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Feasibility Study on the Structural Behaviour of Hybrid Wood Steel Structures Using Finite Element Analysis

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Abstract— This project involves a detailed study of steel-wood hybrid structures. Hybrid structures combine benefits of dissimilar materials to overcome their individual limitations. Various advantages and challenges of steel-timber hybrid structures are presented. Benefits include increase in tensile capacity, seismic performance, fire resistance of the structure, and cost savings. Challenges with this type of hybrid structures originate from the differences in the properties of the materials used. To elaborate on these types of hybridization and their advantages and challenges, case studies of steel-timber are provided. The considered software are CATIA and ANSYS. Software's are evaluated in terms of their ability to model linear and non-linear materials. Among the software's ANSYS is found to be the most suitable for modeling hybrid wood and steel structures. In this study of a hybrid structure consisting of steel moment frame and wood shear wall is modeled with ANSYS. Static analysis and Response spectrum analysis are performed on the structure and it is observed that wood shear wall significantly reduce the lateral deflection of the system. In this thesis a five storey hybrid steel wood structure is modeled with software CATIA 2015 and analysis with software ANSYS 2015. Seven cases are considered for static analysis, to knowing about the effect of shear wall in the structure. Five cases are considered for model and seismic analysis then the maximum lateral deflection in each cases are compared The deflection in each case is compared to the deflection of the steel frame alone.

Index Terms— Oriental strand board, Wood-Steel ,Hybrid structures,cross laminated timber.

1 INTRODUCTION

Hybrid systems are commonly used throughout the world, and are present in many types of structures with many different types of materials. A hybrid system is any system that combines two or more structural materials. Among the hybrid systems steel and concrete hybridization is most common; these include concrete on metal deck supported on steel beams as a floor system. Steel structures are very common in the world due to its short construction time period and high strength. But it's in an emerging way in the construction field in India especially in Kerala. For the improvement of strength and overcome the other individual limitations of steel structures it can be combine with other materials like hybrid systems. Steel and timber hybrid systems are less common but do exist.

This project involves a detailed study of steel-wood hybrid structures and their application in construction industry. Effective timber and steel hybridization creates a system where steel is used minimally only where high strength and ductility are needed. Steel is much stronger and provides significant post-yield deflection capability, known as ductility. Steel moment frames are extremely ductile, with large deflections during seismic events. Wood is comparatively much weaker usually requiring larger members, resulting in stiffer systems; wood does not produce post-yield deflection, especially when loaded perpendicular to the grain. Several issues are immediately obvious with this type of seismic force resisting system, the largest being the incompatibility associated with the difference in material properties; the incompatibility of steel and timber mean the connections are an important problem. Despite this, the light, cheap, and environmentally friendly nature of wood makes it a good material to pair with stronger, more ductile steel. Many options exist for hybridization of steel and timber within a vertical seismic resistance system. To effectively create a hybrid system it is important to understand the properties of both steel and wood. Benefits include increase in tensile capacity, seismic performance, fire resistance of the structure, and cost savings. Challenges with this type of hybrid structures originate from the differences in the properties of the materials used.It is important to note that timber is a material with less reliable strength characteristics than steel and concrete because it is a natural material. Timber characteristics are extremely dependent on the species of tree and specific qualities of the wood harvested; growing conditions can have a large impact as well as local imperfections in the wood, such as knots.

To elaborate on these types of hybridization and their advantages and challenges, case studies of steel-timber, concrete-timber and steel-concrete structures are provided. Currently there are no material and design standards for hybrid wood-steel structures. The purpose of the analysis is to perform a static analysis and see the effect of wood shear walls on the lateral deformation of steel frame building.

The shear walls are provided for buckling resistance of the building. The use of shear wall-buildings is quite common in some earthquake prone regions. Connections of shear walls to the structure transfer horizontal forces to the shear wall. This transfer creates shear forces throughout the height of the wall between the top and bottom shear wall connections. Usually, architectural design leads to the existence of doors and windows within shear walls. Shear walls, which are quite common in earthquake resisting structural systems, may have openings for doors, windows and building services or other functional

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reasons. Such openings create regions of disturbed stress flow.

Aim of this project is to investigate the behaviour of steel and wood hybrid structure and the effect of shear wall over that.Among a verity of software CATIA5 is found to be the most suitable for modelling hybrid wood and steel structures and analysis is done by using ANSYS 2015 software. In ANSYS static analysis, model analysis and seismic analysis (response spectrum) is performed on the structure and observed that effect of shear wall in the structure. The effect of material on lateral deflection is also studied. Another aim of the project is identify which design will be better, stable and cost effective.

Cases to be considered for analysis are listed below.

- The first case (Case 1)- Considers the steel frame alone with wooden floor,
- In the second case (Case 2)-Steel frame having shear wall installed the whole bays with wooden floor.
- In the third case (Case 3) - The shear walls installed only in the centre of the frame.
- In the fourth case (Case 4) - The shear walls implemented in alternative span of the building.

Total deformation and stress in each case is compared to the deflection of the steel frame alone by using static analysis and seismic analysis.In this study shear wall materials are also changed for the comparison of deformations. For that use OSB (oriented strand board) and CLT (cross laminated timber) for shear wall. Deflection in each case is compared to the deflection of the steel frame alone (Case 1) from the static and seismic analysis.

2 Objective and Methodology

2.1 Objective of the study

- To develop the new ideas of seismic resistant structure with the help of detailed literature review.
- To develop, validate and demonstrate a FE-based modelling methodology for accurate simulation of hybrid structures.
- A review of Literature reveals that validated methodologies for hybrid structures are absent or scarce, presumably due to the complexity of response, where in the constitutive and interaction properties of various components must be accurately modelled.
- To investigate the behaviour of hybrid components by Oana stanila and Nicolate Teranu [6] under the analysis of hybrid polymeric composite-timber beams using numerical modelling.
- To conduct a parametric study by with and with out shear wall with different materials in various positions.
- To develop the new ideas of seismic resistant structure with the help of detailed literature review.
- To conduct a parametric study on with and with out shear wall with different materials in various positions.
- To refine the design method available based on study.

2.2 Methodology

The methodology used to complete this dissertation is described in the following steps:

- Review of hybrid component levels and hybrid
- Prepare a plan for five story building.
- Select suitable materials for making hybrid components in the building.
- Modelling the structure using CATIA software.
- Import the modelled structure to the ANSYS software.
- Analyse the structure using ANSYS software.
- Selection of suitable elements from ANSYS element Library.
- Once meshing is completed, solving the problems using once with appropriate loads and boundary conditions.
- Obtaining the result and plotting in ANSYS postprocessor.
- Compare the different structures in the case of shear wall implementation and find out the cost effective way.

2.3 Modelling

Five storied hybrid structures are modelled using ANSYS software .First storey height of each building was 4.5 m and all other storeys were 3.5 m height. The two N-S exterior bays were 9m in length, the one interior N-S bay was 6 m, and centre to centre spacing of the E-W frames was 6m. For the formation of hybrid structure steel, wood and oriented strand board are used.

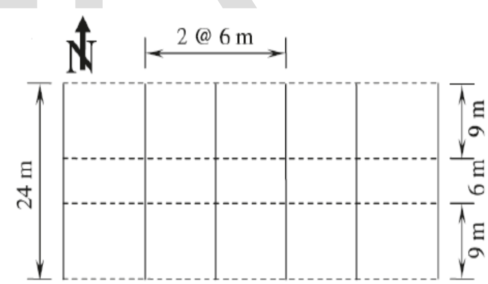

Fig1. Plan of structure.

2.4 Sectional properties of structre

Components include beams, columns, slab and shear walls etc are explained below.

2.4.1 Hybrid Beams

Beams are the flexural member in the buildings. It can transfer the loads. The material used for the construction of beams is steel. Beams have the capability to resist deflection after providing loads especially steel beams. The beams are having cross section W 310 x 85mm (Nominal Depth & Weight). Beam is an 'I 'section taken by ASTM A6-86 approach.

2.4.2 Hybrid Columns

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Columns are the compression members, which has the capacity to transfer the loads from beams. The material used for the construction of columns is steel. Use I sections for making columns can resists buckling also. The columns are having cross section W310 x 180mm (Nominal Depth & Weight). Columns are considered in this study by ASTM approach as I- section taken by ASTM A6-86 approach.

2.4.3 Hybrid slab

A flat piece of concrete or other material put on the walls or columns of a structure. It serves as a walking surface but may also serve as a load bearing member. Here hybrid slab have wood and steel .The thickness of the slab is 150mm.

Table 1. Shows the dimensions of beams and columns

Components	Dimensions (mm)
Beam dimensions	W310 x 85
Column dimensions	W310 x 180
Slab	150

Table 2. Sectional Properties for W310 x 179 and W310 x 86

W (Nominal Depth & Weight) (mm x kg/m)	Nominal Depth, H (mm)	Width, W (mm)	Web thickness, t_w (mm)	Flange thickness, t_f (mm)	Weight (kg/m)
310 x 179	310	313	28.1	28.1	179
310 x 86	310	254	16.3	16.3	86

3 MATERIALS USED FOR THE FORMATION OF HYBRID COMPONENT

3.1. Steel

Steel is the main material used for the formation of the building. Steel is a material which has good ductility, fire resistance and good strength etc are not indented. Only the initial, introductory paragraph has a drop cap.

Table 3. Property of steel.

Density (kg/m3)	7800
Modulus of Elasticity (Mpa)	200000
Compressive Strength (Mpa)	400-1000
Tensile Strength (Mpa)	400-100
Yield strength (Mpa)	350

3.2 Timber

The structural use of mass-timber, such as cross-laminated timber (CLT) is gaining popularity in North America. One reason is the height limitation imposed on light-frame timber structures. Incorporating timber and steel in a timber-steel hybrid system is one possible way to overcome this height limitation. The recent introduction of CLT to the North American market has added to the revived interest in extending the application of wood-based systems. The potential of steel moment resisting frames with CLT infill walls is demonstrated in previous researches. It was identified that a very important system detail is to provide a stiff connection between infill wall and steel frame while providing enough ductility to the system to fulfil seismic performance requirements.

Table 4. Properties of CLT elastic material parallel to the grain

Elastic Modulus(E) (Mpa)	12000
Shear Modulus (G) (Mpa)	250
Compressive Strength (Mpa)	24
Tensile Strength (Mpa)	16.5
Crushing Strength (Mpa)	30
Shear Strength (Mpa)	5.2

3.3 Oriented Strand Board (OSB)

Oriented strand board is manufactured in wide mats from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with wax and synthetic resin adhesives (95% wood, 5% wax and resin).

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Table 5. Property of oriented strand board (OSB)

Properties	Face(zero)	Core(90)
Ex	4160Mpa	740Mpa
Ey	1650 Mpa	2520 Mpa
Ez	400 Mpa	250 Mpa
Gxz	85.7 Mpa	44.6 Mpa
Gyz	55.7 Mpa	68.6 Mpa
Gxy	1250 Mpa	1250 Mpa
γxz	0.226	0.226
γyz	0.226	0.226
γxy	0.226	0.066

The different models are designated are listed below.

Model 1: frame alone with wooden floor.
Model 2: Steel frame having OSB shear wall in the whole bays with wooden floor.
Model 3: Steel frame having OSB shear wall in the centre bays with wooden floor.
Model 4: Steel frame having OSB shear wall in the alternative bays with wooden floor.
Model 5: Steel frame having wooden shear wall in the whole bays with wooden floor.
Model 6: Steel frame having wooden shear wall in the centre bays with wooden floor .frame
Model 7: Steel frame having wooden shear wall in the alternative bays with wooden floor.

The beam sections are created as a part in assembly design according to the geometrical specifications of W 310 x 86 sections and column sections are created according to the geometrical specifications of W310 x 179 shown in Table 5.1. The bay width of the frames is taken as 9m at the edge bays and 6m at the centre bays. Storey height as first story having 4.5 and others are 3.5m.The models are created and for the purpose of analysis and reduce calculation time each of them is split into one-fourth because of symmetry. The following figures show the different frame models created in CATIA V5. All models are created using Top-Down method where components are created as parts under the product, i.e., assembly design. A basic sketch of the column sections are created first in the sketcher workbench.

Then its 3D model is created in the part design by using the pad tool. After that the pattern of the I-section is made using pattern option to create the other columns. Secondly, the beam section is created in the sketcher workbench and then it is padded and patterned as per the requirements. Floors are then created under sketcher of a different part design and are padded, patterned and mirrored to place it at necessary locations. Different shear walls sections are created under sketcher of different part designs and also under different planes. The planes under which each part is created can be viewed after creating the whole model by selecting the geometric axis option under the corresponding part from the specification tree.

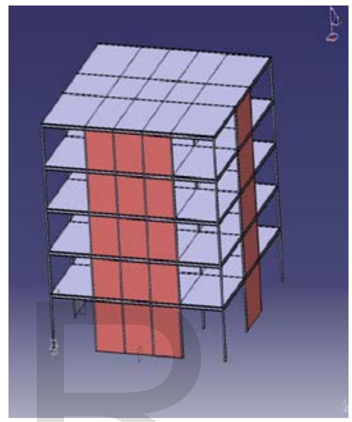

Fig.2. CATIA model steel frame alone

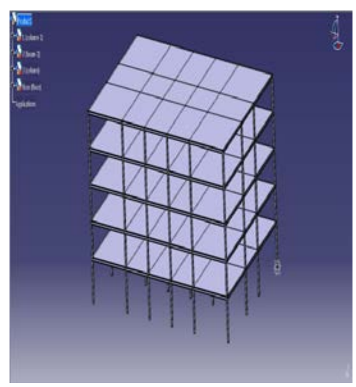

Fig.3: CATIA model steel frame having shear wall in the centre bays with wooden floor

4. Analysis

4.1 Static analysis

For static analysis, consider dead load of structure and gravity loads andalso consider gravity load as 9.81m/s2. fixed supports provided on structure.
Model-1 steel frame along with wooden floor carries a load of 2.1999e-003 Mpa.

model-2 - 1.252e-003 Mpa. model-3- 4 1.8412e-003 Mpa

model- 4 - 2.0003 Mpa model-5-252Mpa

model-6 -1.252Mpa model-7-2.0003 Mpa

4.2 Model analysis

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. Any physical system can vibrate. Detailed modal analysis determines the fundamental vibration mode shapes and corresponding frequencies. The frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and that can be analytically analysed using model analysis. Structural element such as complex steel floor system can be particularly prone to perceptible vibration, irritating building occupants or disturbing sensitive equipment. For model analysis 6 mode shapes are considered then compare the total deflection of 5 models using graph.

Table.7 Total deformation values of shear wall under model analysis.

Models	Total deformation values(m)	Von Mises stress values (Pa)
Model 1	.19505	6.1429e8
Model 2(OSB)	.14187	4.1357e8
Model 3(OSB)	.43752	9.7666e8
Model 4(OSB)	1.3126	1.2823e9
Model 5(WOOD)	0.13758	3.2265e8
Model 6(WOOD)	0.16679	6.0609e8
Model 7(WOOD)	0.84562	4.2421e9

4.3 Seismic analysis

Earthquakes has become the most disastrous natural calamity in the present era, and the existing buildings techniques have proved to be a drawback to resist such huge ground motions, so here the models are analytically analysed using seismic analysis. Seismic analysis of the frame is based on the Ahmadabad frequency response spectrum (FRS).The frequency and acceleration are taken corresponding to FRS.

5 RESULTS AND DISCUSSIONS.

5.1 Results obtained from static analysis

As mentioned earlier, static analysis after applying corresponding dead load and gravity loads produces the Von-mises stress contour and values and total deformation for each model.

Table 6: Total deformation values of shear wall under static loading

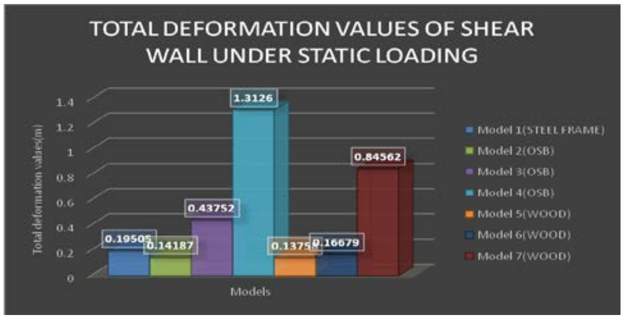

Fig.4: Models-Total deformations graphs from static analysis.

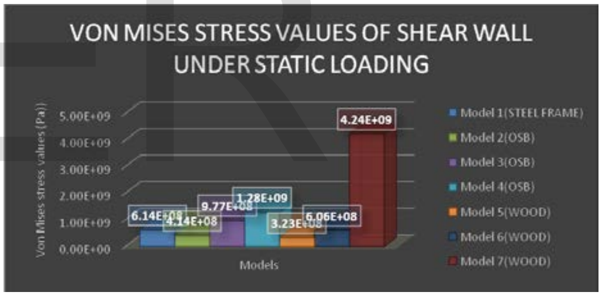

Fig.5: Models-Von Misses stress graphs from static analysis.

From the above results which compare the total deflection and stress values of different frames under the static analysis it can be, concluded that the least total deflection and stress value is in model-5:steel frame having wooden shear wall in the whole bays with wooden floor. But consider cost and aesthetic view of the structure we can adopt the model: 6 steel frame having wooden shear wall in the middle bays with wooden floor. From the static analysis, it is found that understand the hybrid structure can resist deflection due to given loading. Hence this type of structure can be adopted in various locations especially in earthquake prone areas. For model analysis and seismic analysis five models from the above models which have been selected. Selected models are listed below

Model 1: frame alone with wooden floor.
Model 2: Steel frame having OSB shear wall in the whole bays with wooden floor.

Models	Total deformation values(m)	Von Mises stress values (Pa)
Model 1(SF)	1.8402e-9	7.0828e-6
Model 2(OSB)	1.3489e-5	1.9973e-5
Model 3(OSB)	1.2284e-6	4.3915e-6
Model 5(WOOD)	1.1503e-5	1.5196e-6
Model 6(WOOD)	2.2005e-6	6.7767e-6

Model 3: Steel frame having OSB shear wall in the centre bays with wooden floor.

Model 5: Steel frame having wooden shear wall in the whole bays with wooden floor.

Model 6: Steel frame having wooden shear wall in the centre bays with wooden floor.

5.2 Results of model analysis

In model analysis consider six mode shapes. Each mode shapes have different natural frequencies.

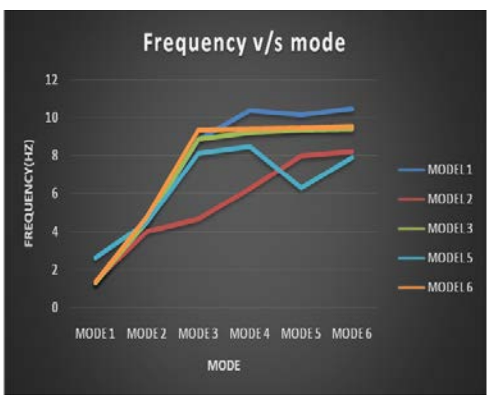

Fig.6: Mode number -Frequency graphs from model analysis.

5.3 Results of seismic analysis

Table 8: TotaldeformationValues Of Shear Wall Under seismic analysis

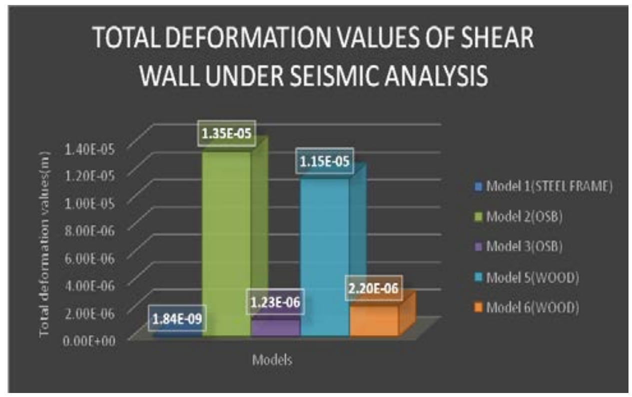

Fig.7: Models-Total deformations graphs from seismic analysis.

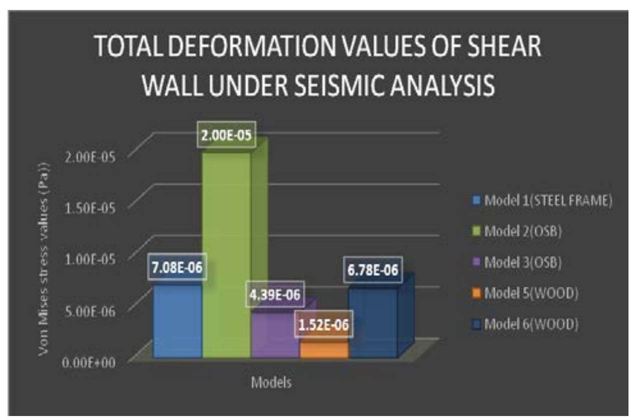

Fig:8. Von mises stress -model graphs from seismic analysis.

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From the results the results are concluded that the total deformation under seismic analysis least in the models having shear wall .but in the case of steel frame alone have large deformation. So the effect of shear wall is an important in this type of structures.

Frequency(Hz)	1.3141	4.496	8.8243	10.372	10.162	10.464
Model1 (Total deformation(mm)	0.161	0.149	0.1873	0.7338	1.0799	0.75864
Frequency(Hz)	1.3866	4.0221	4.6903	6.2964	7.9955	8.2232
Model2(Total deformation(mm)	0.15922	1.8026	0.16846	2.0757	2.1777	1.1273
Frequency(Hz)	1.3237	4.5262	8.8769	9.203	9.345	9.3961
Model3(Total deformation(mm)	0.16036	0.16886	0.20227	1.1056	0.80306	0.80738
Frequency(Hz)	2.6166	4.5231	8.127	8.4964	6.3309	7.9348
Model5(Total deformation(mm)	0.15508	1.8065	2.2654	1.1347	2.1196	0.16708
Frequency(Hz)	1.3655	4.8266	9.383	9.4087	9.4549	9.5503
Model 6(Total deformation(mm)	0.16266	0.17937	1.0003	0.9516	0.94803	1.0746

6 CONCLUSIONS AND FUTURE SCOPE OF WORK

Hybrid structures combine benefits of dissimilar materials to overcome their individual limitations. It increases the tensile capacity, seismic performance, fire resistance of the structure, and cost savings etc. steel and wood hybrid structure is one of the good hybrid combinations in this studies and researches are going on all over the world, this study can be expected to be a small contribution to the same. Steel and Timber hybrid buildings show significant promise as a reliable seismic force resisting system. Around the world, steel and wood hybridization is being used more and more frequently. Despite this, Canada is just beginning research on this type of system. Other parts of the world including Japan and New Zealand show many different types of wood hybridized systems, some examples are given with wood diaphragm and wood hybrid braced frames. The stress variations, load carrying capacities and stress-strain relations of the frame systems were studied which showed that the hybrid wood and steel with wooden shear wall having more load carrying capacity, least deflection and low stress values under a given loading condition than the OSB shear walls. Thus the importance of using shear wall in the structure was stated clearly. From the model and seismic analysis it was very clear that the hybrid structure having wood and steel have more effective to earthquakes. Furthermore, as earthquakes has become the most disastrous natural calamity in the present era, and the existing buildings techniques have proved to be a drawback to resist such huge ground motions, its far time to develop new systems to overcome this disadvantage and wood and hybrid structures are considered to be one such invention. In that context, different studies to reveal various properties and performance of such a system is of utmost importance and here, the aim was to contribute a bit towards that which was achieved completely within the limited facilities and information available.

6.2 Conclusions

- Implementation of nonlinear static method and response spectrum method of analysis to study behaviour of hybrid wood and steel structure and the best material for shear wall, location for shear wall in hybrid wood and steel structure, analytically using the Finite Element Analysis Software ANSYS was done successfully, thereby achieving the objective of the study.
- The results obtained like, graphical representation of total displacement v/s models, stress v/s models from static and seismic analysis satisfy the typical curves and relationship criteria for hybrid structure.

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- The results are concluded that the total lateral deformation and stress of model-3 and model-6 under seismic analysis are comparatively lower than other models. So the effect of shear wall is an important in this type of structures.

- After analysing all the result parameters, it was clear that the wood and steel hybrid structure having wooden shear wall at the middle spans model showed the best performance in all cases.
- Analysis result showed that the hybrid wood and steel with wooden shear wall having more load carrying capacity, least deflection and low stress values under a given loading condition than the OSB shear walls.
- From the model and seismic analysis it was very clear that the hybrid structure having wood and steel have more effective to earthquakes

6.3 Future scope of the work

As mentioned, wood and steel hybrid structure having wooden shear wall at the middle spans model is the most recently emerged efficient wood and steel hybrid system, that fact itself enhances the scope of this work. Variations can be made in the study for further investigation about wood and steel hybrid structure**.**

- Frames with different material other than wood and OSB considered for this study can be analyzed and evaluated to study their behaviour and to find more cost effective material.

- Storey height and bay width of the frames can be varied with the same shear wall patterns or other chosen ones.

- Same study can be done with large models by varying the number of storeys and bays.

- Linear buckling and nonlinear buckling analysis can be carried out to study the critical buckling behaviour of the structure.

- The end conditions can be considered as hinged to model the frames in more realistic conditions.

- In the model analysis, modes of the structure can be increased.

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