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Appendix A

FAILURE MODES

Forces in Service Pipes

At the most basic level pipe failures are caused by applied forces exceeding the residual strength of the metal. The forces applied to pipes have been investigated in detail elsewhere (Rajani, Zhan and Kuraoka, 1996). The forces applied to water pipes can be considered as five types: those produced by internal water pressure; bending forces; crushing forces; soil movement induced tensile forces; and temperature induced expansive forces. Gray cast iron pipe systems were generally designed to withstand only internal pressure and crushing forces. The loads that produce latter forces were assumed in the standards as a result of ground weight or truck loading above the pipe. *Figure A.1* graphically presents some failure modes and some condition directly causes corrosion.

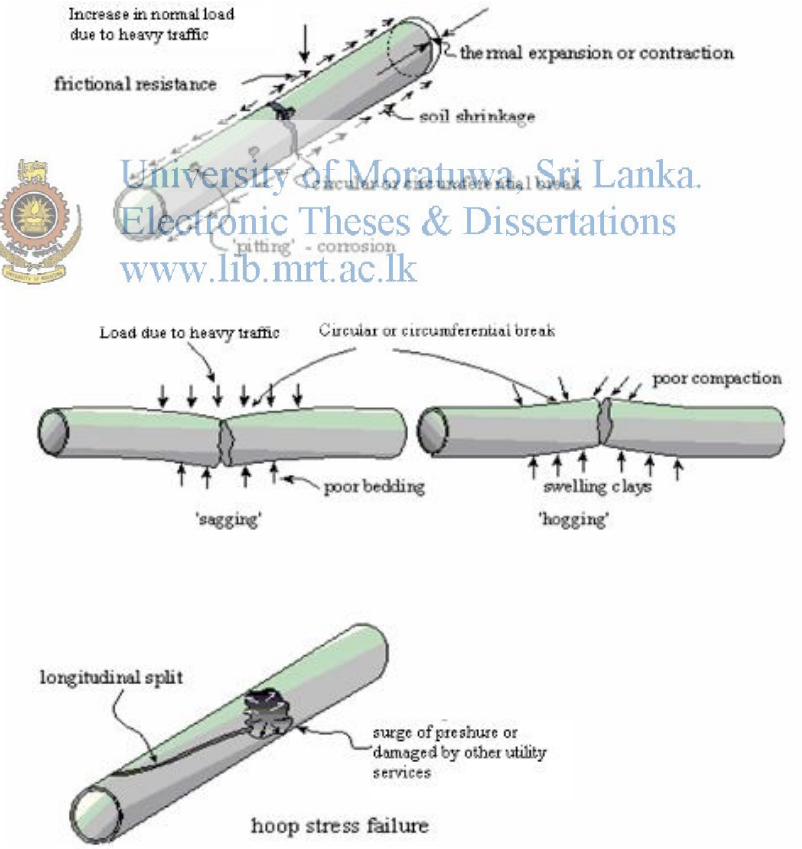


Figure A.1: Failure modes for buried pipes: direction tension (top left), bending or flexural failure (middle) and hoop stress (bottom).

Failure Modes *Appendix A.2*

The term “failure modes” refers to the actual manner in which cast iron pipes fail, rather than the mechanism that causes the failure. These modes vary depending on the diameter of the pipe. Smaller diameter pipes have lower water pressure but also smaller moments of inertia, which makes them more susceptible to longitudinal bending failures. Larger pipes have higher water pressure and higher moments of inertia, producing a tendency to longitudinal cracking and shearing at the bell.

Left pipe: bell splitting at top of pipe, circumferential cracking at middle of pipe.

Right pipe: corrosion through-hole at top of pipe, chain created corrosion pitting at middle of pipe, elongated corrosion pitting with blow out hole at bottom of pipe.

Generally these failure modes will not be seen on the same pipes.

Figure A.2 : Failure modes for, small (<380 mm) diameter pipe

Blowout holes

However, corrosion by itself or in conjunction with internal water pressure can also cause pipe failures. In this case corrosion pitting occurs until the pipe wall has thinned to the point where the water pressure blows out the remaining, very thin pipe wall. This type of corrosion failure may produce a very small hole or a large one, depending on how localized the corrosion process has been and the pressure experienced by the pipe.

Circumferential cracking *Appendix A.3*

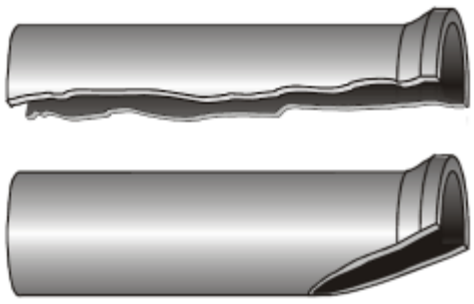
Circumferential cracking is the most common failure mode for small diameter (<380 mm diameter) gray cast iron pipes (*Figure A.2*). Typically this type of failure is caused by bending forces applied to the pipe. The resulting failure occurs in a manner similar to a twig snapping, with the failure crack propagating across the circumference of the pipe. This type of failure may also be caused by soil movements producing tensile forces on the pipe, producing a simple tensile failure.

Bell splitting

This failure mode also appears to be most common in small diameter pipe. Joints in cast iron pipes were originally sealed using rope packed between the bell of one pipe and the spigot of the other. Molten lead was then poured into the joint to complete the seal. This failure mode is different from the longitudinal splitting shown in *Figure A.2* both because of different causes and because the crack terminates just below the bell of the pipe once the stresses produced by the thermal expansion have been relieved.

Longitudinal cracking

Longitudinal cracking appears to be confined to large diameter pipes. This failure mode may be due to internal water pressure, to crushing forces acting on the pipe or possibly to compressive forces acting along the pipe. Any of these loadings could result in a longitudinal crack. Once the crack has initiated, it may travel the length of the pipe. In some instances cracks have formed on opposite sides of the pipe. The end result has been the removal of a section of the top of the pipe, producing a hole that may be as long as the pipe and taking up a third of its circumference.



Left pipe: Longitudinal splitting.

Right pipe: Bell shearing. Corrosion pit failure modes are also common on these pipes.

Figure A.3 : Failure Modes for large (>500 mm) diameter pipe.

Bell shearing

Appendix A.4

Large diameter pipes generally have high a moment of inertia to produce the circumferential failures shown in *Figure A.3*. However, large diameter gray cast iron pipes do fail by having a section of the bell shear off as shown in *Figure A.3*. A possible cause of this failure mode is compressive forces pushing the spigot of a pipe into the bell of the next pipe in the pipeline. However, bending forces are more likely to be the cause of this type of failure. Simple compressive loading would tend to produce a crack that propagates down the length of the pipe, but a bending force would produce the type of shearing shown in the *Figure A.1*. An example of this mode was seen in a 1999 failure of a 500 mm diameter main in Labugama (Transmission main from Labugama to Maligakanda; service reservoir near Neluwattuduwa village).

Spiral cracking

Some medium (380 mm –500 mm) diameter pipes experience a unique failure mode where the crack in the pipe appears to start in a circumferential fashion and then propagates down the length of the pipe in a spiral fashion. This failure mode rarely can be seen in Colombo city distribution. However these types of failure always associate with surging conditions in pumping mains. The appearance of this failure mode also suggests that the failure is produced by a combination of bending forces and internal pressure.

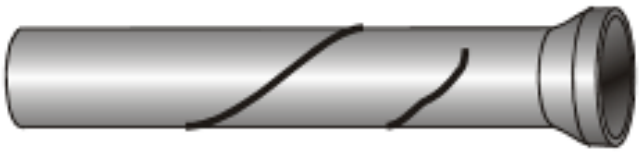


Figure A.4 : Spiral failure mode in mid-diameter (380 mm –500 mm) pipe. Corrosion pitting failures have also been seen in these pipes.

Appendix A.5

Frequency of Live Pipe Line Failure

Distribution pipe leaks are major problem present cast iron pipe network. These leaks can be brought categorized in to two. That is major leaks and service leak. Although generally both type of leaks can be visible or invisible. Therefore types of leaks categorization can be considered comparing water wastage quantity. That means quantity wasted either service line or the distribution line decided type of leaks. However Cast iron distribution main both type of leaks are common. Frequency of the leaks is directly affecting the annual budget of the utility service and Non-revenue water component as well.

With urbanization of Colombo city and some development activities indirectly influence achieve the objective of NWS&DB.

Some identified leaks shown in *Figure A.5*, *Figure A.6* and *Table A.1*.

Major leaks

Figure A.5 – Major leaks

Service leaks *Appendix A.6*

Figure A.6 – Service leak

Table A.1 - Randomly selected major leaks from February 2012 to May 2014 (Only cast iron)

REF NO	ADDRESS	CITY DIV.
24879	NO.430,OLD MOOR STREET	COLOMBO 12
25448	NO.125,GABOON LANE	COLOMBO 11
31538	SAANCHCHIAARAACHCHI WATHTHA	COLOMBO 12
32783	64/158,ST LUSIYA STREET	COLOMBO 13
38444	NEAR S.L.F.P OFFICE,DARLEY ROAD	COLOMBO 10
39418	NO:187,BAUDHALOGA MAWATHA	COLOMBO 03
39495	115,HAVELOCK RD,	COLOMBO 05
41565	NO.538.GALLE. ROAD	COLOMBO 03
41662	538, GALLE RD	COLOMBO 03
42535	538,GALLE ROAD	COLOMBO 03
42561	NO-538,GALLE RD	COLOMBO 03
46162	NO 61/A, FLOWER RD CO 07	COLOMBO 07
48324	NO.20.2in.CROSS. STREET	COLOMBO.11
48411	NO 172 SRIMATHBANDARANAYAKA MW ARMOUR ST.	COLOMBO 13
50642	DUBLICATION ROAD-BAKADALE ROAD,BAMBALAPITIYA	COLOMBO 04
50867	AMAR BOUR JUNCTION	COLOMBO 13
51823	NO-11, NIDAHAS MW	COLOMBO 07

70049	NO-138,SANGAMITHTHA	COLOMBO 13
72907	NO-14,FRANK FORT PLACE	COLOMBO 04
73551	01, ASCOT AVENU,	
73810	P.G MARYIN COMPANY,THIMBIRIGASYAYA HANDIYA	COLOMBO 05
74417	17,BAUDHALOKA MAWATHA,	COLOMBO 04
75689	NO:01 1ST DIVISION MARADANA	COLOMBO 10
75704	no 63 SAMAGIWATHTHA NARAHENPITA	COLOMBO 05
75757	NO.30.ABDUL.JABBAR.MAWATHA	COLOMBO 12
75760	NO.19.SANGAMITTA.MAWATHA	COLOMBO 13
75792	1D,PARK WAY	COLOMBO 05
75802	230,TORINTON AVENUE	COLOMBO 07
75823	18/16,DAABARE MW	COLOMBO 05
75855	161 WATTA, JAMPATA STREET,	COLOMBO 13
75861	GATEWAY COLLEGE, 60, VAJIRA RD,	COLOMBO 04
75886	43/101, PURWARAMA RD, KIRULAPANA	COLOMBO 05
75913	21, 1ST MARADANA	COLOMBO 10
75988	OLD PRIVATE BUS STANDE,GUNASINGHAPURA	COLOMBO 12
76025	212,THIMBIRIGASYAAYA RD	COLOMBO 05
76028	2,C.M.C QUARTERS,PARK LANE	COLOMBO 05
76033	6,HAVELOCK PLACE	COLOMBO 05
76044	NEAR TO 70A,LOARIS RD	COLOMBO 04
76065	NEAR TO85,AMAR STREET	COLOMBO 12
76116	NO-42/16,EVER GREEN PATH RD,DABARE MW	COLOMBO 05
76138	MATERNITY HOME JINTHUPITIYA STREET,	COLOMBO 13
76141	02, KALINGA MW,	COLOMBO 05
76156	04,PARK TERRACE, PARK RD,	COLOMBO 05
76211	22,PALMAIRA AVENUE	COLOMBO 03
76218	NO 411/20/A,GALLE RD CO 04	COLOMBO 04
76357	KALI AMMA KOVILA ASALA,RATHNAM PARA	COLOMBO 13
76387	56/10E.B.D.DAABARE MW	COLOMBO 05
76391	256,MADYAMA PARA,ADURUFFU VEEDIYA	COLOMBO 12
76403	NEAR AMANA BANK, DUPLICATION HANDIYA,	COLOMBO 04
76405	BULAS RD,BOWTHAALOAKA MW HANDIYA	COLOMBO 05
76443	240/1,TOARINGTON AVE	COLOMBO 07
76500	601WATTA.NO.601/10.BLOUMENDHAL.ROAD	COLOMBO.13
76522	NO.142/64/A.KIRIMANDALA.MAWATHA.	COLOMBO.05

76583	NO-37/23,KIRIMANDALA MW, NARAHEPITA	COLOMBO 05
76602	SAKVITHI LANE,THIMBIRIGASYAYA RD	COLOMBO 05
76609	NO:174,MESANGER STREET	COLOMBO.12
76618	HON DINES GUNAWARDANA HOME	COLOMBO 05
76626	NO 135,ESIPATHANA MW HAVELOCK TOWN CO 05	COLOMBO 05
76630	NO 9,HAVELOCK RD COLOMBO 05	COLOMBO 05
76631	NO 9,HAVELOCK RD COLOMBO 05	COLOMBO 05
76679	NO.80.JAWATTA.ROAD	COLOMBO.05
76704	NEAER TO 94/42,KIRULAPPANA MW	COLOMBO 05
76765	05,HAVELOC K RD	COLOMBO 05
76784	NEAR TO 142/3,SAMANALA UYANA,KIRIMANDALA M	COLOMBO 05
76858	NO 440,UNIYAN PLACE CO 02	COLOMBO 02
76959	44,ST.JEMS RD,COCHCHIKADE	COLOMBO 13
77041	NO-23/8,JAYA RD, BAMBALAPITIYA	COLOMBO 04
77099	PRIVATE BUS STAND,SONDERSPLACE,GUNASINGHEPURA	COLOMBO 12
77108	NO-40,HUSANIA ST	COLOMBO 12
77112	NO.43.JAWATTA.ROAD	COLOMBO 05
77243	NEAR THE METANITIHOME,JINTHUPITIYAST	COLOMBO 13
77257	:PANCHIGAWATTHA SIDE(METER-180)	COLOMBO 10
77294	NO.230,TORRINGTON AVENUE	COLOMBO 07
77490	123,BANDARANAIKE MAWATHA	COLOMBO 12
77494	84/38,NAAWALA RD,	COLOMBO 05
77504	43/B,SUMMIT FLAT	COLOMBO 05
77512	NO 177A,NAWALA RD NARAHENPITA	COLOMBO 05
77513	NO 177A,NAWALA RD NARAHENPITA	COLOMBO 05
77541	41/10,MOHANDIRAM DABARE MAWATHA, N'PITA	COLOMBO 05
77611	NEAR THE 83WATTHA,NEW MOOR STREET	COLOMBO 13
77616	IN FRONT OF THE LANKEM ,SANGARAJA MW	COLOMBO 10
77617	NEAR THE WANAWILASHOTEL,MASEENGERST	COLOMBO 12
77619	NEAR THE AMOUR ST POLICE,O-77,AMOUR ST	COLOMBO 12
77650	NO-15,KILDAS PLACE, BAMBALAPITIYA	COLOMBO 04
77663	NEAR TO 19,SEA BEACH LANE	COLOMBO 11
77696	1,SEA BEACH LANE	COLOMBO 11
77768	NO 30/36,STATION RDKIRULAPANA	COLOMBO 05
77814	21/M/100,DHABAREY MAWATHA	COLOMBO 05
77853	12/119,GAJABA RD,MANNINTOUN	COLOMBO 05

77855	62,KIRIMANDALA MAWATHA, SAMAGIWATTHA	COLOMBO 05
77856	62,KIRIMANDALA MAWATHA, SAMAGIWATTHA	COLOMBO 05
77864	63,SAMAGIWATTHA ,NARAHENPITA	COLOMBO 05
77917	NO.51/23/C/06.MOHIDEEN MASJID.ROAD	COLOMBO.10
77924	NO-257/101,ADURUPU VEEDIYA	COLOMBO 13
77949	NO-22/3,SEA BEACH LANE	COLOMBO 11
77981	NO:372,BOWDAHALOGA MAWATHA	COLOMBO 07
78048	NO 42,MESENJER STREET CO 12	COLOMBO 12
78060	35,JAMPATA STREET	COLOMBO 13
78116	ST. KILDAS.LANE.KOLLUPITIYA	COLOMBO.03
78166	58,MASSENJAR STREET	COLOMBO.12
78196	234, NEWMOOR STREET	COLOMBO.12
78200	380/3/1/1, SNGARAJAMAWATAH	COLOMBO 10
78306	133,OLD MOOR STREET	COLOMBO 12
78331	NEAR SHED,SANGARAJA WATARAUMA	COLOMBO 10
78336	NEAR RAILWAY QUATERS,SLAVE ISLAND	COLOMBO 02
78347	257/101,WOLFHANDAL STREET	COLOMBO 12
78352	NO 157/28 WILSON PERERA MW	COLOMBO 14
78484	85/23CENTRAL RDCOLOMBO 12	COLOMBO 12
78493	104/28 SRISANGA RAJA MW COLOMBO 10	COLOMBO 10
78494	104/28 SRISANGA RAJA MW COLOMBO 10	COLOMBO 10
78536	NO.18.QUEEN S TERRACE.BAMABALAPITIYA	COLOMBO 04
78556	NO.7.ADAMALY.PLACE.KOLLUPITIYA	COLOMBO 03
78596	NO.10.ST.KILDAS.ROAD.KOLLUPITIYA	COLOMBO 03
78612	NO.27.HULTSDORF.STREET	COLOMBO 12
78636	NEAR TO 15,ST.KILDAAS RD	COLOMBO 03
78747	15,HILDAS PLACE	COLOMBO 03
78814	SAMAGIPURA HOUSINGS ST JOSHEP STREET	COLOMBO 14
78825	NO.202.SEA.STREET	COLOMBO 11
78834	NO 295 THIBIRIGASYAYA RD	COLOMBO 05
78901	208,HETTI VEEDIYA	COLOMBO 12
78903	NEAR PEOPLESBANK,TECHNICAL HANDIYA	COLOMBO 10
78959	111 WATHTHA ABDULL HAMEED STREET	COLOMBO 12
78993	254,MASSENGER STREET	COLOMBO 12
79203	NEAR TO NINE WELTH HOSPITAL KIRIMANDALA MW	COLOMBO 05
79204	4/97,THALAKOATUWA GARDEN	COLOMBO 05

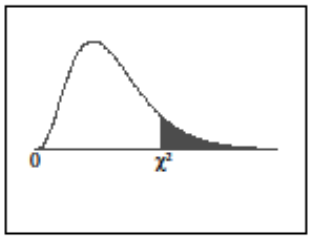
79210	37/27,EVERGREEN PARTHRD,KIRIMANDALA MW	COLOMBO 05
79327	NO.40.HUSSAINIYA.STREET	COLOMBO.12
79403	NO 179,MIRANIYA STREET CO 12	COLOMBO 12
79414	NO.218/01/29.WOLFENDHAL.STREET	COLOMBO.13
79424	NO-54/10,SANCHI ARACHCHI WATHTHA	COLOMBO 12
79478	NEAR THE 111 WATHTHA,MOHIDIN,MASJID RD	COLOMBO 12
79504	NO-125,NEW MOOR ST	COLOMBO 12
79508	NO:125,NEW MOOR STREET	COLOMBO 12
79549	SANGARAJA MAWATHA(NEAR THE:SALIKA HOTEL	COLOMBO 10
79552	NO:212,PARANA JHONE STREET	COLOMBO 12
79601	126/1,DIAS PLACE,	COLOMBO.12
79603	NO:234,SANGARAJA MAWATHA	COLOMBO 10
79788	NO0 218,SEC STREET CO 11	COLOMBO 11
79789	NO-41 WATHTHA,ABDUL HAMEED ST	COLOMBO 12
79814	NO 76,ST.SEBASTHIYAN CO 12	COLOMBO 12
79963	257/11,TOARINGTON MW	COLOMBO 05
79989	NEAR.THE.KURUDUWATTA.POS OFFICE	COLOMBO 07
80041	17, SQUARED PLACE	COLOMBO 03
80051	NO.195/2.GALLE.ROAD.BAMBALAPITIYA	COLOMBO 04
80053	NO.195/2.GALLE.ROAD.BAMBALAPITIYA	COLOMBO 04
80151	87/5/1/1,ABDUL HAMID STREET	COLOMBO 12
80350	184,OLD MOOR STREET	COLOMBO 13
80353	NEAR RAHUMANIYA CHURCH,OLD MOOR STREET,	COLOMBO 13
80481	118,JAMPATA STREET	COLOMBO 13
80566	118,JUMPATAH STREET	COLOMBO 13
80677	NEAR TO 55,ABDULHAMEED STREET	COLOMBO 12
80714	122/A,JUMPATAH STREET	COLOMBO 13
80716	122/A,JINTHUPITIYA VEEDIYA	COLOMBO 13
80856	F/U/3/8,DIAS PLACE,GUNASINHAPURA	COLOMBO 12
80867	NO.94.DIAS.PLCE	COLOMBO 12
80950	BU 1/1,GUNASINGHAPURA HS	COLOMBO 12
80963	95WATTA.ABDL HAMEED.STREET	COLOMBO.12
80997	98,ABDULHAMEED STREET	COLOMBO 12
80998	75 GARDEN,ABDULHAMEED STREET	COLOMBO 12
80999	NEAR TO 111 GARDEN ABDULHAMEED STREET	COLOMBO 12
81013	NO.111/10.ABDUL.HAMEED.STREET	COLOMBO.12

81064	NO 113,JAMPATA STREET CO 13	COLOMBO 13
81119	NO 87/5/1/1 ABD\ULL HAMEED STREET	COLOMBO 12
81159	NO:424,UNION PLACE	COLOMBO 02
81171	57/77,ABDUL HAMEED STREET,	COLOMBO 12
81208	74WATTA,ABDUL HAMEED STREET	COLOMBO 12
81233	44,ST.ANTONEYS MW,	COLOMBO 13
81260	ADAM BOSS PALLIYA PITUPASA,	COLOMBO 11
81287	NEAR ST SEBASTIAN CHURCH, SANGARAJA MAWATHA	COLOMBO 10
81290	83/73, RAMANATHAN FLAT, JUMPETTAH LANE	COLOMBO 12
81302	NEAR B.O.C,BODIRAJA MAWATHA	COLOMBO 11
81343	NEAR TO BOC	COLOMBO 11
81357	111,WATHTHA,ABDULHAMEED STREET	COLOMBO 12
81358	95 WATHTHA,ABDULHAMEED STREET	COLOMBO 12
81360	75 WATHTHA,ABDULHAMEED STREET	COLOMBO 12
81366	95.WATTA.ABDUL.HAMEED.MAWATHA	COLOMBO.12
81368	91.WATTA.NEW.MOOR.STREET	COLOMBO.12
81460	32 WATTA,MARTISLANE	COLOMBO 12
81575	93,NEW MOOR STREET,	COLOMBO 12
81576	NO-111,ALUTH YOHN ST	COLOMBO 12
81587	187,BANDARANAYAKE MW,	COLOMBO 12
81588	157,MIRANIYA STREET,	COLOMBO 12
81694	65/10 ABDULL HAMEED STREET	COLOMBO 12
81701	WATARAUMA ASALA PAHLA PAVEMENT EKA	COLOMBO 12
81869	HABAR QUARTES, ABDUL HAMIED MAWATHA	COLOMBO.12
81870	NEAR TOP 60NEWMOOR STREET	COLOMBO 12
81937	NEAR TO 94,OLD MOOR STREET	COLOMBO 12
82082	NO.194.WATTA.SRI.KADIRESHAN.STREET	COLOMBO 13
82215	NEAR TO 94,OLD MOOR STREET	COLOMBO 12
82248	30,SEBASTHIAN RD	COLOMBO 12
82407	MAWLANA WATHTHA,1ST DIVISION MARADANA	COLOMBO 10
82416	ENTRANCE,14 WATTA,ST SEBASTIYAN MAWATHA	COLOMBO 12
82419	NEAR THE:CEYLON BANK,SRI SANGARAJA MAWATHA	COLOMBO 10
82436	IN FRONT OF THE SEYLANBANK,SANGARAJA MW	COLOMBO 10
82450	243,DAM STREET	COLOMBO 12
82480	257/1,WOLFANDHAL STREET	COLOMBO 12
82486	NO-120,PRINCE OF GATE,	COLOMBO 12

82584	NERA.THE.SEYLAN.BANK.SRI.SANGARAJA.MAWATHA	COLOMBO 10
82617	NEAR.THE.ST.ANTHONYS.CHURCH.ST.ANTHONYS.	COLOMBO 13
82630	248,SEA STREET,	COLOMBO 12
82645	INFRONT OF KOCHCHIKADE PALLIYA	COLOMBO 13
82905	343/A,OLD MOOR STREET	COLOMBO 12
82913	44/80,ST ANTHONYS MAWATHA	COLOMBO 13
82975	NO-111,PRINCE S GATES	COLOMBO 12
83137	03, SCHOOL LANE	COLOMBO 09
83138	201,LAFEER MAWATHA	COLOMBO 12
83139	47,NASER MAWATHA	COLOMBO 12
83142	PHIKARINSRDJONSAN	COLOMBO 12
83186	111WATTA.ABDUL.HAMEED.STREET	COLOMBO 12
83263	NO:111WATTHA ABDUL HAMEED STREET	COLOMBO 12
83323	76/10,KADIRESION VEEDIYA	COLOMBO 12
83372	NO 2/37,SAMANALA UYANAKIRIMANDALA MW NARAHENPITA	COLOMBO 05
83399	NO 138/1 ISIPATHANA MW	COLOMBO 05
83427	76/6, DRAM STREET	COLOMBO 12
83431	151/1,DRAM STREET,	COLOMBO 02
83436	1/2,DRAM STREET,	COLOMBO 12
83439	111/A,NEW MOOR STREET	COLOMBO 12
83442	113, NEW MOOR STREET,	COLOMBO 12
83446	113,1142,NEW MOOR STREET	COLOMBO 12
83514	NEAR TO 124,3RD CROSS STREET	COLOMBO 11
83636	NO:87,UNION PLACE	COLOMBO 02
83700	NO 20,2TH CROSE STREET CO 11	COLOMBO11
83710	NO:55/78,ABDUL HAMEED STREET	COLOMBO 12
83725	NO 47/A,KADIRESHANRD CO 11	COLOMBO 11
83908	52 WATTA,KESELWATTA	COLOMBO 12
83915	52/2,ST SEBASTIAN PARA	COLOMBO 12
83955	NO:52,BLUE MENDEL ROAD	COLOMBO 12
84027	NO-371, R A DE MEL MW	COLOMOB 03
84133	NO 118/1/4,ST.ANTHNISE MW KOCHCHIKADE CO 13	COLOMBO 13
84155	E/7/1, PIYADHARSHANA MAWATHA,	COLOMBO 10
84240	68,WAXHALL STREET	COLOMBO 02
84246	334,TB JAYA MW	COLOMBO 02

84353	234,OLD MOORSTREET	COLOMBO 12
84380	NO 234 OLD MOOR STREET	COLOMBO 12
84389	NO 95 ABDULL HAMEED STREET	COLOMBO 12
84553	95,ABDULHAMID STREET,	COLOMBO 12
84745	NEAR.THE.LANKA. BANKS.BODHIRAJA.MAWATHA	COLOMBO 12
84862	53,MASSENGER STREET	COLOMBO 12
84870	23, PUMALLOGE,CENTERRD	COLOMBO 12
84887	NO.113.2IN.CROSS.STREET	COLOMBO .11
84895	NEAR THE:PAN ASIA BANK,SRI SANGARAJA MAWAT	COLOMBO 10
84912	NO:P/5,LOKET LANE,SRI SANGARAJA MAWATHA	COLOMBO 10
85085	NO 95 ABDULLHAMEED STREET	COLOMBO 12
85275	86/27,ST BENADICT MAWATHA	COLOMBO 13
85340	334/1,BLUEMANDHAL PARA	COLOMBO 13
85421	36,USAVIYA PARA	COLOMBO 12
85472	NEAR THE:BCC COMPANY MEERANIYA STREET	COLOMBO 12
85508	100/18,SRI RAMANADANA MAWATHA,	COLOMBO 13
85594	45,PRICE GATE	COLOMBO 12
85596	195,MIRANIYA VEEDIYA	COLOMBO 12

Chi-Square Distribution Table



The shaded area is equal to α for $\chi^2 = \chi^2_\alpha$.

df	$\chi^2_{.995}$	$\chi^2_{.990}$	$\chi^2_{.975}$	$\chi^2_{.950}$	$\chi^2_{.900}$	$\chi^2_{.100}$	$\chi^2_{.050}$	$\chi^2_{.025}$	$\chi^2_{.010}$	$\chi^2_{.005}$
1	0.000	0.000	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086	16.750
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812	18.548
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475	20.278
8	1.344	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090	21.955
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666	23.589
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209	25.188
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.300
13	3.565	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688	29.819
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000	34.267
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409	35.718
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805	37.156
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191	38.582
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566	39.997
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932	41.401
22	8.643	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289	42.796
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638	44.181
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980	45.559
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314	46.928
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642	48.290
27	11.808	12.879	14.573	16.151	18.114	36.741	40.113	43.195	46.963	49.645
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.993
29	13.121	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588	52.336
30	13.787	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892	53.672
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691	66.766
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154	79.490
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379	91.952
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425	104.215
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329	116.321
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116	128.299
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807	140.169

Appendix C

Schedule of barrel thickness for water pipe of 18/40 iron strength from code of practice ANSI/AWWA C101-77

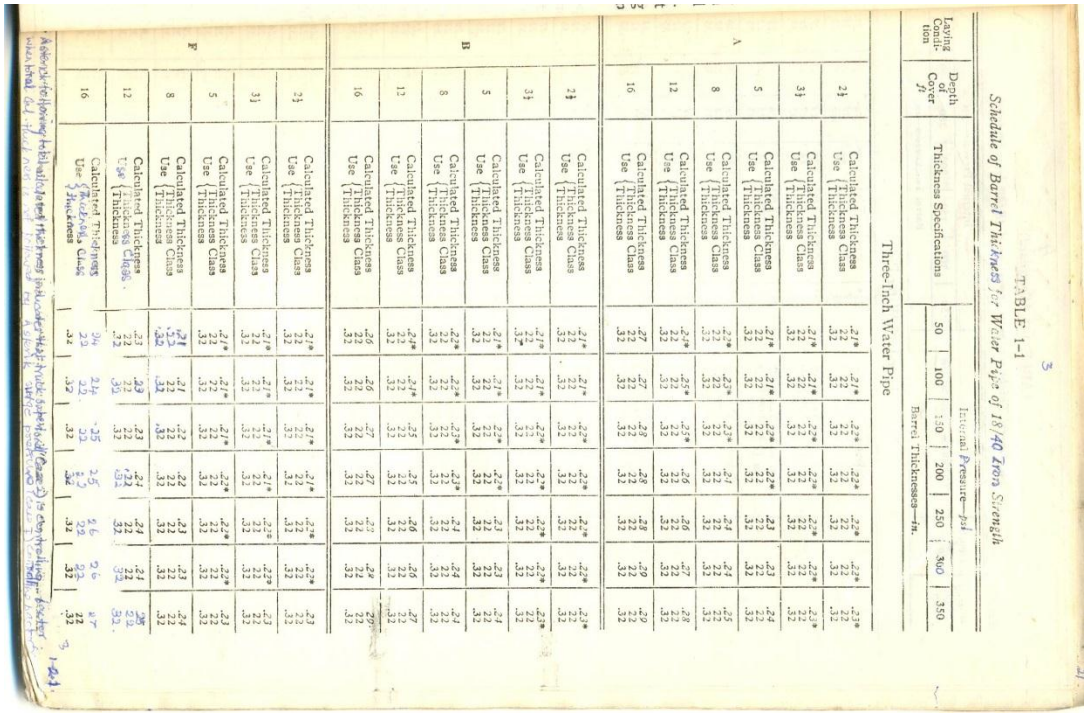


TABLE 1-1

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Three-Inch Water Pipe

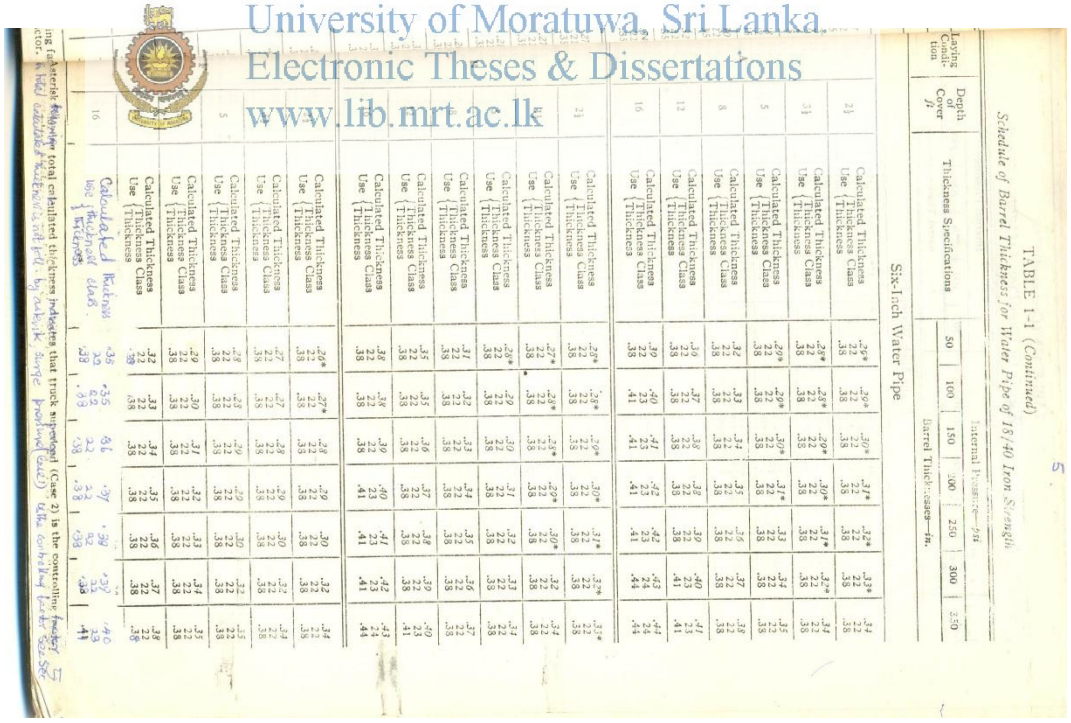


TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Six-Inch Water Pipe

Appendix D

Standard thickness class of cast iron pipes from code of practice ANSI/AWWA C101-77

TABLE 1–7—*Standard Thickness Classes of Cast-Iron Pipe*

(See note on facing page)

Pipe Size in.	Thickness for Standard Thickness Class Number—in.										
	20	21	22	23	24	25	26	27	28	29	30
3			0.32*	0.35	0.38	0.41	0.44	0.48	0.52	0.56	0.60
4			0.35*	0.38	0.41	0.44	0.48	0.52	0.56	0.60	0.65
6		0.35*	0.38	0.41	0.44	0.48	0.52	0.56	0.60	0.65	0.70
8	0.35*	0.38	0.41	0.44	0.48	0.52	0.56	0.60	0.65	0.70	0.76
10	0.38*	0.41	0.44	0.48	0.52	0.56	0.60	0.65	0.70	0.76	0.82
12	0.41*	0.44	0.48	0.52	0.56	0.60	0.65	0.70	0.76	0.82	0.89
14	0.43	0.48*	0.51	0.55	0.59	0.64	0.69	0.75	0.81	0.87	0.94
16	0.46	0.50*	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99
18	0.50	0.54*	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07
20	0.53	0.57*	0.62	0.67	0.72	0.78	0.84	0.91	0.98	1.06	1.14
24	0.58	0.63*	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25
30	0.68*	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46
36	0.75*	0.81	0.87	0.94	1.02	1.10	1.19	1.29	1.39	1.50	1.62
42	0.83*	0.90	0.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79
48	0.91*	0.98	1.06	1.14	1.23	1.33	1.43	1.56	1.68	1.81	1.95

Ring test load equivalents (*w*) of trench loads- lb/linft from code of practice ANSI/AWWA C101-77

TABLE 1–4

Ring Test Load Equivalents (w) *of Trench Loads*—lb/lin ft*

Laying Condition	Pipe Size *in.*	Depth of Cover—*ft*							
		2½	3½	5	8	12	16	20	24
Case 1—Ring Test Load Equivalent of Earth Load (Use With Surge Pressure)									
A	3	396	565	817	1,324	2,000	2,674	3,343	4,026
	4	491	704	1,024	1,663	2,515	3,367	4,222	5,074
	6	672	974	1,428	2,337	3,548	4,756	5,487	5,754
	8	826	1,211	1,791	2,948	4,491	5,635	6,120	6,446
	10	974	1,448	2,157	3,576	5,376	6,198	6,770	7,163
	12	1,111	1,674	2,520	4,239	5,839	6,774	7,433	7,902
	14	1,235	1,887	2,865	4,822	6,304	7,356	8,115	8,659
	16	1,341	2,085	3,196	5,176	6,776	7,954	8,804	9,433
	18	1,446	2,265	3,513	5,506	7,250	8,548	9,509	10,224
	20	1,552	2,433	3,815	5,839	7,728	9,150	10,224	11,033
	24	1,770	2,730	4,372	6,509	8,693	10,378	11,678	12,680
	30	2,093	3,167	5,087	7,520	10,161	12,256	13,915	15,237
	36	2,437	3,626	5,713	8,537	11,643	14,167	16,220	17,882
	42	2,761	4,083	6,341	9,556	13,078	16,104	18,554	20,560
	48	3,102	4,550	6,991	10,580	14,646	18,061	20,928	23,354
	54	3,437	5,022	7,650	11,609	16,161	20,039	23,346	26,161
	60	3,778	5,493	8,313	12,643	17,815	22,028	25,776	28,998
B	3	355	508	734	1,189	1,797	2,402	3,004	3,617
	4	438	628	913	1,483	2,242	3,002	3,764	4,523
	6	585	838	1,224	2,036	3,098	4,111	4,780	5,014
	8	709	1,039	1,537	2,530	3,855	4,836	5,252	5,531
	10	824	1,224	1,823	3,024	4,546	5,244	5,724	6,057
	12	926	1,395	2,100	3,533	4,866	5,645	6,194	6,586
	14	1,007	1,511	2,311	3,933	5,142	6,000	6,618	7,062
	16	1,079	1,677	2,570	4,163	5,449	6,397	7,080	7,586
	18	1,147	1,797	2,786	4,367	5,750	6,779	7,541	8,109
	20	1,214	1,903	2,985	4,568	6,046	7,158	7,998	8,631
	24	1,339	2,066	3,307	4,924	6,577	7,852	8,836	9,593
	30	1,524	2,305	3,703	5,473	7,396	8,921	10,128	11,090
	36	1,709	2,543	4,006	5,986	8,165	9,935	11,373	12,540
	42	1,879	2,778	4,315	6,503	8,899	10,959	12,626	14,015
	48	2,074	3,042	4,674	7,074	9,792	12,076	13,993	15,615
	54	2,259	3,300	5,027	7,629	10,620	13,169	15,342	17,191
	60	2,455	3,569	5,401	8,215	11,575	14,312	16,747	18,841
F	3	261	374	540	875	1,322	1,767	2,210	2,661
	4	323	463	673	1,093	1,653	2,213	2,774	3,334
	6	434	629	923	1,510	2,292	3,073	3,545	3,718
	8	528	774	1,144	1,883	2,869	3,600	3,910	4,118
	10	612	910	1,355	2,247	3,378	3,895	4,254	4,502
	12	691	1,041	1,566	2,635	3,630	4,211	4,620	4,912
	14	755	1,154	1,753	2,949	3,856	4,500	4,964	5,297
	16	812	1,262	1,934	3,133	4,101	4,815	5,329	5,709
	18	861	1,350	2,093	3,281	4,320	5,093	5,666	6,092
	20	915	1,435	2,250	3,444	4,558	5,396	6,029	6,506
	24	1,018	1,570	2,514	3,742	4,999	5,968	6,715	7,291
	30	1,157	1,751	2,812	4,157	5,618	6,776	7,693	8,424
	36	1,310	1,949	3,070	4,588	6,257	7,613	8,716	9,610
	42	1,443	2,134	3,315	4,996	6,837	8,418	9,699	10,766
	48	1,586	2,326	3,573	5,408	7,485	9,231	10,697	11,937
	54	1,726	2,522	3,842	5,830	8,116	10,063	11,724	13,138
	60	1,881	2,735	4,139	6,295	8,869	10,967	12,832	14,436

* A safety factor of 2.5 is included. These ring test load equivalents are based on the earth loads in Table 1–8.

Internal pressure (p)from code of practice ANSI/AWWA C101-77

TABLE 1–5

Internal Pressures (p)*

Pipe Size *in.*	Rated Working Pressure—*psi*							
	10	50	100	150	200	250	300	350
Case 1—Internal Pressure With Surge Pressure Allowances†								
3	—	425	550	675	800	925	1,050	1,175
4	—	425	550	675	800	925	1,050	1,175
6	—	425	550	675	800	925	1,050	1,175
8	—	425	550	675	800	925	1,050	1,175
10	—	425	550	675	800	925	1,050	1,175
12	—	400	525	650	775	900	1,025	1,150
14	—	400	525	650	775	900	1,025	1,150
16	—	375	500	625	750	875	1,000	1,125
18	—	375	500	625	750	875	1,000	1,125
20	—	350	475	600	725	850	975	1,100
24	—	338	463	588	713	838	963	1,088
30	—	325	450	575	700	825	950	1,075
36	—	313	438	563	688	813	938	1,063
42	—	300	425	550	675	800	925	1,050
48	—	300	425	550	675	800	925	1,050
54	—	300	425	550	675	800	925	1,050
60	—	300	425	550	675	800	925	1,050
Case 2—Internal Pressure Without Surge Pressure Allowances								
3–60 all	25	125	250	375	500	625	750	875

* Safety factor of 2.5 included.
† For surge pressure allowances, see Table 1–10.

Appendix G

Nomograms from code of practice ANSI/AWWA C101-77

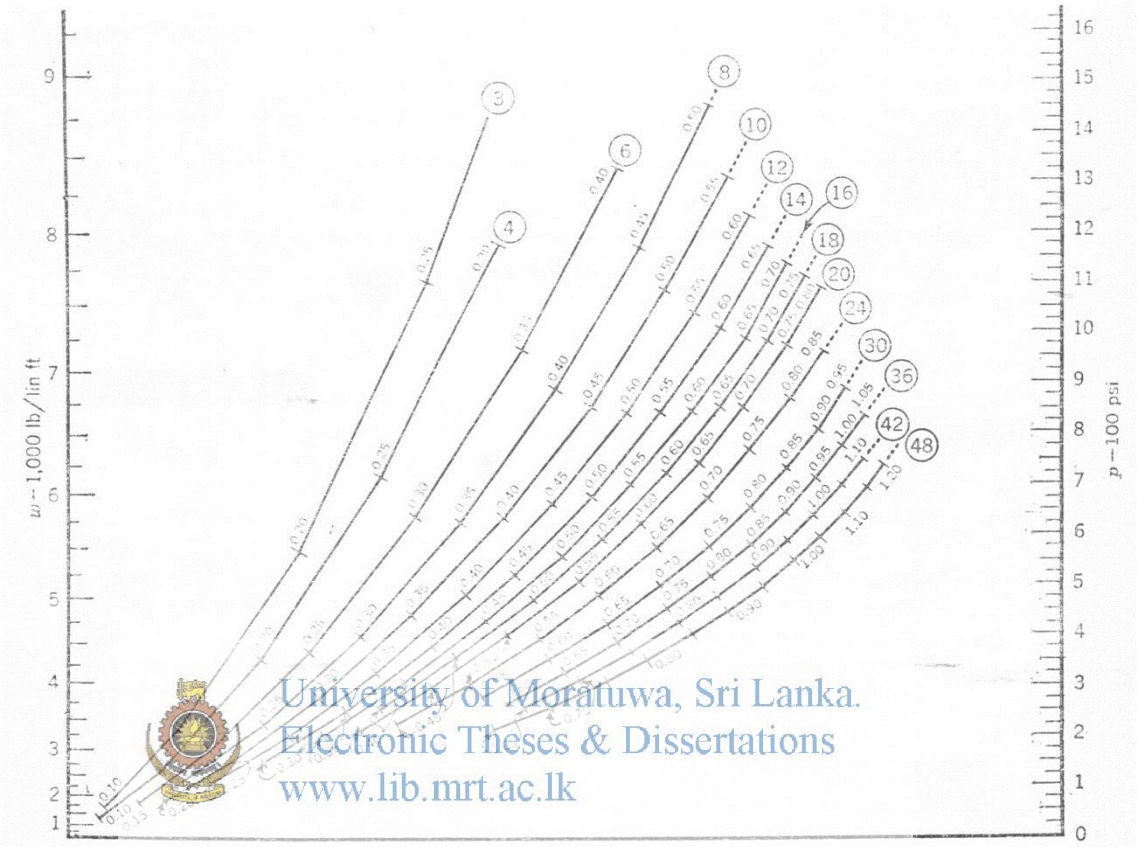


Fig. 1–1. Thickness Nomogram for Pipe of 18/40 Iron Strength, Low-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S equals 18,000, R equals 40,000. The encircled values at the end of each curve are for pipe size in inches.

Appendix H

Observation of pipe line thickness
Observation data sheet 01

Ultrasonic Thickness Gauging Record

Date of Test	:	13-06-2012
Location	:	NWSDB, Maligakanda, Colombo 10 (reservoir site)
Diameter	:	3”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Maligakanda reservoir site
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	7.2	5.2	6.8	7.9	6.775	6.408
Point 2	8.3	9.1	7.5	7.8	8.175	7.733
Point 3	6.5	6.3	5.7	6.9	6.350	6.006
Point 4	6.7	6.8	6.3	4.2	6.000	5.675

* Corrected Ave. = Correction factor X Indicated Average
Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel
= 5600/5920 = 0.9459

Nominal Thickness of pipe: 9.6 mm
Installed year: N/A

Observation data sheet 02

Ultrasonic Thickness Gauging Record

Date of Test	:	18-06-2012
Location	:	NWSDB, Flower road, Colombo 07.
Diameter	:	6”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Flower road.
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	9.3	6.7	8.8	10.2	8.750	8.277
Point 2	10.7	11.6	9.7	10	10.500	9.932
Point 3	10.2	9.1	6.1	7.8	8.300	7.851
Point 4	8.7	8.8	8.1	5.4	7.750	7.331

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 12.4 mm
Installed year: N/A

Appendix H.3

Observation data sheet 03

Ultrasonic Thickness Gauging Record

Date of Test : 10-12-2012
Location : NWSDB, Maligakanda, Colombo 10 (reservoir site)
Diameter : 3”
Project : Analysis of corrosion and remaining thickness of a pipe line
Test Object : selected section of internal distribution line of Maligakanda reservoir site
Material : Grey cast iron (Hard)
Instrument : Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer : Mitech N05/90
Couplant : Ultragel
Technique : Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	5.1	7.1	7.9	6.9	6.750	6.385
Point 2	9.1	7.8	7.6	8	8.125	7.685
Point 3	5.9	6.4	6.2	7	6.375	6.030
Point 4	6.7	6.8	6.4	4.1	6.000	5.675

* Corrected Ave. = Correction factor X Indicated Average
Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 9.6 mm
Installed year: N/A

Observation data sheet 04

Ultrasonic Thickness Gauging Record

Date of Test	:	19-12-2012
Location	:	NWSDB, Flower road, Colombo 07.
Diameter	:	6”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Flower road.
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	6.6	9.2	10.2	8.9	8.725	8.253
Point 2	11.6	10	9.8	10.3	10.425	9.861
Point 3	7.6	8.3	8	9	8.225	7.780
Point 4	9.7	9.2	9.6	7.1	8.900	8.419

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 12.4 mm
Installed year: N/A

Appendix H.5

Observation data sheet 05

Ultrasonic Thickness Gauging Record

Date of Test	:	05-06-2013
Location	:	NWSDB, Flower road, Colombo 07.
Diameter	:	6”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Flower road.
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	6.8	9.7	7.9	9.4	8.450	7.993
Point 2	9.1	11.2	9.9	9.8	10.000	9.459
Point 3	8.1	8.2	10.3	10.2	9.200	8.702
Point 4	8.8	8.5	8.1	5.4	7.700	7.283

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 12.4 mm
Installed year: N/A

Observation data sheet 06

Ultrasonic Thickness Gauging Record

Date of Test	:	18-06-2013
Location	:	NWSDB, Maligakanda, Colombo 10 (reservoir site)
Diameter	:	3”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Maligakanda reservoir site
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	5.3	7.5	6.1	7.3	6.550	6.196
Point 2	8.2	8.7	7.7	7.6	8.050	7.614
Point 3	6.3	5.6	6.4	7.1	6.350	6.006
Point 4	6.8	6.6	6.3	4.2	5.975	5.652

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 9.6 mm
Installed year: N/A

Appendix H.7

Observation data sheet 07

Ultrasonic Thickness Gauging Record

Date of Test : 05-11-2013
Location : NWSDB, Maligakanda, Colombo 10 (reservoir site)
Diameter : 3”
Project : Analysis of corrosion and remaining thickness of a pipe line
Test Object : selected section of internal distribution line of Maligakanda reservoir site
Material : Grey cast iron (Hard)
Instrument : Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer : Mitech N05/90
Couplant : Ultragel
Technique : Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	4.5	6.2	7.6	7.8	6.525	6.172
Point 2	8.2	8.6	7.4	8.1	8.075	7.638
Point 3	6.7	5.9	5.8	6.8	6.300	5.959
Point 4	6.6	6.9	6.2	4.2	5.975	5.652

* Corrected Ave. = Correction factor X Indicated Average
Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel
= 5600/5920 = 0.9459

Nominal Thickness of pipe: 9.6 mm
Installed year: N/A

Appendix H.8

Observation data sheet 08

Ultrasonic Thickness Gauging Record

Date of Test	:	18-11-2013
Location	:	NWSDB, Flower road, Colombo 07.
Diameter	:	6”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Flower road.
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	7.8	8	9.8	10	8.900	8.419
Point 2	10.6	11.1	9.6	10.5	10.450	9.885
Point 3	8.7	7.6	6.5	8.8	7.900	7.473
Point 4	8.5	9.1	8	6.4	8.000	7.567

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 12.4 mm
Installed year: N/A

Appendix H.9

Observation data sheet 09

Ultrasonic Thickness Gauging Record

Date of Test	:	13-02-2014
Location	:	NWSDB, Maligakanda, Colombo 10 (reservoir site)
Diameter	:	3”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Maligakanda reservoir site
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	4.8	6.3	7.8	7.1	6.500	6.148
Point 2	7.4	9.1	7.5	7.8	7.950	7.520
Point 3	6.5	6.3	5.7	6.9	6.350	6.006
Point 4	6.7	6.8	6.3	3.3	5.775	5.463

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 9.6 mm
Installed year: N/A

Appendix H.10

Observation data sheet 10

Ultrasonic Thickness Gauging Record

Date of Test	:	21-02-2014
Location	:	NWSDB, Flower road, Colombo 07.
Diameter	:	6”
Project	:	Analysis of corrosion and remaining thickness of a pipe line
Test Object	:	selected section of internal distribution line of Flower road.
Material	:	Grey cast iron (Hard)
Instrument	:	Mitech – MT 200 Ultrasonic Thickness Gauge
Transducer	:	Mitech N05/90
Couplant	:	Ultragel
Technique	:	Pulse-echo contact method

Ultrasonic thickness measurement results (All measurements are in millimetres)

	Reading A	Reading B	Reading C	Reading D	Average	Corrected Ave. *
Point 1	6.2	8.1	10	9.2	8.375	7.922
Point 2	9.6	11.8	10.7	10	10.525	9.956
Point 3	8.4	9.1	7.4	8.9	8.450	7.993
Point 4	9.7	8.8	8.1	6.3	8.225	7.780

* Corrected Ave. = Correction factor X Indicated Average

Where Correction Factor = Ultrasound velocity in hard cast iron / Ultrasound velocity in steel

= 5600/5920 = 0.9459

Nominal Thickness of pipe: 12.4 mm
Installed year: N/A

Appendix I

Thickness measurement instrument

Observation of thickness of live grey cast iron pipes through Ultrasonic Thickness Gauge

Figure 14 :Mitech – MT 200 Ultrasonic Thickness Gauge Instrument

Appendix J

Measuring thickness of 3” dia live cast iron line

Figure 15 : Measuring thickness of 3” dia Live cast iron line

Appendix K

Observed pressure readings,

Observed Place- Independence Avenue 250 mm

Date & Time	Pressure m	Date & Time	Pressure m
17-06-12 23:00	9.61	18-06-12 11:00	9.09
17-06-12 23:15	9.84	18-06-12 11:15	9.12
17-06-12 23:30	10.14	18-06-12 11:30	9.19
17-06-12 23:45	10.43	18-06-12 11:45	9.22
18-06-12 00:00	10.73	18-06-12 12:00	9.29
18-06-12 00:15	10.99	18-06-12 12:15	9.29
18-06-12 00:30	11.28	18-06-12 12:30	9.19
18-06-12 00:45	11.57	18-06-12 12:45	9.16
18-06-12 01:00	11.84	18-06-12 13:00	9.12
18-06-12 01:15	12.00	18-06-12 13:15	9.09
18-06-12 01:30	12.16	18-06-12 13:30	9.06
18-06-12 01:45	12.46	18-06-12 13:45	9.03
18-06-12 02:00	12.72	18-06-12 14:00	8.90
18-06-12 02:15	12.91	18-06-12 14:15	8.83
18-06-12 02:30	13.11	18-06-12 14:30	8.86
18-06-12 02:45	13.31	18-06-12 14:45	8.83
18-06-12 03:00	13.50	18-06-12 15:00	8.86
18-06-12 03:15	13.66	18-06-12 15:15	8.93
18-06-12 03:30	13.83	18-06-12 15:30	8.99
18-06-12 03:45	13.93	18-06-12 15:45	8.99
18-06-12 04:00	14.09	18-06-12 16:00	8.96
18-06-12 04:15	14.15	18-06-12 16:15	8.86
18-06-12 04:30	14.09	18-06-12 16:30	8.86
18-06-12 04:45	13.96	18-06-12 16:45	8.80
18-06-12 05:00	13.66	18-06-12 17:00	8.63
18-06-12 05:15	13.18	18-06-12 17:15	8.60
18-06-12 05:30	13.08	18-06-12 17:30	8.54
18-06-12 05:45	12.55	18-06-12 17:45	8.54
18-06-12 06:00	11.97	18-06-12 18:00	8.57
18-06-12 06:15	11.28	18-06-12 18:15	8.54
18-06-12 06:30	10.53	18-06-12 18:30	8.57
18-06-12 06:45	10.01	18-06-12 18:45	8.63
18-06-12 07:00	9.58	18-06-12 19:00	8.76
18-06-12 07:15	9.29	18-06-12 19:15	8.86
18-06-12 07:30	9.22	18-06-12 19:30	8.96
18-06-12 07:45	9.12	18-06-12 19:45	9.06
18-06-12 08:00	9.03	18-06-12 20:00	9.12
18-06-12 08:15	8.96	18-06-12 20:15	9.25
18-06-12 08:30	8.86	18-06-12 20:30	9.29
18-06-12 08:45	8.83	18-06-12 20:45	9.29
18-06-12 09:00	8.83	18-06-12 21:00	9.39
18-06-12 09:15	8.80	18-06-12 21:15	9.19
18-06-12 09:30	8.76	18-06-12 21:30	8.83
18-06-12 09:45	8.86	18-06-12 21:45	8.73
18-06-12 10:00	8.90	18-06-12 22:00	8.86
18-06-12 10:15	8.86	18-06-12 22:15	8.96
18-06-12 10:30	8.90	18-06-12 22:30	9.16

Appendix K.2

Observed Place- Thurstan Road 250 mm

Date & Time	Pressure m	Date & Time	Pressure m
18-12-12 11:30	10.037	18-12-12 23:30	11.219
18-12-12 11:45	9.969	18-12-12 23:45	11.489
18-12-12 12:00	10.037	19-12-12 00:00	11.793
18-12-12 12:15	10.037	19-12-12 00:15	12.063
18-12-12 12:30	10.003	19-12-12 00:30	12.333
18-12-12 12:45	9.936	19-12-12 00:45	12.704
18-12-12 13:00	10.003	19-12-12 01:00	12.941
18-12-12 13:15	10.037	19-12-12 01:15	13.177
18-12-12 13:30	10.172	19-12-12 01:30	13.481
18-12-12 13:45	10.172	19-12-12 01:45	13.751
18-12-12 14:00	10.104	19-12-12 02:00	13.919
18-12-12 14:15	10.037	19-12-12 02:15	14.122
18-12-12 14:30	9.902	19-12-12 02:30	14.291
18-12-12 14:45	10.037	19-12-12 02:45	14.493
18-12-12 15:00	10.104	19-12-12 03:00	14.628
18-12-12 15:15	10.138	19-12-12 03:15	14.696
18-12-12 15:30	10.206	19-12-12 03:30	14.831
18-12-12 15:45	10.206	19-12-12 03:45	14.898
18-12-12 16:00	10.071	19-12-12 04:00	14.966
18-12-12 16:15	9.969	19-12-12 04:15	14.966
18-12-12 16:30	9.902	19-12-12 04:30	14.831
18-12-12 16:45	9.834	19-12-12 04:45	14.729
18-12-12 17:00	9.733	19-12-12 05:00	14.561
18-12-12 17:15	9.53	19-12-12 05:15	14.054
18-12-12 17:30	9.598	19-12-12 05:30	13.413
18-12-12 17:45	9.53	19-12-12 05:45	12.772
18-12-12 18:00	9.53	19-12-12 06:00	12.502
18-12-12 18:15	9.463	19-12-12 06:15	12.029
18-12-12 18:30	9.463	19-12-12 06:30	11.286
18-12-12 18:45	9.564	19-12-12 06:45	10.678
18-12-12 19:00	9.699	19-12-12 07:00	10.442
18-12-12 19:15	9.868	19-12-12 07:15	10.172
18-12-12 19:30	9.902	19-12-12 07:30	9.936
18-12-12 19:45	10.037	19-12-12 07:45	9.8
18-12-12 20:00	10.104	19-12-12 08:00	9.733
18-12-12 20:15	10.273	19-12-12 08:15	9.632
18-12-12 20:30	10.375	19-12-12 08:30	9.598
18-12-12 20:45	10.341	19-12-12 08:45	9.53
18-12-12 21:00	10.408	19-12-12 09:00	9.53
18-12-12 21:15	10.138	19-12-12 09:15	9.497
18-12-12 21:30	9.969	19-12-12 09:30	9.53
18-12-12 21:45	9.902	19-12-12 09:45	9.564
18-12-12 22:00	10.037	19-12-12 10:00	9.564
18-12-12 22:15	10.206	19-12-12 10:15	9.699
18-12-12 22:30	10.341	19-12-12 10:30	9.733
18-12-12 22:45	10.543	19-12-12 10:45	9.699
18-12-12 23:00	10.78	19-12-12 11:00	9.699
18-12-12 23:15	10.982	19-12-12 11:15	9.699

Observed Place- CWW Kanangara MW 450 mm *Appendix K.3*

Date & Time	Pressure m	Date & Time	Pressure m
04-06-13 20:45	12.30	05-06-13 08:45	10.75
04-06-13 21:00	12.40	05-06-13 09:00	10.68
04-06-13 21:15	12.00	05-06-13 09:15	10.61
04-06-13 21:30	12.00	05-06-13 09:30	10.65
04-06-13 21:45	12.06	05-06-13 09:45	10.71
04-06-13 22:00	12.30	05-06-13 10:00	10.78
04-06-13 22:15	12.40	05-06-13 10:15	10.85
04-06-13 22:30	12.54	05-06-13 10:30	10.95
04-06-13 22:45	12.84	05-06-13 10:45	10.92
04-06-13 23:00	13.04	05-06-13 11:00	10.88
04-06-13 23:15	13.35	05-06-13 11:15	10.81
04-06-13 23:30	13.62	05-06-13 11:30	10.95
04-06-13 23:45	13.89	05-06-13 11:45	10.95
05-06-13 00:00	14.19	05-06-13 12:00	10.95
05-06-13 00:15	14.49	05-06-13 12:15	10.98
05-06-13 00:30	14.66	05-06-13 12:30	10.92
05-06-13 00:45	14.90	05-06-13 12:45	10.88
05-06-13 01:00	15.13	05-06-13 13:00	10.95
05-06-13 01:15	15.34	05-06-13 13:15	10.92
05-06-13 01:30	15.51	05-06-13 13:30	11.05
05-06-13 01:45	15.74	05-06-13 13:45	11.15
05-06-13 02:00	15.91	05-06-13 14:00	11.22
05-06-13 02:15	16.08	05-06-13 14:15	11.19
05-06-13 02:30	16.18	05-06-13 14:30	11.25
05-06-13 02:45	16.23	05-06-13 14:45	11.35
05-06-13 03:00	16.32	05-06-13 15:00	11.35
05-06-13 03:15	16.45	05-06-13 15:15	11.35
05-06-13 03:30	16.52	05-06-13 15:30	11.39
05-06-13 03:45	16.69	05-06-13 15:45	11.42
05-06-13 04:00	16.65	05-06-13 16:00	11.29
05-06-13 04:15	16.55	05-06-13 16:15	11.19
05-06-13 04:30	16.45	05-06-13 16:30	11.08
05-06-13 04:45	16.38	05-06-13 16:45	11.12
05-06-13 05:00	16.08	05-06-13 17:00	11.05
05-06-13 05:15	15.47	05-06-13 17:15	10.95
05-06-13 05:30	14.97	05-06-13 17:30	10.95
05-06-13 05:45	14.86	05-06-13 17:45	11.05
05-06-13 06:00	14.46	05-06-13 18:00	11.05
05-06-13 06:15	13.78	05-06-13 18:15	10.98
05-06-13 06:30	13.01	05-06-13 18:30	11.02
05-06-13 06:45	12.40	05-06-13 18:45	11.19
05-06-13 07:00	12.00	05-06-13 19:00	11.35
05-06-13 07:15	11.86	05-06-13 19:15	11.52
05-06-13 07:30	11.66	05-06-13 19:30	11.56
05-06-13 07:45	11.56	05-06-13 19:45	11.59
05-06-13 08:00	11.56	05-06-13 20:00	11.66
05-06-13 08:15	11.35	05-06-13 20:15	11.86
05-06-13 08:30	11.02	05-06-13 20:30	11.93

Appendix K.4

Observed Place- Dharmapala MW 250 mm

Date & Time	Pressure m	Date & Time	Pressure m
07-11-13 21:15	9.091	08-11-13 09:15	8.416
07-11-13 21:30	8.922	08-11-13 09:30	8.382
07-11-13 21:45	9.091	08-11-13 09:45	8.483
07-11-13 22:00	9.193	08-11-13 10:00	8.449
07-11-13 22:15	9.395	08-11-13 10:15	8.517
07-11-13 22:30	9.699	08-11-13 10:30	8.416
07-11-13 22:45	10.003	08-11-13 10:45	8.517
07-11-13 23:00	10.273	08-11-13 11:00	8.517
07-11-13 23:15	10.51	08-11-13 11:15	8.618
07-11-13 23:30	10.847	08-11-13 11:30	8.821
07-11-13 23:45	11.117	08-11-13 11:45	8.855
08-11-13 00:00	11.32	08-11-13 12:00	8.956
08-11-13 00:15	11.455	08-11-13 12:15	8.855
08-11-13 00:30	11.725	08-11-13 12:30	8.753
08-11-13 00:45	12.13	08-11-13 12:45	8.787
08-11-13 01:00	12.333	08-11-13 13:00	8.787
08-11-13 01:15	12.603	08-11-13 13:15	8.821
08-11-13 01:30	13.008	08-11-13 13:30	8.821
08-11-13 01:45	13.413	08-11-13 13:45	8.72
08-11-13 02:00	13.649	08-11-13 14:00	8.551
08-11-13 02:15	13.886	08-11-13 14:15	8.618
08-11-13 02:30	13.987	08-11-13 14:30	8.585
08-11-13 02:45	14.156	08-11-13 14:45	8.416
08-11-13 03:00	14.358	08-11-13 15:00	8.483
08-11-13 03:15	14.459	08-11-13 15:15	8.517
08-11-13 03:30	14.561	08-11-13 15:30	8.618
08-11-13 03:45	14.628	08-11-13 15:45	8.686
08-11-13 04:00	14.729	08-11-13 16:00	8.618
08-11-13 04:15	14.729	08-11-13 16:15	8.281
08-11-13 04:30	14.696	08-11-13 16:30	8.281
08-11-13 04:45	14.392	08-11-13 16:45	8.449
08-11-13 05:00	13.919	08-11-13 17:00	8.314
08-11-13 05:15	13.413	08-11-13 17:15	8.314
08-11-13 05:30	13.346	08-11-13 17:30	8.314
08-11-13 05:45	12.839	08-11-13 17:45	8.247
08-11-13 06:00	12.434	08-11-13 18:00	8.281
08-11-13 06:15	11.759	08-11-13 18:15	8.314
08-11-13 06:30	11.084	08-11-13 18:30	8.416
08-11-13 06:45	10.611	08-11-13 18:45	8.517
08-11-13 07:00	10.206	08-11-13 19:00	8.551
08-11-13 07:15	9.665	08-11-13 19:15	8.787
08-11-13 07:30	9.226	08-11-13 19:30	8.787
08-11-13 07:45	9.125	08-11-13 19:45	8.956
08-11-13 08:00	9.057	08-11-13 20:00	9.024
08-11-13 08:15	8.99	08-11-13 20:15	9.091
08-11-13 08:30	8.889	08-11-13 20:45	9.26
08-11-13 08:45	8.686	08-11-13 21:00	9.395
08-11-13 09:00	8.483	08-11-13 21:15	9.294

Observed Place- Layardsbroadway 200 mm *Appendix K.5*

Date & Time	Pressure m	Date & Time	Pressure m
29-01-14 15:00	30.102	30-01-14 03:00	36.531
29-01-14 15:15	31.617	30-01-14 03:15	36.565
29-01-14 15:30	30.978	30-01-14 03:30	41.442
29-01-14 15:45	31.483	30-01-14 03:45	48.6
29-01-14 16:00	28.081	30-01-14 04:00	48.365
29-01-14 16:15	14.021	30-01-14 04:15	19.891
29-01-14 16:30	13.886	30-01-14 04:30	19.756
29-01-14 16:45	13.987	30-01-14 04:45	19.453
29-01-14 17:00	14.021	30-01-14 05:00	19.115
29-01-14 17:15	13.751	30-01-14 05:15	18.643
29-01-14 17:30	13.616	30-01-14 05:30	17.867
29-01-14 17:45	13.447	30-01-14 05:45	17.125
29-01-14 18:00	13.143	30-01-14 06:00	16.18
29-01-14 18:15	13.751	30-01-14 06:15	20.228
29-01-14 18:30	14.392	30-01-14 06:30	34.108
29-01-14 18:45	14.392	30-01-14 06:45	33.402
29-01-14 19:00	14.291	30-01-14 07:00	32.728
29-01-14 19:15	14.594	30-01-14 07:15	32.122
29-01-14 19:30	14.729	30-01-14 07:30	31.988
29-01-14 19:45	14.696	30-01-14 07:45	33.705
29-01-14 20:00	14.898	30-01-14 08:00	31.651
29-01-14 20:15	14.189	30-01-14 08:15	31.685
29-01-14 20:30	14.088	30-01-14 08:30	31.954
29-01-14 20:45	13.919	30-01-14 08:45	31.887
29-01-14 21:00	14.257	30-01-14 09:00	32.021
29-01-14 21:15	13.919	30-01-14 09:15	29.53
29-01-14 21:30	13.886	30-01-14 09:30	29.462
29-01-14 21:45	13.953	30-01-14 09:45	29.361
29-01-14 22:00	14.223	30-01-14 10:00	29.698
29-01-14 22:15	31.718	30-01-14 10:15	29.226
29-01-14 22:30	33.301	30-01-14 10:30	23.97
29-01-14 22:45	33.267	30-01-14 10:45	13.211
29-01-14 23:00	34.007	30-01-14 11:00	13.211
29-01-14 23:15	34.344	30-01-14 11:15	17.328
29-01-14 23:30	34.512	30-01-14 11:30	30.641
29-01-14 23:45	34.782	30-01-14 11:45	30.641
30-01-14 00:00	35.017	30-01-14 12:00	30.776
30-01-14 00:15	35.286	30-01-14 12:15	30.506
30-01-14 00:30	35.455	30-01-14 12:30	31.449
30-01-14 00:45	35.724	30-01-14 12:45	30.439
30-01-14 01:00	35.892	30-01-14 13:00	30.641
30-01-14 01:15	35.926	30-01-14 13:15	29.866
30-01-14 01:30	36.027	30-01-14 13:30	29.765
30-01-14 01:45	36.094	30-01-14 13:45	30.607
30-01-14 02:00	36.262	30-01-14 14:00	30.742
30-01-14 02:15	36.329	30-01-14 14:15	30.675
30-01-14 02:30	36.296	30-01-14 14:30	30.607
30-01-14 02:45	36.363	30-01-14 14:45	6.085

Appendix K.6

Observed Place- Regal Cinema 300 mm

Date & Time	Pressure m	Date & Time	Pressure m
21-02-14 12:45	7.7759	22-02-14 00:45	9.7344
21-02-14 13:00	7.7759	22-02-14 01:00	10.0452
21-02-14 13:15	7.8381	22-02-14 01:15	10.2628
21-02-14 13:30	7.9002	22-02-14 01:30	10.5425
21-02-14 13:45	7.9935	22-02-14 01:45	10.7601
21-02-14 14:00	7.9002	22-02-14 02:00	10.8844
21-02-14 14:15	7.9624	22-02-14 02:15	11.0087
21-02-14 14:30	7.9002	22-02-14 02:30	11.133
21-02-14 14:45	7.8381	22-02-14 02:45	11.133
21-02-14 15:00	7.9313	22-02-14 03:00	11.102
21-02-14 15:15	7.8692	22-02-14 03:15	11.2884
21-02-14 15:30	7.7448	22-02-14 03:45	11.506
21-02-14 15:45	7.6204	22-02-14 04:00	11.5681
21-02-14 16:00	7.4339	22-02-14 04:15	11.4127
21-02-14 16:15	7.9313	22-02-14 04:30	11.102
21-02-14 16:30	8.0246	22-02-14 04:45	10.9776
21-02-14 16:45	7.9624	22-02-14 05:00	10.7912
21-02-14 17:00	7.8381	22-02-14 05:15	10.4804
21-02-14 17:15	7.6204	22-02-14 05:30	9.9209
21-02-14 17:30	7.4028	22-02-14 05:45	9.4235
21-02-14 17:45	7.2784	22-02-14 06:00	8.9572
21-02-14 18:00	7.4028	22-02-14 06:15	9.579
21-02-14 18:15	7.4339	22-02-14 06:30	9.4235
21-02-14 18:30	7.4339	22-02-14 06:45	9.1127
21-02-14 18:45	7.465	22-02-14 07:00	8.7707
21-02-14 19:00	7.6826	22-02-14 07:15	8.7086
21-02-14 19:15	7.6204	22-02-14 07:30	8.6775
21-02-14 19:30	7.807	22-02-14 07:45	8.6153
21-02-14 19:45	7.8692	22-02-14 08:00	8.2111
21-02-14 20:00	8.1801	22-02-14 08:15	8.2422
21-02-14 20:15	8.2733	22-02-14 08:30	8.2733
21-02-14 20:30	8.5531	22-02-14 08:45	8.0868
21-02-14 20:45	8.4599	22-02-14 09:00	7.7759
21-02-14 21:00	8.4909	22-02-14 09:15	7.7759
21-02-14 21:15	8.3044	22-02-14 09:30	7.8381
21-02-14 21:30	6.812	22-02-14 09:45	7.8381
21-02-14 21:45	6.5633	22-02-14 10:00	8.0868
21-02-14 22:00	6.812	22-02-14 10:15	8.0868
21-02-14 22:15	6.9986	22-02-14 10:30	8.2111
21-02-14 22:30	7.1852	22-02-14 10:45	8.1801
21-02-14 22:45	7.5272	22-02-14 11:00	8.0868
21-02-14 23:00	7.9313	22-02-14 11:15	8.3355
21-02-14 23:15	8.2733	22-02-14 11:30	8.4288
21-02-14 23:30	8.4599	22-02-14 11:45	8.3355
21-02-14 23:45	9.1438	22-02-14 12:00	8.1801
22-02-14 00:00	9.1127	22-02-14 12:15	7.8692
22-02-14 00:15	9.2992	22-02-14 12:30	7.7448
22-02-14 00:30	9.5168	22-02-14 12:45	7.7137

Appendix L

Instrument use to measure the Live pressure of Grey Cast Iron Pipes

(Prime Log 2i logger)

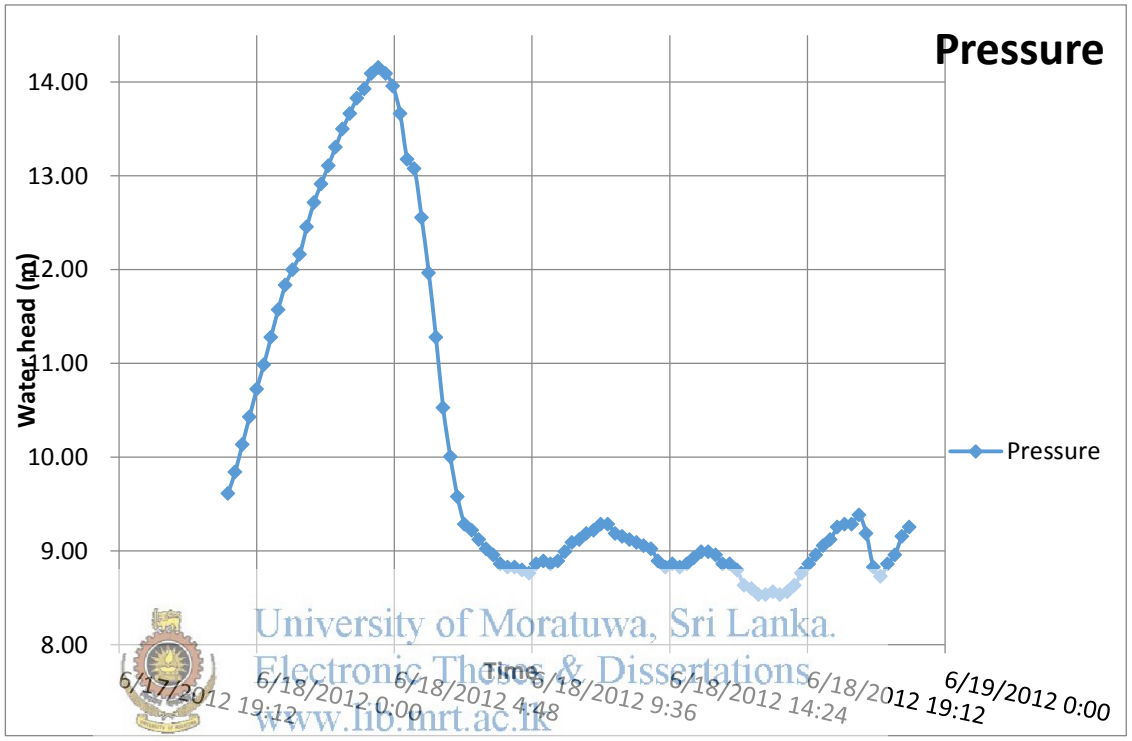
Figure 01 : – Prime Log 2i Pressure logger

Figure 02 : Measuring Pressure of 3" dia Live cast iron line

Appendix M

Graphically presentation of pressure reading with time

Independence Avenue 250 mm

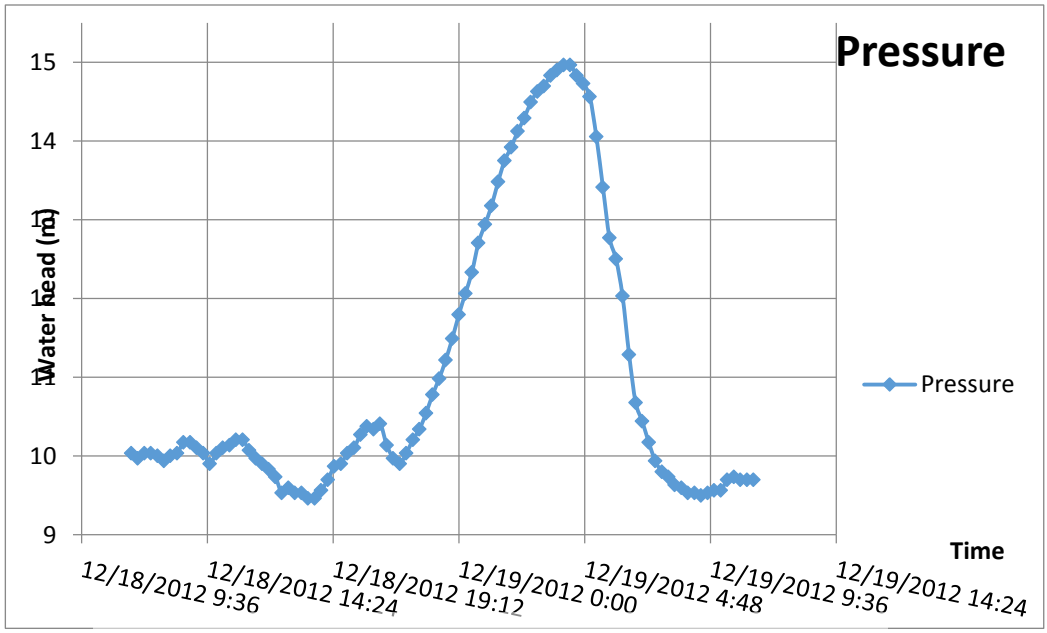


Date & Pressure	Minimum	Maximum	Mean
18-06-12 17:30	8.54		
18-06-12 04:15		14.15	
			10.07

Figure 29 :Live pressure distribution with time Independence avenue 250 mm

Appendix M.2

Thurstan road 250 mm

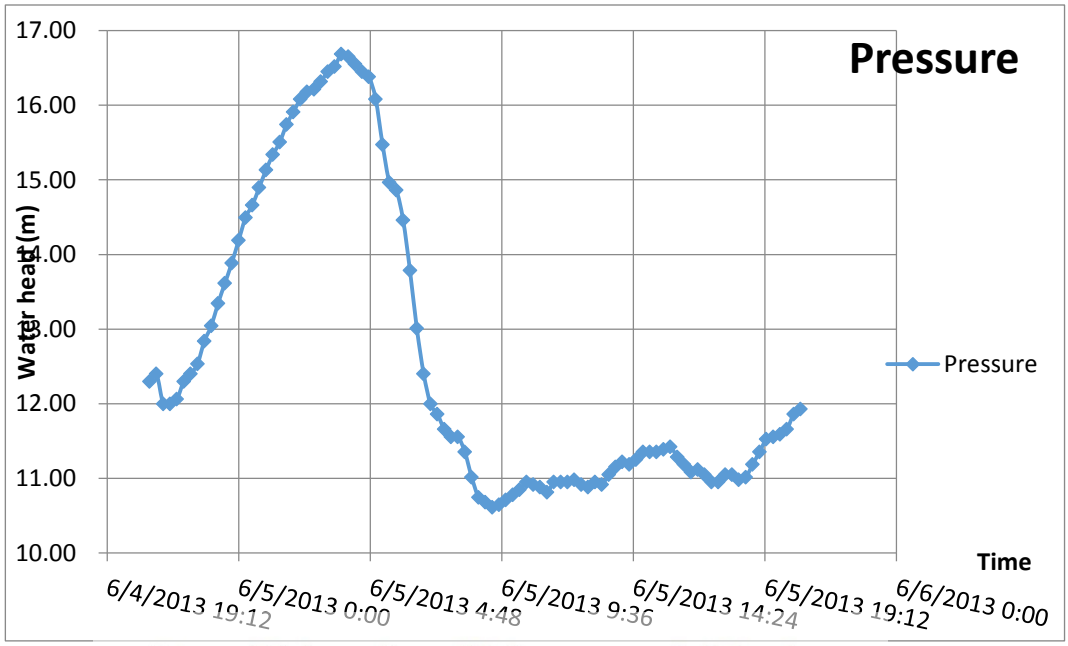


Date & Pressure	Minimum	Maximum	Mean
18-12-12 18:15	9.463		
19-12-12 04:15		14.966	
			11.02

Figure 29 : Live pressure distribution with time Thurstan road 250 mm

4.8.3 Albert crescent 450 mm

Appendix M.3

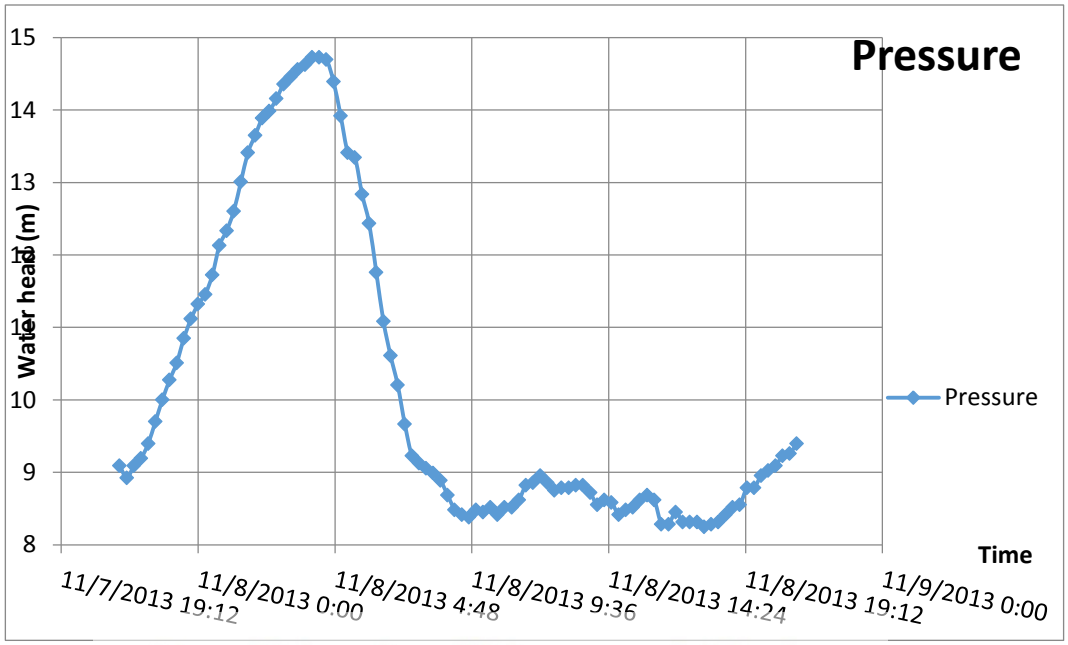


Date & Pressure	Minimum	Maximum	Mean
05-06-13 09:15	10.61		
05-06-13 03:45		16.69	
			12.61

Figure 30 : Live pressure distribution with time Albert crescent 450 mm

Appendix M.4

4.8.4 Dharmapala mawatha 250 mm

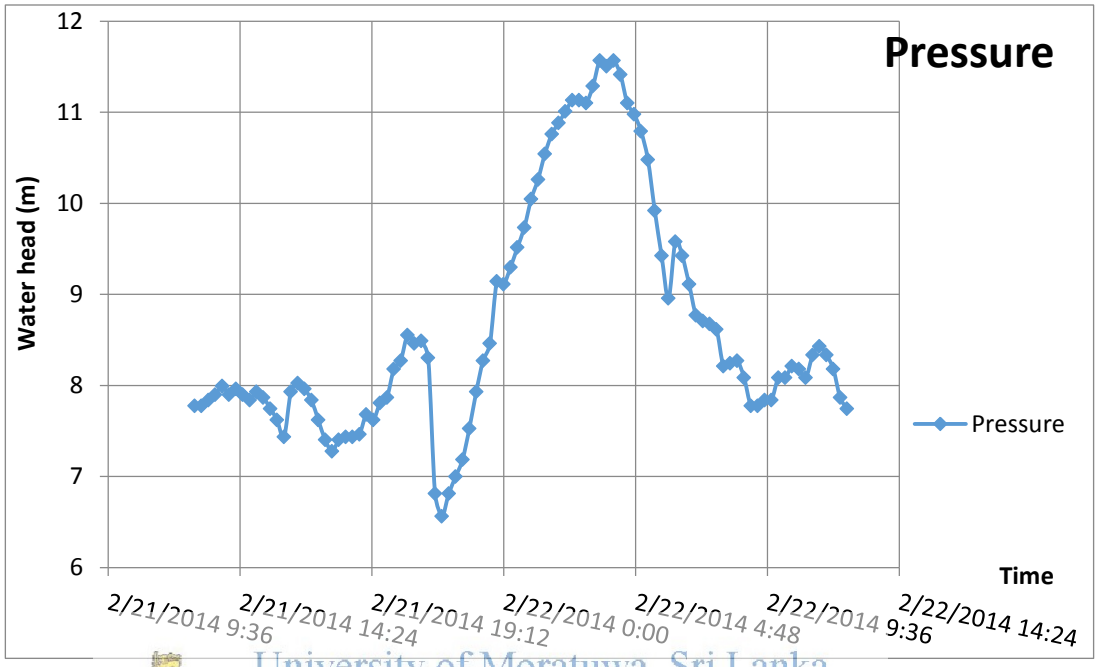


Date & Pressure	Minimum	Maximum	Mean
08-11-13 17:45	8.247		
08-11-13 04:15		14.729	
			10.15

Figure 31 : Live pressure distribution with time Dharmapala Mawatha 250 mm

4.8.5 Regal cinema 300 mm

Appendix M.5



Date & Pressure	Minimum	Maximum	Mean
21-02-14 21:45	6.5633		
22-02-14 04:00		11.5681	
			8.65

Figure 32 : Live pressure distribution with time Regal cinema 300 mm

Appendix N

Colombo city south water distribution system