Sudbury Neutrino Observatory
Cavity Floor Bolt Seal Tests & Results

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SNO Report STR-97-026
August 12, 1997

Introduction

A butyl rubber gasket and stainless steel seat have been designed for anchor bolts for tie down cables for the photomultiplier support sphere. Stainless steel eyebolts will be installed with grout in holes drilled into the floor concrete of the SNO cavity. In this report, tests of the water sealing properties of the gasket against a polyurethane (Urylon 201-25) coating similar to that installed on the cavity floor are summarized. The effectiveness of several gasket sealing compounds as secondary water seals are also evaluated. A pull test for a grouted bolt in concrete is also reported. In general, the current design is found to be satisfactory for interior water pressures up to 60 psi, and optimum torque and sealing compounds are recommended. Displacements occurring during a 4400 lb pull test are found to be small compared with the gasket compression, so that water sealing is not compromised for this upper load value.

Seal Design

A cross-section of the gasket, gasket seat and bolt design is shown in Figure 1. In the floor anchor bolts, stainless steel bolts with smooth finishes near the gasket, a threaded section above for seal compression and a cable eye on top, will be used. In the tests outlined below, a 6-layer Urylon 201-25 polyurethane disk (0.20 inches thick) supported by a 0.25 inch steel disk, is used against the flat side of the butyl gasket.

Compression and Torque Tests

The seating properties of the butyl rubber gasket were investigated by measuring the amount of compression of the seal assembly as a function of applied torque on the 3/4 inch nut on the top of the assembly. Torques were measured with a calibrated torque wrench (Armstrong Tools # 64-402) - these were rechecked after each thickness measurement. Results for gasket 1 are shown in Figures 2 and 3 and in Tables 1 and 2 in Appendix 1. To establish the loading on the gasket with applied torque, a separate compression test was carried out on the same assembly, using a calibrated engineering press (in the School of Engineering at Laurentian University). Compression results for this test are shown in Figures 3 and 4 and in Table 4 of Appendix 1. Clearly there is a direct correspondence between applied torque and compression load. A linear least squares fit to torque and load values at similar compressions gave the relationship:

$$W = -16.10 + 3.31\,T$$

where W is the compression load (lbs) and T is the applied torque (ft.lb), over the compression range 0 to 0.33 cm and torques up to 100 ft.lb. The greater compressions seen for torques up to 20 ft.lb, are interpreted as indicating an initial seating deformation of the gasket. It appears that torques near 50 ft.lb. give adequate compression of the gasket (about 0.25 cm) and do not excessively deform or `bulge out' the top of the gasket.

Water Pressure Tests

The floor seals must form a waterproof barrier at the polyurethane floor covering for cavity water at a pressure of typically 35 psi (corresponding to a head of 80 feet). A test chamber was constructed of ABS pipe, using a water filter base, so that the gasket assembly could be pressure tested with various torques and sealing compounds. The test configuration is shown in Figure 5. Note that the top steel plate is sealed with a separate rubber gasket (glued to the plastic top of the test chamber. Since there is no sealant at the central bolt - a clearance hole was made in the test chamber top - any leakage of water from the interior of the seal is easily seen at the top of the chamber. Pressure tests were made using normal water pressures available in the Fraser Science Building 5th floor - normally 65 psi but not less than 50 psi. Tests were usually made overnight (minimum of 12 hours). Results of a series of tests on the butyl rubber gasket, mild steel seat and stainless steel bolt assembly are given in Table 3 of Appendix 1. They show no evidence of leakage for all torques at or above 15 ft.lbs. Torques less than this amount gave unreliable sealing for the bare gasket-seat configuration.

Several gasket sealing compounds were investigated as secondary water seals (should the applied torque be reduced e.g. through a shift of position of the grouted bolt). Three compounds made by Loctite Canada Incorporated, were investigated. Sealant was applied between the rubber gasket and the upper steel seat, between the gasket and the polyurethane disk and on the interior hole surface of the gasket. The bolt seal was assembled, torqued to 25 ft.lb. and allowed to dry for 24 hours. Tests at several torques (from 25 ft.lb. to 0) were then carried out, each for 24 hour periods The first of these was a gasket forming silicone compound (Permatex Ultra Blue 77C) which did not bond well to either butyl rubber or steel. This material did not provide any extra water sealing - leaks were observed at torques near 15 ft.lb. The other two compounds (Loctite Superflex Silicone RTV 12529 and Loctite Permatex `the Right Stuff' # 25892) bonded well to both butyl rubber and steel and formed a strong seal at the bolt. In both these tests, torques could be reduced to zero with no evidence of leakage at an interior water pressure of close to 60 psi. Full details are given at the end of Appendix 1.

Bolt Pull Tests

A 3/4 inch stainless steel stud was machined to give a threaded section at both ends and a smooth sealing section in the middle. It was installed at the centre of a 12 inch diameter concrete cylinder, prepared from normal Portland concrete mix. The bolt was installed by Hilti Limited personnel in Sudbury, using standard procedures: a 13/16 inch hole through 7 inches of concrete, grouted with Hy 150 compound and twisted into the hole. After a several day set time, the bolt was fitted with the water seal gasket, gasket seat, washer and nut, as per Figure 1, and torqued to approximately 50 ft.lb. A pull test using a tripod base resting on the top of the concrete cylinder and a threaded connection to the top of the bolt was carried out at the School of Engineering. Deflections were measured between the bolt tip and the top of the concrete cylinder (tripod base). Results for two tests (30 minutes apart) involving loads of up to 2000 kg

(4400 lb) are shown in Figure 6. The figure shows deflections during the application (left hand plot) and removal of the load over a 5 minute period. The safe limit for loading for a 3/4 inch bolt in the cavity floor has been set at about 6000 lb (as per recommendation from Hilti Ltd.), but maximum expected loading is 2000 lb. Clearly, deflections at these loads are quite small - about 0.12 mm maximum. By comparison for a 6 inch long typical steel bolt, with Young's modulus $Y = 2 \times 10^{11}$ N/m^2, a load of 2000 kg would give a deflection of 0.052 mm, about 43% of the observed total deflection. From the graph, any permanent deflection appears to be of order 0.01 mm. For this test sample, satisfactory deflections under load are observed, corresponding to an elastic modulus near 8.6×10^{10} N/m^2 . These deflections are small compared to the gasket compression at 50 ft.lb. torque (about 2.5 mm), and the water seal is not compromised.

Conclusions and Recommendations

The current design and materials for the gasket bolt seal appear to be satisfactory, with good sealing characteristics for interior water pressures near 60 psi, at applied torques of 15 ft.lb. or more. An applied torque on the top nut of 50 ft.lb. is recommended. This torque would result in a compression of about 2.5 mm for the gasket, corresponding to a compression load of about 150 lbs. The effects of an upward load (of up to 4400 lb), investigated through the pull test, show small deflections (up to 0.12 mm), which have negligible effect on the gasket compression and water sealing properties.

Extra protection against water leaks through the bolt can be obtained through the use of a sealing compound on all gasket surfaces. Of the compounds tested, two are satisfactory - we would recommend the Loctite Superflex Silicone because of its clear colour and easier application.

Fig. 1

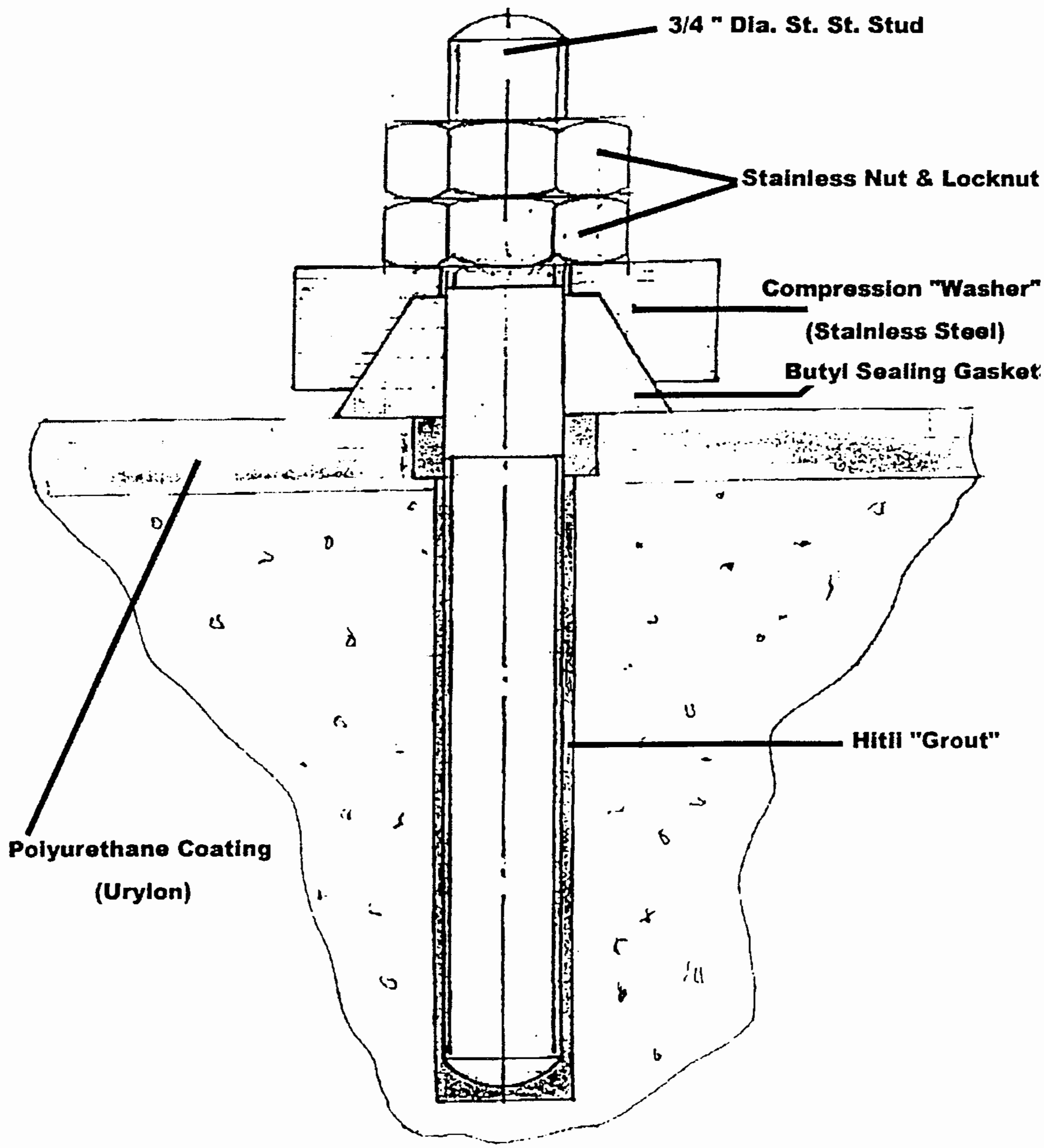

3/4 " Dia. St. St. Stud
Stainless Nut & Locknut
Compression "Washer"
(Stainless Steel)
Butyl Sealing Gasket
Hitli "Grout"
Polyurethane Coating
(Urylon)

Fig. 2

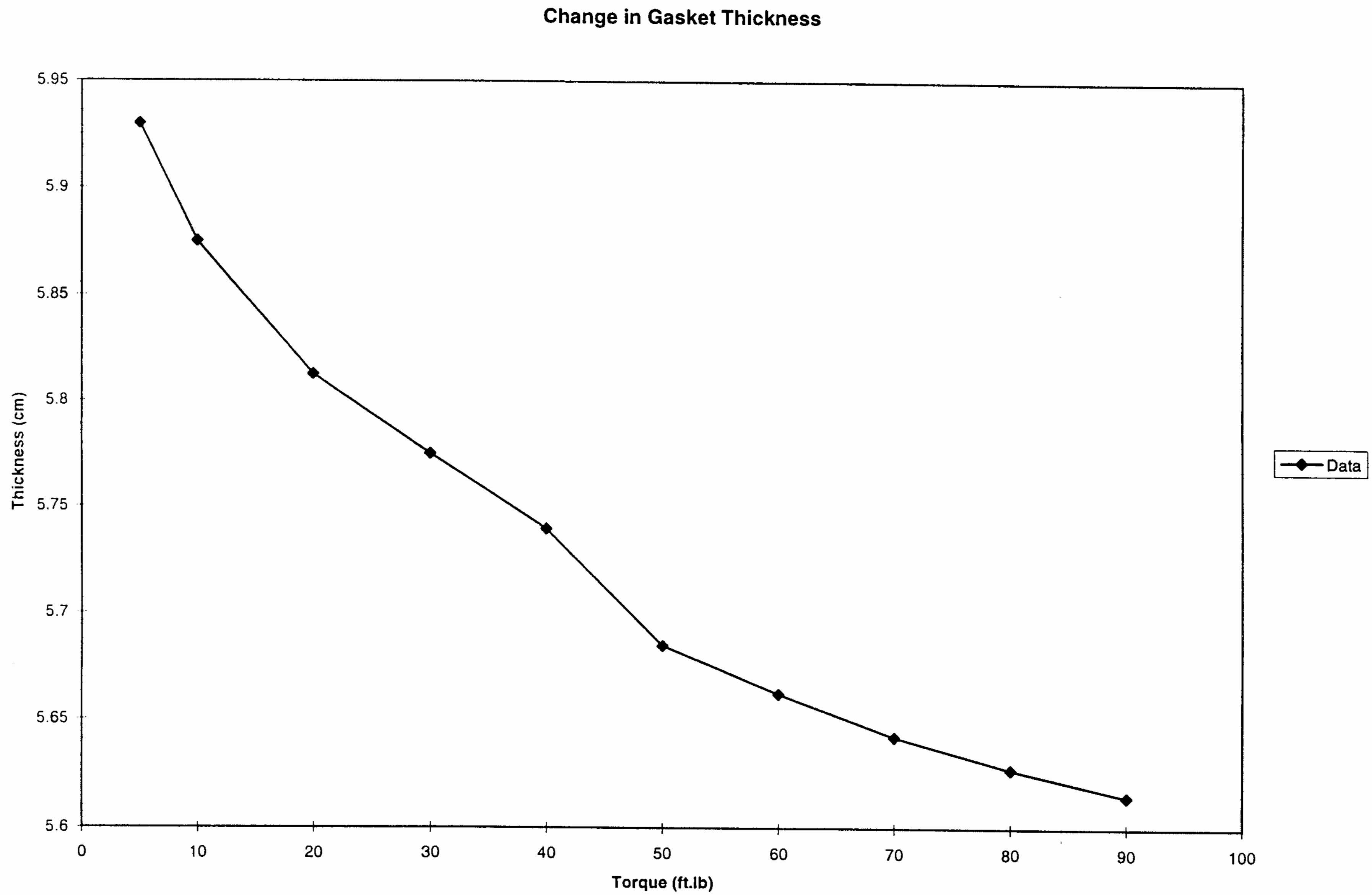
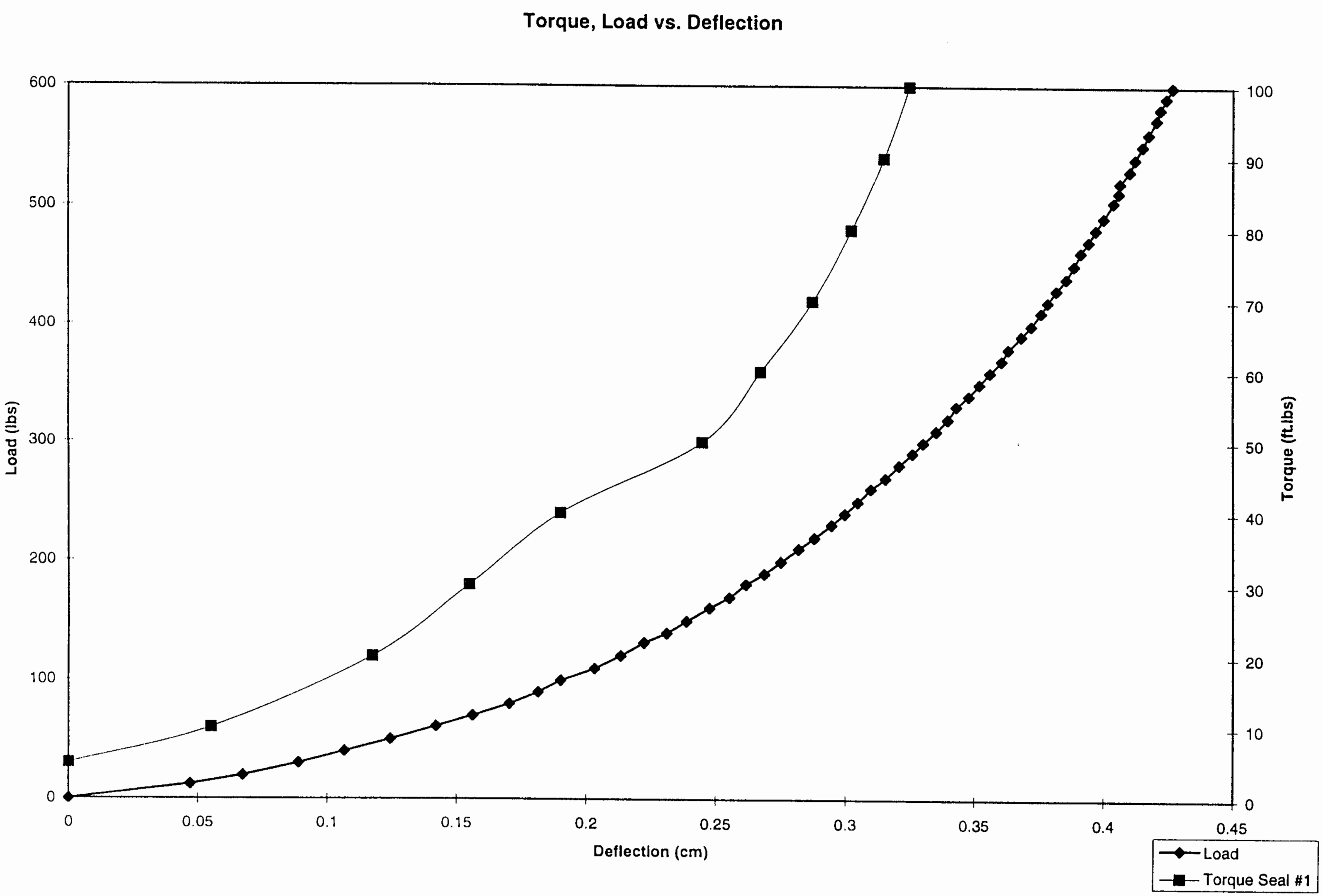
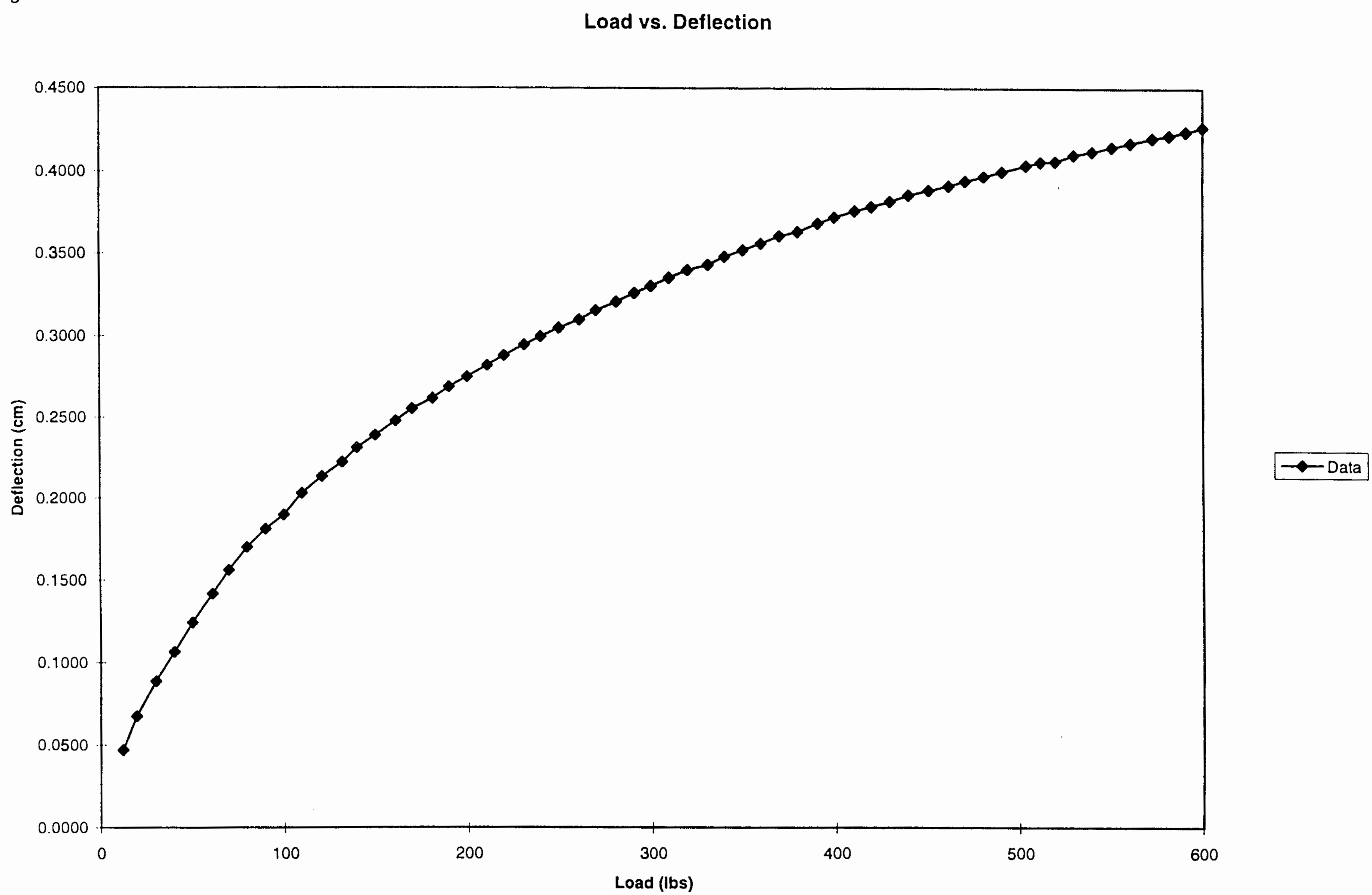

Change in Gasket Thickness
Thickness (cm)
5.95
5.9
5.85
5.8
5.75
5.7
5.65
5.6
0
10
20
30
40
50
60
70
80
90
100
Torque (ft.lb)
Data

Fig. 3



Torque, Load vs. Deflection
Load (lbs)
600
500
400
300
200
100
0
Torque (ft.lbs)
100
90
80
70
60
50
40
30
20
10
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
Deflection (cm)
Load
Torque Seal #1

Fig. 4



Load vs. Deflection
0.4500
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
Deflection (cm)
0
100
200
300
400
500
600
Load (lbs)
Data

Fig. 5

Test Chamber Used to Determine Effectiveness of The Urylon Seal

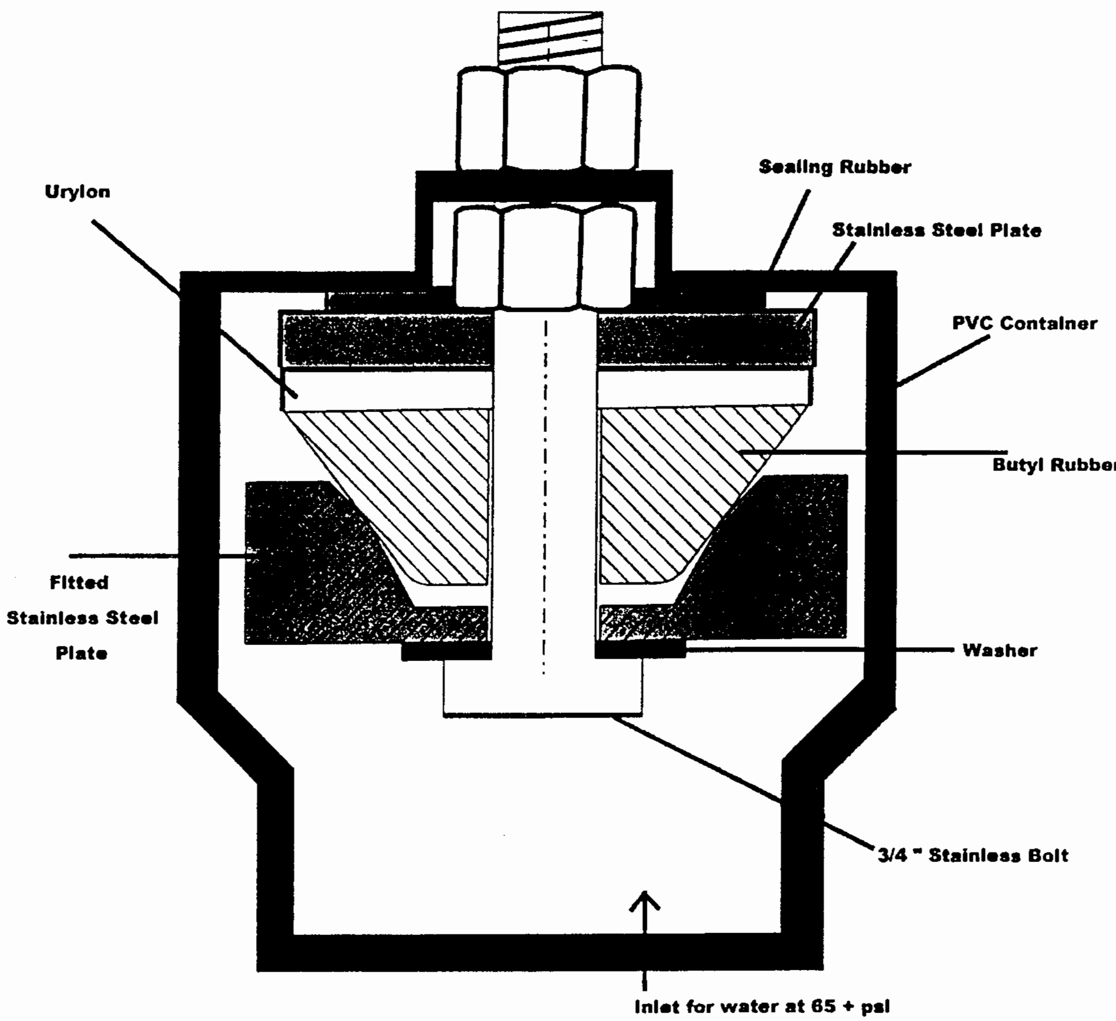
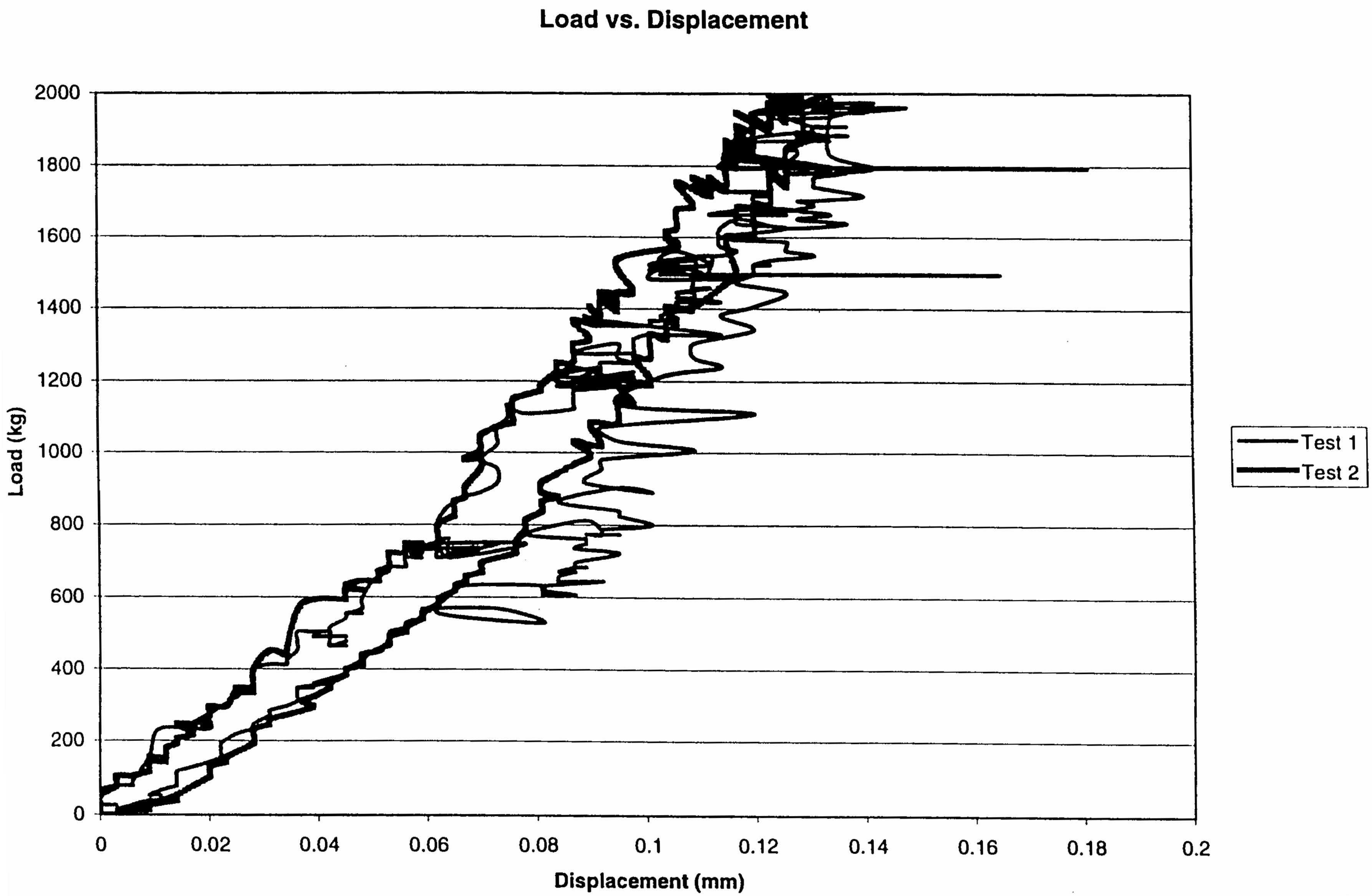


Figure 6. Pull test results for a grouted 3/4 inch bolt in concrete.



Summary of Urylon Seal Tests and Observations

May 5th — Began work on constructing the apparatus that would be used to exert pressure on the seal.

May 7th — Measured rubber Gasket Thickness vs. Applied Torque, and received the following results.

Table 1.

Torque (ft.lb)	x (left) (cm)	x (right) (cm)	x (avg) (cm)
5	5.940	5.920	5.930
10	5.875	5.875	5.875
20	5.835	5.790	5.813
30	5.820	5.730	5.775
40	5.795	5.685	5.740
50	5.745	5.625	5.685
60	5.715	5.610	5.663
70	5.685	5.600	5.643
80	5.665	5.590	5.628
90	5.650	5.580	5.615
100	5.640	5.570	5.605

where "x" is the thickness of the gasket / coupling combination. (seal #1) Two measurements were taken (left side and right side) and an average thickness was calculated.

Further Observations - noted that our sample piece of Urylon begins to "creep" as the torque is increased above 40 ft.lbs.

May 9th — Began testing seal #1 against varying amounts of applied pressure to determine if there was a leak. Decided that between 50 and 60 psi would be sufficient .

May 16th — Began first monitored test of seal #1. Set torque on gasket to 50 ft.lbs and pressurized apparatus to 50 psi.
Constructed a second gasket / coupling combination (seal #2) this time using a larger piece of Urylon to prevent "creeping", and measured gasket thickness vs. Applied Torque. The results were as follows :

Applied Torque vs. Gasket Thickness

Table 2.

Torque Applied			Thickness			
(ft.lbs)			(cm)			
		S1	S2	S3	S4	Avg. Thickness
10		7.385	7.325	7.375	7.390	7.369
20		7.340	7.305	7.310	7.325	7.320
30		7.280	7.275	7.285	7.290	7.283
40		7.260	7.260	7.240	7.270	7.258
50		7.255	7.225	7.235	7.245	7.240
60		7.215	7.205	7.210	7.225	7.214
70		7.210	7.185	7.115	7.175	7.171

where S1, S2, S3, S4 are 4 equally spaced positions around the gasket / coupling combination were the thickness was measured and then averaged.

May 17th Began regular testing of Seal #1 at varying Torques to determine the minimum torque required to prevent leaking.

Table 3.

Date	Torque	Starting	Final	Comment
Start		Pressure	Pressure	
	(ft.lbs)	(psi)	(psi)	
May-20	50	50	25	Leak in apparatus not gasket
May-21	40	60	50	No visible water leaks
May-22	30	60	43	No visible water leaks
May-23	20	60	47	No visible water leaks
May-26	15	65	47	No visible water leaks
May-27	10	66	10	Water leaked through seal

Seal became unreliable at torques less than 15 ft. lbs.

May 23rd Using a press and Seal #2, the Change In Gasket Thickness vs. Applied Load was measured. See Table 4. for values.

Table 4.

Load Applied (Pounds)		Deflection in 1000 of (inches)	Deflection (inches)	Deflection (cm)	Load Applied (Pounds)		Deflection in 1000 of (inches)	Deflection (inches)	Deflection (cm)
12		18.5	0.019	0.047	310		132.0	0.132	0.335
19.5		26.5	0.027	0.067	320		133.8	0.134	0.340
30		35.0	0.035	0.089	331		135.1	0.135	0.343
40		42.0	0.042	0.107	340		137.0	0.137	0.348
50		49.0	0.049	0.124	350		138.6	0.139	0.352
61		55.9	0.056	0.142	360		140.2	0.140	0.356
70		61.5	0.062	0.156	370		142.0	0.142	0.361
80		67.0	0.067	0.170	380		143.0	0.143	0.363
90		71.4	0.071	0.181	391		145.0	0.145	0.368
100		74.8	0.075	0.190	400		146.5	0.147	0.372
110		80.0	0.080	0.203	411		148.0	0.148	0.376
121		84.0	0.084	0.213	420		149.0	0.149	0.378
132		87.5	0.088	0.222	430		150.3	0.150	0.382
140		91.0	0.091	0.231	440		151.8	0.152	0.386
150		94.0	0.094	0.239	451		153.0	0.153	0.389
161		97.5	0.098	0.248	462		154.0	0.154	0.391
170		100.5	0.101	0.255	471		155.2	0.155	0.394
181		103.0	0.103	0.262	481		156.3	0.156	0.397
190		105.8	0.106	0.269	491		157.5	0.158	0.400
200		108.3	0.108	0.275	504		159.0	0.159	0.404
211		111.0	0.111	0.282	512		159.8	0.160	0.406
220		113.4	0.113	0.288	520		160.0	0.160	0.406
231		116.0	0.116	0.295	530		161.5	0.162	0.410
240		118.0	0.118	0.300	540		162.3	0.162	0.412
250		120.0	0.120	0.305	551		163.4	0.163	0.415
261		122.0	0.122	0.310	561		164.3	0.164	0.417
270		124.2	0.124	0.315	573		165.5	0.166	0.420
281		126.3	0.126	0.321	582		166.1	0.166	0.422
291		128.4	0.128	0.326	591		167.0	0.167	0.424
300		130.0	0.130	0.330	600		168.0	0.168	0.427

Results of Seal Tests using Loctite Superflex Silicone as an added Sealant

Date	Applied Torque (ft. lbs)	Initial Pressure (psi)	Final Pressure (psi)	Description
June 25	35	65	60	No Visible Leaks
June 26	25	60	45	No Visible Leaks
June 27	15	65	60	No Visible Leaks
July 2	10	65	60	No Visible Leaks
July 3	5	65	40	No Visible Leaks
July 4	0	65	60	No Visible Leaks

Loctite Superflex Clear Silicone is an industrial grade sealant used for bonding, sealing and gasketing applications. It bonds and seals metal, glass, ceramic, painted and enameled surfaces, most plastics and rubbers including other silicone rubber.

The cartridge that was used in our particular experiment was provided by :

Loctite Canada Inc.
Mississauga, Ontario.

The sealant was placed between the rubber gasket and the upper steel coupling and between the gasket and the Urylon surface. The seal was then placed under a torque of 25 ft. lbs. and left to cure for a period no less then 24 hours prior to being tested.

The values seen in the table above are based on the seal remaining under pressure for a period greater then 24 hours. i.e. The torque was adjusted and the test chamber pressurized in the morning and a final pressure measurement made the following day. In each case the system had stabilized at its final pressure.

Results of Seal Tests using Loctite "Right Stuff" as an added Sealant

Date	Applied Torque (ft. lbs)	Initial Pressure (psi)	Final Pressure (psi)	Description
July 4	25	70	66	No Visible Leaks
July 5	15	65	60	No Visible Leaks
June 6	10	70	65	No Visible Leaks
July 7	5	65	60	No Visible Leaks
July 8	0	65	60	No Visible Leaks

The "Right Stuff" is a product of Loctite Inc. and is classed as a gasket maker, not a sealant. However, after discussion of its sealant abilities, it was decided that we should test it as well.

One major draw back of the "Right Stuff" product is its black colouring, making it less desirable to work with then the above discussed Superflex clear Silicone.