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Research Article

Background of Double Tee Construction and Need for Standardized Precast Double Tee for Indian Building Industry

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Abstract: The small scale residential and commercial office spaces in India are mostly engineered and built using reinforced concrete cast-in-place design and construction methods. Even though precast concrete engineering and design methods are well developed and practiced in advanced countries, the same has not happened in India. Though some major projects in metropolitan cities have been completed in precast engineering and construction, precast concrete engineering is still very premature for small scale residential and commercial infrastructure. Although factors such as centuries-old practice, availability of inexpensive labor have been primary causes for cast-in-place concrete construction, lack of technology and research outcome reach, unavailability of standard products and methods, inadequate shipping and handling capabilities that require reliable transportation infrastructure also weigh in towards cast-in-place construction as opposed to precast construction.

This research started with the primary objective of identifying and developing standard precast double tee concrete beam-slab members for Indian market. Precast double tee concrete members (often called as DT) are very standard flooring and roofing options in advanced countries. These members can offer very viable concrete flooring and roofing solution to most of the residential and small office spaces in India. However, the member designs for Indian market will be significantly different from standard designs seen elsewhere in other countries. Manufacturing capabilities, shipping capacities, crane handling limitations, truck sizes and highway transportation constraints being so different from advanced countries, demand for standard geometry and design that fits local needs.

In the first part of this research, a thorough background of PCI standard DT member showing its geometry and standard design is given. An introduction to PCI load tables is done showing examples on its application. After that a market survey has been conducted to understand the design and construction practices of precast double tee members supplied by some of the Indian precasters. An effort has been made to capture the preferences such as span of the members, fully precast versus partial precast with field topping, thickness of topping slab, and prestressing strand size. Also, the survey questions tried to identify shipping and handling limitations due to transportation restrictions. Finally, the results are analyzed and trends are presented. Effort is made to learn the precast practices in Indian market. It is found that there is no standardized double tee member design available for Indian precast market.

It is concluded that the idea of developing standard DT member for Indian precast segment will be a very useful contribution and encourages the authors to continue with developing standard design for typical precast prestressed DT members for small scale residential and commercial structures in India

Keywords:

1. Introduction

The scale of residential and commercial building market in India is massively large. India is the country with over one and half billon population and a large portion of the population is young and in productive working age group. The housing, business and commercial needs of these people drive for infrastructure needs on a very large scale. Whether they are single family dwellings, apartment complexes, small office spaces or big office spaces, mass transit projects or highway projects, the need and demand for civil engineering infrastructure is always high. Large scale transportation infrastructure especially bridge construction has leaned well towards precast engineering and construction technologies. Post-tensioned box girder bridges with segments that are transversely pre-tensioned (Raju, 2018), precast in plant and shipped to field and erected using span by span construction, segmental construction or balanced cantilever construction have become popular choices for elevated viaducts on high speed metro rail projects as well as some highway flyover and bridge structures. Engineers and contractors on these major infrastructure projects realized that minimal field form work, quick erection and construction, high quality control, little inconvenience to traffic are some of the major advantages of going for precast construction on these kinds of projects.

However, the utilization of precast construction in residential and office buildings in India is very minimal. This is the case especially with single family housing and small office spaces. These are buildings that have built up floor area from few hundred to few thousand square foot and can go from one level to five levels high above ground. Most of these types of structures are built using age-old cast-in-place construction methods employing manual labor and onsite material mixing and placement. While old practices, inadequate shipping and handling

methods are some of the causes for not moving towards precast construction in these cases, poor awareness of precast technology, unavailability of standard products and standard design methods too are to be blamed.

The authors believe that precast can become more popular and favored mode of construction in India if the precast member design, shipping, handling and erection methods are standardized. Standardized designs use standard geometry and reinforcement. Standardized designs use standard product dimensions. These standard product dimensions are developed keeping in mind the crane handling, truck shipping, limits and highway legally permitted loads. Load tables and load charts can be developed and readily used without need for rigorous analysis and design methods on each project every time. The load charts will provide details such as self weight loads, superimposed dead loads, allowable live loads, the span range and prestressing strand number, size and pattern for standard section geometries and beam-slab depths. An engineer can quickly refer to the load charts and come up with steel reinforcement details for the given span and loads on a specific project in less than a day's time. Because standard designs and member dimensions fit shipping, handling and transportation limits, the engineer need not worry about those issues and can straight away adopt the standard member design for the project. The entire engineering project is drastically simplified. The advantage of this process is multi-fold. First, it will allow small precasters and small contractors get interested into precast building because they do not need large design teams. Routine projects can be quickly designed and constructed by these small precasters. Second, standard designs use standard form work, standard truck sizes, standard lifters, standard materials such as one strand size, standard mesh size, select rebar sizes. All this standardization makes product readily available in market. Third, great economies are achieved in the process. Standard designs cut down cost of engineering, standard materials cut down purchase and procurement costs as well as time, standard dimensions and geometry remove the hurdles associated with legal permits. More importantly, standard designs infuse confidence in precasters because the designs are proven and vetted, they know the load charts are well designed and the overall process is thought off. Overall standardization brings good news to engineers, precasters and more importantly the customers.

The process of standardization starts with the most common beam-slab member in precast industry; the double tee. The first step in standardizing design process is to identify and develop a standard geometry for the member. For this purpose, a market research has been conducted as part of this study. The objective of this research is to interview various precast manufacturers in India and collect information that helps understand the current precast products manufactured by them and methods used. We will navigate into the details of market survey, the questions, the answers and the outcomes of the market research in the section of this paper. The most important outcome of the market research however is that there is no standard precast double tee member developed so far for Indian construction industry. There are no standard design methods such as load tables and load charts ever developed. This stresses the need for standardization of designs and construction methods for precast members in India. Because there is no standard double tee member so far in Indian market, the authors henceforth propose to name the standard double tee beam-slab member being developed in this research study as 'Indian Double Tee' (IDT).

2. Background Of Double Tee Construction And Standardization

The authors' idea of developing standard precast double tee member for Indian construction market is inspired by a similar method adopted by Precast/Prestressed Concrete Institute (PCI) in developing a standard double tee member for American market. PCI has been very instrumental in standardizing precast designs and promoting precast engineering and construction across North America. PCI developed their handbook (PCI Design Handbook 8th Ed, 2017) expanding on the research contributions of many authors in the development of standard double tee (Edwards 1978, Nasser et al 2015). Their standard double tee is 12 ft wide and about 28 inches deep (often referred by PCI as 12DT28). Precast double tee members are a staple of precast concrete industry in the United States (Jonnalagadda et al, 2021). Subsequently lot of research has been conducted in optimizing this member with openings and studying their behavior (Barney et al 1977, Savage et al 1996, Classen & Dressen 2015, Jonnalagadda et al, 2021).

Double tee members are very vital in creating sustainable civil engineering infrastructure. Because these members are very robust and durable, they can be used in many commercial structures with very few serviceability issues in the long term. Innovative beam-slab products such as NEXT (New England Extreme Tee bulb) are inspired from standard double tee members. These NEXT beams are used for building bridge decks that take much heavier truck loads. These products help build sustainable infrastructure that minimizes infrastructure deficiencies (Jonnalagadda & Ross, 2016), reduce structural obsolescence (Jonnalagadda et al, 2015), slows down condition deterioration over years (Jonnalagadda & Ross 2016), and minimize maintenance and life cycle costs (Jonnalagadda & Ross 2017).

The standard DT comes in two versions, one with standard 2 in precast flange slab that is topped with another 2 to 3 inches of cast-in-place slab at the job site. The other one is a standard 4 in fully precast slab. Figure 1 shows the standard 12DT28 member from PCI Handbook (PCI Design Handbook 8th Ed, 2017).

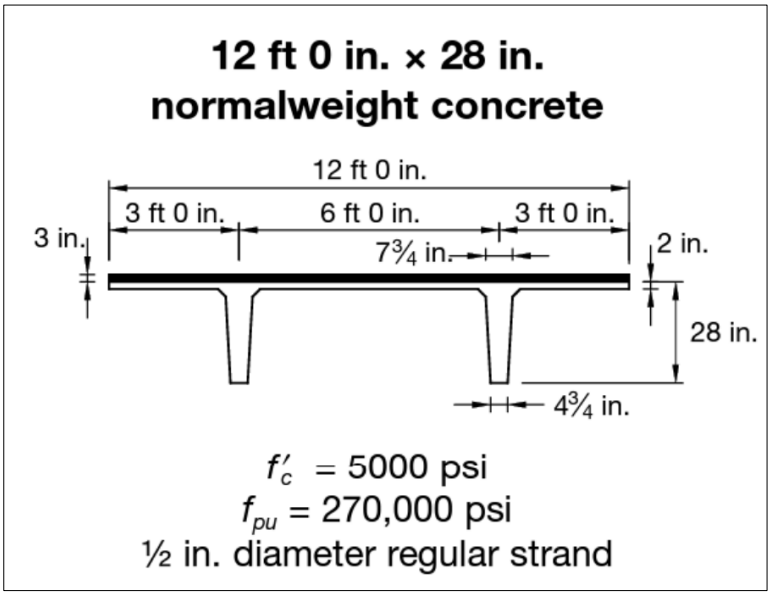

Figure 1: PCI standard 12DT28 member (PCI Design Handbook, 2017)

The PCI standard double tee member shown above is 12ft wide and 28 inch deep out of precast bed. The flange is made of 2in concrete slab. The picture shows a field topped concrete slab of about 3 in thick on top of the 2 in precast slab. The member has two stems (or webs) each about 7-3/4" thick on the top flaring down to about 4-3/4" at the bottom. The standard distance between the stems is 6 ft whereas the flange overhang beyond the web is 3ft. PCI also provides load charts for standard member designs. Figure 2 shows the load charts for 12DT28 member with 3 in field topping.

12DT28 + 3

Table of superimposed service load capacity, lb/ft², and cambers, in. — **3 in. normalweight topping**

Strand pattern	y_s (end) y_s (center), in.	Span, ft																	
		40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72
108-S	6.00 6.00	132 0.9 0.7	114 0.9 0.6	98 1.0 0.6	84 1.1 0.4	72 1.1 0.4	59 1.1 0.3	50 1.1 0.1	42 1.1 -0.1	35 1.1 -0.4	25 1.0 -0.9							
128-S	7.00 7.00	160 1.0 0.9	140 1.1 0.8	121 1.2 0.8	108 1.2 0.7	92 1.3 0.6	79 1.3 0.6	67 1.3 0.4	58 1.3 0.2	48 1.3 0.0	38 1.3 -0.3	28 1.3 -0.6						
148-S	8.00 8.00	182 1.1 1.0	160 1.2 1.0	141 1.3 1.0	122 1.4 1.0	108 1.4 0.9	94 1.5 0.8	82 1.5 0.6	70 1.5 0.5	57 1.5 0.2	47 1.5 0.0	37 1.5 -0.5	28 1.5 -0.7					
168-S	9.00 9.00	200 1.2 1.1	176 1.3 1.1	154 1.4 1.1	136 1.4 1.1	122 1.5 1.0	106 1.6 0.9	90 1.6 0.7	78 1.6 0.6	66 1.7 0.4	54 1.7 0.2	44 1.8 -0.2	34 1.6 -0.5	24 1.6 -0.9				
168-D1	13.00 3.75			202 1.7 1.5	178 1.8 1.5	154 1.9 1.5	136 2.0 1.5	122 2.1 1.4	113 2.2 1.3	101 2.2 1.1	88 2.3 0.9	76 2.3 0.7	64 2.3 0.4	54 2.3 0.0	46 2.3 -0.4	37 2.2 -0.9	29 2.2 -1.4	
188-D1	14.39 4.00							144 2.3 1.7	128 2.4 1.6	114 2.5 1.4	101 2.5 1.2	88 2.6 1.0	76 2.6 0.8	65 2.6 0.4	54 2.6 0.0	46 2.6 -0.4	38 2.5 -0.9	30 2.5 -1.5

Figure 2: PCI load table for standard prestressed 12DT28 with 3 in cast-in-place slab (PCI Design Handbook, 2017)

In the above figure, the strand pattern designation can be understood from the legend provided in Figure 3. For instance, 108-S indicates that the design needs 10 strands of 8/16th in diameter (1/2" diameter strands) and the strands are running straight through the profile of the beam-slab. The numbers inside the table indicate the superimposed service load capacity in pounds per square foot (psf) that the member can carry for the given span. Please note that 21 psf is roughly equivalent to 1 KN/m^2. The table also shows estimated short term and long term cambers of the DT member for that particular design.

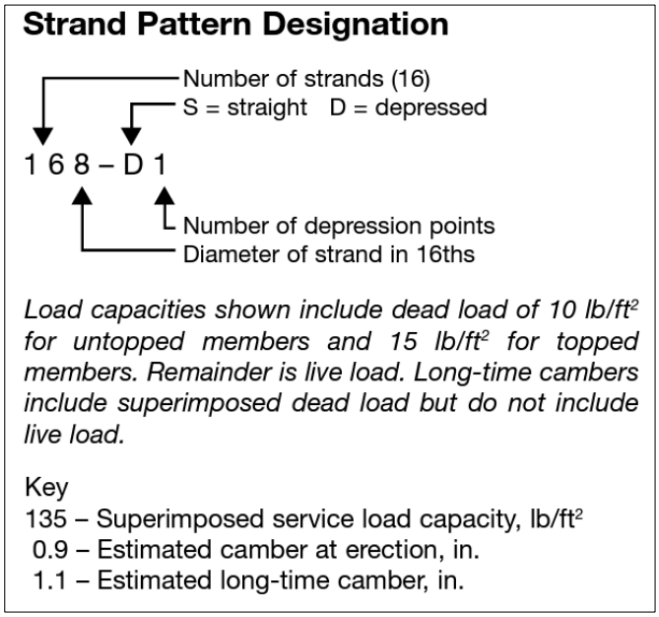

Figure 3: Strand pattern designation (PCI Design Handbook, 2017)

For any given situation, the precast DT member can be designed quickly in accordance with the provided load tables. Members are fabricated in long line beds at the precast plant as per the design and shop drawings. Once the initial concrete strength reaches minimal strength (2500 psi in general) required for the transfer of prestress forces, the prestressing strands are cut with welded-torch. After the prestress force is transferred to the member, the member is ready to be stripped from the bed. The stripping process is usually done within 12 to 15 hours of pouring concrete as soon as initial concrete strength is achieved. This lets the casting bed to be cleaned and greased so that it is ready for pouring concrete for the next set of members.

Figure 4 shows a precast double tee member being stripped from long line casting bed to be taken to the storage yard. Lifting bars or double prestress strand loops are commonly used to lift the members from the casting bed using two-point pick method. The loops or bars are usually located one at each stem location at both ends of the double tee. In total, 4 lifting loops are required for each double tee.

Figure 4: Stripping DT from long line casting bed (PCI Design Handbook, 2017)

Double tee members are moved to the storage yard after they are stripped from the bed. Figure 5 shows stacking of double tee members at precast storage yard. Most of the plants have large storage yards but only few hundred feet of casting beds. In general,four to five double tees of about 50 ft length can made out of long line beds each day. So, it is very important to quickly move the double tees from casting beds to storage yards such that casting beds can be reused. Stacking of double tees is a common practice. Stacking is an efficient way of

utilizing storage space to stack as many double tees as possible. Each stack can typically carry 3 to 4 double tees on top of one another.

Figure 5: Stacking of DT members at storage yard (PCI Design Handbook, 2017)

The members are then shipped on truck trailers to the project site to be erected for construction as shown in figure 6. Once the DT are brought to the job site, they are erected into their place (usually either on pre-erected beams or walls). Once the DT are erected, the joints between the two adjacent double tee members and the corner spaces between double tees and columns, and the edge spaces between double tees and girders are grouted either using cast in place concrete or cementitious grout material. These joints are usually about ½" wide. Backer rods are put in the joints to provide support for the grout until it hardens.

Figure 6: Shipping DT to project site (PCI Design Handbook, 2017)

Figure 7: Erection of DT members at project site (PCI Design Handbook, 2017)

3. Market Research Survey Methodology

The authors started by creating a market research survey about Indian precast market. The survey has two main objectives. The first objective is to understand the awareness of precast double tee construction in India and to learn if there is a standard precast double tee product in Indian precast industry. The second objective is to find out the capabilities and constraints with respect to fabrication, transportation, and erection of these members such that these things are kept in mind while proposing a standard member for the market.

The Survey Monkey™ website has been used by the authors to reach out to precast engineers and contractors. The survey has been created with a questionnaire that had ten questions. In total seven participants responded. This is lower than what the authors expected. In talking to the precast engineers and contractors who participated in the survey, the authors felt that knowledge in the precast industry is shared only in very close private circles and very few are willing to share their engineering and construction practices with others.

One reason could be that there is no standard advisory body for precast industry in India such as PCI in United States which would bring precast engineers and contractors together to share their practices and knowledge. Even though Indian Roads Congress (IRC) and Indian Standards (IS) act as statutory code bodies in India for bridge and building industry respectively, they provide code guidelines (IRC-18 2000, IRC-06 2014, IS-1343 2012) that are more geared towards design of prestressed concrete buildings and bridges. These code bodies do not have dedicated specifications with respect to precast engineering, construction and methods which are evolving very rapidly in the last two decades and will outperform cast-in-place methods in India in the near future.

In total, the survey was created with ten questions. All are either multiple choice type or descriptive type. The questions related to awareness of product, types of projects, member geometry, strand details, and weight limits on the product. Table 1 lists all ten questions included in the market survey.

Question#	Question	Answer choices			
1	Are you aware of the PCI precast DT beam	Yes	No		
2	Has your company ever manufactured precast DT beam	Yes	No		
3	What kind of projects are most commonly built using precast DT beam	Residential	Commercial	Bridge decks	Parking structures
4	What is the most common span range for DT usage	descriptive answer			
5	What kind of precast DT members does your company build	Fully precast		Partially precast with CIP concrete	
6	What is the most common prestressing strand size used	10mm (3/8”)	12mm (1/2”)	14.2mm (9/16”)	others
7	What is the common cast in place concrete thickness over the DT	50mm (2”)	75mm (3”)	100mm (4”)	N/A

8	What is weight limit of DT that does not require special transport permit	descriptive answer		
9	What is the single major stopping issue against the use of precast DT	descriptive answer		
10	Would you be interested in a more detailed interview on this subject	Yes	No	

Table 1: Market Research Survey Questions

The above survey is then distributed to several engineers and contractors associated with precast construction. More than twenty people have been sent the emails with a link to the survey. The authors awaited more than three months to receive the responses after multiple follow ups. Finally seven participants responded to the survey questions.

Finally the results of the survey are collected from data analysis module of SurveyMonkey™. In the following section, the results of the survey are presented using graphical methods. A discussion is made about the common practices, the patterns, the common capabilities and limitations of the precast industry in India based on the outcomes of the survey.

4. Results And Discussion

Looking at the responses received from seven participant engineers and contractors of the survey gives some insights into the thinking of the Indian precast industry, its awareness of global practices, its capabilities and constraints in precast construction, and some general idea about the industry.

To start with, it seems the Indian precast industry is well aware of the PCI double tee beam section. About 86% of the respondents mentioned that they are aware of PCI DT product. About 14% mentioned that they are not aware of precast DT. However, about 60% of the respondents mentioned that their company manufactures precast DT. It seems that even though some respondents do not work at a precast facility that manufactures DT beam-slabs, they are still aware of the concept of PCI DT beam.

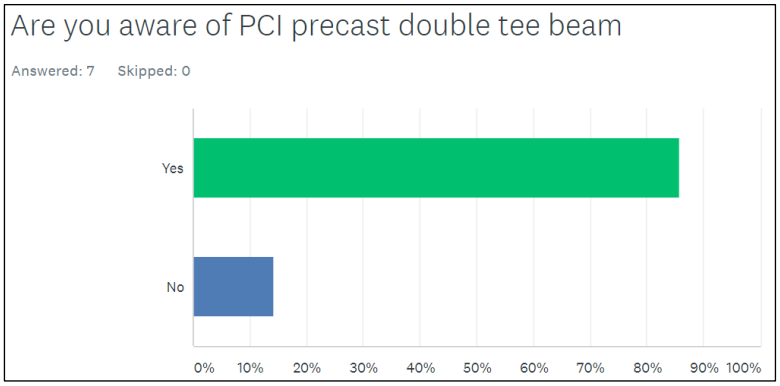

Figure 8: Survey responses about awareness of PCI DT

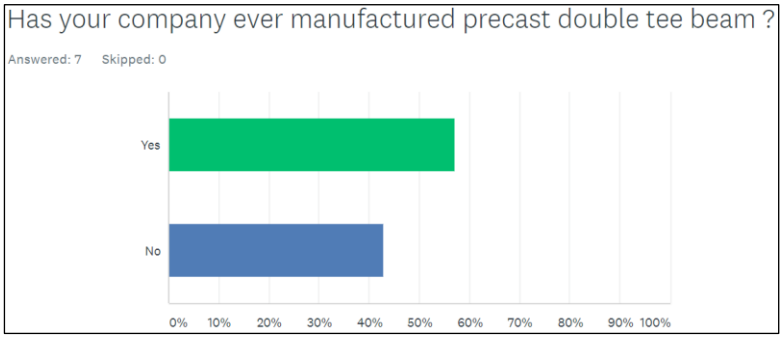

Figure 9: Survey responses about manufacture of DT members

The response to the question about what kind of projects are most commonly built using precast DT, about 42% said parking lots and the rest of the participants were divided evenly between bridge decks and commercial building slabs. This is interesting because DT members are most common solution for parking lots and have limited use in commercial floors. However, their use in bridge decks without major changes is quite rare.

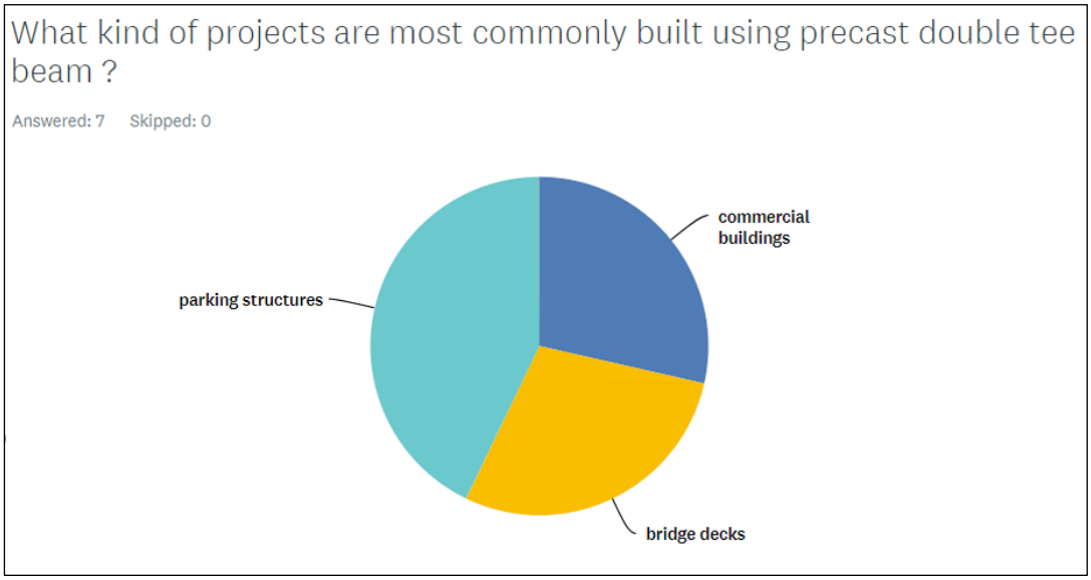

Figure 10: Survey responses about projects using DT members

There was no clear response on the span range for precast DT members, but overall 12m (39ft) and 18m(60ft) spans seemed to be reasonable responses.

In general, there are two types of DT members; fully precast DT and partially precast DT with cast-in-place concrete topping slab added over precast slab during construction process. The top surface of precast DT is made rough or rake finish to receive cast-in-place concrete slab. The precast DT acts as form work and both the precast and cast-in-place topping behave compositely to take superimposed loads. This procedure is very successful as it saves huge form work costs and provides robust structural strength and lateral stability to the structure. While fully precast DT members are more common for lighter gravity loads in non-seismic regions, partially precast DT with cast-in-place topping are more common in structures in seismic regions with heavy gravity loads. This survey included a question on their relative volume of usage in Indian market. The results of the survey indicated that about 60% of the members are made fully precast DT while 40% of the members are partially precast DT members with cast-in-place topping slab.

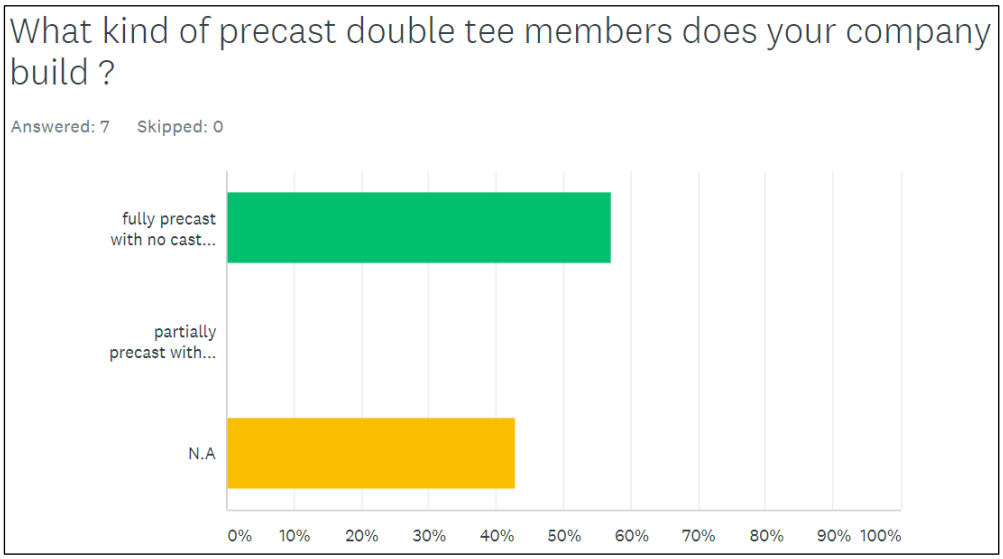

Figure 11: Survey responses about full and partial precast DT members

The responses shown in Figure 12 indicate that 12 to 12.7 mm (1/2”) and 15.2 (0.6”) mm sizes appear to be the most common strands used in precast DT members that are prestressed.

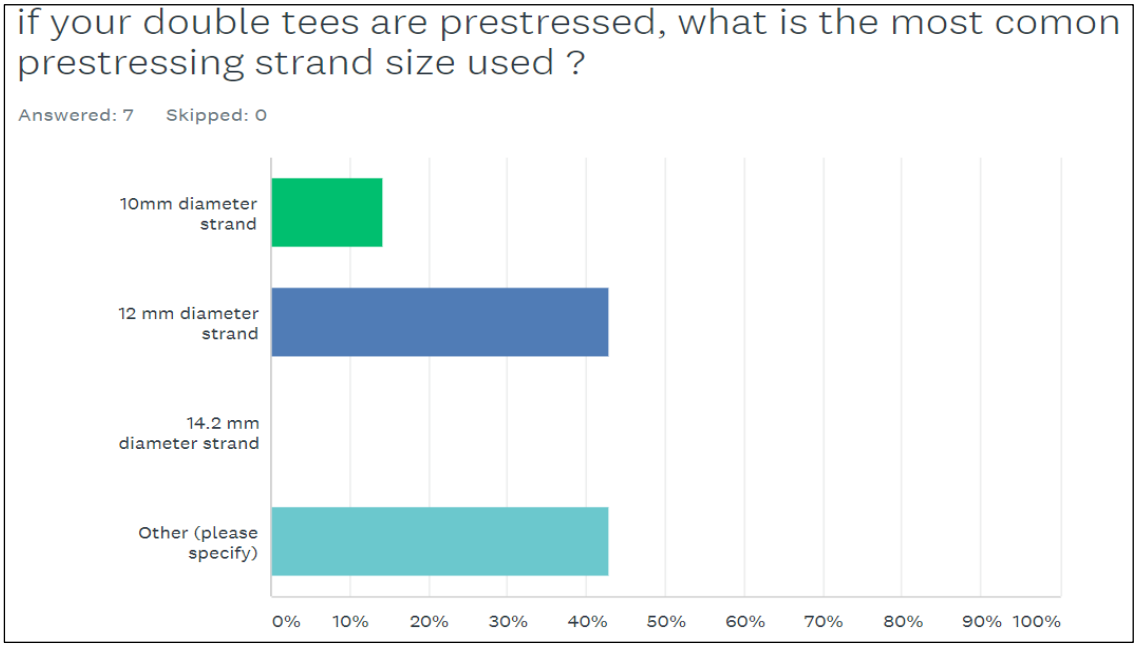

Figure 12: Survey responses about prestress strand sizes

('Others' include 12mm, 12.7mm and 15.2 mm)

It may be noted that when partially precast DT member with cast-in-place topping slab are designed, a 4 inch slab seems to more favoured over 2 inch and 3 inch topping slabs in the survey. This response seems a bit odd because heavier toppings increase overall costs and are not favoured unless they are really required. In the United States, 2 inch and 3 inch thick topping slabs are most commonly used for normal range of loads seen in parking and commercial structures.

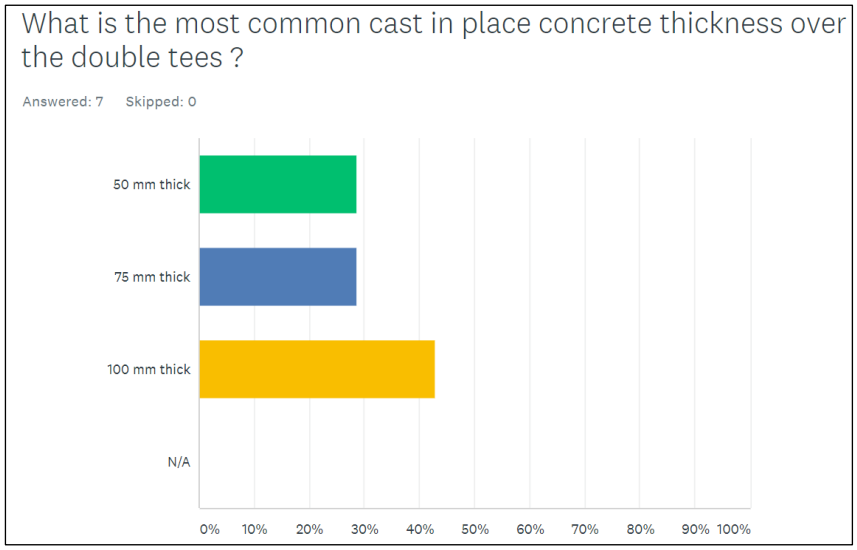

Figure 13: Survey responses about thickness of cast-in-place slab over DT members

One of the important objectives of this survey was to learn the shipping limitations on the weight of the precast members that can be transported on trucks trailers without special permits in India. From the survey responses, it appears that about 25-30 MT (55-66 Kip) is the gross vehicular weight limits of the regular trucks that does not require a special permit. It is common for trucks to have an empty weight of 6 to 10 metric tons (13-22 Kip). This means the maximum weight a precast member is limited to because of truck gross vehicular weight limits is about 20MT (44 Kip). This input is very important in the process of developing standardized products because the geometry of the member governs the weight of the member and hence geometry can be established in the beginning of the design process.

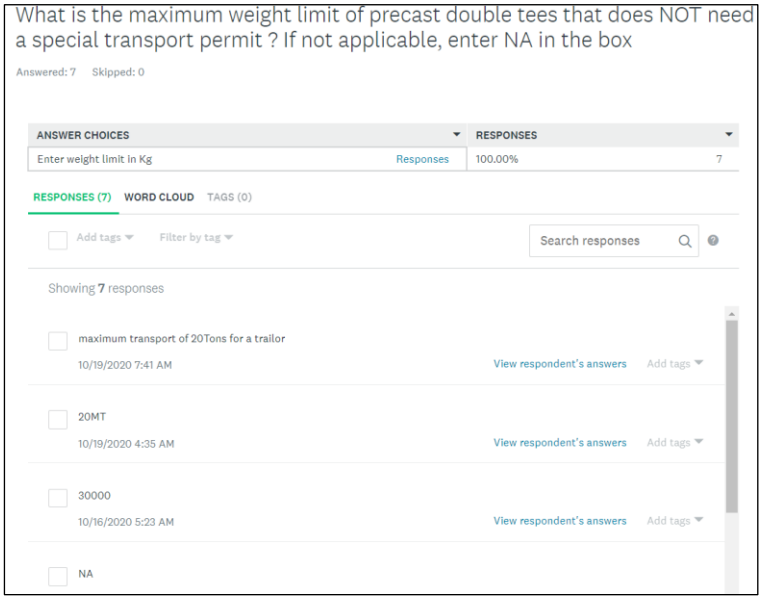

Figure 14: Survey responses about gross weight limits on trucks

The survey included couple of general questions. One of them is to identify the stopping factors against precast in becoming more popular choice of construction in India. The respondents gave an array of opinions in this regard as shown in Figure 15.

The awareness of precast engineering methods, construction practices and project costs seemed more reasonable issues among the survey response outcomes for this question.

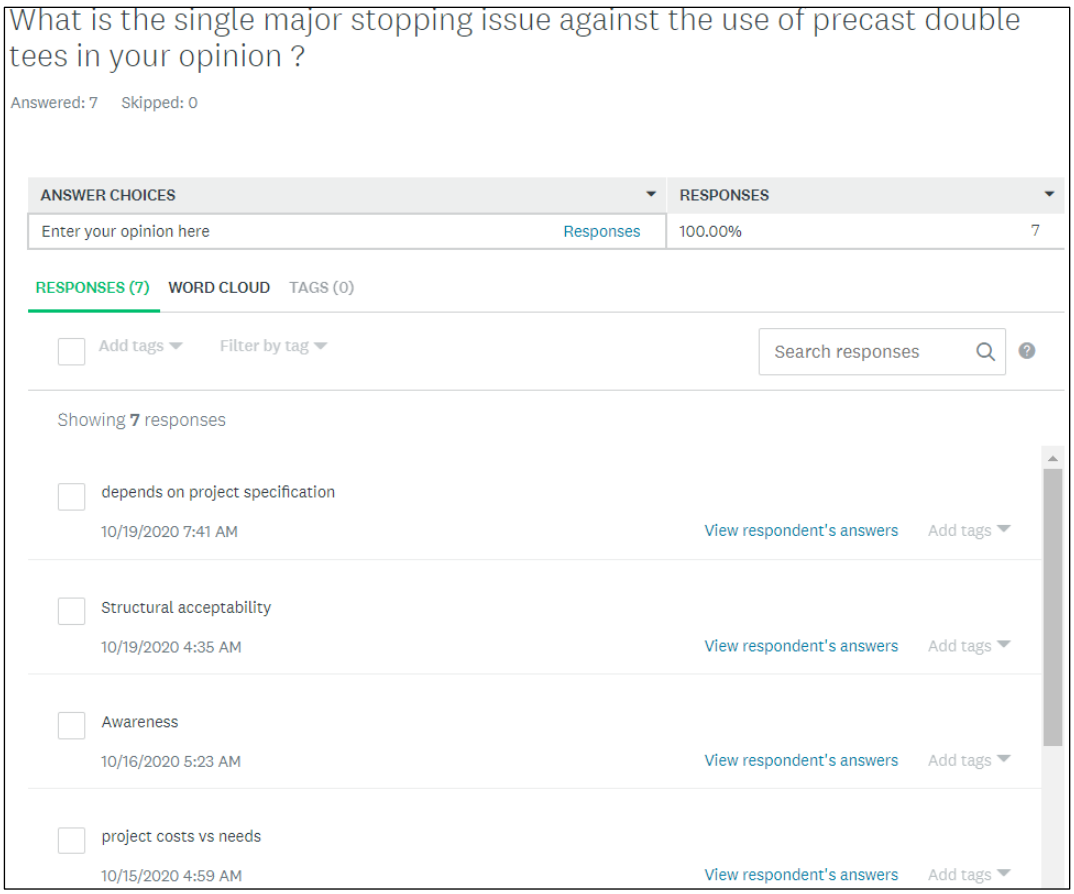

Figure 15: Survey responses on general questions

It is interesting to note that 90% of the respondents voted no when asked if they are ready to be contacted by phone to ask more detailed questions about the precast industry practices, challenges and opportunities. This could be for multiple reasons such as time constraints and other professional and personal reasons. However, this lack of sharing of knowledge will hinder the collaboration among the engineers and researchers in civil engineering industry ultimately deterring the progress of civil engineering and construction technology in India.

5. Conclusions

This research study started with a detailed background knowledge of PCI precast double tee beam-slab and put forward the idea of developing standardized prestressed precast double tee beam-slabs for Indian residential and commercial construction market. To understand the current state-of-precast engineering and construction in India, and to understand the requirements and challenges in developing this product a detailed market research survey is conducted using SurveyMonkey™ website. The survey is created with ten questions that interviewed the survey participants on topics such as geometry, strand sizes, projects, transportation weight limits, and general items such as awareness and need for standard products. In total about ten participants responded confidentially. Their responses are recorded and analyzed.

In this study, responses are presented graphically and discussed in detail. It is concluded that the state-of-precast has not evolved much in India especially with regards to small scale residential and commercial projects. There are no standard design and construction methods commonly adopted across the industry among multiple precasters. The authors believe that lack of awareness, age old practices of cast-in-place construction, lack of technology outreach, and lack of quality control processes required for precast methods are the major factors limiting the growth of precast engineering methods in India.

There is a great need for standardization of precast product engineering and construction methods across the industry. With standard designs and methods, products can be designed very quickly and precast contractors can build structures more confidently in quick and efficient ways. This will provide tremendous growth opportunities for precast construction in India and create major shift from cast-in-place construction to precast construction. This shift to precast is very essential to bring down construction time, eliminate ridiculously high labor costs, improve construction quality and as a whole help the Indian customer with quality infrastructure at low cost and short duration.

Finally it seems a reasonable conclusion that the authors' idea about developing standard prestressed precast double tee beam-slab for Indian market appears very useful and will be a valuable contribution to the Indian precast industry and its growth in India. As a natural extension to this initial study, the authors in currently in the process of identifying standard geometry and developing standard design for prestressed precast double tee beam-slab member that will fit as ideal floor member for typical small scale residential and commercial projects in India. This part of the research will be disseminated in the near future.

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