COMPARISON OF STRIPPING-TIMES OF FORMWORK FOR REINFORCED CEMENT CONCRETE STRUCTURES IN SELECTED CODES OF PRACTICES

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Abstract

Reinforced cement concrete (RCC) is one of the most widely used composite construction materials worldwide for constructing shelters and infrastructure. Formwork is needed in RCC work to give different dimensions to various concrete elements. Estimating the stripping time of formwork is a big issue in RCC work as safety and the economy are both dependent on this. In the study, a review of codal provisions of the Indian, British, American, Japanese, German, and Ugandan Standards on stripping time of formwork was carried out. It was found that there is no uniformity across countries on the formwork stripping issue. Some codes rely on achieving a minimum strength while some codes rely on specifying the minimum time for stripping and some codes specify both. Our findings showed that most of the codes are silent on the stripping time when the temperature is less than 15 degrees Celsius. All codes do specify that formwork should not be removed if it results in excessive deflection or if it results in cracks and damages in the newly constructed RC structures. Some of the codes have suggested carrying out field tests and NDTs to determine the stripping time in case there is a variation in the conditions specified in the standards. In general, for flexural members, stripping time for bottom formwork is recommended when the compressive strength of the freshly placed concrete achieves a strength of more than or equal to 70% of the concrete design strength. The stripping times of different concrete elements as specified in codes of practices followed in different countries vary from twelve hours to twenty-eight days. However, some codes have listed the stripping period of formwork in terms of compressive strength of in situ concrete varying from 3.5 MPa to 14 MPa (N/mm^2).

Keywords: Codal provisions; Formwork; Stripping time.

1. INTRODUCTION

Formwork removal should wait till the hardened concrete has sufficient strength to take all loads acting on it. The stripping period of formwork mainly depends on the types of cement and the grade of concrete, ambient temperature, and relative humidity [1, 5, 6]. It plays a significant role in ensuring economy in reinforced cement concrete (RCC) structures. Further, stability and safety are the prime concerns for engineers in any civil engineering infrastructure; whereas, high-rise RCC structures are the hallmark of modern civilization. Generally, the development of RCC structures requires a series of construction activities such as fixing of formwork, tying of rebar (steel), concrete pouring, leveling, and finishing of concrete, removal of formwork, and lastly, curing of concrete [6,16]. The time interval between the arrival of fresh concrete on formwork to the removal of formwork from concrete structures is known as the stripping period of formwork for matured concrete.

There are not many journal papers and other primary literature dealing with the stripping time of formwork for RCC structures. Also, there is a lack of studies to explore the effect of temperature on formwork stripping. Further, the authors couldn't find a comparative study on the formwork stripping time mentioned in various codes of practice.

A study conducted by Okafor and Ewe [2] estimated the formwork removal time of different RCC elements based on the time for strength development in concrete by making use of 150 × 150 × 150 mm cubes of design-grade concrete made of ordinary Portland cement Type-I, Class 32.5, from a Nigerian cement company. Curing was performed under controlled temperatures, and the cubes were demoulded after 24 hours and stored in a curing tank for 56 days at 23°C. A close observation of the concrete mix ratio revealed higher cement contents and quicker cement hydration [2]. The water-cement ratio adopted was in the range of 0.44-0.57. The slump of fresh concrete adopted was 30-60 mm and 60-180 mm. After doing the suitable correlation and regression analysis, the stripping time for different grades of concrete for M20, M25, M30, and M35 concrete was estimated as 10.3, 11.90, 20.20, 20.10 days for the medium slump range while they were 11.16, 14.11, 23.36, and 20.10 days for high slump range concrete, respectively [2]. The study concluded that

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a lower water-cement ratio and higher concrete grades could help speed up construction scheduling and formwork stripping activities. Finally, the researchers concluded that structural concrete with a higher slump value and lesser strength would take longer to remove the formwork [2]. This is logical and well-understood, considering that higher slumps created from high w/c ratio will result in weaker concrete, and therefore will require greater time to set before formwork can be safely stripped.

The principle of maturity is a well-recognized technique for determining in situ strength of concrete [7]. This is also a reliable method for estimating of stripping period of formwork and thus can prove to be helpful in formwork planning at construction sites. Concrete maturity indicates how far the curing process has advanced [6, 16, 23]. Concrete's maturity is correlated with temperature, passage of time, and increase in strength [7]. It is symbolized by an index value that is field-measurable in real-time. Saul [19] was the first to connect maturity to the product of temperature and interval of time.

Saul [19] presented the principle known as the maturity rule, as "concrete of the same mix at the same maturity (reckoned in temperature-time) has approximately the same strength whatever combination of temperature and time go to make up that maturity." Thus, the maturity method is a method for accounting for the effects of temperature and time on concrete strength development. The method provides a relatively straightforward approach for estimating in-place strength during construction [24].

The maturity technique predicts the actual in-place strength of the concrete found by any acceptable method. The strength of structural elements varies locally depending [22] on maturity due to curing conditions that cause a variable rate of strength development [5,6,19]. The maturity method for concrete testing has the following primary advantages:

1. The strength of concrete can be determined quickly using the maturity method
2. The values so obtained are close to real values
3. The number of test specimens required for quality assurance (QA) and quality control (QC) procedures are also fewer.

Carino and Lew [3] studied the effect of time and temperature on the strength development of concrete and explained the application of the 'maturity principle' of cement concrete. The method is a very straightforward method for estimating in-place strength during construction. The method's origins are traced back to the late 1940s and early 1950s in England during work on concrete steam curing. Interest arose in the United States in this method after the technology was transferred to the USA, as a result of efforts by the Federal Highway Administration [3]. For the first time in an RCC construction project, the researchers explained the formwork planning idea utilizing the concrete maturity principle. Further, the study offered the strength maturity relationship for the various grades of concrete mix and concluded that different concrete mixes actually have different maturity functions [3].

A system advanced by John *et al.* [4], known as the maturity method, works on the idea that compressive strength is proportional to age, temperature history, and concrete mix. The ensuing data is used for determining the stripping time.

However, we review the different codal provisions of RCC structures on formwork stripping periods for some randomly chosen developed and developing countries such as India, the UK, the USA, Japan, Germany, and Uganda. These codes were considered to have some geographical distribution. Usually, most of the codes of practice provide a formwork removal period in terms of the number of days for different structural elements such as columns, beams, slabs, etc., Nevertheless, some codes suggest the stripping period based on the compressive strength of concrete.

Overall, this paper summarizes the codal provisions of different countries for the formwork stripping timelines for RCC structures.

2. THE STANDARD NORMS FOR FORMWORK STRIPPING PERIODS IN DIFFERENT COUNTRIES

The strength-gaining capacity of cement concrete depends on ambient temperature, type of cement, water-cement ratio, type of coarse aggregate, fineness modulus of fine aggregate, type of admixture used, methods of curing, types of structural elements, the dimensions of concrete members, and workmanship quality during pouring [17,18]. The time of formwork stripping is also called formwork removal or strike-off formwork. Formwork should naturally not be removed from reinforced cement concrete (RCC) structures until the concrete has gained sufficient strength, to prevent permanent damage to the concrete element [22]. The guidelines and standards of different countries invariably look to the strength gained at the time of removal, although in different ways and using different formulas, rubrics, and criteria. When formwork is removed from RCC structures, it is essential to look at the stability and safety of the remaining temporary structures at the construction site, as well. The salient features of stripping times from the codes of different countries are now discussed below:

2.1 Indian standard recommendation [IS: 456 (2000)][8]

The recommendation on stripping time of formwork is enumerated in IS: 456 (2000) [8]. However, this is only applicable when the ambient temperature exceeds 15°C, and ordinary

Table 1: Formwork removal time for different RCC elements by Indian standards[8] [Source: IS: 456 (2000)[8]. Bureau of Indian standards]

S. NO.	TYPES OF FORMWORK	MINIMUM TIME BEFORE REMOVING FORMWORK
1.	Vertical formwork to beams, columns, and walls	16-24 hours
2.	Horizontal formwork, i.e., soffit formwork to slabs (props to be refixed immediately after the removal of formwork)	3.0 days
3.	Horizontal formwork, i.e., soffit formwork to beams. (Props to be refixed immediately after removal of formwork)	7.0 days
4.	Vertical props to slabs:	
4.1	- Spanning up to 4.5 m	7.0 days
4.2	- Spanning over 4.5 m	14.0 days
5.	Vertical props to beams and arches:	
5.1	- Spanning up to 6 m	14.0 days
5.2	- Spanning over 6 m	21.0 days

Portland cement (OPC) is used in RCC. According to the standard, the formwork can be stripped only when the concrete has attained a capacity of at least two times the stress to which it may be acted upon at the time of stripping of formwork [8,25]. The formwork stripping time for different elements of RCC structures is provided in Table 1.

When the temperature changes, and the cement is not OPC, the IS code suggests that the stripping time, as mentioned above, may be appropriately adjusted. IS: 456 (2000) [8] states that "the number of props left under, their sizes, and their location shall be such that they can safely sustain the whole dead weight of the slab, beam, or arch as the case may be, as well as any live load likely to arise during curing or future construction." It can be observed from the given stripping time data that it is a function of simply the distance between the supports and the types of flexure members used, such as beams and slabs [25]. The vertical props would be required for twenty-one days under the beam and arches when the span is more than six meters [8, 25].

2.2 Japanese standard recommendation (JSCE-16)[9]

The formwork removing period for RCC structures related to the Japan Society of Civil Engineers [9] is based on the compressive strength of concrete. This standard explains that formwork should not be taken out until the concrete has reached the strength as specified in Table 2 for different types of RCC members.

If RCC members are exposed to live loads after the removal of formwork, the concrete's compressive strength, RCC structure type, RCC characteristic, and value of dead and live loads will all be considered to discover when the formwork should be stripped to prevent cracks and damage in newly constructed RCC structures [9]. Further, it is obvious that the surface of concrete should not be damaged while removing the formwork.

Table 2: The Japanese requirement of compressive strength of concrete just before removing formwork [9] (Source: Japan society of civil engineers (JSCE), Standard specifications for concrete structures - 2007 "Materials and construction")

S. NO.	TYPE AND POSITION OF THE SURFACE OF FORMWORK	ILLUSTRATION (ELEMENTS)	COMPRESSIVE STRENGTH (MPa)
1.	Vertical or almost vertical surfaces of thick member	Sides of footings	3.50
2.	Upper surfaces of inclined members		
3.	Outside surfaces of small arch structures		
4.	Vertical or almost vertical surfaces of the thin member	Sides of columns, walls, and beams	5.00
5.	Lower surfaces of members inclined at 45 degrees or more		
6.	Inside surfaces of small arch structures		
7.	Slabs and beams of bridges and buildings	Bottoms of slabs and beams, Inside surfaces of arch structures	14.00
8.	Lower surfaces of members inclined at 45 degrees or less		

The Japanese standard code is based only on the compressive strength of the concrete being used. Flexural strength is not considered here. The JSCE does not take into consideration the types and grades of concrete for estimating the allowable time for formwork removal.

2.3 British standard recommendation (BS 8110-1:1997[10] and reaffirmed in 2007[20])

According to the British standard, [10, 20] the removal period of formwork depends on the factors such as -

1. concrete strength,
2. stresses in the concrete at any point during the construction period, including stresses induced by disturbance at the casting position and subsequent handling in the case of precast units,
3. curing (sec 6.2.3 of BS),
4. subsequent surface treatment requirements, and
5. presence of re-entrant angles requiring formwork to be removed as soon as possible after concrete has set to avoid thermal cracking.

When removing formwork at an early stage from vertical surfaces such as walls, columns, and beam sides, extreme precautions should be taken to avoid damaging the concrete. If necessary, relevant curing procedures should be provided as soon as the vertical formwork is removed at such an early stage, and the concrete should be protected from temperature extremes using appropriate insulation. Hence, gain in concrete strength and the type of material used for formwork affect the stripping time of the formwork. Table 3 summarizes the BS recommendations for concrete built with Portland cement of 42.5 N/mm^2 or higher and sulfate-resistant Portland cement of 42.5 N/mm^2 or higher [10, 20].

It is possible to use shorter durations to strike formwork, if the strength determined via the maturity method gives suitable results. Further, when concrete strength reaches 10 N/mm^2 in a flexural member, or when the concrete strength is double the stress of the stress caused by formwork removal, the formwork may be removed. However, it should be ensured that during form removal, the concrete element should not result in unacceptable deflection [10, 20].

From Table 3, one can calculate the stripping periods of different elements of RCC structures. For example, if the ambient temperature is 5°C, then vertical formwork to columns, walls, and large beams can be stripped in 20 hours (300/15 = 20). Similarly, for an ambient temperature of 5°C, it requires 6.67 days for horizontal formwork to slabs; 16.67 days for horizontal formwork to beams, including props to slabs; and 24 days for removing vertical props from beams.

2.4 American standard [ACI 347-04 [11] and reaffirmed in ACI 347R-14(2014)[21]] Recommendation

According to ACI 347-04 [11] and ACI 347-14 [21], the engineer/architect should calculate the concrete's minimum strength requirement and decide the formwork stripping time based on the site needs [11, 21], before removing formwork from RCC elements. A minimum elapsed time for formwork removal must be decided based on the situation. The deflection should be limited to reasonable amounts, and there should be no visible concrete damage owing to the striking of formwork due to the withdrawal of support.

If forms are removed before the curing time has satisfactorily elapsed, efforts should be made to ensure that the curing [19] process continues and the concrete is appropriately protected from the weather. Supporting forms should not be removed from structural elements until they can support their own weight as well as any permitted superimposed load. However, formwork and shoring should be constructed in such a way that they can be removed swiftly and securely without causing damage to the

Table 3: Minimum stripping time for formwork (British) [10, 20] [Source: British standard (BS 8110-1:1997) [20], Structural use of concrete – Part 1: Code of practice for design and construction. 1997]

S. NO.	TYPES OF FORMWORK	MINIMUM TIME BEFORE REMOVING FORMWORK	
		SURFACE TEMPERATURE OF CONCRETE	
		16°C AND ABOVE (DAYS)	t°C (ANY TEMPERATURE FROM 0°C to 16°C)
1.	Vertical formwork to columns, walls, and large beams	12 hours	300/ (t + 10) hours
2.	Horizontal formwork to slabs	4.0 days	100 / (t + 10) days
3.	Horizontal formwork to beams and props to slabs	10.0 days	250 / (t + 10) days
4.	Props to beams.	14.0 days	360/ (t + 10) days

Note: Only Portland cement (PC) and sulfate-resistant Portland cement (SRPC) of higher cement strength classes are affected by these values.

Table 4: American guidelines for formwork stripping time [11,21] (Source ACI 347R-14) [21]

S. NO.	REINFORCED CONCRETE MEMBERS		FORMWORK REMOVING TIME
1.	Walls		12 hours
2.	Columns		12 hours
3.	Sides of beams or girders		12 hours
4.	Pan joist forms	(a) 760 mm wide or less	3.0 days
		(b) Over 760 mm wide	4.0 days
5.	Joist, beam, or girder soffits	Where design live loads are	
		Less than dead loads	Greater than dead loads
5.1	Arch centers	14.0 days	7.0 days
5.2	3 to 6 m clear span between structural supports	14.0 days	7.0 days
5.3	Over 6 m clear span between structural supports	12.0 days	14.0 days
6.	One-way floor slabs		
6.1	Under 3 m clear span between structural supports	4.0 days	3.0 days
6.2	3 to 6 m clear span between structural supports	7.0 days	4.0 days
6.3	Over 6 m clear span between structural supports	10.0 days	7.0 days
7.	Two-way slab systems	Reshoring, if necessary, is employed as soon as possible after stripping operations are done, but no later than the conclusion of the working day in which stripping takes place.	

concrete or upsetting the internal bonds of concrete, allowing it to accept its share of the load "gradually and uniformly" [11, 21]. When removing formwork supports, protecting enclosures, and turning off the heating and curing systems, the contract specifications should be observed. When doing conventional beam or cylinder tests to determine stripping periods, test specimens should be cured in a condition similar to those encountered at the construction site. The curing records can be used by the engineer/architect to determine whether form stripping should be reviewed or approved. Testing cylinders cured on site, or non-invasive tests on the concrete in-situ, is the recommended method of estimating stripping time because it is a function of concrete strength. In the absence of such criteria, the ACI code provides recommendations (see Table 4) on the time period up to which the formwork should be left in position so long as the ambient temperature is greater than 10 degrees Celsius [11, 21].

The stripping times mentioned in Table 4 can be reduced to half, if high early-strength concrete is utilized and if the engineer/ architect approves it. If surrounding temperatures are lower than 10 degrees Celsius, or if retarding admixtures are applied, the stripping time should be extended at the engineer's discretion.

"Shorter stripping times listed for live load to dead load ratios greater than 1.0 are the result of more reserve strength being available for dead load in absence of live load at time of stripping" [11, 21]. The American Standard for removal of formwork is based on the ratio of dead load to live load, span and conditions of support, the width of joists, types and nature of horizontal slabs.

2.5 German standard recommendations (DIN 1045-3) [13]

The implementation of the German Code [12, 13, 14] for concrete structures applies together with the European Standard (EN 13670: 2009) [13], DIN EN 13670 [13], and the draft for development for concrete performance, production, placing, and compliance criteria (DD ENV 206-1992). German norms regarding the stripping period of formwork depend on the curing period of the RCC component. DIN [12] requires that formwork be removed once the concrete has reached an appropriate strength in terms of load-bearing capacity and deflections, as well as when the formwork no longer needs curing. Further, the German code also suggests that while removing formwork, precautions are to be taken so as to not disturb the surface of the final set of concrete and not to be overstressed in different reinforced concrete structures. Striking should be made in a manner that will not subject the structure to impact, overload, or damage to the permanent structure.

The German standard stripping time is based on the curing period, which depends on the ratio of two days' mean compressive strength of concrete to twenty-eight days' mean compressive strength of concrete ($r = f_{cm2} / f_{cm28}$). Based on the ratio "r", the strength development of concrete is divided into the groups of the fast, medium, slow, and very slow curing periods as provided in Tables 5 and 6. The curing period of concrete also takes into consideration the exposure classes XM, which is explained in DIN 1045-2:2001 [12]. The stripping time of formwork shall be in accordance with the requirements given in Tables 5 and 6 [12,13,14].

In the absence of detailed information, the British application document and the DIN standard both recommend that the formwork be removed in the following order: two days for "non-load-bearing formwork (such as vertical formwork of beams, formwork for walls, and formwork for columns)"; five days for slabs cast in situ concrete; and ten days for direct load-bearing formwork, such as soffits of beams or slabs.

Table 5: Minimum duration of post-treatment of concrete for the exposure classes (Source: DIN 1045-2) [12] (German) [12-14]

THE SURFACE TEMPERATURE OF CONCRETE (t°C)	MINIMUM DURATION OF CURING TIME IN DAYS			
	DEVELOPMENT OF CONCRETE STRENGTH ($r = f_{cm2}/f_{cm28}$)			
	FAST	MEDIUM	SLOW	VERY SLOW
	$r \geq 0.5$	$r \geq 0.3$	$r \geq 0.15$	$r < 0.15$
$t \geq 25$	1.0	2.0	2.0	3.0
$25 > t \geq 15$	1.0	2.0	4.0	5.0
$15 > t \geq 10$	2.0	4.0	7.0	10.0
$10 > t \geq 5$	3.0	6.0	10.0	15.0

Note:
1. Strength development of concrete "r" is defined as ratio of the mean values of the compressive strengths after 2 days and after 28 days.
2. The air temperature may be used instead of the surface temperature of the concrete.
3. If necessary, interpolation can be performed on all intermediate values.
4. At temperatures below 5°C, the curing time must be extended by the time during which the temperature was below 5°C.
5. The curing time must be increased suitably if the final setting time for concrete exceeds 5 hours.
6. Exposure classes X0, XC1, and XM are defined in DIN 1045-2 [12] as concrete without reinforcement, concrete wet or dry, and concrete subjected to wear and tear, respectively.

Table 6: Minimum duration of post-treatment of concrete for exposure classes XC2, XC3, XC4, and XF1. Source: DIN 1045-2 [12] (German) [12-14]

THE SURFACE TEMPERATURE OF CONCRETE (t°C)	MINIMUM DURATION OF CURING TIME (DAYS)		
	DEVELOPMENT OF CONCRETE STRENGTH ($r = f_{cm2}/f_{cm28}$)		
	FAST	MEDIUM	SLOW
	$r \geq 0.5$	$r \geq 0.3$	$r \geq 0.15$
$t \geq 25$	1.0	2.0	4.0
$25 > t \geq 15$	2.0	4.0	7.0
$15 > t \geq 10$	4.0	8.0	14.0

Note:
1. 1 to 5 are the same as mentioned in Table 5.
2. XC2, XC3, XC4, and XF1 are defined in DIN 1045-2 [12] as concrete wet but rarely dry, concrete with moderate humidity, concrete alternatively wet and dry, and damp concrete with the attack by freezing and thawing, respectively.

Last, but not least, the German standard establishes a curing period for concrete between 1 and 15 days based on the strength development ratio "r". In this case, the curing time is referred to as the "stripping time" of formwork for concrete by the German Standard and is scientifically applied to all grades of concrete.

2.6 Ugandan code (standard specifications for building works part 1 - section 4) recommendations

The recommendations for stripping time of formwork in Uganda are provided in the standard specifications for building works part 1 - section 4 Ministry of Works and Transport. According to this specification, formwork striking must be carried out in such a way that the concrete is not subjected to unexpected shock or harm, and it must not be withdrawn before the concrete has hardened adequately. Table 7 shows the minimum time that must elapse between the placement and compaction of the concrete and the removal of the formwork for various areas of the building [15].

The data supplied in Table 7 is intended to serve as a guide for regular cement concrete under typical settings and hardening circumstances. The striking times may be adjusted based on the Project Manager's instructions for vibrated concrete, extreme weather conditions, or unique surface finishes.

Table 7: Minimum times for striking formwork (Uganda) [15]. (Source: Standard specifications building for works. Ministry of works and transport. Government of Uganda. 2013)

S. NO.	LOCATION	REMOVAL OF FORMS ONLY (DAYS)	REMOVAL OF PROPS (DAYS)
1	Vertical members (side of beams, walls, and columns)	4.0	-
2	Horizontal members (soffit of main slabs)	12.0	28.0
3	Horizontal members (soffit of secondary slabs)	6.0	24.0
4	Horizontal members (soffit of beams)	12.0	28.0

However, the contractor's obligations and overall responsibility are not relieved by complying with the conditions. Should it be discovered that the formwork was removed prematurely, any damage resulting from this must be repaired totally at the contractor's expense [15]. Since the ambient temperature is not specified, the four-day [15] stripping intervals for removing vertical formwork can be used in both hot and cold weather. It requires some adjustments because four days of stripping time for vertical formwork is typically not permitted in hot weather, because of the possibility of concrete getting damaged due to lack of proper curing.

3. DISCUSSION

Every country has its own standard and guidelines regarding the stripping time of formwork for RCC structures based on the climatic condition of the country and numerous other factors. Based on a comparative study of the stripping period of formwork for RCC components, it is found that all countries recommend twelve hours to four days stripping period for columns, walls, and vertical sides of beams. Similarly, for horizontal elements, it is recommended that the stripping period for bending dominant members such as beams and slabs based on applied loadings and spans range from four days to twenty-eight days. From the extensive and detailed literature survey, it is observed that Uganda's standard recommendations for formwork regarding the stripping period are very conservative. IS: 456 (2000) [8] is also conservative in comparison to German and UK codes.

Planning a formwork system is a vital component of a construction project. If the environment temperature is 0°C, then only the BS code is available in the form of standard guidelines, which recommends 30 hours of stripping time for columns and walls, and between 10-36 days of stripping time for slab and beam formwork, respectively [12]. Removing formwork too soon might result in accidents and poor concrete quality. Similarly, late formwork removal can hurt the project's cost and schedule. In practice, if the temperature during nighttime concreting operation is above 10°C, vertical formwork can be struck the following day.

Concrete must be cured and protected during the initial phases of the strength-gaining process and after the final setting time has passed. The German standard is unique in this respect. According to German codes, the formwork should not be removed until the curing and protection procedure is in place. German standards define the minimum number of days for post-treatment as the stripping time of formwork for concrete. However, the Indian standard emphasizes on the adequate curing alone and not anything related to protection. The British standard goes into great length to describe the curing procedure. However, the Japanese code is silent regarding the curing process. Additionally, the American standard also does not go into great detail in the concrete curing process. In addition, the stripping sequence for a two-way slab, which describes how to remove the formwork, is exclusively available only in the American standards, and not explained in other standards.

The Japanese standard provides the stripping time in terms of the compressive strength of concrete. The British standard provides stripping periods in days and is applicable for OPC and sulfate-resistant Portland cement (SRPC) when the ambient temperature is greater than 16°C, and also when between 0°C to 16°C.

The Indian standard suggests stripping time in days, and is applicable for OPC only, and only when the ambient temperature is greater than 15°C. It is silent for other cement types and other ambient temperatures. The American standard specifies the stripping period in days when the ambient temperature is above 10°C, including the minimum strength requirements before removing the formwork and applying the non-destructive test (NDT) criteria. Only American standards offer guidelines for the NDT regarding the time required to strip formwork.

The German standards are particularly detailed when describing the formwork stripping period for concrete and the conditions thereof related to the relative strength gain. Similarly, the British standards provide concrete formwork stripping time in-depth related to the ambient air temperature; while the American standards also provide concrete formwork stripping time in detail in relation to dead loads and design live loads.

4. CONCLUSIONS

From the comparative study of various codes regarding the stripping time of formwork, the following conclusions can be derived:

1. The American standard and British standard both recommend a 12-hour stripping time for vertical member formworks of RCC elements, but the Indian standard recommends 16-24 hours. On the other hand, German standards call for a longer duration of stripping time, and are therefore the most conservative, being extremely focused on not risking concrete health. For vertical members, the Uganda code specifies four days of stripping time, and the criterion for Japanese standard in terms of concrete compressive strength attained is 3.5 MPa, which is achieved very quickly, in reality in most conditions.
2. According to the Japanese standard, the required compressive strength of concrete for formwork stripping periods for soffits of beams and slabs is 14.0 MPa; similarly,

the BS requirement is 10.0 MPa. Other codes indicate stripping times in days.

3. Vertical props from RCC beam soffits are required to be removed in accordance with the Uganda code in 28 days, the Indian standard code in 21 days, and the American Standard and British standard codes in 14 days. All standard regulations prescribe different stripping times depending on the cement type and grade used. The type of cement used in the Uganda code and the Japanese standard, on the other hand, was not stated.

4. There is a significant similarity between the American standard and British standard regarding the formwork stripping period for RCC members. When the temperature exceeds 15°C, and OPC is used in comparison to other standards, the Indian standard stripping period for RCC elements is detailed in a table in days. Furthermore, the German standard follows a more precise pattern for stripping time considering the effect of the strength development ratio.

5. All standards, norms, guidelines, and codes stipulate that while removing formwork there should be no damage to existing concrete, no corner damage and cracks in matured RCC constructions, no extra deflections in RCC components, no additional stresses created in concrete, and no concrete spalling from primary RCC elements. The security, reliability, economy, safety, and stability of RCC constructions are addressed by all standards during formworks stripping operations.

Eventually, it is seen that whereas the formwork stripping time is an important concern in concrete construction, for countries big and small, different countries use different criteria to decide the stripping time. Some consider the relative strength gained before recommending formwork removal (German); some go by the ambient temperature (British), because higher temperatures indicate a faster strength gain; while the Americans decide based on whether the relative live loads on the structure are less than or more than the dead loads activated for the structure. The Indians and Ugandans go by the type of structure, while the Japanese go by the type of structure and the strength gain.

5. RECOMMENDATIONS FOR FUTURE STUDY

Some regulations only offer the formwork removal time at specified temperatures (say 15°C) and specific types of cement (say OPC). Thus the geographical areas experiencing low temperatures throughout the year need a separate study. The impact of variable ambient air temperature and curing temperature on freshly laid concrete should be considered when calculating the stripping period for formwork, because it is well known that increasing the ambient or curing temperature can result in earlier removal of formwork. For this reason, an experimental study on the impact of cement types, ambient temperature, and grades of concrete on the formwork stripping time for concrete structures is recommended.

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