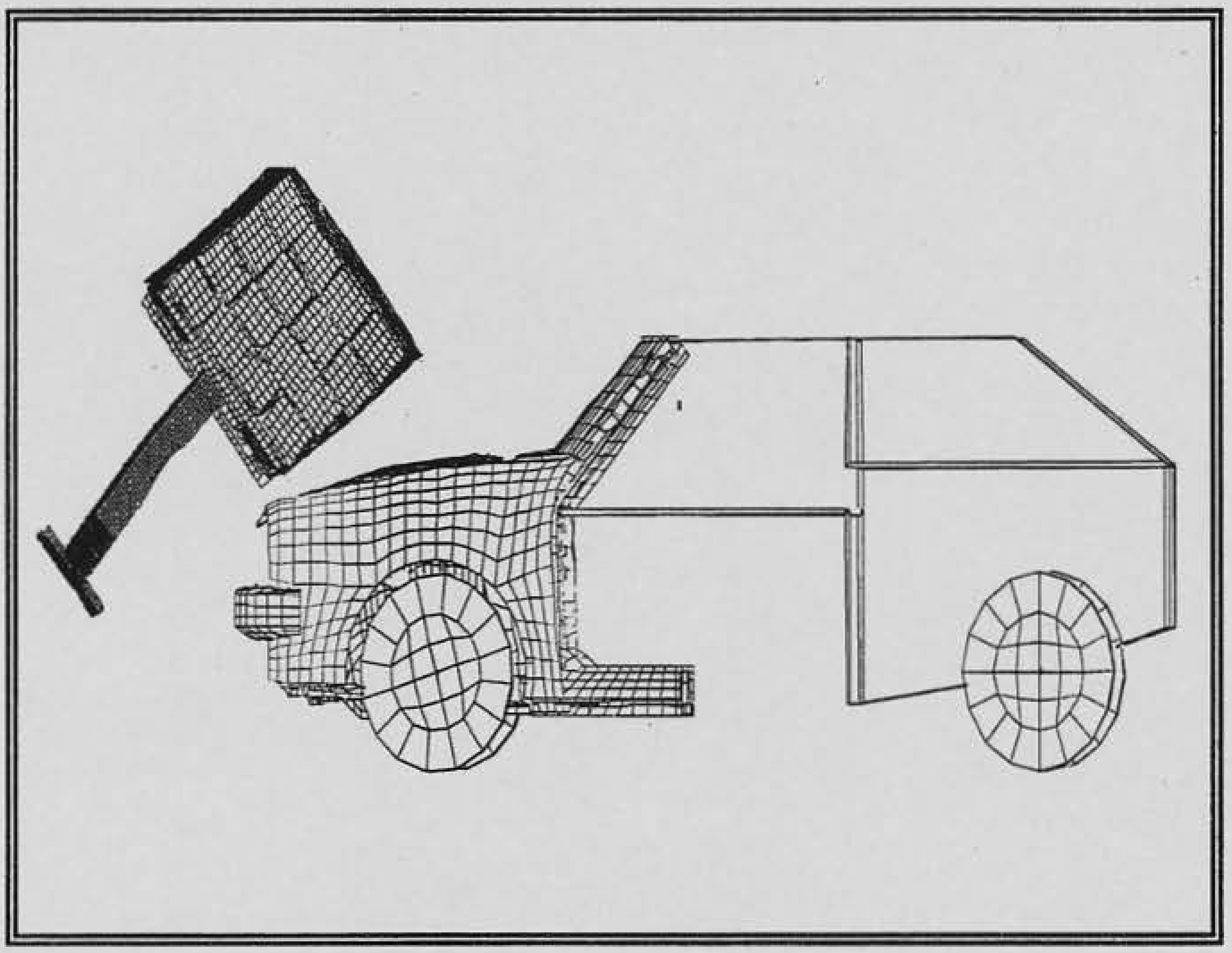
Eric Keller

Design and Testing of a Breakaway Base for a Cluster Box Unit and a Neighborhood Delivery & Collection Unit



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9. Abstract

The United States Postal Service (USPS), in response to the potential threat to motor vehicle and occupant safety should a collision occur with roadside-installed centralized-delivery equipment such as Neighborhood Delivery & Collection Box Units (NDCBUs) and Cluster Box Units (CBUs), requested that the Midwest Roadside Safety Facility (MwRSF) design a new breakaway mechanism to potentially improve the safety performance of these units.

A literature search and evaluation was performed to investigate the current state-of-the-art in breakaway mechanisms. Design calculations and bogie impact tests were conducted on several conceptual designs in order to select the best alternative. The final design was tested with a 2.2-kN (500-lb) horizontal static pull test, and a 500 hour salt spray test to determine the durability of the breakaway design. Additionally, LS-DYNA3D, a large deformation nonlinear finite element analysis (FEA) code, was used to simulate actual crash test scenarios on the CBU's and estimate its relative safety performance.

The results of the study produced a new breakaway base that potentially improves the safety performance of the CBU when impacted by a vehicle. FEA predicted that the CBU's would meet the safety performance criteria set forth in NCHRP 350 with the exception of the occupant compartment intrusion criteria. FEA methods are currently unable to determine the extent, if any, of occupant compartment intrusion into the windshield, due to the CBU projectile. It is recommended that full-scale crash tests be performed in order to investigate windshield intrusion, as well as to further evaluate the safety performance of the system. This testing would be required to fully satisfy NCHRP 350 recommendations.

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1 INTRODUCTION

1.1 Problem Statement

The United States Postal Service (USPS) has expressed a need for the development of a breakaway mount for centralized-delivery equipment such as Cluster Box Units (CBUs) and Neighborhood Delivery & Collection Box Units (NDCBUs) that are mounted near roadsides. It has been anticipated that a total of nine types of centralized-delivery units will require breakaway mounts. The aluminum-style CBU has three different types of mailbox configurations as does the plastic CBU. In addition, the steel NDCBU has three different configurations.

1.2 Objective

The objective of this research study is to design and analyze several breakaway mounts for aluminum and plastic CBUs, and steel NDCBUs.

The breakaway mounts shall: (1) be designed to meet the crash test requirements of NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1); (2) require minimal modifications to existing pedestal designs for retrofit; (3) be designed for easy installation; (4) be designed for minimal production cost; (5) be designed for a 20 year usable life; and (6) be designed so that the unit cannot be set back up without proper repair or replacement if knocked over.

1.3 Scope

Prior to laboratory testing, a literature search and concept evaluation was performed to investigate the current state-of-the-art in breakaway mechanisms for mailbox supports, sign posts, luminaire supports, and all other roadside safety hardware. Following the concept investigation, the most feasible alternatives were selected and investigated further.

Design calculations were performed on the CBU to determine the minimum strength required for the breakaway device, to support the structure. Following these design calculations, prototype designs were constructed on different concepts and evaluated with bogie impact tests. The bogie tests were used to select the best alternative. Once the best alternative was selected, a 2.2-kN (500-lb) horizontal static pull test according to USPS-B-1118E 3.5.12, and a 500 hour salt spray test according to USPS-B-1118E 3.5.11 were performed on the structure.

Finally, LS-DYNA3D, a large deformation nonlinear finite element analysis code, was used to simulate actual crash test scenarios on the CBUs with the new breakaway mechanism at the pedestal's base. Finite element analysis was used to obtain occupant, CBU, and vehicle behaviors in the collisions. From this analysis, a reasonable prediction was made on the safety performance of the device, based on the guidelines set forth by NCHRP 350.

2 BACKGROUND AND CONCEPT DEVELOPMENT

The USPS installs centralized delivery equipment at suitable locations throughout the country in order to speed up the mail service and, ultimately, to reduce costs. These pieces of equipment may contain from 8 to 16 delivery compartments as well as collection compartments and parcel receptacles. Currently, the USPS constructs the CBUs from three types of materials: aluminum, plastic, and steel.

Specifically, the aluminum and plastic CBUs are broken down into three distinct types that are shown in Appendix A, and described below.

- Type I - One box with 13 medium size compartments, 1 collection compartment, and 1 parcel receptacle, and with a pedestal height of 435 mm (17 in.).
- Type II - One box with 12 standard delivery compartments, 1 collection compartment, and 1 parcel receptacle, and with a pedestal height of 787 mm (31 in.).
- Type III - One box with 16 standard delivery compartments, 1 collection compartment, and 2 parcel receptacles, and with a pedestal height of 435 mm (17 in.).

The steel receptacles are more specifically called a neighborhood delivery & collection box unit (NDCBU) and are classified into three types as well.

- Type I - One box with 8 compartments, rear loaded through a master door and mounted on a pedestal at a height of 800 mm (31.5 in.).
- Type II - One box with 12 compartments, rear loaded through a master door and mounted on a pedestal at a height of 800 mm (31.5 in.).
- Type III - One box with 16 compartments, rear loaded through a master door and mounted on a pedestal at a height of 800 mm (31.5 in.).

Type I and III, aluminum and plastic CBUs have a similar geometry, with a very short pedestal. Type II aluminum and plastic CBUs have a similar geometry to the steel NDCBUs. The pedestal geometry and compartment sizes for all three types of steel NDCBU are identical, the only difference between the three types is their relative size.

2.1 Background

The Midwest Roadside Safety Facility (MwRSF) was tasked by the USPS with determining a new breakaway mechanism to potentially improve the safety performance of roadside installed centralized delivery equipment such as NDCBUs and CBUs. Initial efforts by MwRSF showed that very little research had been performed with vehicular impact testing of centralized delivery units. The only such case was documented in a 1984 report by the Texas Transportation Institute (TTI) (2). The report documented a vehicle crash test involving an 895-kg (1945-lb) Honda Civic impacting a NDCBU at a speed of 100.2 km/h (62.3 mph) and at the 1/4-point of the vehicle's front end. The NDCBU was supported by a steel post and attached to a concrete foundation with four anchor bolts. During the test, the NDCBU was destroyed, and the steel post was fractured. As the post was bent over, the vehicle began to uplift and subsequently rolled over six times. Results from this test demonstrated the need for breakaway mounts on NDCBUs and CBUs.

2.2 Breakaway Base Concepts

Prior research conducted on breakaway mailbox supports have been on rural mailbox structures. Several studies have been performed on improving the impact characteristics of single support structures found along rural roadways. However, implementing breakaway features developed for rural mailboxes on CBUs is not feasible due to differences between the single support structure of a rural mailbox and the larger, wide base support found on most centralized delivery units.

Several breakaway mechanisms taken from existing safety devices, as well as new concepts, are listed below and also shown in Appendix B.

1. Slip Base - This feature is commonly used with luminaire supports and sign posts, and are found in many configurations (i.e. 3-bolt triangular and 4-bolt rectangular).
2. Frangible Transformer Bases - This feature is commonly used on luminaire and transformer bases, and consists of a brittle, cast aluminum base that fractures upon impact.
3. Breakaway Couplings - This device is a brittle plastic coupling that is used on road closure

gates as well as luminaire supports. This device, as tested by MwRSF on road closure gates, is made by TRANSPO and PrecisionForm. A similar device is described in Patent No. 4,052,826, which also incorporates a fracture initiating washer.

4. Frangible Pole Support - This feature is another variation of breakaway luminaire support, as described in Patent No. 4,154,037.

5. Fire Hydrant Coupling - This feature is a frangible coupling used on barrel sections of fire hydrants and is described in Patent No. 4,717,178.

6. Breakaway Utility Pole Shear Base Structure - This feature, known commercially as the "Shakespear Light Pole", is a recent improvement of the frangible aluminum base described in concept no. 2. This design is described in Patent Nos. 4,813,199 and 5,088,683.

7. Breakaway connector. This device is a simple anchor bolt which has a reduced section to allow the bolt to fail in a prescribed area. Different configurations of this connector are produced by TRANSPO and described in Patent No. 4,923,319.

8. Reduce Anchor Bolt Size - This design concept would reduce the area of the bolts currently used in the base making the connection weaker.

9. Change Anchor Bolt Material - This design concept would replace the currently-used ductile anchor bolts, with a more brittle material. A brittle material would fail more easily under an impact load and absorb less energy.

10. Fracturable or breakaway nut - This design concept would utilize a fracturable nut, comprised of plastic or composite, which would fail in a brittle mode under an impact load.

2.3 Performance Evaluation Criteria

The safety performance of the cluster box unit was evaluated according to the guidelines presented in NCHRP 350 (1) and the 1994 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (3). These guidelines, shown in Tables 1 and 2, require two compliance tests in order to evaluate the performance of a breakaway support device such as the pedestal of a CBU. These two compliance tests are designated as level 3 tests (Tests 60 and 61). Descriptions of these tests are as follows:

1) Test 3-60: An 820-kg (1808-lb) vehicle impacting the support structure head-on at a nominal impact speed of 35 km/h (21.7 mph) with the center of the front bumper aligned with the center of the installation at an impact angle of 0-20 degrees. The objective of this test is to investigate the breakaway or fracture mechanism of the support.

2) Test 3-61: An 820-kg (1808-lb) vehicle impacting the support structure head-on at a nominal impact speed of 100 km/h (62.1 mph) with the quarter point of the front bumper aligned with the center of the installation at an impact angle of 0-20 degrees. The objective of this test is to investigate the trajectories of both the test installation and the test vehicle.

In addition, NCHRP 350 specifies that the support should be fully equipped with full height structures, which includes mailboxes. The test may involve multiple supports, such as multiple mailbox supports. Orientation and spacing should be representative of in-service conditions. For crash tests on mailbox supports, the number and size of mailbox should be the largest that normally would be used on the support system.

Finite element analysis was used to simulate these test conditions on a Type III steel NDCBU, and to simulate the test 3-61 impact condition on a Type I and Type II aluminum CBU both using a single mailbox structure. Even though NCHRP 350 specifies the impact of the mailbox support with the largest size that normally would be used, the behavior of the Type II box was judged to be more critical due to its higher center of mass.

Table 1. NCHRP Report 350 Safety Evaluation Guidelines. (1)

Evaluation Factors	**Evaluation Criteria**	
Structural Adequacy	B.	The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.
	H.	Longitudinal occupant impact velocity should satisfy the following limits: Preferred: 3 m/s (9.8 fps) Maximum: 5 m/s (16.4 fps)
	I.	Occupant ridedown accelerations should satisfy the following longitudinal and lateral limits: Preferred: 15 G's Maximum: 20 G's
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	N.	Vehicle trajectory behind the test article is acceptable.

Table 2. AASHTO 1994 Safety Evaluation Guidelines (3).

Evaluation Factors	**Evaluation Criteria**
Vehicle Change in Speed (ΔV)	Satisfactory dynamic performance is indicated when the maximum change in velocity of the vehicle, striking a breakaway support at speeds from 20 mph to 60 mph (32 km/h to 97 km/h does not exceed 15 fps (4.57 m/s), but preferably does not exceed 10 fps (3.05 m/s)

3 PROTOTYPE DESIGN

The test results on the full-scale crash test conducted by TTI showed that the two upstream anchor bolts were bent to a large degree, and then pulled through the base plate of the pedestal. The large amount of energy that was absorbed by the base plate and bolts contributed significantly to the vehicle uplift and subsequent rollover. Further evaluation suggested that the reason the bolts pulled through the base plate, rather than shearing off, was due to the large amount of ductility the bolts possessed. To eliminate the danger of rollover, the connection currently used needs to be replaced with a breakaway mechanism that will fracture more readily when impacted.

Many of the breakaway base concepts discussed in Section 2.2 involved the use of an intermediate fracturable piece between the base of the feature and rigid anchor bolts placed in a concrete footing. It was determined that the best alternative for this application would be to eliminate the intermediate piece and simply make the anchor bolt connection brittle and fracturable. Therefore, after examining several breakaway designs used on single support roadside structures, it was determined that the most feasible alternative would be to simply replace the existing anchor bolts with a bolt that was more brittle, smaller in diameter, and of a higher strength.

3.1 Initial Design

Due to the fact that mailboxes in use are constructed of steel, aluminum, and plastic, it was desired that the new anchor bolt be compatible with all three mailbox configurations. Therefore, the selections were narrowed to stainless steel and fiber reinforced plastics. Design calculations were made to determine the minimum bolt properties required to pass the 2.2-kN (500-lb) pull test specified by the USPS, with a safety factor of two.

3.1.1 Static Load Calculations

USPS specifications require that the CBU withstand a 2.2-kN (500-lb) load applied 914 mm (36 in.) above the base with less than 6-mm (1/4-in.) permanent set. The base is anchored by four bolts in a 102-mm by 254-mm (4-in. x 10-in.) rectangular pattern. It is assumed that the shear force is distributed among the four bolts, or 550 N/bolt (125 lb/bolt). This force is insignificant in comparison to the tensile force applied to two of the bolts due to the moment created by the 2.2-kN (500-lb) load applied 914 mm (36 in.) above the base. The resulting axial force for two bolts is calculated using Equation (1).

$$F_A = \frac{(2.2)(914)}{102} = 19.8\ kN\ (4450\ lbs) \quad \textbf{(1)}$$

This calculation is made in the most critical direction of loading on the mailbox base. As seen in Figure 1, the critical direction is the direction perpendicular to the flow of traffic in normal installations.

This force is distributed between the two bolts, resulting in a 9.9 kN (2250-lb) load per bolt. Equation (2) was used to calculate the safety factor for candidate anchor bolts with respect to this load condition.

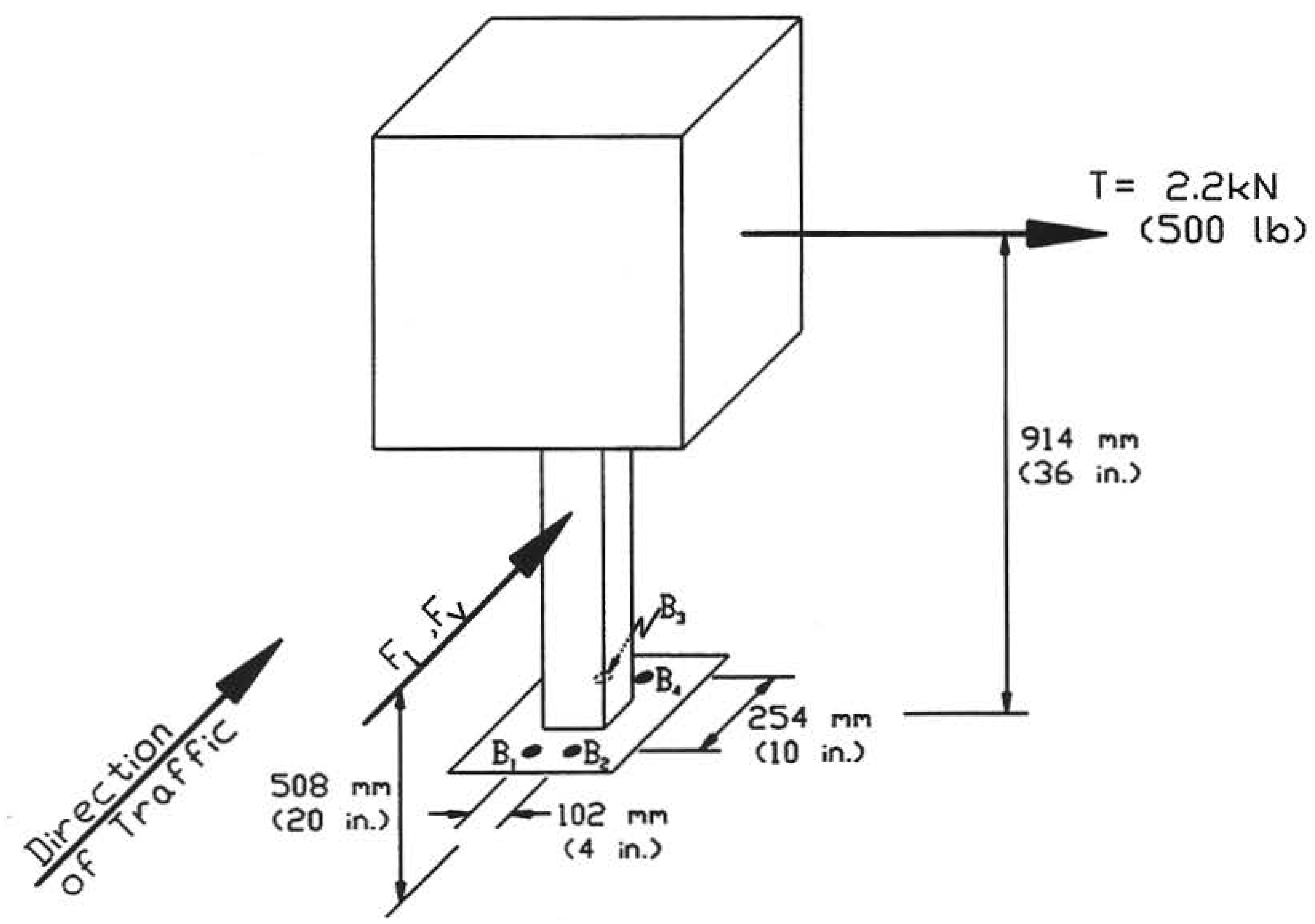


Figure 1. Design Loads on CBU.

$$S.F. = \frac{S_y A_t}{F_A} \tag{2}$$

In Equation (2), S_y is the yield stress of the material, and A_t is the tensile stress area of the bolt. This safety factor is summarized in Table 3 for various candidate anchor bolts.

3.1.2 Dynamic Load Calculations

The next objective was to obtain an approximation of the forces that would be imparted on an impacting car from the fracture of the anchor bolts. To compute this, the following assumptions are made: (1) the CBU is a rigid body; (2) the upstream bolts fail in tension first, as the mailbox pivots about the downstream bolts; and (3) following failure of the upstream bolts, the downstream bolts fail in shear.

Figure 1 shows the forces involved during an impact. F_I is the force required by the impacting vehicle to fail the bolts at B_1 and B_2 in tension. An approximate height of the bumper for many mini-compact cars is 508 mm (20 in.). Impact along the 254-mm (10-in.), longitudinal direction will impart the greatest impact force on the vehicle. An estimate of this force can be calculated using Equation (3). In Equation (3), S_u is the ultimate strength of the material.

$$F_I = \frac{(2\ bolts)(254\ mm)(S_u)(A_t)}{508\ mm} = S_u A_t \tag{3}$$

Assuming the bolts at B_1 and B_2 fail first in tension, the impacting vehicle then shears the two bolts at B_3 and B_4. The force F_V required to shear these two bolts is found using Equation (4).

$$F_V = (2\ bolts)(0.577)(S_u)(A_t) \tag{4}$$

The final calculation tabulated in Table 3 is the maximum deceleration on the vehicle. This is found by dividing the maximum force, either F_V or F_I, by 820 kg (1780 lb), or the mass of a small vehicle.

Table 3. Candidate Anchor Bolts

Material	Yield Strength S_y	Ultimate Strength S_u	% elongation	Bolt Size	Cost per foot[1]	Static Load S. F.	F_1	F_V	Vehicle Decel.
ASTM A193 B8M (316 SS)[2]	240 MPa (35 ksi)	(585 MPa) (85 ksi)	60%	13 mm (½ in.)		2.21	53 kN (12.0 kip)	62 kN (13.9 kip)	7.8 G's
Grade 410H[3] SS	620 MPa (90 ksi)	760 MPa (110 ksi)	18%	6 mm (1/4 in.)		1.27	15.6 kN (3.5 kip)	18 kN (4.0 kip)	2.2 G's
				8 mm (5/16 in.)	$4.95	2.10	25 kN (5.7 kip)	29 kN (6.6 kip)	3.7 G's
Grade 410HT[4] SS	825 MPa (120 ksi)	(1100 MPa) 160 ksi	12%	6 mm (1/4 in.)	$8.76	1.69	23 kN (5.1 kip)	26 kN (5.8 kip)	3.3 G's
Grade 416 SS	550 MPa (80 ksi)	620 MPa (90 ksi)	15%	6 mm (1/4 in.)		1.13	13 kN (2.9 kip)	15 kN (3.3 kip)	1.8 G's
				8 mm (5/16 in.)	$10.25	1.86	21 kN (4.7 kip)	24 kN (5.4 kip)	3.0 G's
Grade 316SH[5] SS	620 MPa (90 ksi)	790 MPa (115 ksi)	12%	8 mm (5/16 in.)	$6.50	2.10	27 kN (6.0 kip)	31 kN (6.9 kip)	3.9 G's
Grade 8 Steel Bolt	825 MPa (120 ksi)[6]	1030 MPa (150 ksi)	10-20%	5 mm (No. 12)		1.29	26 kN (3.6 kip)	19 kN (4.2 kip)	2.3 G's
				6 mm (1/4 in.)		1.70	21 kN (4.8 kip)	24 kN (5.5 kip)	3.1 G's
				8 mm (5/16 in.)		2.79	35 kN (7.9 kip)	40 kN (9.1 kip)	5.0 G's
FIBREBOLT® MMFG Co.	13.8 kN (3100 lb)	17 kN tension (3790 lb) 55 MPa shear (8 ksi)	?	16 mm (5/8 in.)		1.38	17 kN (3.8 kip)	8 kN (1.8 kip)	1.0 G's
	20 kN (4500 lb)	23 kN tension (5150 lb) 55 MPa shear (8 ksi)	?	19 mm (3/4 in.)	$3.57 $1.77/nut	2.0	23 kN (5.2 kip)	12 kN (2.7 kip)	1.5 G's

[1]Cost for purchasing small quantities in 1.83-m (6-ft) lengths.
[2]Material currently used in the anchor bolts.
[3]H-Hardened and tempered at 565°C (1050°F) minimum.
[4]HT-Hardened and tempered at 274°C (525°F) minimum.
[5]SH-Machined from strain hardened stock.
[6]Used proof strength for this material.

3.2 Anchor Bolt Material Alternatives

The new anchor bolts should consist of stainless steel or fiber reinforced plastic, so that the anchor bolts could be used on the CBU systems with steel, aluminum, and plastic pedestals without the possibility of galvanic corrosion. After polling vendors across the Midwest, the following alternatives were found to be readily available and were selected for bogie testing. Bolt size and material selection was made on the basis of the design calculations summarized in Table 3.

- 5/16 in. dia. Grade 416 Stainless Steel: S_y=551 MPa (80 ksi), S_u=620 MPa (90 ksi), 15% elongation.
- 5/16 in. dia. Grade 410H Stainless Steel: S_y=620 MPa (90 ksi), S_u=760 MPa (110 ksi), 18% elongation.
- 1/4 in. dia. Grade 410HT Stainless Steel: S_y=825 MPa (120 ksi), S_u=1100 MPa (160 ksi), 12% elongation
- 3/4 in. dia. MMFG FibreBolt: S_y=20 kN (4,500 lb) in *tension*, S_u=23 kN (5150 lb) in *tension* and 55 MPa (8 ksi) in *shear*.

3.3 Embedment Options

For retrofitting existing CBU's, or for installing CBU's on existing concrete pedestals, the most effective method of fixing the anchor bolts is to use a chemical embedment procedure. Using chemical embedment options, the anchor bolts can be installed in existing concrete pedestals by drilling a hole in the concrete, and partially filling the hole with the chemical mixture. By properly installing the threaded anchor bolts into the hole, the chemical adhesive hardens and after allowing a proper curing time, the chemical adhesive develops the full strength of the concrete as well as the anchor. Various chemical embedment options are shown in Table 4.

Chemical embedment options were selected over mechanical/expansion anchors due to several factors. First, the 8-mm (5/16-in.) diameter mechanical anchors that are available cannot develop the ultimate tensile capacity of the anchor bolt material used in this design. Second, products from several companies were investigated such as DWYIDAG Systems International, Williams Form Engineering Corp., HILTI, Ramset/Red Head, and Rawl. Most suppliers start with an anchor for 10-mm (3/8-in.) diameter rods and bolts.

The standard method of cast-in-place anchor bolts also can be used in locations where new footings are constructed. Modifications to the anchor bolt for this situation are discussed in Chapter 8.

Table 4. Chemical Embedment Options for Stainless Steel Threaded Rods

Vendor	Chemical Option	Threaded Rod					Epoxy Tensile Properties			
		Material[1]	Length mm (in.)	Dia. mm (in.)	Embedment Depth mm (in.)	Hole Size mm (in.)	Ultimate Bond Strength MPa (ksi)	Tensile Strength MPa (ksi)	Elonga-tion at Break (%)	Modulus of Elasticity MPa (ksi)
Sika Corp.	Sikadur 32, Hi-Mod	316SH SS	152 (6)	8 (5/16)	127 (5)	11 (7/16)	13 (1.9)[3] 17 (2.4)[4]	35.1 (5.1)[7]	1.8[7]	2200 (320)[8]
	Sikadur 31, Hi-Mod Gel	316SH SS	152 (6)	8 (5/16)	127 (5)	11 (7/16)	17[6] (2.4)	24.8 (3.6)[8]	0.4[8]	2690 (390)[7] 5170 (750)[8]
	Sikadur Injection Gel	316SH SS	152 (6)	8 (5/16)	127 (5)	11 (7/16)	18 (2.6)[5] 18 (2.6)[6]	37.2 (5.4)[8]	1.3[8]	1860 (270)[7] 2820 (410)[8]
HILTI	HEA Adhesive Capsule 9.5 mm ϕ x 89 mm long	316SH SS	152 (6)[2]	8 (5/16)	127 (5)	12 (15/32)	≈54 kN (12 kip)			
	HY150 Adhesive	316SH SS	152 (6)	8 (5/16)	127 (5)	9.5 (3/8)	≈34 kN (7.6 kip)			3445 (500)
Rawl	Foil-Fast Injection Gel Cartridge System[9]	316SH SS	152 (6)	8 (5/16)	127 (5)	9.5 (3/8)	≈35 kN (7.9 kip)			

[1] - Material specification is currently under investigation and may include several 400 series stainless steels (i.e., 410, 416, and 422) specification. Note that 316SH designates the strain-hardened variety of 316 stainless steel (S_y = 620 MPa (90 ksi), S_u = 790 MPa (115 ksi), elongation=12%).
[2] - The 6-in. long rod must include a double wedge-type bevel on one end and used to properly install the HEA adhesive capsule.
[3] - 14 day (moist cure) - plastic concrete to steel.
[4] - 14 day (moist cure) - plastic concrete to hardened concrete.
[5] - 14 day (moist cure) - hardened concrete to steel.
[6] - 14 day (moist cure) - hardened concrete to hardened concrete.
[7] - 7 day property.
[8] - 14 day property.
[9] - Rawl uses Sikadur Injection Gel in a cartridge system.

4 BOGIE TESTING

Twelve bogie tests were performed at 35 km/h (22 mph) on four anchor bolt configurations. A "bogie" pedestal, which is shown in Figure 2, was fabricated from standard 4-in by 6-in. steel tubing and used to simulate the geometry of an actual CBU pedestal. A 55-lb weight was attached 12 inches above the top of the pedestal with plywood, to simulate the presence of a mailbox at the appropriate center of mass. The 140-mm (5.5-in.) long anchor bolts were epoxied 114 mm (4.5 in.) deep into a concrete base and set with a structural adhesive that conformed to ASTM C-881 and AASHTO M-235 specifications (Sikudar 32, Hi-Mod) (4).

The "bogie" bases were then impacted with an 827-kg (1800-lb) bogie vehicle having a bumper height of 533 mm (21 in.), and a vehicle speed of 35 km/h (21.8 mph). Results of the tests are documented in the Table 5. and in Appendix C.

It should be noted that the TTI test was conducted at 100.2 km/h (62.3 mph) instead of 35 km/h (21.8 mph), however for a breakaway roadside device such as this, the slow speed test is probably a better indicator of the safety performance of the breakaway mechanism itself, due to the lower kinetic energy present in the impacting vehicle. The lower energy level present in a vehicle at low speeds could result in a higher change in velocity after fracturing the anchor bolts. Regardless, from the change in velocity, it can be seen that the new design alternatives are much less severe.

The failure mode described in Table 5, describes how the "bogie" base fails upon impact in each test. Illustrations of this failure mode are show in Figures 3 and 4. Ten of the bogie tests failed in the bending mode, in which the base of the pedestal rotated about its front lip, while two of the tests failed in the shear mode. Change in velocities for these two modes were relatively equal, and the conditions that produced a different failure mode were unknown. The TTI full-scale test exhibited extreme bending about the base of the pedestal, which contributed to the high decelerations, change in velocity, and yaw angle that was present in the test.

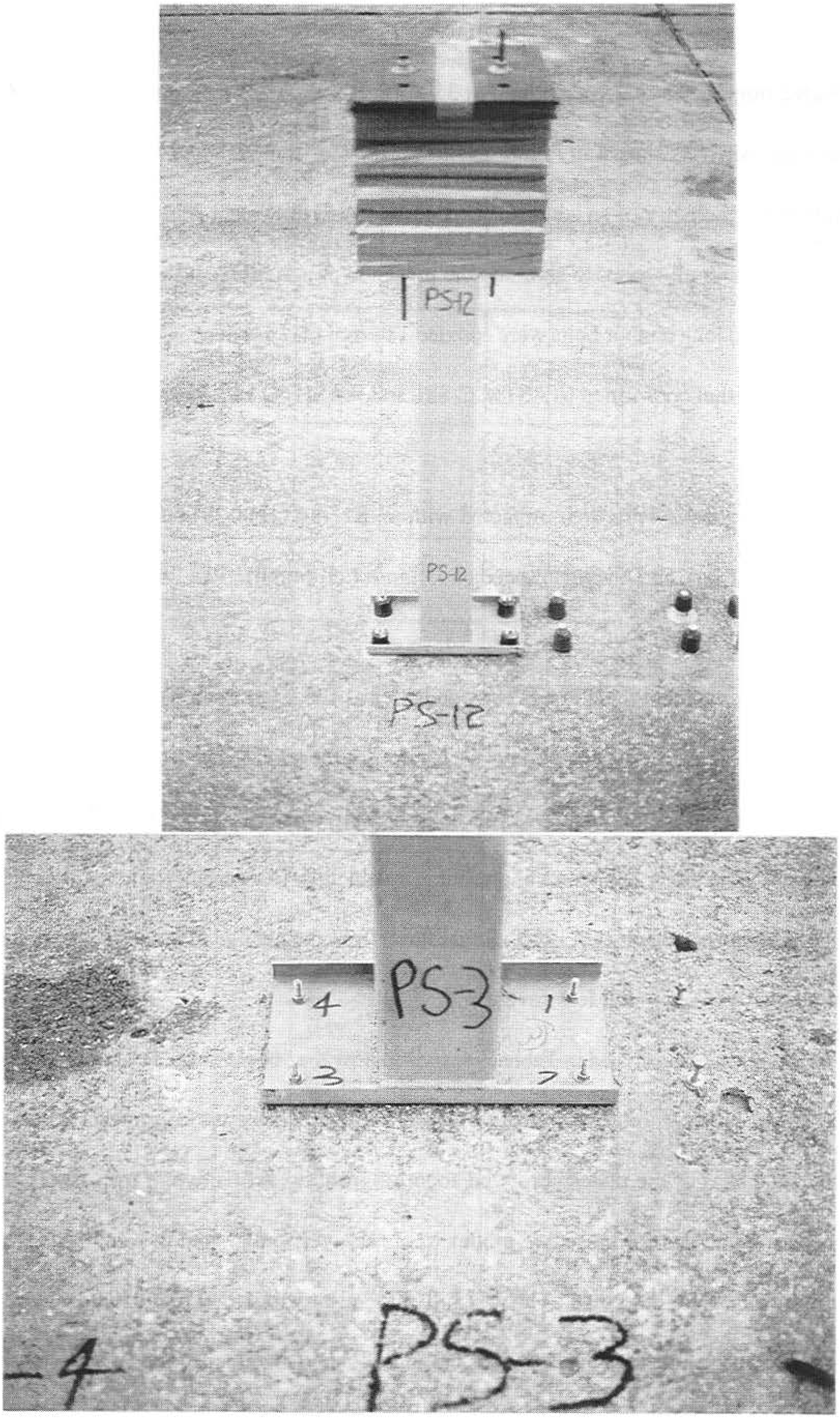


Figure 2. "Bogie" Pedestal and Anchor Bolt Closeup

Table 5. Bogie Test Results

Anchor Bolt Material	Test	50 ms Deceleration g's	Change in Velocity m/s (fps)	Base Failure Condition
1/4-in. Grade 410HT Stainless Steel	PS-1	6.6	0.7 (2.3)	Shear
	PS-2	6.8	1.1 (3.6)	Bending
	PS-3	6.8	1.1 (3.6)	Bending
5/16-in. Grade 410H Stainless Steel	PS-4	6.8	1.3 (4.3)	Bending
	PS-5	6.8	1.3 (4.3)	Bending
	PS-6	5.0	1.4 (4.6)	Bending
5/16-in. Grade 416 Stainless Steel	PS-7	6.6	1.6 (5.2)	Bending
	PS-8	6.9	1.3 (4.3)	Bending
	PS-9	6.5	1.0 (3.3)	Shear
3/4-in. FIBREBOLT	PS-10	6.8	1.3 (4.3)	Bending
	PS-11	6.0	1.5 (4.9)	Bending
	PS-12	6.8	1.1 (3.6)	Bending
TTI Test Results ½-in. 304 SS (2)	***2343-1***	***7.4***	***4.7 (15.5)***	***Extreme Bending***

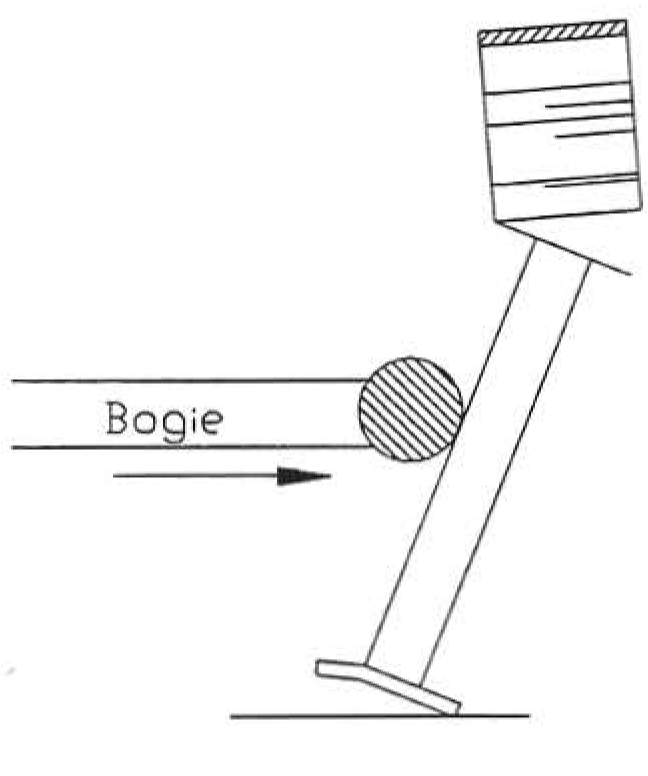


Figure 3. Bending Failure Mode.

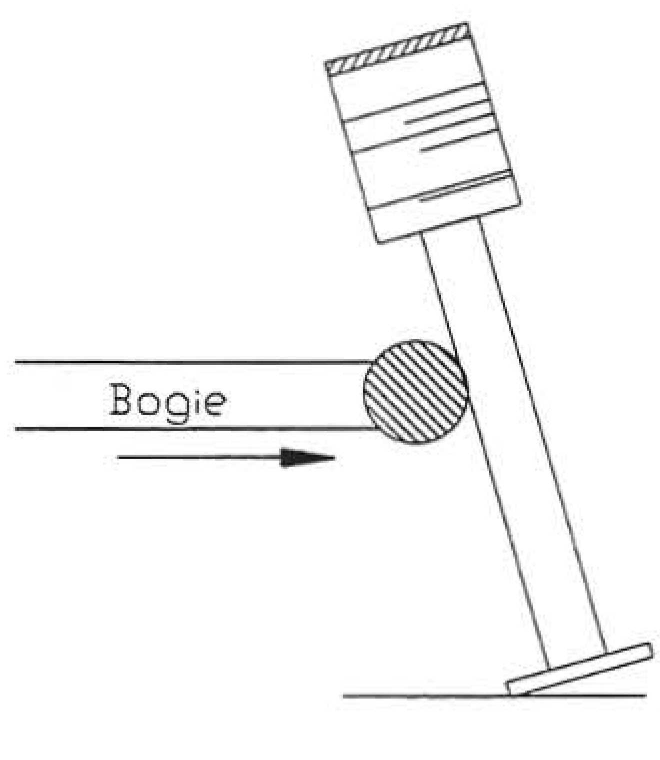


Figure 4. Shear Failure Mode.

4.1 Material Selection

Due to the fact that all four alternatives fractured in a relatively similar manner and at a relatively similar force level, additional criterion were used to select the best alternative for the anchor bolt material. The FIBREBOLT was eliminated due to the fact that the threads could be damaged easily during handling, as the surface of the material was too brittle. The fibre-reinforced plastic material did not provide any additional advantages to outweigh the problems involved in handling and acquisition.

The 6-mm (1/4-in.) Grade 410HT SS was eliminated due to the fact that its small relative size could create perception problems in the field. In addition, the smaller bolt could present problems in installation and adaption to existing bases. Like the fibre-reinforced plastic bolt, this smaller diameter bolt did not provide any advantages to outweigh the potential problems that may occur in its use.

5 STATIC TESTING

To verify the structural integrity of the cluster box unit and its anchor, static pull tests were performed on the CBU's according to USPS-B-1118E 3.5.12. The test required that a load of 2.2 kN (500 lbs) be applied against each side of the unit with the pedestal fixed at the base and the box secured to the pedestal. The horizontal load was applied by a strap placed around the box 914 mm (36 in.) above the pedestal base. The USPS specification requires, that when the load is released, the unit shall return to within 6 mm (1/4 in.) of its original horizontal location, as measured 762 mm (30 in.) above the pedestal base.

5.1 Test Setup and Data Acquisition

Figure 5 shows the general setup for the static pull tests. A hydraulic cylinder was used to provide a horizontal force at a height of 914 mm (36 in.) above the ground. For the steel NDCBU's, the bottom of the box was only 787 mm (31 in.), so the displacement was measured at a height 787 mm (31 in.) above the ground. A 44.5 kN (10 kip) load cell was placed in series with the cable that was attached to the cylinder to record the force level being applied on the box. A string potentiometer was fixed to the bottom of the box to record the displacement of the box as the force was applied. The string potentiometer was also used to measure the permanent set in the system after the load was released.

USPS-B-1118E 3.5.12. requires that the structural integrity be checked in each direction. To satisfy this, each box tested was pulled in both the longitudinal direction, where $d = 25.4$ cm (10 in.), and the more critical lateral direction where $d = 10.2$ cm (4 in.). In addition, each box tested was pulled until failure in the critical, lateral direction to investigate the safety factor on the design, and to get a more complete view of the structural integrity of the system.

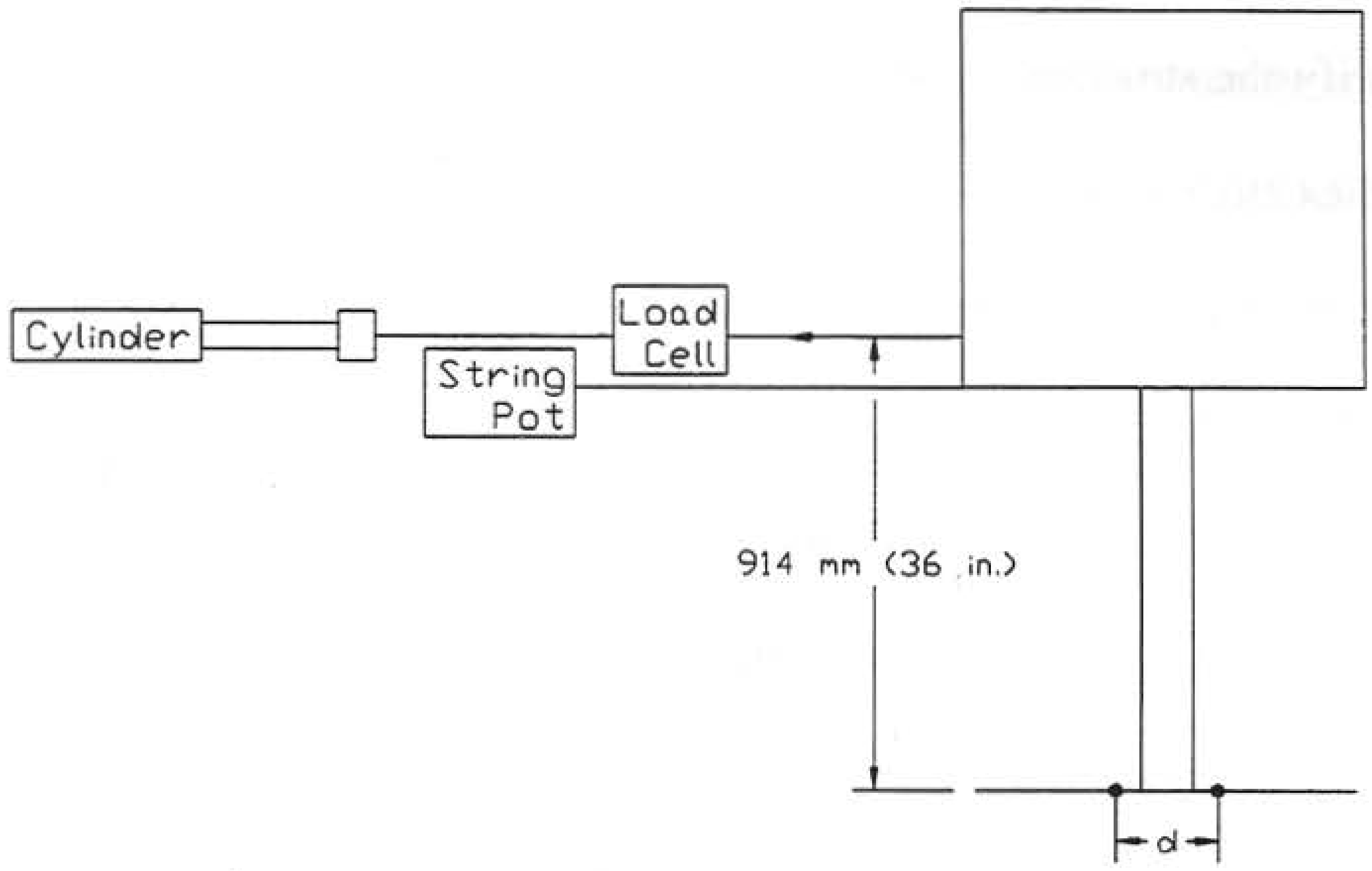


Figure 5. Static Test Setup.

5.2 Static Test Results

Table 5 summarizes the results of the static testing. The table summarizes the anchor bolt material used in each test as well as the epoxy used to fix the anchor bolts into the concrete slab. Tests designated *A* and *B* were the standard structural integrity tests specified in USPS-B-1118E 3.5.12., while the tests designated *C*, were the ultimate load tests to failure. All three tests were performed on the same box installation. The box type listed in Table 5 refers to the CBU designation mounted at the test installation. For example, *St. III*, indicates that a Type III Steel NDCBU was tested. Peak force is the maximum force that the installation was subjected to during the loading. For the structural integrity tests, the final deflection is the permanent set of the system after the load was removed. For the tests to failure, the final deflection is the total deflection at failure. Load deflection curves are shown in Appendix D for the static tests to failure.

The static tests were also performed to investigate different alternatives for epoxies listed in Table 4. All tests passed the structural integrity test except the HILTI HEA Adhesive Capsule option, however, it is noted that the capsule was used in a manner for which it was not designed. The capsule was designed for 10-mm (3/8-in.) diameter rods, not the 8-mm (5/16-in.) rods that were used. Also, the hole in the concrete was specified to be drilled at 10.9 mm (15/32 in.) diameter, but the hole was actually drilled at 12.7 mm (½ in.). Therefore, it was highly possible that the test configuration requires more bonding agent than was provided by the capsule due to more void space around the anchor bolt.

During the tests to failure, the anchor bolts were the first components to fail in the steel NDCBU's that were tested. The anchor bolts did not fail in the tests to failure of the aluminum and plastic CBU's, rather the pedestal on the respective boxes experienced the failure.

On the aluminum Type II CBU, Test PSS-5C, the pedestal was configured with plates bolted, rather than welded, to the top and bottom of the column. The bolts that secured the pedestal column to the pedestal plate failed in tension as the load reached the maximum value of 7.0 kN (1580 lbs). The failure mode of this aluminum pedestal is shown in Figure 6.

On the plastic Type III CBU, Test PSS-6C, the molded fibre-reinforced plastic pedestal fractured at the section that bolts the mailbox unit to the pedestal. This fracture mode and location are shown in Figure 7. The CBU was under a static load of 1.6 kN (1717 lbs) when the pedestal fractured.

Table 6. Static Test Results

Test	Bolt Material	Epoxy	Box Type	Test/ Direction	Peak Force kN (lbs)	Final Deflection mm (in.)	Remarks
PSS-1A	410H	Sika	St. III	Longit.	2.2 (502)	1.0 (0.04)	Passed structural integrity test
PSS-1B	410H	Sika	St. III	Lateral	2.3 (510)	1.0 (0.04)	Passed structural integrity test
PSS-1C	410H	Sika	St. III	Fail/Lat.	5.5 (1230)	101 (4.0)	Downstream bolts failed in tension
PSS-2A	316SH	Rawl	St. II	Longit.	2.1 (473)	0.2 (0.01)	Passed structural integrity test
PSS-2B	316SH	Rawl	St. II	Lateral	2.5 (567)	0.2 (0.01)	Passed structural integrity test
PSS-2C	316SH	Rawl	St. II	Fail/Lat.	7.2 (1619)	220 (8.6)	Downstream bolts failed in tension
PSS-3A	316SH	Hilti	St. II	Longit.	2.1 (472)	0.2 (0.01)	Passed structural integrity test
PSS-3B	316SH	Hilti	St. II	Lateral	2.4 (531)	0.5 (0.02)	Passed structural integrity test
PSS-3C	316SH	Hilti	St. II	Fail/Lat.	7.6 (1717)	240 (9.5)	Downstream bolts failed in tension
PSS-4A	316SH	Capsule	St. II	Longit.	2.4 (571)	1.0 (0.04)	Passed structural integrity test
PSS-4B	316SH	Capsule	St. II	Lateral	1.4 (324)	N/A	Bolt pulled out of epoxy capsule- failed structural integrity test
PSS-5A	316SH	Rawl	Al. II	Longit.	2.5 (553)	0.5 (0.02)	Passed structural integrity test
PSS-5B	316SH	Rawl	Al. II	Lateral	2.4 (544)	1.3 (0.05)	Passed structural integrity test
PSS-5C	316SH	Rawl	Al. II	Fail/Lat.	7.0 (1580)	107 (4.2)	Screw failure in aluminum pedestal.
PSS-6A	316SH	Rawl	Pl. III	Longit.	2.5 (552)	0.2 (0.01)	Passed structural integrity test
PSS-6B	316SH	Rawl	Pl. III	Lateral	2.5 (566)	3.8 (0.13)	Passed structural integrity test
PSS-6C	316SH	Rawl	Pl. III	Fail/Lat.	7.6 (1717)	66 (2.6)	Plastic pedestal fractured

Epoxy References:
Sika - Sikadur 32, Hi-Mod
Rawl - Rawl-Foil-Fast Injection Gel Cartridge System
Hilti - HILTI-HY150 Adhesive
Capsule - HILTI-HEA Adhesive Capsule (3/8-in. dia. X 3½-in. long)

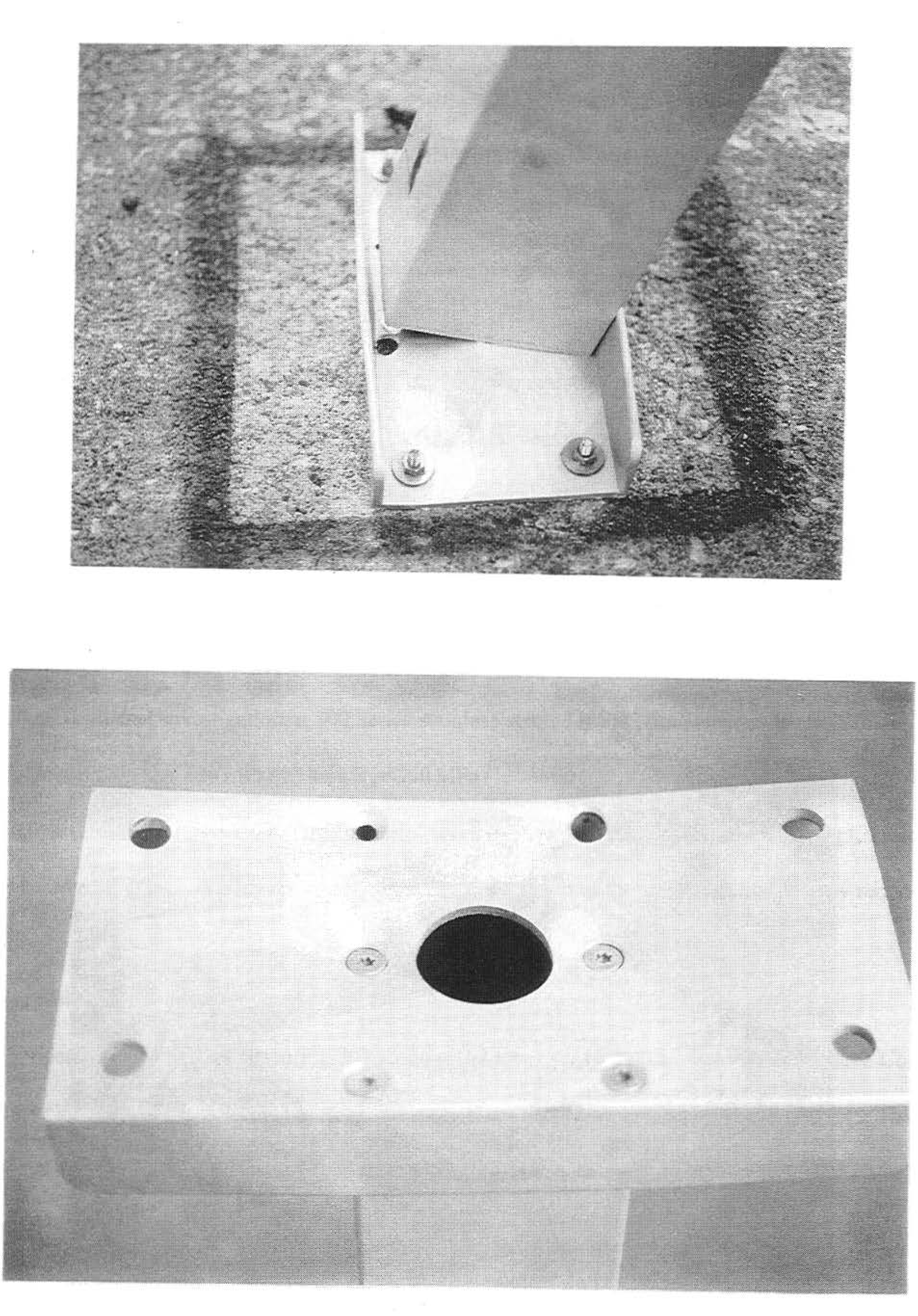


Figure 6. Bolt Failure on Aluminum CBU Pedestal During Static Test

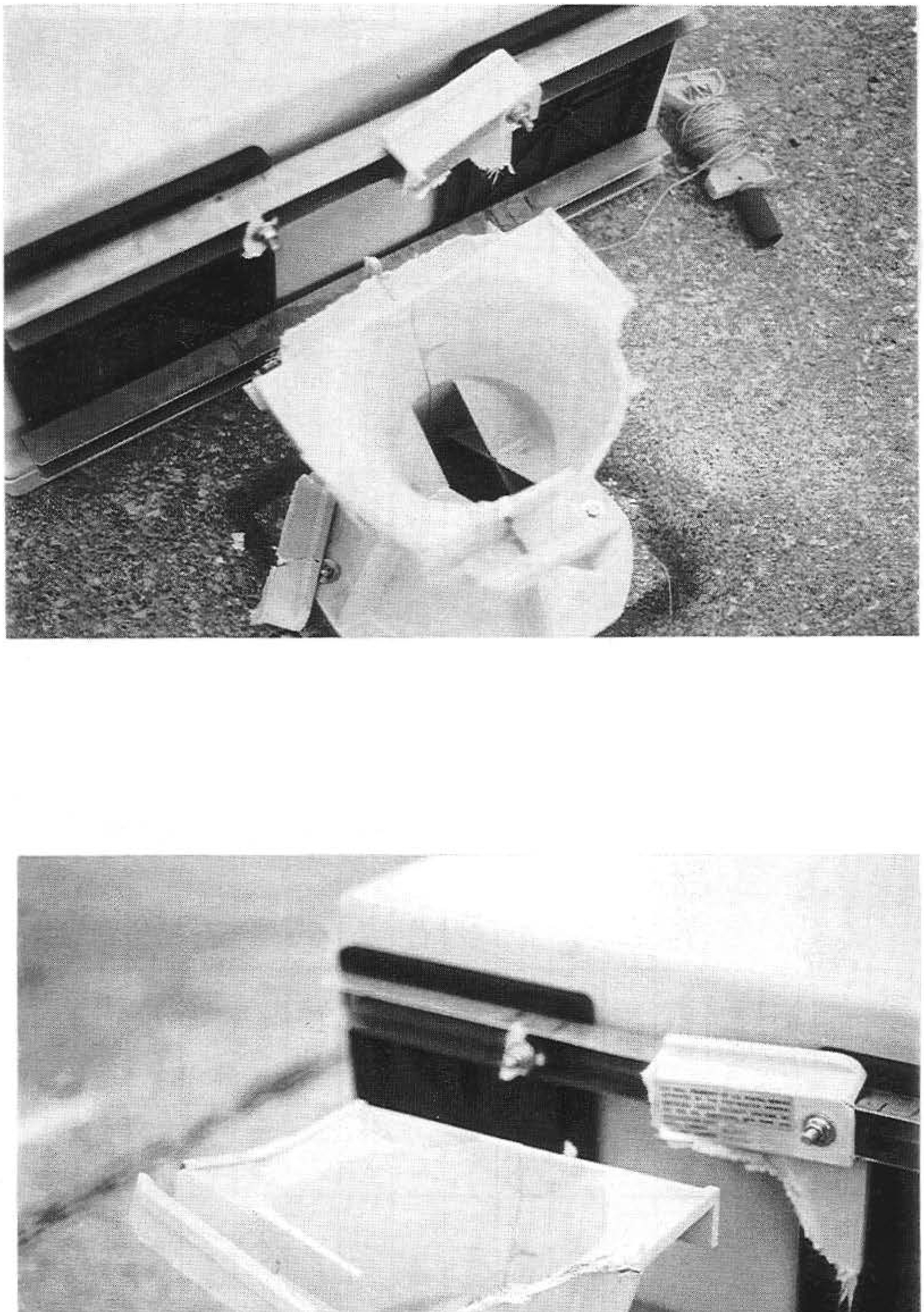


Figure 7. Fracture of Plastic CBU Pedestal During Static Tests.

6 CORROSION TESTS

To demonstrate that the breakaway base will stand up to the corrosive environment that is present on roadways, salt spray tests were conducted according to USPS-B-1118E3.5.11 on the three different types of bases: steel, aluminum, and plastic using 316SH stainless steel anchor bolts cast in place.

6.1 Corrosion Resistance of Candidate Anchor Bolt Materials

A review of industry manuals on stainless steel (5) shows that the 400 series martensitic stainless steels initially chosen in this study may not be as corrosion resistant as the 300 series austenitic stainless steels currently being used by the USPS. The 300 series stainless steels contain 8-14% nickel as well as 17-20% chromium. The presence of nickel in the 300 series stainless steels give them a greater corrosion resistance than the 400 series steel which contain no nickel and only 11-14% chromium. However, due to the availability of the 400 series stainless steels, it was considered critical that it be used for the initial testing to establish the validity of this breakaway base design; since they met strength and ductility requirements.

After further investigation, a 300 series stainless steel, 316SH (strain-hardened) was found with physical properties (S_y = 620 MPa (90 ksi), S_u = 790 MPa (115 ksi), 12% elongation) similar to the 400 series materials tested in the bogie tests. This material was used for the anchor bolts in the static pull tests. It should be noted that the strain hardening that increases the strength of the stainless steel slightly reduces its corrosion resistance.

6.2 Corrosion Test Setup

Four concrete blocks measuring 203 x 356 x 102 mm (8 x 14 x 4 in.) were sent to Artech Corp. in Chantilly, Virginia to conduct the 500 hour salt spray tests, according to USPS-B-1118E3.5.11. Three of the blocks contained four 316SH stainless steel anchor bolts in a standard 102 x 254-mm (4 x 10-in.) bolt pattern. Two of the four anchor bolts were cast into place in the concrete, and two of them were epoxied into the block using Rawl-Foil-Fast Injection Gel. A steel, aluminum, and plastic pedestal was bolted to the top of the three blocks with a 316SH stainless steel nut and retrofit washer, which will be discussed in Chapter

8. The fourth block had twelve bolts, consisting of three rows of four of 316SH, 410H, and 416 anchors cast in place into the concrete. The fourth block was used for the purpose of comparing the corrosion resistance of the three materials.

6.3 Corrosion Test Results

Following the completion of the 500 hour salt fog test, Artech Corp. sent a letter describing the results of the tests, the letter is shown in Appendix E. Photographs were taken of the four blocks, and are shown in Appendix F.

The block containing the steel pedestal had no rust or corrosion on the pedestal or hardware holding the pedestal to the concrete block. The anchor bolts in the blocks containing the aluminum and plastic pedestals had a small amount of red rust visible on the bolt tops, where the bolts had been cut to length.

The fourth block containing the three different bolt materials showed the difference in response of each material to the salt fog exposure. The 316SH bolts were reported to have no visible rust. However, the 410H and 416 stainless steel bolts had penetrating rust in the threads and on the faces of the nuts. The rust was worse on areas of stressed metal, such as threads.

Because of the corrosion present in the 400 series stainless steel bolts, it is recommended that 316SH stainless steel be used as the anchor bolt material.

The Rawl-Foil-Fast Injection Gel epoxy, used to attach selected anchor bolts to the concrete blocks, was not affected by the salt spray test.

7. FEA SIMULATION

Finite element analysis (FEA) was used to predict the results of full-scale vehicle crash tests into a CBU. By impacting the CBU with a mini-compact car model, we can observe how the design changes made to the CBU anchor bolts will affect its safety performance. The accuracy of the FEA model of the anchor bolts was verified by comparing the simulation results with the bogie test results discussed in Chapter 4. Behavior of the system as a whole was validated by making a FEA model simulating the full-scale test conducted by TTI in 1984 (2).

LS-DYNA3D, a nonlinear, explicit finite element code was used in the simulation of the impact. Because of its advanced sliding interfaces and shell element formulation algorithms, LS-DYNA3D is an excellent tool for simulating the impact conditions of a moving vehicle.

7.1 Bogie Test Simulation

The first step in creating an accurate model of the CBU system is to get a valid model of the anchor bolts used to secure the base to the concrete footing. To validate the anchor bolt model, an FEA model of the bogie tests discussed in Chapter 4 was constructed. To model the pedestal base and anchor bolts, fully integrated, selectively reduced solid elements were used, Figure 8 shows the bolt model. The fully integrated solid element formulation was required in order to eliminate zero energy modes in the simulation (6). The bolts were given the material properties of 410H stainless steel described in Table 3.

The pedestal, modeled using shell elements, was impacted by an FEA model of the bogie vehicle. Point masses were used to simulate the presence of weight on top of the wood block. The wood block was modeled using solid elements.

The bogie vehicle model was obtained from the FHWA (Federal Highway Administration). The bogie model was modified to have the same impactor as used in the physical bogie tests.

Sequential views of the bogie simulation are shown in Figure 9. The mode of failure exhibited in the simulation compared with the physical tests very well, as shown by comparing the simulation results with

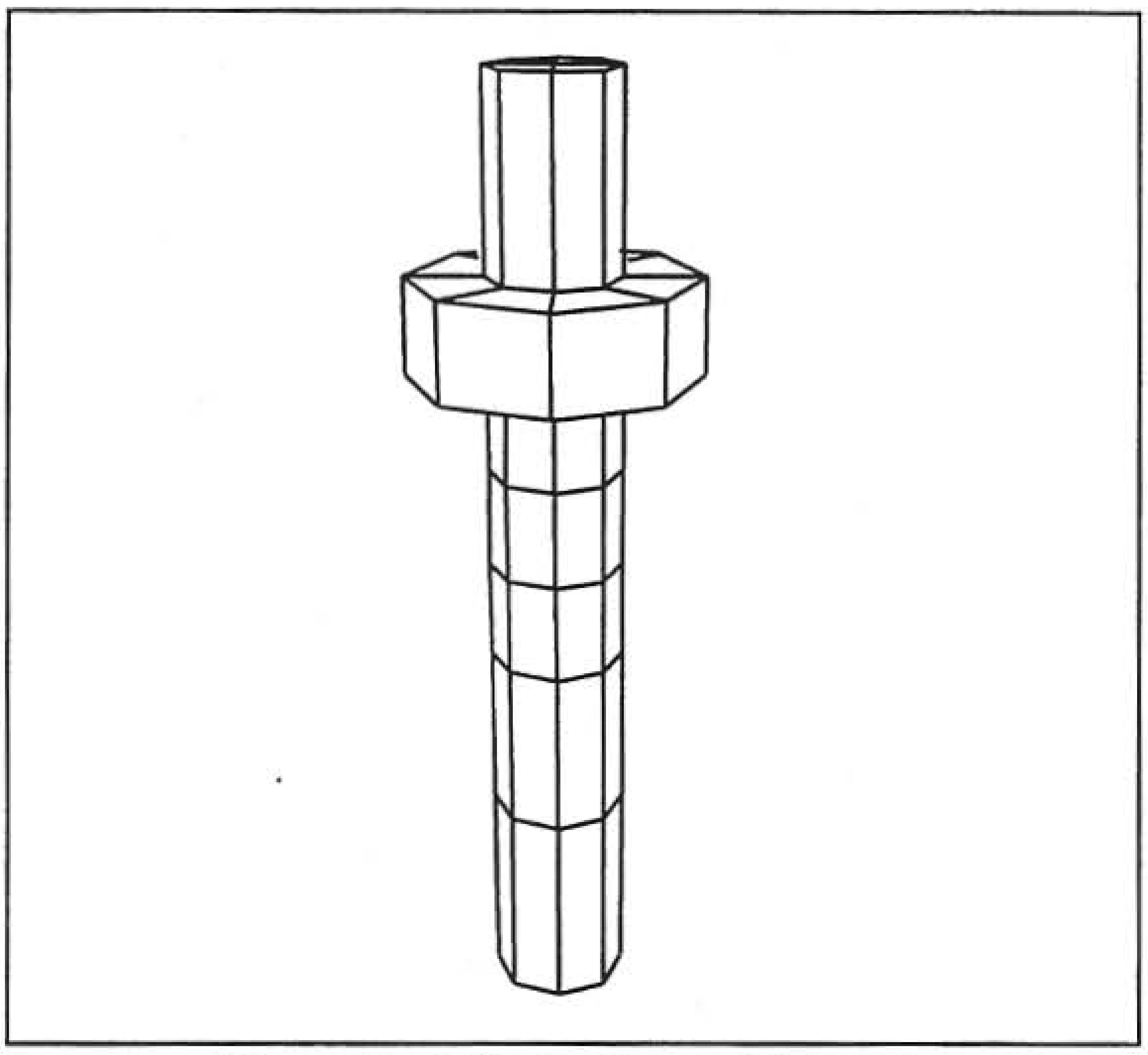


Figure 8. FEA Anchor Bolt Model.

Figure 3. In addition, the acceleration and change of velocity of the bogie vehicle in the simulation compared very well with the values in Table 5, the 50 ms average of the acceleration trace was 5.1 G's in the simulation and the change in velocity was 1.1 m/s (3.5 ft/sec).

7.2 Simulation of TTI Full Scale Crash Test

The next step in the FEA simulation of the CBU was to model the 100.2 km/h (62.3 mph) crash test conducted by TTI in 1984. Goals of this study were to obtain acceleration data and yaw angle data. In addition, it was desired that the mailbox fly apart in a similar manner as the actual TTI test. Successful simulation of the TTI test provided a baseline model that demonstrated that the FEA model was accurate to a certain degree. From there predictions were made with a relative degree of certainty about the safety performance of the CBU with modified anchor bolts.

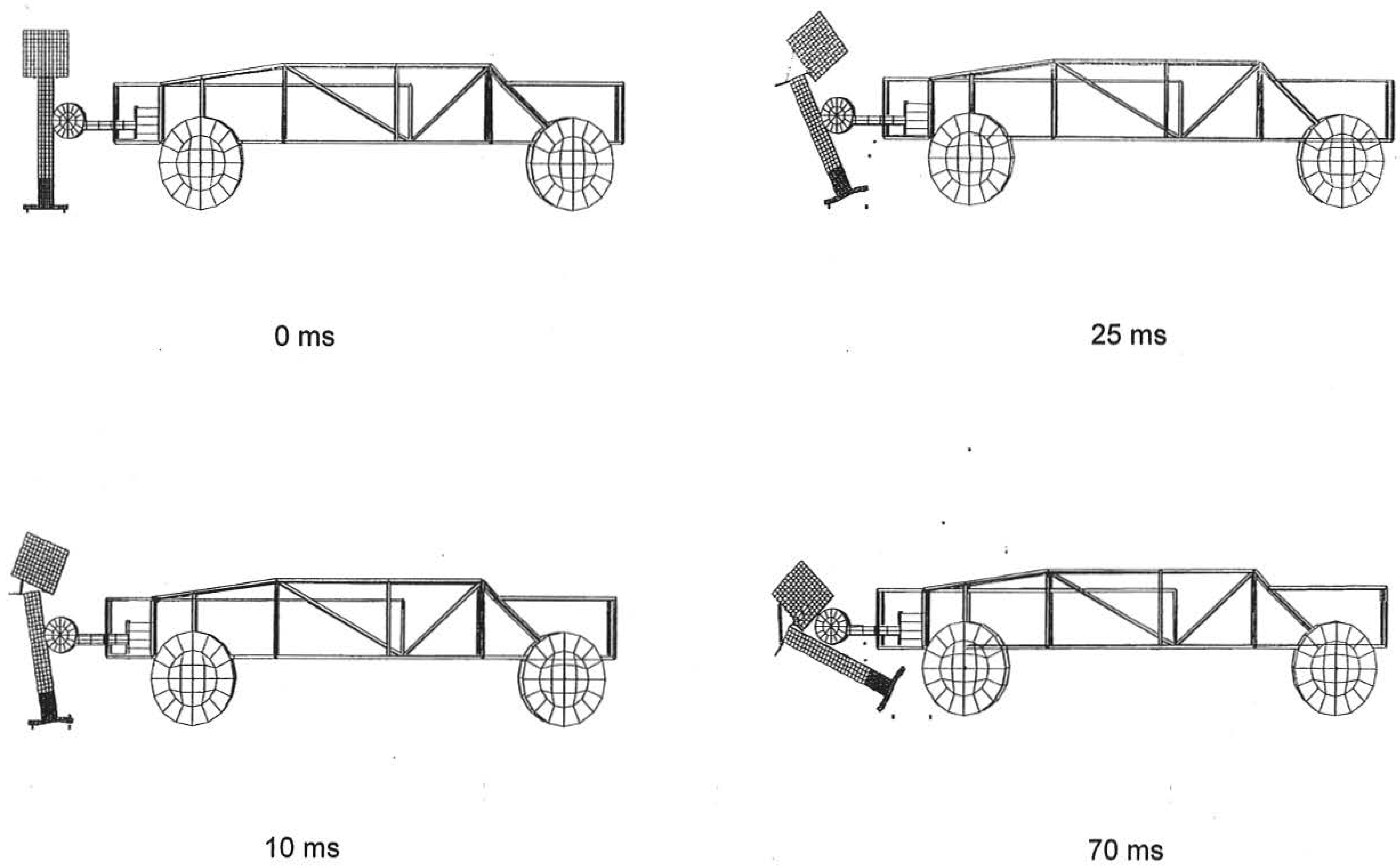


Figure 9. Sequence of Bogie Simulation.

Since the main contributor to the vehicle rollover in the TTI test was the introduction of a large yaw angle in the impacting car, it was desired that the yaw angle of the car model be examined after impact. However, the car model used in the simulations was designed to investigate vehicle deformation in a front end collision, and not necessarily the vehicle dynamics due to weaknesses in the suspension and tire models. Nonetheless, a relatively good comparison was made in the yaw angle obtained in this baseline model test; therefore, any yaw angles measured in subsequent simulations could be used in analyzing the safety performance of new designs.

7.2.1 FEA Model Description

Exact design specifications were not available on the Type III NDCBU used in the TTI test, so close approximations were made in modeling the geometry of the structure. Fully integrated solid elements were used to model the 305-mm x 305-mm x 4.8-mm (12-in. x 12-in. x 3/16-in.) flat steel base used in the test. The 12.7-mm (½-in.) diameter anchor bolts were modeled in a manner similar to the bolt model used in the bogie tests. The bolts in this test were given the material properties of ASTM A193 stainless steel described in Table 3.

The pedestal used in the test consisted of 89-mm (3.5-in.) square, structural steel tubing. This was modeled using shell elements of mild carbon steel. On top of the pedestal, a 16 box unit was mounted with dimensions of 545 mm x 670 mm x 610 mm (21.5 in. x 26.5 in. x 24 in.). Nodal point constraints were placed at various locations in the box to model the rivets that hold the box together. These constraints were prescribed to fail at a level twice as large as the manufacturers specified load capacity of the rivets. Using twice the specified capacity reduced the errors that are introduced by spiking force levels that are present in explicit integration techniques for impact simulation.

The NDCBU model was impacted with a finite element model of a Honda Civic obtained from Lawrence Livermore National Laboratories. Since a majority of the impact occurs at the front end of the car, it was relatively finely detailed. The rear of the car was consolidated into a less detailed rigid body. The vehicle model impacted the NDCBU at 100.2 km/h (62.3 mph) offset 1/4-point to the passenger's side, like the impact conditions in the TTI crash test.

7.2.2 Simulation Results

Figure 10 shows the sequential views of the FEA model of the TTI test. Time/event correlation matches very well with the full scale crash test, as well as accelerometer data. The simulation had a maximum 50 ms deceleration of 6.8 G's and a change in velocity of 3.4 m/s (11.1 ft/s). The actual crash test had a maximum 50 ms deceleration of 7.4 G's and a change in velocity of 4.7 m/s (15.5 ft/s). The discrepancy in the change in velocity arises largely from the fact that the simulation was terminated at 150 ms, and the vehicle continues to decelerate after that point. At 150 ms, the vehicle model has a yaw angle of 8 degrees, which is the approximate yaw angle reported at this time in the vehicle crash test report (2).

7.3 NDCBU Simulation

Following the creation of the two validation models, FEA could be used to predict the behavior of a Type III NDCBU under an impact and examine the effects of the design changes to the anchor bolts. The behavior of the NDCBU was studied by impacting it at two different speeds, 100 km/h (62 mph) and 35 km/h (22 mph).

7.3.1 NDCBU Model Description

Since complete design plans were available for the NDCBU, the FEA model of it was constructed as accurately as possible. As in the bogie tests, fully integrated solid elements were used to model the base of the pedestal and the anchor bolts, the anchor bolts were given the material properties of 410H stainless steel. The body of the pedestal was modeled using shell elements with mild steel properties. The components of the 16 box Type III NDCBU were modeled as close to the design plans as possible. As in the TTI simulation, nodal constraints were used to model the rivets that held the box together. Similarly, the rivets were given failure criteria which was twice as large as the manufacturers load capacity.

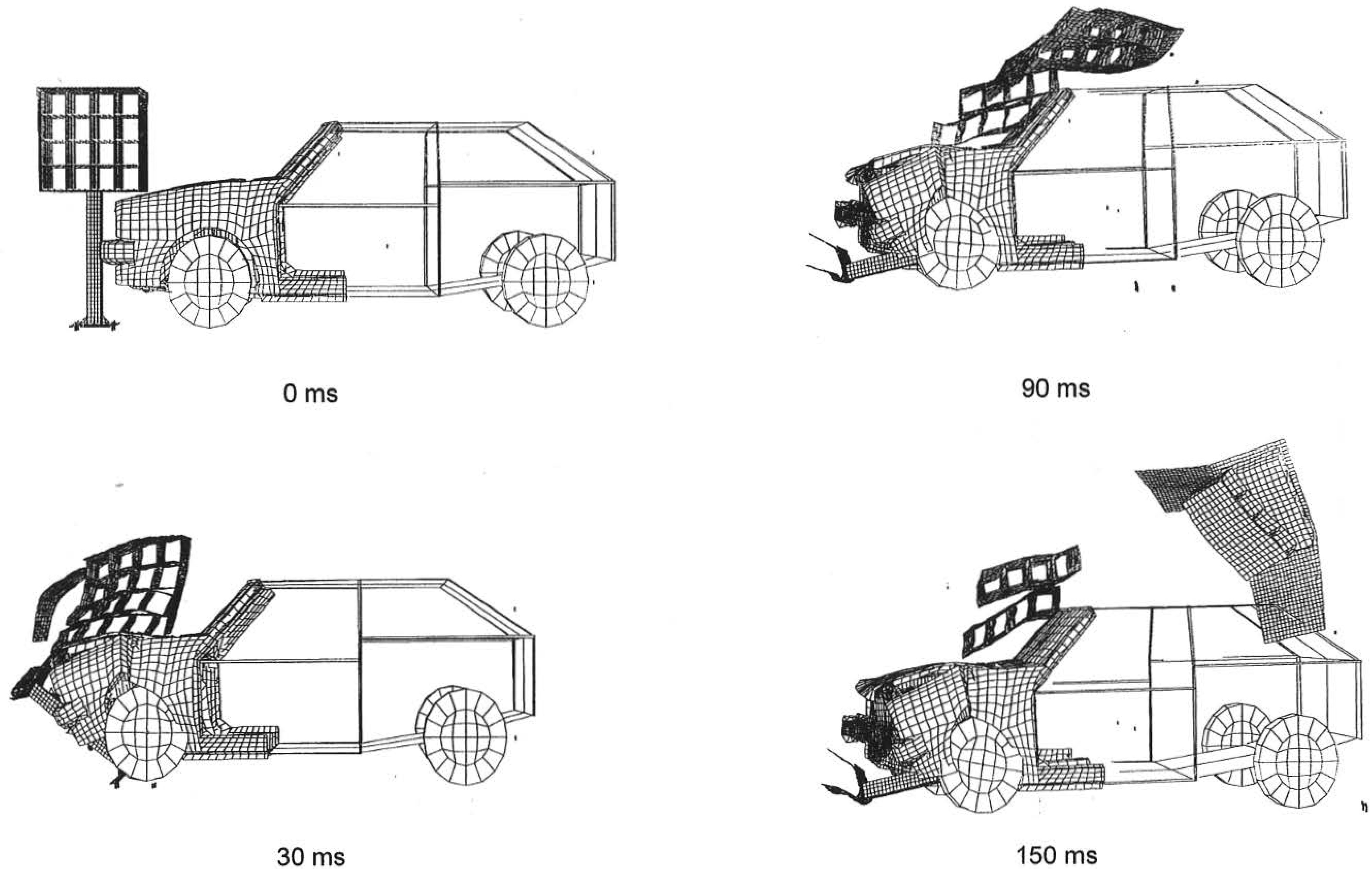


Figure 10. TTI Simulation Sequence.

The NDCBU model was impacted with the same Honda Civic model used in the TTI simulation. The vehicle model was offset to its 1/4-point, and given the initial velocities specified for the low and high speed tests.

7.3.2 High Speed NDCBU Simulation Results

The first prediction simulation of the NDCBU was a high speed impact at 100 km/h (62 mph). Sequential views of the results are shown in Figure 11.

By 9 ms, the new anchor bolts had fractured at ground level, and the base sheared away from the ground and out in front of the car. The base of the pedestal continued to rotate around the contact point with the vehicle. As the base rotated, the box itself slid up the hood of the automobile and at 200 ms, impact with the windshield is imminent. At this time, the box has a relative velocity of 3.3 m/s (10.8 ft/s) with respect to the moving vehicle. However, it is uncertain whether the box will penetrate the windshield. The complex dynamics of the flying NDCBU, the contact between the NDCBU and the front end structure, and the unavailability of a good windshield glass model make the penetration question not feasible through FEA. A physical test would be required to fully evaluate the system.

The vehicle model undergoes a maximum 50 ms deceleration of 3.8 G's and a maximum change of velocity of 1.1 m/s (3.6 ft/s). The ridedown deceleration and occupant impact velocity criteria used in NCHRP 350 were not applicable, since it was determined that the hypothetical occupant did not contact the dashboard during the 200 ms simulation time. No noticeable yaw developed in the car model as it impacted the NDCBU.

The feature passes NCHRP 350 guidelines with the exception of evaluation criteria *D*, which states that debris and other fragments from the test article should not penetrate or show potential for penetrating the occupant compartment. The amount of potential for penetration from the mailbox through the windshield is uncertain at this time.

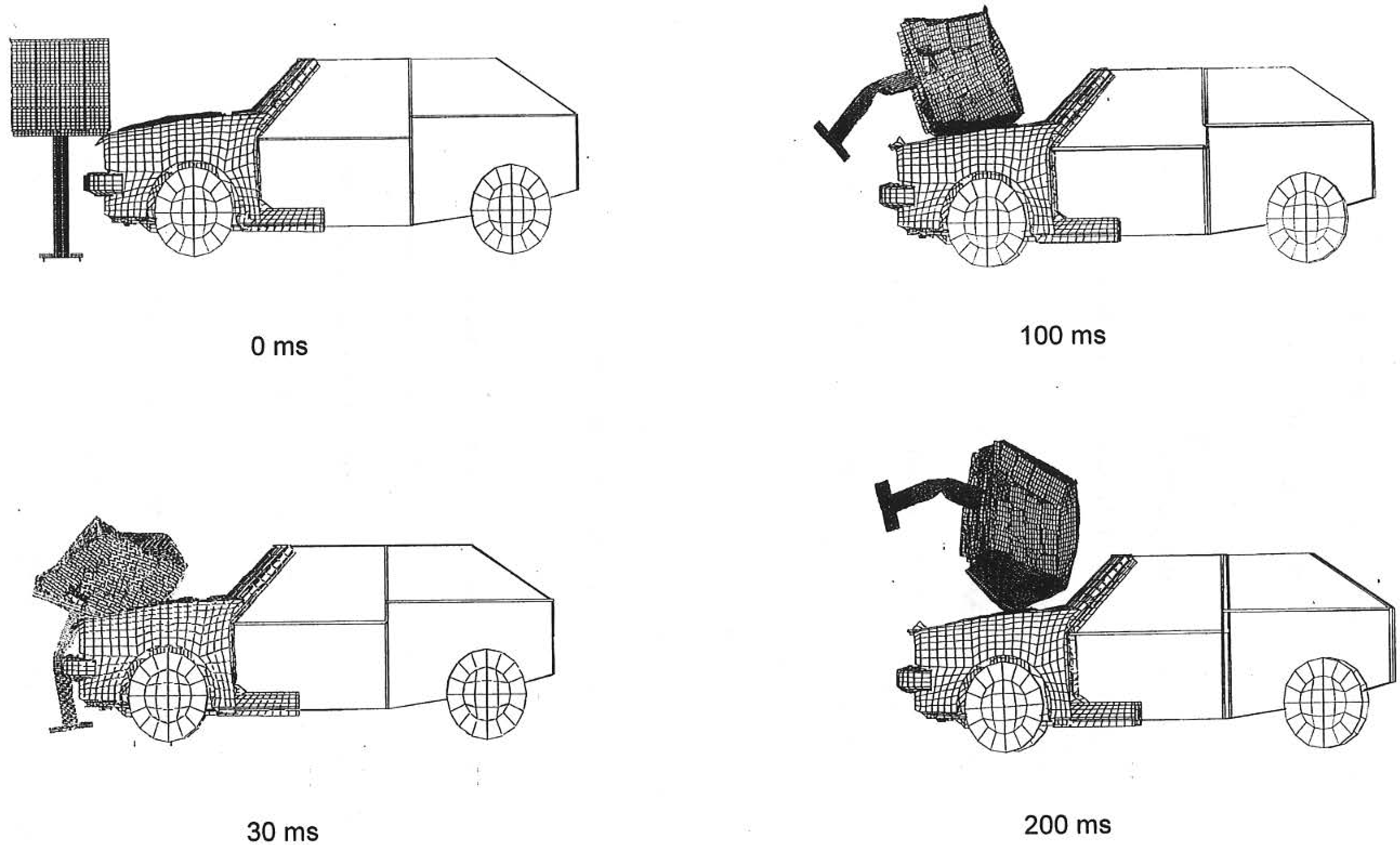


Figure 11. NDCBU High Speed Simulation Sequence.

7.3.2.1 Comparison of NDCBU Simulation with TTI Simulation

From examining the sequential views in Figures 10 and 11, and the acceleration and velocity traces shown in Figures 12 and 13, it can be seen that the change in anchor bolts has a profound effect on the safety performance of the NDCBU. In the NDCBU simulation, the pedestal broke away more easily from its anchor and flew safely in front of the vehicle. This action imparted very little force on the vehicle as compared to the large deceleration that occurred during the TTI simulation as the pedestal was bent under the car, and the anchor bolts were slowly pulled from the pedestal base. By eliminating this large force at impact, the yaw was also eliminated in the vehicle. The yaw was the main instability, which was believed to cause the rollover which occurred in the full-scale vehicle crash test.

By reducing the force level caused to break the pedestal from its anchor, and significantly reducing the possibility of rollover, the NDCBU becomes a much safer roadside feature. The main concern remaining deals with the impact of the NDCBU with the windshield of the vehicle. Without performing full-scale vehicle crash tests, this danger potential cannot be quantified. However, it is predicted that the relative impact between the NDCBU and windshield is quite low.

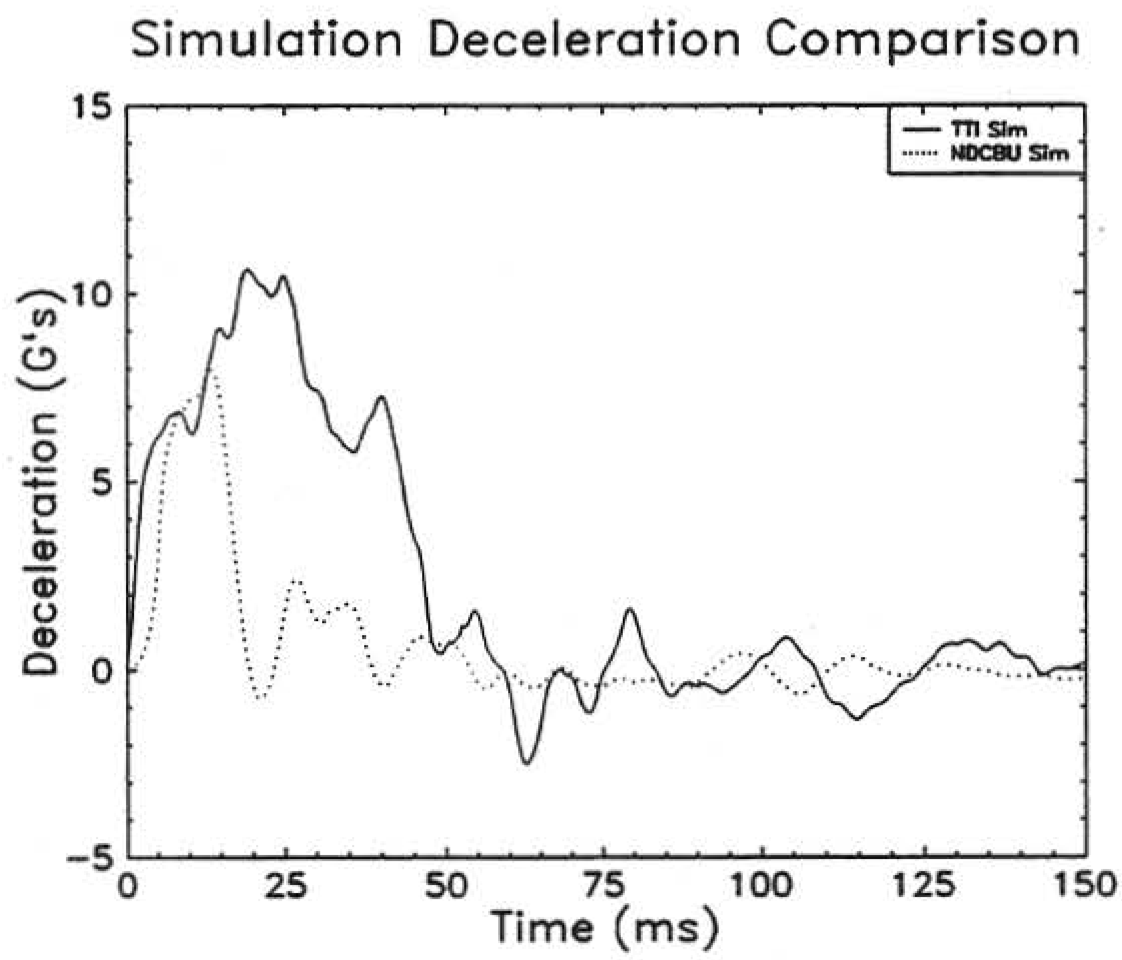


Figure 12. Simulation Deceleration Comparison

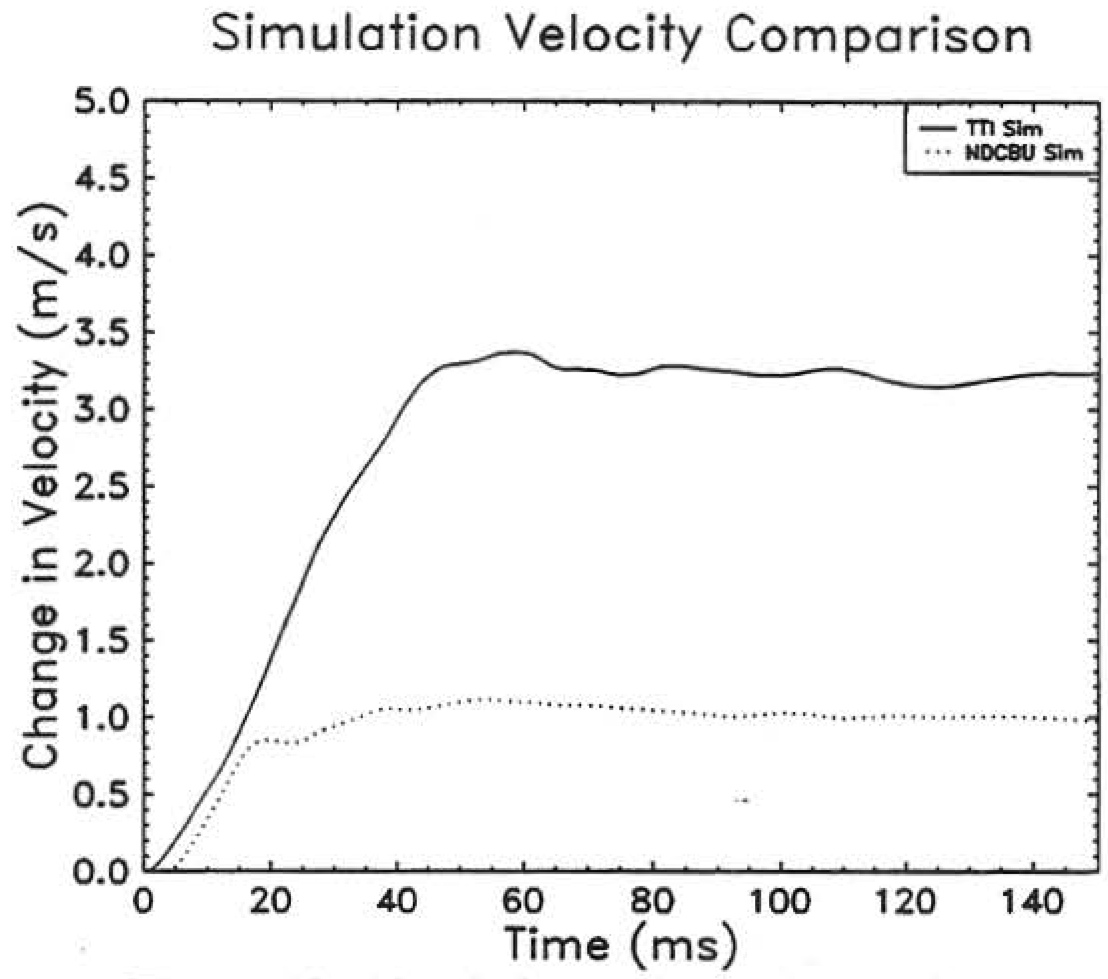


Figure 13. Simulation Velocity Comparison

7.3.3 Low Speed NDCBU Simulation Results

Often, the most critical test used to evaluate the safety performance of breakaway devices is a low speed crash test. Therefore, a low speed simulation, 35 km/h (22 mph), was performed on the Type III NDCBU model described in section 7.3.1. Sequential views of the simulation is shown in Figure 14.

The anchor bolts fail at approximately 25 ms, and the base of the pedestal is directed in front of the vehicle. The NDCBU develops separation in front of the vehicle during the 250 ms of the simulation. It appears that the mailbox may remain in front of the car while the driver brings the car to a controlled stop. This scenario is ideal, in providing a safe roadside device.

The pedestal passed all criteria set forth in NCHRP 350. The vehicle model undergoes a maximum 50 ms deceleration of 2.2 G's and a maximum change of velocity of 0.8 m/s (2.5 ft/s). The ridedown deceleration and occupant impact velocity criteria used in NCHRP 350 were not applicable, since it was determined that the hypothetical occupant did not contact the dashboard during the 250 ms simulation time. No noticeable yaw developed in the car model as it impacted the NDCBU.

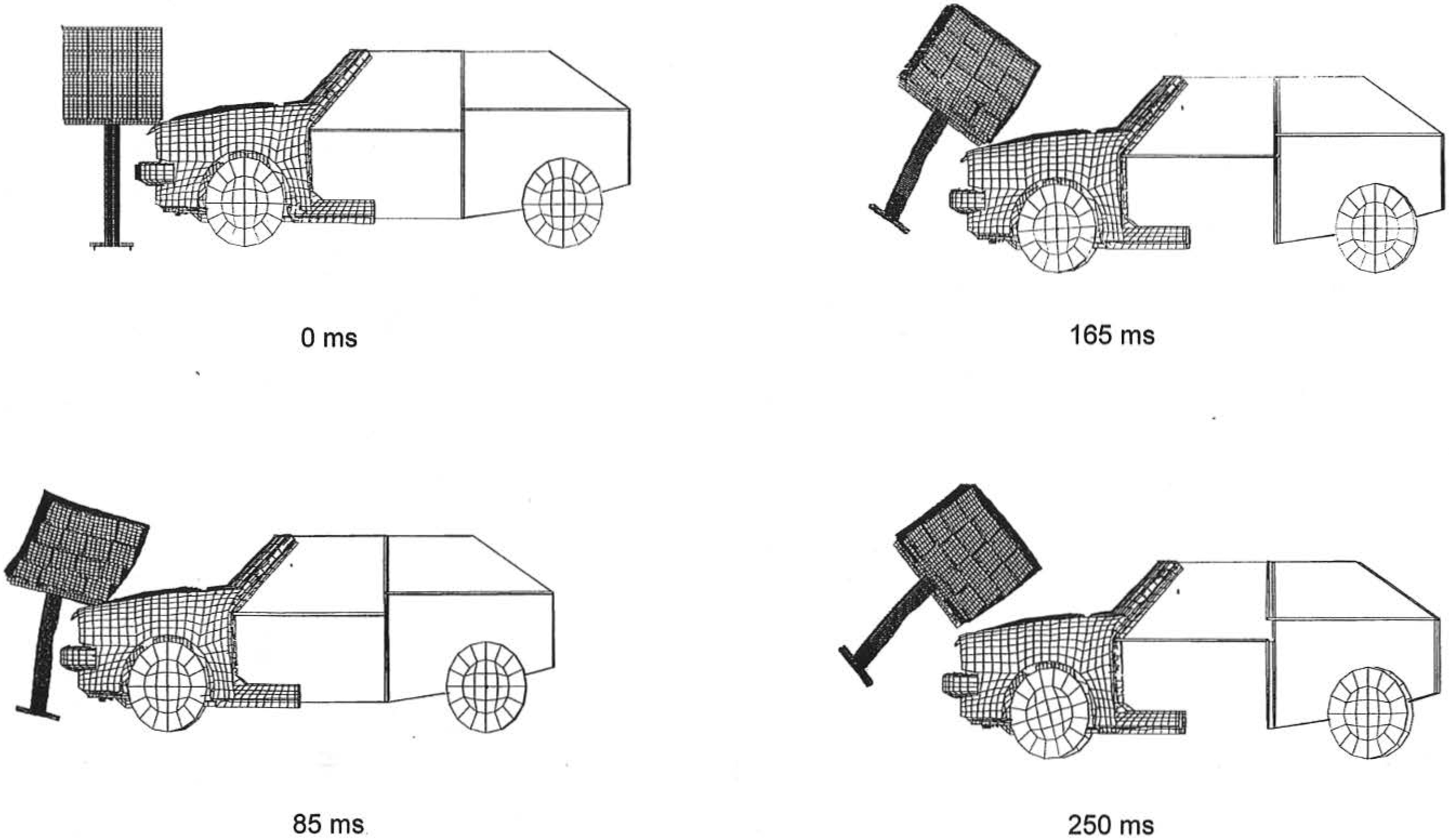


Figure 14. Low Speed NDCBU Simulation Sequential Views.

7.4 CBU Simulation

Due to problems with excess corrosion, the USPS installation procedures are phasing out the primarily steel NDCBUs and replacing them with aluminum and plastic CBUs. Therefore, it is important to predict the safety performance of the CBUs. Two FEA models were constructed and impacted at 100 km/h (62 mph) by the Honda Civic vehicle model used in previous simulations. The first simulation made was a Type II aluminum CBU and the second simulation was a Type I aluminum CBU.

The plastic CBU was not simulated due to the fact that the material properties of the plastic were unknown, and an accurate model would not be possible without performing laboratory tests on the plastic material used in the construction of the CBU. It is believed that the plastic CBU pedestal would fracture in a brittle manner similar to a frangible transformer base. In this case, it is speculated that the anchor bolts would not fail, but rather the pedestal itself would act as a frangible breakaway base, projecting the box out in front of the vehicle.

7.4.1 CBU Model Description

Since complete design plans were available for the CBU, the FEA model of it was constructed as accurately as possible. As in the NDCBU simulation, fully integrated solid elements were used to model the base of the pedestal and the anchor bolts. The anchor bolts were given the material properties of 410H stainless steel. The body of the pedestal was modeled using shell elements. All components of the CBU were given the material properties of 6061 aluminum, except for the stainless steel anchor bolts. As in the NDCBU simulation, nodal constraints were used to model the rivets that held the box together. Similarly, the rivets were given failure criteria which was twice as large as the manufacturers load capacity.

Both CBU models, Type II and Type I, were modeled identically except for their overall geometry. The Type II CBU has a longer pedestal and a smaller box, while the Type I CBU has a shorter pedestal and a larger box. The CBU model was impacted with the same Honda Civic model used in the NDCBU simulation. The vehicle model was offset to its 1/4-point, and given the initial velocities of 100 km/h (62 mph).

7.4.2 CBU Type II Simulation Results

Sequential views of the CBU simulation are shown in Figure 15. The anchor bolts fail at approximately 11 ms, and the base of the pedestal is directed in front of the vehicle. The CBU rotates about its contact point and slides up the hood of the vehicle. At approximately 80 ms, the mailbox impacts the base of the windshield of the vehicle with a relative velocity of 7.1 m/s (23 ft/s). It then appears from the simulation that mailbox starts to fly over the top of the car. Again, it is uncertain whether the box will penetrate the windshield. The complex dynamics of the flying CBU, the contact between the CBU and the front end structure, and the unavailability of a good windshield glass model make the penetration question not feasible through FEA. A physical test would be required to fully evaluate the system.

The vehicle model undergoes a maximum 50 ms deceleration of 3.7 G's and a maximum change of velocity of 1.0 m/s (3.2 ft/s). The ridedown deceleration and occupant impact velocity criteria used in NCHRP 350 were not applicable, since it was determined that the hypothetical occupant did not contact the dashboard during the 200 ms simulation time. No noticeable yaw developed in the car model as it impacted the CBU.

7.4.3 CBU Type I Simulation Results

After several attempts, a successful simulation could not be made of the Type I aluminum CBU. However, preliminary results showed that the impact was dissimilar from the Type II aluminum CBU impact. The initial simulation results show that the CBU pedestal would bend about its base plate at impact in a similar manner to the bolted pedestal shown in Figure 6; however, the pedestal that was modeled consisted of a welded pedestal. In the simulation, rather than failing the anchor bolts, as happened in the previous simulations, the welded pedestal deformed to a great extent about the pedestal base, and the thin aluminum pedestal tube was torn apart.

The degree of certainty about the accuracy of this preliminary model is uncertain, however it raises some concerns about the behavior of the large CBUs in an impact situation. No further comments could be made about the safety performance of a Type I CBU. It was determined that a significant amount of more work would be required to make an accurate FEA model of the Type I CBU.

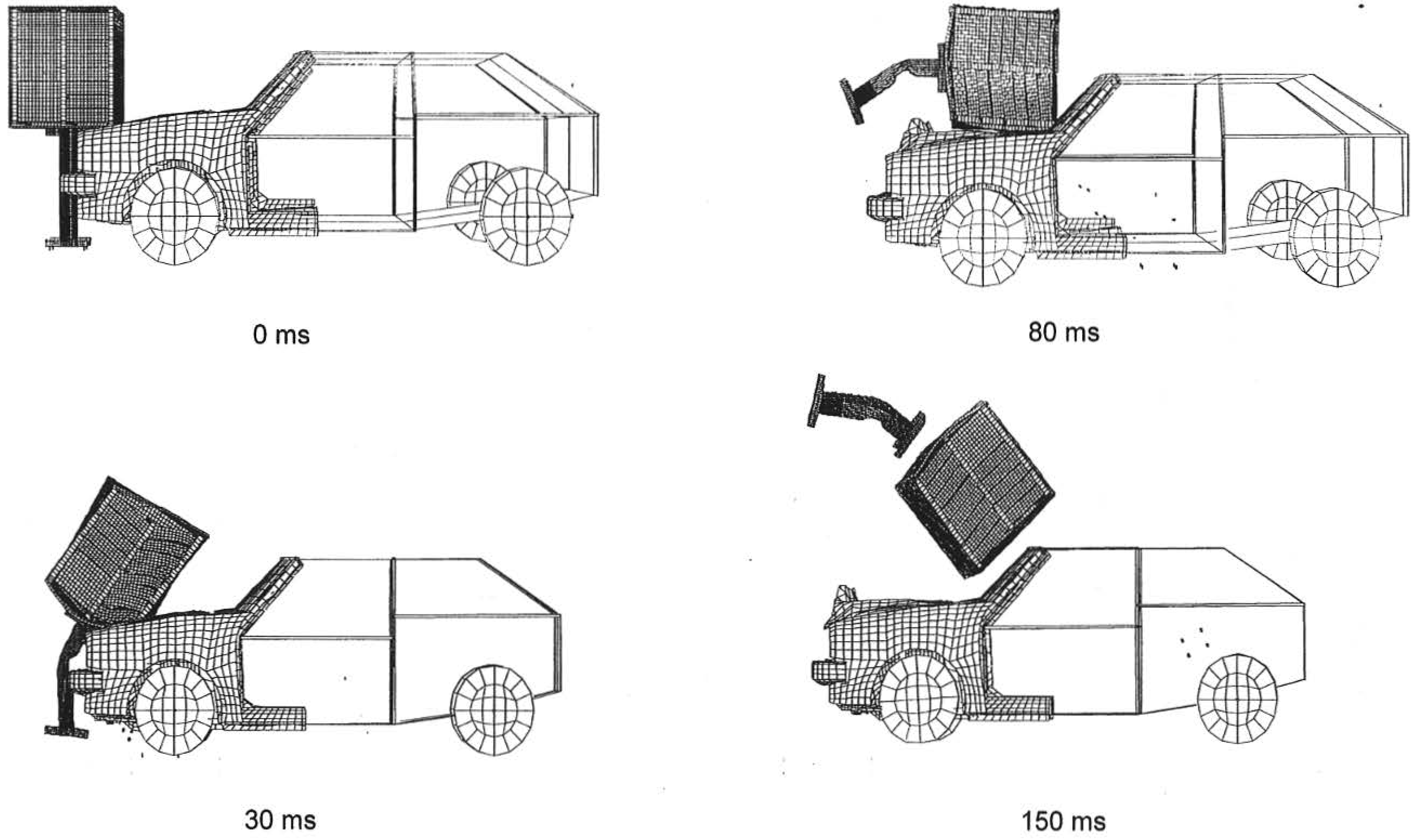


Figure 15. Simulation Sequence for CBU Type II.

8 INSTALLATION PROCEDURES AND COSTS

Three 316SH stainless steel anchor bolt design alternatives, utilizing the breakaway design proposed in this study, could be used in the installation of NDCBUs and CBUs, and are shown in Figure 16. Designs A and B-2 are designed for cast-in-place use in newly poured concrete, while Designs B and C are designed to be used as a retrofit for existing concrete slabs. Installation instructions and descriptions for both cases are described below.

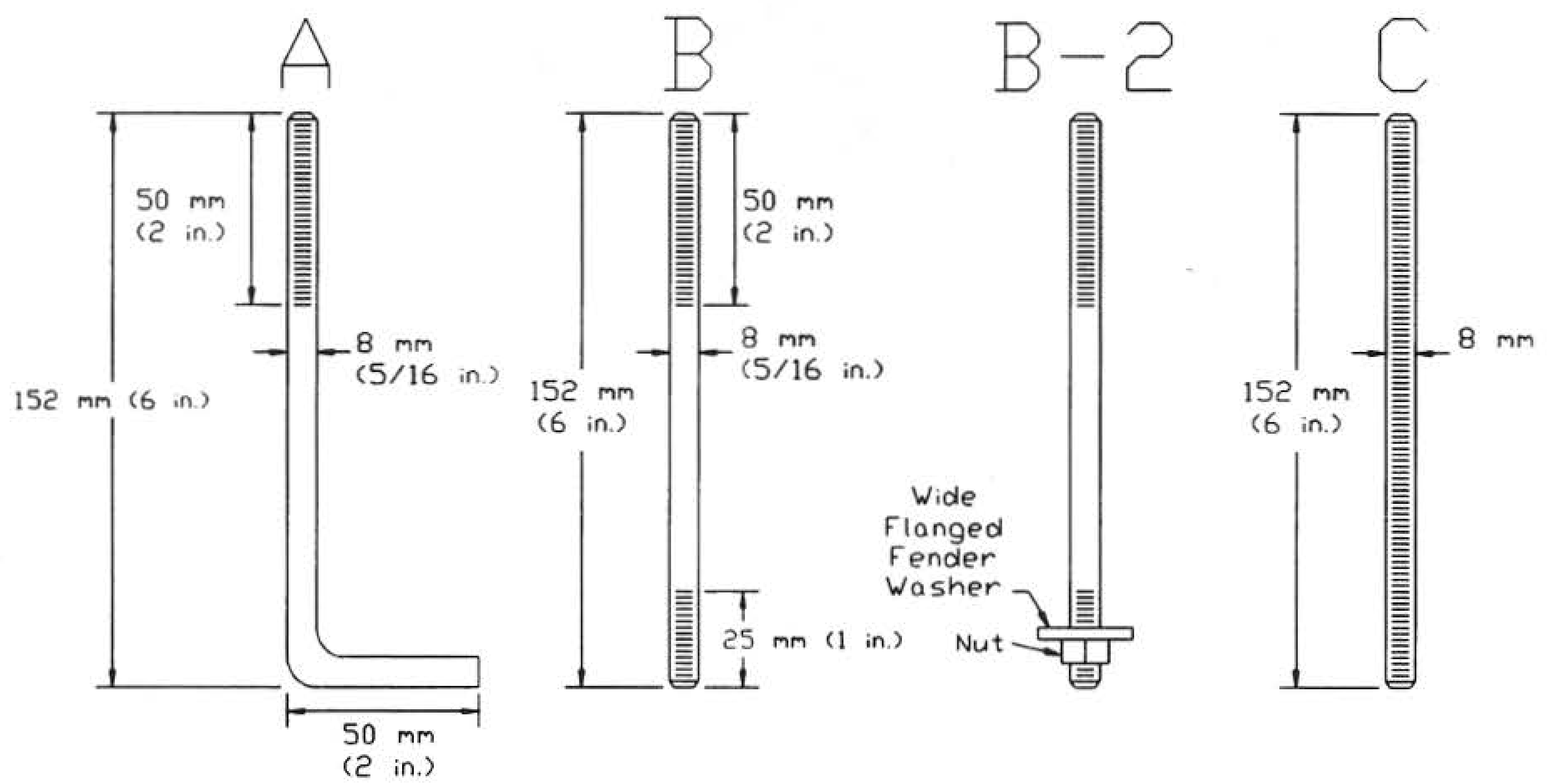


Figure 16. Anchor Bolt Alternatives

8.1 Installation Instructions for Newly Poured Concrete

Anchor bolts A and B-2 were designed to be cast-in-place in newly formed concrete. Design A is a standard anchor bolt shape consistent with the design currently used by the USPS. Design B-2 was formulated to eliminate the need for two different bolt types in stock, this design develops the pullout strength in the concrete with the use of a wide flanged fender washer, with an outside diameter of 38 mm (1-1/2 in.) that is held in place by a nut at the embedded end of the anchor bolt.

Since the wide flanged fender washer used in design B-2 will be embedded in the concrete and devoid of moisture and oxygen, this washer does not need to be constructed of stainless steel, since corrosion will not be a problem.

8.2 Retrofit Installation Instructions

Anchor bolts B and C have been designed in retrofitting the anchor bolts on an existing concrete slab. Both designs will work in a similar manner but slightly different material costs.

To install this bolt design in an existing concrete slab, first the mailbox system must be removed and the existing anchor bolts need to be cut-off flush with the surface of the concrete. Following removal of the mailbox system, four 9.5-mm (3/8-in.) holes need to be drilled in the concrete slab in a 102-mm by 254-mm (4-in. x 10-in.) pattern to a depth of 127 mm (5 in.). After the holes are drilled, excess dust must be removed with compressed air to create a relatively clean environment with the surfaces free of dust and dry.

The next step is to partially fill the holes with the chemical epoxy. It is recommended that an epoxy system such as the Rawl-Foil-Fast injection gel cartridge, the Sikadur 32, Hi-Mod epoxy, or Hilti HY150 adhesive system be used. The hole should be filled to about 50% capacity with the epoxy. The anchor bolt, design B, then needs to be placed in the chemical in a twisting manner. This twisting method of placement insures that the epoxy fills the threads of the anchor bolt and eliminates air pockets to create a rigid embedment. Once the anchor bolt has been embedded into the full depth of the hole, the epoxy level should be flush with the surface of the concrete. Any excess epoxy needs to be removed from the surface of the concrete before the chemical cures and hardens.

Following installation, the manufacturer's requirements for cure times and temperatures should be followed. It is recommended that a wood template be used to keep the anchor bolts in the proper 102-mm by 254-mm (4-in. x 10-in.) pattern while the epoxy cures. The total installation process should require 1 man-hour of labor, or 2 workers working for 30 minutes together on the retrofit installation.

8.3 Retrofit of New Design to Old Mailbox Pedestals

Ideally, the new anchor bolt design would be used in conjunction with a redesigned pedestal that incorporates smaller bolt holes. But with the large inventory of existing pedestals, it was necessary to develop a retrofit washer that could be used to fit the smaller bolts with the larger holes in the existing pedestals. This new washer, shown in Figure 17, will adapt a 16-mm (5/8-in.) hole to an 8-mm (5/16-in.) bolt. This washer could also be turned upside-down and used with pedestals that had the smaller hole, if needed, otherwise a standard stainless steel washer can be used with redesigned pedestals.

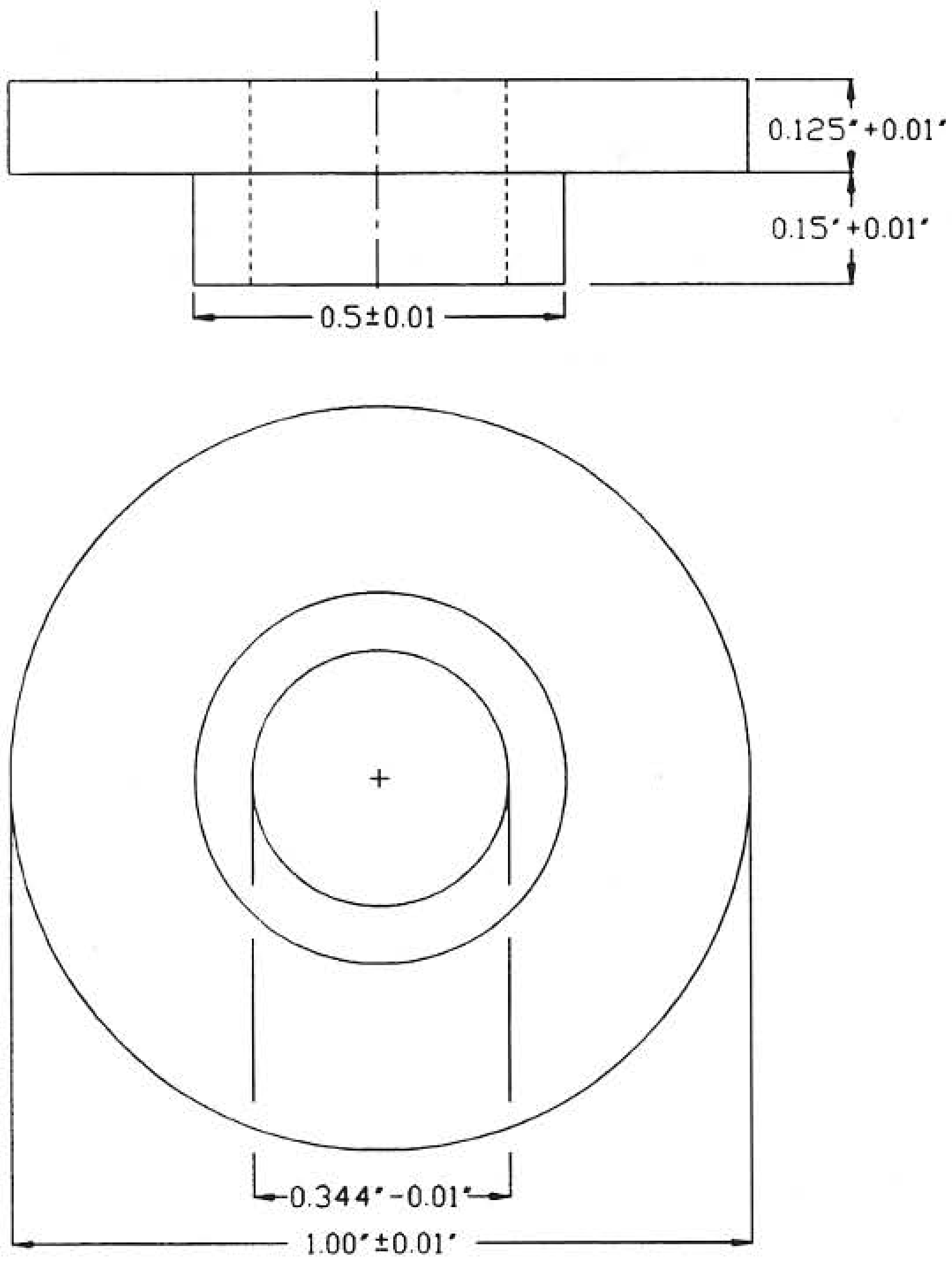


Figure 17. Retrofit Washer

8.4 Material Costs for Installation

Table 7 below shows a relative material cost to retrofit the CBU anchor bolts to give the CBU the breakaway characteristics that were discussed in this report. All of the cost estimates were made with the assumption that 1000 pieces would be ordered, or enough to retrofit 250 systems. It should be noted that as the quantity ordered increases, the cost per unit will decrease.

Table 7. Material Cost Estimates.

Design:	**Anchor Bolt A**			**Anchor Bolt B/C**			**Anchor Bolt B-2**		
Materials Needed	**Qty.**	**Unit**	**Total**	**Qty.**	**Unit**	**Total**	**Qty.**	**Unit**	**Total**
Bolt A[1]	4	$1.067	$4.27						
Bolt B/C[1]				4	$0.832	$3.33	4	$0.832	$3.33
Retrofit Washer[2]	4	$1.290	$5.16	4	$1.290	$5.16	4	$1.290	$5.16
Chemical Epoxy[3]				4 holes	$0.500	$2.00			
Wide Flanged Washers[4]							4	$0.052	$0.21
Nuts[1]	4	$0.500	$2.00	4	$0.500	$2.00	8	$0.500	$4.00
Total Cost			**$11.43**			**$12.49**			**$12.70**

Sources:
[1]Nebraska Bolt, Lincoln, NE (402) 466-8456
[2]Lincoln Machine, Lincoln, NE (402) 434-9148
[3]Concrete Industries, Inc., Lincoln, NE (402) 434-1800
[4]Tool House, Inc. Lincoln, NE (402) 476-6673

9 SUMMARY AND CONCLUSIONS

Full scale vehicle crash tests conducted by TTI in 1984 demonstrated the danger potential of a neighborhood mailbox, or cluster box unit (CBU). When the vehicle impacted the structure, a large amount of energy was absorbed by the mailbox at initial contact, which created a large yaw angle in the impacting vehicle which resulted in vehicle rollover. After evaluating several existing concepts and designs, researchers concluded that replacing the 13-mm (½-in.) ASTM A193 B8M stainless steel anchor bolt with a 8-mm (5/16-in.) 316SH stainless steel anchor bolt would create a breakaway base that would reduce the possibility of vehicle rollover.

Low speed bogie tests and finite element simulation was performed to show that the new breakaway base significantly improved the safety performance of the CBU. The simulations showed that the CBU would meet the safety performance criteria set forth in NCHRP 350 with the exception of the occupant compartment intrusion criteria. Not enough information was present to determine if there would be a potential danger of the CBU penetrating the windshield of the impacting vehicle.

No side impact simulations were performed due to the fact that the Federal Highway Administration (FHWA) and the National Highway Transportation Safety Administration (NHTSA) have not provided FEA models of vehicles constructed for side impact simulations. In addition, the safety performance of two CBUs mounted in-line and side-by-side was not investigated. To investigate this, it would first be necessary to validate the FEA simulations with actual full-scale crash tests on a single NDCBU or CBU prior to attempting to predict the dynamic response of multiple units placed adjacent to one another.

Static design calculations were performed to determine the best anchor bolt material to use that would fracture in a brittle manner, but sustain the structural integrity test required by the USPS. These calculations were followed up with static structural integrity tests which demonstrated that the CBU would withstand the load conditions of everyday use. Following the structural integrity test, corrosion tests were performed to insure that the components of the breakaway base would withstand the extreme corrosion conditions which are present at CBU locations.

In addition, it was concluded that 416, 410H, or any other stainless steel that conformed to critical mechanical properties, would have similar safety performance properties as the 316SH stainless steel. It is very important that the substitute material meet the yield strength (greater than 80 ksi), and percent elongation (less than 20%) requirements. The substitute material may have a lower yield strength, in which case the size must be scaled up, but its percent elongation must be less than 20%, or the system has not been improved. However, it should be noted that the 400 series stainless steels have a lower corrosion resistance than the 300 series stainless steels, and this should be considered when substituting anchor bolt materials.

In summary, a new breakaway base for the United States Postal Service's cluster box units was designed that significantly improves the safety performance of the CBU. Finite element simulations showed that the CBU would meet the safety performance criteria set forth in NCHRP 350 with the exception of the occupant compartment intrusion criteria.

10 RECOMMENDATIONS

Based on the results of this study, it is recommended that a series of full-scale crash tests be performed on the various configurations of cluster box units to insure that they meet safety performance criteria set forth in NCHRP 350. Full-scale crash testing is currently the only feasible method to investigate the potential of the CBU to penetrate the windshield of the impacting vehicle.

To fully comply with NCHRP 350, it is recommended that both high speed, 100 km/h (62 mph), and low speed, 35 km/h (22 mph), crash tests be performed on Type I and II aluminum CBUs, Type I or III plastic CBUs, and Type III steel NDCBU. If the full-scale crash tests match well with the FEA simulations, then it is recommended that FEA simulations be used to investigate other impact scenarios.

11 REFERENCES

1. *Recommended Procedures of the Safety Performance Evaluation of Highway Features*. National Cooperative Research Program Report 350, Transportation Research Board, Washington, D.C., 1993.

2. Campise, W.L., and Ross, H.E., Jr., *Test and Evaluation of Neighborhood Mailbox*. Research Report 343-2, Study No. 2-18-83-343, Texas Transportation Institute, Texas A&M University, College Station, TX, March 1984.

3. *Standards Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials (AASHTO), 1994.

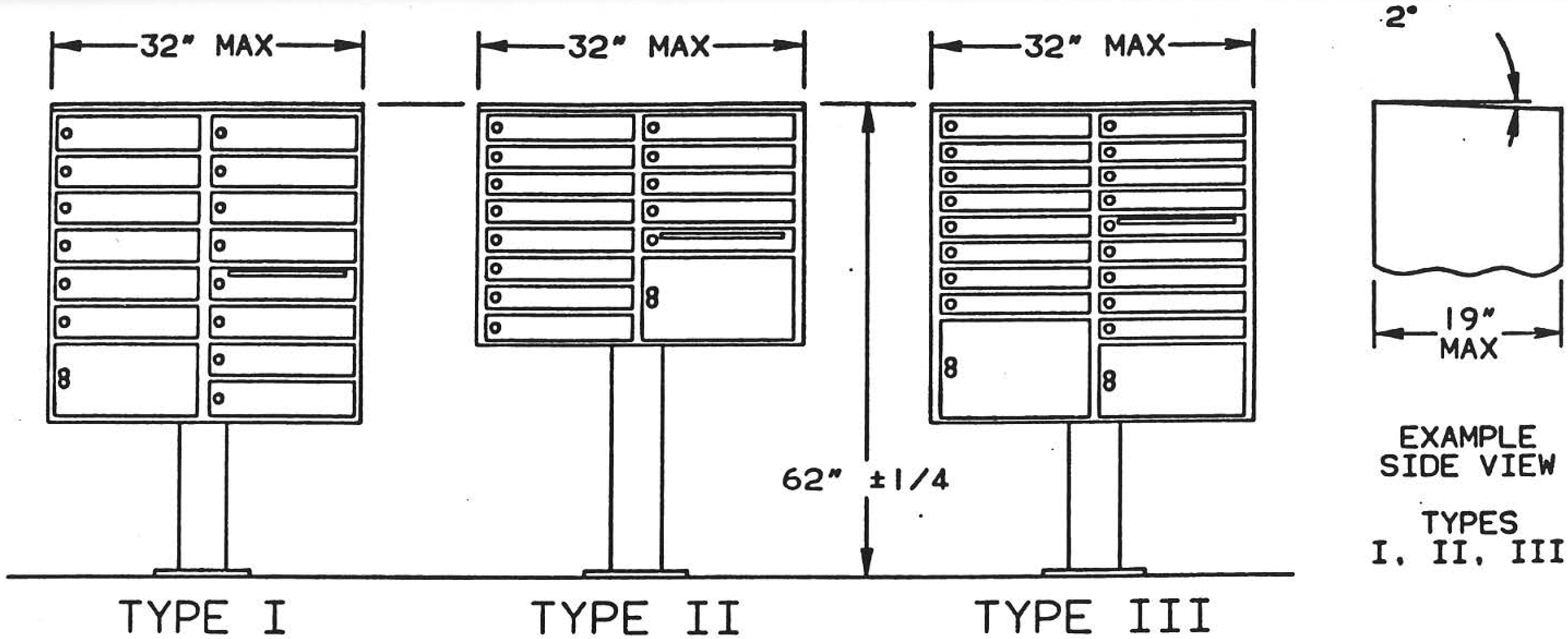
4. *Sika Data Book*, Sika Corporation, Lyndhurst, N.J., 1994.

5. Buyer's Guide to Stainless Steel, Joseph T. Ryerson and Son, Inc. Chicago, IL. 1988

6. Hallquist, J.O., Stillman, D.W., and Lin, T., *LS-DYNA3D User's Manual*, Livermore Software Technology Corporation, 1993.

APPENDIX A

Cluster Box Unit Classification



NOTES:

1. TYPES I AND III REQUIRE USPS DRAWING NUMBER D-1000052-2, PEDESTAL.

2. TYPE II REQUIRES USPS DRAWING NUMBER D-1000052-1, PEDESTAL.

3. OVERALL HEIGHT MUST BE THE SAME FOR ALL TYPES.

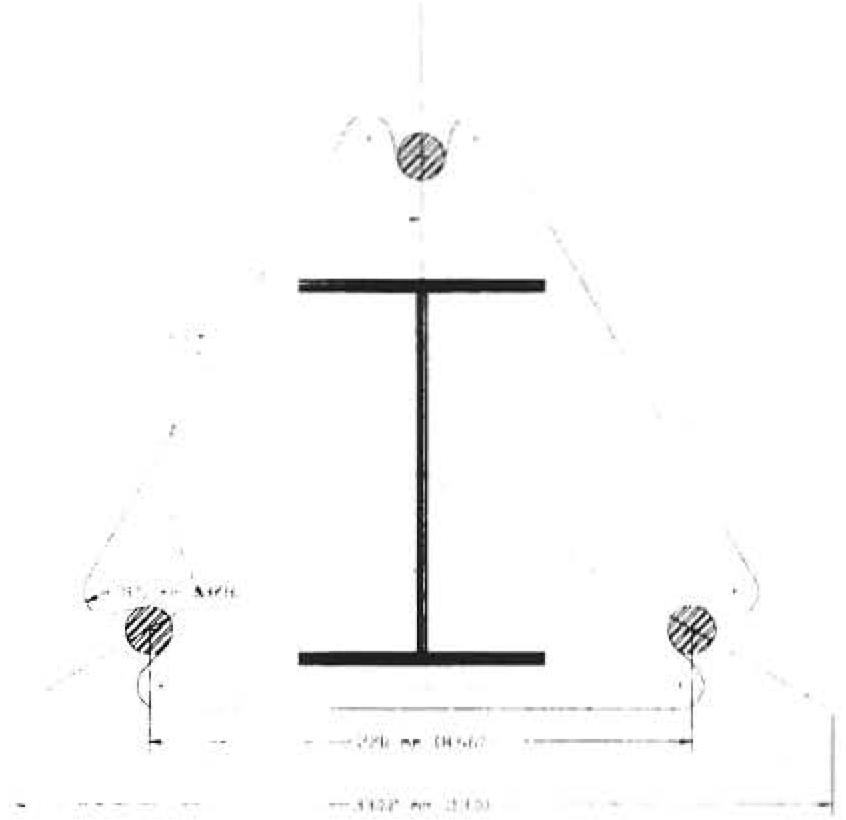
CBU CONFIGURATION DRAWING

FIGURE 1

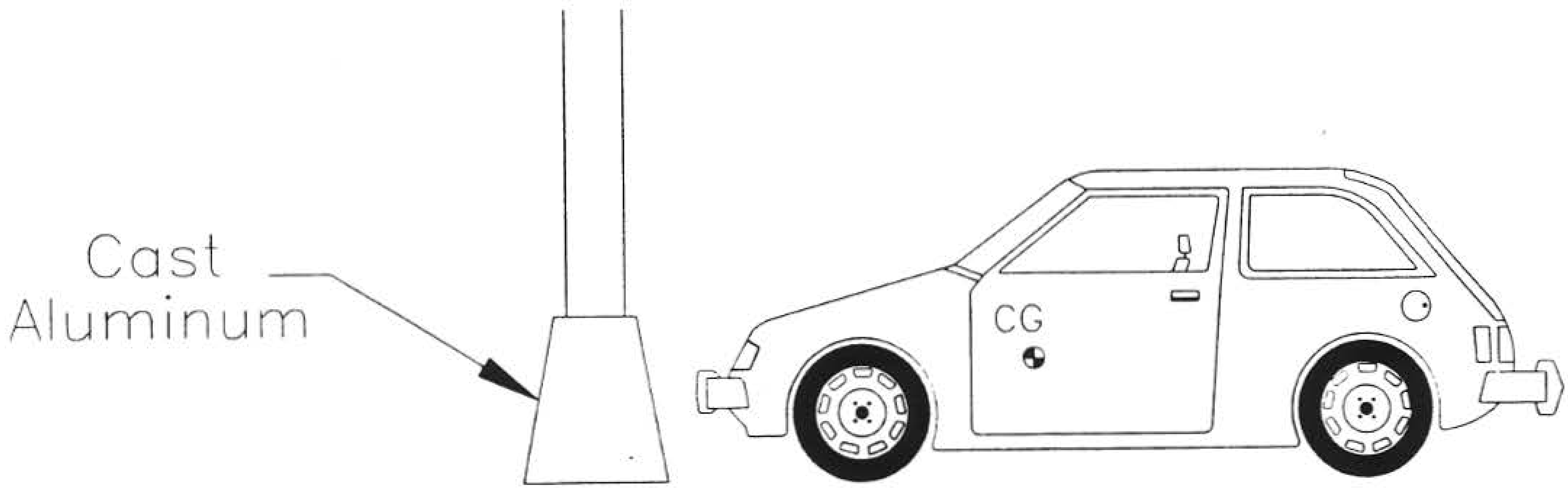
APPENDIX B

Design Concepts

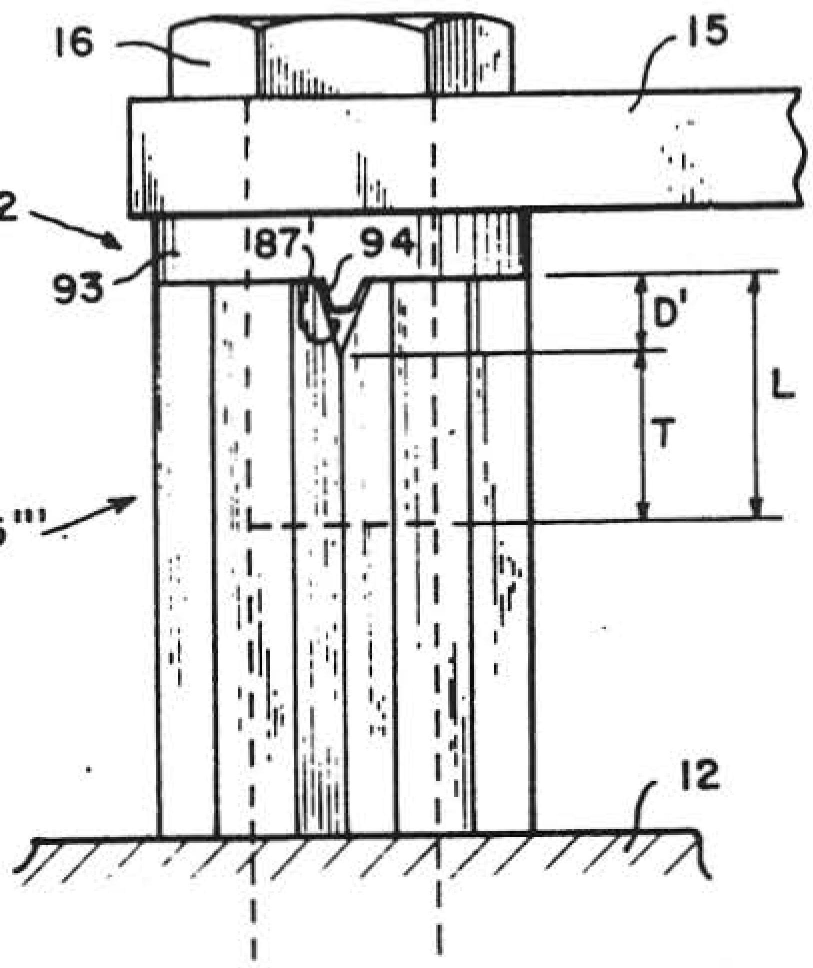
1. **Slip Base**

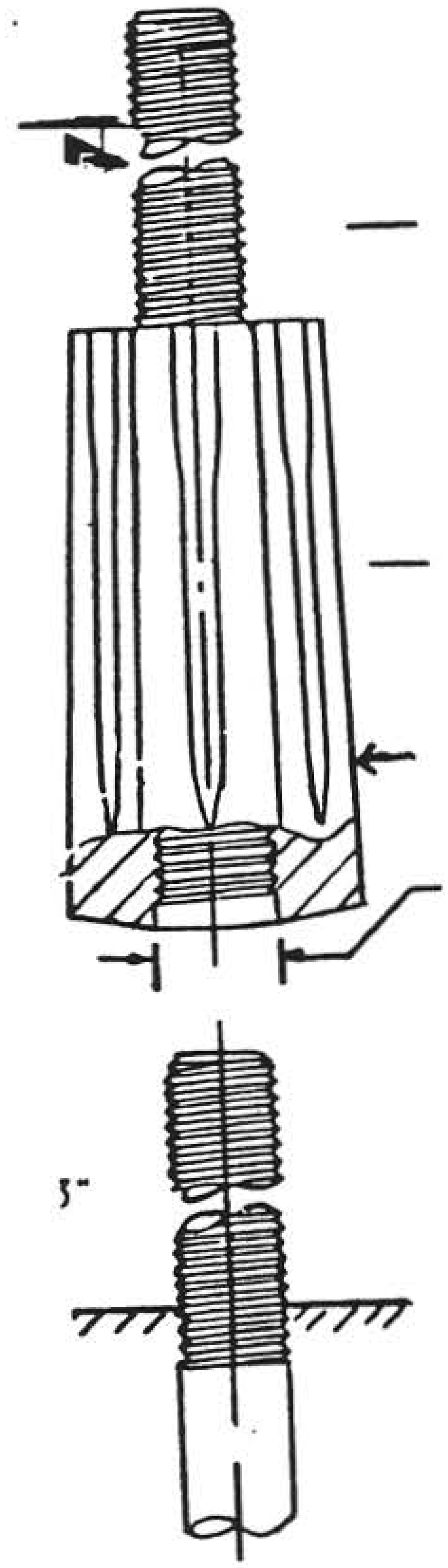


2. **Frangible Transformer Base**

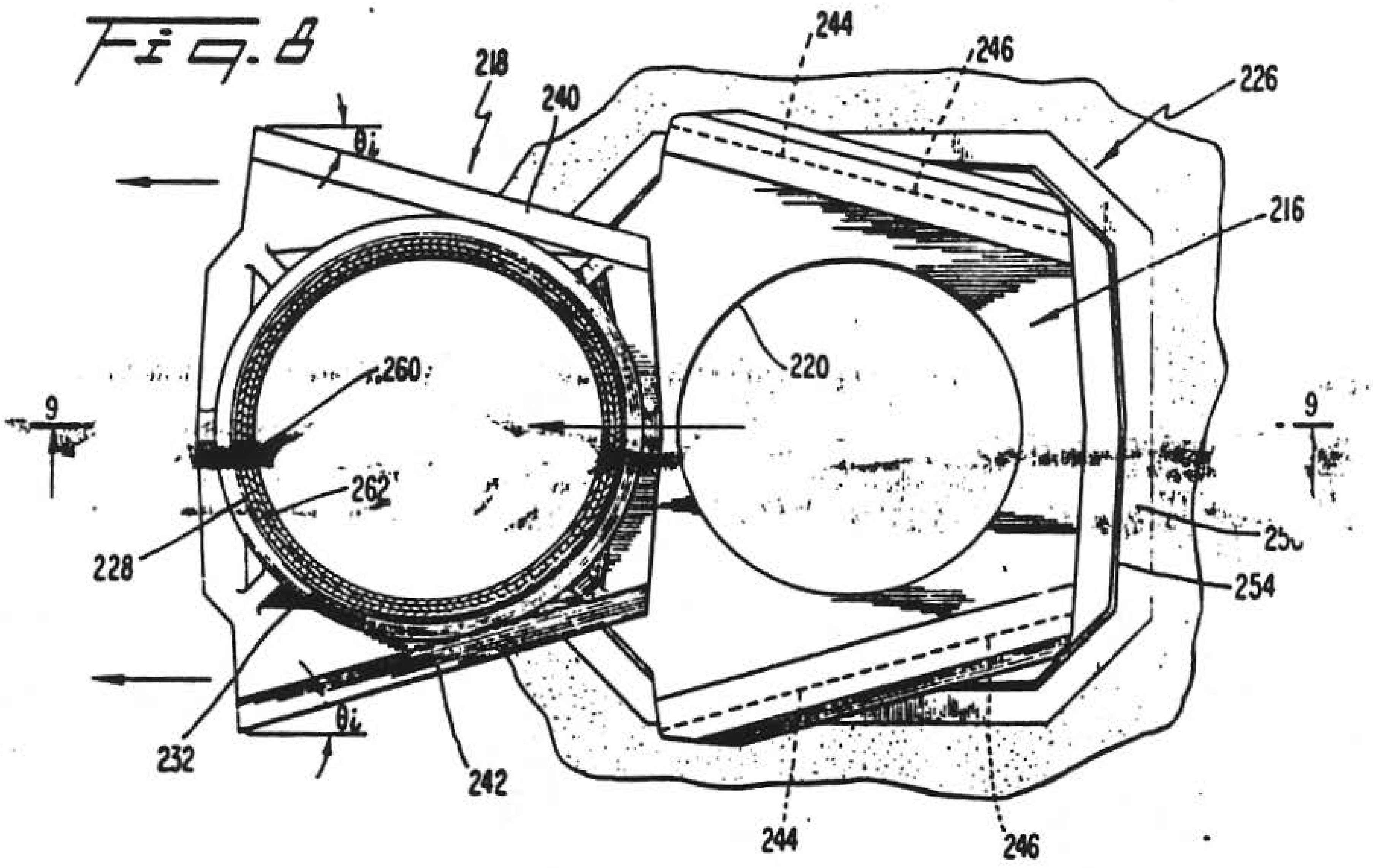


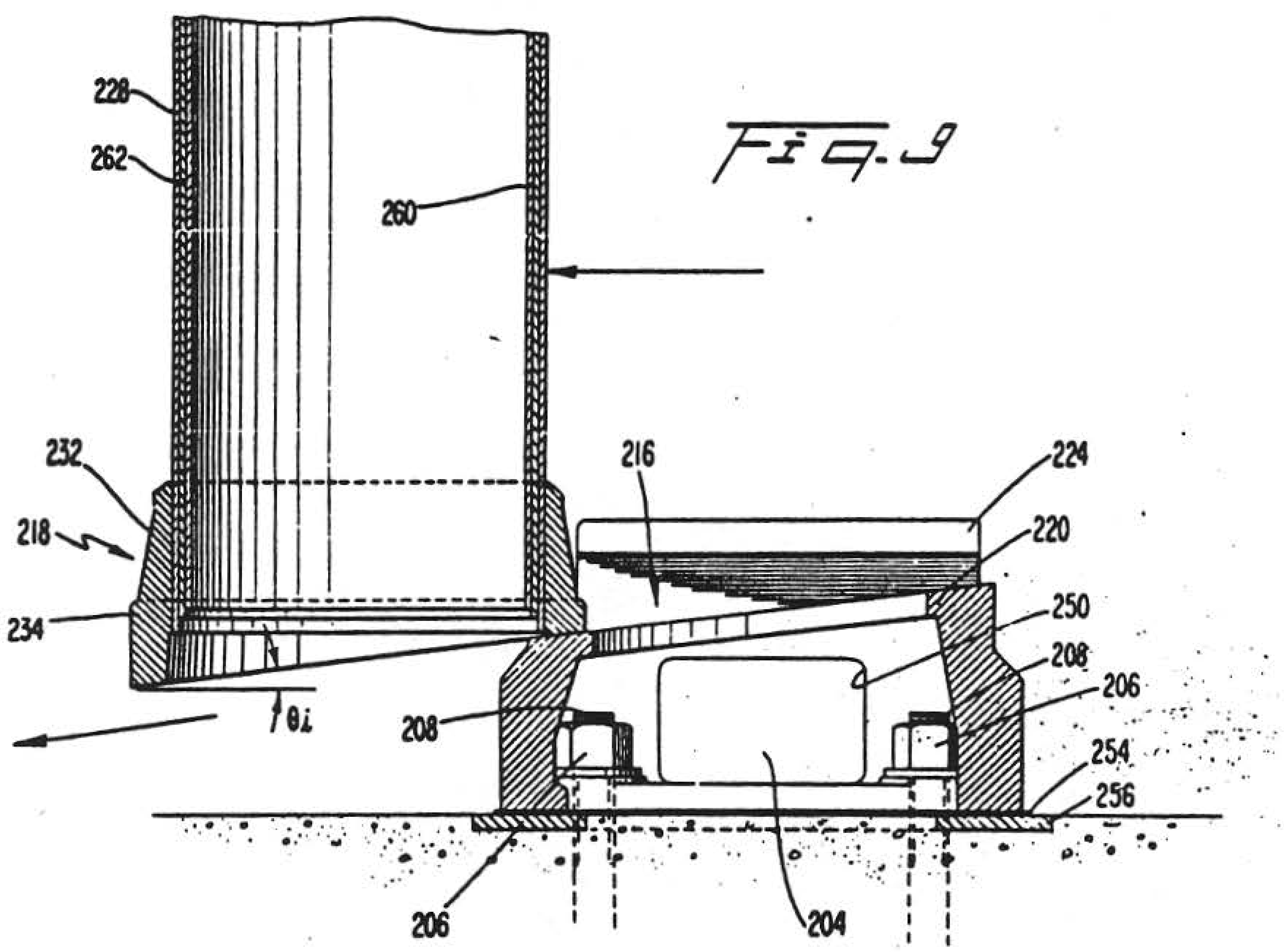
3. Breakaway Coupling





4. Frangible Pole Support





5. Fire Hydrant Coupling

FIG. 2

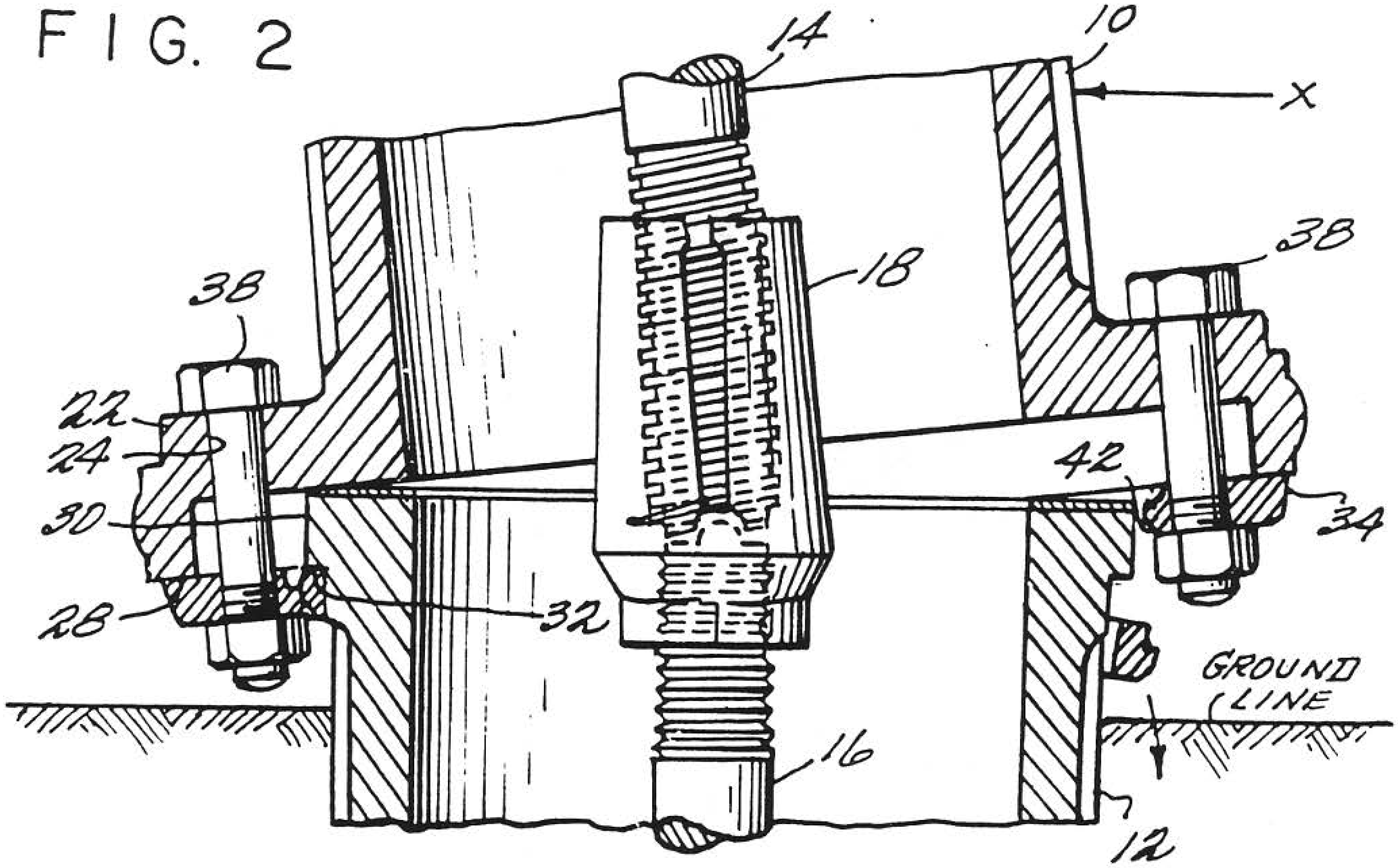
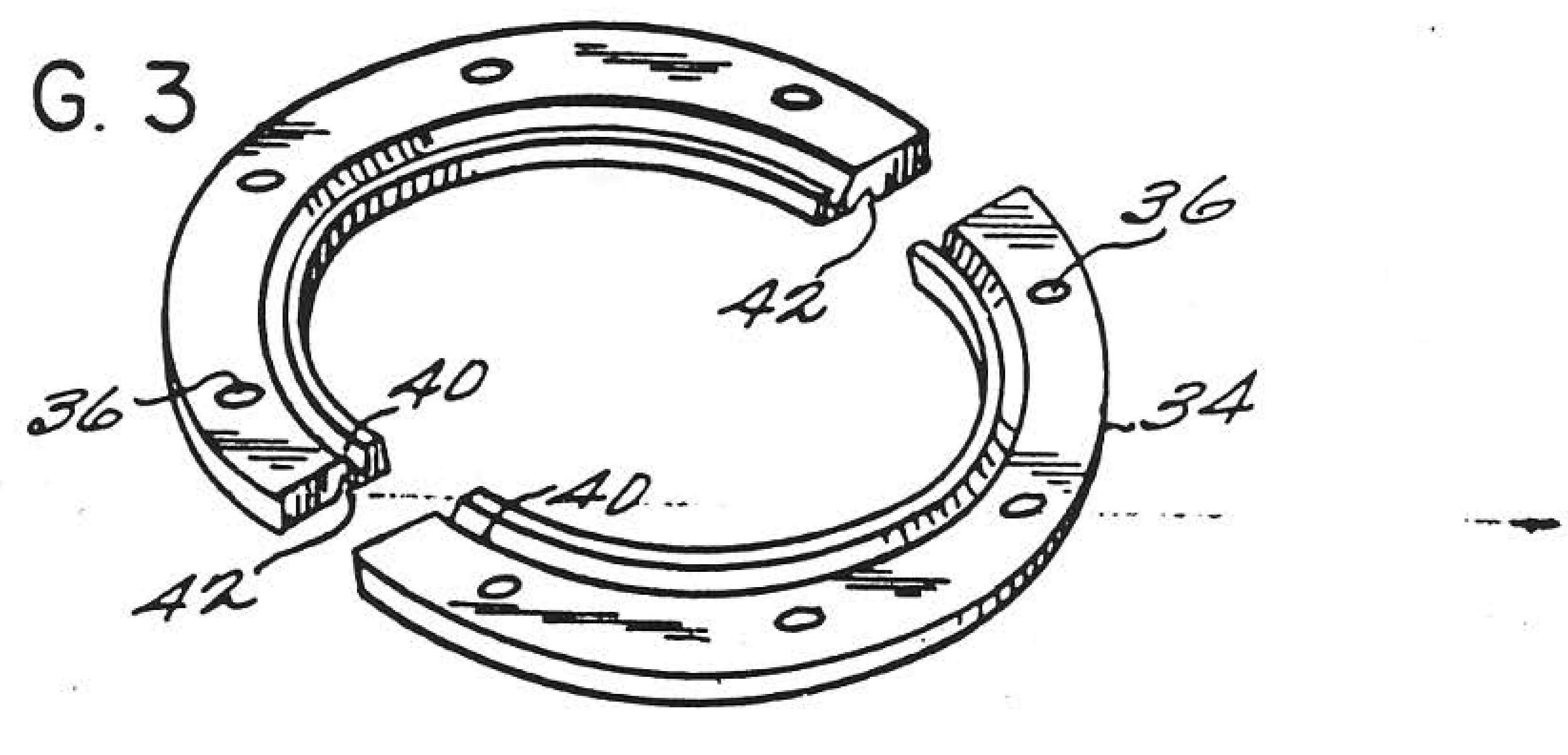


FIG. 3



6. Breakaway Utility Pole Concept

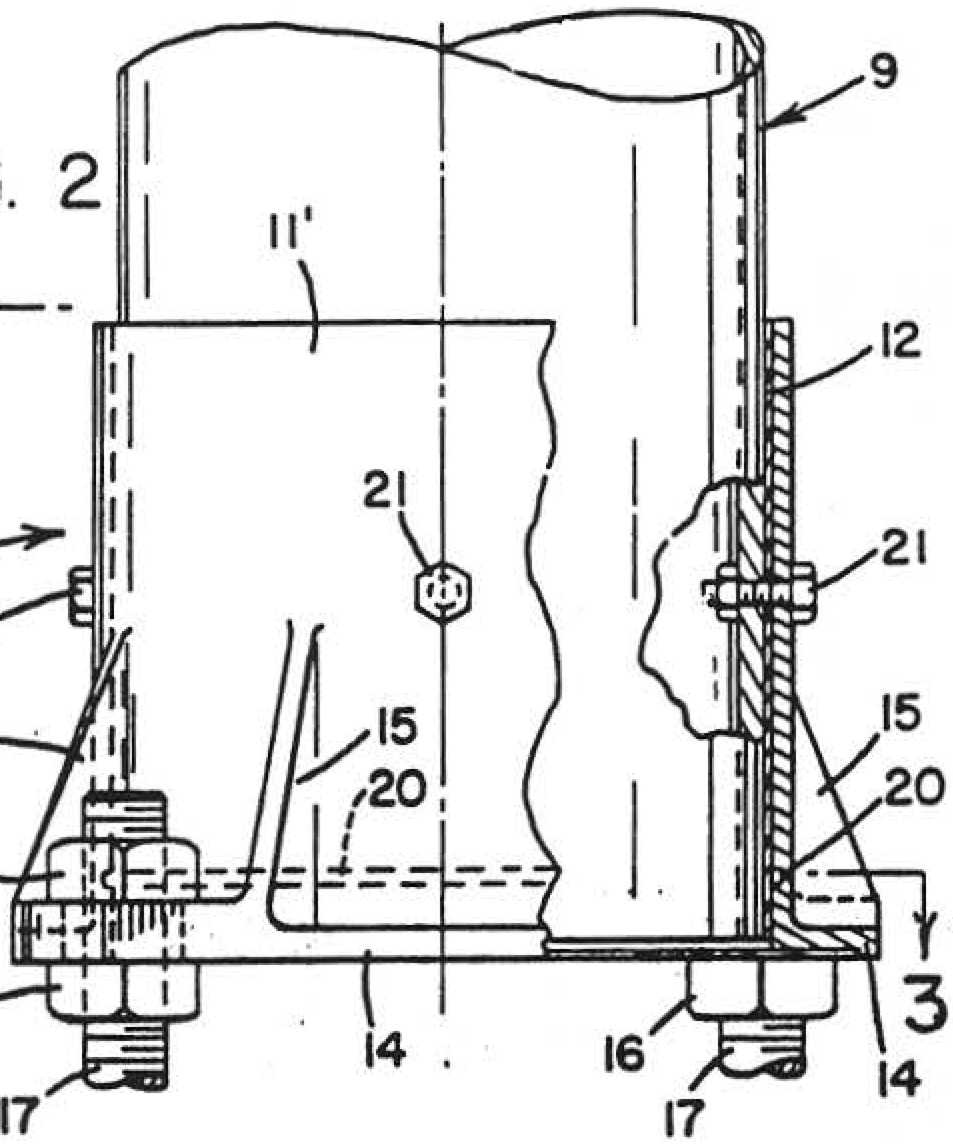


FIG. 2

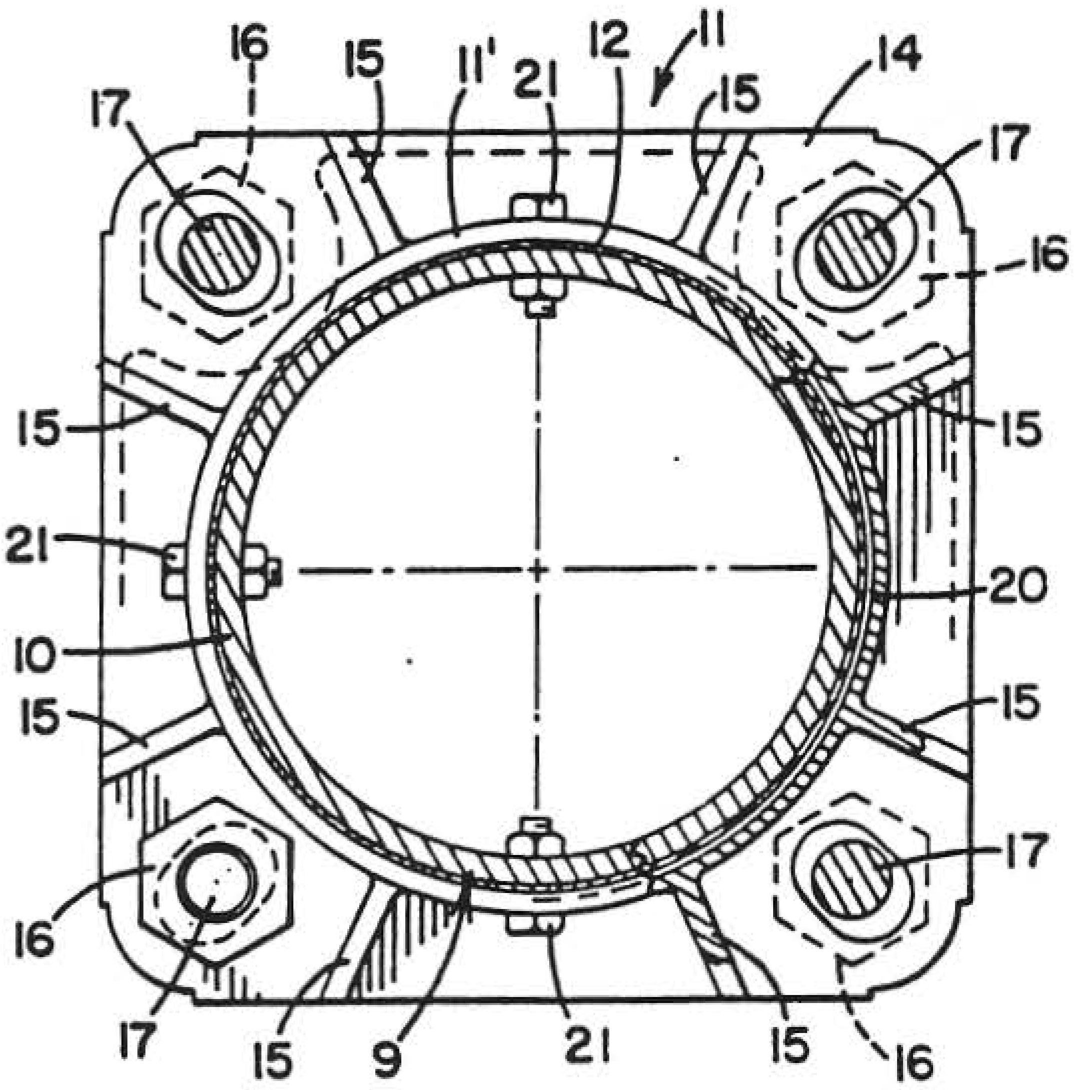


FIG. 3

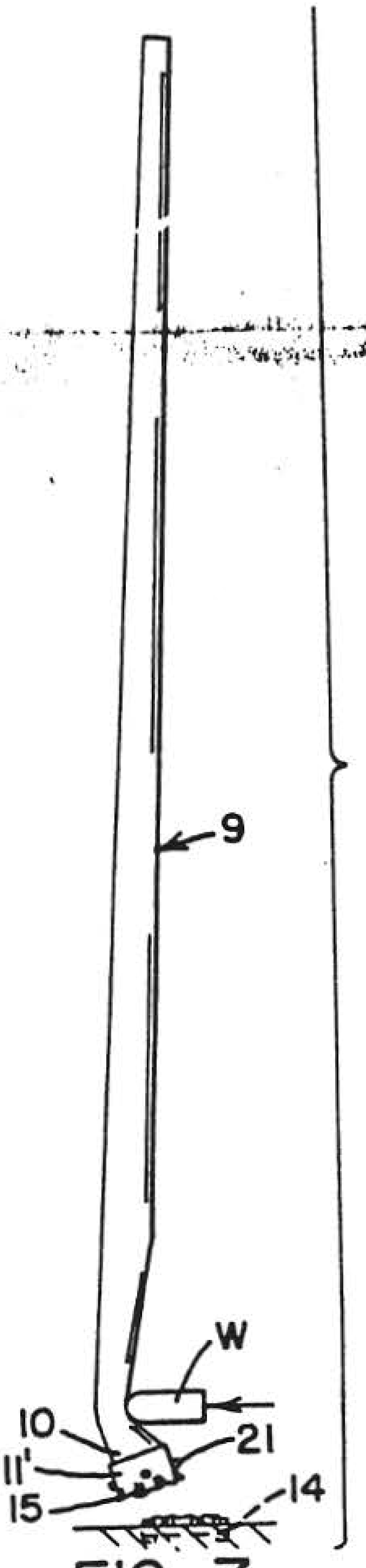


FIG. 7

7. Breakaway Connector

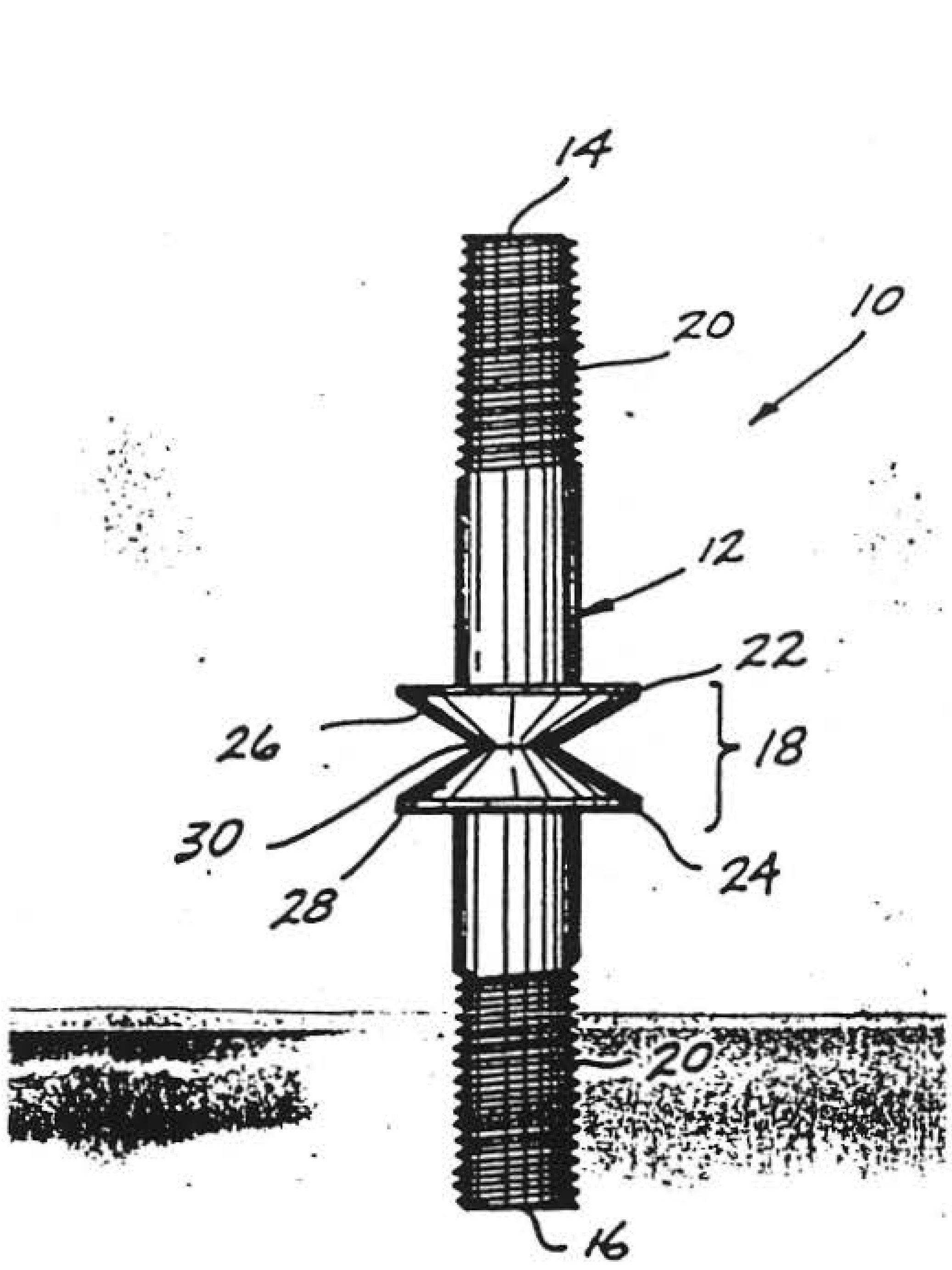
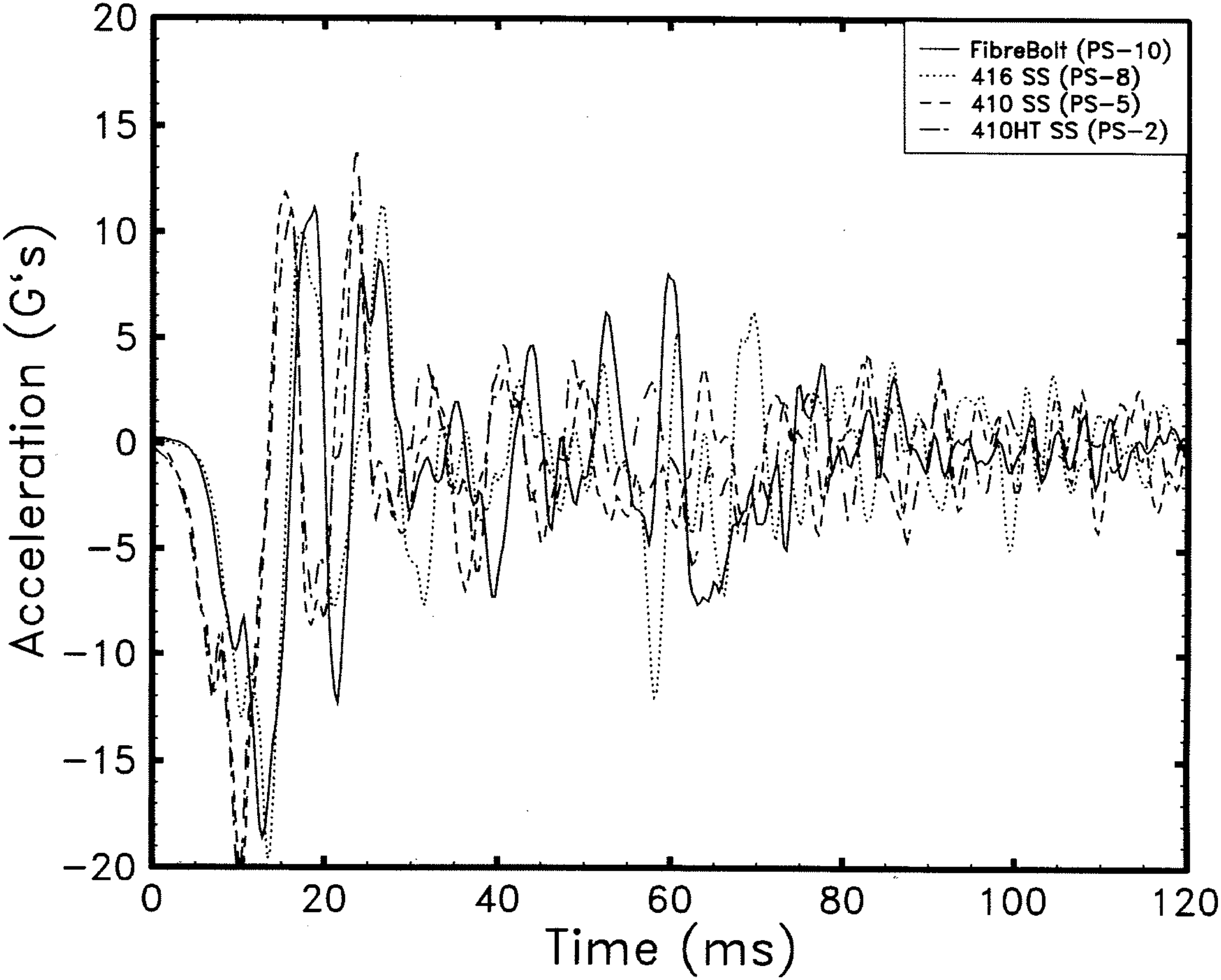


Fig. 1.

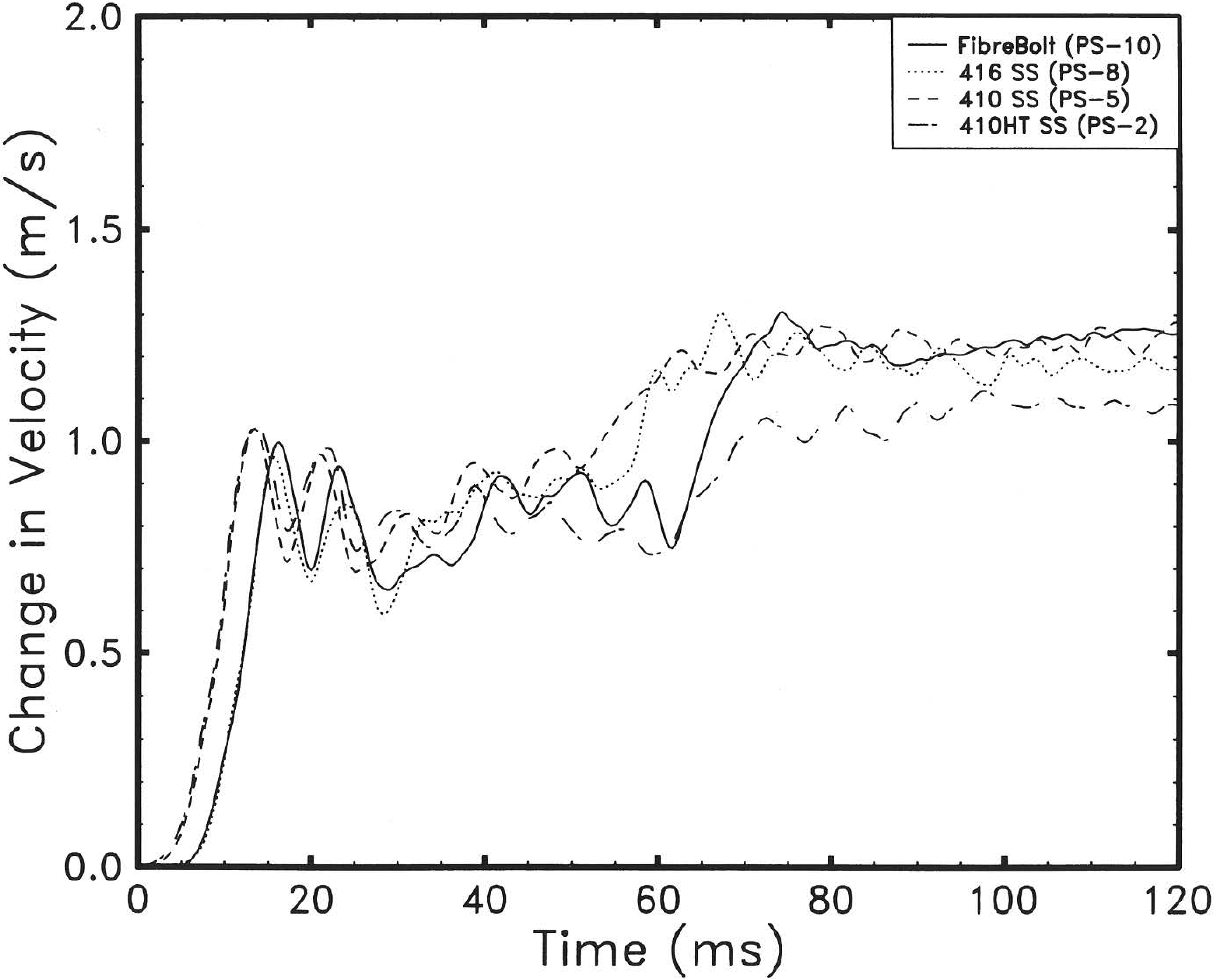
APPENDIX C

Bogie Test Results

Acceleration Comparison

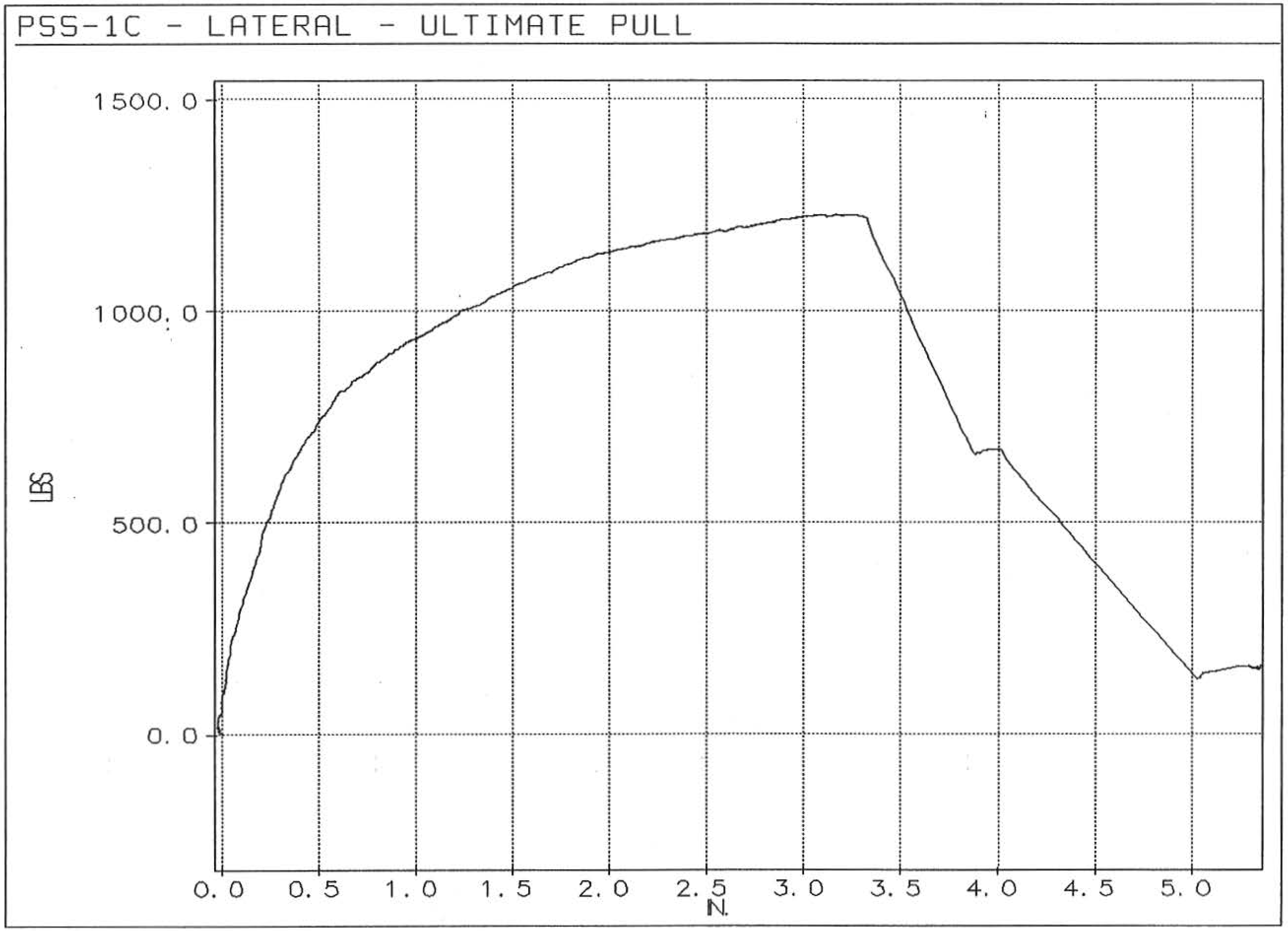


Change in Velocity Comparison



APPENDIX D

Static Test to Failure Results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LBS
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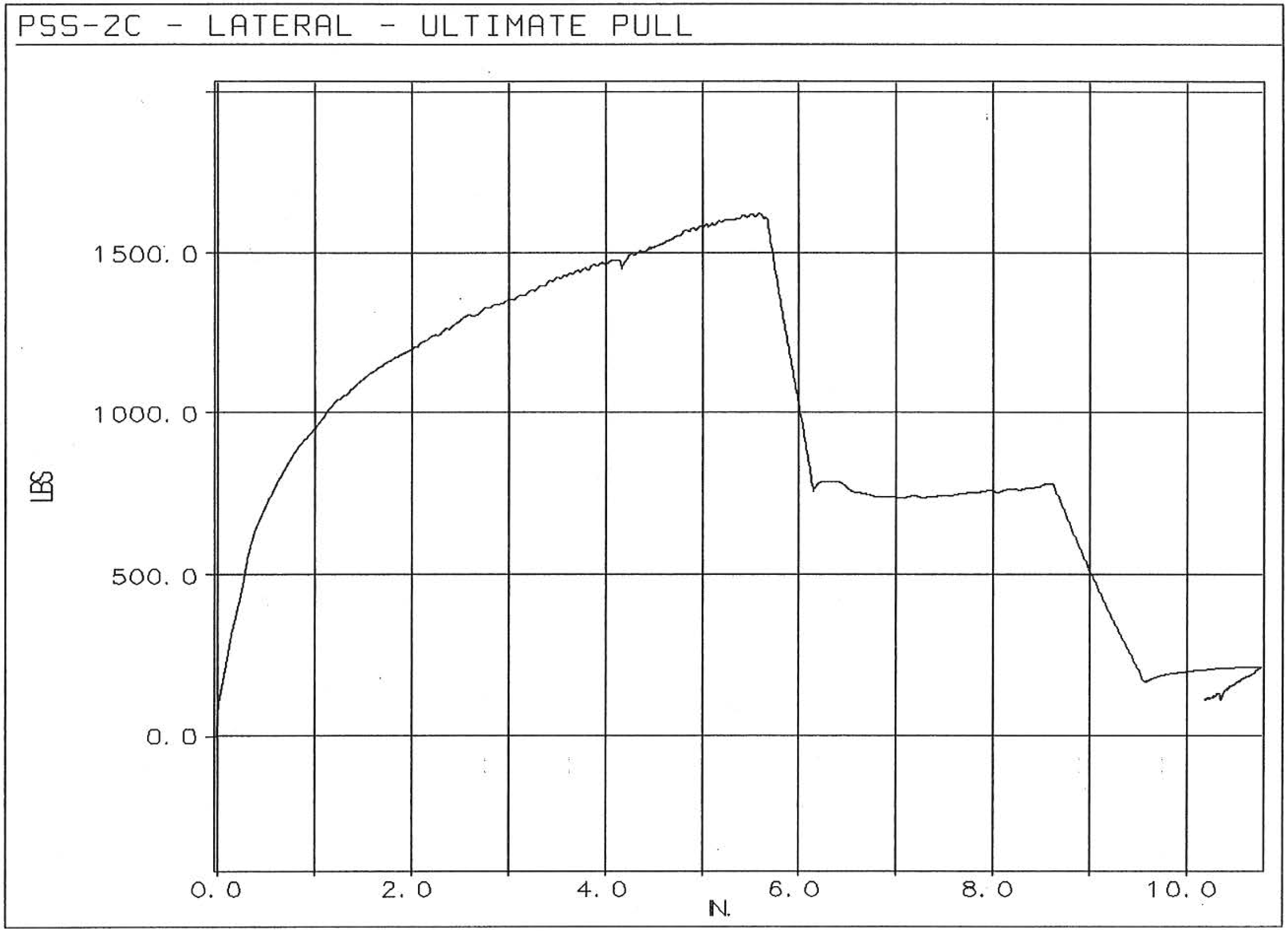
4.5
5.0
IN.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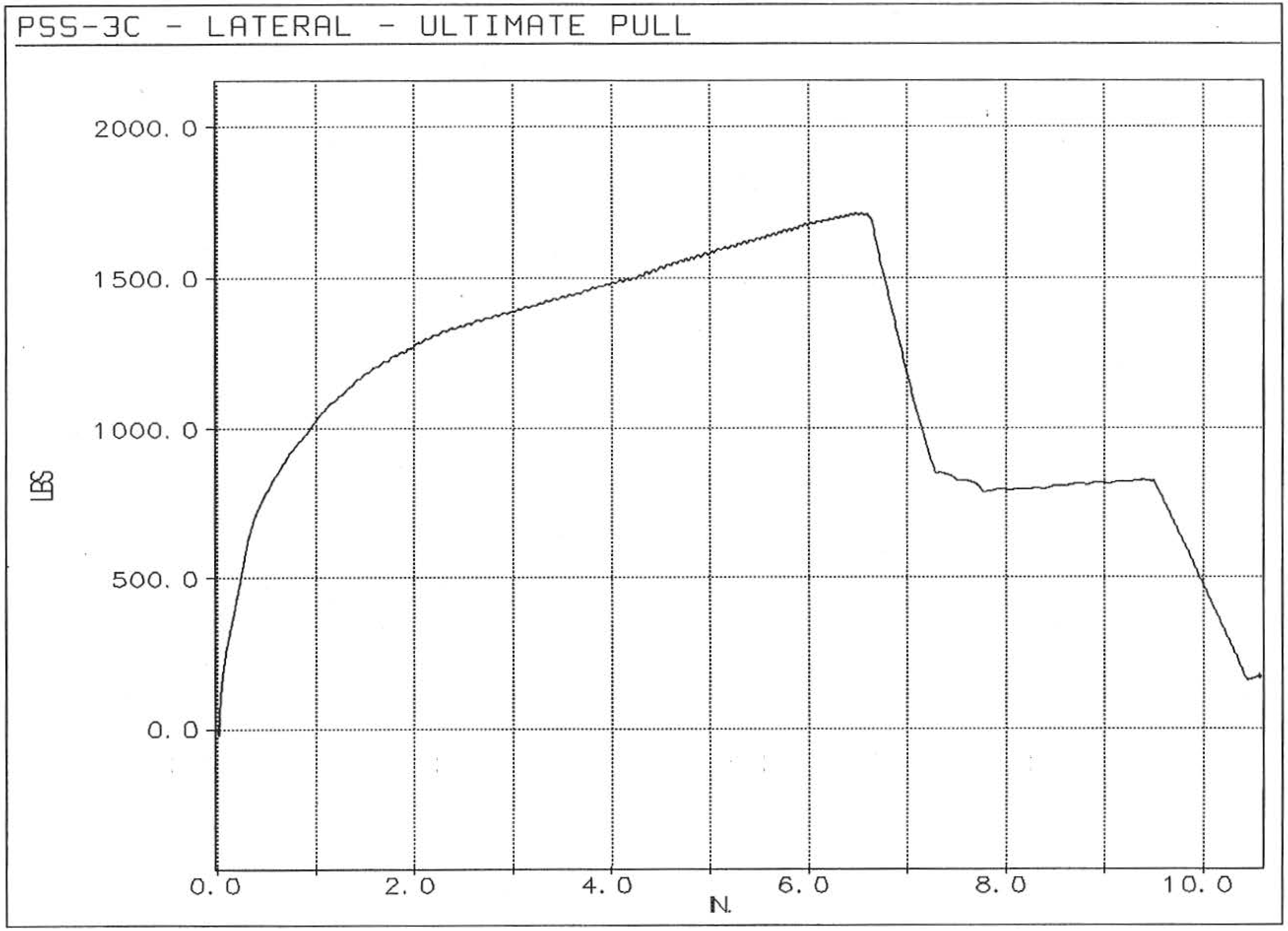
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10. 0
IN.


PSS-5C - LATERAL - ULTIMATE PULL
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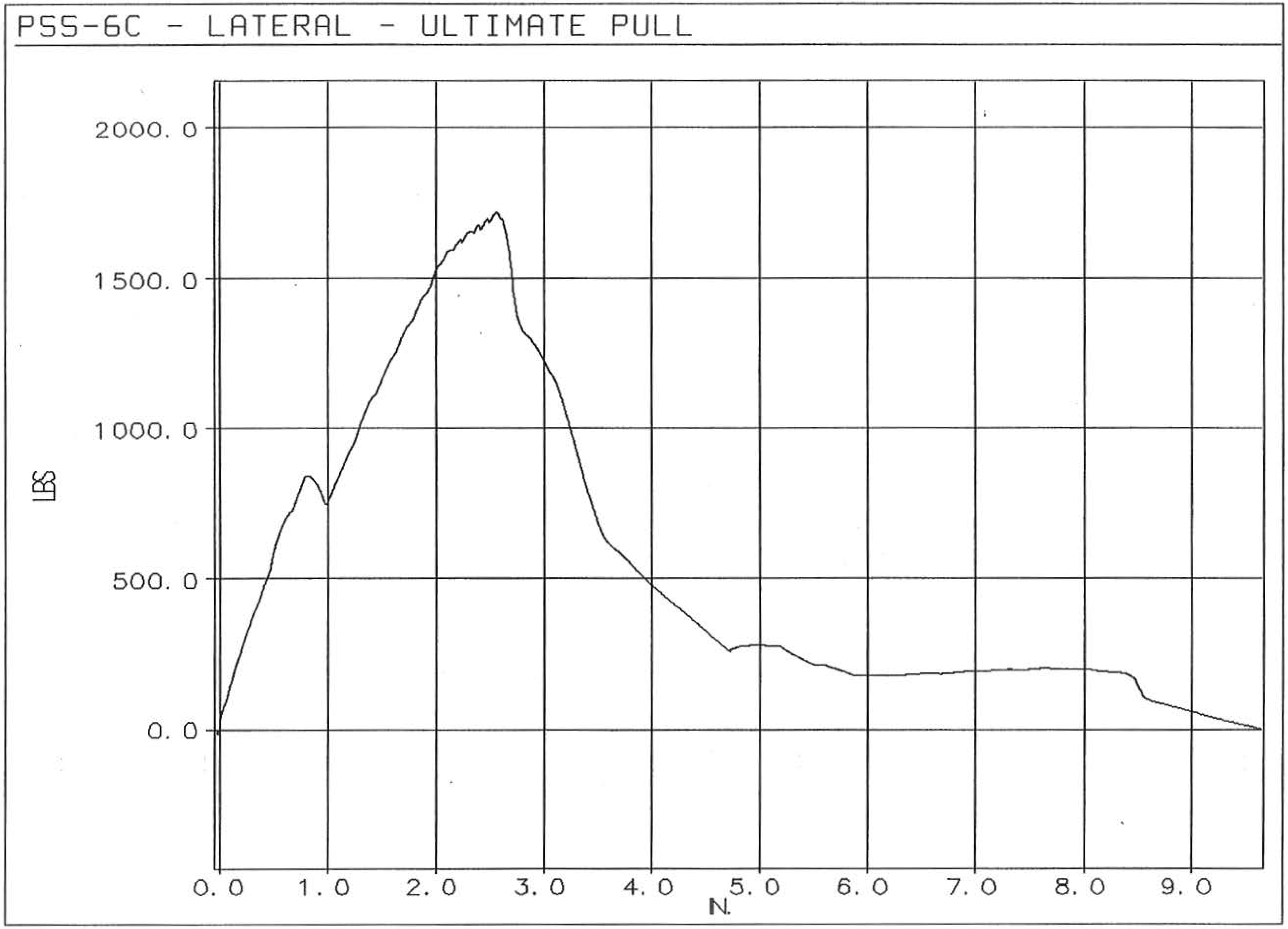
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6. 0
7. 0
8. 0
9. 0
IN.

APPENDIX E

Correspondence

University of
Nebraska
Lincoln

Midwest Roadside Safety Facility
Civil Engineering Department
1901 'Y' Street, Bldg. C
P.O. Box 880601
Lincoln, NE 68588-0601

February 20, 1996

Mr. Skip Martin
ARTECH CORP.
14554 Lee Road
Chantilly, Virginia 22021-1632

Dear Mr. Martin:

From your previous telephone conversations with both myself and Ken Krenk, you indicated that ARTECH CORP. could perform salt spray resistance testing of several prototype mailbox components for us in the near future. At this time, we are ready to have our prototype mailbox anchors and rods tested in the salt spray (fog) chamber according to ASTM B 117-94.

It is our intention to have four fixtures tested in your chamber. If possible, we would like all four fixtures to be tested at the same time. Each of the four fixtures consists of a 4-in. x 8-in. x 14-in. concrete block with threaded rods embedded in the surface and/or mailbox pedestals attached to the surface. The following fixtures are to be tested and described below:

Fixture No. 1: Concrete block with four 316SH stainless steel rods, washers, and nuts used to attach an aluminum pedestal (pedestal part of CBU mailbox system).
Fixture No. 2: Concrete block with four 316SH stainless steel rods, washers, and nuts used to attach a steel pedestal (pedestal part of NDCBU mailbox system).
Fixture No. 3: Concrete block with four 316SH stainless steel rods, washers, and nuts used to attach an plastic pedestal (pedestal part of CBU mailbox system).
Fixture No. 4: Concrete block with three rows of four rods each consisting of 316SH, 410 HT, and 416 stainless steels and/or washers and nuts.

Typically, the steel NDCBU mailboxes and pedestals are tested for 50 hours of exposure (paragraph 4.2.11 of Publication 18) and the aluminum and plastic CBU mailboxes and pedestals are tested for 500 hours of exposure (paragraph 3.5.11 of USPS-8-1118E). However, we would like all of them tested in the 500 hour test and, if possible, also document the corrosion on the steel pedestal and anchors (Fixture No. 2) after 50 hours of exposure. Please let me know if this is a possibility.

Also, what type of documentation is provided when we hire your services (i.e., photographs, description of corrosion, letter report, etc.). In the past, you have stated that this testing would cost approximately $400 for whatever amount of pieces could fit into one chamber. Is that still the same and are there any additional charges?

Please call me to discuss the following information. My phone number is (402) 472-6864.

Sincerely,

Ronald K. Faller

Ronald K. Faller, P.E.
Research Associate Engineer

Enclosures (2): paragraph 4.2.11 of Publication 18
paragraph 3.5.11 of USPS-8-1118E

ARTECH CORP.
14554 Lee Road • Chantilly, Virginia 22021-1632
(703) 378-7263 • Washington, D.C. Metro 968-TEST • Fax (703) 378-7274

March 29, 1996

Mr. Ronald K. Fuller
University of Nebraska - Lincoln
Midwest Roadside Safety Facility
Civil Engineering Department
1901 Y ST., Bldg. C
P. O. Box 880601
Lincoln, NE 68588-0601

Subject: Salt Fog Testing per USPS-B-1118E.

Reference: P. O. No. QL753344-T
ARTECH C62.080

Dear Mr. Fuller:

ARTECH was requested to perform a 500 hour salt fog test on a variety of concrete blocks, pedestals, and related hardware. The testing has been completed. This letter summarizes the observations on the tested components.

Pedestal #1 has no rust or corrosion on the pedestal or on the hardware holding it to the concrete block. The bolt and nut assemblies on the top plate have a substantial amount of white corrosion with red rust visible on the corners of the bolt head and nut.

Pedestal #2 is essentially identical to pedestal #1 in terms of visible corrosion. The red rust on the hardware in the top plate is substantially worse, including a wash of rust from the bolt flowing across the top plate.

Pedestal #3 had no top plate hardware. The pedestal does not appear to be metallic. The hardware fastening the pedestal to the concrete base has a small amount of red rust visible on the bolt tops.

The three sets of bolts in the concrete block differ markedly in their response to salt fog exposure. The 316 bolts have no visible rust. The 410 bolts, washers, and nuts, and the 416 bolts (no washers or nuts were present on the 416 studs) have penetrating rust in the threads and on the faces of the nuts. The rust is worse on any area of stressed metal, whether the stress was from the machining of the threads, tightening a bolt, or other sources.

The three pedestals and the concrete block will be returned under separate cover. If ARTECH can be of any additional assistance, on this or other matters, please contact us at any time.

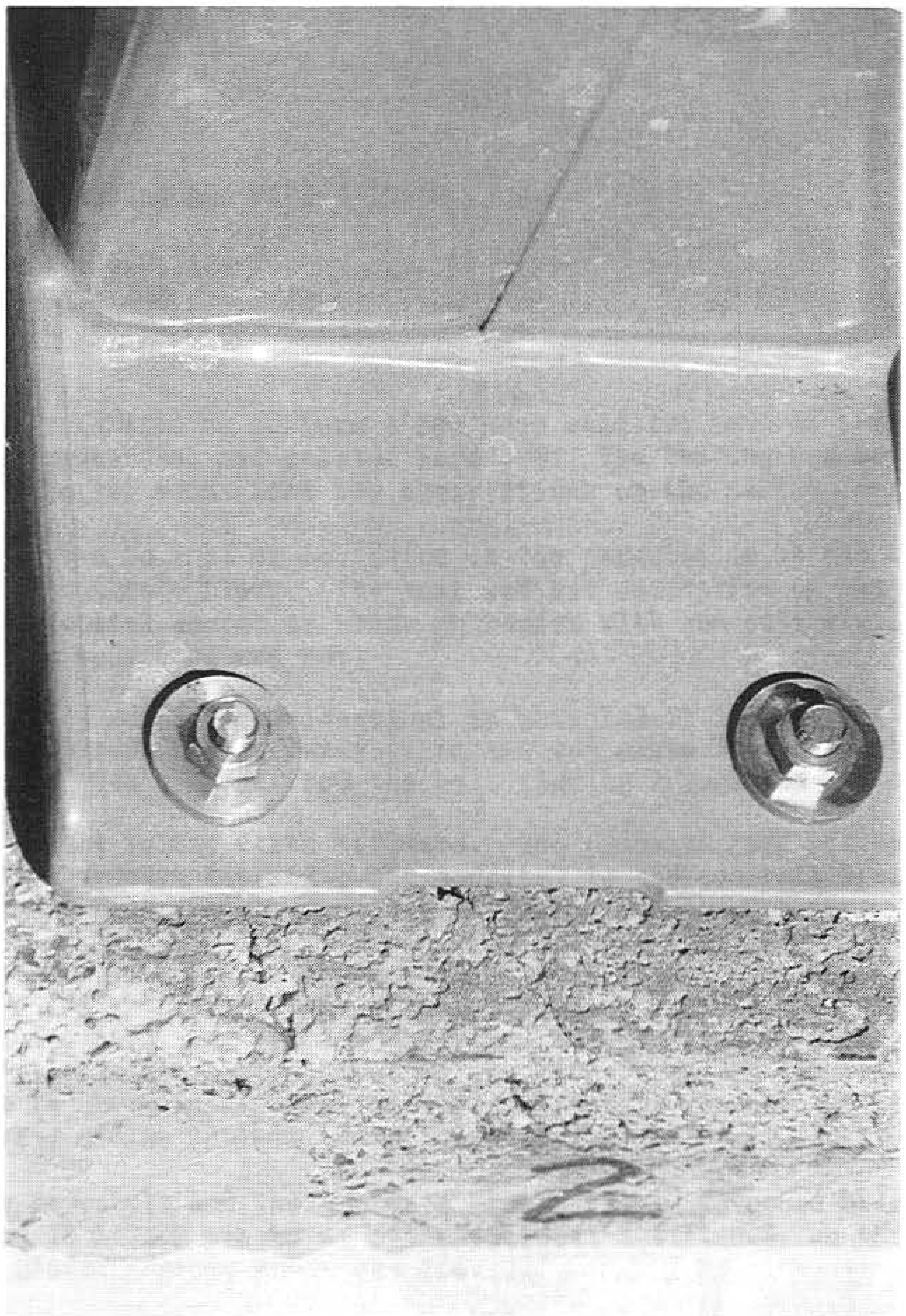
Sincerely,
ARTECH CORP.

Keith W. Flohr

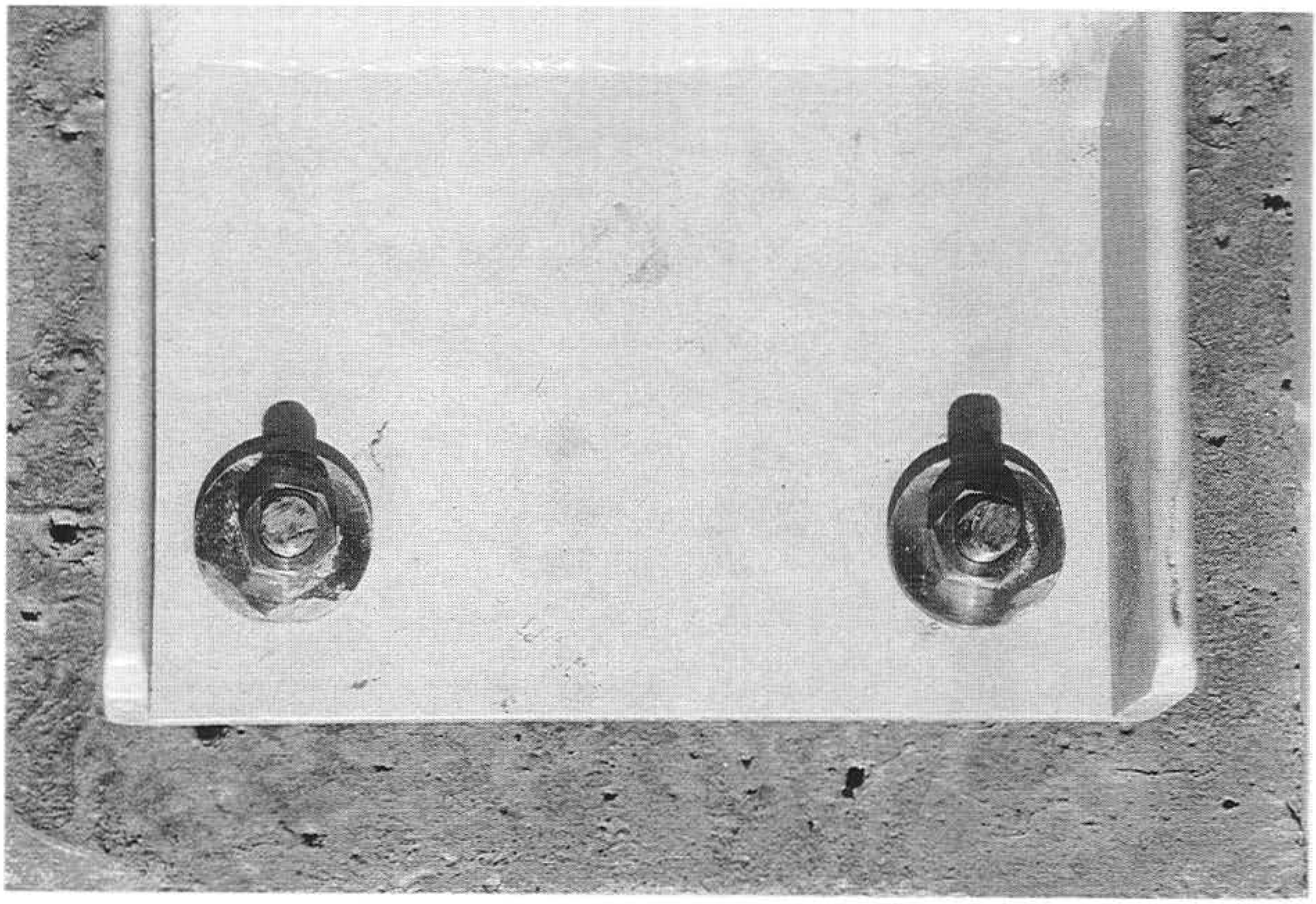
Keith W. Flohr
Manager, Analytical Services

APPENDIX F

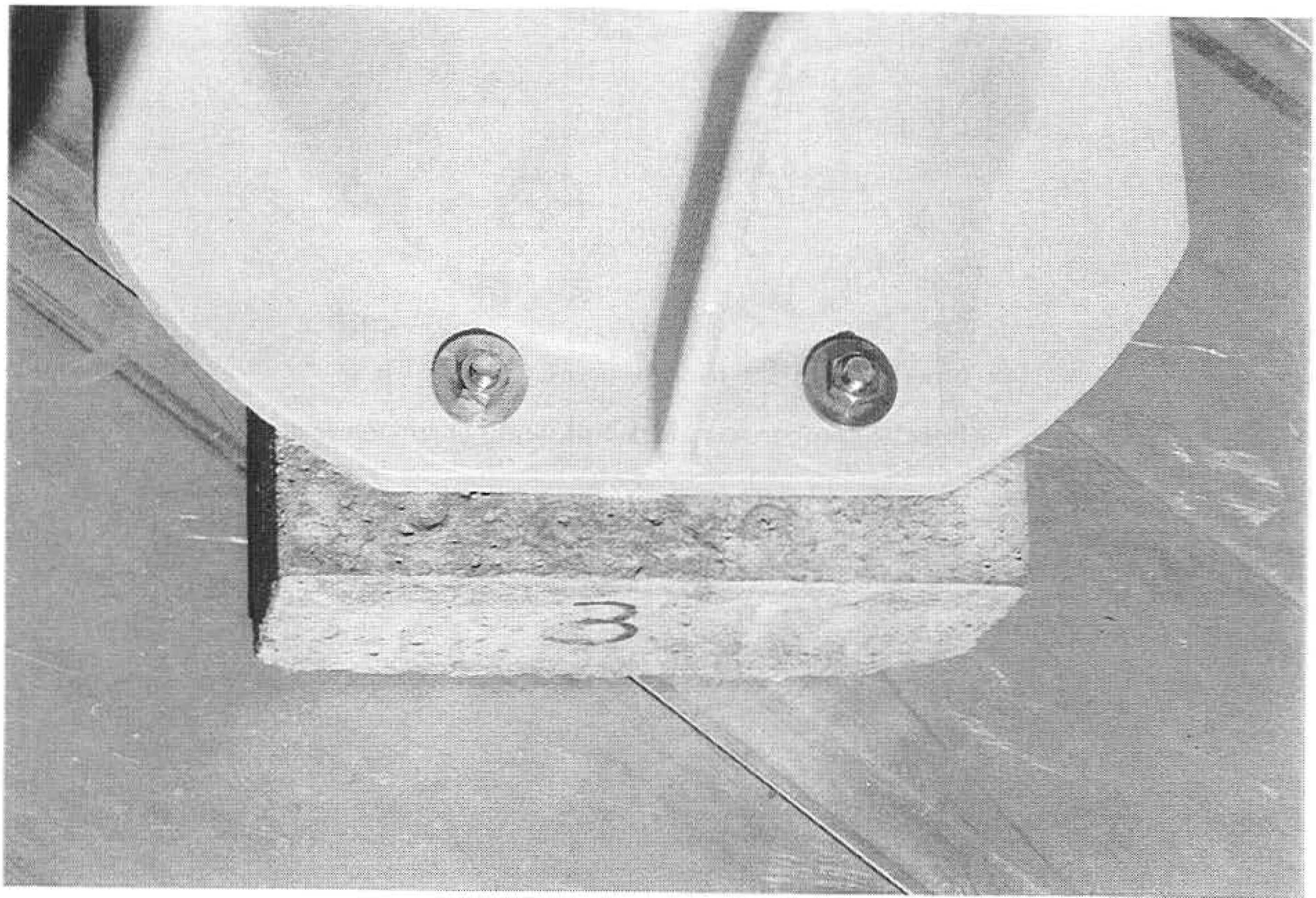
Corrosion Test Results



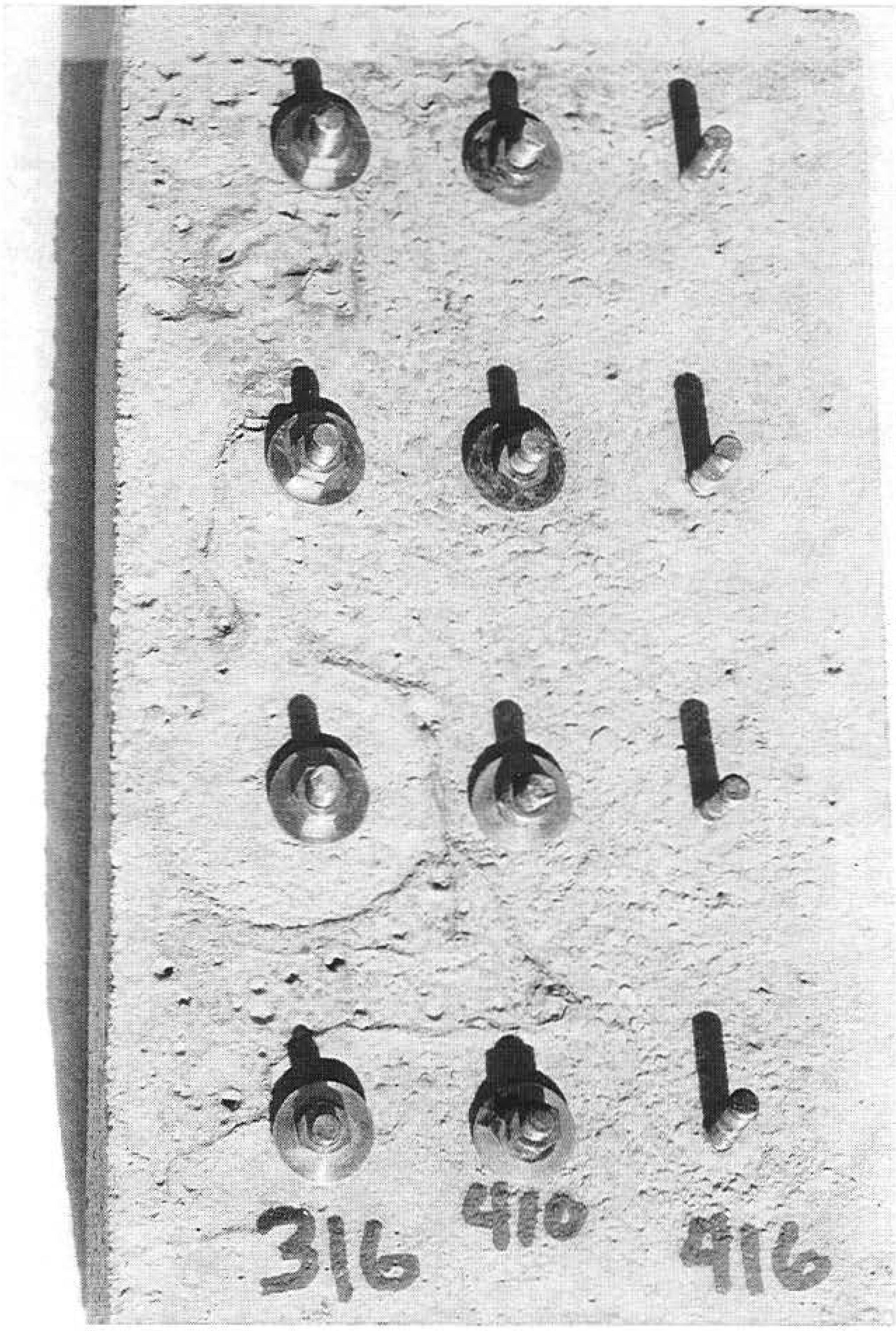
Anchor bolts on steel pedestal following corrosion test.



Anchor bolts on aluminum pedestal following corrosion test.



Anchor bolts on plastic pedestal following corrosion test.



Material comparison block following corrosion test.