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SEISMIC RESILIENCE IN ANCIENT INDIAN TEMPLES

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Abstract

The study of Indian temples reveals that these were carefully planned and built. The temples have always been an integral part of Indian cultural heritage. The skillful planning, methodology and rigorous measurements in temple building suggests that they partially bear the stress of natural hazards because of such building methods. Some of the temples come under the seismic zone v, which is the most active zone where earthquakes of high magnitude have occurred during past years. This paper will deal with the style, design, structural system and construction of large temples in ancient India with special reference to the region of Himachal Pradesh and Gujarat. These temples have been able to survive against the seismic forces and other environmental hazards till date. There are various temples which were built keeping in mind the technology that the structures withstand the earthquakes and other natural calamities.

INTRODUCTION

India is a vast country and is renowned throughout the world because of its monumental structure both secular and religious. The ancient master builders were aware of the destruction caused by natural forces to the man made construction. The temple structures are designed to withstand the shock of earthquakes and not to crumble down. Depending on the seismic zone these structures were located in, they were constructed to withstand a certain magnitude of earthquakes. By the term earthquake resistant it is not assumed that it is earthquake proof, it could lastly crumble down in piles if the earthquake of higher magnitude occurs. The key idea in making a building earthquake resistant is to make it ductile i.e. to give it a certain flexibility to

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shake horizontally. Stiff buildings when faced with earthquakes, would go down, but the flexible one would sway and come back to their original position. The idea is to soften the impact of the earthquake and not let the building absorb the energy.[1]

This paper will emphasize on the evolving aspect of resilience of infrastructure with special reference to Indian temples in Himachal Pradesh and Gujarat which had been victimized through the tragic occurrence of major earthquakes. The marvelous Indian religious structures are actually built on some kind of norms, proportions and measurements which is thus evident from various textual sources which lay down the rules of architecture such as the *Vishnudharmottara Purana* (5^{th} – 7^{th} century AD), the *Mansara* (6^{th} – 7^{th} century AD), the *Mayamata* (6^{th} – 7^{th} century AD), the *Samrangnasutradhara* (11^{th} century AD) and various other *Vastushastras* and the *Shilpasastras* composed during ancient period. The Indian temple is a complex convergence of mathematical, geometrical and astronomical calculations. From multiple to one, from periphery to the center, from the exoteric to esoteric the Indian temple is a map of the meeting between the man and the god.[2]

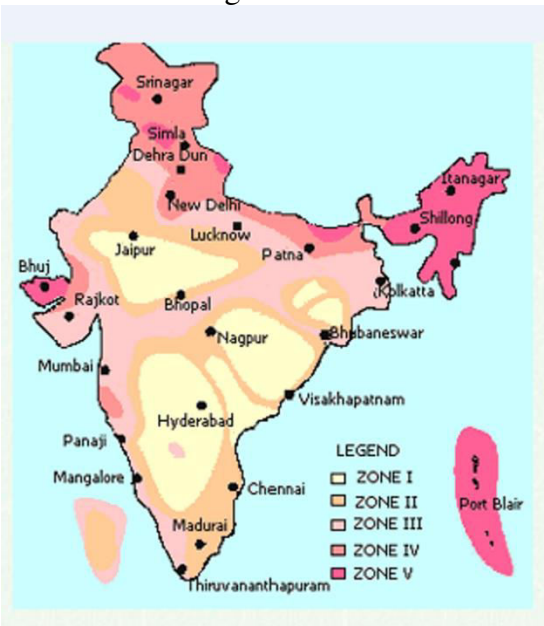

Fig 1 (SEISMIC ZONES OF INDIA)
(Source: http://earthquake.usgs.gov/hazards/)

Earthquake is a natural calamity which causes enormous disruption and destruction. India has witnessed several earthquakes since ages. The basic reason for the occurrence of the earthquake in India is the moving of the Indian plates into the Eurasian plates underground which tend to shake the upper habitation. Indian states lie in different seismic zones resulting into diverse levels of disturbances. Indian territory is distributed into V seismic zones (fig 1.) with respect to severity of earthquakes. Amongst all zones – zone V is seismically the most active where earthquakes of magnitude 8 or more could occur.[3] The respective areas which fall in the seismic zones-V are Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Gujarat and North East

[1] http://Indianexpress.com/article/explained/explained-biggestkiller-earthquakes-1900-2014/
[2] Marbia, Albanese "*Architecture in India*" White Star Publisher,Italy, 2004, p.6.
[3] http://earthquake.usgs.gov/hazards/

Himalayas. The study by historians, archaeologists as well as geologists poignantly reveals that 75% of the monuments falling in zone V of earthquake have already been damaged to quite an extent by the tremors. This factor cannot be ignored as the religious structures coming in the periphery of this zone have been drastically affected.

The temple or *prasada* or *mandir* or *devalaya* according to various textual sources is manifested and identified as the most sacred entity in Indian territory. The earliest shrines probably were without any kind of boundary wall or a well standardized structure from bottom to top, gradually the system of building the temples changed. Thus, the evolution of temple structure gained enormous architectural forms under various dynasties of Indian sub continent. This paper will thus provide an insight into the building techniques involved in Indian temples to sustain natural seismic forces.

Science and technology plays an important role while building up any form of structure whether on a leveled or a rough platform of ground. The *Vastuvidya* or the *Vastushastra*- the science of residence or abode forms a subdivision of the *Shilpashastras*. The radical connotation of the word *Vastu* is very wide and the range of discourses in the *Vastushastras* is very comprehensive. The *Mansara* defines: "the place where men and gods reside is called *Vastu*". The *Vastuvidya* contains within its category the science of civil and military engineering, architecture and building.[4] The *Vastuvidya* helped the architects to build massive structures adopting all the technologies specified in the work so as they could withstand the natural calamities in future. The 32nd chapter of the *Brihat Samhita* of Varahamihira a text of sixth century describes the term 'earthquake'as *Bhukamp*, *Bhumikamp*, *Kampa* and also describes the circumstances leading to earthquake.[5] The Indian temples were built by the chief architect called the *Sthapati*, who actually was the master builder and planned the temple keeping all factors in mind.

The ground plan of Indian temple is purely based on geometrical sectioning of the land. The temples have been designed keeping in mind the human figure. The beginning of temple construction is very sacred keeping the religious aspect in mind but on the other hand if we infer upon the scientific aspect, the division of land is done on the basis of dividing equal section which may reduce the intensity of force only on one part or section of the temple. The temple structure is based on *Vastpurushamanadala* as referred to by Stella Kramrisch in her work the *Hindu Temple*. She describes that the "temple must be built according to definite rules and it must be firm." But the firmness does not primarily refer to a substitution of flimsy materials, such as mud, sand, wattle walls and bamboo posts by those of greater permanence; nor to the avoidance of careless construction in brick or stone nor to the desirability of such additional wall strength which would withstand earthquakes.[6]The basic form of the *Mandala* or *Manduka* is 'square' which represents the earth and the 'circle' represents the universe.[7] The *Mandala* is a

[4]Binode Bihari Dutt , *Town Planing in Ancient India*, New Asian Publishers, Delhi, 1977, pp 1-2.
[5] P.V.S Shastri, et.al, *Varahamihira's Brihat Samhita,* M.B.D. Electric Printing, Banglore, 1946,p. 270.
[6]*Isanasivagurudevapaddhati* and *Vaikhanasagama cited in* Stella Kramrisch, *The Hindu Temple,*Motilal Banarasidass, Delhi, 1976.p.12.
[7] Surender Kumar et.al. "*Building Science of Ancient Indian Temples".* in proceedings: National Conference on Innovative Development in Science, Technology& Management (NCIDSTM- 2015), published by: International Journal of Engineering Sciences Paradigms and Researches, March 1,2015, Haryana.p.100.

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grid of large and small squares and it is traditionally distributed into two types. The initial one is based on four central squares divided into sixty-four squares. The second fundamental type of ground plan is obtained – the *Paramshayin*, based on nine squares and divided into eighty-one squares.[8]The division of the *Vastumandal*a describes the various components of the temple. This simple division of square; permutation and combination became the base for the development of more complex temple in India.[9]

Symmetry means that a figure or a building to be in a balanced shape or to be in a geometrical configuration. The symmetrical forms are always preferred to those configurations with non-symmetrical profile, because asymmetry tends to produce eccentricity between the center of mass and center of rigidity, which result in torsion. On other hand asymmetry tends to stress concentration. In an earthquake resistant building it is very important to keep in mind the proportions while building it. The Indian doctrine of proportion is designed not only to correlate the various parts of building in an aesthetical manner but also to bring the entire building into a magical harmony with space.[10] According to Stella Kramrisch the norms of measurement and proportion of the temple reduces the earthquake pressure on the temple structures.[11] Four kinds of proportionate measurements of the *Prasada* are mentioned in the *Matsya Purana*.[12] The height of the wall equals to its outer length. The body of *Prasada* is a cube; its high superstructure is twice as high as the width of the *prasada*. On these fixed norms of proportion the elaboration and specific shapes are superimposed which distinguish each single variety of temples.[13] The module of proportionate measurements is either architectural or it is taken from the main cult object. The *Brihat Samhita* of Varahamihira gives only one norm of proportionate measurement whereas the *Vishwakarmaprakasha* and the *Matsya Puarana* convey wider information.[14] The standard compendium the *Samragnasutradhara* of Bhoja Parmara shows modification in the proportionate measurement of the temple.[15] The different formats of proportions actually gave strength to the building to fight against the natural calamities.

The temple architects have immensely used the ancient textual sources while erecting these religious entities. They tried to use the maximum of solid construction material to make the temple stand for posterity. The material used for building temple also gave it strength to fight against the natural calamities. Major construction material found in ancient India for building was clay, stone, wood, mud bricks, lime, timber, plaster and bamboo. The material played a significant role in overall aesthetics, constructional techniques and monumental character of a temple.[16] The brick was the main component while beginning the construction. According to Stella, the installation of brick (*Istaka-nyasa*) is the main foundation rite of the temple.[17]The stone was other material used as the substitute to brick. Therefore brick and stones were carefully laid down and joined. The stones were kept in position without any cementing material. For

[8] Marbia Albanese, op.cit, p. 14.
[9]Surender Kumar et.al., op.cit, p.100.
[10] Ibid.
[11] Stella Kramrisch, *The Hindu Temple*, Vol I, Motilal Banarasidass, Delhi, 1976, p. 237.
[12] Matsya Puarana cited in Stella Kramrisch, *The Hindu Temple,* p.228.
[13] Ibid.
[14] Ibid.238.
[15] Ibid, 244.
[16] Surender Kumar et.al., op.cit, p,100.
[17] Stella Kramrisch, op.cit, 105.

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joining the construction material together iron clamps were used for wooden joints. The stone blocks were held together with iron dowels. The *Sudhasila* (plaster) and *Vajralepa* (glue) cement and coating were applied for durability.[18] There were three kinds of joints used in the temple structure. The first one called the mortice and tenon joint (fig 2) which was mostly used to hold the horizontal assemblage. The second type of joint was the lap joint (fig 3) which was basically used for the vertical assemblage. The last kind of joining method was the mortice and tenon joint with a peg fixed (fig 4) between two stones.[19] This was usually used to avoid the movement of the stones due to lateral forces. The other kind of material which was used was bamboo which is lighter in weight and less destructive. Whether the bamboo is used in brick or carved in stone, the curves are copied in bent wood and mixed in brick and stone. Bamboo has a blending nature and its inherent quality and subtle nature gave it a permanency which its physical nature could not do.[20] Lime is one of the construction material which was used commonly as a binding material mixed with some natural additives because it had a good cementing ability.[21] It can be concluded that the builders or architects (*sthapatis*) were aware of the properties and importance of durability of different types of construction material thus they used different building material in different regions.

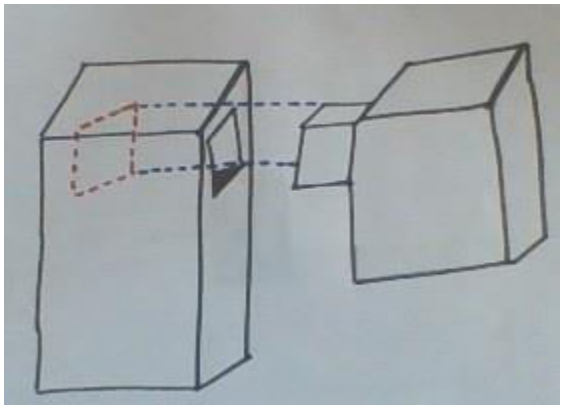

FIG 2: Mortice and tenon joint: horizontal

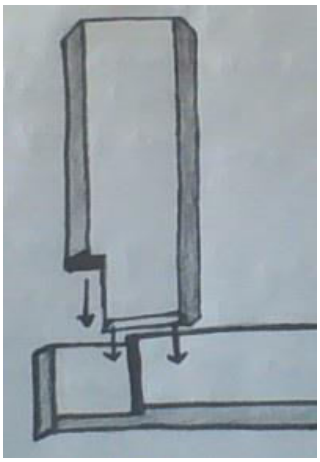

FIG 3: The lap joint: vertical

(Source: www.himalayanacademy.com) (All drawings by the Author)

[18] Stella Kramrisch, op.cit, 121.

[19] Shewta Vardia, " *Building Science of Temple Architecture",* In Erasmus Mundus Programme, Universidade do Minho, Portugal,2008, p.56.

[20] Stella Kramrisch, op.cit, 125.

[21] H.A. Wankhede, et.al, "*Sustainable Material and Construction Techniques in Ancient India*" In Imperial journal of interdisciplinary research (IJIR), vol.2, Issue-7,Pune, 2016.

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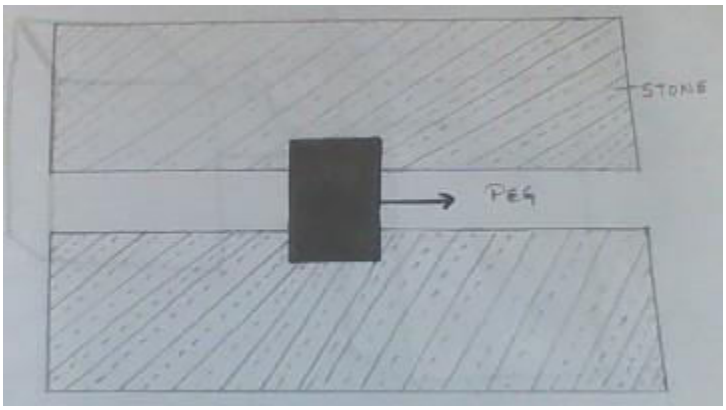
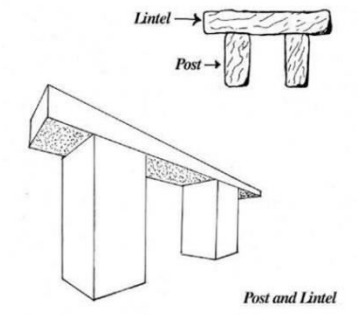
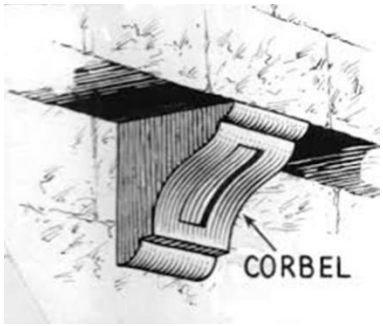


FIG 4: Mortice tenon joint with a peg (Drawing by the Author)
(Source: Shweta Vardia, *Building science of Indian temple architecture*)

Two formats were prevalent in the structural plan. The first one was the 'trabeated' (fig 5) and the other was 'Corbelled' (fig 6) technique. Initially the most favorable method which was adopted was the trabeate which later on shifted to corbel. In the first technique the various arrangements between vertical elements (Pillars and Pilasters) and horizontal elements (cross beams and lentils) was used to provide stability to the structure. On the other side in the corbelling technique, the stones or the bricks in each horizontal course was projected out to bridge the gap between two walls to diminish until it can be closed to the single piece of stone or brick. The corbelling technique was used to create the interiors of the temple and the stone shells of the superstructure that rise above the sanctuary. Later in the 13th century use of iron clamps and wedges to hold the stone slab together, allowed the special feature of corbelling in which horizontal stone layers were projected out over large spans and cut into unusual shapes to produce highly decorative ceiling schemes.[22]



(FIG 4) Trabeated Design
(Source:http://www.pinterest.com
/vanessapius/art-history-terms/)



(FIG5) Corbelled Design
(Source:study.com/academy/lesson/
what-are-corbels-in-architecture-
definition-uses.html)

[22] Shewta Vardia, op.cit, pp. 29, 30.

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There are enough instances of these designs in our country. The construction of temple was long and a tremendous process. There was a whole team of architects involved in the framework which initially included the *Sthapati* (designer architect) who was well versed in the traditional sciences, mathematics and the *Shilpasastras*. The *Sutragrahin* (Surveyor), *Taksaka* (Sculptor) and *Vardhakin* (builder-plasterer-painter)[23] were under the main architect who assisted him in the construction of the building. The selection of the site, soil, material, plan and execution was carried out by them. The priority was given to the proper selection of the site suitable for laying town and temple foundation[24].They followed the prescriptions enumerated in the *Vastushastras* so that there is effect of the seismic forces. Earthquake forces are generally felt at ground level. The ground floor had to carry its lateral load as well as the pressure of upper floors too. This phenomenon was well understood by the Indian master builders. The technology which they followed was the structural plan density building in which the total area of all vertical structures were divided by the gross floor area. The size and structural density was more in Indian temples as compared to the present day buildings. For an RCC framed building it is generally 3% but in Indian temples was as high as 47 % in the case of Sun temple, Konark.[25] The technological framework while building the lateral part termed as *shikahara* is worth describing. The structural system used in construction of the tall pyramidal temple roof is designed for greater structural strength.[26] In the north Indian temples, the cavity above the cella narrows towards the top in a curve like manner called *Shikhara,* although the cella is often too wide as compared to that of its height. Similarly in South India, stone was used only in the lower storey, while upper storeys were made up of brick courses and wooden beams. In addition to this, the temple tower above becomes progressively narrower towards the top corresponding to the tired division of façade which demonstrates the gradual decrease in mass of the South Indian temple towers. This phenomenon resulted in light weight structures which apparently looked massive.[27] The stones used at the corners were either interlocked (fig 6) or provided with iron clamps.[28] (fig7)

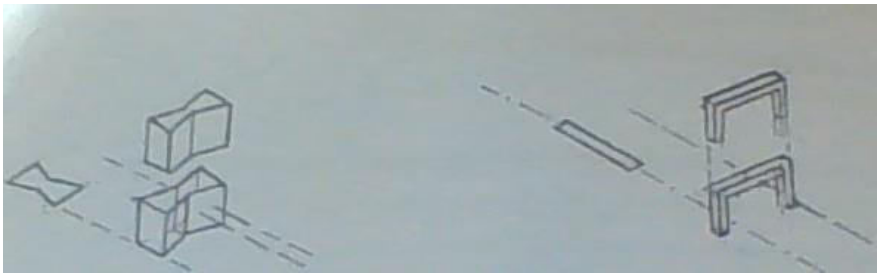

Fig 6: Interlocking of stones Fig 7: The use of iron clamps

(Source: "Architectural heritage and seismic design with reference to Indian temple architecture", in the Proceedings of 13th World conference on Earthquake Engineering, Paper no 2819)

[23] Stella Kramrisch, op.cit,p.9
[24] Renu Thakur,*"Utilising Urban Space: Some Elements of Town Planning in India,C. AD 600-1200."* in *Leagcy of Indian Art: Continuity and Change*, ed., Ashvini Agrawal, Aryan Books International, New Delhi,2013, p.213.
[25] Vasudha A. Gokhale., op.cit
[26] Ibid.
[27] Ibid.
[28] Ibid.

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The Pallavas used an excellent method to add stability to stone masonry. They laid it without the mortars with carefully worked out joints. Thin layers of large granite panels were inserted at regular intervals which acted as binders. This phenomenon provided an increased structural strength against sideways movement to the temple.[29] The other type of technology which was in vogue was pilasters and the pillars which actually were the strength of the structure and held strongly the upper and the lower storey of the structure. The earthquake might force the building to break apart but these colonnades were made to carry some of the load of the roof. In 13th century, a region of south India was ruled by Kakatiyas, who invented the 'Sandbox' technology in structures to withstand the seismic forces as is evident from the Ramappa temple, Warangal. This technology came to the notice of Indian Archaeological department during 1980s. They conducted research in collaboration with NIT Warangal on this constructional technique and found that it had everlasting effect to constrain the effect of the seismic forces which struck the building. Though the area of Warangal does not come under the seismic zone; but the architects were aware of the dangers of seismic forces and thus 'Sand box' technology was adopted by them.

The above mentioned points clearly describe about the methodology which was adopted by the architects while building up the structures. The *sthapati* avoided the use of wet, soft soil while building structures as it could harm the built structure in future. The carefulness of the master craftsman and his team is evident from the number of temples and secular structures surviving till date. The concept of ductility, deformability and damageability were known to the architects. Earthquakes have demolished many Indian temples but the remaining structures convey the hard work and talent these master builders put in while constructing marvelous structures.

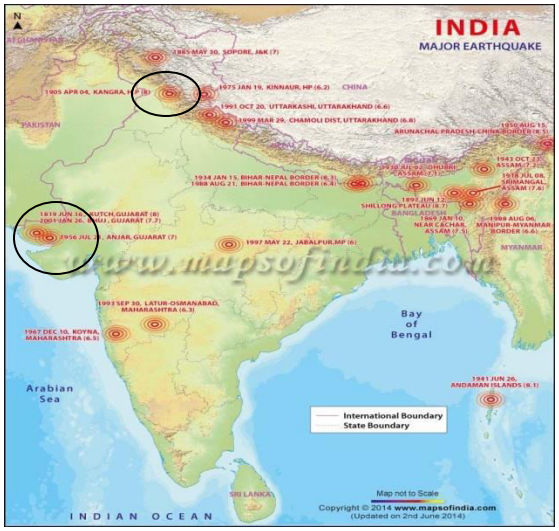

Fig 8: Showing earthquakes in the region of Himachal Pradesh and Gujarat
(Source: www.mapsofindia.com)

The northern and the western regions of India have been struck by major earthquakes. There were two major earthquakes which have drastically affected the regions of Himachal Pradesh and Gujarat. Many of the established and well built temples were destroyed. In the state

[29] Vasudha A Gokhale., op.cit.

of Gujarat, the Kutch region had suffered a major earthquake twice in 1819 and 2001 respectively. The earthquake brought huge destruction to the inhabitants as well as the structures with a high density magnitude of 8.0 and 7.7 on Richter scale. However, facing this fierce earthquake the famous and incredible Sun temple of Modhera (fig 9), Shiva temple at Kera, Punvareshwar temple, Bhadreshwar temple, Somnath temple and Dwarka temple were not much affected and are intact till date after renovation taken from time to time.

The state of Himachal Pradesh also suffered a devastating earthquake in 1905 with its epicenter at Kangra district with a density of 8.0 on Richter scale resulting into destruction of human life and property. The considerable damage was done to the ancient temples in the state. The religious and secular structures in the Kangra district, the famous temple of Baijnath (fig10) and rock cut temple at Masroor (fig11) were affected. Most of the *Shikharas* of the temples have fallen down and considerable damage had been caused by the earthquakes.[30] The temples in the Kangra fort, the Adinath and Ambika Devi were completely ruined by this earthquake but the foundation remained intact.[31] The structures have faced considerable destruction but survived this earthquake and are intact till date. The temples of Chamba and Bharmour region, like the Lakshmi Narayan temple (fig 12), Narsimha temple and Chitrari temple are affected to some extent but were not demolished wholly, however tilting of pillars, the fractures in walls are witness to the devastating earthquake. The Chaini Kothi, a temple of 17th century located in kullu, Himachal Pradesh is a great tower in its present condition and is more than 45 meters tall. The upper two storeys of the monument were lost in the fateful Kangra earthquake in 1905, but the rest of the monument stands in its traditional majesty and grandeur.[32] (fig13) However, the temples were later renovated and repaired to save them for posterity. The constructional practices of those times and expertise of the master craftsman and his team provided them strength to tolerate seismic forces to great extent which saved them for the present generation and are still encouraging present day builders to build such structures which do not wither away completely and can survive in the seismic zones.

[30] Laxman S Thakur., *The Architectural Heritage of Himachal Pradesh- Origin and Development of Temple Styles,* Munshiram Manoharlal, New Delhi, 1996, p.39.
[31] Ibid. p.74.
[32] O.C Handa., *Temple Architecture of the Western Himalayas: Wooden Temples,* Indus Publications Company, New Delhi, 2001, pp.188.

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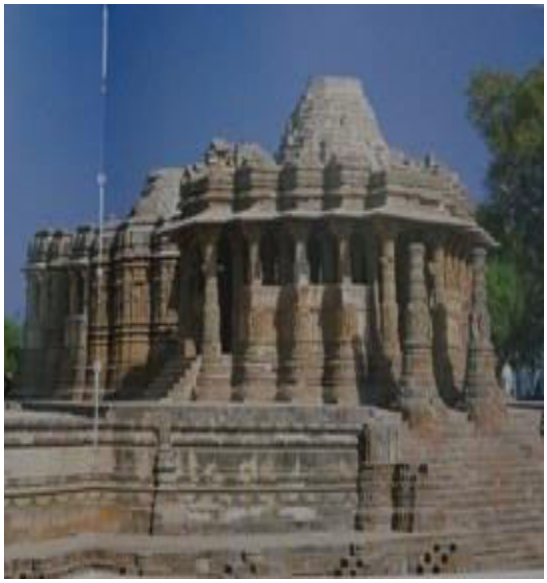

Fig 9: Sun Temple, Modhera
(Source: Maribia Albanese, *Architecture in India*)

Fig10: Baijanath Temple, Kangra
(Source: Annaul report, ASI, 1906-06)

Fig11:Masroor temple, Kangra (Source: Laxman S. Thakur ,*The Architectural Heritage of Himachal Pradesh- Origin and Development of Temple Styles*)

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Fig 12: Lakshmi Narayan Temple, Chamba
(Source: Subhashini Aryan, *Himadari Temples*)

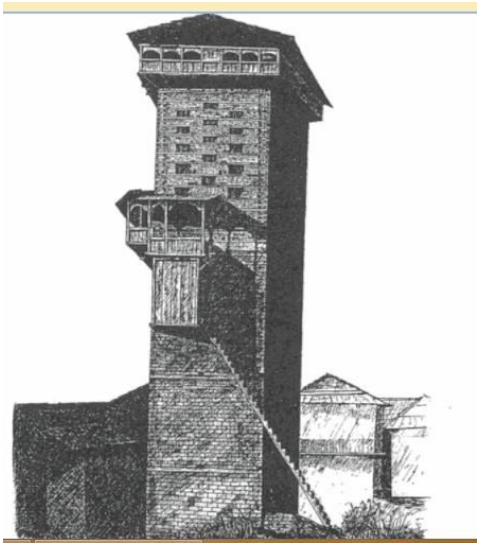

Fig 13: Chaini Kothi Temple, Kullu
(Source: O.C. Handa, *Temple Architecture of Western Himalaya*: *Wooden Temples*)

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BIONOTE

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