International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** VI **Month of publication:** June 2026

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

Investigation of Cementitious Material Oozing through Dams and Its Implications on Structural Health

D. D. Parkhe , P. D. Nemade, SangaleVrushali Manik, Deshmukh Rutuja Bharat, Deshmukh Sakshi Dattatray
Department of Civil Engineering, Karmaveer Adv.Baburao Ganpatrao Thakare College of Engineering, Nashik, Maharashtra, India

Abstract—Concrete and masonry dams subjected to prolonged seepage undergo progressive physicochemical deterioration through calcium leaching, wherein calcium hydroxide ($Ca(OH)_2$) dissolvesand migrates with seepage water, compromising cement paste integrity. This study investigates cementitious material collected from seepage-affected drainage galleries of two major Maharashtra dams—Upper Wardha Dam (Amravati) and Hatnur Dam (Jalgaon)—through systematic chemical analysis per IS 4032:1985. Seven parameterswere determined: Loss onIgnition(LOI), SiO_2, R_2O_3, CaO, MgO, SO_3, andInsolubleResidue(IR). The CBIP methodology was applied to estimate cement loss per tonne of leached material.Results confirm significant CaO depletion (36–44% vs. 60–67% in fresh OPC) and extremely elevated LOI (>30%), confirming calcium leaching as the dominant deterioration mechanism. Estimated cementlossis 0.63t/t for UpperWardhaDamand0.67t/tfor HatnurDam.Bothdamsareclassifiedat moderatedeterioration,requiring periodic monitoring rather than immediate structural intervention.

IndexTerms—Calciumleaching,Cementitiousmaterial,Damstructuralhealth,CBIPmethodology,IS4032,Seepage,UpperWardha Dam, Hatnur Dam, Chemical deterioration, Efflorescence.

I. INTRODUCTION

Dams are critical hydraulic structures serving irrigation, drinking water supply, hydropower, and flood control. In India, where rainfall is seasonal and unevenly distributed, dams are central to water resource management. However, long-term exposure to hydrostatic pressure and continuous seepage drives progressive structural deterioration that must be systematically monitored [2].

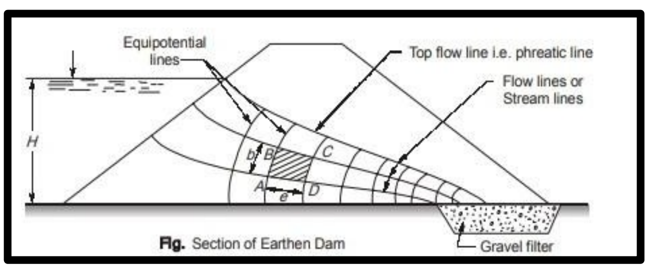


Fig. Section of Earthen Dam

This paper presents asystematicchemical investigationof cementitious material oozing from the drainage galleries of Upper Wardha Dam (Amravati) and Hatnur Dam (Jalgaon), applying CBIP Miscellaneous Report No. 10 for cement loss estimation and IS 4032:1985 for chemical analysis. The quantitative,sensor-analoguedata-collectionphilosophymirrors automated precision monitoring systems in modern infrastructure [1].

A. Motivation

Cementitious material oozing through dam faces signals active transport of cement paste and leachates along seepage paths. Persistent oozing indicates hydraulic connectivity and deterioration warranting structural health monitoring (SHM). Understanding this phenomenon is critical for early damage warning, evidence-based maintenance, and cost-effective rehabilitation planning.

B. PaperOrganization

Section II reviews literature; Section III describes the problem and dams studied; Section IV details methodology; Section V presents results; Section VI provides comparative analysis; Section VII discusses remedial measures; and Section VIII concludes with recommendations.

II. LITERATUREREVIEW

A. CalciumLeachinginDam Concrete

Nieetal.[4]demonstratedthatsoft-water-inducedcalcium leachingcausesmeasurablemicrostructuraldeteriorationindam concrete, combining SEM/ICP-MS microscopy with numerical modelingto predict long-term dissolutiondepthandmechanical propertyreduction. Guo et al. [5] developeda coupled seepage-dissolution numerical model, finding that dissolution increases porosity and permeability of anti-seepage walls—directly paralleling field observations at both dams studied here.

B. Mechanical EffectsofLeaching

Huang et al. [6] confirmed that calcium leaching reduces compressive strength, increases porosity, and shortens service life. Zhang et al. [7] quantified increased porosity/permeability due toleachingand recommendedminimizing $Ca(OH)_2$ content andaddingSCMstoslowdeteriorationrates.Wangetal.further showed lower cement content and high permeability increase leaching rates [8].

C. SeepageControl andSHM

El-Molla [9] reviewed modern seepage detection and treatment methods including grouting and cutoff walls, highlighting gaps in continuous monitoring for material loss. Vigneswaranetal.[10]demonstratedfieldgroutingstrategiesto arrest oozinginmasonrydams. Theanalogytoautomatedsensor-driven irrigation control [1] is instructive: chemical markers in leached material serve as quantitative triggers for maintenance interventions, analogous to soil moisture thresholds triggering pump control.

D. ResearchGap

Integrated chemical characterization studies on Indian dams using the CBIP methodology—with comparative deteriorationstagingacrossmultiplestructures—remainlimited. This work addresses that gap through field-collected sample analysis from two dams with differing construction periods and reservoir characteristics.

III. PROBLEMSTATEMENTANDSTUDY DAMS

A. ProblemStatement

Progressive seepage through cracks, joints, and porous zones in concrete or masonry dams leads to dissolution and transportofcementitiousmaterial,precipitatingasefflorescence or ooze on dam surfaces and gallery floors. No IS standard specifies permissible limits for chemical constituents of dam leached material. Consequently, IS 4032:1985 (Methods for Chemical Analysis of Hydraulic Cement) is used as a reference baseline with CBIP Report No. 10 guidelines for cement loss estimation.Sevenconstituentsaretested(allas%bydryweight):

- Loss on Ignition (LOI)
- SiliconDioxide(SiO_2)
- Metal Oxide($R_2O_3 = Fe_2O_3 + Al_2O_3$)
- CalciumOxide(CaO)
- Magnesium Oxide(MgO)
- Sulphate(SO_3)
- InsolubleResidue (IR)

B. UpperWardhaDam

Upper Wardha Dam (D02982), also known as Nal Damayanti Sagar, is built on the Wardha River near Simbhora village, Morshitaluka, Amravati district. It is a composite dam: central masonry/gravity spillway (~331.50 m) with earthen embankment wings (~5,588.50 m), total length 5,920 m, masonry height 46.20 m. Gross storage capacity: 786.48 MCM (27.8 TMC); catchment area: 4,302 km²; gross command area: 1,04,400 ha. Construction completed 1993; spillway has 13 radial gates.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

C. HatnurDam

Hatnur Dam (D02977), also known as the Tapi Project, is constructedacrosstheTapiRivernearHatnurvillage,Bhusawal taluka, Jalgaon district. Composite earthfill dam with masonry/gravity and spillway sections; total length 2,580 m; height 25.50 m. Gross storage: 388.00 MCM; catchment area: 29,430 km². Completed 1982; 41 radial gates (12 m × 6.50 m); design discharge ~26,423 m³/s.

IV. METHODOLOGY

A. SampleCollection

Cementitious material (semi-solid/sludge) was collected from foundation galleries, drainage sumps, and downstream oozing locations at both dams. For Upper Wardha Dam, six samplesweretakenatchainagesCH-893.5m,778.5m,715m,682.5 m, 672 m, and 940.5 m. For Hatnur Dam, four samples werecollectedatRD-910,945,985,andCH-1045.Samples(~1 kg each) were sealed in polyethylene bags with identification marks per CBIP Report No. 10 guidelines.

B. ChemicalAnalysis(IS4032:1985)

All tests were performed per IS 4032:1985. Key procedures:

- LOI:1.00gsampleheatedat900–1000°Cfor15minin muffle furnace; loss in weight recorded.
- SiO_2:0.5gdissolvedinHCl,evaporatedonsteambath, filtered (Whatman No. 40); residue weighed.
- R_2O_3:CombinedhydroxidesprecipitatedbyNH₄OHfrom SiO_2 filtrate; ignited at 1050–1100°C.
- CaO:Calciumoxalategravimetricmethod;ignitedat1100–1200°C.
- MgO:Mgammoniumphosphategravimetricmethod; MgO% = W × 72.4.
- SO_3:$BaSO_4$ precipitation; ignited at 800–900°C; SO_3% =W× 34.3.
- IR:HCl-insolubleresiduedigestedinNa_2CO_3;ignitedat 900–1000°C.

C. CementLoss(CBIPMethodology)

Per CBIP Report No. 10 (1986), OPC contains 44% calcium by mass; thus 1 tonne cement = 440 kg Ca = 814 kg $Ca(OH)_2$. The CaO content of leached material is stoichiometricallyconvertedto$Ca(OH)_2$usingthefactor74/56=
1.321.Cementlossisthen:

CementLoss=[CaO_{ma^3}(kg)×(74/56)]/814

V. OBSERVATIONSAND RESULTS

A. UpperWardhaDam—ChemicalResults

Table Ipresentschemicaltestresultsfor six samples from the Upper Wardha Dam foundation gallery.

Parameter	S-1	S-2	S-3	S-4	S-5	S-6
LOI(%)	37.00	36.00	36.70	31.00	37.83	37.83
SiO_2(%)	7.02	8.00	6.00	4.04	4.86	6.66
R_2O_3(%)	7.60	5.74	5.10	4.80	3.14	5.14
CaO(%)	36.00	37.42	37.00	41.96	40.52	40.52
MgO(%)	5.07	3.63	4.31	4.87	4.65	3.20
SO_3(%)	1.03	1.34	1.03	3.78	1.29	1.29
IR(%)	6.28	7.87	9.86	9.55	7.71	5.36

TABLEI.ChemicalTestResults—UpperWardhaDam(%)

B. HatnurDam—ChemicalResults

TableIIpresentschemicaltestresultsforfoursamples from Hatnur Dam drainage gallery.

Parameter	S-1RD910	S-2RD945	S-3RD985	S-4CH1045
LOI(%)	36.00	39.00	33.00	33.00
SiO_2(%)	5.00	4.00	4.00	5.06
R_2O_3(%)	9.94	6.84	6.00	6.64

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

CaO(%)	41.20	36.00	43.00	43.92
MgO(%)	2.90	6.52	4.37	3.37
SO_3(%)	1.72	1.34	4.96	3.15
IR(%)	3.24	6.30	4.67	4.86

TABLEII.ChemicalTestResults—HatnurDam(%)

C. CementLoss Estimation

AverageCaO:UpperWardha=38.90%;Hatnur=41.03%.

ApplyingCBIPmethodology:

Dam	AvgCaO%	CaOkg/t	$Ca(OH)_2$ kg	Conv.Factor	Cement Loss t/t
UpperWardha	38.90%	389	514	74/56	0.63
HatnurDam	41.03%	410	542	74/56	0.67

TABLEIII.CementLossEstimation(CBIP Method)

VI. COMPARATIVEANALYSISAND ENGINEERING INTERPRETATION

A. ComparisonwithIS269 Limits

IS 269 specifies limits for fresh OPC. These serve as a reference baseline for assessing chemical alteration in dam leached material, not as pass/fail criteria. Table IV presents the comparison.

Param	IS269 Limit	UpperWardha	Hatnur	Trend
LOI	≤5%	31–38%	33–39%	VeryHigh
CaO	60–67%	36–42%	36–44%	Depleted
IR	≤2%	5.4–9.9%	3.2–6.3%	Elevated
SO_3	≤3.5%	1.0–3.8%	1.3–5.0%	MostlyOK
MgO	≤6%	3.2–5.1%	2.9–6.5%	Normal
SiO_2	18–25%	4.0–8.0%	4.0–5.1%	Depleted

TABLEIV.ComparisonwithIS269ReferenceLimits

B. Key Observations

- CaO↓(36–44%vs.60–67%fresh):Confirmscalcium leaching.
- LOI↑(>30%vs.≤5%limit):Advancedcarbonationand ageing of hydrated cement phases.
- IR↑(5–10%vs.≤2%):Cementpasteremoval;Upper Wardha more affected.
- SO_3:Mostlywithinlimits;onelocalizedhighvalueat Upper Wardha (3.78%).
- MgO:Withinpermissiblelimitsatbothdams;no magnesium attack.
- SiO_2:Greatlyreducedfromfreshcementrange(18–25%), consistent with silica dissolution.

C. DeteriorationStaging

TheconvergenceofCaO↓+LOI↑+IR↑unambiguously identifies calcium leaching as the primary deterioration mode, consistentwiththeself-reinforcingcycle:$Ca(OH)_2$dissolution→ porosity increase → greater seepage → further leaching [4,5,6].

- UpperWardha Dam: CaO 36–42%,LOI >30%, IR 5–10%→ Moderate to Active Deterioration.
- HatnurDam:CaO36–44%,lowerIR,normalSO_3→Early to Moderate Deterioration.

No evidence of severe sulphate attack or magnesium-induceddeteriorationwasfoundateitherdam.Structural integrityisnotimmediatelythreatened;deteriorationis progressive and manageable.

VII. REMEDIAL MEASURES AND RECOMMENDATIONS

A. Preventive Measures

- Dense,lowwater-cementratioconcretetominimize seepage pathways.
- UseofSCMs(flyash,GGBS,silicafume)toconsumefree $Ca(OH)_2$.
- Upstreamfacetreatmentwithrichmortarmasonry,Khanki facing, or gunite lining.
- Properaggregateselectiontoavoidalkali-aggregate reaction.
- Pressuregroutinginlocalizedgalleryzonesshowing elevated oozing.

B. MonitoringRecommendations

- Chemicaltestingofcementitiousdepositsevery2–3years.
- Trend analysis of CaO, LOI, and IR over time.
- Seasonalmonitoringofseepagedischargequantityand calcium concentration.
- 20–30 year chemical deterioration tracking program.
- Initiatedetailed structuralreview if CaOfallsbelow 35%.
- Riskclassificationupdateevery5years.

C. FutureScope

Futureworkshouldinclude:(i)SEM/XRDmicrostructural analysis of leached material; (ii) long-term seepage water chemistry trend analysis; (iii) IoT/sensor-based remote gallery monitoring analogous to automated sensor-driven infrastructure systems [1]; (iv) seepage-dissolution coupled numerical modelling; and (v) evaluation of SCM-based repair grouts for improved leaching resistance [7].

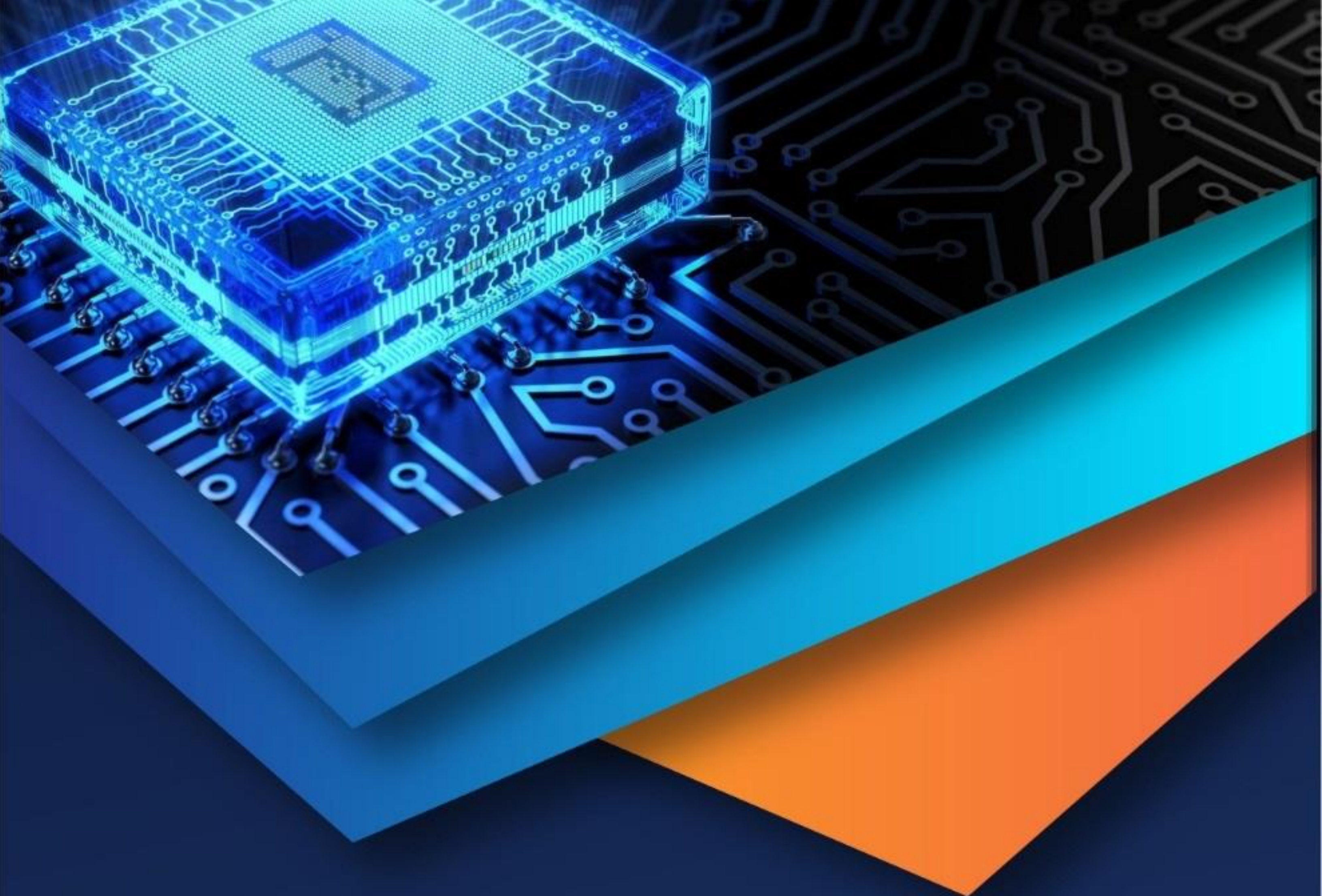
VIII. CONCLUSIONS

Thispaperpresentedasystematicchemicalinvestigationof cementitiousmaterialoozingfromtwomajorMaharashtradams. Key conclusions are:

1) Both dams exhibit calcium leaching as the primary deteriorationmechanism,confirmedbyCaOdepletion, elevated LOI, and increased insoluble residue.
2) Estimated cement loss is 0.63t/t (Upper Wardha Dam) and
3) 0.67t/t (HatnurDam) perthe CBIPmethodology.
4) UpperWardhaDam:ModeratetoActiveDeterioration. Hatnur Dam: Early to Moderate Deterioration.
5) Noevidenceofseveresulphateormagnesiumattackat either dam.
6) Chemical ageing (LOI >30%) is significant at both dams, reflectinglong-termcarbonationofhydratedcementphases.
7) Periodic chemical monitoring every 2–3 years is recommended;immediatestructuralinterventionisnot warranted.
8) Thequantitative,data-drivenmonitoringapproachparallels precision sensor-based infrastructure management philosophies [1,2].

REFERENCES

[1] M.KumarandS.Singh,“PLCBasedSmartIrrigationSystem,” IJERT, vol. 8, no. 4, pp. 120–124, Apr. 2019.
[2] A. PatelandR.Shah,“SolarTrackingSystemforEfficientPower Generation,” IJSRET, vol. 7, no. 2, pp. 301–305, Feb. 2020.
[3] BureauofIndianStandards,IS4032:1985,MethodsofChemical Analysis of Hydraulic Cement, New Delhi.
[4] D.Nieetal.,“AMethodologytoEvaluateLong-TermDurabilityof Dam Concrete Due to Calcium Leaching,” Materials, vol. 14, pp. 1–20, 2021.
[5] C. Guo et al., “Durability Analysis of Concrete Cutoff Wall ConsideringSeepageandDissolutionCoupling,”Water(MDPI), 2024.
[6] D.Huangetal.,“EffectofLeachingonMechanicalPropertiesand Durability of Concrete,” Elsevier, 2024.
[7] W. Zhang et al., “Reduction of the Calcium Leaching Effect on PhysicalandMechanicalPropertiesofConcrete,”Construction and Building Materials, 2023.
[8] J.Wangetal.,“StudyonLong-TermDurabilityandLeachingof Cementitious Materials in Backfills,” Sustainability (MDPI), 2023.
[9] D. A. El-Molla, “Seepage Control, Detection, and Treatment in EmbankmentDams:AReview,”ArabianJournalofGeosciences, Springer, 2025.
[10] R.Vigneswaranetal.,“SeepageControlinMasonryGravity Dams through Dam Body Grouting,” INCOLD/CWPRS Proceedings, 2019.
[11] CBIP, Guidelines for Measurement, Testing and Analysis of SeepagefromMasonryorConcreteDam,Misc.ReportNo.10, Oct. 1986.
[12] BureauofIndianStandards,IS269,OrdinaryPortlandCement— Specification, New Delhi.
[13] MERI,ChemicalAnalysisofSeepageThroughMajorDamsin Maharashtra, TM No. MT/256, Dec. 2003.
[14] CentralWaterCommission,GuidelinesforSafetyInspectionof Dams, New Delhi, 2018.
[15] K. Nakarai, “Modeling of Calcium Leaching from Cement Hydrates,”J.AdvancedCementTechnology,J-stage,2006.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY