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Seismic Analysis of Sustainable Timber Structures – Dhajji-Dewari Houses in Kashmir

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Abstract - *In Kashmir earthquakes have occurred on a regular basis over centuries and local population have adapted to its recurrence. In order to resist these previous earthquakes satisfactorily two old building design systems known as Dhajji-dewari and Taq systems have been put into practice widely. Presently, the cities throughout Kashmir valley can be easily characterized by this typical vernacular Kashmir house. This construction practice is generated from use of local materials , abundantly available blue-pine coupled together to built these Timber framed house which satisfactorily suit the local extreme climate, soil type, distinct natural environment and culture and most importantly the high seismic risk of the area. This incredible vernacular Kashmir house system, However, is being phased out after the destructive earthquake of October 2005. The objective of this work is to assess the effects of earthquake loads on different types of timber framed masonry wall systems(Dhajji-Dewari) and their seismic resistance .Timber framing in different configurations will be modeled and analyzed .In this study, Response Spectrum Analysis and Capacity Spectrum Analysis will be carried out to study the seismic behavior of such masonry structures. The results will be compared with the conventional rigid masonry with RCC lintels. This study presents the seismic performance of the Dhajji-Dewari for different types of timber configuration. The Top Max joint deflection, Max base Shear, Time period of Dhajji-dewari houses have been obtained with the help of analysis for different models. Analysis is carried out using finite element software CSI SAP 2000.*

Key Words: Earthquakes, Sustainable Resource, Response Spectrum, Seismic Zones, Brick Infill, Timber, Dhajji-Dewari,

1. INTRODUCTION

Earthquakes are the most destructive natural calamities which lead to a huge loss of life, property and economy. On 8 October, 2005, a magnitude 7.4 on righter scale earthquake took place the Kashmir valley (A Himalayan disputed region administered in parts by India and Pakistan), also the other areas affected were parts of India, Afghanistan and Pakistan. Around 90 thousand people died because of this earthquake, and an approximate 40 lakh people were left shelter less. The Kashmir earthquake took place at 9:25 am (IST) and was epicentered about 19 kilometers NE of Muzafarabad, which is the capital town of Pakistan-ruled Kashmir.

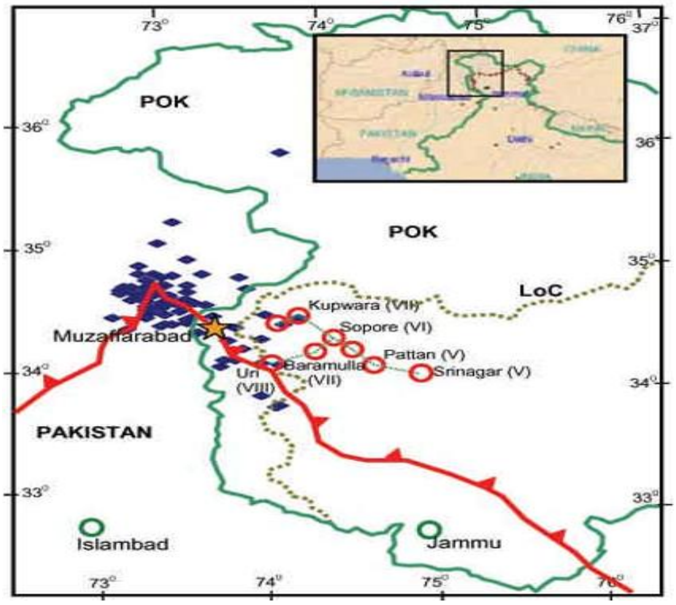

Fig -1: Location of earthquake

Kashmir valley is situated at the fault line of the Indian and Eurasian tectonic plates—the convergence of this Eurasian plate Indian plate caused the creation of the Great Himalayan Mountains— which makes the region prone to hazardous seismic earthquakes. The October 2005 quake was among one of the worst earthquakes to ever hit the area. It resulted in widespread destruction throughout the Kashmir regions, part of India-Ruled Kashmir; Pakistan-administered Kashmir; Pakistan's North-West Frontier Province; and northern areas of Pakistan. Damage to some extent was also reported from Afghanistan and north parts of India. House forms that are of a different kind. A traditional way of life and building construction type is a result of this isolation and hence maximizes the use of locally available resources. This research discusses and analyses the house construction in terms of the above mentioned way of life, but particularly in terms of available local materials and the distribution of these materials through developed construction techniques into a structural system that is flexible and has the potential for seismic resistance. Key construction technique like the 'DHAJJI-DEWARI', will be analyzed in detail, while understanding its role within an overall construction system and as compared to the conventional more brittle masonry houses. Throughout Kashmir, traditionally used timber framed brick masonry construction consists timber framework with burnt-clay brick infill which generate a patch-work of masonry, this masonry is held within by small timber panels which can be framed in different configurations. The outcome from this composite combination results in the formation of a new form of patchwork masonry, which has proved to be way more superior and efficient in resisting earthquake forces than conventional brick masonry. There was very less or no damage observed in such structures even during Richter 7.4 intensity October 2005 earthquake. This Dhajji-Dewari system of construction is believed to posses outstanding Earthquake resistant features.

Fig -2: Dhajji-Dewari surviving October 2005 earthquake.

The objective of this study is to understand the mechanism of Sustainable Dhajji-Dewari houses using FEM software SAP-2000 and compare their results with conventional masonry house models. The Response spectrum analysis is performed as per IS 1893-2000.

2. LITERATURE REVIEW

Significant study was carried out on behavior of timber-framed house and vernacular architecture of Kashmir. A few published works on Kashmir earthquake and response of Dhajji-Dewari. Mohd Akeeb dar and Sajad Ahmad[1] discusses about the traditional systems like Taq and Dajji-Dewari built historically in Kashmir valley, their architectural significance and how economically these timber framed structures behaved satisfactorily in an event of an earthquake. Various representations give us an idea about the structural configuration of these systems. Durgesh C Rai and C.V.R murthy[2] The team Durgesh C Rai and C.V.R murthy carried out a Reconnaissance survey of the Indian controlled Kashmir part of affected region. They visited the Srinagar city, major northern towns Baramulla, sopore and uri. Also the border areas of kupwara and tangdhar. They assessed the damage to the buildings and housing structures. In the paper they mention how they were surprised by the collapse of Rubble stone masonry walls even due to much lesser shaking. Along the Highways they visited various major civil engineering projects like dams and hydroelectric projects .The assessed various housing areas which are largely load bearing type masonry structures ,usually laced with timber. The floors diaphragms were usually flexible. These typical structures locally referred to as Dhajii-Dewari amazed the surveyors as they had performed really well against the earthquake forces. These typical box type houses were simple masonry structures which had a simple patchwork of masonry confined by small vertical and horizontal timber members. They say that there was no collapse even the regions of intense shaking. K.M.O Hicyilmaz, T.Wilcock, C.Izatt, J.da-Silva and R. Langenbach[3] In this research the Authors studied the Dhajji-Dewari houses which were built in great numbers after October 2005 earthquake .As there was little or no research based data available to back the great seismic resistance claim. They aimed to analytically model the building to study the behavior of such houses. In this research seismic Analysis was carried out to a box type timber framed structure to understand its behavior and performance during a massive earthquake. The timber members and the brick infill were modeled accurately by giving the respective properties. They carried out Response Spectrum analysis and Push-over Analysis on the building to assess the overall performance. V.R.Shah and Riyaz Tayyibji[4] discuss about the development of construction practices by incorporating locally available material into a structural system that is flexible and has the potential of seismic resistance. The TAQ and Dhajji-Dewari systems were studied in detail and their overall role in construction was studied. A case study was carried out to discuss the limitations of modern methods of structural analysis, and extensions required for a better understanding of traditional structures and construction. it also discusses the need to regain the confidence in traditional construction techniques , with their ability to respond to a seismic resistance while simultaneously responding to other issues such as local availability of material, climate etc. The paper brings out the inclusive way in which traditional buildings deal with issues of structure, rather than viewing them in isolation.

3. CONSTRUCTION OF DHAJJI-DEWARI

- The Dhajji-Dewari system is much lighter and slender form of wall construction.
- It is built up from timber framing, small confiner panel are constructed first.
- The timber frames are then filled with either of mud brick masonry or burnt clay brick masonry.
- In few cases, stone masonry is also used as an infill material.
- This vertical and horizontal timber frame formed is usually braced diagonally against shear failure

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Fig -3: Dhajji-Dewari house under construction.

4. OBJECTIVE

- To perform Response Spectrum Analysis Using IS 1893-2000 code for Zone-V on different timber framed walls, single storey house with different configurations of timber frames, double storey house with different configurations of timber frames (Dhajji-Dewari) (Box Type Structure) models in SAP-2000.
- To determine Top Maximum Deflection in the models (both walls and houses).
- To determine Maximum Base Shear in the models (both walls and houses).
- To determine Time period of all the models.
- To determine the mechanism of the Dhajji-Dewari that make it seismic resistant.
- Comparison of results for Timber braced Dhajji-Dewari with conventional Lintel banded masonry box type houses.

5. RESPONSE SPECTRA ANALYSIS FOR WALLS

The two models of Dhajji-Dewari (Timber framed wall) with timber framing are modeled in two different configurations as Cross Timber and Diagonally Braced members respectively. The modeling is done using SAP 2000 software. The configuration of the walls is accordance with traditional construction practice which is being employed in Seismic zone V of Kashmir. Non –Linear analysis is carried out to know the inelastic behavior of the wall structures as the capacity of the Dhajji-Dewari depends on its ability to dissipate energy and ductility.

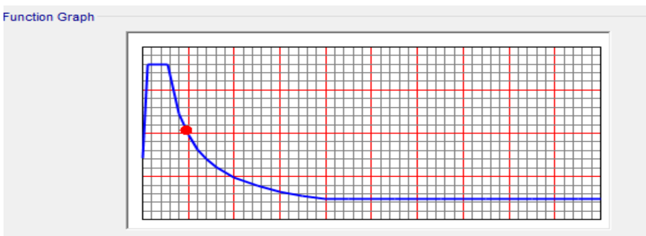

Fig -4: Response spectra for Zone-V as per IS 1893 2000.

In this Research, Response spectrum analysis is carried out as per IS 1893-2000 codes and the response of the wall in terms of Top maximum displacement, Maximum acceleration, Time period and Max base shear have been studied. A 2m x 3m cross framed Dhajji-Dewari wall is subjected to response spectrum analysis and analysis results are observed.

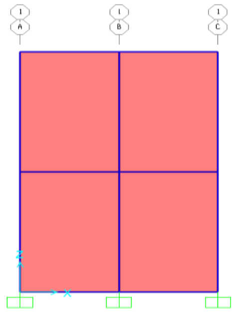

Fig -5: Elevation of cross framed Dhajji-Dewari wall.

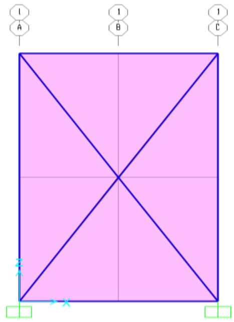

Fig -6: Elevation of diagonal framed Dhajji-Dewari wall.

The properties of the Timber beams and brick walls such as elastic modulus, poison's ratio, mass density, compressive strength are defined in the material definition section of the SAP 2000 software as the material properties are not of the standard ones.

Sl.No	PARAMETERS	VALUES
1	Depth of wall	100 mm
2	Dimensions of the wall	2m x 3m
3	Depth of Timber member	100 mm
4	Width of timber member	100 mm
5	Lintel band Dimension	100 mm x 100mm
6	Box-Type House dimension	4m x 4m x 3m
7	Slab Thickness	125 mm
8	Concrete and rebar	M20 and Fe500
9	Density of Timber-kairu	560kg/m^3
10	Modulus of Elasticity of Timber	10Gpa

11	Ultimate Tensile Strength of Timber	35Mpa
13	Density of brick infill	1800kg/m^3
14	Poisons ratio	0.23

Table -1: Parameters of Dhajji-Dewari

6. SINGLE STOREY BOX-TYPE HOUSE

Three models, two of which are Box Type single storey houses made up of Dhajji-Dewari (Timber framed wall) with timber framing modeled in two different configurations as Cross Timber and Diagonally Braced members respectively and also one Box-Type house made of conventional lintel banded walls. The dimensions of the Box-Type houses are kept at 4mX 4m with 3m floor height. Rigid concrete slab of thickness 125mm is provided. The slab loading is provided as per IS 1875(part 1) .The modeling is done using SAP 2000 software. The configurations of the house is accordance with traditional construction practice which is being employed in Seismic zone V of Kashmir. Non –Linear analysis is carried out to know the inelastic behavior of the Box Type Structures as the capacity of the Dhajji-Dewari house depends on its ability to dissipate energy and ductility. In this Research, Response spectrum analysis is carried out as per IS 1893-2000 codes and the response of the single storey house in terms of Top maximum displacement, max Acceleration at top Joint, Modal Period and frequency and Max base shear have been studied.

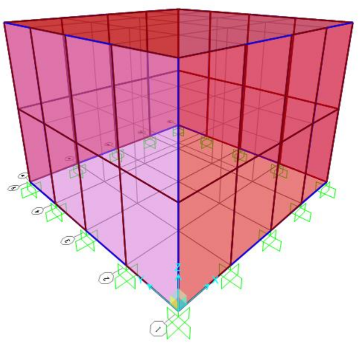

Fig -7: Single storey cross framed Dhajji-Dewari house prepared in SAP-2000.

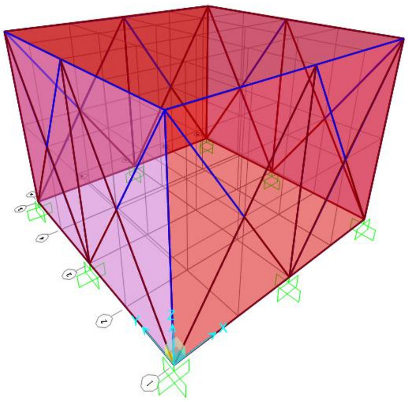

Fig -8: Single storey diagonal framed Dhajji-Dewari house prepared in SAP-2000.

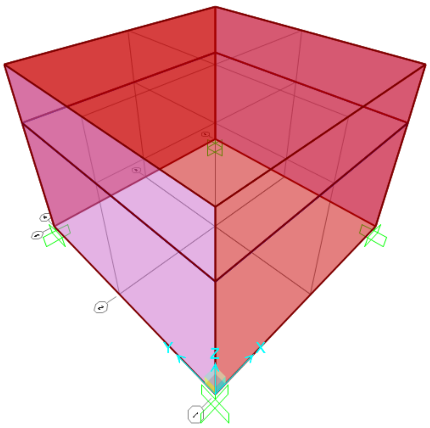

Fig -9: Single storey Lintel banded masonry house prepared in SAP-2000.

7. DOUBLE STOREY BOX-TYPE HOUSE

Three models, two of which are Box Type double storey houses made up of Dhajji-Dewari (Timber framed wall) with timber framing modeled in two different configurations as Cross Timber and Diagonally Braced members respectively and also one Box-Type house made of conventional lintel banded walls. The dimensions of the Box-Type houses are kept at 4m X 4m with 3m floor height each. Rigid concrete slab of thickness 125mm is provided. The slab loading is provided as per IS 1875(part 1) .The modeling is done using SAP 2000 software. The configurations of the house is accordance with traditional construction practice which is being employed in Seismic zone V of Kashmir. Non –Linear analysis is carried out to know the inelastic behavior of the Box Type Structures as the capacity of the Dhajji-Dewari house depends on its ability to dissipate energy and ductility. In this Research, Response spectrum analysis is carried out as per IS 1893-2000 codes and the response of the single storey house in terms of Top maximum displacement, Max Acceleration at top Joint, Modal Period and frequency and Max base shear have been studied.

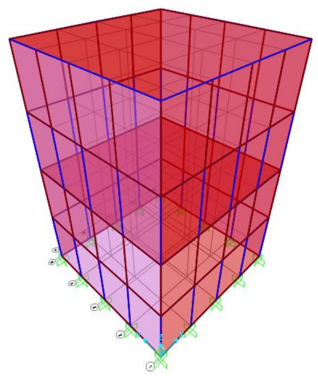

Fig -10: Double storey cross framed Dhajji-Dewari house prepared in SAP-2000.

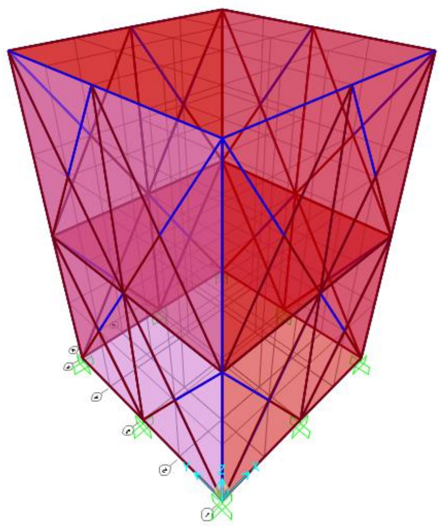

Fig -11: Double storey diagonal framed Dhajji-Dewari house prepared in SAP-2000.

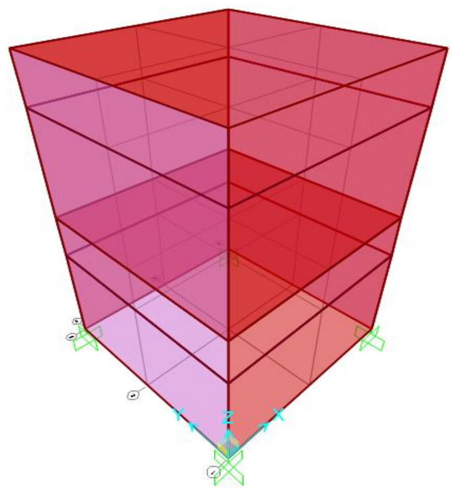

Fig -12: Double storey Lintel banded masonry house prepared in SAP-2000.

8. RESULTS AND DISCUSSION

Different Models in SAP-2000

Model 1	Cross Frame wall model
Model 2	Diagonal Frame wall model
Model 3	Cross Frame Single Story House
Model 4	Diagonal Frame Single story House
Model 5	Lintel banded single storey house
Model 6	Cross Frame double storey house
Model 7	Diagonal Frame double storey house
Model 8	Lintel banded double storey house

8.1 Top Maximum Deflection

Type of Model	Top Joint max Deflection (mm)
Model 1	29.49
Model 2	30
Model 3	7.738
Model 4	9.19
Model 5	0.042
Model 6	7.726
Model 7	9.722
Model 8	1

Table -2: Top Maximum deflections

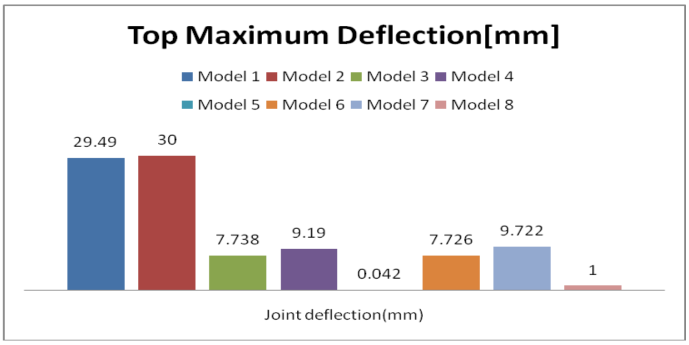

Chart -1: Top Maximum deflections

- With the comparison of all other models lintel banded houses have less top joint deflection as compared to Dhajji-Dewari ones.
- Joint deflection remains slightly higher for Dhajji-Dewari structures as they provide least stiffness and allow structure to show higher flexibility to dissipate great amount of lateral energy.
- Increase of imposed loads also restricts joint deflection hence with increase in vertical loading structure becomes more earthquake resistant.
- In Dhajji-Dewari, Cross framed structures show less deflection as compared to Diagonally framed ones,

Therefore configuration of timber members alters the joint deflection.

8.2 Time Period

Type of Model	Time period(sec)
Model 1	2.087
Model 2	2.11
Model 3	0.106
Model 4	0.234
Model 5	0.485
Model 6	0.301
Model 7	0.29
Model 8	0.10118

Table -3: Time period (sec)

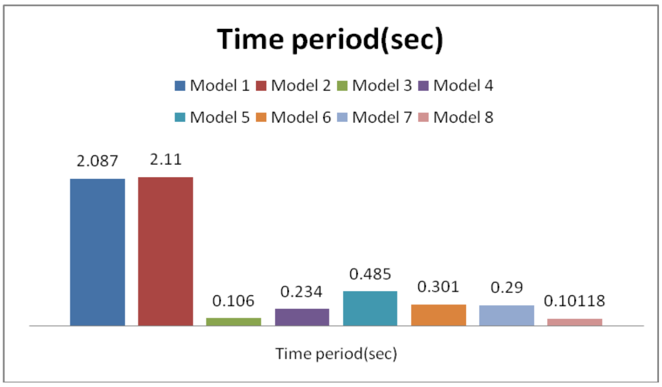

Chart -2: Time period (sec)

- It is seen that time period is elevated at around 2 seconds for Dhajji-Dewari wall panel models (Model 1 and Model 2) as compared to other models.
- For the box type structure of Dhajji-Dewari wall system, Cross framed Single storey house and diagonally framed house have less time period as compared to conventional lintel banded house.
- Reduced time periods when subjected to earthquake make them more favorable for earthquake resistance.

8.3 Accelerations

Type of Model	Acceleration (mm/sec²)
Model 1	270
Model 2	265
Model 3	37.43
Model 4	20.94
Model 5	682.73
Model 6	147
Model 7	92.03
Model 8	1325.27

Table -4: Acceleration (mm/sec²)

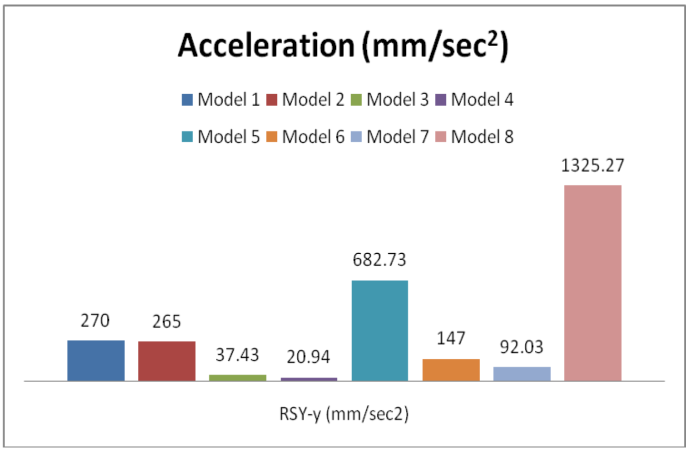

Chart -3: Acceleration (mm/sec²)

- It can be observed that the Dhajji-Dewari wall models are subjected to more Acceleration than box type structures. Hence making separate walls more prone to earthquake damage.
- The box type single storey houses are subjected to less acceleration, which reasons for comparatively more deflection in them.
- The Box type Dhajji-Dewari houses show great lateral resistance as they are subjected to very less acceleration.
- The conventional RCC lintel Banded houses are subjected to higher acceleration, which results in damage to the structures during an onset of earthquake.
- The more brittle nature of RCC lintel banded houses and higher acceleration makes them more prone collapse during an earthquake.

8.4 Base shear

Type of Model	Base Shear (kN)
Model 1	2.686
Model 2	2.79
Model 3	2.664
Model 4	6.804
Model 5	7.34
Model 6	25.056
Model 7	24.318
Model 8	28.056

Table -5: Base Shear (kN)

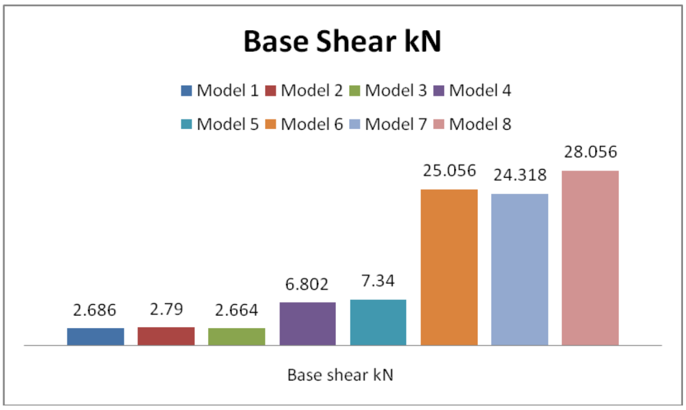

Chart -4: Base Shear (kN)

- It can be observed that single storey cross framed Dhajji-Dewari model has least base shear among others.
- Conventional masonry model has higher base shear than rest of models, which concludes that are subjected to higher lateral forces.

9. CONCLUSIONS

- The work has shown that it is possible to model the sustainable timber framed traditional Dhajji-Dewari structures.
- Dhajji-Dewari can safely resist earthquakes in high seismic regions of the world like in Zone-V of Kashmir region when designed properly.
- The Timber members act as masonry confiners, which in this case subdivide the brick infill into smaller portions which restricts the loss of brick wall portion and inhibits progressive destruction.
- The Dhajji-Dewari houses behave as a flexible structure and therefore display larger deflection within the permissible limits.
- This system possesses the characteristic high capacity to dissipate the energy by allowing greater overall deflection and friction between infill walls and timber members.
- These Dhajji-Dewari houses are lighter and therefore attract less base shear and less acceleration as compared to conventional masonry structures.
- It is also possible to grow Timber-Deodar required for such houses as much as demanded particularly in Kashmir region and, therefore it is recommended that such sustainable construction which causes less carbon Emission/footprint are followed in the parts of the country includes higher seismic zones.
- It may be highlighted that because such timber can be grown in abundance in Kashmir valley, it cannot cause any deforestation.
- Last but not the least is to underscore that such houses are time tested in Kashmir valley which is seismic Zone V and what is done in present work is only a reconfirmation of the facts more logically and scientifically.

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