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A Technical Note on

Challenges of Construction at a Very High Altitude and Remotest Part of India - Ladakh

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1. INTRODUCTION

Civil Engineering is the backbone of any construction and by implication for infrastructure build up. It is a bit of paradox that while the world is recognizing the Indian prowess in the domain of Information technology and in the domain of Pharma; especially vaccine, but the revolutions in the domain of Civil engineering have gone unnoticed. India's contribution in the field of civil engineering in terms of research/ development and construction practices have been amazing, to say the least. In this connection it needs to be appreciated that the border areas of India especially in North and Northeast pose tremendous challenges for construction activities due to a very challenging terrain & weather conditions, equivalent of which is not available anywhere else in the world. In addition, connectivity for these border areas, for a substantial part of the year, is an issue as roads get closed due to accumulation of snow. Further, these areas lack substantially, local resources for construction. It is therefore a tribute to Indian engineers who, despite all odds, are still finding technical solutions to the challenges faced in these areas.

2. SPECIFIC ISSUES RELATED TO LADAKH

Ladakh is the Northern most region of India (Fig. 1). It is not only one of the remotest parts but is also located in hills which are at substantially high altitude (Fig. 2). Construction in Ladakh is quite a challenge for civil engineers and needs to be examined for evolving a strategy to find technology driven solutions for improving the effectiveness of the construction practices in Ladakh.

3. PHYSICAL/ GEOGRAPHICAL PARAMETERS OF LADAKH

It may be noted that in this paper we are concentrating only on those areas of Ladakh which are presently under Indian control. These consist of main Indus valley, the more remote Zanskar and Suru valleys (in the south) and Nubra valleys (to the north over Khar dung La in the Ladakh mountain range, a high motorable pass at 5,359 m (17,582 ft)). It is separated from the Union Territory of Jammu & Kashmir by Great Himalayan Range and the area across the Karakorum range is under the illegal occupation of China. Towards its West is Gilgit Baltistan which is under the illegal occupation of Pakistan.

Figure 1 - Mountain ranges in Ladakh
(Source: https://www.mapsofindia.com/maps/ladakh/ladakh-physical.html)

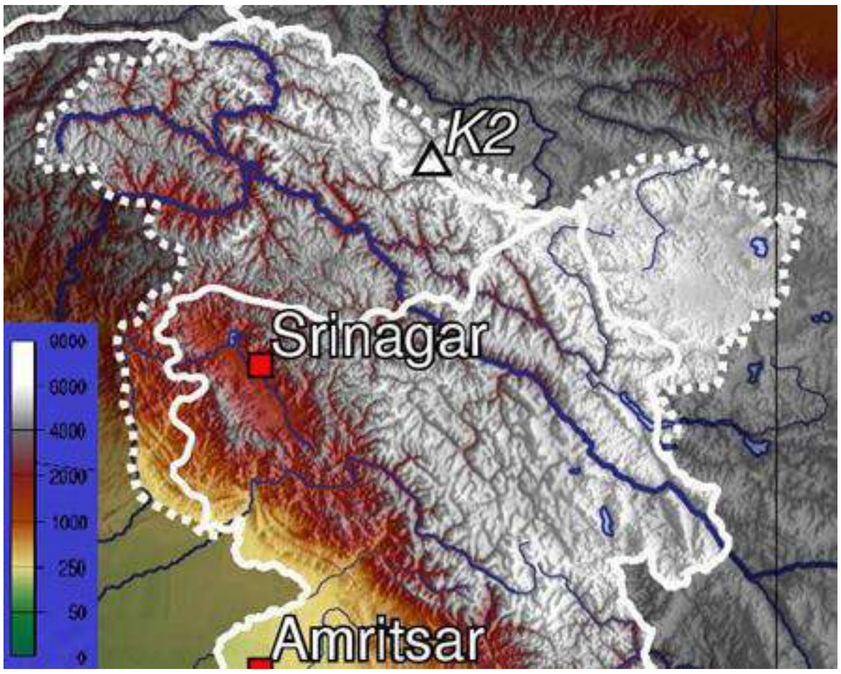

Figure 2 - Ladakh and its varying altitude
(Source: https://www.wikiwand.com/en/Geography_of_Ladakh)

3.1 Geography

Ladakh is the highest plateau in India with most of it being over 3,000 Metres. It extends from the Great Himalayan Range to Kunlun Ranges (presently area between Karakoram and Kunlun Rages is under the illegal occupation of People's Republic of China) and includes the upper Indus River valley and many other river valleys. The mountain ranges in this region were formed over 45 million years by the folding of the Indian Plate into the more stationary Eurasian Plate. It needs to be noted that the drift still continues, causing frequent earthquakes in the Himalayan region. As such, complete Ladakh lies in the Seismic Zone-IV of the country, which means that the area is at a very high risk in terms of vulnerability to earthquakes. The peaks in the Ladakh Range are at a medium altitude close to the Zoji-La (5,000–5,500 m) and increase toward southeast, culminating in the twin summits of Nun-Kun (7,000 m). The Suru and Zanskar valleys form a great trough enclosed by the Himalayan Range and the Zanskar Range. Rangdum is the highest inhabited region in the Suru valley, after which the valley rises to 4,400 m at Pensi-La, the gateway to Zanskar. Ladakh is a high-altitude desert as the Himalayas create a rain shadow, generally denying entry to monsoon clouds. Average yearly rain fall is 80 mm. The main source of water in Ladakh is the winter snowfall on the mountains. Cloud burst in the region in 2010 had been attributed to abnormal rain patterns and retreating glaciers, both of which have been found to be linked to global climate change.

3.2 Flora

Vegetation is extremely sparse in Ladakh except along streambeds and wetlands, on high slopes, and irrigated places. About 1250 plant species, including crops, were reported from Ladakh. Natural vegetation commonly seen along watercourses includes sea buckthorn, wild roses of pink or yellow varieties, tamarisk, caraway, stinging nettles, mint, Physochlaina praealta, and various grasses.

3.3 Weather Condition

The climate is cold and dry, with scanty precipitation that falls mainly as snow in winter. The air temperature during winter ranges between -23°C and -8°C. The weather of winter in Leh is mercilessly cold as the snow starts to cover the hamlet gradually. As the days go by, temperatures dip further. Because of the rarefied atmosphere (lack of oxygen) acclimatization is necessary on arrival in Ladakh. Acclimatization gets quite difficult during winters because of the snowfall. One of the localities, Dras located in the South of Ladakh close to Zoji-La , is reputed to be one of the world's coldest permanently inhabited places, with winter temperatures falling to as low as −40 °C or colder. The windier part of the year lasts for 5.5 months, from January 23 to July 06, with average wind speeds of more than 9.5 km/h. Because of elongated winter season working season in Ladakh region is limited to about six months; from May to October. Adverse weather besides affecting human efficiency also affects efficiency of construction equipment.

3.4 Connectivity to the Region

There are two main roads that connect Ladakh with the rest of the country, NH-1 connecting Srinagar to Kargil and Leh, and NH-3 connecting Manali to Leh. A third road to Ladakh is the Nimu-Padam-Darcha Road, which is under construction (Fig. 3).

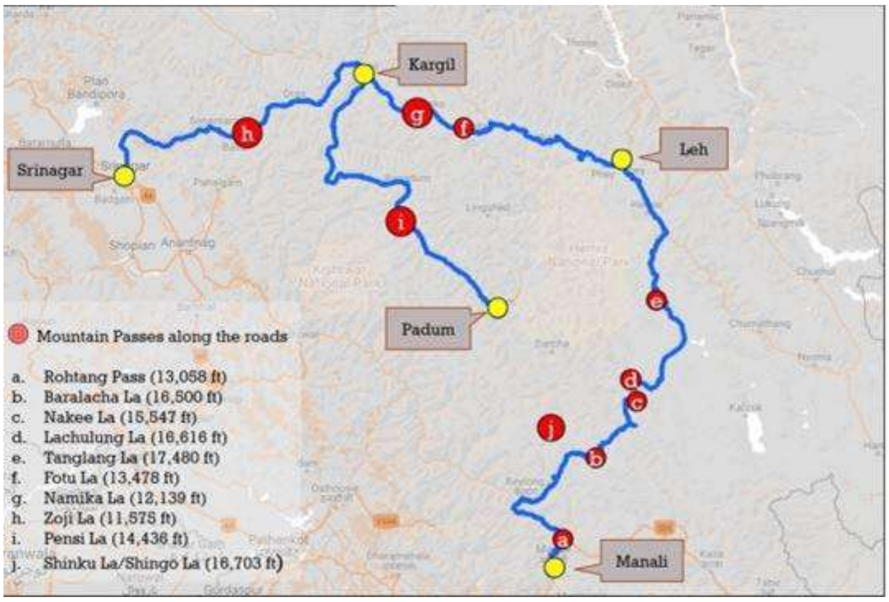

Figure 3 - Connectivity in Ladakh
Source: https://www.indiatoday.in/india/story/connecting-ladakh-india-growing-road-network-to-link-borders-with-the-mainland-1713978-2020-08-22

There is an airport in Leh, from which there are daily flights to Delhi and weekly flights to Srinagar and Jammu. There are two airstrips at Daulat Beg Oldie and Fukche for military transport. Another air strip is coming up at Nyoma which would also be used for military purpose. It will be interesting to share that Army engineers used a very innovative technique to establish the feasibility of an air strip at Nyoma. They used a soil stabilizing agent RBI-Grade 81 to stabilize the soil to enhance its load bearing capacity to the extent that an Aircraft; AN-32 could land there. Airport at Kargil, was intended for civilian flights but is currently used by the Indian Army, though efforts are on to get it certified for civil flights.

RBI Grade-81 is an advanced soil stabiliser that re-engineers the in-situ soil and increases its strength and load bearing capacity. It is patented worldwide and in India, and is the only Stabiliser that is registered as a “Soil Stabiliser” in its country of origin. In a world where connectivity is paramount, and resources are increasingly constrained, soil stabilization is the perfect solution to construct world-class roads that are better, stronger, cheaper and environmentally friendly. RBI Grade-81 was developed in South Africa to construct roads and highways capable of supporting loads from heavy machinery in critical areas. The technology was subsequently bought over privately and developed and optimised even further. It has since been used in the construction of all kinds of roads, highways, airstrips, helipads, high altitude roads, forest roads and other pavements worldwide for more than twenty years. *Source: An internet upload: https://www.rbi81.in/*

4. AVAILABILITY OF BUILDING MATERIAL

Earth (sun-dried mud bricks), and timber made from poplar trees are the primary building materials which are obtained locally and have high insulating properties. Mud bricks and mud plaster store heat in the day and radiate it during the cold nights. Stones are also used for greater stability of the structure, however, it needs to be appreciated that stones are not available in adequate quantity.

Therefore, either stones will have to be transported from lower reaches or for better construction hollow blocks made of cement/ concrete blocks are made use of. local wood such as willow and apricot are often used for decorating doors, windows, and other household items.

5. LOCAL ARCHITECTURE

It needs to be appreciated that despite the harsh surroundings, humanity has continued to live in Ladakh since time immemorial. The survival can be attributed to evolution of a highly efficient and climatically sensitive vernacular architecture. Again, it needs to be underlined that the Vernacular architecture is not static, and it has been undergoing incremental changes with the changing times. One of the most important components of the vernacular architecture is Sustainability, which is achieved by firstly; utilizing local materials like; mud bricks, quartzite stones, timber from poplar trees, grass etc and secondly; local construction technologies. The buildings in Ladakh have a distinctive spatial arrangement to deal with the climatic conditions. For making interior of the house warm, Ladakh's residents have been harnessing the sun's energy through the use of traditional architecture that incorporates climate - controlling passive techniques. No wonder a typical Ladakhi House achieves as high as 40ºC temperature differential between outside and inside temperatures. The phenomenon of the Climate change is having impact on building construction and availability of building materials. Therefore, wherever it is not possible, non-indigenous technologies and materials from outside the Union Territory of Ladakh are required to be imported.

Climatic-controlled passive technique is a passive static solar type system, referred as Trombe wall, is made of dark-coloured building material and covered with vertical glass, whereby ventilated air can circulate between the wall and the glazing. Vents are located at the wall’s top and bottom to allow air to enter the indoor. Following Figure 4 shows a schematic representation of a Trombe wall. It works by absorbing the sun's rays and converts them into heat energy. The stored heat gradually conveys through the wall to the indoor surface by conduction and convection at night.

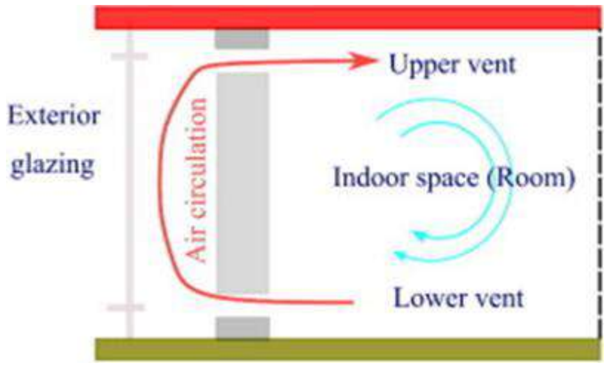

Figure 4- Climate-controlling passive technique (Qingang et al., 2022)

Exploitation of local resources; earth and timber, necessitates specific technologies. Builders are required to construct new forms in accordance with the physical qualities of brick to solve the roofing problem; the trunk of native poplar trees as beams has been the innovative solution. Traditional buildings in Ladakh, like those in Tibet, are made of stones, timber, and mud in various forms, such as sun-dried mud bricks and rammed earth for floor and roof plastering (Figs. 5 & 6).

The structures reflect the people's way of life, with cow pens on the ground floor and Buddhist altar chambers on the top. Most of the houses are two-storey structures. The Ground Floor is usually used for housing cattle, as a storage space, and a collection point for lavatory waste. Since the kitchen and sleeping areas are adjacent, the heat generated during cooking contributes to the overall warmth of the interior during the night.

Figure 5 -Typical Ladakhi building (Nasir & Kamal, 2021)

Figure 6 -Use of sun-dried earth blocks for construction (Nasir & Kamal, 2021)

The fundamental unit of masonry building is sun-dried earth blocks. They are used in the construction of 300 or 450 mm thick walls and are usually made in sizes of 300 x 150 x 150 mm. Alluvial material along the banks of the Indus river was used to create these earth bricks. Stone blocks are sometimes used in the lower courses of walls for extra strength and water resistance, especially in low-lying areas. Finally, mud plaster is used to complete the wall.

Roofs are built with flat spans utilizing the trunks of native poplar trees as beams, spaced 50-60cm apart. The trunks have an average diameter of 15 cm and a length of 3 to 4 metres. Poplar willows spread in the other direction are used to cover these timber members. Willows usually have a thickness of 20 to 30 mm. Over the layer of willows, a 15 to 20 cm layer of dried grass, hay, etc. is laid and finished with a clayey mud plaster. The bottom storey on the ground has mud floors, while the upper storey has wooden floors, which provide improved thermal comfort. Rammed earth is used for flooring and mud plaster is used for roof. The buildings are well-insulated with mud and straw to make them suitable for the local temperature, and the more essential room within the house is always planned in such a way that it faces south for sunlight with attended use of 'green house effect' to trap the heat from sunlight.

6. SOME OF THE CHALLENGES OF CONSTRUCTION IN LADAKH

6.1 Limited Working Season

During winters construction work cannot continue as such work will have to be finished in one season of 4-5 months. Therefore, way forward will be pre-engineered buildings (Fig. 7) or structures based on Tubular Light Steel Frame (TLSF) (Fig. 8). These are new engineering innovations to make custom built structures which can help to overcome shortage of local building material and limitation of working season. The civil engineering is progressing further and the new concept of 3D printed buildings could be the way ahead (Fig. 9).

Figure 7 - Frame work of a pre-engineered building

Figure 8 - Tubular steel light frame-based structure

In structural engineering, a Pre-Engineered Building (PEB) is designed by a PEB supplier or PEB manufacturer with a single design to be fabricated using various materials and methods to satisfy a wide range of structural and aesthetic design requirements. This is contrasted with a building built to a design that was created specifically for that building. Within some geographic industry sectors pre-engineered buildings are also called Pre-Engineered Metal Buildings (PEMB) or, as is becoming increasingly common due to the reduced amount of pre-engineering involved in custom computer-aided designs, simply Engineered Metal Buildings (EMB).

Tubular steel frame is pervasively used in the construction industry and is perhaps most immediately recognizable as the structure of scaffolding systems. These galvanized lengths of hollow steel are designed with excellent mechanical stability and good impact resistance to withstand demanding working conditions.

Figure 9 - A typical 3D printed construction

3D printing in construction (3DCP), makes use of robotics to deposit construction material in layers, creating walls, floors and roofs. Some essential supports and reinforcements can be prefabricated by the machine and incorporated into a house as it is being built. It is a far quicker way to create a structure than building a brick/ stone & Mortar or a RCC based construction. Just as a comparison instead of four months which takes a house to build using conventional techniques, a 3D printed 2,000 square foot house can take as little as 7-10 days to erect (Mathur, 2023). To cater for the limitation of the economic viability, it is recommended that as a special case certain tax benefits can be considered for Ladakh to make it economically viable.

6.2 Local Weather Conditions

Because of low temperatures and rarefied atmosphere, the setting of cement is a major issue. Certain additives for quick setting will have to be used. Also, these climatic issues impact efficiency of the labour force as well as that of machines. This limitation makes the case for the use of new technologies mentioned in Sub-Para above.

6.3 Lack of Availability of Local Labour

Local labour is not available and as such labour is being brought from lower reaches. These days, due to emphasis on infrastructure build up in rest of the country, availability of labour is increasingly becoming a challenge. The solution to this lies in leveraging technology which itself gets impacted due to low temperatures and therefore the only solution is to effectively optimize the use of the available working season and go in for advanced building construction technologies mentioned in Section 6.1.

6.4 Transportation of Building Material

There is a very limited availability of the building material locally and therefore a very efficient transportation model will have to be evolved to transport building material to Ladakh, within the competing priorities of the requirement to transport the other logistic needs. Here, it needs to be appreciated that cement will have to come from lower reaches and it has a limited shelf life. To further add to difficulty, the setting time of the cement increases due to low temperatures. Therefore, a Just in Time (JIT) model for the transportation of the cement and its utilisation will have to be thought of. Probably once Zoji-La tunnel gets completed the challenges associated with the transportation of material will get substantially eased out.

6.5 Power Requirement

Earlier most of the power requirement was being met through either Diesel Generating Sets or 'Off Grid Renewables'. The related problem was derated life of batteries and the environmental hazard on account of use of diesel. Now that Ladakh has been connected with the National grid the problem has been substantially addressed. However, problem in remote areas still persists. Way ahead would be to further expedite stretching the power grid to remote areas as soon as possible.

The performance of all batteries drops drastically at low temperatures; however, the elevated internal resistance will cause some warming effect by efficiency loss caused by voltage drop when applying a load current. At –20°C (–4°F) most batteries are at about 50 percent performance level. Although Ni-Cad can go down to –40°C (–40°F), the permissible discharge is only 0.2C (5-hour rate). Specialty Li-ion can operate to a temperature of –40°C but only at a reduced discharge rate; charging at this temperature is out of the question. With lead acid there is the danger of the electrolyte freezing, which can crack the enclosure. Lead acid freezes quicker with a low charge when the specific gravity is more like water than when fully charged.

Reference: An internet upload: https://batteryuniversity.com/article/bu-502-discharging-at-high-and-low-temperatures#:~:text=The%20performance%20of%20all%20batteries,about%2050%20percent%20performance%20level

6.6 Design

In RCC Construction snow load for the roof design will have to be incorporated. Similarly, design will have to cater for earth quake resistance. Also window designs will have to be such that sun light can be leveraged effectively for room heating. One of the new practices which is being followed for construction entails beam-column structures with beams and PCC blocks. This strategy entails use of working season optimally. Modern management techniques for the project management like Prima Vera or MS Project will have to be resorted to, to reduce any kind of wastage of time, effort or resources.

6.7 Sewage Disposal

Presently Ladakh does not have a central sewage disposal system. Also, non-degradation of sewage due to low temperatures is an issue. Thus, traditional method of dry composting of toilets is continued to be used. However, due to excessive tourist load this system is becoming inefficient because decomposition time due to lower temperatures is longer. Thus, for sewage treatment the sewage will have to be subjected to secondary and may be tertiary treatment for its hygienic disposal. Here it needs to be noted that below 15ºC bacteria goes dormant and thus the only solution is to put heat panels around the sewage plant to maintain the temperature around 20ºC for STP to function effectively. It also further needs to be noted that management of waste other than sewage to make area clean will have to be planned for which system of 'Waste to Energy' and utilization of plastic waste will have to be incorporated in the planning process.

In most cases, the bacteria used in water treatment plants function optimally at temperatures between 68°F and 95°F. These microorganisms can still function at a slowed rate with lower temperatures.
Ref: https://waterchillers.com/blog/post/temperature-control-of-wastewater-process#:~:text =In%20most%20cases%2C%20the%20bacteria,and%20render%20the%20process%20ineffective.

6.8 Pollution

Construction activities consume a substantial amount of energy and natural resources, at the same time, producing a large number of by-products. This means that the earth's resources are being depleted at a significantly faster rate than they are being replenished. Similarly, the manufacturing of tons of by-products releases undesirable materials into the environment, damaging it further. Therefore, construction indeed causes pollution of air, water, land, and noise besides consuming natural resource which result into avoidable scarcity and environmental degradation. An optimal solution of pollution within the envelope of continuing construction will have to be found out.

7. CONCLUDING REMARKS

Construction in remote areas is quite challenging and if it is Ladakh, then challenges further get accentuated. Here it needs to be appreciated that the geographical conditions and physical separation of Ladakh is unique and there is no parallel not only in India but anywhere else in the world. Therefore, the civil engineering fraternity will have to do deep diving into the research and development in conjunction with industry and come out with tailor made solutions specific to Ladakh region.

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