Koti Banal Architecture of Uttrakhand in India: An Earthquake Safe Construction

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Abstract

Aim: *Uttarakhand's 'Koti Banal' architecture reflects indigenous reality & community participation. It exhibits a thorough understanding of native materials & aesthetics. Despite being located in an area that is very susceptible to earthquakes, Uttarakhand has a rich history of building multistory homes. Both the Kumaoni & Garhwali languages of the region have distinct phrases for distinguishing a building's four floors. This research aims to show that the inhabitants of this difficult, earthquake-prone area mastered the ability of building earthquake-resistant structures long before the structural engineering rules guiding such construction were developed.*

Methodology: *In-depth studies show that by 1000 B.P., the area had already created a unique & complex kind of architecture that could withstand earthquakes. Koti Banal architecture, to give it its proper name.*

Findings: *It turns out that the area has created a sophisticated and aesthetically pleasing method of building that is both earthquake-proof & resistant. Around 880 B.C., Koti Banal construction reached its zenith. Built on comparable principles to contemporary framed structures, this architectural style nonetheless displays the process of site selection, construction of the platform for lifting the multistory structure, and detailing of the entire construction.*

Research Implications: *Lack of patronage, resources, & awareness, this architecture's representative structures are degrading swiftly. This study raises awareness of these structures' heritage importance, enabling conservation & maintenance initiatives.*

Value: *Indigenous knowledge systems, local building materials, community participation, & abilities of Uttarakhand are the subjects of this study.*

Keywords: Koti Banal, Uttarakhand, Architecture, Earthquake, Construction

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1. Introduction

Koti Banal style architecture is what makes the state of Uttarakhand so special. According to the World Housing Encyclopedia's Housing Report on Timber Reinforced Stone Masonry, a town in the Yamuna Valley is named Koti Banal. This place utilizes extremely scientific & earthquake-resistant building techniques based on indigenous knowledge. Existing literature indicates that this architectural style emerged as early as one thousand years ago. Koti Banal's design wasn't constrained via any existing regulations. It was built at a time when the ideas of science & earthquake resistance were away from the comprehension of the general public. Despite all of these obstacles, the designs of the multistory residences appear to adhere to the current seismic building requirements.

Form & proportion, a modest and single entry, and joinery details are distinguishable earthquake safety qualities of these dwellings. Multiple examples of buildings in this type have stood the test of time for at least 200-300 years. Traditional wisdom, local materials, communal effort, and expert craftsmanship are all on display here. Notable characteristics of Koti Banal buildings that make them earthquake-proof include:

i. **Site Selection:** From a seismic perspective, the stability of the slope and the use of solid ground have been essential components for construction.

ii. **Building Plan & Massing:** Koti Banal houses have a central axis that is symmetrical, a rectangular floor plan, and are enclosed to protect against earthquakes. The structure's seismic performance is not compromised in the lack of or sparseness of decorative elements, such as paintings or metalwork, and instead features wood carvings. Connecting walls run along the narrower axis of these multi-family houses. By creating a rigid box with these overlapping walls, the building's resilience to earthquakes is greatly increased. The normal height for such houses is between 7 and 12 meters. Traditional American houses tend to be five floors tall. These constructions are characterized through their simple design, complex, substantial, and elevated base, limited window openings, and shear walls, among other defining characteristics.

iii. **Ductility, Deformability, & Damageability:** Ductility & deformability are crucial characteristics of a structure's seismic resistance. They permit the structure to tolerate significant deformation without collapsing. Damageability is another property that permits a structure to sustain significant damage without partial or complete failure.

iv. **The Choice of Materials:** wood & stone from locally were used in the construction of this structure. Stone is a brittle material but wood is ductile. Wood is a ductile material with the potential to absorb the force of an earthquake; hence it was used extensively in the construction of these homes.

Devastating earthquakes struck Uttarakhand in 1720 (the Kumaun Earthquake) and 1803 since the state is located in an earthquake prone area (the Garhwal Earthquake). It is unusual to see a single-story traditional house in the region nowadays, with the exception of cattle stalls, due to the region's high frequency of earthquakes (Chalak in Kumaoni; local vernacular) (channi in Kumaoni; the local parlance). The Kumanoni language has four separate words for flooring (ground, goth; first, chaak; second, paan; third, chaj) while the Garhwali language has six (ground, kholi; first, manjua; second, baund; third, baraur). No language will accept the introduction of a new word until it is used routinely. This is quite suggestive of the prevalence of multi-story dwellings in the area.

In order to protect against earthquake-related losses, builders drew on the knowledge of earlier generations and experimented with locally sourced building materials, which led to the creation of a distinctive architectural style. The structural evolution trends that were used to maintain adequate structural strength & pliability during this time included the strategic use of dry stone masonry & stone-lime-mud-clay mortar masonry in combination with the extensive accessibility of wood. In the Garhwal region, along the Yamuna and Bhagirathi rivers, you can find a number of old buildings of four or five stories (known as Chaukhat & Panchapura, respectively). If these ancient buildings hadn't been reinforced against earthquakes, they would have been destroyed long ago.

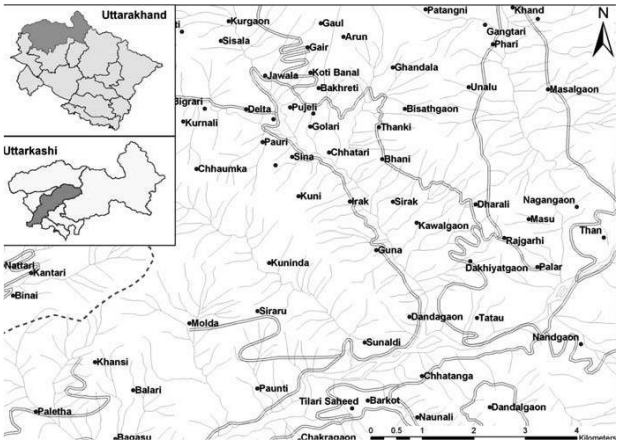


Figure: 1 Location Map of Study Area

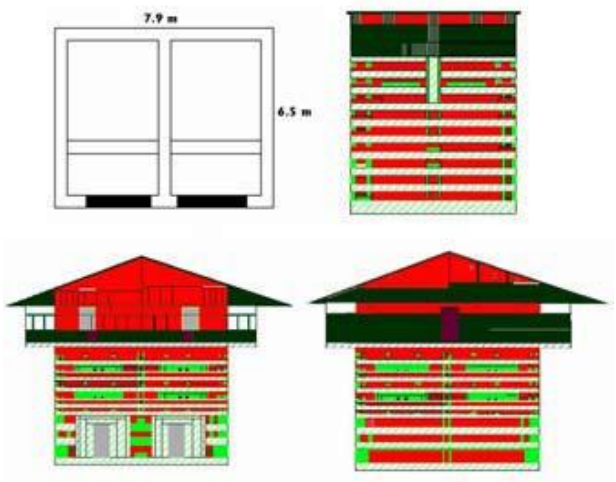
1.1 Earthquake protection & conventional building techniques

In light of mounting pressures, humans have perfected resource management practices & life support systems to protect their own communities. The continued existence & dominance of relatively unspecialized species is proof that humans have devised novel strategies for ensuring their own survival in the face of overwhelming odds. The core assumption of earthquake safety, which asserts that structural safety is the vital to preventing loss of human life during a seism genic event, was quickly understood via communities residing in

earthquake-prone regions. This fundamental knowledge headed to the development of creative methods for limiting human casualties caused by structure collapse. Famous Kashmiri building techniques like Dhajji-dewari & Taq make use of locally produced stone & timber in a specific way to provide the necessary level of seismic safety. The Quetta bond is just one more way that people have tried to lessen the damage from quakes. Traditional structures that have endured for generations in an earthquake-prone area may have incorporated earthquake-resistant features. Investigating these buildings in detail may turn up new information about their unique building method, and by improving upon established practices; a superior regional building strategy may be created.

1.2 Concerning structural safety-related factors

Koti Banal's design is predicated on the practical application of wood, which has many advantages as a building material. As a result of its strength & light weight, wood is an excellent material for construction since it reduces the amount of energy released by ground acceleration in comparison to other materials. One other advantage of wood-frame systems is that they dissipate energy by flexing more than those made of other materials.



Source: Rautela &Chandra Joshi (2008)

Figure: 2 Plan & elevation of the five-storied structure of Koti Banal architecture

Source: Abhay Aswal (2017)

Figure: 3 The Simple yet impressive architecture defines traditional houses

When an earthquake strikes, the forces acting upon a building are proportional to its mass and the amount of ground acceleration, but the way a building reacts to an earthquake depends on its dimensions & stiffness. Since the mass of a building is typically located near its top and bottom, those levels will experience the greatest lateral forces as a result of the earthquake's ground motion. There must be no cracking in the walls under this pressure, and the building as a whole must be fastened firmly to the ground. Koti Banal's design incorporates a number of unique details meant to improve the building's resistance to seismic activity. Among these are:

- The mass & rigidity are distributed symmetrically & identically, thus the point of the resulting earthquake forces coincides with the point of the resulting resistive forces. Thus, the buildings' torsion is prevented or greatly reduced, enhancing their shock resistance.
- The primary shape of the building's girders is rectangular. These beams are appropriate for bending members because they have a width-to-weight ratio of 2:3. These wooden beam components are much larger than what is required to guarantee adequate safety. As a result, the space rigidity & strength criteria are met via the construction system. This helps even more with shock resistance.
- When correctly built & utilized, wood has minimal structural limits. Wooden structures have a higher strength-to-weight ratio than steel & concrete structures. This shows weak inertial

forces throughout a seismic event. To withstand earthquake stresses caused by the inertial force acting on the structure, the architecture of Koti Banal employs a wide range of timber assemblages.

- In Koti Banal buildings, the timber ground and ceiling act as diaphragms that may expand and contract as needed. These diaphragms are considered flexible via FEMA 310; however the vertical elements must be rigid. These structures have stone masonry walls along their vertical elevation, which are strong enough to give the required strong support in both the horizontal and vertical planes.
- Wood is an elastic-plastic material capable of absorbing earthquake forces. The wooden components in these constructions are joined utilizing both housing & nailing techniques (Figure 4), which provides for little angular displacement. This joint, which is excellent for stress absorption, combines the benefits of a pin joint and a rigid junction into a semi-rigid joint.

Source: Rautela & Chandra Joshi (2009)

Figure: 4 Housings & nails used to secure the timber components of the Koti Banal structure

- Wood-frame construction, walls & floors wrapped with structural wood panels, and the all-important use of concrete. Within their intended operating range, these walls and floors are extremely strong and rigid; when stressed to their limit, they tend to yield gradually while still supporting significant loads. These structures can absorb a great deal of force before breaking due to their high ductility.

According to studies, this form of construction is most prevalent in the northern portion of the state of Uttarakhand, as well as in many other regions of India and a few neighboring nations. Field research reveals that this architectural style is now observed in 3 types:

i. Modified Style
ii. Original Style
iii. Original Morphology, but new materials

1.2.1 Koti Banal architecture - Structural features

Because inertial forces are proportional to an object's mass, bigger structures are exposed to greater earthquake forces. Similarly, greater ground acceleration increase structural stress. As a result, the earthquake forces acting on a building are directly proportional to both its mass and the amount of ground acceleration. As a result, earthquake damage to buildings varies widely depending on both the characteristics of the structure itself and the nature of the ground beneath it. At a construction site, the parameters of seismic ground motion are dependent on factors like:

- where a building is located in relation to the epicenter of an earthquake;
- intensity of the quake;
- earthquake epicenter depth
- The state of the soil where work will be done.

The size and rigidity of a building determine how it will react during an earthquake. In the event of an earthquake, wooden buildings are particularly vulnerable to strong peak ground acceleration. Walls must be strong enough to withstand loads from the roof & floor, and the whole building must be securely fastened to the ground. Among the most important factors determining a timber building's resilience to earthquakes are:

- A connection to the foundation;
- the durability & pliability of the walls;
- The stability & continuity of the horizontal features (such as the roof, the floor, & ceiling)

2. Literature Review

Uttarakhand is situated in a highly seismically active area of the Indian subcontinent. This has led to the development of a unique architectural style, known as Koti Banal, which has been widely used for about a thousand years. Radiocarbon dating reveals an early emergence of earthquake preparedness practices in the region. The architects apparently knew what they were doing when they designed this building, because it can withstand earthquakes without much damage. Koti Banal is the form of architecture that emerged as a result of human adaptation to seismic disturbances in the natural environment, drawing on indigenous expertise and materials. Innovative survival techniques have been evolved via human communities across the globe as a result of experience, explorations, empirical knowledge, and ingenious abilities. Seismic activity is frequently felt through the inhabitants of mountainous places. They soon understood the fundamental premise of earthquake safety, namely, that the best way to reduce casualties is to ensure that buildings are safe. Because of this fundamental idea, the koti banal architecture was developed, which ensured the safety of any building it was used in. Haste to protect the community led to the use of traditional knowledge systems & experimentation with locally available building materials that resulted in a distinctive architectural style. This style displays structural evolution trends in which wood was used in combination with dry stone masonry and stone-lime/clay mortar masonry to provide adequate strength & flexibility.

The main body of the house was constructed from alternating layers of treated wood & stone rocks, with the latter being linked to the former in the corners via ingenious joinery. Reinforcing the structure was wooden beams that ran from the centre of one set of walls to the centre of the other set, crossing in the centre. This set up served to split the building in half and provide the joists needed to support the floors on each level. The upper floors were framed via balconies with wooden railings. Many stories were connected with wooden ladders, which were often fashioned with the hands from a single tree trunk. Local stones were used to construct the roof, which was then supported via a wooden framework. Wood was widely used in the building's construction and ornamentation. The entire structure in Koti Banal architecture was supported through a wooden frame, much like the RCC frames of modern high-rises. The gaps were filled with rocks. These walls supported the vertical weight, although the horizontal weight was distributed across a network of joists that ran across both directions. The exterior of the structure was reinforced with two beams running in opposite directions to lessen the effects of earthquakes. The building was set on a platform that was lifted two to four meters into the air. The solid platform loaded with stones maintained the building's center of gravity & center of mass low to the ground. This reduced the risk of the tall building toppling over during an earthquake. While regular shapes are less likely to distort & sustain damage during an earthquake, irregular ones are less likely to withstand the shaking. Stone & bricks are commonly utilized in the construction of non-engineered buildings in rural areas, and it is especially important to ensure that these materials are reinforced to maximize their earthquake resistance (Rautela, P., et. al 2008).

Jain, P., Singh, I., & Jain, M. (2021) study indicates that the primary land use in the Uttarakhand urban region is developed land. During the selected fourteen-year period, the built-up area has expanded by 68 percent (1.89 square kilometers) as a result of the construction of new buildings and built the area on agricultural land, vegetation cover, and diverse open spaces. The area covered by vegetation and agricultural land has decreased with 22 percent (1.83 square kilometers) and 18 percent (0.03 square kilometers), respectively. The area of open space has decreased with 19% (0.03 km2) as a result of uncontrolled development. 19%, 22%, and 18%, respectively, of open space, vegetation, and agricultural land are lost owing to urbanization as a result of the continuing development of the city, as evidenced by the approach employed in their research.

Cattle were intended to be housed in the "Goth" basements of these buildings. It had one door that led to the courtyard. Goth was connected to the ground level with a wooden stairway with a cover. During the winter, this shelter was used to access the livestock without traversing the snow-covered, chilly courtyard. The slightly ajar

lid also enabled the transfer of the heat created by the cattle to the higher floors. The local people utilized this science to keep their houses warm. The upper levels were constructed of wood coated with local soil in several locations.

The Koti Banal Building also has stairs and carvings that were all done by hand. The similarities between temple architecture and home design are seen in the carvings & themes used in both. The carvings in Kumaun are more noticeable than those in Garhwal. These handmade techniques give these buildings a sense of cultural identity.

The Koti Banal architectural style must be understood and meticulously documented. The traditional knowledge systems incorporated in this approach would open up new avenues for investigating community-oriented sustainable practices that have withstood the test of time has been demonstrated to be environmentally beneficial. The majority of these homes are disappearing as a result of maintenance difficulties & concerns about comfort. If these problems could be resolved, the dwellings may continue to thrive with the required adjustments. The deconstructed materials from these residences are being used to construct new, contemporary homes. People need to be taught the importance of preserving these buildings so that future generations can enjoy the region's architectural heritage. This would provide scientists an opportunity to study the Uttarakhand architectural style in depth & undertake experiments to found its significance in the present world (Arya, A.S 2000).

3. Case Studies

In a few villages of the Uttarakhand's Garhwal region. A little village close to the Tibet border, Village Malari is located in the Dhauli Ganga valley of the Nanda Devi Biosphere reserve. The majority of the village about 900 people is members of the Bhotia Tribe. Between the months of April & November, Malari is inhabited through its inhabitants. Due to harsh living conditions, they descend to lower altitudes during other months. The primary sources of income in this region are agriculture & livestock husbandry. The UNSECO includes Malari on its list of World Heritage Sites. Most of the buildings in the village are at least 200 years old & are constructed in the Koti Banal style or a derivative thereof. It is significant use for plastering; the soil of Khar possesses a high binding capacity. This hamlet employs the koti banal architectural style in its purest form, with all construction carried out by the community itself.

Source: Saraswat, S., & Mayuresh, G. (2017)

Figure: 5 ongoing developments in the traditional Koti banal architectural style in the town of Purola

Also, the village of Gainchwan follows similar examples. Gainchwan is a small village in the Mori block of the Uttarkashi district with a population of roughly 800 and more than 180 homes. The primary sources of income are agriculture and livestock husbandry. The majority of the village's buildings is at least 100 years old & generally adheres to the identical architectural style. Commonly utilized for plastering is clay soil. Village Purola displays a structure that employs modern building materials while keeping the region's fundamental architectural style. Detailing Village Malari, documentation reveals the following significant elements of this style:

i. Simple configuration using lineal geometry
ii. Construction on a sturdy, elaborate, & elevated platform
iii. Utilization of local building materials judiciously — stone & wood
iv. Wooden beams were included in regular height increments to provide structural support for the building
v. Limited Opportunities for Climate Concerns

vi. Shear Walls are utilized to manage lateral stresses and seismic disturbances.
vii. Low embodied energy since, in theory, only locally available resources are utilized

The constructions have simple rectangular floor designs. The length to width ratio of their elevated platform is between 5 and 9 meters. The asymmetry ratio of these buildings is 1.11 - 1.40. In order to reduce the potential for twisting and stress concentration, the structures are symmetrical in terms of both mass & stiffness. Such constructions are more resistant to earthquakes. First, the structure's timber framework is secured, and then the spaces are filled with stones. This resembles contemporary framed construction in that it supports both vertical and horizontal loads. According to the available literature, the platform is built using dry stone masonry and is between 2 and 4 meters above ground level. Because it keeps the centre of gravity near to the centre of mass and the ground, the base platform is crucial. The walls on all four sides are built with stone and wood in alternating layers. Wooden beams spanning from one side's centre to the others provide supplemental stability. Single-family homes are the intended use for these buildings. These buildings have a single main entrance that is situated on the ground floor, above the foundation platform. Only manually constructed wooden ladders made from a single tree trunk provide access to the higher stories. Each and every one of the created shapes demonstrates the community's skill. Both the interior and external spaces are living cases of the communities' craft skills & tacit knowledge. The kitchen & living room display the fine application of ringed and weaving crafts for day-to-day necessities. There are also a few wood sculptures in dwellings, which serve as decorations and celebrate life.

Findings

Incorporating the design & construction concepts of the Koti Banal style of architecture into modern buildings possesses enormous possibilities. This architectural style revealed some of the fundamental concepts of earthquake-resistant building. According to the available literature, the platform is built using dry stone masonry and is between 2 and 4 meters above ground level. Because it keeps the centre of gravity near to the centre of mass and the ground, the base platform is crucial. The walls on all four sides are built with stone & wood in alternating layers. Wooden beams spanning from one side's centre to the others provide supplemental stability. Single-family homes are the intended use for these buildings. Few changes have been made to the village of Gainchwan in response to the evolving demands of the people. However, the morphology remains unchanged. In the community of Purola, current building materials are used. However, the building style is authentic Koti Banal. The decline of ancient knowledge systems and the dearth of trained craft-people have both affected and been overcome with the arrival of new building materials like cement, as well as via market strategies & government regulations in the hills of Uttarakhand. This has resulted in the widespread adoption of a form of architecture more at home in flat-lands than in hilly terrain.

Conclusion

Study indicates that the region's inhabitants had the traditional knowledge and skill to create earthquake-resistant structures over a thousand years ago. The architecture of Koti Banal, which reached its height around 880 ± 90 years before present, incorporates nearly all earthquake safety measures, & the functioning of these structures has been confirmed with a number of earthquakes. The modifications to the Koti Banal architectural style reflect the societal and environmental transformations that have occurred over time. Due to current objectives, it is difficult to preserve construction processes and past vernacular forms, they indicate. Particularly vulnerable to the aforementioned shifts are macro-level components, such as building materials, techniques of construction, and house shape. Market dynamics (supply & demand) and the availability of resources (both of which are beyond the control of the community) also play a significant role. The community as a whole has felt the effects of recent large-scale alterations to the built environment. And there's the additional problem that vernacular customs are dying out. If anything fundamental about the house's design or culture is altered, such the removal of

goth elements, the result can be a dramatic visual shift.

Numerous historic Koti Banal-style structures are found to be abandoned and rapidly deteriorating because of lack of care. People are dismantling these old buildings in order to reuse the dismantled materials in the construction of new, contemporary homes. The general public must be made aware of & educated on the problem of preserving these historic structures. As a means of providing future generations with a sight of the architectural tradition of the region, it is necessary to safeguard architectural examples of Koti Banal as historic landmarks. This would also afford researchers the opportunity to examine in depth this architectural style of Uttarakhand.

The decline in the market for stone & wood buildings has led traditional masons to quickly switch to cement. It is inevitable that traditional building methods will lose their distinctive features because they are not being passed on to new generations. Therefore, it is vital to understand and document the finer points of traditional building techniques. This construction style might receive a new lease on life if conventional building materials & methods were modernized.

Indigenous arts & crafts, such as regional wood carvings, craft & weaving, can also be included in the planning & design of dynamic & practical spaces. Also, it is recommended that the government make sure that any proposed new constructions adhere to the prevailing forms & help keep the state's exclusive character.

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