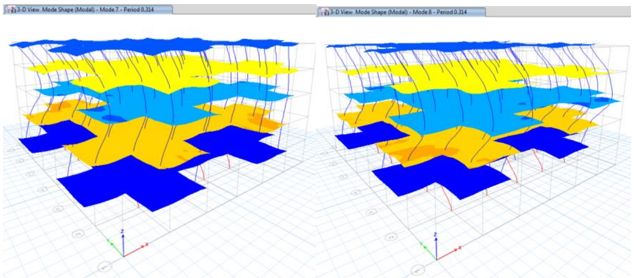


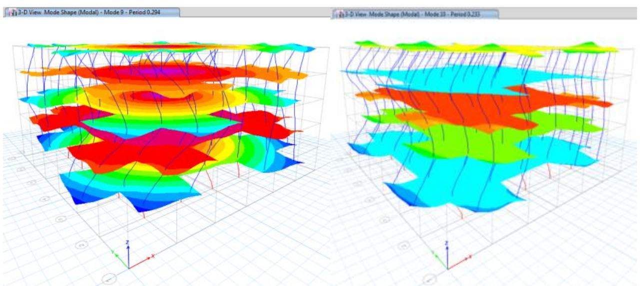
Modal displacement & deformation for H- shape structure

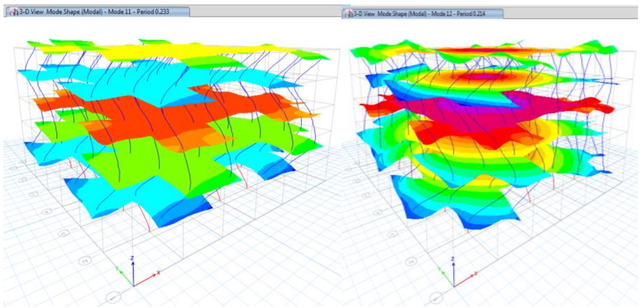




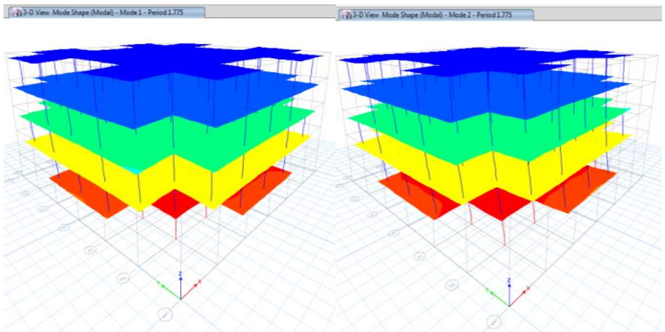


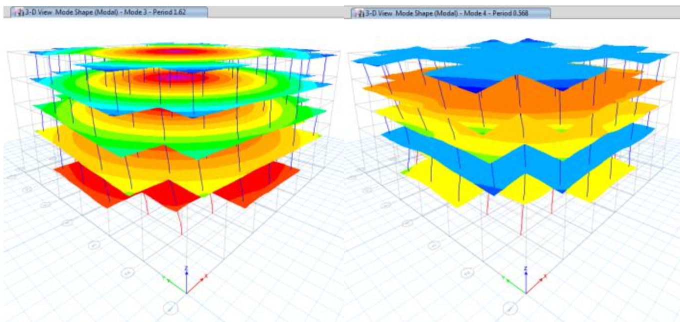


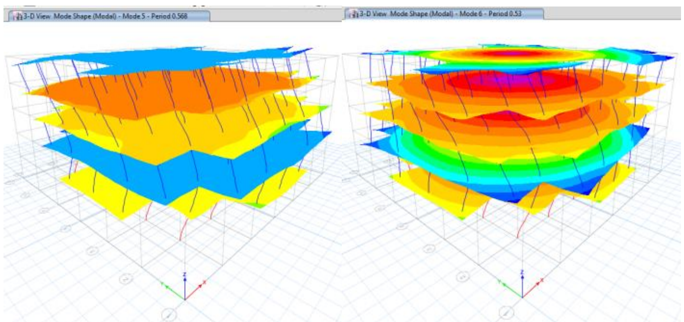


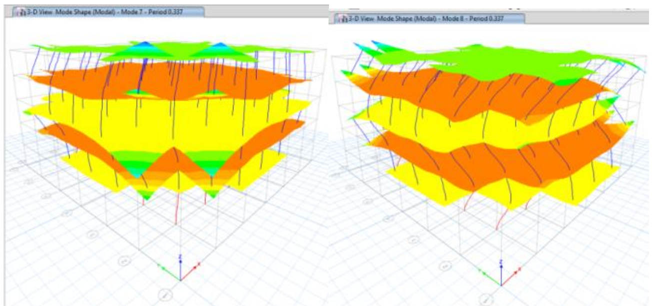


Modal displacement & deformation for H-PLUS shape structure









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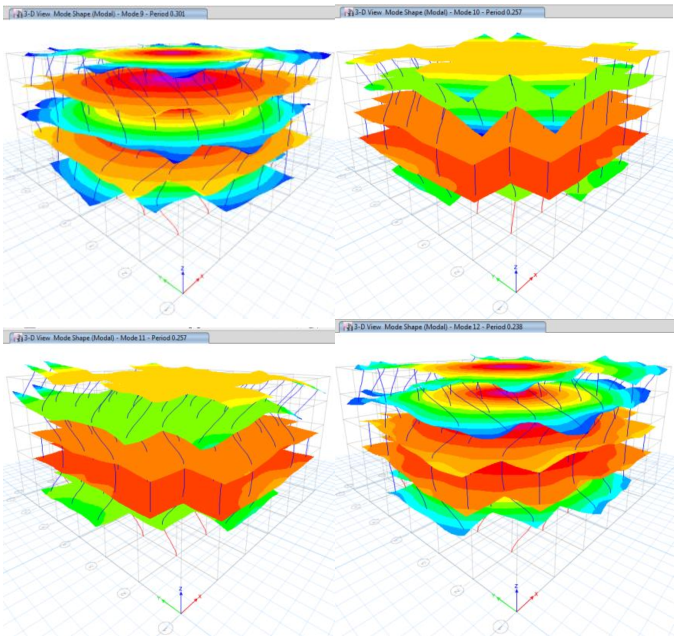
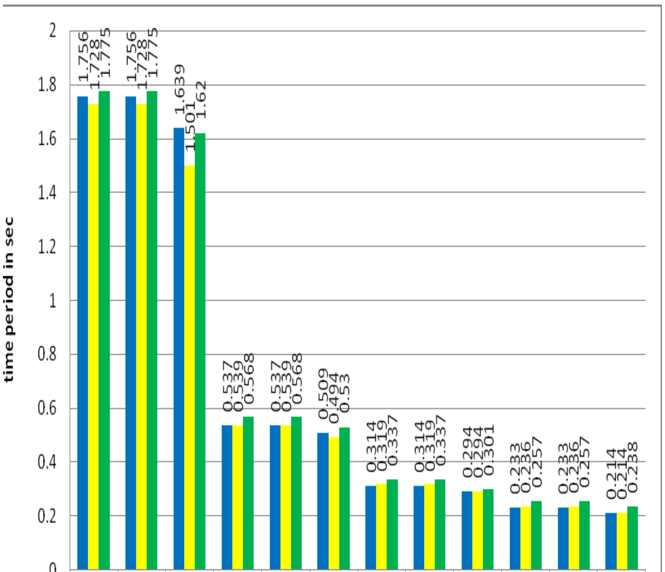
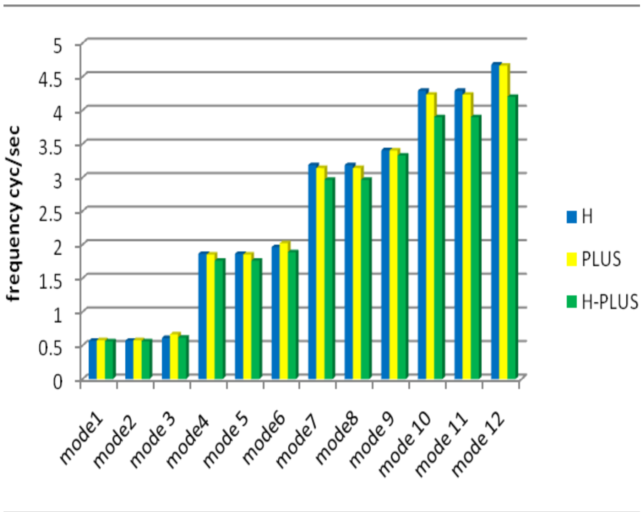


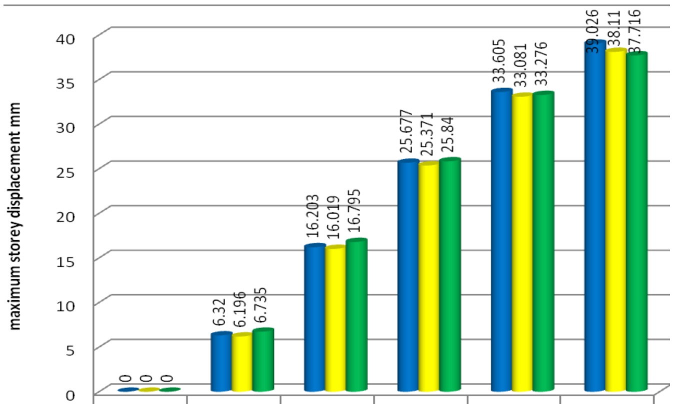
COMPARISON OF THE RESULTS OF RESPONSE OBTAINED IN EACH



	Modal 1	Modal 2	Modal 3	Modal 4	Modal 5	Modal 6	Modal 7	Modal 8	Modal 9	Modal 10	Modal 11	Modal 12
H	1.756	1.756	1.639	0.537	0.537	0.509	0.314	0.314	0.294	0.233	0.233	0.214
PLUS	1.728	1.728	1.501	0.539	0.539	0.494	0.319	0.319	0.294	0.236	0.236	0.214
H-PLUS	1.775	1.775	1.62	0.568	0.568	0.53	0.337	0.337	0.301	0.257	0.257	0.238

Time period & frequency comparisons for different modes

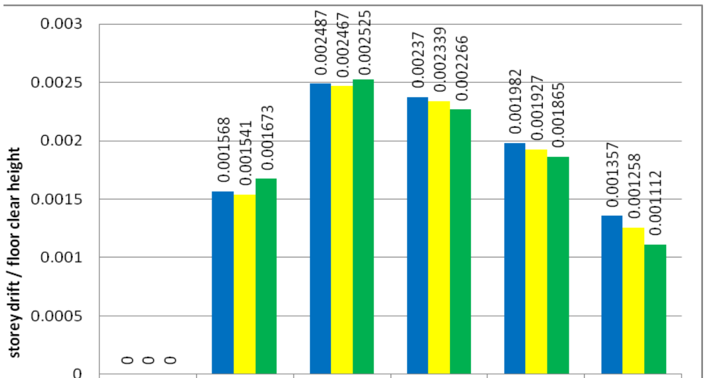




	Base	Story1	Story2	Story3	Story4	Story5
H	0	6.32	16.203	25.677	33.605	39.026
PLUS	0	6.196	16.019	25.371	33.081	38.11
H-PLUS	0	6.735	16.795	25.84	33.276	37.716

Comparison of maximum storey displacements for H, PLUS & H-PLUS

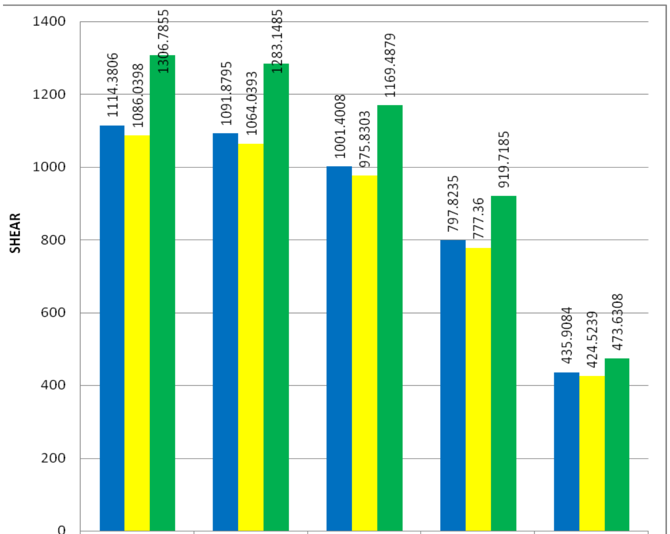
- Top storey displacement is maximum for H-shape structure
- Top storey displacement is maximum for HPLUS-shape structure



	Base	Story1	Story2	Story3	Story4	Story5
H	0	0.001568	0.002487	0.00237	0.001982	0.001357
PLUS	0	0.001541	0.002467	0.002339	0.001927	0.001258
H-PLUS	0	0.001673	0.002525	0.002266	0.001865	0.001112

Comparison of storey drifts for H, PLUS & H-PLUS

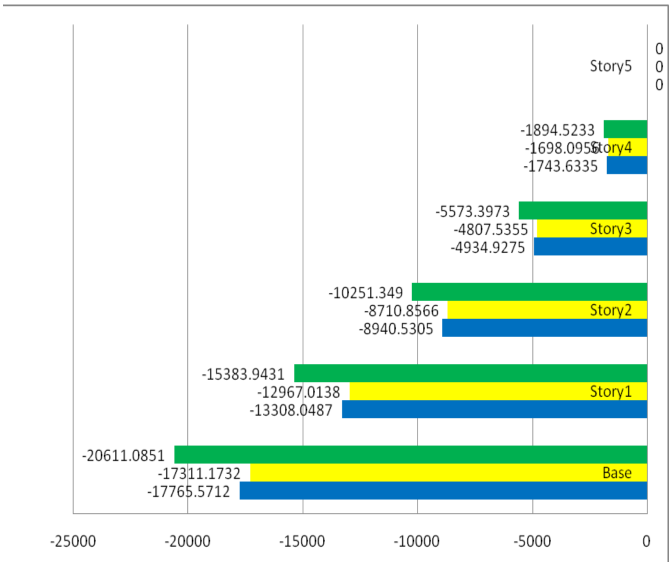
- Inter storey drift is maximum for H-shape structure
- Inter storey drift in H-PLUS structure keeps decreasing as we move up the storey



	Story1	Story2	Story3	Story4	Story5
H	1114.3806	1091.8795	1001.4008	797.8235	435.9084
PLUS	1086.0398	1064.0393	975.8303	777.36	424.5239
H-PLUS	1306.7855	1283.1485	1169.4879	919.7185	473.6308

Comparison of storey shear for H, PLUS & H-PLUS

- Storey shear is maximum for H-PLUS shape structure

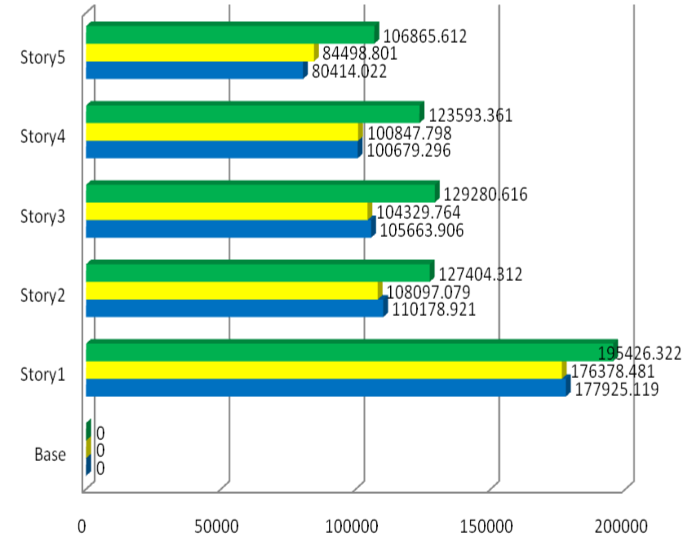


	Base	Story1	Story2	Story3	Story4	Story5
H-PLUS	-20611.0851	-15383.9431	-10251.349	-5573.3973	-1894.5233	0
PLUS	-17311.1732	-12967.0138	-8710.8566	-4807.5355	-1698.0956	0
H	-17765.5712	-13308.0487	-8940.5305	-4934.9275	-1743.6335	0

Storey overturning moment in kN-m

Comparison of storey overturning moment for H, PLUS & H-PLUS

- H-PLUS shape structure has maximum storey overturning moments



	Base	Story1	Story2	Story3	Story4	Story5
H-PLUS	0	195426.322	127404.312	129280.616	123593.361	106865.612
PLUS	0	176378.481	108097.079	104329.764	100847.798	84498.801
H	0	177925.119	110178.921	105663.906	100679.296	80414.022

Comparison of storey STIFFNESS for H, PLUS & H-PLUS

- Storey stiffness is maximum for H-PLUS shape structure

Conclusion:

Structures with different projections can have different response parameters. The difference in mass distribution can have different effect on structure with same projection area. Vertically asymmetric structures are not adopted due to seismic effects, but the current study is indicating that by combining two different types of projections properly in structures similar to the one we have adopted certain response parameters can be altered to some extent. The study also highlights the lateral loading effects of such large projection structures with waffle slab & circular column system. To establish the fact & understand the behaviour much deeply non linear analysis can be done in future to obtain adequate data for much accurate results.

Future Scope of Studies

1) Non-linear analysis can be done using non-linear pushover analysis or non-linear time history Analysis.

2) Study of the structures by varying the total height of the structure and its torsional effect can be studied.

3) The study of these structures can be modified by varying the projection areas compared to the inner area of the square symmetric structure.

4) The study can be carried out on asymmetric structures with the same amount of projections.

5) Dynamic Analysis of the structures with alternate projection can be done, by keeping projection in alternate floors and increasing the height of the structure.

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BIOGRAPHIES

Author: Suvradeep Saha
M Tech in Structural Engineering
NIT JIS Group (MAKAUT WB), formerly known as WBUT