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Challenges in Traditonal Concrete Slab Construction for Housing Buildings in Developing Countries and Critical Need for Novel Methods

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ABSTRACT
The traditional cast-in-place reinforced concrete slab construction is the primary mode of slab construction for typical single family home slabs in India. This method is widely followed despite the concerns with regard to quality, costs and time demands of the method. This study starts with a discussion about the background and evolution of this construction method, the socio-economic context during which this method evolved, and the subsequent social and economic changes that happened in India in the last few decades. This study elaborates the construction processes in this method followed by the typical design and reinforcement details for a typical slab layout commonly seen in typical single family housing units in India. The study identifies the various problems associated with this method of construction in the current socio-economic context in the country and highlights the major challenges and concerns with this construction. Finally, the authors emphasize the critical and urgent need for builders, engineers and owners of these single family concrete buildings to adapt and move towards novel construction methods and materials for housing slab members to achieve quality, economy and efficiency in slab construction.

KEY WORDS: cast-in-place, concrete, double-tee, home, housing, India, precast, slab, ultra-high-performance-concrete

I. INTRODUCTION AND BACKGROUND

The Traditional Cast-In-Place (called as 'TCIP' hereafter) concrete frame and slab system is an outcome of a deep old practice in India among builders and masons with regard to building residential homes in India. Easy availability of labor, scarce populations, limited housing, lack of manufacturing technology in India during the 19th century,all formed the basis for this TCIP construction method in which skilled masons were able to build reinforced concrete slabhousing units with very limited knowledge about the engineering principles behind it.

In this method of construction, foundations are typically built with isolated pad footing or out of in-situ concrete piles (using manual augurs for drilling)when the soil is not conducive for shallow foundations. Upon drilling shafts into the soil using manual augurs, the foundation steel cage is placed and foundation piles are concreted. The foundation steel is left projected up to 4 to 5ft above the ground so that column steel can be lapped to these bars later (figure 1).

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Figure 1: Workers drilling augurs for concrete piles (top left), placing steel reinforcement into the pile shaft and concreting (top right), foundation steel extended up to tie with column steel(bottom)

In order to construct columns, standard wooden or iron box shutters are fixed around the column cage depending on the size of the column. Column reinforcement is projected out at beam locations so column-beam steel can be tied together for monolithic or integrated behavior as shown in figure 2. The concrete is then poured into these box shutters and allowed to harden for upto 14 days.

Figure 2: formwork for plinth beams (top left), plinth beams being concreted & compacted (right), completed plinth beams with column steel in place (bottom left)

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In the meanwhile, the work on tying of reinforcement cages for the beams is carried by workers at the site on the ground. The erection of temporary formwork for beam and floor system is very cumbersome and laborious. Wooden panels and bamboo logs are used for making the formwork (figure 3). Several wooden logs are placed as temporary posts to support rectangular wooden panels readily available in sizes of 4 to 8ft. These planks are attached on top of bamboo posts and beams using iron nails. These wooden panels are usually cleaned and oiled so concrete does not stick to them when beams and slab are poured.

When the formwork is completed, workers climb on top of the wooden panels to lift the prebuilt beam reinforcement cages from the ground, place them within the beam formwork and tie the beam reinforcement to the column steel projecting out. The workers arrange the reinforcement steel on top of the slab formwork.The slab reinforcement is connected to the beam reinforcement as per detailing drawings provided by the approving engineer. The entire reinforcement steel detailing is then inspected by the engineer and after his approval, concrete is poured over the entire floor slab. Figure 4 illustrates these stages in the construction process.

Figure 3: Formwork for slab construction built out of bamboo posts, decks and wooden panels

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Figure 4: Worker tying slab reinforcement on stop of formwork deck (top left), Engineer inspecting reinforcement details (top right), slab concrete pour from chute (bottom left), workers doing concrete finish (bottom right)

This fresh concrete slab is covered with plastic tarps to protect fresh concrete from heat and rain. The concrete is allowed to harden for about 12-24 hours after which it is water-cured for about 10 to 14 days regularly. Curing ponds are made on top of the hardened slab to retain water on the slab to reduce heat of hydration as shown in figure 5. At the end of 14 to 28 days when the slab concrete is expected to have sufficient strength, all the temporary formwork supporting the slab including bamboo posts and wooden panels is removed.

This completes the construction of the traditional cast-in-place RCC slab for traditional concrete residential housing units in India. The method is repeated for each of the floors if the building has multiple floors.

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Figure 5: Covering fresh concrete with Tarp (left), Water curing the completed slabs using curing pond method (right)

An overwhelming majority of single family homes are built using this method of construction even today. Even though concrete materials and technology have evolved substantially over the last century, the construction methods of residential homes in India have not reaped the benefits of novel methods. As such, the cost of construction as well as the costs of owning a home have been quite high and beyond the reach of majority of Indians.

In the next sections of this paper, a summary of the typical design and reinforcement details of the TCIP concrete floor slab construction is presented. The buildingcode references, material specifications and member geometry are discussed. Followed by this, an elaborate discussion about the challenges of the current TCIP method of construction andits effects on the efficiency and economies of construction is documented. An urgent and critical need to advance towards alternate methods, materials of construction and designs is recommended.

DESIGN DETAILS OF TYPICAL CAST-IN-PLACE CONCRETE SLAB

Detailed designs of any structural member are specific to the size of the rooms, the span of the slab and specific loads occurring on the member. However a vast majority of the typical single family slab designs in India are largely similar in slab geometry and reinforcement detailing. The main reason behind this is that the floor slab designs that are most commonly seen around for Indian housing units are designed for upper bound spans based on average loading requirements and service performance criteria defined by Indian standards 456.

Except a small spectrum of housing buildings where the room sizes and loads may fall outside these upper bound values, the vast majority of the housing unit sizes are well within these bounds, and hence their designs are conservative and covered by the typical standard geometry and reinforcement. This standardization though not efficient orcost effectivestemmed out of another major reason, engineers seldom oversee the construction of typical housing units in India, builders and masons lead the construction activities in most of the cases. Most of these builders and masons do not have a formal education or technical knowledge required to understand the engineering principles of design and construction. As such having a standard approved slab design that covers the typical housing slab requirements makes it much easier for these builders and masons to execute the construction activities out of repetition and practice rather than knowledge of the underlying engineering principles. Of course, this practice is not new to civil engineering profession, many signature constructions in the world historically were completed by construction workerswith noformaldegrees. However, economies and efficiencies might not be a priority in such scenarios.

In this section, an effort is made to identify the typical design details of the floor slabs based on slab layout plan identified by authorsemulating typical floor slab layouts used for housing units in India as shown in figure 6. The slab design details presented here are a synthesis of

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information from multiple sources as well as author's observation and understanding of the TCIP slab construction in India. The materials, loads, design and detailing specifications of concrete buildings in India are bound by the specifications of Indian Standard[1] which is the code of practice for the design and construction of plain and reinforced concrete members.Thetypical material strengths, the loads, the slab thickness, and the commonly usedreinforcement details of theTCIP floor slab are documented in table 1.

Materials	**Cement:** Ordinary Portland cement (Grade 53) is commonly used. This cement gives a minimum of 53 MPa of compressive strength at the age of 28 days. **Concrete:** M20 nominal mix is commonly used. Specific design mixes are used by some builders. These mixes give about 20-25 MPa of compressive strength at the end of 28 days **Steel:**The steel grade most commonly used these days is Fe 500, In the older days, Fe 250& Fe415 were commonly used.
Loads	**Self weight of the members:** The self weights of the members are calculated based on concreteunit weight of 2500 Kg/m^3 **Super Imposed Dead Loads:** Minimum super imposed dead loads are 0.25 kN/m$^{2.}$ This is to account for floor finishes such as tiles, marble or granite finishes **Super Imposed Live Loads:** Minimum super imposed live loads are considered as 2.0 kN/m^2
Geometry	**Slab Span**: The slab span ranges are in line with room widths which are most commonly limited to 12 to 16 ft in slab span direction. **Slab Thickness**: Reinforced concrete slab thicknessesrange from 100-125 mm
Reinforcement	**Reinforcement Ratio:**Primary flexural reinforcement is of gradeFe500, and size8mm bars. Reinforcement is arranged in 2 layers, one layer at the bottom of the slab at midspan locations (to resist positive flexure) and the other at the top of the slab overintermediate beams (to resist negative flexure). The clear cover to steel is typically kept at 25mmm from the surface of the slab. Similar size and spacing of reinforcement is provided as secondary reinforcementin the orthogonal direction as well. This reinforcement in many cases is governed by the minimum temperature and shrinkage reinforcement and is about 0.15% of cross sectional area of slab. This total steel can be distributed between top layer and bottom layers of reinforcement. **Spacing of Reinforcement:** The maximum spacing of reinforcement is usually 200-250 mm based on design strength and shrinkage and temperature requirements, however it is limited to a maximum of twice the slab thickness (which is about 200-250 mm for 100-125 mm thick slabs)

Table 1: Typical Design Details of Traditional CIP floor slabs in typical Indian homes

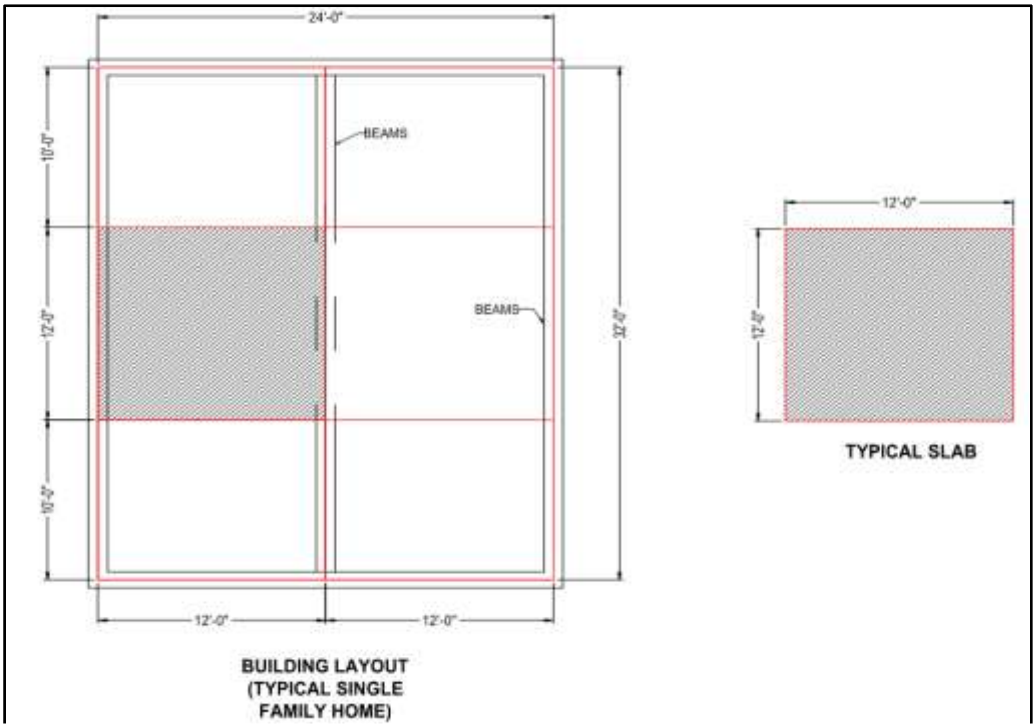

Figure 6: TypicalBuilding & Slab Layout of Single Family Home

CHALLENGES OF TRADITIONAL CAST-IN-PLACE SLAB CONSTRUCTION

While this traditional RCCfloor slab constructionseems likea robuststructural arrangementby virtue of its rigid frame behavior and provides redundant load paths, it is neither cost-effective nor relevant for the current socio-economic context. This conventional method causes significant delays to construction schedules andthe construction activity is prolonged for long periods of time. To quote a realistic example, the author's brother'stiny home which is just about 500 ft^2 of floor area and built over two elevated floor levels took about two years for completion of the structural frame alone.

To look at the history, theTCIP concrete beam and slab construction was effective and economical until two decades ago when social and economic factors were completely different from the current situation. The cost of labor, cost of materials, form work was very inexpensive in those days. Availability of labor was abundant and stacking of construction materials such as cement bags, sand, gravel, bricks, stone on the street-sides of the neighborhood in the vicinity of the constructed structure was feasible due to low population densities and far fewer motor traffic on the streets. Noise from construction activities, pollution and public nuisance wasn't even a concern as the number of construction activities were far fewer and spread in time and space.

However, those social and economic conditions do not prevail anymore. The current social and economic conditions in India are astronomically different from the conditions during the days when the TCIP concrete home construction evolved. The standard of living climbed up substantially. The graduation levels of Indian students is higher than that of some of the developed countries in the world. India has become one of the leaders in the fields of sciences, medicine, engineering and information technology. The Gross Domestic Product (GDP) of the country raised from 189 billion US dollars in1980 to 3.5 trillion US dollars in 2021 as per International Monetary Fund reports[2].Changes occurredat remarkable speed and intensity in the last two decades.

All the above mentioned improvements also lead to changes in the social and economic conditions and affected businesses and industries very significantly in terms of costs of construction. The prices of construction materials inflated exponentially. With increased education and availability of technology jobs, the traditional construction work force which came from poor income families is not available as much anymore. The availability of higher wages elsewhere lead to severe labor shortages in construction field. The

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reduction in the availability of the labor, the increase in standards of living, the price inflation and the massive shortage for cheap work force all contributed to astronomical rise in construction material costs, labor costs, and formwork costs.

Figure 7: Stacking of construction materials on the street (top& bottom left), Concrete mixing on street (bottom right)

Adding to these troubles is the space shortage and traffic congestion that was created by the increased human population densities. On-site stacking of construction materials is a major nuisance these days and is almost not acceptable (figure 7& 8). Traditional curing methods that require large scale watering of structural members is another constraint as it could lead to mosquito breeding and health issues in the neighborhood in addition to possible flooding on the streets and inconvenience to neighbors. On site tying of reinforcement cages poses safety issues to workers, especially that there are no occupational safety norms enforced in India for residential home construction workers (figure 9). All these factors made TCIP construction in urban India, a serious challenge.

Figure 8: Stacking bricks and stone on street (left), Curing ponds are favorite spots for mosquito breeding (right)

Despite all these unfavorable conditions, the construction of residential small family housing in India hasn't evolved much. Construction is still carried in the same old traditional TCIP method.This is mainly due to lack of knowledge and training of the builders, masons and construction workersin alternate methods of construction. The small family residential housing engineers and builders in India are largely disconnected with evolving methods of construction. Also, is the lack of flexibility and readiness to try out alternate methods.

Figure 9: Misalignment of beam formwork (top left), unsafe work conditions (right), fresh concrete prone to rain flooding-inadequate cover (bottom left)

Sticking to this method of construction despite all the above mentioned major inadequacies obviously raises serious questions about the quality, economy and safety of construction (figure 9). The author during his informal inspections of his brother's home during construction, had very often noticed tendencies for deviations from code specifications and quality processes. The author had to intervene and guide to rectify the errors during every stage of construction such as ensuring right method of material stacking, adhering to proportioned concrete mix quantities, adhering to design geometry and reinforcement of structural members, ensuring sufficient lap lengths and spacing of steel reinforcement, advising on adequate and timely water curing of structure and about many other activities during the entire period of construction.

There was a huge need for guidance and advise not only in terms of engineering and construction quality but also in terms of worker safety (Figure 9) and minimal public inconvenience (Figures 7, 8). While all these interventions lead to a significantly improved and acceptable outcomes in terms of quality of construction, it eventuallylead to increased construction period and associated costs. At the end of construction, it is clear, the TCIP slab construction for small family housing in India is not relevant anymore to the socio-economic context, there is an immediate and urgent need to adapt to alternate materials and methods of house construction.

CRITICAL NEED FOR EMBRACING NOVEL CONSTRUCTION METHODS

In light of the challenges associated with traditional cast-in-place slab construction and the major concerns about the quality and cost of construction andproject schedules, the author believes that there is a critical need for embracing novel construction methods for slab construction for single family homes in India. As such there are many methods of slab construction that evolved in the last decade or so that are not only very efficient in terms of quality and speed of construction but also provide huge economies in costs.

Methods such as prestressed and precast construction[3], waffled slab construction, steel-concrete composite decks, double-tee slabs [4], lightweight and efficient double-tee members[5], and hollow-core slabs are some of the novel slab systems that can provide excellent substitutesto the typical cast-in-place slab construction. Similarlynew materials such as Ultra-High-Performance Concretecan provide great economies and efficiencies in slab constructionby virtue of improved strength and durability [6,7].A feature common to most of these novel methods is minimal to no formwork requirement. Also plant manufactured concrete is used as opposed to onsite made concrete. Ram et al outlined in detail about the benefits of precast concrete for Indian construction markets [8]. The study discussed the background about double-tee members and the need for developing standard designs for precast products in line with charts and tables developed by PCI [9]. These alternate construction methods aid in promoting sustainable civil engineering practicesby improving quality, durabilitytoenhance life of structuresand reduce structural deterioration due to prematureageingas advocated by research studies [10].

The purpose of this report is not only to educate the builders and owners of small homes about the limitations, the technical and social obsolescence[11, 12] of the TCIP method of construction but also to force them to think about the critical need to develop alternate and novel methods of construction and adapt to these new methods toenable quality and cost-efficient construction of housing slabs in India.

A separate paper identifying the novel methods of construction that have great potential to substitute cast-in-place construction is warranted.This subsequent study can be a natural extension of the work documented this paper andoffers scope for future dissemination of knowledge aboutthe alternate construction methods.

II. CONCLUSIONS

The following conclusions are made at this end of this study.

- The drastic change in socio-economic conditions and the rise in inflation skyrocketed the cost of construction materials and skilled labor
- Growth of economy created jobs and wealth thereby making availability of skilled construction labor a major problem
- Rising costs and inadequate labor made adverse impacts on the quality and efficiency of construction
- Dense human populations and improved way of living made onsite stacking of construction materials, formwork, and onsite concrete manufacture a nuisance
- The cast-in-place slab construction which proved to be a robust method earlier is no more relevant to the prevailing socio-economic conditions in India
- There is a critical need for Indian single family home engineers, builders and owners to embrace novel slab construction methods that have evolved in modern times and can prove to be very pertinent and beneficial to single family homes

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