Response of Buried Pipes to Static Overpressures

by

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Indroduction

Buried pipes are used mainly for water supply and drainage besides many other applications such as pipe lines for oil etc. They are manufactured from different materials in various shapes and sizes and are subjected to live loads i.e. superimposed loads and gravity loads i.e. weight of medium in which they are laid. Considerable work has been done to study the response of buried pipe analytically (using elastic theory) and numerically (using approximate methods such as finite element and finite difference techniques) by Burns (1964), Hoeg (1968), Abel (1973), Anand (1967), Katona (1976), Ramakrishnan (1979), Valliapan (1977). However, experimental work in the area of buried pipes has not received much attention from research workers.

Marino and Riley (1964) studied response of structural models subjected to static and dynamic over pressures experimentally. The models were studied for different diameter to thickness ratios and for influence of end closure systems. It was observed that increase in soil overpressures has significant influence on the hoop bending of cylindrical shell and with increase in flexural rigidity of cylinder, the model deformation was less under the load. Allgood (1964) and Luscher and Hoeg (1965) also studied response of buried pipe experimentally.

In the present investigation, experimental studies were conducted on shallow buried flexible pipes subjected to surface pressures applied over finite areas. Aluminium and P.V.C. circular pipes were buried in loose and dense conditions of sand bed and their response was studied for soil cover to diameter of pipe ratios of 1.0, 1.5 and 2.0. The selection of relatively important dimensionlesss parameters was done by dimensional analysis. Various important parameters considered are hoop strain and crown deflection of pipe, surface pressure, modulus of pipe and soil, depth of embedment, diameter and thickness of pipe, Poisson's ratio of pipe and soil and angle of internal friction and relative density of soil.

Experimental Studies

Dimensional Analysis

The dimensional analysis has been carried out for various parameters to study the response of shallow buried pipes experimentally. It is extremely

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useful for correlation purposes as it permits presentation of experimental data in a concise and useful form. The main advantage of dimensional analysis of a problem is that it reduces number of variables in a problem by combining dimensional variables to form non-dimensional parameters. Buckingham π theorem (Pao 1961), Rouse (1959) and Streeter (1962) has been used for dimensional analysis of the problem. Figure 1 shows the buried pipe and the various parameters used in the present investigation.

The tweleve relevant parameters for the study have been identified as : θ_1, the hoop strain developed in buried pipe when subjected to uniform surface pressure p ; γ the unit weight of soil : D, the soil cover on the pipe ; I_D, the relative density and ϕ the angle of internal friction of soil; ν_p and ν_s the Poisson's ratios of pipe and soil respectively ; E_p and E_s the elastic modulii of pipe and soil respectively ; d, the diameter of pipe ; t, the thickness of pipe ; and δc, the crown deflection of pipe.

By applying Buckingham π theorem and solving various equations by equating dimensional exponents of both sides, the following functional representation can be obtained (Kataria 1980).

$$\epsilon_1 = f_1\left(\frac{p}{\gamma d}, \frac{D}{d}, \frac{E_p}{E_s}, \frac{d}{t}, \frac{E_p}{\gamma d}, \nu_s, \nu_p, I_D, \phi\right) \qquad ...(1)$$

$$\frac{\delta c}{d} = f_2\left(\frac{p}{d\gamma}, \frac{D}{d}, \frac{E_p}{E_s}, \frac{d}{t}, \frac{E_p}{\gamma d}, \nu_s, \nu_p, I_D, \phi\right) \qquad ...(2)$$

For buried pipes subjected to surface pressure, it has been found that the effect of Poisson's ratios of pipe and soil is relatively negligible (Abel et al (1973). For a particular value of γ, I_D and ϕ are constant. The parameter $\frac{E_p}{\gamma d}$ is not relevant being ratio of elastic modulus of pipe to

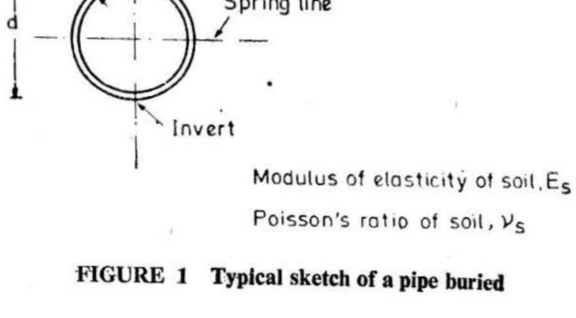


FIGURE 1 Typical sketch of a pipe buried

the product of unit weight of soil and diameter of pipe. Hence the effect of the remaining dimensionless parameters has been studied.

Properties of Soil and Pipe Material

(*a*) *Soil*

The granular soil used was sand from river Ganga near Kalpi. This sand is well graded as can be seen from the grain size distribution curve shown in Figure 2. All the experiments were conducted with soil in air dry state. As it is difficult to prepare homogeneous bed of Cohesionless soil, the tests were conducted either for loose or very dense conditions of sand bed. For Cohesionless soils relative density gives a useful measure of compaction and its values are obtained as per IS 2720 part XIV (i.e.)

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \qquad \ldots(3)$$

$$I_D = \frac{\gamma_{max}}{\gamma} \times \frac{\gamma - \gamma_{min}}{\gamma_{max} - \gamma_{min}} \qquad \ldots(4)$$

where e, e_{max} and e_{min} are inplace void ratio and void rotio in the loosest and the densest conditions of soil respectively. γ , γ_{max}, γ_{min} are in-place unit weight of soil and unit weight of soil in the densest and the loosest condition respectively.

Shear strength characteristics of sand were found by conducting direct shear tests. Modulus of elasticity of soil was determined from the plate load test (Lambe, 1973) using (for circular rigid loaded areas)

$$E_s = \Delta q_s \frac{R\pi}{\rho_s}\left(1 - \nu_s^2\right) \qquad \ldots(5)$$

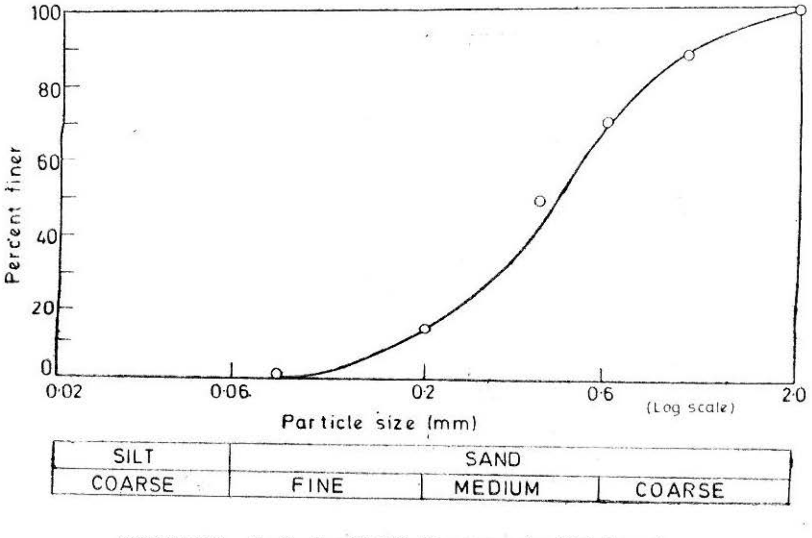


FIGURE 2 Grain size distribution curve for Kalpi sand

where ρ is settlement, $\triangle qs$ is the average stress over circular loaded area of radius R.

The tests were conducted for 1.55 g/c.c. and 1.77 g/c.c densities and the Young's modulii were found to be 40 kg/cm^2 and 580 kg/cm^2 respectively while Bowles (1974) report its value as lying between 50 and 200 kg/cm^2 in loose condition and 500 and 1000 kg/cm^2 in dense condition. Low value of Young's modulus has been obtained in the former case because sand was in very loose state ($I_D = 19.4$ per cent). The ϕ—value of sand was determined from the direct shear test and co-efficient of earth pressure at rest, K_o, was found by (Lambe, 1973),

$$K_o = 1 - \sin \phi \qquad \ldots(6)$$

After finding K_o, ν_s was obtained from (Selig, 1975),

$$= \frac{K_o}{1+K_o} \qquad \ldots(7)$$

The different properties of sand (soil) thus obtained and used in the computations are tabulated below.

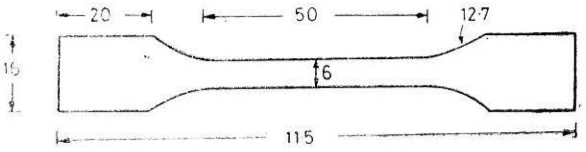
TABLE 1

Properties of Kalpi Sand

Sl. N.o	Name of property	Various numerical values
1.	Density of sand (soil) in loose condition (air dried) (By pouring from 15 cm height)	1.55 g/c.c.
2.	Density of sand (soil) in dense condition (airdried) By compacting with hand compactor)	1.77 g/c.c.
3.	I_D value for loose condition	19.4 per cent
4.	I_D value for dense condition	89.7 per cent
5.	Angle of internal friction ϕ of	
	(*i*) in loose condition	32°
	(*ii*) in dense condition	42°
6.	Young's modulus of elasticity of soil	
	(*i*) in loose sand	40 kg/cm^2
	(*ii*) in dense sand	580 kg/cm^2
7.	Poisson's ratio of soil	
	(*i*) in loose condition	0.25
	(*ii*) in dense condition	0.32

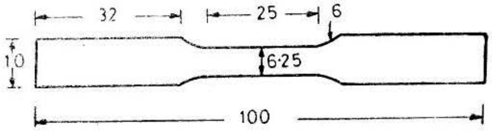
(*b*) *Pipe*

P.V.C. and Aluminium pipes each of 90,110 and 140 m.m. diameters were used in experimental studies. P.V.C. pipes are commercially available while Aluminium pipes were fabricated by rolling and welding of Aluminium sheet to the required diameters. Specimen specifications for tension test for P.V.C. and Aluminium pipes have been shown in Figure 3 and are as per ASTM standards (1969) and (1969) Poisson's ratio for P.V.C. and Aluminium have been obtained by measurement of strains in longitudinal and in the lateral directions of tension specimen by CT—3 strain gauges bonded along both directions. The Young's modulii and Poisson's ratio were determined by testing tension specimens in Instron machine and Material Testing Systems respectively at the Advanced Centre for Material Systems, Indian Institute of Technology, Kanpur.



(a) P.V.C. Tension specimen

NOTE:
All dimensions are in mm



(b) Aluminium tension specimens

FIGURE 3 Tension specimens of pipes

The average values of modulii of elasticity and Poisson's ratios for P.V.C. and Aluminium thus obtained tally closely with those given in literature (Encyclopedia of Polymer Science and Technology (1971) and Lambe (1973)) as tabulated below.

TABLE 3

Young's Modulus and Poisson's Ratio From Tension Specimens

Sl. No.	Pipe material	Young's Modulus $E_p \times 10^5$ kg/cm^2	Poisson's ratio ν_p
1.	P.V.C.	0.224	0.31
2.	Aluminium	3.550	0.35

Strain measurements

Paper-backed rectangular strain rosettes with gauge factor 2 and resistance 120 ohms were used to find the state of strain at a point. Some tests were conducted for inside and outside measurement of strain at a point and the difference was found to be neflegible. Hence for the simplicity of instrumention, subsequent tests were conducted with strain rosettes fixed outside only.

Four rectangular rosettes one each at crown and invert and two at spring line were glued outside each pipe. Rossette bonding was achieved by using cellulose nitrate cement (SR-4) and adequacy of bond was checked. After proper bonding, about 1.25 m long flexible wires were soldered to the strain rasettes to facilitate proper placing of pipe inside the tank for different depths of burial.

Two B. L. H. switching units model 220 were used for giving input signal of strain in each channel to strain indicator. In the rear panel of above unit, there was provision for connecting ten gauges and output terminals were provided on the front panel. For each unit connections were carried out for two arm brigde with common compensating gauge. For accurate measurements lengths of all the wires from active and compensating gauges were kept the same. The above 10 point switching unit needs no calibration.

The Budd's strain indicator model P 350 was used for measurement of strains. Its least count is 2 microinch/inch. The value of strain was obtained by substracting initial reading from the final reading. The positive values give tension in active gauges and negative values compresssion in active gauges.

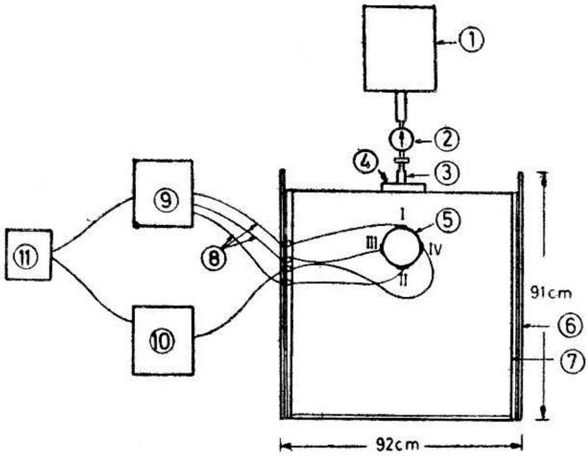
Experimental Set-up and Testing Procedure

A line diagram of experimental set-up has been shown in Figure 4. A. M. S. tank with perspex sheets placed along the walls of tank was used to study the response of buried pipes. Strain-controlled machine was used to transfer load on the buried pipe. A. M. S. rigid strip of size 65 cms × 10 cms × 0.9 cm was used for transferring load uniformly from the plunger. To measure load, a proving ring, which was connected to plunger, was used. The rate of loading for all the experiments was kept constant at 0.02 inch/min. (0.0508 cm/min.)

P. V. C. and Alumunium pipes of 90,110 and 140 m.m. diameters were tested for soil cover-to-diameter ratios of 1.0, 1.5 and 2.0 for loose and dense sand beds. Thus a total of 36 experiments were conducted—18 on P. V. C. pipes and 18 on Aluminium pipes as mentioned in Table 3. For Aluminium pipes, because of increase in d/t ratio with increase in diameter of pipe, lower loads were applied to avoid higher magnitudes of strains and deflections. Different colour leads were used from strain rosette to switching units to identify the three strain gauges placed in different directions in the rosette. For each test following procedure was adopted :

(*a*) The initial readings of all the 12 channels were noted.

(*b*) The initial readings of all the four dial gauges, (i. e.) two for crown deflection and two for strip deflection, were noted.



① Loading frame
② Proving ring
③ Plunger
④ Strip for loading
⑤ Pipe (I, II, III and IV are strain rossettes at crown invert and spring line)
⑥ M. S. Tank
⑦ Perspex sheet
⑧ Flexible wires
⑨ ⑩ Switching units
⑪ Strain indicator

FIGURE 4 Experimental set up

(*c*) The load was applied in regular intervals and for each load final readings of the 12 channels and 4 dial gauges were noted.

For selecting regular interval of load, due consideration was given to avoid damage of strain rosettes.

Results

The experimentally observed strain data has been reduced in the form of hoop strains and hoop stresses. Principal strains and priucipal stresses i. e. hoop strains and hoop stresses and longitudinal strains and longitudinal stresses are given by (Dally and Riley, 1978)

$$\epsilon_{1,2} = 1/2\,(\epsilon_A+\epsilon_C) \pm \tfrac{1}{2}\sqrt{(\epsilon_A-\epsilon_C)^2+(2\epsilon_B-\epsilon_A-\epsilon_C)^2} \qquad \ldots(8)$$

TABLE 3

Pipe Dimensions and Testing Conditions

Sl. No.	in g/c.c.	Pipe material	d in m.m.	t in m.m.	$\frac{d}{t}$ ratio	Length of pipe in cms.	D/d ratio	Successive load	
								Incremention kg.	No. of such increments
1.	1.55	P.V.C.	90	2.25	40	65	1.0,1.5	35.8	4
2.	,,	,,	110	2.76	,,	,,	2.0		,,
3.	,,	,,	140	3.50	,,	,,	,,	,,	,,
4.	1.77	,,	90	2.25	,,	,,	,,	35.8	6
5.	,,	,,	110	2.76	,,	,,	,,	,,	,,
6.	,,	,,	140	3.50	,,	,,	,,	,,	,,
7.	1.55	Al.	90	1.55	60	60	,,	17.9	4
8.	,,	,,	110	,,	70	,,	,,	,,	,,
9.	,,	,,	140	,,	90	,,	,,	,,	,,
10.	1.77	,,	90	1.55	60	,,	,,	35.8	4
11.	,,	,,	110	,,	70	,,	,,	,,	,,
12.	,,	,,	140	,,	90	,,	,,	,,	,,

$$\sigma_1 = \frac{E_p}{1-\nu_p^2}(\epsilon_1+\nu_p\epsilon_2) \qquad \ldots(9)$$

$$\sigma_2 = \frac{E_p}{1-\nu_p^2}(\epsilon_2+\nu_p\epsilon_1) \qquad \ldots(10)$$

$$\tan 2\phi = \frac{2\epsilon_B-\epsilon_A-\epsilon_C}{\epsilon_A-\epsilon_C} \qquad \ldots(11)$$

where ϵ_A, ϵ_B and ϵ_C are strains measured in A, B and C directions respectively; ϵ_1 and ϵ_2 are major principal strain (hoop strain) and minor principal strain (longitudinal strain) respectively; σ_1 and σ_2 are major principal stress (hoop stress) and minor principal stress (longitudinal stress) respectively. Equation 10 gives two values of θ, namely θ_1 which refers to the angle between the longitudinal axis i. e. A axis and the axis of hoop strain and θ_2, which is the angle between the A axis and the axis of longitudinal strain.

As already explained, results are plotted in terms of dimensionless parameters. Typical curves of ϵ_1 Vs $\frac{P}{\gamma d}$ and $\frac{\delta C}{d}$ Vs $\frac{P}{\gamma d}$ for P. V. C. and Aluminium pipes of 90 m. m. diameter are shown in Figures 5, 6 and 7.

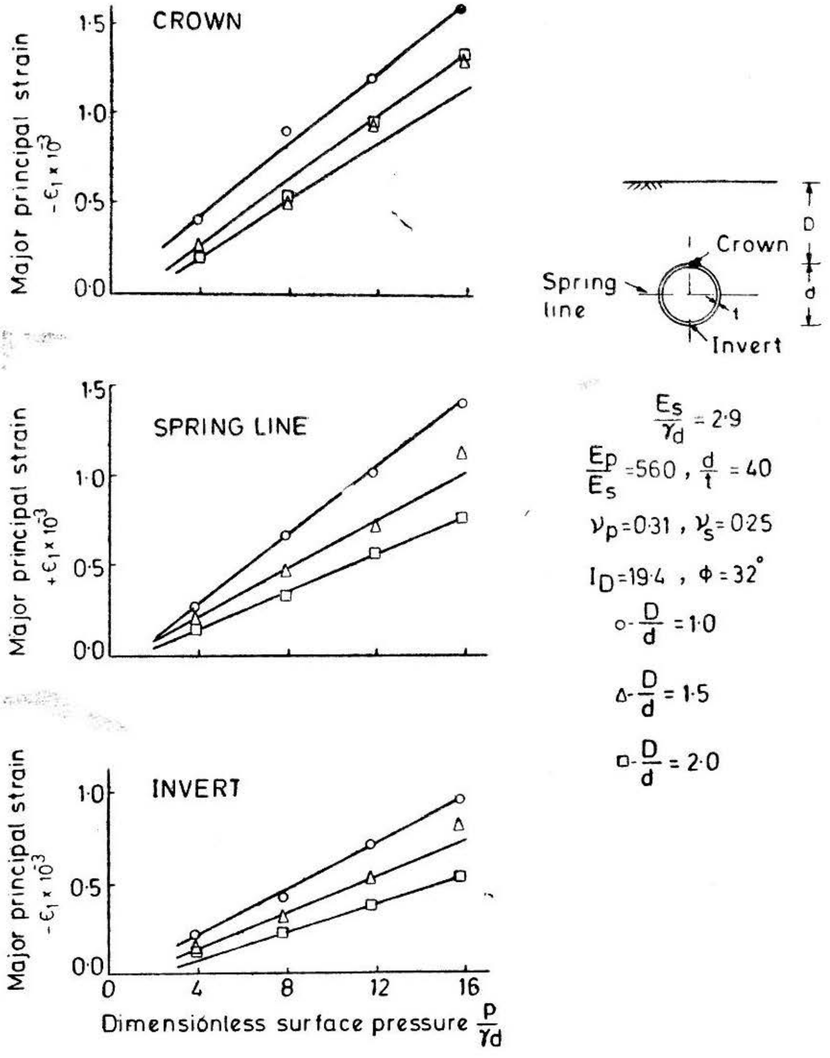


FIGURE 5 Variation of ϵ_1 with p/γ_d for 90 mm P.V.C. pipe in loose sand

It has been observed that ϵ_1 value is very close to ϵ_C value measured in C direction because strain along longitudinal direction is neglegible. The angle θ_1 is 90° and θ_2 is 0° allowing for experimental errors. It has also been observed that crown and invert are in compression and spring line (both ends) in tension when subjected to surface pressures.

The variation of ϵ_1 with respect to $P/\gamma d$ for different values of $\frac{D}{d}$ (i. e.) $\frac{D}{d} = 1.0$, 1.5 and 2.0 have been presented in Figures 5 and 6 for both pipe materials and dense as well as loose conditions of sand bed.

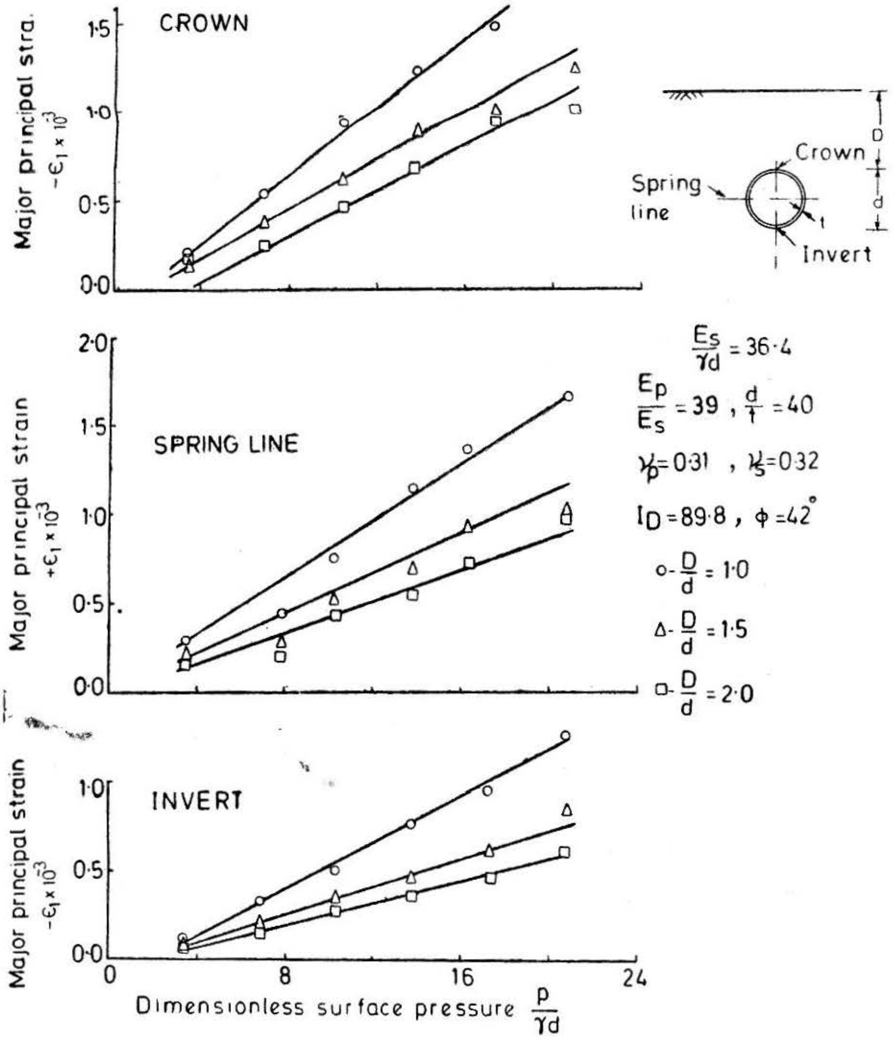


FIGURE 6 Variation of ϵ_1 with p/rd for 90 mm P. V. C. pipes in dense sand

The following trends can be observed from these Figures 5 and 6

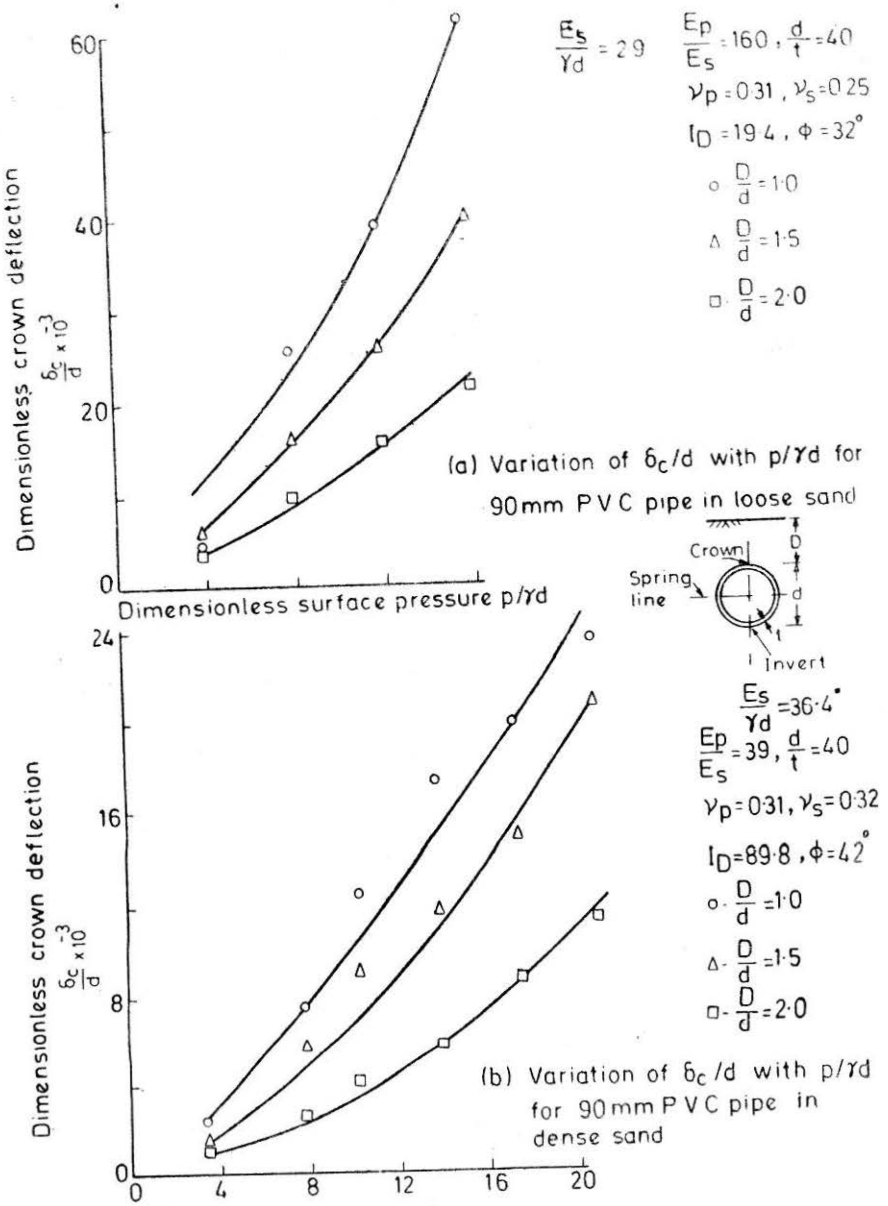
The variation of ϵ_1 with $p/\gamma d$ can be seen to be linear at crown, spring line and invert of the pipe.

The above three graphs for crown, spring line and invert were found to originate from near the origin. (but not passing through origin probably because of soil confining pressure).

The ϵ_1 value was found to decrease as D/d value increase from 1.0 to 2.0.

The strain values were found to be more for loose sand bed than those for dense sand bed because modulus of soil in the former case was less than in the later case.

The variation of $\delta c/d$ with $p/\gamma d$ was studied for different D/d ratios and and rato of elastic modulii *Ed/Es*. A typical graph has been shown in Figure 7. The variation of δ/cd with $p/\gamma d$ was found to be non-linear for



(a) Variation of δ_c/d with $p/\gamma d$ for 90mm PVC pipe in loose sand

(b) Variation of δ_c/d with $p/\gamma d$ for 90mm PVC pipe in dense sand

FIGURE 7 Variation of $\delta c/d$ with p/rd for 90 mm P. V. C. pipe in Sand

Aluminium as well as P. V. C. pipes. The strain were found to increase with increase in *d/t* ratio for Aluminium pipes. The strain values were found to decrease as *D/d* ratio increases from 1.0 to 2.0.

Conclusions

Based on these experimental studies following conclusions can be arrived at

The hoop strain ϵ_1 decreases as *D/d* ratio increases from 1 to 2.

For same *D/d* ratio, the effect of social modulus on strain is greater for 140 m. m. diameter pipe than for 90 m. m, pipe for both P. V. C. and Aluminium pipes.

The strain values for loose sand bed are more than those for dense sand bed which can be expected since the modulus of soil in the former case was less. This in a way shows the effect of *Ep/Es* ratio.

The crown deflection is directly proportional to hoop strain in the pipe for both the pipe materials.

Variation of dimensionless crown deflection $\delta c/d$ with $p/\gamma d$ is non-linear for both P. V. C. anp Aluminium pipes.

Variation of hoop strain ϵ_1 with dimensionless surface pressure $p/\gamma d$ is linear at the crown, the spring line and the invert for both P. V. C. and Aluminium pipes.

The increase in *d/t* ratio in case of Aluminium pipes results in an increase in strain values.

The effect of pipe diameter and depth of burial on surface deflection is negligible for both loose and dense sand beds. The surface deflection is much more for loose sand bed than for the dense sand bed for both Aluminium and P. V. C. pipes.

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