World Housing Encyclopedia

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HOUSING REPORT
Timber-reinforced Stone Masonry (Koti Banal Architecture) of Uttarakhand and Himachal Pradesh, Northern India

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Summary

Despite being located in a high seismic risk area, a region in the Himalayan states of Uttarakhand and Himachal Pradesh (Northern India) exhibits an elaborate tradition of constructing multistoried

houses. In the Rajgarhi area of Uttarkashi district (Uttarakhand) a large number of intact buildings of the distinct construction type known as Koti Banal can be found. Koti Banal is the name of a village in the Yamuna Valley which represents the traditional knowledge and understanding of earthquake effects on buildings and their earthquake resistant design. Investigations suggest that the region had evolved this elaborate and magnificent earthquake-safe construction style as early as 1,000 years before present. This architectural style further demonstrates the existence of elaborate construction procedures based on principles somewhat akin to that of blockhouse construction. Many features of these buildings are considered as the basics of modern earthquake-resistant design. Generally, ornate multistoried houses with abundant use of wooden beams are characteristic of Rajgarhi area. For buildings of the Koti Banal architecture, locally available building materials such as long thick wooden logs, stones and slates were judiciously used. The height of these structures varies between 7 and 12 m above the base platform which consists of dry stones. These structures are observed to have four (Chaukhat) to five (Panchapura) stories. It is reported that especially buildings of the Koti Banal architecture withstood and performed well during many past damaging earthquakes in the region. In a report on the effects of the 1905 Kangra earthquake (M 7.8), Middlemiss (1910) already describes the well performance of these ?(..) top-heavy constructions? located along steep slopes of the Kangra-Kulu epicentral area, which differed ?entirely from the sun-dried brick-built structures of the Kangra Valley. The performance of these structures has also been corroborated by eye-witness accounts during the 1991 Uttarkashi earthquake which had a magnitude of mb 6.6 in an epicentral distance of 30 km during which many new buildings collapsed while these structures did not suffer any damage. The reasons that these buildings outlived so many centuries mainly lie in their structural configuration which clearly demonstrate that their builders already had the idea of dynamic earthquake actions, particularly out-of-plane failure of masonry walls. The buildings are further characterized by a number of advantageous design features such as regular plan shapes, the sensible use of locally available building materials, the integration of wooden beams over the total height of the building as well as small openings and the arrangement of shear walls.

1. General Information

Buildings of this construction type can be found in in the northern part of the state Uttarakhand and the southern part of the state Himachal Pradesh in Northern India. The most magnificent examples of the Koti Banal architecture are observed in the valley of the river Yamuna in Rajgarhi area where many villages have a fair number of these houses. Similar structures are however also present in the valleys of the rivers Sutlej and Tons (Figure 2). However, buildings of comparable type denoted as 'cribbage' or 'timber reinforced stone masonry' are known over the whole northern part of the Indian subcontinent including Afghanistan, Pakistan, India, and perhaps Nepal and Bhutan. This type of housing construction is commonly found in rural areas.

Though this kind of construction is presently observed only in rural areas there might have been similar structures located also in urban areas which might have been replaced by more modern structures due to the compulsions of growing economy and business. Evidentially, lack of maintenance has led to the deterioration and the complete destruction of many of these structures.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is not being built. Investigations suggest that the region had evolved this distinct construction style as early as 1,000 years before present. Similarities in the architectural principles and structural details suggest their possible evolution under one single architectural school.

Figure 1. General view of a typical building located in Rajgarhi area and a sketch taken from Middlemiss (1910) illustrating structures of this type in the Kangra Valley.

Figure 2. Map illustrating the respective region in Himalayan India where Koti Banal buildings are found.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. In most cases, Koti Banal structures were erected separately without any buildings in the immediate vicinity. Especially those located in the villages may also be built close to each other or to other building types (Figure 3) When separated from adjacent buildings, the typical distance from a neighboring building is 2.0 - 4.0 meters.

2.2 Building Configuration

Koti Banal buildings are characterized by very simple rectangular plan configurations while the lengths and widths are varying between 4 and 8 meters. The ratio between both dimensions varies between 1.1 and 1.4. Figures 4 and 5 illustrate typical plan shapes of a single- and a two-unit construction, respectively. Internal walls only exist in the 2-unit buildings separating the main living area on each floor at the buildings rear side from a vestibule at the front. The upper two floors additionally have external balconies (wooden verandah) which are constructed with a wooden railing running around the whole building. The balconies are supported by cantilevering wooden logs of the flooring system (Figure 6). According to Middlemiss (1910) it is this projecting balcony which gives the house the false appearance of being top-heavy and unstable. Generally the buildings rest upon a raised and elaborated stone-filled platform out of dry stone masonry which is the continuation of the foundation trench made of field and rubble stones. The height of the platform varies between 2 and 4 m above the ground (Figure 7). Figure 8 exemplarily shows the elevation of a five story structure with interstory heights ranging between 2.20 and 2.50 m. In the lower part, the walls consist of a wooden cribbage configuration with orthogonally arranged wooden logs interconnected at the junctions by wooden pins/tenons (Gujja Khoonta). For the two bottommost layers single wooden logs while for the upper layers double wooden logs are used (Figure 9). The open spaces (height ~ 30 cm) between the horizontal logs are furnished with well-dressed flat stones which are dry-packed or by using a paste of pulses (lentils) as mortar (Figure 10, Figure 11). This wooden cribbage structure is not used for the upper parts of the wall where the dressed stones have a load-bearing function (Figure 9). The thickness of the walls is determined by the thickness of the two parallel arranged wooden logs which is mostly between 50 and 60 cm. The structure is further reinforced by wooden beams which are perpendicular attached to the wooden logs at the middle of the walls connecting two parallel outer walls. These beams provide the joists supporting the floorboards of each story (Figure 12). The walls parallel to the floor beams are supported in out-of plane action by providing a large timber log, longer than the building dimension and having holes at the two ends. A vertical member (shear key) having length equal to several storey heights, is inserted into the hole which provides support to the walls in out-of-plane direction (Figure 13). Koti Banal structures in general have a single small entry and relatively small openings which are surrounded by strong wooden elements to compensate for the loss of strength (Figure 14). In general, no windows are provided at ground floor level.

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Buildings of the Koti Banal construction type only have one main entrance at ground floor level above the foundation platform. The access to upper floors is solely provided by wooden ladders made of a single wooden trunk (Figure 15). The reasons for not providing a second means of escape could not be completely identified. However, due to their massive walls, some of the buildings have also been used as fortress against enemy attacks of e.g. the British Gurkha army. The Gurkhas lay seize of the building for several weeks, but could not enter into it. According to tales from the local people, narrow connection tunnels to close rivers still exist which were used to supply the people with potable water. Today, the fact that no second means of escape is foreseen does not represent any particularity in India since this is generally not provided in daily construction practice.

2.4 Modification to Building

It is assumed that buildings of the Koti Banal architecture were designed and constructed under the influence of one particular architectural school that put less priority on the comfort of inhabitants. In order to improve the comfort of the buildings a number of variations and modifications to the original construction style had started to creep in as early as 728 +/- 60 years before present. In some cases larger doors and windows have been provided for better ventilation and comfort. Externally arranged verandas made of timber and resting on massive columns have also been added in order to gain additional living space (Figure 16). A modified type of Koti Banal architecture can be found in Gona village where the principles of Koti banal architecture were not strictly followed. The roofs of these structures are observed to be comfortably high while the internal wall layouts vary on every floor. Detailed observations reveal that the basic elements of seismic safety have been compromised within these buildings. The Gona type may well represent earlier stages of the evolution of the Koti Banal architecture. The use of horizontal wooden logs in the vertical walls is similar to the concept of seismic bends (ring beams) in modern masonry buildings. Somehow, the practice of the Koti Banal constructions was slowly abandoned such that modifications of the original construction principle can be observed in the region. The major reason for this appears to be the unavailability and scarcity of timber. A gradual shift from the closely spaced timber logs to increasing heights between them filled with stones is visible in the local construction (Figure 17). For contemporary constructions in the region, no such logs (ring beams) are used anymore. Recently, many Koti Banal structures face serious adverse effects being caused by the surrounding building development. Unplanned construction directly taking place next to Koti Banal buildings and encroaching upon these old structures as well as the partly demolition in order to use the disassembled building materials for new buildings seriously affect the dynamic behavior of these traditional structures during earthquake shaking. In addition, these negative effects are accelerated by the structural deterioration due to the lack of maintenance and preservation.

Figure 3. Representatives of Koti Banal structures being located close to each other.

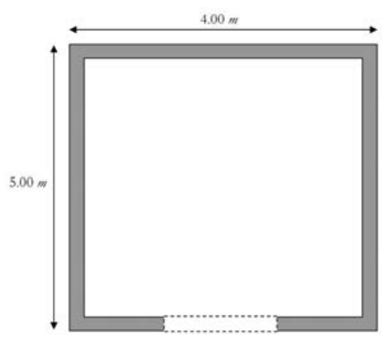


Figure 4. Typical plan shape (of ground floor) of a single-unit building.

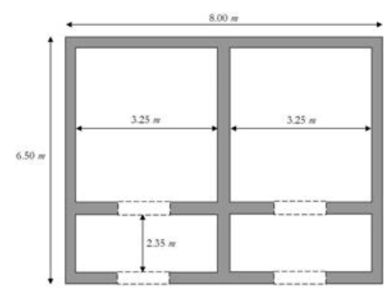


Figure 5. Typical plan shape (of ground floor) of a two-unit building being vertically separated.

Figure 6. Detailing of the cantilevered balcony construction at the forth storey level.

Figure 7. Detailing of the foundation platform made of dry-packed dressed stones.

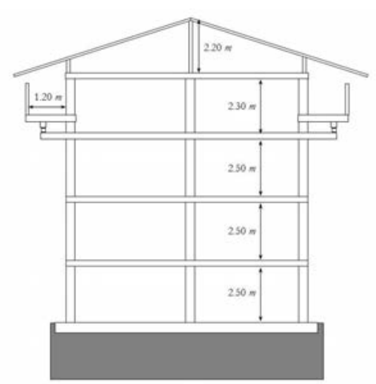
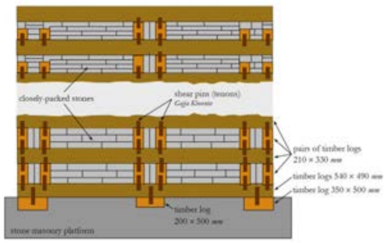


Figure 8. Elevation of a 5-storey Koti Banal building.



Vertical cross-section illustrating the wall construction principle in the lower 'cribbage' part and the upper part.

Figure 10. Arrangement of wooden logs and well-dressed flat stones for the walls.

Figure 11. Arrangement of wooden logs and well-dressed flat stones for the walls.

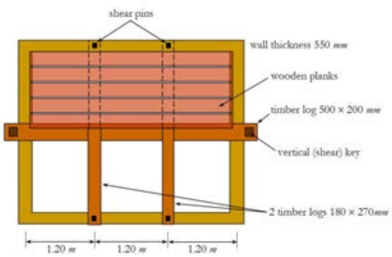


Figure 12. Detailing of the flooring construction.

Vertical members ('shear keys') attached to the outer façade to prevent out-of-plane failure of the walls.

Figure 14. Detailing of door and window openings.

Figure 15. Ladders made of a single trunk used for access to upper floors.

Figure 16. Modification of the Koti Banal construction principle: arrangement of external verandas resting on massive columns.

Figure 17. Modification of the Koti Banal construction principle: wooden logs are only arranged as ring beams between layers of stone. The interspacing heights between the layers of wooden logs range between tens of centimeters up to one meter.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐

		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☑

Timber-reinforced stone masonry.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Gravity loads from the floor construction (dead loads) or from live loads on the roof (e.g., snow) are transferred to the massive wall system which basically consists of a hybrid timber-reinforced stone masonry system. In the lower parts of the walls the timber logs are interconnected establishing a very solid cribbage while the timber elements on the upper parts are mainly of a reinforcing purpose. The walls further transfer the loads to a stone-filled base platform which is the continuation of the stone foundation.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The system of horizontally pairs of wooden logs which are connected to each other by wooden shear pins/tenons (Figure 18) act like a wooden frame which is braced by well-dressed flat stones in between the logs increasing the bearing and lateral capacity of the construction. This especially in the lower parts of the walls where the wooden frame is continuous in three dimensions and the stones do not carry any loads. The stones between the logs are mostly assembled without any grout or mortar thus enabling a certain level of flexibility and allowing lateral deflections of the building without damage effects. The bottommost wooden logs are embedded within the base platform. Outer walls parallel to the floor beams are supported in out-of plane action by vertical shear keys over several storeys (Figure 13).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 4 and 8 meters, and widths between 4 and 5 meters. The building has 3 to 5 storey(s). The typical span of the roofing/flooring system is - meters. According to Middlemiss (1910) the main dimensions of the buildings are 9 haths by 9 haths, 11 by 9, 15 by 9, 15 by 11, and 18 by 11. A hath corresponds to 1.5 feet which means that the widths of the buildings vary between 4 and 5 m and the lengths between 4 and 8 m. The typical span of the flooring system in general is half of the building width. The typical storey height in such buildings is 2.20 - 2.50 meters. The typical structural wall density is more than 20 %. Precisely, the structural wall density ranges between 40 and 45 %.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐

	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

Wood planks resting on wooden joists supported by beams or walls: The floors consist of wooden beams and planks (Figure 12). Since no cross/inclined planks are used, it is expected to act as flexible diaphragm. The floor beams are shear pinned with the wall logs and thus provide support to the walls orthogonal to the beams, in out-of-plane action. Wood planks or beams that support slate tiles: The roof construction consists of a wooden frame which is expected to act as a flexible diaphragm. It is further furnished with large slate tiles (Figure 19).

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Foundation trench filled with rubble and field stones. In case of outcropping rock at the surface, the platform out of dry stone masonry is directly erected onto ground without any embedded foundation (Figure 7).

Figure 18. Detailing of the connection means at the wall corner. The horizontally placed wooden logs are connected by rectangular-shaped wooden pins. (Photographs show the rectangular holes foreseen at the log ends.)

Figure 19. Detailing of the wooden roof construction and the roofing by large slate tiles.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). Normally one family occupies one building. In those buildings which are vertically separated two living units (of the same family) are present. Due to successive division of the property, nowadays different storeys are owned by different people but having the same family roots. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

Generally the buildings have a single room on every floor with a vertically distributed usage. While the ground floor is used for cattle or grain storage, the upper floors are used as living and bed rooms. The kitchen is generally on the top floor. In some buildings, dry toilets are located at the cantilevering parts of the balcony at forth story (Figure 20). While the original occupancy was pure residential, nowadays these buildings are mainly used for storage purposes. Reasons for this lie mainly in the buildings' inconvenience caused by low ceiling heights, small openings and the kitchen at the top.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

Nowadays, the economic level of the few inhabitants ranges between poor and middle class. At the time of construction, the builder definitely belong to the rich social class.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☑
4:1	☐
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☐
Personal savings	☐
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

Due to missing records, no statement can be made here. In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

At some structures there is a dry toilet located on the 4th floor. In general, the cultural ethics of the region stipulates that bathrooms and toilets should be spatially separated from the residential living space. .

4.4 Ownership

The type of ownership or occupancy is ownership by a group or pool of persons.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☐
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☑
Long-term lease	☐
other (explain below)	☐

Figure 20. Toilet (outhouse) attached to the balcony at forth floor at the buildings backside.

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐

Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☑	☐	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☐	☑
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	wall thicknesses up to 1.5 ft leading to high dead loads	1) flexibility during dynamic shaking since no rigid mortar is used between the stones 2) bearing capacity to high vertical loads 3) prevention of out-of-plane failure through vertical (shear) keys at the outside ranging over several storeys	no damage patterns caused by earthquakes have ever been reported
Frame (blockhouse-style wooden logs)	-	1) spatial load bearing structure 2) bearing of shear forces through shear pin (tenon) connections between the wooden logs 3) flexibility and weather resistance due to the use of Devdar timber (native cedar) 4) beams are mostly rectangular in shape with a width/height ratio of 2:3 and a cross-section area larger than needed for adequate safety 5) openings are surrounded by wooden elements which are part of the frame	
Roof	1) high dead loads due to heavy roofing material (slate tiles) 2) inverted pendulum effect due to concentrated mass at the buildings top (larger dimensions of the upper stories) 3) flexible diaphragm effect	larger dimension of the upper stories thus leading to higher story masses is compensated by the use of less stones and more wooden elements	
Floors	flexible diaphragm effect	floor beams that run from the middle of one wall to the opposite wall provide additional stability to the walls	

The building configuration provides adequate safety against lateral shear, but there is no apparent safety measure against overturning. These buildings which are up to five storeys tall have survived the overturning effects even of strong earthquakes due to two reasons: (i) good aspect ratio of the buildings, and (ii) the use of lighter timber construction in the upper two storeys. Both mass and stiffness are uniformly distributed in elevation and in plan. Thus allowing pure lateral deflection during dynamic shaking while avoiding torsional effects. The primary structural system mainly consists of wooden elements. If designed and used properly, wood assemblies offer a high strength-to-weight ratio compared with other modern work materials. This results in low inertia forces during an earthquake. Siting of these buildings is another important aspect for their safety against earthquakes. These buildings are generally situated at firm ridge or plane ground having rock outcrop.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *C: MEDIUM VULNERABILITY (i.e., moderate seismic performance)*, the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is *E: LOW VULNERABILITY (i.e., very good seismic performance)*.

Vulnerability	**high**	**medium-high**	**medium**	**medium-low**	**low**	**very low**
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☐	☑	☐	☐	☑	☐

5.4 History of Past Earthquakes

Date	**Epicenter, region**	**Magnitude**	**Max. Intensity**
1720	Kumaun earthquake	M > 8.0	
1803	Garwhal earthquake	Mw 8.09	
1897	Shillong Plateau earthquake (Assam)	Mw 8.1	
1905	Kangra earthquake	M 7.8	I = VIII
1934	Bihar/Nepal earthquake	Ms 8.1	
1950	Assam earthquake	M 8.6	I = XI
1991	Garhwal earthquake (epicenter: Almora, 170 km distance to Uttarkashi)	mb 6.1 (IMD), Ms 7.1 (USGS)	I (MMI) = VIII
1999	Chamoli earthquake (Gharwal region)	Ms 6.6, ml 6.8 (IMD), mb 6.3 (USGS)	I (MMI) = VIII

The entire Himalayan terrain is recognized as being highly vulnerable to earthquakes (Bilham et al., 2001; Feldl and Bilham, 2006) and in the past the region has been jolted by four great earthquakes (with local magnitudes > 7.5): 1897 Shillong Plateau earthquake, 1905 Kangara earthquake, 1934 Bihar/Nepal earthquake and 1950 Assam earthquake apart from Kumaun earthquake of 1720 and Garhwal earthquake of 1803 (Thakur, 2006). Regions between the rupture zones of the great earthquakes are recognized as seismic gaps that are interpreted to have accumulated potential slip for generating future great earthquakes. The entire state of Uttarakhand falls in the seismic gap of the 1934 Bihar/Nepal earthquake and the 1905 Kangara earthquake and is categorized into Zone IV and V of the earthquake zoning map of India (IS 1893 - Part 1: 2002). The region has also witnessed seismic events of lesser magnitude (e.g., 1991 Garhwal earthquake, 1999 Chamoli earthquake). Figure 21 illustrates the recent seismicity of the respective Himalayan region with the investigation area shown in Figure 2. Notes on vulnerability rating: The Koti Banal architecture is a mixed construction of timber and dressed stones which are according to EMS-98 denoted as simple stones. Since the primary load-bearing capacity is provided by the system of timber logs, the vulnerability class of the entire structure will be mainly determined by this material. Pure timber structures in general are classified into vulnerability class D with a probable range between C and E (and a less probable range B). Accounting for the wall fillings out of dressed stones and the additional masses a reduction of the vulnerability class into C (D) may be suitable.

Figure 21. Epicenters of the major past earthquakes in the respective Himalayan region.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	wooden logs, dressed stones			
Foundation	field and rubble stones			
Frames (beams & columns)	Devdar (cedar) timber			The timber is of very high quality, strength and resilience. In most cases, wooden logs which were even exposed to all kinds of weathering are intact even after several hundred years, without any special maintenance.
Roof and floor(s)	Devdar (cedar) timber			

6.2 Builder

Due to the high age of these buildings, this question cannot be answered. However, it is supposed that the builders themselves had lived in the buildings and that these real estates had not been erected for speculation purposes. Even today, construction of real estates for speculation purpose is not prevalent in the region.

6.3 Construction Process, Problems and Phasing

It is reported that the construction process of Koti Banal buildings basically consisted of two steps. First the wooden construction was erected before filling up the intervening voids with dressed stones. However, this may only be true for the lower part where the stones were only used to fill up the voids. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

The practice in the area is to construct the buildings by traditional masons who inherited their skills from their fathers. The concept of modern architecture and engineering is not prevalent in the region, even today. The main construction expertise was brought in by local artisans. Architects or engineers did not participate in the planning or construction process.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

In India no development rules exist for this building type. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s) and No one. Prolonged non-maintenance and neglect of many Koti Banal buildings has taken its toll and many have turned too weak to be put to human use. However, even the better maintained buildings are not being used either. Poverty (18 %), scarcity of wood (42 %), lack of skilled artisans and inconvenience in regular maintenance (18 %), structural weakness due to prolonged non-maintenance (18 %) and general living inconvenience (2 %) were cited as reasons for abandoning these multistoried houses.

6.8 Construction Economics

Today the construction of these buildings would be too inefficient due to the high timber prices and the necessary construction technology. It is supposed that several tens of workers had been required to build these structures. Obviously the erection of these structures had been a community effort.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

The majority of existing buildings had been observed in the region. However, no strengthening or retrofitting measures could be observed. The reason for this may lie in the fact that this construction typology evolved over centuries accounting for the experienced performance during earthquake action and thus had been optimized. All modifications observed at the buildings rather reduced their seismic behavior than can be seen as a strengthening or retrofitting measure.

8.2 Seismic Strengthening Adopted

8.3 Construction and Performance of Seismic Strengthening

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