

**SERVICE LIFE MODELLING OF BIOGENIC
SULPHURIC ACID DEGRADATION OF
CONCRETE IN SEWAGE ENVIRONMENT**

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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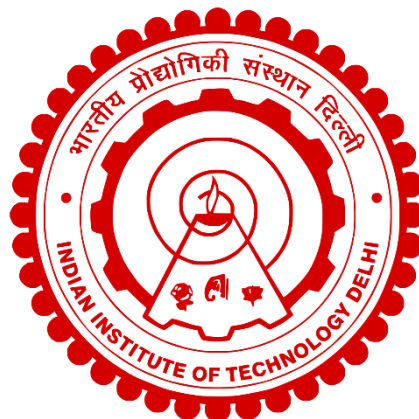
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CERTIFICATE

This is to certify that the thesis titled “**SERVICE LIFE MODELLING OF BIOGENIC SULPHURIC ACID DEGRADATION OF CONCRETE IN SEWAGE ENVIRONMENT**” submitted by Mr. Ankur Bansal to the Indian Institute of Technology Delhi, for the award of ‘Doctor of Philosophy’ in the Department of Civil Engineering, is a record of the bonafide research work carried out by him under my supervision and guidance. He has fulfilled the requirements for the submission of this thesis, which, to the best of my knowledge, has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other university or institute for the award of any other degree or diploma.

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ABSTRACT

In a sewage environment, the durability of concrete sewer pipes and sewer infrastructures is affected by Biogenic sulphuric acid (BSA) attack. Most of these sewer pipes and sewer structures are laid underground, and therefore, their deterioration remains hidden. This deterioration, being undetected, leads to the sudden collapse of these pipes before their designed life. Various models are available throughout the world to predict the deterioration of concrete pipes due to biogenic sulphuric acid attacks, however, these models need a large amount of input data to accurately predict the outcome. No work has been done to date to predict the degradation of concrete pipes in the environment existing in the sewages in India. Also, none of the models incorporate the variability of the input parameters to determine the service life of concrete in sewer pipes. It is very important to incorporate this variability because the sewage conditions vary from location to location and depend on many social and environmental factors.

In this study, a service life prediction model has been developed to determine the life of the concrete cover of these sewer pipes, by incorporating the various models that are available in the literature from other countries. These models are adapted, assembled, or modified for Indian conditions, incorporating the variability of the input parameters for Indian sewers.

To develop the service life prediction model, first, the process model has been developed to determine the degradation of concrete due to BSA attack. Thereafter, Indian sewage conditions were studied to determine the values of various input parameters and their variations to be used in the equations obtained from the process model. Then, an algorithm was developed to calculate the service life of concrete covers for the available input data for Indian conditions, Indian Standard Codes, and the Indian sewage manual using the Monte Carlo simulation technique. The model includes integrated service life concepts along with a statistical probabilistic approach to predict the life of the concrete cover of sewer pipes.

A sample calculation is thereafter performed using the service life prediction model for existing Indian sewage conditions to predict the service life of concrete cover for various confidence levels. It was observed that the service life of cover, thus obtained, is almost

half the designed service life for 95% confidence level. However, for 50% confidence level, it reaches three-fourth of the designed service life.

To understand the impact of each individual parameter and different distribution sensitivity, an analysis was performed, both by varying the mean values keeping the same distribution and also by keeping the mean same and different distributions of the input variables. After performing the sensitivity analysis, it was observed that the life of concrete cover is most sensitive to the COD value in the sewage system followed by the alkalinity of the concrete as compared to the other input parameters. After performing the sensitivity analysis, it was observed that the life of concrete cover is most sensitive to the COD value in the sewage system as compared to the other input parameters. It was also observed that different distributions of the input parameters also affect the life of concrete covers.

One of the major objectives of this work was to quantify the amount of sacrificial layer based on the importance and service life requirement of these pipes. Through the current work, probabilistic service life model has been developed for the problem of BSA corrosion in the concrete sewer pipes. It is hypothesised that the life of concrete pipes can vary significantly even for same average value of input variables considering the fluctuations for different confidence levels. In current work, through various calculations, it is shown that for designed life of sewer pipes with different service life requirements, one can obtain different cover of concrete pipes, which means economical design.

Finally, a reverse calculation was performed, based on various confidence levels and service life requirements, to determine the thickness of the sacrificial layer. This sacrificial layer will assist urban planners and designers to accurately and economically design sewer pipes for the required service life, based on the desired confidence level.

सार

सीवेज वातावरण में, कंक्रीट सीवर पाइप और सीवर अवसंरचना का स्थायित्व बायोजेनिक सल्फ्यूरिक एसिड (बीएसए) हमले से प्रभावित होता है। इनमें से अधिकांश सीवर पाइप और सीवर संरचनाएं भूमिगत हैं, और इसलिए, उनकी गिरावट छिपी रहती है। इस गिरावट का पता नहीं लगने के कारण, इन पाइपों को उनके डिज़ाइन किए गए जीवन से पहले ही अचानक ढह जाना पड़ता है। बायोजेनिक सल्फ्यूरिक एसिड हमलों के कारण कंक्रीट पाइपों के बिगड़ने की भविष्यवाणी करने के लिए दुनिया भर में विभिन्न मॉडल उपलब्ध हैं, हालांकि, इन मॉडलों को परिणाम की सटीक भविष्यवाणी करने के लिए बड़ी मात्रा में इनपुट डेटा की आवश्यकता होती है। भारत में सीवेज में मौजूद वातावरण में कंक्रीट पाइप के क्षरण की भविष्यवाणी करने के लिए आज तक कोई काम नहीं किया गया है। इसके अलावा, कोई भी मॉडल सीवर पाइप में कंक्रीट के सेवा जीवन को निर्धारित करने के लिए इनपुट मापदंडों की परिवर्तनशीलता को शामिल नहीं करता है। इस परिवर्तनशीलता को शामिल करना बहुत महत्वपूर्ण है क्योंकि सीवेज की स्थिति एक स्थान से दूसरे स्थान पर भिन्न होती है और कई सामाजिक और पर्यावरणीय कारकों पर निर्भर करती है।

इस अध्ययन में, अन्य देशों के साहित्य में उपलब्ध विभिन्न मॉडलों को शामिल करके, इन सीवर पाइपों के कंक्रीट कवर के जीवन को निर्धारित करने के लिए एक सेवा जीवन भविष्यवाणी मॉडल विकसित किया गया है। इन मॉडलों को भारतीय परिस्थितियों के लिए अनुकूलित, असेंबल या संशोधित किया गया है, जिसमें भारतीय सीवरों के लिए इनपुट मापदंडों की परिवर्तनशीलता शामिल है।

सेवा जीवन भविष्यवाणी मॉडल विकसित करने के लिए, सबसे पहले, बीएसए हमले के कारण कंक्रीट के क्षरण को निर्धारित करने के लिए प्रक्रिया मॉडल विकसित किया गया है। इसके बाद, प्रक्रिया मॉडल से प्राप्त समीकरणों में उपयोग किए जाने वाले विभिन्न इनपुट मापदंडों के मूल्यों और उनकी विविधताओं को निर्धारित करने के लिए भारतीय सीवेज स्थितियों का अध्ययन किया गया। फिर, मोंटे कार्लो सिमुलेशन तकनीक का उपयोग करके भारतीय परिस्थितियों, भारतीय मानक कोड और भारतीय सीवेज मैनुअल के लिए उपलब्ध इनपुट डेटा के लिए कंक्रीट कवर के सेवा जीवन की गणना करने के लिए एक एल्गोरिदम विकसित किया गया था। मॉडल में सीवर पाइप

के कंक्रीट कवर के जीवन की भविष्यवाणी करने के लिए एक सांख्यिकीय संभाव्य दृष्टिकोण के साथ एकीकृत सेवा जीवन अवधारणाएं शामिल हैं। इसके बाद विभिन्न आत्मविश्वास स्तरों के लिए कंक्रीट कवर के सेवा जीवन की भविष्यवाणी करने के लिए मौजूदा भारतीय सीवेज स्थितियों के लिए सेवा जीवन भविष्यवाणी मॉडल का उपयोग करके एक नमूना गणना की जाती है। यह देखा गया कि इस प्रकार प्राप्त कवर का सेवा जीवन, 95% विश्वास स्तर के लिए डिज़ाइन की गई सेवा जीवन का लगभग आधा है। हालांकि, 50% आत्मविश्वास के स्तर के लिए, यह डिज़ाइन किए गए सेवा जीवन के तीन-चौथाई हिस्से तक पहुंचता है।

प्रत्येक व्यक्तिगत पैरामीटर और अलग-अलग वितरण संवेदनशीलता के प्रभाव को समझने के लिए, एक विश्लेषण किया गया था, दोनों समान वितरण को रखते हुए माध्य मानों को अलग करके और इनपुट चर के समान और अलग-अलग वितरण को रखते हुए संवेदनशीलता विश्लेषण करने के बाद, यह था देखा गया है कि कंक्रीट कवर का जीवन सीवेज सिस्टम में सीओडी मूल्य के प्रति सबसे अधिक संवेदनशील होता है, इसके बाद अन्य इनपुट मापदंडों की तुलना में कंक्रीट की क्षारीयता होती है। संवेदनशीलता विश्लेषण करने के बाद, यह देखा गया कि कंक्रीट कवर का जीवन अन्य इनपुट मापदंडों की तुलना में सीवेज सिस्टम में सीओडी मूल्य के प्रति सबसे अधिक संवेदनशील होता है। यह भी देखा गया कि इनपुट मापदंडों के विभिन्न वितरण कंक्रीट कवर के जीवन को भी प्रभावित करते हैं।

इस कार्य का एक प्रमुख उद्देश्य इन पाइपों के महत्व और सेवा जीवन की आवश्यकता के आधार पर बलि परत की मात्रा का निर्धारण करना था। वर्तमान कार्य के माध्यम से कंक्रीट सीवर पाइपों में बीएसए जंग की समस्या के लिए संभाव्य सेवा जीवन मॉडल विकसित किया गया है। यह अनुमान लगाया गया है कि विभिन्न आत्मविश्वास स्तरों के उतार-चढ़ाव पर विचार करते हुए इनपुट चर के समान औसत मूल्य के लिए भी कंक्रीट पाइप का जीवन महत्वपूर्ण रूप से भिन्न हो सकता है। वर्तमान कार्य में, विभिन्न गणनाओं के माध्यम से, यह दिखाया गया है कि विभिन्न सेवा जीवन आवश्यकताओं के साथ सीवर पाइप के डिज़ाइन किए गए जीवन के लिए, कोई कंक्रीट पाइप के विभिन्न कवर प्राप्त कर सकता है, जिसका अर्थ है किफायती डिज़ाइन।

अंत में, बलि की परत की मोटाई निर्धारित करने के लिए, विभिन्न आत्मविश्वास स्तरों और सेवा जीवन आवश्यकताओं के आधार पर एक रिवर्स गणना की गई। यह बलिदान परत शहरी योजनाकारों और डिजाइनरों को वांछित आत्मविश्वास स्तर के आधार पर आवश्यक सेवा जीवन के लिए सीवर पाइपों को सटीक और आर्थिक रूप से डिज़ाइन करने में सहायता करेगी।

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Glossary

A	= Al_2O_3
ABCB	= Australian Building Codes Board
AC	= Asbestos Cement
AFm	= Alumino Ferrite- Monosulphate
AFt	= Alumino Ferrite Trisulphate (Ettringite)
ASR	= Alkali Silica Reaction
ASTM	= American Society for Testing and Materials
ATP	= Adenosine Tri Phosphate
BOD	= Biological Oxygen Demand
BSA	= Biogenic Sulphuric Acid Attack
BS-EN	= British Standard European Norm
C	= CaO
Ca/Si	= Calcium to Silica Ratio
CAC	= Calcium Aluminate Cement
CaO	= Calcium Oxide/ Portlandite
CCF	= Crown Corrosion Factor
COD	= Calcium Oxygen Demand
CPCB	= Central Pollution control board
C-S-H	= Calcium Silicate Hydrate
CSOM	= Chemolithotroph Sulphate Oxidising Microorganism
DEF	= Delayed Ettringite Formation
DLS	= Durability Limit State
DO	= Dissolved Oxygen
DOL	= Dolomite Aggregate
DWC	= Double Wall Corrugated
F	= Fe_2O_3
FIB	= International Federation for Structural Concrete
GGBS	= Ground Granulated Blast Furnace Slag
H_2S	= Hydrogen Sulphide/ Sulphide
HAC	= High Alumina Cement
HDPE	= High Density Poly Ethylene

IS	= Indian Standard
IS	= Indian Standard
ISO	= International Organization for Standardization
ITZ	= Interfacial Transition Zone
LC ³	= Limestone Calcined Clay Cement
LFM	= Life Factor Method
MCS	= Monte Carlo Simulation
MIC	= Microbiologically Induced Corrosion
MK	= Metakaoline
NP	= Non-Pressure
OPC/PC	= Ordinary Portland Cement
PE	= Poly Ethylene
PFA/FA	= Pulverized Fly Ash
PPC	= Pozzolana Portland Cement
PSC	= Portland Slag Cement
PSOM	= Photoautotrophic Sulphate Oxidising Microorganism
PVC	= Poly Venial Chloride
RC	= Reinforced Concrete
RCC	= Reinforced Cement Concrete
RH	= Relative Humidity
RILEM	= The International Union of Laboratories and Experts in Construction Materials, Systems and Structures/ Reunion Internationale des Laboratoires et Experts des Materiaux, Systemes de Construction et Ouvrages
RPC	= Reactive Powder Concrete
S	= SiO ₂
SATIR	= Saure Angriff Transport Instationar Reaktion
SCM	= Supplementary Cementitious Material
SF	= Silica Fumes
SIL	= Silicious Aggregates
SLS	= Serviceability Limit State
SOM	= Sulphate Oxidizing Microorganism
SRM	= Sulphate Reducing Bacteria/microorganism

STP	= Sewage Treatment Plant
TCF	= Turbulence Corrosion Factor
TSS	= Total Suspended Solids
UCT	= University of Cape Town
ULS	= Ultimate Limit State
US-EPA	= United States Environment Protection Agency
VES	= Virginia Experimental Sewer
VFA	= Volatile Fatty Acid
w/c	= Water to Cement Ratio
WATS	= Wastewater Aerobic/anaerobic Transformations in Sewer
WWTP	= Waste Water Treatment Plant