Health of Ammonia Horton Spheres and Foundations – A Case History

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SYNOPSIS: Liquid Ammonia is stored under pressure in steel Horton spheres (diameter 17 m) under operating pressures of 5-6 kg/cm^2. These spheres are supported on twelve steel columns, concrete pedestals, concrete ring beam and raft or pile foundation depending on the soil conditions. The continuous circular ring beam rests on 72 concrete piles each 45 mm dia and 17 to 20 m long. The second identical Horton sphere is supported on a raft foundation.

The two Horton spheres have been subjected to a hydrostatic loading of 1.7 kg/cm^2 and an additional pressure of 7.3 kg/cm^2 for performance check.

Strains were measured at the crowns, four equatorial points and in six columns. The test results indicate that the spheres and the columns behaved consistent with theoretical values. The concrete in foundations was found to be of good quality corresponding to M20 grade.

The settlements under four columns of the fully loaded actual structure were within anticipated limits i.e. 4-6 mm.

INTRODUCTION

Liquid ammonia required in the production of urea is usually stored under pressure in steel Horton spheres. The operating pressure in these spheres is generally 5 to 6 kg/cm^2 in addition to the liquid head. The safety of these spheres and their foundations is of paramount importance in view of the possible pollution and environmental hazards which may be caused due to the failure of such structures.

The paper reports the actual case record on the performance of the two 17 m diameter spheres and adequacy of foundations when subjected to a loading of 1.7 kg/cm^2 and an additional pressure of 7.3 kg/cm^2. These structures are located in Northern India were commissioned in years 1972 and 1973. These spheres are made of low carbon steel bearing classification No. JIS G 3126 Class 2 SLA 33A and are supported on twelve 570 mm mild steel hollow circular columns, Figure 1. The spheres are reported to have performed satisfactorily so far. However, in view of long time since commissioning and deterioration of shell/concrete due to urea, the assessment of health of sphere was considered essential.

The steel columns are inturn supported by concrete pedestals connected by a ring beam, Figure 2. In one of the spheres, the ring beam was resting on a raft foundation while in the other it rested on 72 concrete piles each 450 mm diameter and 17 to 20 m long.

To assess the health of the Horton spheres strains were measured at the crown, bottom and four equatorial points through suitably pasted electrical resistance gauges. Six of the twelve columns of each sphere were also instrumented for strain measurements. The shell thickness was measured at twelve points to detect the extent of corrosion and also to detect the spread of cracks in welded seams.

The quality of concrete used in the pedestals and ring beam were tested by the ultrasonic pulse technique and Schmidt rebound hammer test. The foundation settlements were also observed at four diametrically opposite columns through suitably mounted dial gauges on independent datums.

FOUNDATIONS

The settlement of the foundations of the Horton spheres was recorded at five equal intervals to achieve a liquid pressure of 1.7 kg/cm^2. The settlements were also recorded when the spheres were pressurised upto 7.3 kg/cm^2 to achieve a total pressure of 9.0 kg/cm^2.

These settlement records are shown in Tables 1 and 2. The settlements were recorded using dial gauges with a least count of 0.01 mm mounted through magnetic bases on independent datums. During the hydro test the load at every stage was maintained constant and the reading recorded when the settlement was complete. The data indicates that the settlements of the four columns were practically equal indicating a uniform settlement of the foundations. The magnitude of settlements was very small and within the permissible limits as specified for water towers and silos (IS:1904-1978). The foundations could thus be considered safe under the stipulated pressure of 9.0 kg/cm^2.

TABLE 1. Settlement Record of Horton Sphere on Piles (Horton Sphere 1)

Sl.No.		Pressure	Col. 1 Dial Read	Col. 1 Sett. (mm)	Col. 4 Dial Read	Col. 4 Sett. (mm)	Col. 7 Dial Read	Col. 7 Sett. (mm)	Col. 10 Dial Read	Col. 10 Sett. (mm)	Av. Sett. (mm)
1		0.00	10.24		18.16		17.42		8.73		
2		0.30	14.18*	-	18.29	0.13	17.36	0.06	8.72	0.01	0.07
3	1/5	0.35	14.26	0.08	18.33	0.17	17.35	0.07	8.72	0.01	0.08
4	2/5	0.68	14.33	0.15	18.45	0.29	17.32	0.10	8.75	0.04	0.15
5	3/5	0.85	14.41	0.23	18.47	0.31	17.32	0.10	8.80	0.09	0.18
6	4/5	1.50	14.43	0.25	18.50	0.34	17.21	0.21	8.81	0.10	0.23
7	5/5	1.70	14.45	0.27	18.54	0.38	17.18	0.24	8.85	0.14	0.26
8		2.25	14.47	0.29	18.57	0.41	17.15	0.27	8.87	0.16	0.28
9		4.00	14.50	0.32	18.57	0.41	17.14	0.28	8.87	0.16	0.29
10		6.00	14.53	0.35	18.58	0.42	17.12	0.30	8.87	0.16	0.31
11		7.65	14.53	0.35	18.59	0.43	17.11	0.31	8.87	0.16	0.31
12		9.00	14.60	0.42	18.62	0.46	17.02	0.40	8.87	0.16	0.36

* Dial reset.

TABLE 2. Load/Pressure-Settlement Record of Horton Sphere on Raft (Horton Sphere 2)

Sl.No.	Pressure: Water head (m)	Pressure: Press. (kg/cm^2)	Col. 1 Dial Read.	Col. 1 Sett. (mm)	Col. 4 Dial Read.	Col. 4 Sett. (mm)	Col. 7 Dial Read.	Col. 7 Sett. (mm)	Col. 10 Dial Read.	Col. 10 Sett. (mm)	Average Sett. (mm)
1	0.00		4.25		19.32		9.19		4.47		
2	2.00	0.20	4.03	0.22	19.24	0.08	9.10	0.09	4.29	0.18	0.1425
3	4.00	0.40	3.79	0.46	19.11	0.21	8.98	0.21	4.07	0.40	0.3200
4	4.50	0.45	3.61	0.64	19.00	0.32	8.92	0.27	3.82	0.65	0.4700
5	5.60	0.56	3.14	1.11	18.76	0.56	8.64	0.55	3.25	1.22	0.8600
	5.30	0.53	3.60*	-	18.10*	-	8.80*	-	3.45*	-	
6	5.60	0.56	3.52	1.11**	18.02	0.56**	8.67	0.55**	3.47	1.22**	0.8600
7	6.00	0.60	3.44	1.19	17.89	0.68	8.69	0.57	3.38	1.31	0.9375
8	7.00	0.70	3.24	1.39	17.76	0.81	8.56	0.70	3.20	1.49	1.0975
9	8.80	0.88	3.04	1.59	17.70	0.87	8.20	1.06	3.00	1.69	1.3025
10	9.10	0.91	3.00	1.63	17.65	0.92	8.13	1.13	2.88	1.81	1.3725
11	10.00	1.00	2.68	1.95	17.53	1.04	8.03	1.23	2.40	2.29	1.6275
12	11.00	1.10	2.28	2.35	17.33	1.24	7.95	1.31	1.80	2.89	1.9475
13	13.60	1.36	1.80	2.83	16.52	2.05	7.15	2.11	0.54	4.15	2.7850
14	14.00	1.40	1.70	2.93	16.45	2.12	7.08	2.18	0.42	4.27	2.8750
15	15.00	1.50	1.50	3.13	16.29	2.28	6.95	2.31	0.16	4.53	3.0625
16	16.00	1.60	1.35	3.28	16.20	2.37	6.86	2.40	0.04	4.65	3.1750
17	17.00	1.70	1.30	3.33	16.15	2.42	6.76	2.48	0.02	4.67	3.2250
	17.00	1.70	1.13*	-	16.25*	-	6.98*	-	24.98*	-	
18		2.10	1.15	3.35	15.90	2.77	6.70	2.76	24.83	4.82	3.4250
19		4.00	1.35	3.55	16.00	2.87	6.88	2.78	25.00	4.89	3.5225
20		6.00	1.56	3.76	16.20	3.07	7.00	2.90	25.20	5.09	3.7050
21		7.70	1.72	3.92	16.40	3.27	7.08	2.98	25.30	5.19	3.8400
22		8.80	1.80	4.00	16.45	3.32	7.15	3.05	25.40	5.29	3.9150

* Dial reset
**Readings adopted from earlier loading.

The grade of concrete normally specified for columns and foundations as per IS:456-1978 is M20 and M15 respectively. In the present case M20 grade concrete had been specified for the pedestals as well as ring beams. The quality of concrete in the pedestals and the ring beams, existing for the past 15 yrs, were expected to suffer a strength loss due to urea containmination through air and seepage water. Therefore, non-destructive testing of concrete pedestals and ring beams were carried out. The rebound hammer observations were taken at 2100 points at various positions on the columns and the ring beams of each sphere. The quality of concrete was found to be very good and higher than M20 barring local variations at a few points. The ultrasonic observations were recorded at 50 points and most of the values were found to be more than 3250 m/sec, indicating that the quality of the concrete existing in the foundations was good.

HORTON SPHERES

The Horton spheres are made of low carbon steel as they are required to contain liquid ammonia at a temperature of 3 to 5°C. To obtain this temperature condition the spheres are heavily insulated with an approximately 75 mm thick thermocole layer, aluminium foil and tin sheets. To study the health and behaviour of the spheres during the hydro test, strain gauges were pasted at the crowns and four equatorial points after cutting pockets in the insulation at the desired locations. At each point the meridional and circumferential strains were measured for the two spheres and are given in Tables 3 and 4. A study of these results shows that the strains developed at all stages of hydrostatic loading at all the twelve points were much lower than the yield strain of the material and correspond to a stress of 1125 N/mm^2. The strains at the four equatorial points were almost equal indicating symmetrical deformation of the spheres. The theoretical computations of the strains at the twelve locations were found to be in close agreement.

TABLE 3. Measured Strains for Horton Sphere-1 Under Hydrostatic Loading

Sl. No.	Differential Pressure	Pressure at Bottom Crown (kg/cm^2)	Temperature (°C)	Date/ Time	Strain in microns: Meridional, Top EW	Meridional, Top NS	Meridional, Bottom EW	Meridional, Bottom NS	Meridional, Equator N	Meridional, Equator S	Meridional, Equator E	Meridional, Equator W	Circumferential at equator N	Circumferential at equator S	Circumferential at equator E	Circumferential at equator W
1	0.0	0.0	27	27.5.87 12.30	0	0	0	0	0	0	0	0	0	0	0	0
2	0.4	0.68	25	27.5.87 14.30	138	112	116	116	94	96	89	87	93	105	102	106
3	0.5	0.85	25	27.5.87 17.00	201	203	202	209	107	109	99	108	98	97	102	98
4	0.6	1.087	25	27.5.87 19.00	209	210	295	296	110	113	104	114	107	107	108	107
5	0.8	1.500	25	27.5.87 21.10	229	234	302	303	124	123	117	113	113	124	127	123
6	0.8	1.500	25	27.5.87 23.50	230	235	392	393	165	163	-	153	153	-	-	-
7	1.0	1.700	25	28.5.87 09.30	241	242	405	406	184	187	192	175	176	177	174	178
8	1.0	4.00	25	28.5.87 10.00	302	304	706	707	294	305	307	316	299	296	293	296
9	1.0	6.00	25	28.5.87 10.15	571	572	983	984	402	401	487	401	405	401	400	411
10	1.0	7.65	25	28.5.87 10.30	795	789	1109	1108	517	528	530	538	515	518	517	508
11	1.0	9.00	25	28.5.87 11.00	892	890	1409	1410	609	619	609	619	611	609	607	609
12	1.0	9.00	25	28.5.87 12.00	901	896	1410	1410	608	619	612	620	617	611	615	610

The original thickness of the spherical shells provided ranged from 28 to 32 mm inclusive of a 3 mm corrosion allowance. Since the exterior surfaces of the spheres are epoxy painted no incidence of corrosion is normally expected. Also, as long as the sphere is loaded with ammonia, the oxygen and moisture have no access to the internal surface, minimising the chances of corrosion. Thickness measurements of the spherical shells were taken at twelve locations in May 1987. These thickness values ranged from 32.08 to 33.36 mm indicating the absence of significant corrosion. An inspection of the welded seams of the Horton sphere shells was also undertaken and the spread of cracks in the welds were observed at thirteen locations. Only at one point a prominant crack was observed which was eliminated by grinding the joint by 3.5 mm.

CONCLUSIONS

The future performance of the Horton spheres depends on the extent of corrosion and efficiency of the welded joints. The concrete in the foundations was found to be uneffected by the environmental pollution and to be in accordance with the design specification even after a lapse of 15 years. The design of foundations was found to be adequate and the settlements were found to be small, uniform and within permissible limits.

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TABLE 4. Measured Strains for Horton Sphere-2 Under Hydrostatic Loading

Sl. No.	Differential Pressure	Pressure at Bottom Crown (kg/cm^2)	Date/ Time	Strain in Microns: Meridional, Top EW	Top NS	Bottom EW	Bottom NS	Equator N	Equator S	Equator E	Equator W	Circumferential at Equator N	S	E	W
1	0.0	0.00	19.6.87 / 2030	0	0	0	0	0	0	0	0	0	0	0	0
2	0.2	0.34	2215	75	72	74	78	44	46	47	46	49	55	56	53
3	0.4	0.68	20.6.87 / 0010	140	113	118	118	96	98	92	93	95	107	103	108
4	0.6	1.087	0325	212	211	290	292	112	115	108	115	110	110	111	109
5	0.88	1.55	1600	235	240	397	395	170	167	162	157	157	153	159	160
6	1.0	1.70	1800	245	246	407	410	189	190	194	179	179	180	177	181
7	1.0	2.00	21.6.87 / 0200	267	263	498	500	212	210	199	215	197	190	191	199
8	1.0	4.10	0215	305	307	715	717	297	309	312	319	307	303	300	305
9	1.0	6.00	0225	577	579	992	995	407	406	490	450	410	406	406	417
10	1.0	7.70	0235	802	795	1115	1113	520	525	530	540	519	520	522	514
11	1.0	8.80	0315	900	894	1405	1405	608	609	610	612	611	618	620	615

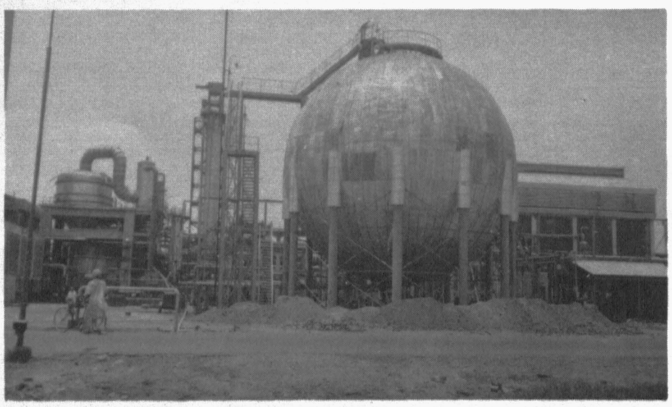

Fig. 1 - HORTON SPHERE

Fig. 2 - CONCRETE COLUMNS AND RING BEAM

pp. 433-44.

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