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A Case for Revival of Traditional Earthquake Resistant Structures in Kashmir

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ABSTRACT- The valley of Kashmir with an area of 222,236 sq Km located in the north of India falls in a very high seismic hazard zone. Kashmir has a recorded history of 5000 years and earthquakes form a big part of that history. The oldest remains of historic buildings are basically earthquake damaged ruins of temples and ancient universities. Because of the frequent occurrence of earthquakes, the people of Kashmir devised methods to live with the earthquakes. Later medieval structures in Kashmir show the emergence of one such method of lightweight construction with a combination of mud and brick that's tied together by timber. This way structures were erected that could withstand earthquakes. This marks the beginning of a vernacular residential architecture in the valley of Kashmir that in our time is known as the Dhajji Dewari. The term "dhajji dewari" is derived from a Persian word meaning a patchwork quilt wall. This architecture was developed by using the material that was locally available making it easily adaptable to the culture, climate and natural environment of the Kashmir region. This striking architecture of the Kashmir valley, considered to be the architectural heritage of Kashmir, has over the last few decades has been considered as symbolic of poverty and has been rapidly replaced by the modern brick with cement-sand mortar form of construction that is constructed in a way which in the event of a high internist earthquake could prove disastrous. Present day plan of structures requires representing maintainability viewpoints utilizing a day-to-day existence cycle point of view, yet additionally the early plan stage where tremor activities have a huge impact concerning the foundational layout. As of late, the seismic assessment of stone work structures utilizing full scale component displaying approaches became well known, by applying execution-based evaluation methodology through nonlinear static (weakling) investigation procedures. This street numbers the approval for these methodologies alluding to two full-scale workmanship structures tried under semi static sidelong stacking and practically obscure in the writing. The test conduct of tried unreinforced workmanship (URM) and confined masonry (CM) structures is thought about against the weakling reaction of the relating computational models. Then, at that point, alluding to ordinary lodging in southern Europe and its standard plan with a built-up concrete (RC) structure, the approved appraisal apparatuses are utilized to assess the quake safe prospects of URM and CM arrangements, in particular as far as greatest pertinent ground speed increases. The brick work arrangements are likewise analyzed as far as development costs against the RC typology. The considered examination instruments present a decent understanding while foreseeing, acceptably, the test conduct, along these lines having the option to be utilized in execution-based plan. Regarding the concentrated-on lodging, the anticipated sucker reactions for the stone work structures signify ability to oppose quakes sufficiently. These designs permit likewise a tremendous expense decrease (up to 25%) against the RC, hence seeming, by all accounts, to be contending choices. However, after the 2005 Kashmir earthquake this method of construction seemed intriguing to some researchers and for the first-time proper researches were conducted on the construction method which showed very promising seismic resistance behavior by this construction method. This paper will attempt to breakdown the findings of those researches and draw suggestions and recommendations based on those findings.

KEYWORDS- Kashmir, Dhajji Dewari, Performance, Timber Frame Bracing, Load Bearing Masonry.

I. INTRODUCTION

Jammu and Kashmir, Azad Kashmir and Gilgit-Baltistan; territories administered by India and the Pakistan-administered belong to a part of the Greater Kashmir Region [3]. The irregular topography explains the temperature variations and is principally regulated by the Himalayas, surrounding mountain ranges and water areas. The weather is not that harsh than the other proximate regions which are at comparatively lower altitude. Alluvial soils found in the valley are susceptible to soil collapse when the intense earthquake hits, thereby a cause for earthquakes to last for a longer duration [3]. With 60 % of the area reckoning on irrigation for crops, the economic sustainability is highly liable on agriculture. Sub-Himalayan and Himalayan zones provide an invaluable source of timber. Witnessing the extensive seismic disasters like the one in 2005, epicenter in Muzzafarbad Kashmir; is in considerate with the fact that the poor infrastructure of buildings cause death to people and not the earthquake itself.

This has given rise to the notion of "build back better" being constantly interpreted as "build back safer" in the field of post disaster reconstruction. Because of this notion,

the world is facing a challenge with respect to identification and promotion of construction materials and methods that will result in safe and affordable housing that is socially and culturally acceptable. The typical mode of construction is reinforced masonry with supplementary help from codes and guidelines that provide a system to make ensure the quality of design and material and workmanship is at par. But this kind of construction is often complex and costly. In contrast buildings that are made using local material and have a history of performing well in earthquakes are often overlooked by designers because of the usual lack of scientific evidence. Money and time are needed to be invested into the vernacular earthquake resistant architecture researches to investigate and provide evidence to their capabilities and make them acceptable and adoptable.

Experience from past quakes has affirmed that the underlying applied plan of a structure is basic to its agreeable exhibition during a tremor. Modelers assume a significant part in fostering this reasonable plan and in characterizing the general shape, size and aspects of a structure. Underlying specialists are liable for giving mathematical evidence of primary security and should work intimately with modelers to guarantee that the plan meets both primary and design necessities. In more modest structures, for example, the bound workmanship structures talked about in this archive, engineers are regularly not involved; designers, assuming that they are involved, work straightforwardly with workers for hire all through the development interaction. Subsequently, it is of basic significance for modelers and manufacturers to get comfortable with and to take on straightforward guidelines connected with the plan and development of restricted brick work structures - this will likewise work with their correspondence with engineers.

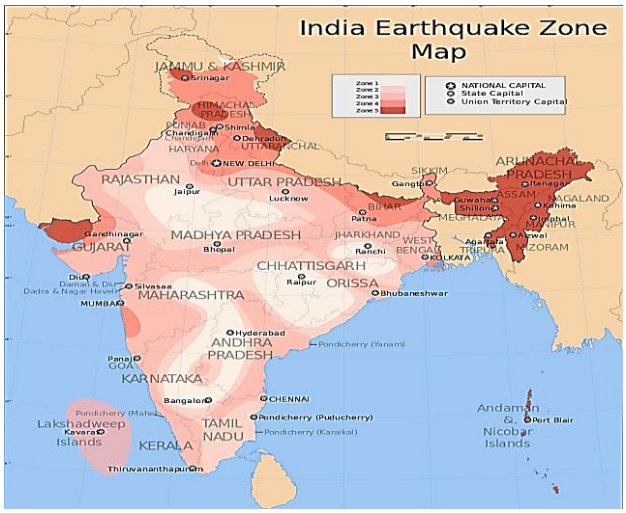


Figure 1: Earthquake intensity -Map of India

The valley of Kashmir is surrounded by tremendously large and extensive mountains of the Himalayas and the Pir Panjal ranges. These mountain ranges have blessed the valley with breathtaking back sceneries and an inexhaustible source of water. These mountain ranges were born as result of this region lying in the area of the collision of Eurasian and Indian tectonic plates (When the Earth Moved Kashmir, 2020). The stress built by these collisions creates faults and one such fault was created on the morning of 8th October 2005, when 7.6 intensity earthquake battered the entire Kashmir region. The earthquake, in a matter of seconds killed around 80,000 people and injured about 100,000. The earthquake damaged an estimated 3 million homes (When the Earth Moved Kashmir, 2020).

A. Susceptibility to Earthquakes

The Himalayas themselves were formed by the colloidal impact of two tectonic plates [Free book]. The Kashmir is a seismically active region that has survived several earthquakes throughout history. The boundary of the Indian tectonic plate collides with the stationary Eurasian plate creating areas of high stress. Between 1904 and 2015, 102 earthquakes were recorded in this region. The

Figure 1: Before and after images of Muzzafarbad [Source BBC,2005Oct]

building designs around Kashmir have been re-modified to deprecate the influence of these earthquakes. UNESCO (United Nations Educational, Scientific and Cultural Organization), following the 2005 Kashmir earthquake, has called for the preservation of local buildings and also discussed the substitutes for earthquake-resistant buildings with intellects and the experts of the concerned domain.

The October 2005 earthquake was the deadliest in a 5000-year documented history of earthquakes of different intensities hitting the valley of Kashmir (JSTOR, 2020). Some of the oldest remaining monumental buildings are earthquake damages ruined buildings. The Kashmiris, a hardy agrarian people, in order to withstand the frequent earthquakes in the valley have indigenously developed a style of construction over the last few centuries called the Dhajji Dewari. There is an immediate need to study the seismic risk of Kashmir, because the seismic hazard of the region is high and the risk in terms of damages to buildings and loss of human life and casualties can be very high due to the density of the houses in the residential areas of the valley (AR Dar, 2020). The total number of buildings in the capital city of Srinagar as per 2011 census was 360, 3632(Census India, 2011) These were categorized according to the density in each area estimating their vulnerability. According to the survey the vulnerability of these houses because of their age increases from the outer city to the inner city.

One of the main attributes of masonry construction is its straightforwardness.

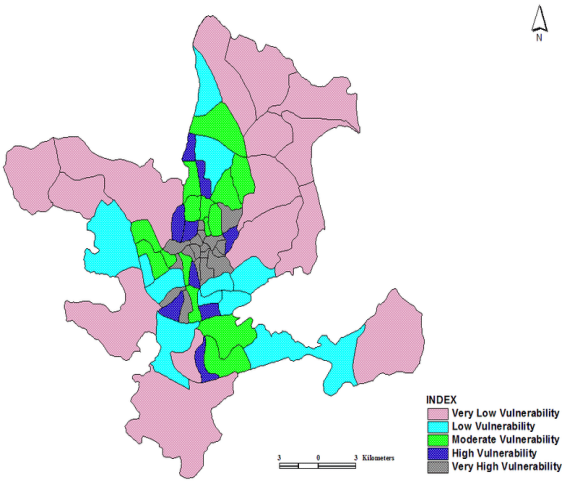


Figure 2: Vulnerability classification of houses according to their density, Census 2011 (Research Gate, 2015)

Putting bits of blocks/blocks/stones on top of one another, with attachment by means of mortar, is a straightforward, however sufficient method. Disregarding its benefits, workmanship has been supplanted by cement and steel as an underlying material in many pieces of the created world, especially in seismically dynamic districts.

Confined masonry development has been arisen as an elective technique when contrasted with unreinforced workmanship and built-up concrete (RC). The framework is contained a workmanship board restricted on all sides by level and vertical RC components with light support proportion. This technique is significantly unique when contrasted with the infill RC outline thinking about its development approach, as the stone work divider is built before the tie segments and bars. Also, the heap move instrument is different in this framework under Gravity and horizontal stacking. The restricting components (tie sections and bars) give solidarity to the brick work board and shield it from complete breaking down, particularly under enormous horizontal twisting.

The buildings in the valley were built as communities, adapted to life in earthquake-hit areas. For example, in locations with soft, water-bearing soils, the development of timber-frame construction is a necessity for the long-term survival of the structure. The heating and cooking systems of these houses have remained intact for a long time due to simpler architecture. The problem occurs when the structures tilt due to rigidness [3]. Stoves were, and still are, made from clay and a copper vessel embedded in the masonry wall to heat the water. Due to the low additional effort, stoves made of galvanized sheet iron are becoming increasingly popular. Woven wicker building systems in Kashmir date back to the 12th century, but it was not until the early 19th century that these systems split into two traditional building styles: Taq and Dhajji Dewari. After the 2005 earthquake, other earthquake-resistant indigenous constructions were found in Kashmir, with certain variations in highly mountainous areas where soft soil is not a problem. The access to good soil for brick making, water and timber, and earthquake resistance are some of the parameters which control the efficacy of vernacular architecture.

II. EVOLUTION OF BUILDINGS

A. Taq (Bhatar) Buildings

Taq is conventional form of construction in Kashmir, known for its resilience to earthquakes. The TAQ system consists of load-bearing masonry walls with timbers included [3]. Masonry is of low strength and is referred to as sand-lime or clay mortar masonry. The brick pillars are connected like a ladder by the wooden beams on each floor and each window level. The symmetrical arrangement of windows is a distinctive feature of TAQ; thereby resisting earthquake collapse. The idea is that by allowing movement of the masonry and confining the wall's brick slurry, structures can be made resistant. All of the weight of the masonry can be placed on the timber, which allows the structure to be held in place. These buildings are flexible enough to sway in the event of an earthquake. The materials in Taq are not ductile and do not show plastic behavior under loading. The behavior exhibited by this kind of flexibility is due to energy dissipation from the friction between the timbers and the masonry; which is due to low-strength clay or lime mortar. Any materials that allow flexibility are readily available in Kashmir, but these naturally occurring materials are typically not strong enough to provide rigidity. These ancient buildings possessed conventional Kashmiri patterns and designs, holding cultural relevance for the community. Much discussions have been held by concerning bodies about introducing modern elements into Taq buildings, but these have proved irreconcilable. The usage of steel rods and the discordant methods such as welding requires more expertise.

1) The Earthquake Resistance of Taq Construction

This construction system has proven to be efficient in seismic areas. According to Professors Rai and Murty, many of the older buildings were of the Taq system, which used logs of timber as horizontal runners incorporated in the heavy walls. These horizontal runners add load resistance to the structure. Because masonry is intertwined with timber, destructive cracking is arrested, spreading deformation evenly, contributing to the energy dissipation; the structure maintains its structural integrity and load-bearing capacity without destabilization The wood runners are used to connect the short wall to the long wall. The system is advantageous in a way that it imparts ductility to the fragile structure., thereby enhancing its energy absorption capacity. The enhancement in energy absorption capacity is a positive influence for the Taq system to withstand earthquakes. However, what makes wood-paneled masonry perform well in earthquakes is its ductility. In this construction system, the role of the mortar is to keep the bricks separated and timber does the job of keeping the bricks intact. The friction and cracking occurring in a masonry wall constrained by timber bands, proves advantageous in terms of earthquake resilience.

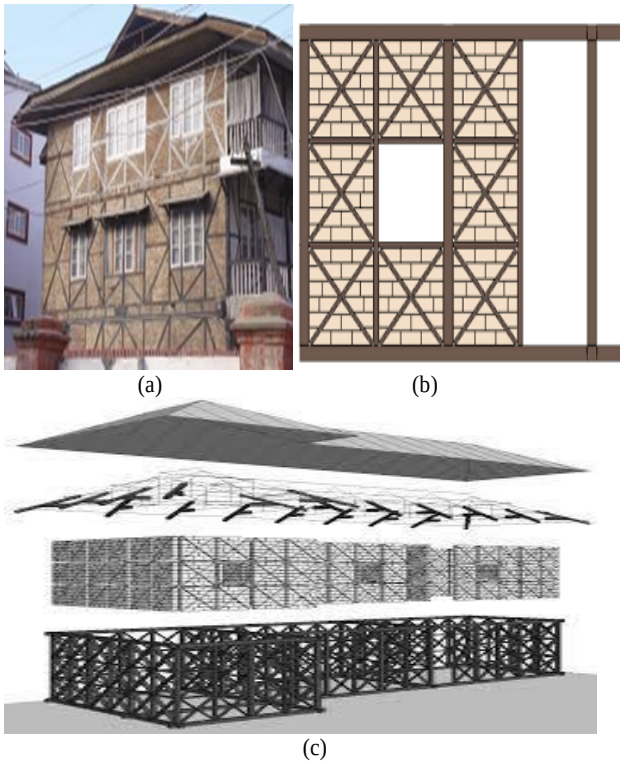
B. Overview of Dhajji-Dewari

The term Dhajji Dewari is derived from a Persian word meaning “patchwork quilt wall” Arup,2020]. The method has been developed by the Kashmiri people over the previous centuries to counter the frequenting earthquakes of the region. The method is mentioned in literature from as early as the 12th century (JSTOR,2020) which essentially marks the beginning of the vernacular urban

architecture that's still seen in the old part of downtown Kashmir (Figure 3).

The dhajji dewari is a very straightforward construction method in which timber frames are braced with cross facing diagonal beams and small spaces are left in between. The spaces left in between are filled with a thin wall of brick or stone masonry that is laid into a very lean mud mortar. (Figure 4 A&B). The vertical and horizontal cage formed by the wooden frame allows for diagonal movement against sheer loading. The buildings are mostly located on flat terrain and are free-standing. Due to the factors such as speed, cost and availability of resources, this type of construction has been used for over 200 years. The skills required are not exhaustive of the work required and these structures perform better than the original Taq buildings.

Towards the end of the 21st century, several people were building in reinforced concrete, but disadvantages included the poor thermal performance of hollow concrete block construction; the effect of which was particularly evident during the cold climate [Ashna,2021]. Many dhajji houses are also used as shelters for livestock. Agriculture and farming being an integral part of Kashmiri society, so it is important to protect animals during an earthquake. As land ownership is the main form of inheritance, it is difficult for communities to relocate to the region. This is another reason why buildings are built tall on a lot, as well as the high density of buildings in these areas. There is a sense of workmanship in making these buildings less complex and reproducible as possible for the community.



(a) (b)

(c)

Figure 4: (a) Representation of a Dhajji Dewari wall.; (b) A Dhajji Dewari wall; and (c) A Dhajji Dewari wall masonry (Source arup.com)

The succeeding section discusses about the various architectural aspects of the evolved dhajji dewari with the main focus on functionality of the structure. A common practice in the valley of Kashmir is to use the Dhajji Dewari for upper story walls and gables (AR Dar, 2020). The structure that is created in this was develops an elasticity and seismic resistance capability known to show resistance to earthquakes compared to plain masonry construction as was proven by the fact that houses made of dhajji dewari suffered little to no damage in the 2005 Kashmir earthquake (arup, 2020).

Structures of this development type can be found in both the Pakistani and India sides of Kashmir. Comparative types of development are found in Britain, France, Germany, Central America, South America, Turkey, Greece, Portugal and Italy and in all probability other Eastern European nations. They are known as half- wood, colombage, Fachwerk, taquezal or bahareque, quincha, hımışand Gaiola individually for certain minor varieties as. This type of development is otherwise called Brick nogged wood outline development in India. As per an article by V.K.Joshi this building type is known as Kat-Ki-Kunni in the locale of Kulu and Pherols in Uttarkashi in Uttaranchal in India [Housing Report,146]

C. Working Principle of Dhajji-Dewari

In the event of an earthquake where dhajji dewari structure has to bear the earthquake, the infill of brick mortar starts working along the between the timber frame and red filing (IITK, 2020). There is a significant sliding and straining between the brick and timber causing the energy of the earthquake to dissipate to a big level (IITK, 2020).

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The basic engineering principle behind the success of this construction method during earthquakes appears to be the absence of any strong and stiff elements. The structure survives by not resisting any seismic activities but instead by swaying them.

Figure 5: Unreinforced wall collapsed whereas the timber frame masonry section is still standing despite inertia

The movement of the masonry panels along the construction joints causes large amounts of frictional damping of the excitation of the building caused by the earthquake. Ordinary brick walls or unreinforced brick walls under the force of a lateral earthquake develop diagonal cracks that then progress to complete destruction of the wall. In case of dhajji dewari the cross bars that are spaced closely prevent the development of diagonal cracks and hence help the wall in withstanding the in-plane and out-of-plane shaking (IITK, 2020).

1) Structural Elements

- *Walls:* The timber braces is being used in newer buildings. Rubble or hewn stone covered with clay mortar is also used. Clay mortar can be reinforced by the adding of lime, natural to avoid mortar shrinkage. The extent of the mortar's hysteretic behavior under seismic action is not known, but unlike sand-cement mortar, the clay mortar is expected to retain ductility, like malleable clay, and therefore capable of continuous to make new connections and its energy absorption ability. The scientific research is needed to quantify the value of mortar in terms of energy absorption.
- *Foundation:* Semi dressed or rubble stone masonry (dry or mud mortar) is used as a resource for foundation building [Housing report,146]. Recently, sand cement mortar and/or reinforced concrete straps and anchor bolts have become more common. The adequacy of the foundation is determined more by the foundation depth and the quality of the stone wall construction and is a crucial factor for defining the efficacy of the structure. The regular use of adhesive bricks, an appropriate ratio of wall height to thickness are also defining parameters.
- *Frames (beams & columns):* Wooden beams covered with wooden planks truss frame, with joinery and wooden dowels and wedges. Main frames made of beams, columns and struts are mostly made of softwood. Specifically, Deodar species is used for procuring timber. The use of wood with good rot and fungus quality is preferable to select for use on components that will be exposed to moisture. Building green timber Dhajji houses will no doubt have its own problems, particularly in cases where significant shrinkage occurs as wet timber frame dries and acclimates to the environment in which it is set. Finally, it is important to emphasize that the choice of wood is an art of craftsmanship and comes with its own set of rules.
- *Roof and floor:* The compact floor and leveled screed Shingles (i.e., wooden roof tiles) connected to wooden purlins, are often made of solid wood planks or planks. Recently, corrugated galvanized steel (CGI) has come into widespread use. The thickness of the metal deck is believed to be very thin, A sense of ambiguity is infused among the experts, researchers towards the longevity of many of the recently constructed roofs due to the fact that galvanized sheets are very thin. Hence, further studies need to be conducted to improvise the material used in constructing the roof and floors so as to withstand the harsh climatic changes and unpredictable seismic influences.

2) Building Concept of Dhajji-Dewari

Confined masonry structures have shown good execution in past quakes. As a general rule, structures of this sort cause experience a few harms in quakes, but when appropriately planned and developed they can support tremor impacts without breakdown. Latin America is unquestionably a district of the existence where restricted brick work development is generally utilized and tried in a few critical tremors related with the locale's high seismic danger. As per Schultz (1994), low-ascent restricted stone work structures have performed very well in past Latin American seismic tremors. This applies to structures normal in arrangement and height, which are delicately stacked and have rather enormous divider thickness. In such cases, restricted workmanship will in general be very sympathetic of minor plan and development imperfections, just as material lacks.

Poor seismic execution has been noted just when gross development blunders, plan defects, or material inadequacies have been presented in the structure plan and development process. Terrible showing is normally connected with tie- segment exclusions, intermittent rafters, lacking stomach associations, and unseemly primary arrangement. Seismic execution of restricted workmanship development in Latin America and different areas of the planet will be examined in this part. The earliest reports portraying the tremor execution of bound stone work structures date back to the 1939 quake (size 7.8) in Chile. In Chillán, where a Modified Mercalli Intensity (MMI) of IX was accounted for, more than half of all assessed bound workmanship structures supported the seismic tremor with practically no harm, though around 60% of unreinforced brick work structures either to some degree or completely imploded, bringing about a loss of life of 30,000. Accordingly, the 1985 Llolleo quake (extent 7.8) with a focal point in the focal piece of Chile, made the breakdown of 66,000 residences and harm another 127,000 abodes (the impacted homes were for the most part adobe development). Out of 84,000 lodging units reviewed after the seismic tremor, around 13,500 units were of bound workmanship development. These structures went from one-to-four stories in stature.

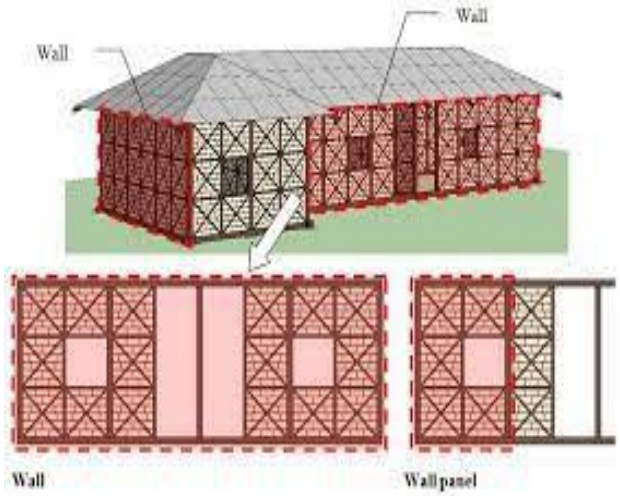

Figure 6: Dhajji Dewari Layout

Out of completely examined structures, the most harm was incurred to medium-ascent structures (3-to-5-stories high); around 22% of these bound stone work structures supported extreme or weighty harm. Low-ascent structures supported exceptionally restricted harm; just 2% of two-story high structures were harmed, while the single-story structures were not generally harmed. Generally speaking, a greater part (76%) of the bound stone work structures were whole (Moroni, Astroza, and Acevedo, 2004). Harm to restricted brick work structures was fundamentally because of the shortfall of tie- sections at divider crossing points or around the openings; this again focuses on the significance of tie-segments in guaranteeing the seismic obstruction of bound workmanship structures.

3) The Earthquake Resistance of Dhajji-Dewari

The Dhajji-Dewari construction system has also proven to be very effective in earthquake-like conditions. The Dhajji-Dewari construction system has been found to cause less or no damage in earthquakes. The presence of wooden studs in dhajji-dewari construction divides the fill, halting the loss of part or all of several panels of masonry, and resisting progressive destruction of the rest of the wall. In addition, the closely spaced studs prevent the propagation of diagonal shear cracks within a single panel and reduce the possibility of out-of-plane masonry failure of thin half-brick walls, even on the higher floors and in the gable end of the walls. The rationale of this weak and flexible masonry infill frame is that there are no strong and rigid elements that could absorb the full lateral force of the earthquake and as a consequence the buildings survive the earthquake by not fully engaging in it.

The engineering principle behind the seismic performance of the Dhajji Walls is meek. The division of the walls into many smaller panels with studs and horizontal members, combined with the use of low strength mortar, prevents the formation of large cracks that can cause the entire panel wall to collapse, while redundancy is provided by many walls present in a standard residential building, thereby plummeting the probability of calamitous failure of the frame [Dhajji Dewari,2019].

Over time, the architecture has evolved in terms of resources, methodology, labor, etc. The following section deliberates about the comparative analysis of modern architecture with the traditional ones and its significance to the masses. The seismic sustainability, deficiency and earthquake damaged patterns of different structural elements such as foundation, wall, infill, roof, roof level, etc. and materials required are elaborated below so that the researchers can dug deeper into nature of the problem.

III. RELATED WORK

Earthquake risks evaluation on individual buildings and a community as whole is a very ardent task entailing to manifold difficulties and in Kashmir the story is no different. Kashmir has 14 districts (JK Govt, 2020) which requires an intensive field survey for vulnerability analysis of the built structures to understand the structural vulnerability of the region. The vulnerability that a building faces from an earthquake depends on a variety of functional and form parameters. Residential buildings are five times more vulnerable to earthquakes than commercial buildings (Cochrane and Schaad,1992).

Cochrane and Schaad in their research in 1992 determined vulnerability of buildings based on the material used and the age of construction along with design as the main indicators of building vulnerability (Cochrane and Schaad,.1992). There is very limited research done to evaluate the dhajji dewari construction. A better investigation is required to understand the structural behavior of the dhajji dewari to boost the confidence of the general population in this particular construction method. There is an immediate need to identify aspects of this construction method that are critical to the reliability of this method.

But the lack of knowledge and research in the field caused the donors to show reluctance. Even the Earthquake Reconstruction and Rehabilitation Authority of Pakistan (ERRA) seemed reluctant to promote this type of construction for the very limited scientific evidence for this type of construction (arup, 2020).

A.H. Shah, A.R. Dar and Jayalakshmi Raju (AR Dar, 2020) used six 50 tonne capacity loading frames of various configurations for determining the ideal bracing arrangements for the construction and used a 200KN hydraulic jacks for application of loads to the frame. The experiment was carried out on the 6 most commonly used bracing configurations in the valley of Kashmir, after carrying out an extensive field survey. The defections were measured in top of the frame and the center of the frame, using dial gauges. They observed a failure pattern in various joints and posts. Vertical cracks were observed in one of the patterns. After performing tests on 6 frame types, it was observed that the best and the most efficient bracing arrangement was the one in Figure 5. Furthermore, they concluded that if the bracings are increased in a wall by 100% it increases the ability of it to resist an earthquake by 300%. (AR Dar, 2020).

K.M.O. Hicyilmaz, T.wilcock, C.Izatt, J.da-Silva and R. Langenbach (WCEE2012_2692, 2008) in their research on the seismic performance of dhajji dewari

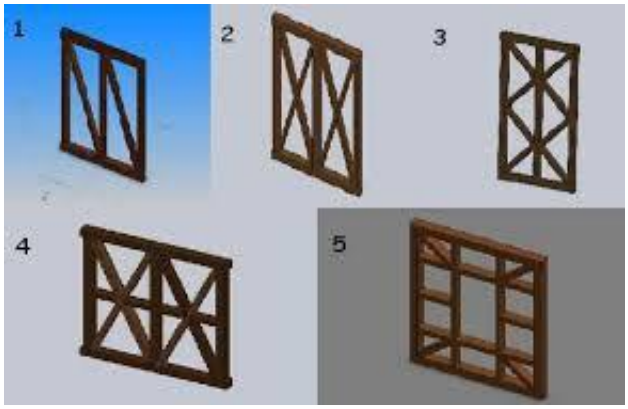

Figure 7: Most commonly used timber frame configurations in dhajji dewari (Source: AR Dar, 2020)

They chose a house of dhajji dewari construction in Pakistan administered Kashmir for a detailed nonlinear dynamic time history analysis (WCEE2012_2692, 2008). They created a detailed LS-DYNA computer model and modeled the timber frame and masonry blocks as solid elements with contact surfaces between all members to account for frictional behavior. They chose a light weight roof system. The performed a nonlinear static push over analysis and nonlinear response history analysis and used RSPMatch2005 to generate the compatible records. They demonstrated how it was possible to model the behavior of a dhajji dewari building. After cross checking their findings with the results of a physical test conducted by University of Engineering and Technology, Peshawar Pakistan, they observed that the analytical model had reproduced the same pattern of deformation that were observed in the physical tests. They maintained in their conclusion that the dhajji dewari is capable of resisting earthquakes in high seismic regions of the world if built properly with proper maintenance. They also concluded that as long as the timber framing remained together during an earthquake it provided confinement to the masonry infill making it critical for the connections to have ductility and strength and that nails and metal straps if used strategically could enhance the performance of the building during an earthquake. One of the most important concussion o their research was that the more the burden on the masonry the more the ability of the system to absorb energy, which made them conclude that the use of dhajji dewari construction on more than one storied structure may be satisfactory. They also concluded that shortening of the braces so that they separate from the timber frame improves the seismic absorption capability of the structure without any adverse effects (WCEE2012_2692, 2008).

In their research titled “In-plane behavior of the dhajji dewari structural system”, researchers Qaisar Ali, Tom Schacher, Mohamad Ashraf, Bashir Alam, Akhtar Naeem, Naveed Ahmad and Muhammad Umar (SAGE journals, 2020), they presented experiments and numerical investigations which included an in plane quasi static cyclic test on conducted in three full scale walls and monotonic tension and bend test on main connections. They constructed three dhajji walls from three different sets of members having dimensions 100mm x 100mm, 50mm x 100mm, 25mm x 100mm. They applied a vertical dead load of 2 KN to simulate roof weight and used nails to secure the joints and connections. Two among the three walls were tested with masonry infills while one was tested without any infill. They left one of the walls without infill to test the effect of infill on the dhajji walls. In the other two walls the brick to mud ratio was 9:1(hard infill) and 7:3(soft infill) respectively. Then a hydraulic jack was used to induce the load on the walls built and a total of 18 tests were carried out and data was obtained using using displacement transducers.

The numerical investigation was carried out using a software that is finite element based called SAP2000 v.08 to do the modeling of the walls. They kept all the characteristics of the numerical modal same as the experimental model. They concluded with their study that dhajji dewari walls bared a lot of load cycles before showing signs of losing structural integrity, proving that they show resilience towards lateral forces. They also concluded that the load bearing capacity of a dhajji wall depends on the quality and performance of the timber configuration framework with very little to no contribution of the masonry infill. The endurance capability of the cross beams and the diagonal members between the vertical posts and the bottom members determine the capacity of the wall to bear a seismic movement. Further they observed that the choice of masonry infill and the difference between them hardly affected the ductility and strength of the dhajji wall. In the numerical investigation they concluded that nonlinear static pushover analysis of simplified numerical models ignoring the effect of infill and employing the elastoplastic curves of connections can be conveniently used for capacity evaluation of dhajji dewari walls. Furthermore, they concluded that since the main timber members did not suffer any damage during the testing, the type of timber used in the constrain of a dhajji dewari structure will not affect the overall performance of the structure, provided the timber used is well seasoned and treated against termites (SAGE journals,2020).

Sidratul Muntaha Anees and M.Sultan Bhat (IAEME, 2015), did a research on assessing the seismic vulnerability of residential buildings in Srinagar, the capital of Kashmir and conducted an intensive field analysis of about 300 houses in all the 68 municipal wards of Srinagar city. They conduced vulnerability analysis of buildings to assess their vulnerability. The concluded that the residential structures located in the inner parts of srinagar locally known as the down town, is very densely populated and has structures usually ground +3 floors that are constructed with poor materials and lead to a very high vulnerability inside the old city. But people who have moved to suburbs have built newer constructions in a more spacious setups mostly with modern construction materials making them less vulnerable to earthquakes. They further concluded that a lack of governmental initiative to check on old structures for signs of weakness by trained civil and structural engineers has led to entire localities become vulnerable and more prone to fatalities and casualty in case of an earthquake. They further concluded that the government has failed to educate the people about common concerns of structural vulnerability which could then be handled at personal levels. According to them seismic evaluation of the buildings should be carried out timely in order to understand and mitigate the risks posed by them.

Most of the other researches done on the subject are about General observations made by researchers during and after the 2005 Kashmir earthquake like by Jitendra K Bothara

and Kubilay M O Hicyilmaz (Bothara,2006) and Randolph Langenbach (Langenbach-1989 APT Article-Bricks, Mortar and Earthquakes, 2020) and these discuss the observed behavior of builds dusking the earthquake and attribute much of the damage done to structural failures and problems of the built environment in Kashmir.

IV. RESEARCH METHODS

A. Literature Review as a Research Method

The research needed a relevant review of literature to support the findings and objectives. The research method is study is a systematic literature review done to find answers to the research questions. The literature review was done from the very limited research on the topic done mostly by community researchers, universities and students.

Table 1:Approaches to literature reviews (Source: Snyder, 2019)

Approach	Systematic	Semi-systematic	Integrative
Typical Purpose	Synthesize and compare evidence	Overview research area and track development over time	Critique and synthesize
Research questions	Specific	Broad	Narrow or broad
Search strategy	Systematic	May or may not be systematic	Usually not systematic
Sample characteristics	Quantitative articles	Research articles	Research articles, books, and other published texts
Analysis and evaluation	Quantitative	Qualitative/quantitative	Qualitative
Examples of contribution	Evidence of effect Inform policy and practice	State of knowledge Themes in literature Historical overview Research agenda Theoretical model	Taxonomy or classification Theoretical model or framework

An overview of literature review approaches was given by Hannah Snyder (Snyder, 2019) that the approaches to a literature review methodology. The systemic review is a research method for identifying relevant research to your field of inquiry and then appraising relevant information along with data collection and analysis. Using this method requires a systematic strategy to review articles and evidence and eliminates bias and makes the findings more reliable and easier to make decisions from.

B. Data Collection and Procedures

All the date was collected from published research articles and papers with extensive field investigation. Hardly any governmental data is available on the subject but whatever could be accessed online has been used for justifying and comparing the results. Almost all the academic documents and journals published along the theme of post disaster reconstruction in Kashmir, dhajji dewari, earthquake resistant housing in Kashmir has been reviewed.

This research paper was structured in four phases of writing a systematic literature review research according to Hannah Snyder (Snyder, 2019). The first phases consisted of designing the review, the second phase consisted of collecting and reviewing the collected data for use. The third part consisted of analyzing the data and abstracting the required information and the fourth part consisted of writing a properly structured paper.

C. Results and Discussions

Research in to the dhajji dewari construction has demonstrated that the method of construction can resist an earthquake, as seen in Kashmir during the 2005 earthquake, if it is built properly and subsequently maintained adequately making it a valid construction form in an earthquake prone zone with limited access to modern earthquake prone material and construction technology. The timber framing of the dhajji dewari is the most important part of the construction and provides the stable confinement to the masonry and keeps it together. The timber framing forms the most crucial part of the construction and therefore requires the connection between timber members to have detailed and sufficient strength. To achieve this there has to be a strategic and cautious use of steel nails and metal straps to strengthen and therefore, improve the performance to connections between members. When constructed properly the dhajji dewari construction dissipates the seismic energy by creating a friction between the timber frame and the masonry infill and the connections. It has been observed that most of the failures in a dhajji dewari construction take place at joints and connection between timber members making them the critical most parts of a construction. Furthermore, if the improvement of the performance of joints is achieved by strapping them together or by metal nails it enhances the performance of the structure. If the bracings on the joints of the timber members are increased by 100% the strength of the structure is increased by 300%. Providing extra support to the joints by metal straps increased the lateral strength of the construction by 300%. Further research is required to warrant the use of nails and metal straps to find an optimum nailing and strapping configurations and therefore the arrangements of the timber members. Nails and metal straps are prone to rusting and eventual loss of strength which could be superseded by further research into the matter and development of an equally successful substitute. Good carpentry connections between the timber frames should not be overlooked. The arrangements and configuration of the timber members needs a lot of further research to find the optimum configuration of timber members for the best possible performance of the structure during an earthquake.

The quality of timber used in the construction needs to be

regulated for better maintenance even though the type of timber used in the construction does not matter if arranged properly. The type of infill used in the dhajji dewari buildings makes very little difference in the structure even though research has shown better results from thin mud mortar structures. To create sustainable and reliable construction technology in a place like Kashmir, where access to modern methods of construction is very limited it is important that researches and developments be made into the available resources to create communities that are safe to live in. Dhajji dewari construction if researched further and implemented properly can offer hope in the field because it ideally uses durable and renewable materials that are locally available in abundance making construction and subsequent maintenance easy.

It has been proven that Dhajji dewari construction offers earthquake resistance and even if it incurs damages during an earthquake, can be easier repaired.

V. CONCLUSION

In this paper, attempts have been made to understand the behavior of a dhajji dewari construction during a seismic activity and to try to figure out ways to generate ways for better and wider acceptance of this method of earthquake resistant building system among the general population of Kashmir and the government. Confined masonry structures have performed well in a few seismic tremors around the world. This kind of development has an incredible potential for saving lives and property in areas of high seismic danger in India. Nonetheless, similar to some other development practice, great seismic tremor execution depends on the accompanying premises: (a) Utilization of good quality materials, (b) Great quality cement and stone work development, and (c) Straightforward compositional plan. It is normal that this straightforward rule including compositional plan and development of bound workmanship structures will be valuable to draftsmen, manufacturers and different gatherings engaged with the structure development.

The method of dhajji dewari is widely under-researched method of construction lacking a validated analytical model. It needs further deep researches to be undertaken to capture its earthquake performance capabilities. Research and investment are required to create building construction and building standard guidelines with evidence-based earthquake engineering for the dhajji dewari method of construction. The same evidence-based earthquake engineering codes for building standards and guidelines could be used to retro-fit existing dhajji dewari constructions. There are very little design guidelines if any and whatever guidance available is through anecdotal findings and some rules of the thumb. These are without doubt valuable but there is no validation with which their reliability can be tested. There is an immediate need for a dhajji dewari buildings code and construction manual for use by the common people.

The government needs to arrange for strict laws and codes be implemented along with regular checks for vulnerability and failures to be conducted by civil engineers and other trained professionals. These regular checks and observations can be used to bring out concerns about the vulnerability of the buildings. Media, both print and electronic, should be used to aware the general population about the concerns of structural vulnerability and the developments made in the field of dhajji dewari for people to adopt the changes and develop stronger communities. The government should introduce dhajji dewari as a subject in university degrees in engineering to enhance the research and interest of people further more.

Deep and detailed testing should be undertaken by governmental funding to understand the use and utility of timber members and their joints and configuration. There is no one optimum bracing pattern that can use the least possible timber and get the best possible result in case of a seismic activity. We need to understand exactly how dependent this construction method is on having good quality timber members and frames. We need to figure out the importance of joints in members. The use of subsidiary retention elements like nails are used extensively in dhajji dewari construction and have proven to enhance the performance of the structure. But nails have a tendency to rust and thus compromise the structural integrity of the construction and could be replaced by proper carpentry.

The concept of attaching nails and other supplementary joint enhancement elements modifies the behavior of the structure in a positive manner but needs research to be understood better. There has to be extensive research on the cyclic loading of nailed joints and its evaluation on the seismic behavior on the entire structure. Metal strapping is also used in many cases but the benefits of these straps and their proper use needs to be understood better and needs new rules of use to make the best possible use of these straps. The same metal straps have to be defined with regard to their importance in different configurations.

Researchers have yet to find out if or not metal straps change the fundamental behavior of a structure, when used extensively, The same stands true for the behavior of infill masonry in dhajji dewari. We know almost nothing about the behavior of masonry infill in dhajji dewari and needs extensive research. We also need to gain understanding of sensitivity of coupling or not coupling perpendicular walls and its importance on the overall performance of the structure. Research is required into what is the safest height for a dhajji dewari wall and when it becomes unsafe for people to decide on the designs of their homes. There is absolutely no research on how a roof on a dhajji dewari house should be constructed for best possible performance even though we know deadweight on the dhajji dewari structure increases its lateral strength.

We have very limited research in this indigenous construction method but a useful idea about how it behaves in an earthquake. Further research into this method of construction can provide an inspiration for development of earthquake compatible construction method to be used in the landlocked and economically backward region of Kashmir. We need to have more and more insights and the engineering know how of this method of construction and its performance vis-a- vis the local economy, the engineering expertise available, supply of labour, production and delivery of the materials required and a very strict inspection of what is constructed. There exists a big gap between the possible and the practical. There has to be stricter engineering regulations enacted. The immediate need is to understand the positives and the negatives of this method of construction and find a way forward to preserve and develop it further. Modern, un-

engineered structures are coming up all around Kashmir, pushing into obsoleteness this vernacular construction method and one of the biggest and unrecognized issue is the cultural loss which it inevitable brings along. Dhajji dewari houses in Kashmir are ancient and represent a tradition. The replacement of these structures with the modern construction is an attempt at destroying that tradition at the hands of people whose ancestors built that tradition. A form alien to the valley of Kashmir is creeping on the landscape.

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