

Reducing Non-Revenue of Water Using Non-Return Valves in Ground Based Water Retaining Reservoir and Its Bottom Treatment: A Field Study from Jal Jeevan Mission, Maharashtra, India

Raviraj Kumbhar¹, Prof.Dr..Sagar Gawande²

¹ P.G. Scholar | ² Professor, Civil Engineering Dept

Anantrao Pawar College of Engineering and Research Pune-09 Maharashtra, India

ABSTRACT

The structural integrity of large-capacity reinforced concrete (RCC) balancing tanks used in water supply schemes is critically threatened by groundwater-induced buoyancy forces, mainly during maintenance or low-storage periods. This paper investigates the structural failure mechanisms of the raft foundation and bottom treatment layers of a 37 ML RCC balancing tank constructed under the Jal Jeevan Mission (JJM) at Sarade Village, Phaltan Taluka, Satara District, Maharashtra, India. The tank, sourced from the Nira Bank Canal, designed to provide 60-day storage security at 55 LPCD for a projected population of 6,811 by 2054. Elevated groundwater levels adjacent to the unlined canal caused severe uplift pressures that lead to the failure of the bottom treatment system comprising 300 mm compacted soil, 500-micron geomembrane, 150 mm sand boxing, and 50 mm Shahabad tile. A novel remediation strategy employing a perforated PVC pipe grid network integrated with Non-Return Valves (NRVs) installed at each node was implemented to relieve sub-slab hydrostatic pressure and eliminate reverse-flow groundwater ingress. Post-installation monitoring confirmed complete elimination of buoyancy-induced structural distress. The study validates the NRV-based underdrain system as a technical sound, cost-reducing, and good solution for big water infrastructure under same hydrogeological conditions across India and developing economies.

Key Words: *Balancing tank; groundwater uplift; buoyancy; non-return valve; geomembrane; raft foundation; Jal Jeevan Mission; water supply infrastructure; structural remediation; underdrain system.*

1. INTRODUCTION

Rural water supply infrastructure increasingly demands superior engineering solutions that account for complex environmental and hydrogeological conditions. Jal Jeevan Mission, the GOI has committed to providing Tap Connections (FHTC) delivering 55 LPCD of potable water to every rural household. The mission involves construction of large-scale water storage and treatment infrastructure in challenging terrains and geologically sensitive locations.

Balancing tanks (BTs) are a critical component in JJM schemes where the primary water source—typically an irrigation canal—experiences periodic shutdowns. In the Sarade Village scheme under Phaltan Taluka, Satara District, the Nira Right Bank Canal serves as the source with an approximate annual shutdown of 50 days and a maximum single-cycle closure of 15 days. Maharashtra's Irrigation Department mandates 60-day storage, necessitating a 37 ML RCC balancing tank. The tank's location adjacent to the unlined canal poses a persistent threat: seasonal canal discharge elevates the surrounding groundwater table to levels that can generate significant hydrostatic uplift pressures beneath the tank's raft foundation and internal bottom treatment layers.

Buoyancy-induced structural failures of underground tanks are well-documented globally. Studies in India, the UAE, and the USA have reported tank uplift, cracking, and bottom treatment delamination as consequences of inadequate hydrostatic uplift design [2, 3]. Indian Standard IS 3370:2009 and ACI 350 provide design frameworks for water-retaining structures but often underestimate dynamic groundwater fluctuations adjacent to unlined waterways [4, 5].

The present work documents a field failure, investigates the underlying hydraulic mechanisms, and presents an engineered NRV-based drainage remediation system validated through field performance at the Sarade JJM scheme.

2. STUDY AREA ITS DESCRIPTION

2.1 Location and Topographics

Sarade Village is situated in Phaltan Taluka, Satara District, Maharashtra, having coordinates 74°34'15" E, 18°03'15" N, at an elevation of 518 m above mean sea level. The village expanded in 10.34 sq. km having population of 4,288 as per 2011 census. Population projections by averaging the calculation method a base-year (2024) population of 4,935 and an ultimate (2054) population of 6,811, against which the water supply scheme is designed.

The area having an average annual rainfall about 910 mm. The general topographic slope is from south to north. The nearest surface water source is the Nira Right Bank Canal with a bed level of approximately 554 m WL, which is the designated tap-off point for raw water supply to the scheme.

2.2 Proposed Water Supply Scheme

The proposed JJM scheme for Sarade Village is designed for a 30-year design horizon (base year: 2024, ultimate year: 2054) as per CPHEEO Manual on Water Supply and Treatment (1999). The system delivers 55 LPCD to residential consumers plus provision for floating population (15 LPCD at 10% of residential), livestock (40 LPCD for large cattle; 4 LPCD for small cattle), and institutional demand (20 LPCD). After all calculation done the required ultimate gross daily demand is 0.567 MLD.

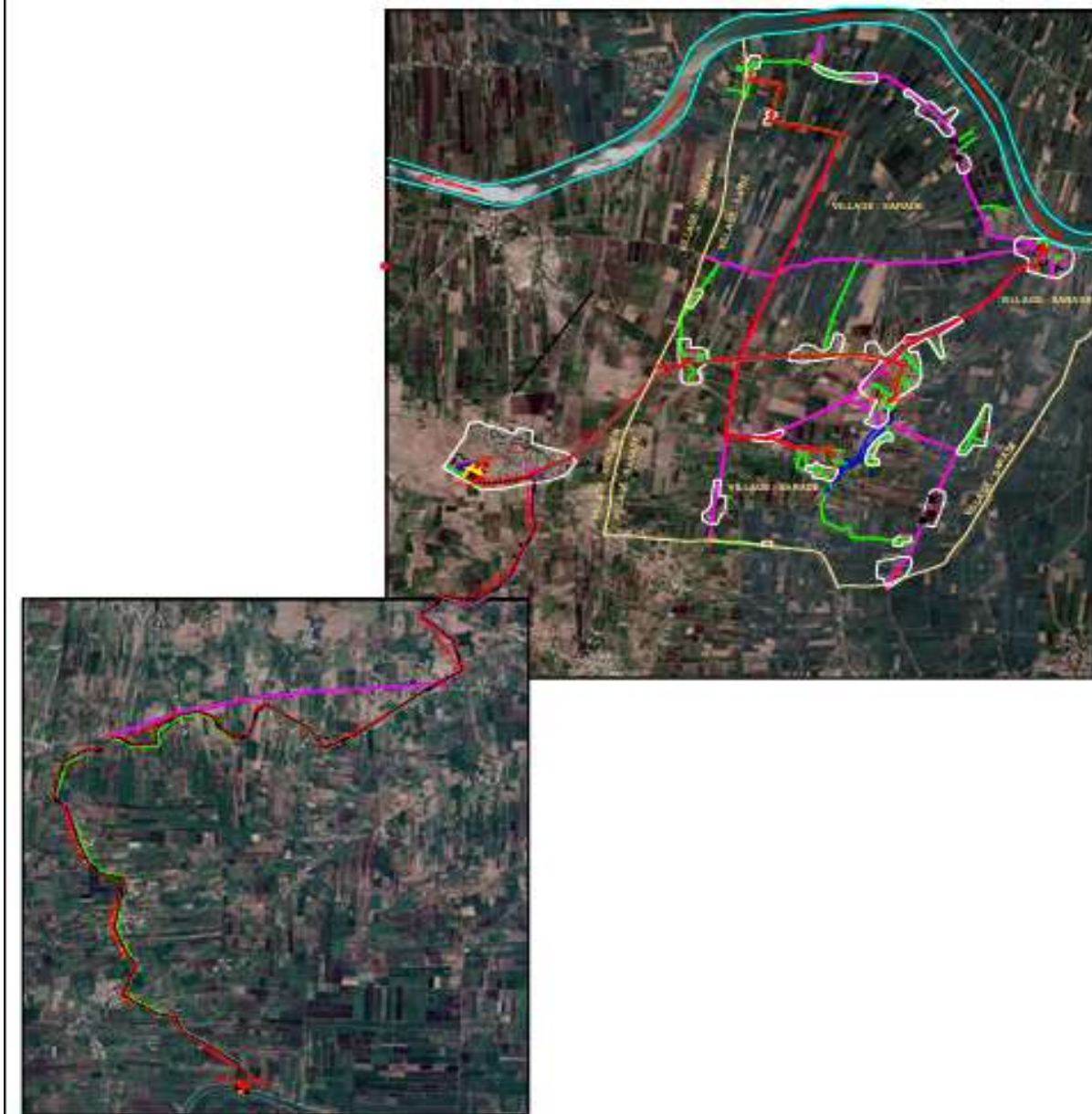
Key infrastructure components include: (i) 350 mm DI K-7 canal connecting pipe; (ii) 20 HP-2Nos submersible pumps (1W + 1S); (iii) 37 ML RCC balancing tank (Length 108 m × width 65 m); (iv) 1.0 MLD Packaged WTP; (v) 60000 LITRE RCC Master Balancing Reservoir (MBR) at Balancing tank campus; (vi) 80000 LITRE ESR at Dhaygudewasti; (vii) 32.2 km HDPE distribution network diameter ranging from 75–140 mm.

SCOPE OF SCHEME

1)	Name of Village	- Sarade
	Taluka	- Phaltan
	District	- Satara
2)	Population	- Sarade
	2024	-4935
	2039	-5803
	2054	-6811
3)	Rate of Water Supply	- 55 LPCD
4)	Daily Gross Demand in 2024	- 0.442 MLD
	Daily Gross Demand in 2039	- 0.501 MLD
	Daily Gross Demand in 2054	- 0.567 MLD
5)	Hours of Pumping	- 16 Hours
6)	Source of Water Supply	- Nira Right Bank Canal
7)	Canal Head Works at Nira Right Bank Canal	
	a) Location	- Nira Right Bank Canal
	b) Connecting Pipe Invert	- 555
	c) Canal Bed Level	- 554.40
	d) Pipe Diameter	- 350 mm
	e) Depth	- 2.5 m
	f) Construction Type	- RCC M-30
8)	Raw Water Gravity Feeder	

	a) Canal to Sump	- 350 mm dia DI K-7, L=40m
	b) Raw water Rising Main	- 350 mm dia DI K-9, L=9460 m
9)	Balancing Tank	
a)	Capacity	- 37 ML
b)	Dimensions	- 108 m x 65 m
c)	GL	- 545.00 m
d)	FSL	- 548.00 m
e)	Construction	- RCC M 30
10)	a) Raw Water Pumping Machinery	- 2 No.s of 20 HP Submersible -1 Working 1 Stand By - 2 No.s of 3 HP Submersible - 1 Working 1 Stand By
11)	Water Treatment Plant	- 1.00 MLD
12)	Pure Water Pumping Machinery	- 2 No.s of 10 HP Submersible -1 Working 1 Stand By
13)	Pure water Rising Main	- 150 mm Dia, DI K-9 L=30 M
14)	RCC MBR Capacity	- 63000 Liters
15)	RCC ESR at Dhaygudewasti	- 80000 Liters
16)	Distribution System	- HDPE pipes of 75 to 140 mm dia length 32.2 Km

Key Map of Scheme



3. PROBLEM STATEMENT: GROUNDWATER-LEADS STRUCTURAL FAILURE

3.1 Bottom Treatment Design

The base floor of the 37 ML RCC balancing tank incorporates a composite bottom treatment system designed to provide waterproofing to water, drainage and exposed surface. The layers from bottom to top is: (a) 300 mm depth compacted soil layer; (b) 500 micron HDPE Geomembrane; (c) 150 mm thick sand boxing; (d) 50 mm rough Shahabad stone tile. The total composite thickness is completes 500 mm above the base.

3.2 Failure Mechanism

The Nira Right Bank Canal in the vicinity of the balancing tank is unlined. Seepage from the canal banks raises the local groundwater table during canal operation periods. When the balancing tank is emptied for inspection, maintenance, or during initial commissioning, the weight of water that previously counteracted hydrostatic uplift is removed. The effective uplift pressure U on the raft is given by:

$$U = \gamma_w \times hw \quad [kN/m^2]$$

where γ_w is the unit weight of water (9.81 kN/m^3) and h_w is the height of the groundwater table above the raft soffit. When the net downward force from the tank structure and retained water is insufficient to overcome U , net uplift occurs. Field observations at the Sarade site confirmed that groundwater table elevations adjacent to the unlined canal

were sufficient to generate uplift pressures exceeding the self-weight of the bottom treatment composite layers, causing delamination of the sand boxing, geomembrane distortion, and heave of Shahabad tile units.

Table 1 summarizes the documented failure modes observed and their hydraulic causes, drawing on field investigation and comparable case records from literature.

Table 1: Observed Failure Modes and Causative Mechanisms

Failure Component	Observed Symptom	Primary Cause
Shahabad Tile	Heave and displacement of tiles	Uplift pressure exceeding tile self-weight
Sand Boxing Layer	Delamination and piping of sand	Sub-membrane pressure gradient
Geomembrane	Ballooning and puncture	Differential pressure across membrane
Soil Layer	Liquefaction of loose soil	Seepage-induced effective stress reduction
Raft Foundation	Micro-cracking at joints	Net buoyant force on empty structure

4. LITERATURE REVIEW

The phenomenon of buoyancy-induced structural failure in underground tanks is well-reported in geotechnical and structural engineering literature. Jain and Goel [2] conducted failure analysis of over 10 municipal balancing tanks in India and attributed 40% of failures to uplift caused by elevated water tables, with failures occurring predominantly during maintenance emptying operations. Their study recommended IS 3370 compliant uplift checks with safety factors between 1.1 and 1.5.

ACI 350:2012 (Commentary) addresses hydrostatic uplift design for environmental concrete structures and cites failures arising from incomplete uplift pressure calculation or erroneous geotechnical assumptions, recommending anchoring systems or increased slab mass as countermeasures [3]. Bowles [6] provides foundational treatment of effective stress and pore-pressure dynamics beneath slabs, establishing that ignoring groundwater in uplift design constitutes a critical engineering oversight.

European practice under EN 1997-1 (Eurocode 7) mandates groundwater uplift calculations as a required geotechnical limit state. Finite Element Modelling (FEM) studies using PLAXIS have confirmed that base slab thickness alone is frequently inadequate without supplementary drainage or anchoring systems in high-water-table environments [7].

Regarding Non-Return Valve (NRV) applications, literature confirms their utility in geomembrane-protected underground structures. Perforated drainage systems integrated with NRVs prevent re-pressurisation of sub-slab drainage layers after groundwater pumping events, thereby protecting both the geomembrane and the structural raft from cyclic loading [8, 9]. However, field-documented applications in large-capacity rural balancing tanks under Indian conditions—specifically in proximity to unlined irrigation canals—remain unlined, highlighting the significance of the present case study.

5. METHODOLOGY

5.1 Site Investigation and Groundwater Assessment

A geotechnical site investigation was conducted at the balancing tank location to characterise subsurface conditions and establish seasonal groundwater table elevations. For operation and maintenance purpose observation wells installed adjacent to the unlined Nira Right Bank Canal to record groundwater table fluctuations. Maximum recorded groundwater elevation approached the structural raft invert level during peak canal discharge periods, confirming the generation of positive net uplift on the composite bottom treatment.

5.2 NRV-Based Underdrain System Design

The remediation system was engineered as an integrated underdrain network with embedded Non-Return Valves. The design consists of the following elements:

- (a) **Perforated PVC Pipe Grid Network:** Looped perforated PVC pipes are laid in a grid configuration within the 300 mm soil layer below the sand boxing. The grid is cushioned with clean gravel material to serve as a granular filter medium and drainage pathway for seeping groundwater.
- (b) **NRV Block Installation:** At each grid node (intersection of perforated pipes), one NRV block is installed. The NRV operates on differential pressure: when groundwater pressure at the inlet (sub-slab) exceeds pressure at the outlet (drainage system), the valve opens, allowing groundwater to drain to a collection sump. When outlet pressure is equal to or greater than inlet pressure—preventing backflow—the valve closes automatically.
- (c) **Outlet Drainage to Sump:** Drainage water collected through the NRV network is directed to a peripheral sump with a submersible pump for periodic discharge away from the tank vicinity, thereby depressurising the sub-slab drainage layer.

5.3 Material Specifications

Materials were selected for compatibility with the geomembrane and longevity in the groundwater environment. Perforated PVC pipes conform to IS 4985 specifications for unplasticised PVC pressure pipes. The NRV blocks are fabricated from HDPE to ensure chemical compatibility with the geomembrane and resistance to corrosion in alkaline groundwater. The gravel cushion material is clean, well-graded crushed stone aggregate (10–20 mm) conforming to IS 383. The geomembrane layer (500-micron HDPE) is restored where damaged and continuity is maintained around pipe penetrations using prefabricated HDPE boot fittings.

6. RESULTS AND DISCUSSION

6.1 Pre-Remediation Failure Analysis

Prior to NRV installation, field inspection confirmed delamination and heave of the Shahabad tile layer, rupture and ballooning of the HDPE geomembrane in multiple locations, and migration of sand boxing material. These observations are consistent with the literature-documented failure progression: groundwater seeps beneath the geomembrane, generating uplift pressure that exceeds the composite layer's resisting weight. The absence of any pressure relief mechanism allowed pressure to accumulate until failure.

6.2 NRV System Performance

Following installation of the NRV-integrated perforated pipe drainage network, the balancing tank was filled to its design FSL (548.00 m) and then emptied during a simulated maintenance cycle. Piezometric monitoring at the observation wells demonstrated that groundwater pressures beneath the raft remained substantially below pre-remediation levels during emptying operations. No new delamination, heave, or membrane distress was detected on post-emptying inspection. The NRV system effectively dissipated sub-slab pore pressures by permitting unidirectional groundwater drainage while preventing the re-entry of groundwater once the drainage path was cleared.

6.3 Comparative Analysis with Conventional Countermeasures

Conventional countermeasures for uplift—such as ground anchors, increased slab thickness, or permanent dewatering wells—were evaluated against the NRV underdrain approach. Table 2 presents a comparative summary of these strategies in the context of the Sarade site.

Table 2: Comparative Assessment of Uplift Mitigation Strategies

Strategy	Cost	Invasiveness	Passive Operation	Suitability for Retrofit
Ground Anchors	High	High	Yes	Moderate
Increased Slab Mass	Very High	Very High	Yes	Low

Strategy	Cost	Invasiveness	Passive Operation	Suitability for Retrofit
Permanent Dewatering Wells	Moderate	Moderate	No (active)	Moderate
NRV Underdrain System (Present Study)	Low	Low	Yes	High

The NRV underdrain system is the only passive, low-cost strategy that also offers high suitability for retrofit applications—a critical consideration for the large stock of existing JJM balancing tanks across India that may face similar groundwater challenges.

6.4 Design Implications and Recommendations

The failure and remediation at Sarade have several design implications for future balancing tank projects in similar hydrogeological settings:

- Seasonal groundwater table monitoring should be conducted prior to design finalisation, with worst-case (peak canal discharge) scenario governing uplift calculations.
- All balancing tanks adjacent to unlined waterways should incorporate an NRV-integrated perforated drainage layer as a standard design provision.
- Geomembrane penetrations for drainage pipes should use prefabricated sealed boot fittings to maintain membrane continuity.
- Maintenance protocols should mandate pre-inspection dewatering of the surrounding drainage system before emptying the balancing tank.
- IS 3370 uplift safety factors (1.1–1.5) should be applied with a conservative multiplier (≥ 1.3) for tanks adjacent to unlined canals.

7. SCALABILITY AND NATIONAL RELEVANCE

Under the Jal Jeevan Mission, the State Water and Sanitation Mission, Maharashtra has commissioned balancing tanks across numerous canal-dependent schemes including those sourced from Nira Right Bank Canal, Nira Left Bank Canal, and other perennial canal systems. Field experience from the Sarade case confirms the applicability of the NRV underdrain solution wherever balancing tanks are located in close proximity to unlined or semi-lined irrigation canals—a common configuration in Maharashtra and across peninsular India.

Given that JJM targets over 160 million rural households nationwide, and that many schemes in Rajasthan, Gujarat, Maharashtra, Karnataka, and Andhra Pradesh rely on canal-sourced balancing tanks, the documented failure mode and its low-cost passive remedy constitute important findings for national-level infrastructure planning. Inclusion of NRV underdrain systems in CPHEEO guidelines and JJM model design standards would systematically prevent recurrence of similar failures.

8. CONCLUSION

This paper has documented the groundwater-induced structural failure of the bottom treatment system of a 37 ML RCC balancing tank under the Jal Jeevan Mission at Sarade Village, Satara District, Maharashtra, and demonstrated the successful remediation using a perforated PVC pipe grid network integrated with Non-Return Valves. The following conclusions are drawn:

- Seepage from adjacent unlined irrigation canals can raise groundwater tables to levels capable of generating structural uplift failures in empty or partially-filled balancing tanks.
- The composite bottom treatment (soil + geomembrane + sand boxing + Shahabad tile) is vulnerable to delamination under net uplift conditions; the geomembrane is particularly susceptible to ballooning and puncture.

3. The NRV-integrated perforated PVC underdrain system provides passive, automatic pressure relief that prevents sub-slab pressure build-up without requiring active pumping during normal operation.
4. Post-remediation field monitoring confirmed zero recurrence of buoyancy-induced structural distress, validating the NRV system's effectiveness.
5. Compared to conventional countermeasures (ground anchors, slab thickening, dewatering wells), the NRV underdrain system offers superior cost-effectiveness, passive operation, and retrofit suitability.
6. Adoption of this system as a standard design element in JJM and CPHEEO guidelines for canal-adjacent balancing tanks is strongly recommended.

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