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Review Article

Overview of the Challenges in the Construction of Multistorey Reinforced Concrete Structure

Arti Sahu [1], S. Shanmugapriya[2]

[1]*Research Scholar, Department of Civil Engineering, Coimbatore Institute of Technology, Tamil Nadu, India*
[2]*Associate Professor, Department of Civil Engineering, Coimbatore Institute of Technology, Tamil Nadu, India*

[1]aartisahu655@gmail.com,

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Abstract - *Reinforced Concrete multistory building construction can be speedup by using sequential floor construction. Builders' demands to remove formwork more quickly have resulted in building collapse. Sequential floor construction involves casting new slabs at a higher level before the lower floors attain their ultimate strength. Shores either completely or partially support the lower floors in this process. Therefore, the correct formwork stripping sequence and understanding of the early loading concept of concrete are required to perform this technique properly. Engaging the available advancements in this technique, such as construction methods, concrete strength advancement, and formwork systems, saves the project's time and cost. In response to the growing demand in the community for this information on new developments, limitations, and the application of construction techniques, this paper was conceived. Researchers can learn more about building construction, and professionals can keep up to date on the latest developments. Building designers and construction professionals may benefit from the paper's findings by refining their current methods and procedures.*

Keywords - *Construction techniques, Formwork, Load distribution, Reshoring, Successive floor construction*.

1. Introduction

The main problem in India is that the developers still practice traditional methods for multistorey building construction. The construction industry in India is resistant to technological change because of the available human labor. Another problem is the lack of standards in putting the technology into action. There were major delays in project completion because of this lack of standardization.

Currently, the construction sector has been revolutionized due to rapid technological advancements. The use of new building materials and modern construction processes are required for the faster construction of successive floor construction. "Early Loading" technology is a new way to build multistory buildings with monolithic frames. It considers the actual loads of existing structures and significantly reduces the construction time [1]–[3]. Early removal of formwork is the process of removing formwork at a lower level before the time [4]. It means slabs at lower levels are loaded early before concrete's full strength [5]. Therefore, slab and shore load at the lower floor level increases. This increase in load differs from the construction technique used for construction.

Shoring is the process of constructing a multistory building by adding floors one by one. It is a common building method in which shoring and striking are the primary operations considered. Researchers recommend intermediate operations to speed up the RC construction process. The construction techniques introduced based on the intermediate operation are Reshoring, Pre-shoring, Back-shoring, and partial striking related to the shoring system for the Early formwork removal. In an intermediate operation, floors are supported completely or partially by the shores [5]–[10].

The main purpose of adopting this construction technique is to save time and cost without compromising safety. The cost is related to how well formwork is used when building successive floors because formwork makes up about 30 to 60 percent of the total cost of reinforced concrete (RC) construction [11], [12]. In India, the choice of a formwork system is still made by the people who use it. A formwork-selection decision greatly impacts the safety, economy, and quality of the project work [13]. In the past, researchers have worked on a model defining the factors that help people to choose appropriate formwork [14], [15]. Some quantitative models have been made using different decision-making tools like fuzzy logic, the AdaBoost algorithm, an artificial neural network (ANN), a boosted decision tree (BDT), and so on [15]–[19]. These models have been used for horizontal and vertical formwork systems to reduce costs. Another concern is time, which can be saved by planning the removal of formwork in a specific order and starting each construction phase of the RC building at the earliest time. Different construction methods influence project performance in different ways. Therefore, selecting an appropriate construction technique enhances project productivity and reduces cost and time.

The construction of RC multistorey buildings is the most common construction project found to overcome the issue of population growth and land shortage. Builders, architects, contractors, and researchers can select the best construction method for the project's goals and conditions if they have the right information and resources. The paper compares and contrasts the removal patterns of various construction techniques. This paper also explains the researchers' improvisations and drawbacks with the simplified method they used to calculate load distribution. This shortcoming prompted the researchers to keep coming up with new ideas for construction. One can find a suitable construction with minimal risk by understanding the improvisation process.

2. Overview of the construction method related to the shoring system

The successive floor construction is introduced to construct the number of floors in the reduced cycle time. Increasing the number of levels of shores is not encouraged as it demands more sets of formworks, which raises the project's overall cost. Furthermore, it also raises the shore loads on lower floors. Different construction techniques/procedures are employed to reduce the shore load. Construction methods refer to utilizing a formwork system to distribute the loads between slab and shore uniformly with their formwork removal pattern. An appropriate method results in fast construction by saving project time and cost.

In multistory building construction, a typical shore/reshore cycle is utilized to illustrate the differences in construction methods. The interconnected assembly comprises slabs, shores, and reshores. Each construction cycle is divided into three phases, according to a generally used construction sequence [20]. See Figure 1. Adding a new floor is phase one. The shores at the lowest level are removed and reinstalled following the construction method (reshoring, pre-shoring, back-shoring, and clearing). Phase three is the striking of the lowest level of reshores. For the new slab to be built, the shores and reshores must be set up in a way that doesn't cause excessive deflections to the interconnected slabs at a lower level. The shore removal patterns for Reshoring, Back-shoring, Pre-shoring, and Partial Strikes are shown below.

2.1. Shoring

Supporting a newly installed floor with vertical supports placed on several lower stories is the traditional technique for multistory construction [21]. Mosallam & Chen in 1990 [7] defined shoring as the construction procedure of casting a new slab supported by vertical shores and then removing the shores at a lower level after the concrete slab achieves its full strength. The load due to each shoring and striking construction phase will be distributed equally among interconnected slabs and shoring systems. However, increasing the number of shore levels may delay the peak load of a slab, but it increases the maximum shore load by adopting this method.

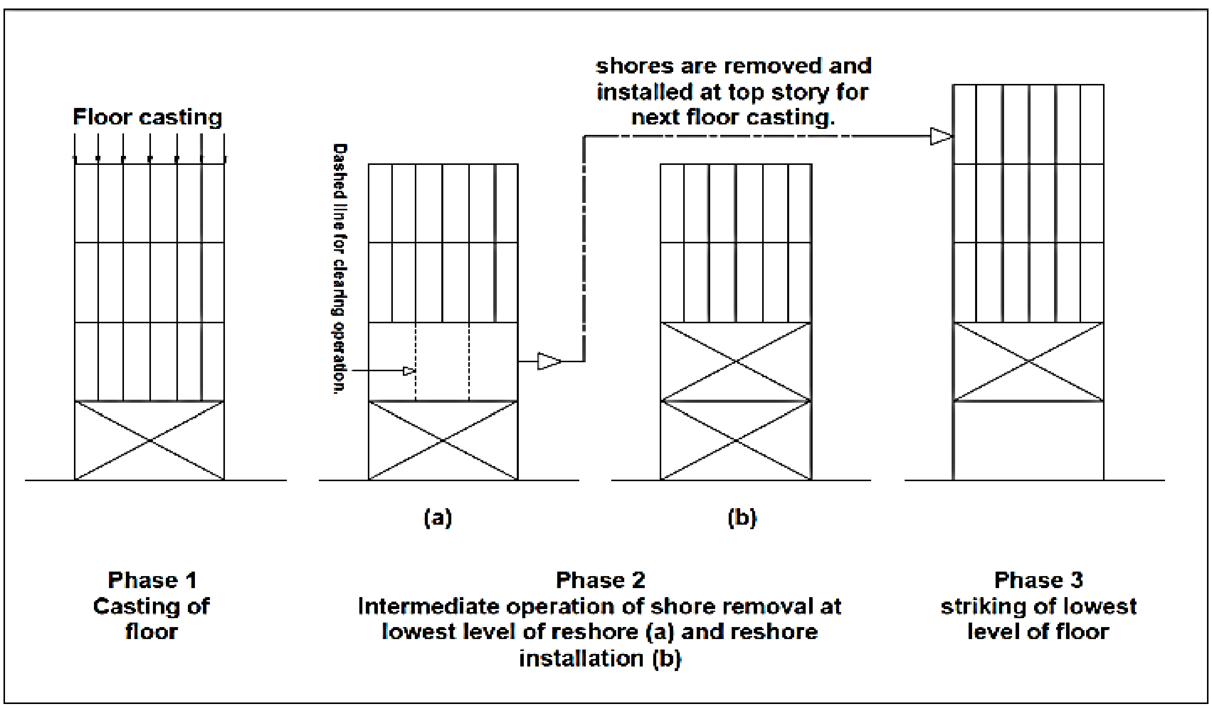

Fig. 1 Phases of Casting Cycle Time

2.2. Reshoring

Reshoring is a method of construction that entails an intermediate operation called reshoring. Usually, for faster speed of construction, one level of shores and multiple levels of reshores or vice versa is recommended [12], [20]. The forms/shores are removed from the lower floors after a few days of casting the slab at the upper level. Hence, permitting the slab to deflect totally. Reshores are reinstalled and are allowed to carry the increased load only. The loads are evenly distributed among the interconnected slabs. Reshoring reduces the maximum load on the slab by letting the slab deflect, causing excessive slab deflection due to insufficient concrete stiffness [5]–[7]. The slab loads imposed by the reshoring method are far lower than those imposed by shoring. Reshoring is imposed at an earlier age of concrete than shoring. Typically, reshoring frees up space for other tasks and reduces construction time and cost.

2.3. Back-shoring

To reduce the deflection of the slab as in reshoring, back-shoring is introduced in which small areas are stripped at a time, and back-shores are reinstalled before any further stripping occurs [7], [22], [23]. During the addition or removal of loads, slabs interconnected by shores/back-shores will deflect equally, and loads shared among the slabs is according to their stiffness. Back shoring can remove forms from concrete early because the small area of slabs is allowed to deflect [22], [24]. Hence the back-shores are assumed to have an initial load, while reshores do not have an initial load due to their snug placement [5], [7]. The effects of early creep are reduced when new slabs carry less load. Back-shoring demands a piece of specialized knowledge and caution to execute the back-shoring and stripping construction phase to avoid overloading of individual shores [5], [25].

2.4. Pre-shoring

A pre-shoring slab is allowed to deflect for a smaller area, and pre-shores are reinstalled. It is described as a shore removal process in which only the specified shores are removed while the rest of the shores are left intact; then, pre-shores are installed in their place [5], [7]. A similar procedure was used to remove the shores and replace them with pre-shores in the sequence shown in Figure 2. It can reduce the length of unsupported spans, which reduces slab deflections [26]. The following are some of the disadvantages of pre-shoring defined by Mosallam & Chen [7] : (a) Close monitoring of the construction process is necessary to reap the benefits. (b) Pre-shoring is more difficult to model than reshoring. To execute pre-shoring, it is necessary to conduct a prior analysis of slab deformations, shore deformations, and load static equilibrium before proceeding.

2.5. Partial striking

Introducing the Partial striking construction method with a clearing operation was a significant step forward in the construction field. The method seems similar to back-shoring but differs as re-installation of reshores/pre-shore/back-shores is not involved in partial striking. It consists of clearing as an intermediate operation which involves removing more than half of the formwork component a few days after casting a new slab [27], [28]. The clearing operation achieves the partial unloading of the system as shore stiffness is reduced, which increases the working area at the site. At the same time, it also increases the load on slabs. After clearing operation, each shore takes a greater load owing to its larger tributary area below the slab [29]. It seems similar to the pre-shoring as slab deflection is also partially allowed here, but it is different as re-installation of the shores is not included here in this procedure.

The literature shows the improvisation in the construction method from shoring to partial striking. The construction industry is developed and advanced today, but builders are still adopting the reshoring construction method. From the literature overview, it is suggested that partial striking is the better option to adopt for the RC multistorey building.

3. Overview of the simplified method used for the various construction method related to the shoring system

Several approaches have been defined in the past to understand the load shared between slab and shore for RC multistorey building construction, but only a few have been practiced in reality. These approaches include numerical analysis (FEM), an analytical approach (ETABs, SAP2000, Staad Pro, SAFE, and others), an approximate method, and a simplified method. Due to the lack of reliance on software to learn, the simplified method is very easy to adopt.

Grundy & Kabaila [8] in 1963 simplified building load distribution on supporting slabs and formwork. This method is still in use today. There was widespread acclaim for this new approach because of its simplicity and ease of use. The Simplified Method is predicated on the following assumptions, which make it simple to apply in any circumstance:

1. Shores have infinite axial stiffness compared to slabs.
2. The bending stiffness of all cured and partially cured concrete slabs is assumed to be the same. As a result, concrete stiffness is considered time-independent.
3. The foundation is equally rigid.

The load factor or coefficient K is the ratio of the load on the floor or prop to the self-weight of the floor using this simplified method. X. Liu et al. (1985) [30] used finite element analysis to examine the simplified

Grundy & Kabaila (1963) method with a finite shore stiffness for the first time. The shore load was overestimated when shore and reshore were assumed to be infinitely stiff [9], [30]. P. C. Stivaros & Halvorsen [31] found similar results when they studied the slab and shore stiffness effect using the Equivalent Frame Model. The study also summarizes factors such as shore-reshore level, shore configuration, and slab type on load distribution in slab deflection.

<table>
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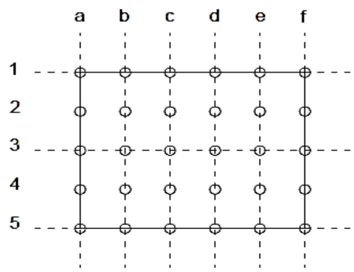
<td>
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<td>Plan view of the formwork with the primary shores placed on a 1m x 1m grid. A dashed line shows the 1m x 2m plywood sheets for deck forming.
Following are the construction methods that can be adopted for the early removal of formwork used to speed up the construction of multistory buildings.</td>
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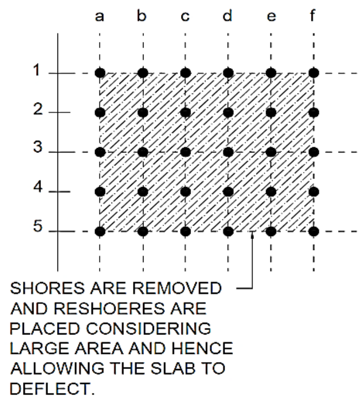
<td>Reshoring

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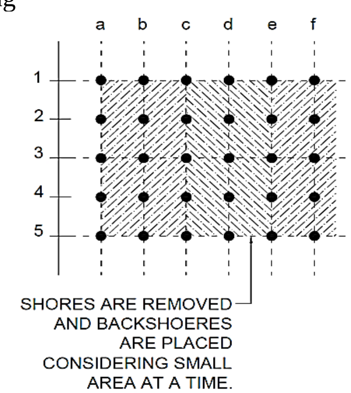
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<tr>
<td>Reshores should be located in the same position on each floor.</td>
<td>Back shoring allows early age stripping since only small areas are unsupported during the removal and replacement process.</td>
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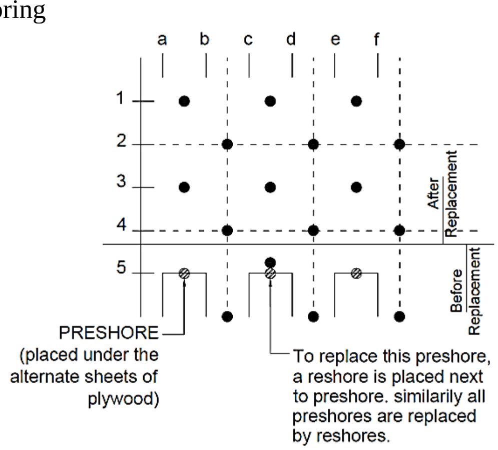
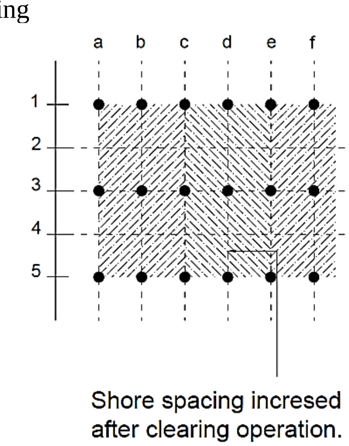
<tr>
<td>Preshoring


Preshoring requires specialized supervision for the shore removal as the positions of reshores differs from the shores' original position.</td>
<td>Partial Striking


Shores and other formwork components (including sheathing board, primary & secondary beams) are removed, allowing the slab to deflect partially. There is no replacement of shores in this method as in other methods.</td>
</tr>
</table>

Fig. 2 Differences in Shore Removal Pattern for Reshoring, Back-shoring, Pre-shoring, and Partial Striking.

During construction, Duan & Chen (1995) [33] proposed yet another model based on two fundamental operations: concrete placement and shoreline removal. According to this operation, the construction load the distribution consists of the following reconsideration of the assumption:

1. Finite shore stiffness should be considered during the construction phases.
2. Since shores are interconnected with slabs, it is necessary to consider the strength of the concrete at various ages to distribute the new load in proportion to their relative stiffness.
3. The load distribution should be incremental, i.e., consider the cumulative loads and displacements for the different construction phases.

A formulation based on deflection compatibility between the slab and shore deformation in terms of their stiffness is proposed to reconsider the slab's uniformly distributed shore load. By assuming that shores are infinitely stiff, Duan & Chen (1995) [33] found that Grundy & Kabaila's (1963) [8] simplified method underestimated the slab load and overestimated the shore load. It was common to practice using three or four consecutive shoring levels at the time. The Duan & Chen method can calculate load ratios for any combination.

Similar considerations of Duan & Chen [33] were taken by D. P. Fang et al. [34] to develop a model which assumes that the curing process alters the stiffness of concrete structural elements. This change depends on the type of cement used and the temperature at which it is cured. As a result, the loads must be redistributed after the freshly poured slab or before any intermediate operation such as reshoring or clearing. However, D. P. Fang et al. (2001) [34] discovered that the majority of cases had similar outcomes as Duan & Chen (1995) [33]. Slab stiffness changes with time, so Beeby (2001) [22] developed a model that uses an approximate method for assessing the load distribution between slab and shore for back-shoring.

In the past few decades, many authors [7], [10], [30], [32], [36], [37] have studied the limitations of the Grundy and Kabaila method. They found that this approach led to the overestimation of shore loads and the underestimation of slab loads at various construction stages of the building. Several authors have proposed a model incorporating reshoring, pre-shoring, and back-shoring construction methods to overcome this limitation. Following are the drawbacks observed in the works of literature:

a) The props are infinitely stiff in the vertical direction compared to the floors. (All the floor loads are transferred directly to the foundations until the first level of props is removed. Considering the deformability of the props, part of a newly cast floor load will flow to the lower interconnected floors).
b) The props are so close to each other that their loads can be considered uniformly distributed on the floor. (it may impair the results when the props are placed far apart. This feature appears in many formwork systems).
c) Load distribution does not depend on the construction speed since the concrete's different ages are not considered. (The pace of construction does not affect the results if all the floors are assumed to have the same stiffness. The results will depend exclusively on the number of levels with shores and reshores.)
d) After removing the shores, the forms are removed, so that floor deflections occur before the installation of any reshore.
e) Load factor results must be increased by 10% to include the self-weight of forms and props.
f) Due to the weight of workers, equipment, materials, dumping, and impacts produced by casting, complementary live loads must be added to the maximum construction load values of the floors and props.

Calderón et al. (2011) [37] introduced a new simplified method for partial striking construction method after Y. A. Alvarado et al. [28] completed their experiment in 2009. By assuming that mean slab deflection coincides with mean shore deflection, slab deformability under different boundary conditions (internal, end, and corner bays) is evaluated. The main hypothesis is supported using the "Equivalent Frame Method," and load distribution between slab and shore is calculated. The following are the assumptions that were taken into consideration when developing the Calderón et al. (2011) [37] simplified method:

a) The time variation of the slab concrete modulus of elasticity is considered.
b) The foundations are rigid.
c) The model is incremental, taking into account cumulative loads and displacements.
d) Shores have finite elastic stiffness.
e) Loads transferred from shores to slabs are uniform.
f) Average slab deformation aligns with average shore deformation.
g) Deformability is estimated using the Scanlon and Murray method for different slab boundary conditions as the internal, end, and corner spans [38].
h) Creep and shrinkage are ignored.

This method has been used to obtain construction loads at each stage of any construction process, considering the finite slab and shore stiffness. Buitrago et al. [29], [39] proposed two different reformulations of the Calderón simplified method. One can calculate the load on the shore over the maximum slab deformation point [29]. Another can calculate the load on each shore for each constructing phase [39]. Y. A. Alvarado et al. (2018) [41] and Calderón et al. (2011) [37] conducted a comparative study with other simplified methods to determine the effectiveness of clearing operations. It has been observed that the results obtained from the proposed new simplified procedure have the best fit among the previously proposed simplified method.

A simplified method for calculating successive floor construction provides the estimated risk involved during construction, estimated maximum load at the floor; required concrete strength for the respective construction cycle time, and a suitable formwork system for the respective construction method. Hence, a cost-effective model can be proposed based on the estimated calculation made by the simplified method. Therefore, there are necessary to define a simplified method that gives accurate load calculation. At the same time, it should be simple to adopt in practice.

4. Overview of the concrete strength development

The advancement of formwork technology has made erecting and removing formwork systems easier and more straightforward [42]. The cycle time for formwork is decreasing dramatically. According to the article [52] published in 2009 by Shivram Bagade and Nagesh Puttaswamy, one-slab-in-week concepts are becoming increasingly popular. In developed countries, the cycle time for faster construction is approximately 4 days or less. To accomplish this, the concrete must reach a minimum required strength within the earliest possible time.

Better workability and early strength development in concrete can be achieved using a higher cement type and a low water-cement ratio [43]. Cementitious content increases thermal and drying shrinkage, but there is a point at which adding more cementitious material will not affect strength [44], [45]. Regarding durability, the Codal provisions govern concrete's minimum and maximum cement content [52]. Water-cement ratio reduction has its limitations, especially on-site. Cementitious materials began to play a role in concrete's ability to withstand high loads by adding strength. Following are the ways to gain early strength in concrete suggested by Benaicha et al. (2016) [3] and Obayes et al. (2020) [47]:

- Adding pozzolanic admixtures like Pozzolanic Fly ash (PFA) or granulated blast furnace slag (GGBS) improves strength by forming secondary C-S-H gel. Adding pozzolanic admixtures, such as fly ash, reduces the strength gain for the first 3-7 days but increases the strength gain after that [43], [45].
- Mineral admixtures such as silica fumes, metakaolin, and rice husk ash (RHS) [48]–[50]. In about 3 days, highly reactive pozzolanic admixtures like silica fume, metakaolin, and RHS will start contributing. The RHS is more reactive than the PFA.
- Using chemical admixtures such as Super-plasticizers and set controlling admixtures will help increase concrete strength. These admixtures have a water reduction capacity of 18% to 40% compared to the control or reference concrete [45], [51].

Combining all or some of the above can be used to get the desired strength. The works of the literature suggest that the construction cycle time for the multistorey building can be reduced with the proper knowledge of cement type and admixtures. This knowledge can reduce the risk of slab failure due to early formwork removal.

5. Conclusion

The speed of construction is measured in terms of construction cycles and the use of formwork. It is now a basic requirement in the construction industry. With faster construction, the main concern is time, cost, safety, and quality. Knowing the information about construction methods proposed by the researcher for successive floor construction gives the efficient utilization of formwork. Shoring, reshoring, pre-shoring, back shoring, and clearing are the construction methods introduced for the successive floor construction.

To ensure the safety of that construction method, one should understand the load distribution pattern involve in that construction method. It helps in assessing the level of risk involved before the project execution. As a result, it is necessary to develop an accurate simplified method for calculating the loads between the slab and the accurate shore. The concrete age and consideration of finite shore stiffness are critical factors in improvising an easier method of successive floor construction.

The simplified method concluded that to reduce the cycle time to 4 days or less, and there is a need for early strength development in concrete. The concrete strength should meet the required minimum strength of the calculated load distribution for the adopted construction method. Hence, good quality early concrete strength can be developed using high-type cement with either mineral or chemical admixtures.

With this adequate knowledge, the time and cost of the RC multistorey project can be reduced to an optimal level. All these construction techniques consist of their benefits and limitations in respect of ease in adaption, striking time, removal pattern of formwork, and most importantly, their load distribution between slab and shores. The correct calculation and understanding of the technique can ease the adaption and reduce the construction time and cost. The simplified and numerical methods were defined for flat slabs only. Hence, these construction methods will be much more effective in utilizing or adopting appropriate formwork.

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