DETERMINATION OF FORMWORK STRIPPING TIME FOR REINFORCED CEMENT CONCRETE MEMBERS AT VARIOUS TEMPERATURES

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by

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The thesis is dedicated to Siddharth's parents and younger brother, Rahul Shankar.

CERTIFICATE

This is to certify that the thesis entitled "**Determination of formwork stripping time for reinforced cement concrete members at various temperatures"**, being submitted by **Mr. Siddharth Shankar (Entry No. 2019CEZ8476)** to the Department of Civil Engineering, Indian Institute of Technology Delhi for the fulfillment of the requirements of the award of the degree of the Doctor of Philosophy**,** is a bonafide record of the research work carried out by him under our supervision and guidance. In our opinion, the thesis work has reached the requisite standard, fulfilling the requirements for the degree of Doctor of Philosophy.

The contents of this thesis, in full or in part, have not been submitted to any other University or Institute for the award of any degree or diploma.

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Siddharth Shankar

ABSTRACT

One of the most accepted composite structural construction materials used globally to build infrastructure and shelters is reinforced cement concrete (RCC). Formwork is essential to RCC construction, ensuring concrete structures are cast precisely and accurately. Determining the duration necessary for removing formwork is a significant concern in reinforced concrete construction, as safety and cost-effectiveness rely on it. The removal of formwork should be delayed until the hardened concrete has attained adequate strength to withstand all applied stresses. The duration of removing the formwork is mostly based on the types of cement and concrete grade, as well as the ambient temperature and relative humidity. There is a scarcity of scholarly articles and other sources specifically addressing the duration required for removing formwork from RCC constructions. Furthermore, there is a dearth of studies, which investigates the impact of temperature on the duration required for formwork stripping. Hence, the author employed an experimental methodology to ascertain the duration required for removing the formwork from RCC structures under varying ambient environmental temperatures.

The study initially entailed thoroughly examining the provisions in the codes of India, Britain, the United States, Japan, Germany, and Uganda concerning the duration required for formwork to be removed. It has been observed that there is a lack of consistency among countries regarding formwork stripping time. Certain codes depend on attaining a minimum level of strength, while others rely on establishing the minimum duration for stripping, and some codes describe both criteria. The results of my study indicate that most codal provisions do not provide specific guidelines about stripping time when the temperature is below 15°C.

Certain codes recommend field testing and non-destructive tests (NDTs) to ascertain the duration required for stripping, especially when there are deviations from the parameters indicated in the standards. Typically, for structural elements that bend, it is advisable to remove the bottom formwork once the freshly poured concrete reaches a compressive strength that is 70% or greater than the intended strength. The duration for removing the formwork of various concrete components, as outlined in the codes of practice adhered to in different nations, ranges from twelve hours to twenty-eight days. Nevertheless, certain regulations have specified the duration for removing formwork based on the compressive strength of the concrete in place, ranging from 3.5 MPa to 14 MPa (N/mm^2).

Based on the experiments conducted by the author, removing the formwork for vertical concrete structures within a time frame ranging from 6 hours to 5.5 days is necessary. The specific duration depends on the type of cement used and the temperature range, which can vary from 0°C to 45°C. The duration for removing horizontal formwork varies from 2.6 to 124.4 days, depending on the cement grade and the ambient temperature range of 45°C to 0°C. It is important to use caution when removing the formwork to avoid excessive stress and potential damage to the concrete, particularly when the surrounding temperature is below 15°C. This is due to the lack of guidance in many standard codes of practice regarding the appropriate period for stripping when the temperature is below 15°C. Based on the laboratory findings from this study conducted at IIT Delhi, it is recommended that nominal mix cement concrete should possess a compressive strength exceeding 3.50 MPa to safely remove the vertical formwork in concrete made with ordinary Portland cement (OPC). For concrete made using Portland Pozzolana Cement (PPC), the compressive strength should be at least 3.25 MPa.

Nevertheless, variations in material properties, environmental circumstances, and construction techniques might influence the time of the stripping process. This study investigates non-destructive testing techniques to ascertain the optimal timing for removing formwork without causing harm to the concrete structure. This research utilizes rebound hammer and ultrasonic pulse velocity (UPV) measurements technique. In the case of flexural members, the bottom formwork should not be removed until the hardened concrete reaches a compressive strength of at least 70 percent. A minimum strength of 3.5 MPa is required for vertical concrete elements to prevent spalling of concrete. Based on these criteria, this study suggests that the formwork should be removed when the rebound number (RN) exceeds 3.0 units and the ultrasonic pulse velocity (UPV) is greater than 2.6 km/s for vertical components. For flexural concrete elements, it is advised that the RN and UPV values exceed 15.0 units and 3.0 km/s, respectively. The proposed technique offers a more reliable and accurate way of evaluating the time at which formwork can be removed, considering different atmospheric conditions and variable compositions of concrete.

The optimal efficiency in RCC construction is attained by removing the formwork as soon as feasible while ensuring that there is no damage caused to the concrete. This study aims to assess the efficacy of superplasticizers and nanomaterials in the fresh concrete mixture for decreasing the time required to remove the formwork from reinforced concrete structures in cold ambient temperatures (below 15ºC). According to the experimental investigation, 0.5% superplasticizers combined with 1% Nano-colloidal silica (NCS) can effectively reduce the time required for stripping, resulting in lower formwork expenses. This effect remains even when the ambient temperature falls below 15ºC. Vertical formwork significantly reduces the time needed for formwork stripping, decreasing it from 4.5 days to just one day within the 0-5ºC temperature range. However, the time required to remove the slab formwork is reduced from 54 to 37 days at 0ºC. The cost analysis

demonstrates that by incorporating 0.5% superplasticizers and 1% NCS into the concrete, the total cost of RCC can be decreased due to the reduction of formwork expenses. This study presents the initial results of experiments carried out in a concrete laboratory to ascertain the compressive strength and extraction time for formwork removal from vertical and horizontal concrete elements using Destructive and Non-Destructive Tests.

The research determines the formwork stripping time for members made of reinforced cement concrete at different temperatures. This information can be used by practitioners in the RCC works carried out at different temperatures, more so when the temperature is below 15ºC.

Keywords: Admixtures, Ambient temperature, Cement, Concrete, Cost analysis, Destructive tests (DT), Horizontal and vertical formwork, Maturity of concrete, Nanomaterials, Non-destructive tests (NDT), Rebound hammer (RH), Stripping period, Superplasticizers, Ultrasonic pulse velocity (UPV).

सारांश

दुनिया भर में अवसंरचना और आश्रयों का निर्माण करने के लिए प्रयुक्त सबसे स्वीकृत समग्र संरचनात्मक निर्माण सामग्री में से एक प्रबलित सीमेंट कंक्रीट (आरसीसी) है। फार्मवर्क आरसीसी निर्माण में आवश्यक है, यह सुनिश्चित करते हुए कि कंक्रीट संरचनाओं को सटीक और सही ढंग से ढाला गया है। फार्मवर्क हटाने के लिए आवश्यक समय निर्धारण प्रबलित कंक्रीट निर्माण में एक महत्वपूर्ण चिंता का विषय है, क्योंकि सुरक्षा और लागत-प्रभावशीलता इस पर निर्भर करती है। फार्मवर्क को तब तक नहीं हटाया जाना चाहिए जब तक कि कठोर कंक्रीट पर्याप्त शक्ति प्राप्त नहीं कर लेता है ताकि सभी लागू तनावों को सहन किया जा सके। फार्मवर्क हटाने की अवधि मुख्य रूप से सीमेंट के प्रकार और कंक्रीट ग्रेड, साथ ही परिवेश के तापमान और सापेक्ष आर्द्रता पर आधारित होती है। आरसीसी निर्माण से फार्मवर्क हटाने के लिए आवश्यक अवधि पर विशेष रूप से चर्चा करने वाले विद्वतापूर्ण लेखों और अन्य स्रोतों की कमी है। इसके अलावा, तापमान का फार्मवर्क स्ट्रिपिंग की अवधि पर प्रभाव का अध्ययन करने वाले अध्ययनों की भी कमी है। इसलिए, लेखक ने परिवेश के विभिन्न तापमानों के तहत आरसीसी संरचनाओं से फार्मवर्क हटाने के लिए आवश्यक अवधि का पता लगाने के लिए एक प्रयोगात्मक पद्धति का उपयोग किया।

अध्ययन में प्रारंभ में भारत, ब्रिटेन, संयुक्त राज्य, जापान, जर्मनी, और युगांडा के कोड में फार्मवर्क हटाने की अवधि के संबंध में प्रावधानों का गहन परीक्षण शामिल था। यह देखा गया है कि फार्मवर्क स्ट्रिपिंग समय के संबंध में देशों के बीच असंगति की कमी है। कुछ कोड न्यूनतम स्तर की शक्ति प्राप्त करने पर निर्भर करते हैं, जबकि अन्य न्यूनतम स्ट्रिपिंग अवधि स्थापित करने पर निर्भर करते हैं, और कुछ कोड दोनों मानदंडों का वर्णन करते हैं। मेरे अध्ययन के परिणाम बताते हैं कि अधिकांश कोड प्रावधान तापमान 15°C से नीचे होने पर स्ट्रिपिंग समय के बारे में विशिष्ट दिशा-निर्देश नहीं प्रदान करते हैं। कुछ कोड क्षेत्र परीक्षण और गैर-विनाशकारी परीक्षण (NDTs) की सिफारिश करते हैं ताकि

यह सुनिश्चित किया जा सके कि मानकों में इंगित मापदंडों से विचलन होने पर स्ट्रिपिंग के लिए आवश्यक अवधि का निर्धारण किया जा सके। आमतौर पर, झुकने वाले संरचनात्मक तत्वों के लिए, यह सलाह दी जाती है कि जब ताजा ढाला गया कंक्रीट लक्षित शक्ति का 70% या उससे अधिक संपीड़न शक्ति प्राप्त कर ले, तो नीचे का फार्मवर्क हटा दिया जाए। विभिन्न कंक्रीट घटकों के फार्मवर्क हटाने की अवधि, विभिन्न राष्ट्रों में अभ्यास किए गए कोडों में उल्लिखित, बारह घंटे से अट्ठाईस दिनों तक होती है। फिर भी, कुछ विनियमों ने साइट पर कंक्रीट की संपीड़न शक्ति के आधार पर फार्मवर्क हटाने की अवधि निर्दिष्ट की है, जो 3.5 MPa से 14 MPa (N/mm^2) तक होती है।

लेखक द्वारा किए गए प्रयोगों के आधार पर, लंबवत कंक्रीट संरचनाओं के फार्मवर्क को हटाने के लिए 6 घंटे से 5.5 दिनों के भीतर एक समय सीमा आवश्यक है। विशिष्ट अवधि प्रयुक्त सीमेंट के प्रकार और तापमान सीमा पर निर्भर करती है, जो 0°C से 45°C तक हो सकती है। क्षैतिज फार्मवर्क हटाने की अवधि 2.6 से 124.4 दिनों तक भिन्न होती है, जो सीमेंट ग्रेड और परिवेश तापमान सीमा 45°C से 0°C पर निर्भर करती है। फार्मवर्क हटाते समय अत्यधिक तनाव और संभावित क्षति से बचने के लिए सावधानी बरतना महत्वपूर्ण है, विशेष रूप से जब परिवेश तापमान 15°C से नीचे हो। यह कई मानक अभ्यास कोडों में उचित अवधि के लिए दिशा-निर्देशों की कमी के कारण है जब तापमान 15°C से नीचे हो। आईआईटी दिल्ली में किए गए इस अध्ययन के प्रयोगशाला निष्कर्षों के आधार पर, यह अनुशंसा की जाती है कि नाममात्र मिश्रण सीमेंट कंक्रीट को सामान्य पोर्टलैंड सीमेंट (OPC) के साथ बनाए गए कंक्रीट में लंबवत फार्मवर्क को सुरक्षित रूप से हटाने के लिए 3.50 MPa से अधिक संपीड़न शक्ति होनी चाहिए। पोर्टलैंड पोज़ोलाना सीमेंट (PPC) का उपयोग करके बनाए गए कंक्रीट के लिए, संपीड़न शक्ति कम से कम 3.25 MPa होनी चाहिए। फिर भी, सामग्री गुणों, पर्यावरणीय परिस्थितियों, और निर्माण तकनीकों में भिन्नताओं का स्ट्रिपिंग प्रक्रिया के समय पर प्रभाव हो सकता है।

यह अध्ययन गैर-विनाशकारी परीक्षण तकनीकों की जांच करता है ताकि फार्मवर्क हटाने के इष्टतम समय का निर्धारण किया जा सके बिना कंक्रीट संरचना को नुकसान पहुंचाए। यह शोध रिबाउंड हथौड़ा और अल्ट्रासोनिक पल्स वेग (UPV) मापन तकनीक का उपयोग करता है। लचीले सदस्यों के मामले में, जब तक कठोर कंक्रीट कम से कम 70 प्रतिशत संपीड़न शक्ति प्राप्त नहीं कर लेता, तब तक नीचे का फार्मवर्क नहीं हटाना चाहिए। लंबवत कंक्रीट तत्वों के लिए न्यूनतम 3.5 MPa शक्ति की आवश्यकता होती है ताकि कंक्रीट की छीलन को रोका जा सके। इन मानदंडों के आधार पर, यह अध्ययन सुझाव देता है कि फार्मवर्क को तब हटाया जाना चाहिए जब रिबाउंड संख्या (RN) 3.0 इकाइयों से अधिक हो और लंबवत घटकों के लिए अल्ट्रासोनिक पल्स वेग (UPV) 2.6 किमी/सेकंड से अधिक हो। लचीले कंक्रीट तत्वों के लिए, यह सलाह दी जाती है कि RN और UPV मान 15.0 इकाइयों और 3.0 किमी/सेकंड से अधिक हों, क्रमशः। प्रस्तावित तकनीक विभिन्न वायुमंडलीय स्थितियों और कंक्रीट की चर रचनाओं को ध्यान में रखते हुए फार्मवर्क को हटाने के समय का अधिक विश्वसनीय और सटीक तरीका प्रदान करती है। RCC निर्माण में इष्टतम दक्षता तब प्राप्त की जाती है जब फार्मवर्क को जितनी जल्दी हो सके हटा दिया जाए, जबकि यह सुनिश्चित करते हुए कि कंक्रीट को कोई नुकसान नहीं हुआ हो।

यह अध्ययन ठंडे परिवेश तापमान (15ºC से नीचे) में प्रबलित कंक्रीट संरचनाओं से फार्मवर्क हटाने के लिए आवश्यक समय को कम करने के लिए ताजा कंक्रीट मिश्रण में सुपरप्लास्टिसाइज़र और नैनोमटेरियल्स की प्रभावकारिता का आकलन करने का उद्देश्य रखता है। प्रयोगात्मक जांच के अनुसार, 0.5% सुपरप्लास्टिसाइज़र को 1% नैनो-कोलॉइडल सिलिका (NCS) के साथ मिलाने से स्ट्रिपिंग के लिए आवश्यक समय को प्रभावी ढंग से कम किया जा सकता है, जिससे फार्मवर्क खर्चों में कमी आती है। यह प्रभाव तब भी बना रहता है जब परिवेश का तापमान 15ºC से नीचे हो। लंबवत फार्मवर्क फार्मवर्क स्ट्रिपिंग के लिए आवश्यक समय को काफी हद तक कम कर देता है, इसे 0-5ºC

तापमान सीमा के भीतर 4.5 दिनों से घटाकर केवल एक दिन कर देता है। हालांकि, स्लैब फार्मवर्क को हटाने के लिए आवश्यक समय 0ºC पर 54 से 37 दिनों तक कम हो जाता है। लागत विश्लेषण से पता चलता है कि 0.5% सुपरप्लास्टिसाइज़र और 1% NCS को कंक्रीट में शामिल करके, फार्मवर्क खर्चों में कमी के कारण कुल RCC की लागत को कम किया जा सकता है।

यह अध्ययन विनाशकारी और गैर-विनाशकारी परीक्षणों का उपयोग करके लंबवत और क्षैतिज कंक्रीट तत्वों से फार्मवर्क हटाने के लिए संपीड़न शक्ति और निष्कर्षण समय का पता लगाने के लिए कंक्रीट प्रयोगशाला में किए गए प्रयोगों के प्रारंभिक परिणाम प्रस्तुत करता है। अनुसंधान विभिन्न तापमानों पर प्रबलित सीमेंट कंक्रीट से बने सदस्यों के लिए फार्मवर्क स्ट्रिपिंग समय का निर्धारण करता है। इस जानकारी का उपयोग विभिन्न तापमानों पर किए गए RCC कार्यों में प्रैक्टिशनर्स द्वारा किया जा सकता है, विशेष रूप से जब तापमान 15ºC से नीचे हो।

कुंजी शब्द: एडमिक्सचर्स, परिवेश का तापमान, सीमेंट, कंक्रीट, लागत विश्लेषण, विनाशकारी परीक्षण (DT), क्षैतिज और लंबवत फार्मवर्क, कंक्रीट की परिपक्वता, नैनोमटेरियल्स, गैर-विनाशकारी परीक्षण (NDT), रिबाउंड हथौड़ा (RH), स्ट्रिपिंग अवधि, सुपरप्लास्टिसाइज़र, अल्ट्रासोनिक पल्स वेग (UPV)

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LIST OF ABBREVIATION

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
BS	British Standard
C-S-H	Calcium-Silicate-Hydrate
CTM	Compression Testing Machine
DIN	Deutsches Institut fur Nornmung (German code)
DT	Destructive Test
HAC	High Alumina Cement
HESPC	High Early Strength Portland Cement
HPC	High-Performance Concrete
IS	Indian Standard
JSCE	Japan Society of Civil Engineers
MC	Material Criticality
MPA	Mega Pascal
NDT	Non-Destructive Test
OPC	Ordinary Portland Cement
PCC	Plain Cement Concrete
PPC	Portland Pozzolana Cement
QA	Quality Assurance
QC	Quality Control
QSC	Quick Setting Cement

RCC	Reinforced Cement Concrete
RHV	Rebound Hammer Value
RPC	Rapid Hardening Cement
SCM	Supplemental Cementitious Materials
SCC	Self-Compacting Concrete
SH	Schmidt Hammer
SP	Special Publication
UPV	Ultrasonic Pulse Velocity