CONTAINMENT LINER PLATE ANCHORS
AND STEEL EMBEDMENTS TEST RESULTS

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SUMMARY

This paper summarizes test data on shear load and deformation capabilities for liner plate line anchors and structural steel embedments in reinforced and prestressed concrete nuclear containments.

Reinforced and prestressed nuclear containments designed and constructed in the United States are lined with a minimum of 0.64 cm steel plate. The liner plates are anchored by the use of either studs or structural members (line anchors) which usually run in the vertical direction. This paper will only address line anchors.

The major operating loads and effects which produce liner compression in reinforced containments are concrete shrinkage and restrained thermal growth. These compressive forces can cause unbalanced loads in the liner plate which result in shear forces in the liner plate anchor. Prestressed containments introduce additional compressive loading in the liner plate due to prestress and concrete creep. Both types of containments must also consider loads from environmental (earthquake and wind) and abnormal (accident) loads.

Static load versus displacement test data is necessary to assure that the design is adequate for the maximum loads. In addition, ASME Section III, Division 2 requires that the liner design consider fatigue. In general, there is only one major thermal load cycle per year resulting from atmospheric temperature change.

The test program for the liner anchors had the following major objectives:
1. Determine load versus displacement data for a variety of anchors considering structural tees and small beams with different weld configurations.
2. From the preceding tests, determine which anchors would lead to an economical and extremely safe design and test these anchors for cyclic loads resulting from thermal fluctuations.

Various concrete embeds in the containment and other structures are subjected to loads such as pipe rupture which results in shear. Since many of the loads are transient by nature, it is necessary to know the load-displacement relationship so that the energy absorption can be determined. In addition, most testing in the past was for round studs with a capacity of about 200 kN and very little information was available for rectangular embed orientations.

The test program for the embeds had the following objectives:
1. Determine load-displacement relationship for various size anchors from 6.5 cm² to 26 cm² with maximum capacities of approximately 650 kN.
2. Determine the effect of various anchor width-to-thickness ratios for the same shear area.

The liner anchor tests in both normal concrete and prestressed concrete specimens illustrated very good ability in resisting cyclic loads. The load range of the applied cyclic load was about 10% of the ultimate liner anchor capacity. The cyclic load was applied at different load levels ranging from about 20% to 70% of ultimate capacity.

The embed tests showed that the shear anchors are not significantly sensitive to the orientation relative to loading. The shear capacity is about 60% of the steel ultimate tensile strength and there was a slight reduction in this percentage as the anchors increased in size.
1. Introduction

This paper summarizes test data on shear load and deformation capabilities for liner plate line anchors in reinforced and prestressed concrete containments and structural steel embedments in reinforced concrete.

Reinforced and prestressed nuclear containment structures designed and constructed in the United States are lined with a minimum of 0.25 inch thick steel plate. The liner plate is anchored either by studs or structural members (line anchors) which usually run in the vertical direction.

The major operating conditions which produce liner compression in reinforced containments are concrete shrinkage and steady-state thermal strain. These compressive forces can cause unbalanced loads in the liner plate which result in shear forces acting on the liner plate anchors. Prestressed containments introduce additional compressive loading in the liner plate resulting from the prestress forces and concrete creep. Environmental loads (earthquake and wind) and abnormal (accident) loads including thermal transients must also be considered for both the reinforced and prestressed containment structures.

Static load versus displacement test data are necessary to assure that the design is adequate for the maximum loads. In addition, Reference 1 requires that the liner design consider fatigue. In general, the liner will experience only one major thermal load cycle per year resulting from atmospheric temperature change.

The line anchor test program had the following objectives:

1. Determine load versus displacement data for a variety of line anchors utilizing structural tees and small beams with different weld configurations.
2. Test line anchors under cyclic loads resulting from annual thermal transients.

Steel embedments in the containment and other structures may be subjected to pipe rupture effects which result in shear. Since these loads are of a transient type, it is necessary to obtain the static load-displacement relationship so that the energy absorption capacities of the steel embedments can be determined. The majority of the previous test programs provided load versus displacement data for round studs with maximum capacities of about 50 kips.

The steel embedment test program had the following objectives:

1. Determine load versus displacement relationship for square and rectangular steel embedments with a cross-sectional areas of 1.0 in² to 4.0 in² and maximum capacities of approximately 150 kips.
2. Determine the maximum capacities of the steel embedments with varying width-to-thickness ratios and constant cross-sectional area.

2. Specimen Fabrication and Test Set-Up

The test set-up of the line anchor specimens and steel embedment specimens is shown in Figures 1, 2, and 3. All specimens were symmetrical about the centerline and had two identical embedded line anchors or steel embedments welded to the attachment plates to simulate the anchorage of a typical 0.25 inch thick liner plate or shear anchor in a concrete structure. The line anchor shapes, embedment sizes, attachment plate thickness and weld configurations are shown in Tables I, II, and III.

The material for the line anchors, attachment plates and steel embedments conformed to ASTM A-36 unless noted otherwise. The line anchors were welded with E6010 electrodes and the embedments were welded with E7016 electrodes. All welding conformed to AWS D.1.1-72.
The concrete used for the test specimens had a maximum size aggregate of 1.5 inches and an average slump of 2.0 inches.

The specimens were cast with the line anchors in the vertical position similar to the line anchor orientation in a typical containment liner plate system. The concrete was vibrated in place with an electrical vibrator. To resist the tensile force produced by the bending moment resulting from the eccentricity between the centerline of the stressing ram and the attachment plate, two 1.0 inch diameter tie bars were provided, as shown in Figure 1 at about 4.5 inches below the line anchor or steel embedment. This force is insignificant in reinforced or prestressed containment structures.

A prestress force of 432 kips was applied to specimens L-5, L-13 and L-14 to simulate the hoop prestress in a prestressed containment structure. The prestress resulted in a calculated compressive stress of 1500 psi. The arrangement of the prestress system is shown in Figure 1 and consisted of one 3.5 inch thick steel bearing plate at the top and bottom of the specimen and six 1.5 inch diameter threaded prestressing rods. The 1.5 inch diameter threaded prestressing rods passed through the top and bottom bearing plates and 72 kips prestress force in each rod was applied by tightening the nuts on the top bearing plate. Each prestressing rod was instrumented with two diametrically opposite electrical strain gages which were calibrated in a testing machine prior to tensioning.

3. Consideration for Cyclic Test Loads for Line Anchors (Specimens L-9 through L-14)

The analytical techniques of Reference 2 were used to determine the transient forces acting on the line anchors.

The cyclic loads were set based on estimates of the annual temperature fluctuations and the resulting shear loads that the line anchors would experience. Figure 4 shows an annual (six day average) temperature cycle for a location in North Dakota, U.S.A. The inside temperature of the containment structure was assumed to be 120°F and the outside temperature varied from 0°F to about 75°F. Extreme temperature values outside this range have no noticeable effect on the average wall temperature and would not significantly affect the liner plate.

Based on the annual temperature cycle shown in Figure 4, one can expect 40 such temperature cycles during a design life of 40 years. Considering a minimum fatigue safety factor of 20 would result in 800 load cycles. The testing was conservatively based on 1000 load cycles. Specimens L-9 and L-13 were tested under 2000 load cycles. After completion of the cyclic load testing, specimens L-9 through L-14 were tested under static load to maximum capacity to determine the effect of the cyclic loading on the line anchor capacity.

Cyclic loads ranging from a minimum of 1.5 k/in to 3.0 k/in to a maximum of 7.5 k/in to 9.0 k/in were applied to the line anchor specimens L-9 through L-14 to simulate liner plate stress and strain variations for different containments with varying levels of prestress and amount of concrete creep and shrinkage. Prestress containments have higher liner plate stress and strain than reinforced containments due to the compressive loads produced by the post-tensioning system and the resulting larger concrete creep.

4. Line Anchor Test Results

The static and cyclic line anchor test results are summarized in Tables I and II and Figures 5 and 6. The maximum capacities shown on Tables I and II are not necessarily the ultimate capacities that the line anchor could resist since testing of specimens L-1 through
L-3 and L-7 through L-10 was discontinued after excessive yielding in the 1/4 inch attachment plate. Line anchor weld failure occurred at the maximum capacity in specimen L-4 at 13.0 kips/in and in specimens L-6, L-11 and L-12 in the range of 9.0 kips/in to 10.0 kips/in. The apparent reduction in the maximum capacity in specimens L-6, L-11 and L-12 resulted from the intermittent (6-12) fillet weld. Testing of specimens L-13 and L-14 was discontinued after reaching a maximum capacity of 15.0 kips/in and 14.7 kips/in, respectively.

The line anchors in the prestressed specimens L-5, L-13 and L-14 exhibited considerably less line anchor deformation when compared to the plain concrete specimens. Under static loading, specimens L-1 through L-4 and specimens L-6 through L-8 showed some "soft" anchor behavior at a line anchor load in the range between 4.0 kips/in to 6.0 kips/in. This "softness" resulted from the first concrete cracking which allowed some line anchor movement. After this initial motion, the line anchor was able to resist loads of up to 13.0 kips/in in the plain concrete specimen L-4 and up to 15.0 kips/in in the prestressed concrete specimens L-13.

Specimens L-7 and L-8 with the Mx13 line anchor exhibited considerably less anchor displacement than specimens with WTSx10.9 or WTSx5.75 anchors. The small displacements exhibited by specimens L-7 and L-8 resulted from the larger stiffness of the anchors and higher concrete compressive (bearing) stresses which can develop along the edge of the flange and the web.

The forces in the 1 inch diameter tie bars are shown in Tables I and II.

Specimens L-9 through L-14 were tested under cyclic load prior to the static testing. The specimens were typically tested under 1000 load cycles except that specimens L-9 and L-13 were tested under 2000 cycles. The highest cyclic load was applied on specimen L-14 ranging from 7.5 kips/in to 9.0 kips/in. No significant additional line anchor displacement or deterioration of specimen L-14 was noticed, after the initial line anchor displacement which occurred during the first few load cycles.

The line anchors in specimens L-9 through L-12 displayed larger displacements after the completion of the cyclic loading than the line anchors in the prestressed concrete specimens L-13 and L-14. The cyclic loading of the specimens did not significantly affect the maximum load capacities and only resulted in some initial displacement as shown in Figures 5 and 6.

The line anchor tests were performed at concrete strengths ranging from 4200 psi to 5400 psi.

The line anchor forces at proportional limit (defined as that force where first concrete cracking was detected) varied between 4.0 kips/in to 5.0 kips/in. This may be due to the fact that specimens were cast from four different concrete batches and the varying age of the specimen at the time of testing.

5. Steel Embedment Test Results

The steel embedment test results are summarized in Tables III and IV and Figures 7 and 8.

The shear capacity in the steel embedments ranged from a minimum of 36.2 ksi in specimen E-10 to a maximum of 50.7 ksi in specimen E-6. The average shear capacity for specimens E-1 through E-10 was 42.8 ksi or approximately 67% of the average ultimate tensile strength of the steel embedment material.

The variation of the width-to-thickness ratios in the range of 1/4 to 4 for a constant cross-sectional area did not result in a significant change in the maximum capacity of the embedments. It was noted that the embedment capacity did not increase linearly with the
cross-sectional area of the embedment.

Embedments with a larger cross-sectional area exhibited a lower maximum shear stress capacity than embedments with a smaller cross-sectional area. The average maximum capacity of specimens E-1 through E-3 with a cross-sectional area of 1.0 in² was 43.7 ksi. The average maximum capacity of specimens E-8 and E-9 with a cross-sectional area of 3.0 in² was 38.7 ksi. The maximum capacity for specimen E-10 with a cross-sectional area of 4.0 in² was 36.3 ksi.

The steel embedment tests were performed at concrete strengths ranging from 4000 psi to 4500 psi. Specimens E-4 and E-5 were tested at a concrete strength of about 4000 psi and specimen E-6 was tested at a concrete strength of about 4400 psi. The steel embedments in specimens E-4, E-5 and E-6 had the same cross-sectional area of 2.0 in². The higher concrete strength of specimen E-6 may have resulted in the higher shear capacity of 50.7 ksi compared to a shear capacity of 46.2 ksi and 45.0 ksi in specimens E-4 and E-5, respectively.

6. Summary and Conclusions

6.1 Conclusions of the Line Anchor Test Program
(a) The maximum shear capacity of all anchors exceeded 9.0 kips/in.
(b) Anchors with continuous welds developed the yield strength of the 1/4 inch liner plate with yield values of approximately 40 ksi.
(c) The anchors were extremely ductile, experiencing maximum displacements in the range of .20 inches.
(d) The line anchor tests on both the concrete and prestressed concrete specimens demonstrated very good ability to resist cyclic loads with no significant effect on the load capacity.

6.2 Conclusions of the Embedment Test Program
(a) In general, the shear strength of the embedments were about 2/3 of the tensile strength of the material based on mill certificates.
(b) There was a reduction in the ratio of shear strength to tensile strength with increasing embedment size.
(c) Orientations of the embedded members had very little effect on the load-displacement capacity for embedments having the same cross-sectional area.
(d) The embedments were very ductile with displacements in excess of 1/2 inch.
(e) When designing shear embedments, a tension anchor plate should be placed on the end to resist any tensile loads which may result from large lateral displacements.

References


<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Shape Of Line Anchor</th>
<th>Yield</th>
<th>Thickness Of Attachment Plate (in)</th>
<th>Proportional Limit</th>
<th>Maximum Capacity</th>
<th>Tie Bar Force At Maximum Capacity (kips/in)</th>
</tr>
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<tbody>
<tr>
<td>L-1</td>
<td>WT5x10.5</td>
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<td>1/4</td>
<td>.02</td>
<td>11.2</td>
<td>.19 N.R.</td>
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<td>.02</td>
<td>10.8</td>
<td>.19 N.R.</td>
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<td>13.0</td>
<td>.27 3.2</td>
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<td>11.0</td>
<td>.08 3.1</td>
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<td>.02</td>
<td>10.0</td>
<td>.28 2.4</td>
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<td>.01</td>
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<td>1/4</td>
<td>.01</td>
<td>10.4</td>
<td>.10 N.R.</td>
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</table>

Notes:

1. Concrete specimen width was 12".

2. Concrete strength at time of testing varied from 4200 psi to 5000 psi.

3. Anchor yield varied between 47 ksi to 53 ksi and ultimate varied between 64 ksi and 72 ksi.

4. The liner plate yield/ultimate was: 42/64 ksi for L-1, L-2, L-7 and L-8; 36/58 ksi for L-3 and L-6; and 46/68 ksi for L-4 and L-5.

5. The tie bar force for specimens L-1, L-2, L-7 and L-8 was not recorded.

6. All welding conformed to AWS D1.1-72: Type E6010 electrodes were used for all welding.

7. The butt weld in specimens L-7 and L-8 was 0.25 inches deep and 0.25 inches wide.

8. *Corresponds to line anchor displacement at maximum static force.

9. **Specimen L-5 was prestressed to 1500 psi.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Shape Of Line Anchor</th>
<th>Weld</th>
<th>Loading 1000 Cycles (k/in)</th>
<th>Total Displ. After Completion Of Load Cycles (in)</th>
<th>Maximum Capacity Force (kips)</th>
<th>Disp.* (in)</th>
<th>Tie Bar Force At Maximum Capacity (kips/in)</th>
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<tbody>
<tr>
<td>L-9</td>
<td>WT5x10.5</td>
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<td>1.5 to 3.0 3.0 to 4.5</td>
<td>0.00 0.05</td>
<td>11.0 0.21</td>
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<td>L-10</td>
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<td>4.5 to 6.0</td>
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<td>10.9 0.19</td>
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<td>WT5x5.75</td>
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<td>9.0 0.21</td>
<td>1.7</td>
<td></td>
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<td>9.9 0.19</td>
<td>1.8</td>
<td></td>
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<td>4.5 to 6.0 6.0 to 7.5</td>
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<td>15.0 0.15</td>
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<td></td>
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<td>L-14**</td>
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<td>14.7 0.20</td>
<td>1.7</td>
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Notes:

1. All liner was 1/4" thick and concrete specimen width was 12".
2. Concrete strength at time of testing varied from 5100 psi to 5400 psi.
3. Anchor yield varied between 49 and 53 ksi and the ultimate strength ranged between 70 and 72 ksi.
4. The liner plate yield/ultimate was 38/58 ksi for L-9 to L-12 and 68/84 ksi for L-13 and L-14.
5. Welding conformed to AWS D1.1-72 with type E6010 electrodes.
6. *Corresponds to line anchor displacement at maximum static force after completion of cyclic load testing.
7. **Specimens L-13 and L-14 were prestressed to 1500 psi.
## Table III  Steel Embedment Test Results

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Embedment Shape</th>
<th>Embed Depth (in)</th>
<th>Thickness Of Plate (in)</th>
<th>Proportional Limit Force (kips)</th>
<th>Disp. (in)</th>
<th>Maximum Capacity Force (kips)</th>
<th>Disp. (in)</th>
<th>Tie Bar Force At Maximum Capacity (kips)*</th>
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<tr>
<td>E-1</td>
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<td>6</td>
<td>1/2</td>
<td>38</td>
<td>.09</td>
<td>40</td>
<td>.38</td>
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<td>43</td>
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<td>.39</td>
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Notes:

1. All welds were full penetration plus 3/16" fillet.
2. Welding conformed to AWS D1.1-72 with type E7016 electrodes.
3. Concrete strength at time of testing ranged between 4000 psi and 4500 psi.
4. Displacement values correspond to maximum load.
5. N.R. indicates "Not Recorded".
6. The embedment yield/ultimate was 42/62 ksi for specimens E-1, E-5, E-6, E-8 and E-9; 43/66 ksi for specimens E-2 and E-3; and 42/74 ksi, 40/64 ksi and 41/64 ksi for specimens E-4, E-7 and E-10, respectively.
7. The concrete was 12" wide for E-1 to E-3 and 36" wide for other specimens.
8. The embedment shape used the following orientation: For specimen E-2*, width = 2", thickness = 0.5"; Figure 3 shows the general orientation of the embedment.
9. *The tie bar force at maximum capacity is the total force in both tie rods.
### Table IV Summary of Steel Embedment Specimens Test Results

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Area (in²)</th>
<th>Width/Thickness (b/t)</th>
<th>$V_u$ (kips)¹</th>
<th>$F_u$ (ksi)²</th>
<th>$V_u/F_u$</th>
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<tr>
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**Notes:**
1. $V_u$ = Maximum Shear Force/Cross-Sectional Area.
2. $F_u$ = Ultimate Tensile Strength Based on Mill Certificates.

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### Figure 1 Test Set-Up for Line Anchor and Steel Embedment Specimens
Figure 2 Forces In Line Anchor Specimens

Figure 3 Orientation Of Steel Embedments

Figure 4 Yearly Ambient Temperature Cycle (Six-Day Average)
Figure 5 Line Anchor Displacement Diagram (Static Load Test)

Figure 6 Line Anchor Displacement Diagram (Static Load Test)
Figure 7 Load Vs. Displacement - Specimens E-1, E-4, E-7 and E-10

Figure 8 Shear Load Vs. Embedment Cross-Sectional Area