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An Assessment of Structural Safety of Cement Mortar Lined Irrigation Water Pipeline by Hydrostatic Test

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Abstract

Structural safety of cement mortar-lined water pipeline is a matter of great concern primarily due to weld defects, fabrication deficiency and assessment of pressure shared by lining. The verification of structural design of such pipeline and assessment of safety is generally carried out by conducting prototype hydrostatic test. The present paper is based on one such type of study conducted by CWPRS, Pune, for Guthpha Lift Irrigation Scheme, Nizamabad, Andhra Pradesh. The pipes of finished internal diameter varying from 1600–2200 mm have been fabricated with 12 mm thick Grade B mild steel complying with IS: 2062 specifications. The pipes have been designed further with internal lining of 15 mm thick cement mortar and external coating of 25 mm cement mortar for an internal design pressure of 6 kg/cm^2*. In order to assess structural safety by conducting prototype hydrostatic test, two lined pipes each of 6 m length and 2200 mm internal diameter have been joined to form a single pipe of 12 m length to eliminate edge effects due to welded bulkheads at the ends. The pipeline has been supported on rigid concrete platform through three saddle supports. Electrical resistance-type strain gauges have been installed at critical locations in high-stressed zones after removing external coating of cement mortar. The pipeline has been tested up to 1.5 times of design internal pressure, i.e., 9.0 kg/cm*^{2}*. The allowable stress as per design has been taken as 0.66 times of yield stress with 90% weld efficiency, which worked out to be 1485 kg/cm*^{2}*. The hoop tensile stresses in steel pipe computed at different locations based on measured strains have been found to vary from 300 to 1000 kg/cm*^{2}* at 9 kg/cm*^{2}* internal pressure and thus remain well within allowable limit. The tensile stresses developed in outer cement mortar coating have been found negligible compared to that developed in the steel pipe indicating that total applied internal pressure has been shared by the steel pipe only.*

Keywords*: Prototype, internal lining, bulkheads, hoop stress, electrical resistance strain gauges*

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INTRODUCTION

Lined pipes for irrigation purposes are mostly designed on certain assumptions [1–3] towards sharing of internal pressure. Verification of structural design of such pipeline becomes mandatory [4] for ensuring the structural safety and is generally carried out by conducting prototype hydrostatic test by simulating internal pressure up to 1.5 times of the designed pressure [5]. The strains are measured at critical locations by installing electrical resistance strain gauges. Hoop and principal stresses are calculated from the measured strains and safety of the pipeline is evaluated by comparing the calculated stresses based on measured strains with allowable/design stresses. One such study has been conducted by CWPRS for Guthpha Lift Irrigation Scheme, Nizamabad, Andhra Pradesh. The lift irrigation scheme has been envisaged to lift 15.30 cumecs water from Godavari river at the shore of Sri Ram Sagar Project in Nizamabad district, to irrigate an area of 15,700 ha by lift-cum-gravity canal system. The water conductor system consists of a 16 km-long buried and exposed pressure pipeline. The buried pipeline is proposed to be laid in trenches with minimum 1.20 m cover of backfill material. The buried pipeline has to be laid on 300 mm thick sand bed where expansive soils are present. In soil, other than expansive soils, the pipeline has to be laid over gravel/murram. The exposed pipeline is supported on intermittent concrete saddle supports at regular spacing of 15 m and anchor blocks at every 200 m interval (Figure 1).

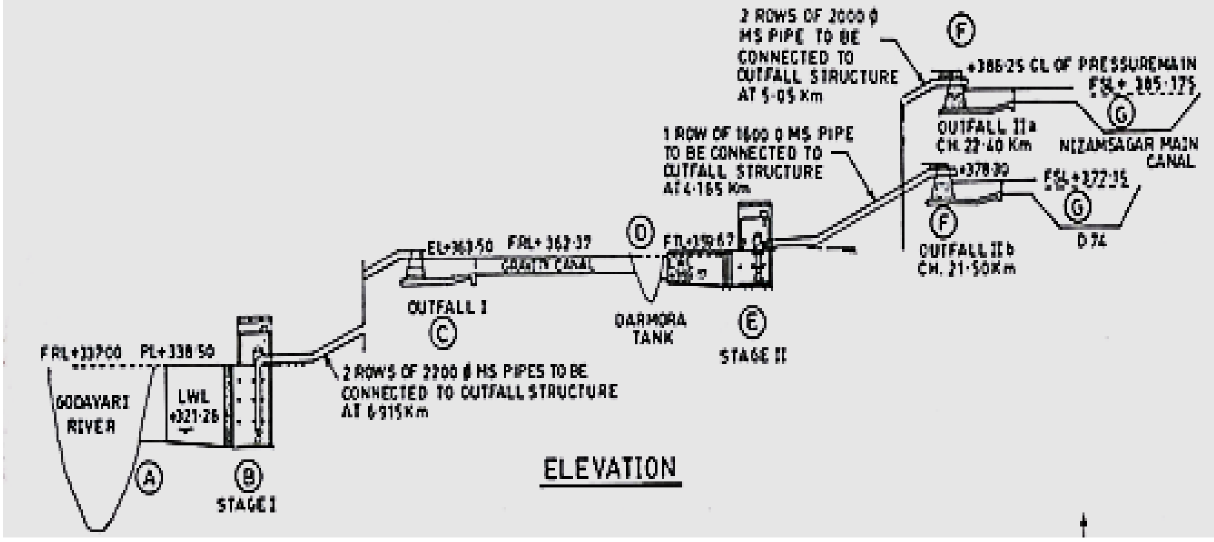

Fig. 1: *Elevation of the Gutpha Lift Irrigation Pipeline.*

MATERIALS AND METHODS

Design and Fabrication of Pipe Ferrules

The lined pipe ferrules have been designed based on recommendations of IS: 5822-1986, IS: 2062-1984 and IWWA Publication manuals using the following data:

Internal diameter of pipe = 1600–2200 mm
Thickness of lining = 15 mm
Thickness of MS plate used = 12 mm
Thickness of coating = 25 mm
Internal test pressure = 9 kg/cm^2
Working internal pressure = 6 kg/cm^2
Density of filling material = 1800 kg/m^3
Height of earth fills = 1.20 m
Vacuum pressure (external radial pressure) = 0.35 kg/cm^2
Modulus of elasticity of steel = 2.1 × 10^{6}kg/cm^2
Soil modulus of fill material = 30 kg/cm^2
Width of trench (diameter$_{\text{outer}}$ + 900 mm) = 3200 mm
Density of water = 1000 kg/m^3
Density of steel = 7850 kg/cm^3
Type of steel = Mild steel grade-B
Yield stress of pipe material F_y = 2500 kg/cm^2
Maximum % of deflection allowed =2% of diameter$_{\text{outer}}$ of steel shell

The permissible stress in the pipe shell has been considered as per the criteria of IWWA manual M1 as follows:

a) Working stress for combined bending and direct tensile stress shall not exceed 60% of yield stress of the material, making due allowance for efficiency of welded joint. however, for Guthpha lift irrigation scheme, maximum working stress for combined bending and direct tensile stress has been considered as 66% of yield stress of the material making due allowance for efficiency of welded joint as 90%.
b) Working stress for combined bending and

direct compressive stress shall not exceed 50% of yield stress making due allowance for weld efficiency.

c) For field welded joint, efficiency factor of 80%, whilst for shop welded joint 90% efficiency has been allowed.

Based on above criteria, permissible stresses have been computed as follows:

In compression = 2500 × (50/100) × (90/100)
= 1125 kg/cm^2
In tension = 2500 × (66/100) × (90/100)
= 1485 kg/cm^2

The pipeline has been designed by considering various loads such as weights of steel pipe, lining and outer coating and water and earth-fill loads by allowing 50% weight transfer to the ground. Compressive and hoop stresses have been computed using standard formulae as per IWWA manual M1. The design of pipeline has been tested against deflection and minimum shell thickness required towards handling of pipes. The pipeline ferrules in lengths of 6 m each have been fabricated at the fabrication workshop with 90% weld efficiency using 15 mm-thick inner cement mortar lining and 25 mm-thick outer cement mortar coating. Temperature reinforcement in the form of wire mesh has been provided on the outer surface of the pipe ferrules below mortar coating.

Prototype Hydrostatic Test

In order to eliminate the end-effect of stress concentrations due to bulkheads welded at both ends to develop internal pressure [6] due to water and air, two ferrules of 6 m length each of the pipeline having finished internal diameter of 2200 mm with steel shell thickness of 12 mm and 15 mm-thick inner cement mortar lining and 25 mm-thick outer cement mortar coating, have been joined together by welding to form a single pipe of 12 m length. The pipe has been supported on four numbers of saddle-type supports [7] and to ensure free movement of the pipe during hydrostatic test, rubber sheet packing with lubricant has been laid at each saddle support below the pipe. Saddle supports have been further rested on MS plate four numbers of size 2000 ×2520 × 25 mm laid on even concrete platform to provide stability and prevent differential settlement during hydrostatic test (Figure 2). Air vent, water inlet and outlet have been provided in bulkheads closing both ends of the pipe. A pressure gauge of 0–20 kg/cm^2 range with a non-return valve has been installed near the water inlet for reading the hydrostatic pressure inside the pipe.

Fig. 2: *Prototype Hydrostatic Test Setup of Lined Steel Pipes.*

Nine critical locations from stress point of view have been selected at three sections along the length of the pipe for strain gauge installation. The first section has been chosen at the intersection of inlet bulkhead and pipe to measure strains developed due to stresses near the bulkhead. The other two sections have been located at a distance of 4.4 m, i.e., twice the inner diameter from each bulkhead end. Three electrical resistance-type biaxial strain gauges have been installed at each section on outer surface of the pipe. In order to facilitate measurement of strains on MS surface at side faces of the pipe, outer cement mortar coating has been removed at places over a small surface area of size 150 × 150 mm at each strain gauge location. In order to study stress transfer, if any, in outer mortar coating, two linear electrical resistance strain gauges of 30 mm length have been installed on outer cement mortar coating at bottom face of the pipe. All the wires have been connected to readout unit, viz., strain indicator P-3500 through two switch balance units having 10 channels each.

After recording initial observations with the pipe empty, the pipe has been filled with water gradually using hydraulic pump. After filling the pipe completely, small internal pressure has been applied and air vent valve has been operated to drain air from pipe and internal pressure has been brought down to zero. This cycle has been repeated three times to remove entrapped air from the pipe and then strain gauge readings have been recorded at zero internal pressure. Afterwards, internal pressure has been increased gradually in steps of 1 kg/cm^2 and held for 10 min at each step before recording observations of all strain gauges. The hydrostatic test has been continued till the test pressure equals 1.5 times of designed pressure, i.e., 9 kg/cm^2 has been reached which has been held up to 15 min and the entire length of pipe including weld joints have been examined minutely for leakage, sweating of joints and damage, if any, to outer mortar coating. Similar procedure to observe pipe behavior under internal hydrostatic pressure has been repeated for three cycles. In each cycle, the maximum pressure first has been brought down to 6 kg/cm^2 and again increased to 9 kg/cm^2 in a single step and strain gauge observations have been recorded. The pressure in pipe has then been reduced gradually from 9 kg/cm^2 in steps of 1 kg/cm^2 and strain gauge observations have been recorded at each step. During the entire test, no leakages or sweating of joints have been noticed. It has been further noticed that strain recovery from all the strain gauges has been at almost 93% level [8].

RESULTS AND DISCUSSIONS

For comparison of measured hoop stresses with computed stresses, initially, hoop and longitudinal stresses in the circular pipe shell have been computed using standard formulae for thin cylindrical shell as follows:

Tensile hoop stress $\sigma_h = p.r/t$

Longitudinal stress $\sigma_l = p.r/2t$

where, p is the internal pressure developed in pipe and r is the internal radius of pipe and t is the shell thickness. The recorded strain gauge observations have been used to compute hoop and longitudinal strains, which are in turn converted to hoop and longitudinal stresses by multiplying with Young's modulus of elasticity 'E' value as follows:

$\sigma = \varepsilon.E$

Where, σ is hoop/longitudinal stress in kg/cm^2 and ε is hoop/longitudinal strain and E is Young's modulus of elasticity of steel in kg/cm^2. The maximum hoop stresses computed based on measured strains vary from 300 to 1000 kg/cm^2 at various strain gauge locations corresponding to 9 kg/cm^2 internal pressure and are found to be within permissible limits. The stresses are found higher near the bulkhead-end due to end-effect but still remain within permissible limits. A typical variation of measured hoop tensile stress with internal pressure in loading and unloading conditions in steel pipe shell is shown in Figure 3.

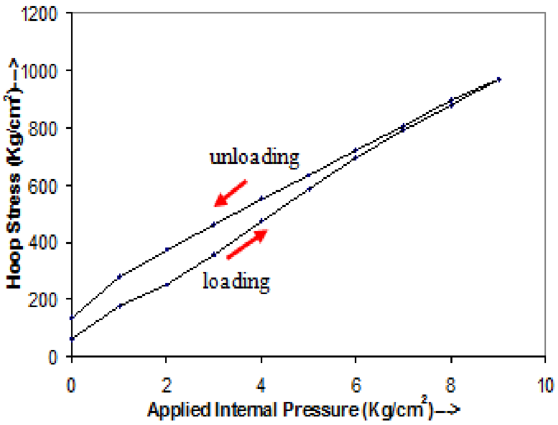

Fig. 3: *Variation of Hoop Tensile Stress with Internal Pressure in Steel Pipe Shell.*

From strain values recorded from strain gauges fixed on outer cement mortar coating, it is inferred that the stresses of the order of 6–14 kg/cm^2 developed when pipe was subjected to test pressure which further indicates that stresses transferred to outer mortar coating are negligible.

CONCLUSIONS

The structural design adequacy of a lined irrigation pipeline of Guthpha Lift Irrigation Scheme has been verified by conducting prototype hydrostatic test. Based on the studies, following important conclusions could be drawn:

- The stresses developed due to internal pressure have been found to be well within the allowable limits up to test pressure.
- All the internal pressure has been taken by MS pipe shell only and no pressure is resisted by cement mortar inner lining.

Thus, no advantage in terms of resistance to internal pressure is seen in providing inner mortar lining in the water pipelines. Moreover, the inner mortar lining gets cracked during application of internal pressure which may further make it ineffective in resisting corrosion. Therefore, inner lining is proposed to be provided using some flexible/viscoelastic material for corrosion resistance in pressure pipes.

- The stress transfer to the outer mortar coating has been found negligible. However, the outer mortar coating is required to be provided for resisting corrosion of outer surface of the steel pipeline.
- The thickness of MS pipe shell designed as 12 mm has been found adequate to withstand internal pressure of up to 9 kg/cm^2 during hydrostatic test.
- Thus Prototype/*in-situ* hydrostatic test has been proven to be essential for ensuring the structural safety of irrigation pressure pipes.

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REFERENCES

1. IS: 3589-2001 – *Indian Standard*: *Steel Pipes for Water and Sewage* (168.3 to 2540 mm outside diameter) Specification (Third Revision)
2. IS: 15155-2002 – *Indian Standard*: *Bar/Wire Wrapped Steel Cylinder Pipes with Mortar Lining and Coating* (Including specials) – Specification.
3. W. W. A Publication No. M1 – *Design of Large Diameter Steel Pipelines.*
4. *Steel Penstocks & Tunnel Liners – Engineering Data.* Vol. 4. American Iron & Steel Institute:
5. *Design, Fabrication, Erection and Maintenance of Steel Penstocks Manual*. CWC, New Delhi.
6. IS: 4880 (Part VII) – 1975 – *Indian Standard*: *Code of Practice for Design of Tunnels Conveying Water Part VII Structural Design of Steel Lining.*
7. IS: 5878(Part VI) – 1975 – *Indian Standard: Code of Practice for Construction of Tunnels Conveying Water Part VI Steel Lining.*
8. IS: 2062-1984 – *Indian Standard*: *Specification for Weldable Structural Steel* (Third Revision).