Shear Capacity of U-Bolt Connections in Transit Buses

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Laboratory tests were conducted to assess the shear capacity of U-bolt connections used in most transit buses to attach the bus frame and body to the bus chassis. These tests involved the connections in two medium-duty transit buses designed and built in Michigan for the Michigan Department of Transportation. For each test specimen, the shear forces applied and the relative displacements of the components representing the bus frame and chassis were recorded. The results indicated no correlation between the initial U-bolt torque and the shear capacity of the connections, whereas very substantial increases in the rate of load application resulted in slight to moderate decreases in the shear capacity. Increases in the number of U-bolts per specimen from two to three caused slight decreases in average U-bolt shear strength, and substantial increases in the chassis depth caused substantial increases in the U-bolt shear capacity.

A study to assess the structural responses of medium-duty transit buses subjected to various levels of bus deceleration has been conducted at the Department of Civil and Environmental Engineering, Wayne State University. This effort has included parametric studies using finite-element modeling and analysis of typical medium-duty transit buses under various combinations of seat belt usage, passenger seat types, and wheelchair loads (*1,2*). The research also involved laboratory tests that were conducted to assess the shear capacity of the U-bolt connections that are used in most transit buses to attach the bus body and frame to the bus chassis. Similar U-bolt connections are also used in many light utility trucks to attach the truck van or storage compartment to the truck chassis.

The laboratory test results that are presented here involve the bus frame-to-chassis U-bolt connections in two medium-duty transit buses that were designed and built in Michigan for the Michigan Department of Transportation (MDOT). These tests were conducted using a Minnesota Testing Systems (MTS) load frame with a capacity of 2500 kN. For each test specimen, the shear forces applied and the relative displacements of the members representing the bus frame and body versus the bus chassis were monitored and videotaped. Thus, the failure mode or modes for each specimen were determined.

Because the principal goal of the project was to assess the capacity of the U-bolt connections in two existing bus designs, no attempt was made to revise or optimize these original bus designs. Such an optimization study of the bus frame-to-chassis connections would have required a widely expanded scope of work. In addition, no attempt was made to assess the impact of other parameters such as low temperatures, moisture, road salt, and cyclic loading on the shear capacity of the connections. This too would have been far beyond the scope of work for the project.

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LITERATURE REVIEW

A comprehensive literature review conducted as a part of the project showed very little research to experimentally assess the behavior of the structural components or connections of a transit bus (*3*). Reports dealing with front-end crash tests of school and transit buses have demonstrated the potential for slippage of the frame-to-chassis connections. One of the buses used in the UCLA crash tests of transit buses, for example, displaced forward by 430 mm (*4*). Transport Canada reported displacements of up to 610 mm for their school bus tests (*5*). Such large displacements would have probably resulted in the deaths of the bus drivers. Severy et al. stated that "collapsing of the passenger compartment applies violent collision forces directly to the driver and passengers, even when they are adequately restrained" (*4*). Therefore, they recommended that "the bus design should insure that the passenger compartment is securely attached to the frame of the bus by appropriately sized shear bolts at frequent intervals from front to rear along both frame members."

In 1986 Thomas Built Buses crash tested a bus that was specially built with unitized construction that, in crash tests, successfully reduced body displacement to 20 mm (*6–8*). However, it is not clear whether this design change has ever been successfully incorporated into production models of transit or school buses. Moreover, research has not yet been conducted to determine if such changes would harm the safety of the bus passengers because of the increased stiffness of the bus structure and hence the potential for increased levels of deceleration felt by the bus passengers in an emergency. Other than the crash tests just discussed, no other experimental studies have been conducted that were aimed specifically at the shear capacity of the bus frame-to-chassis connections.

BUS DESIGNS TESTED

Tests of the bus frame-to-chassis connections were performed for two medium-duty transit bus designs. These designs were based on specifications developed by MDOT in 1989 and 1992. These buses were manufactured in Michigan for MDOT to be used by smaller cities and rural communities throughout the state. Both the 1989 and 1992 bus designs include models with lengths that vary from 6.4 to 8.8 m and with capacities that vary from 22 to 30 passengers. The typical model for each design has a length of 7.5 m with 13 seats for a capacity of 26 passengers.

All of the steel members in the frame and chassis of these buses are cold-formed steel sections with minimum yield stresses of 207 MPa. Figures 1 and 2 contain longitudinal and transverse cross-section views of the 1989 bus that show the structural components

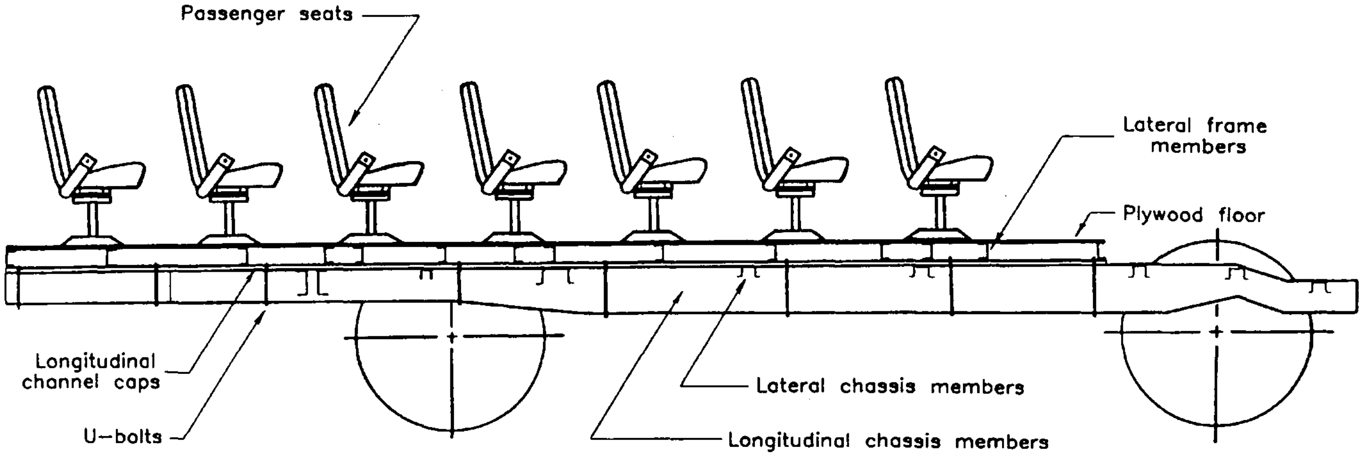

FIGURE 1 Longitudinal cross-section view of bus structure.

of the frame-to-chassis connections. Figures 1 and 2 were first published by Dusseau et al. (*1*). Figure 3 is a cutaway view showing the structural components of the frame-to-chassis connections. The chassis is composed of two longitudinal members that are fabricated from channel sections and are connected at intervals by lateral chassis members. The frame is composed of lateral members that are fabricated from channel sections that run between the bus sidewalls and support the frame (including the skirting and edge members), the floor (including the passenger seats and passengers), and the body (including the doors and windows). The lateral frame members are welded to longitudinal caps that are fabricated from channel sections, that rest on segments of oak filler, and that are attached to the longitudinal chassis members with U-bolt connections and steel shear tabs as shown in Figure 3. The shear tabs are welded along all edges to the longitudinal chassis members and the longitudinal cap members.

TEST SPECIMENS AND PROCEDURES

A schematic diagram of the load frame, test specimen, and connection detail is shown in Figure 4. Each test specimen consisted

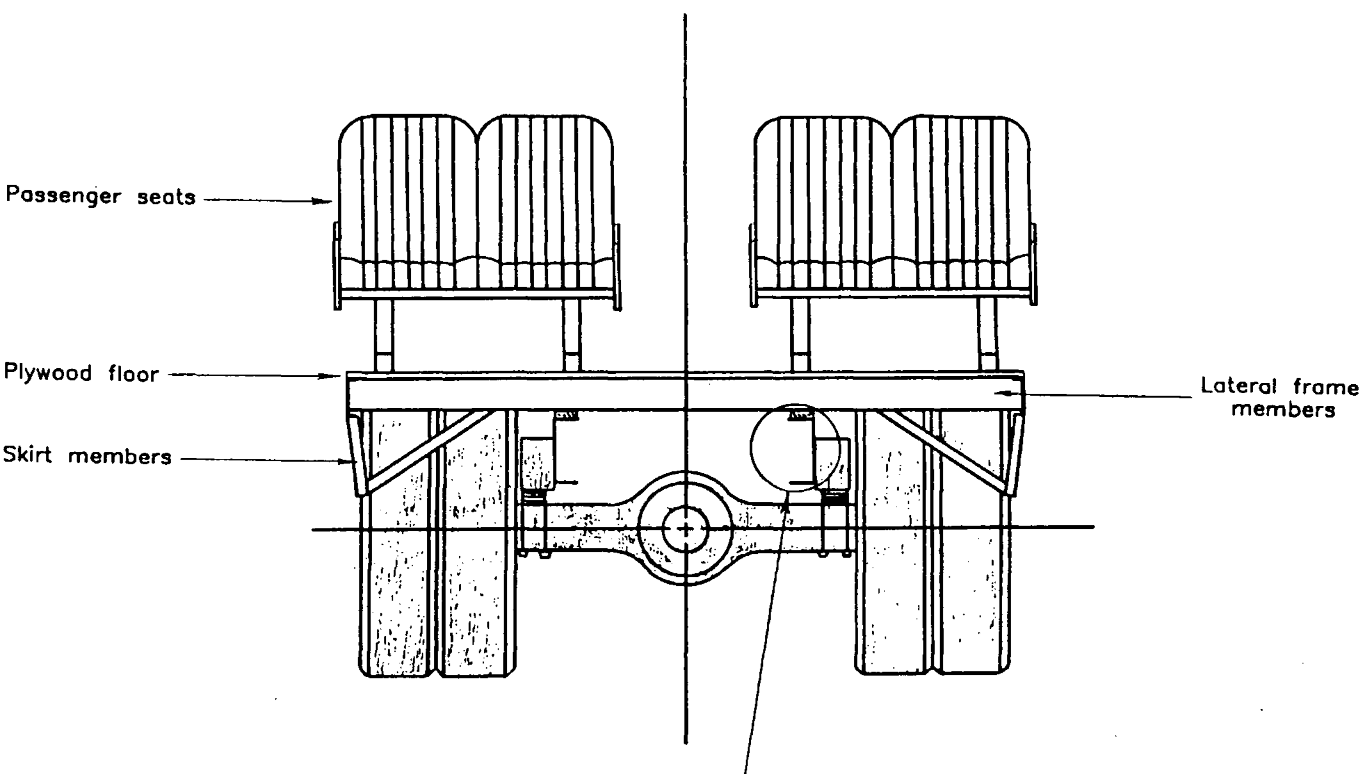

FIGURE 2 Transverse cross-section view of bus structure.

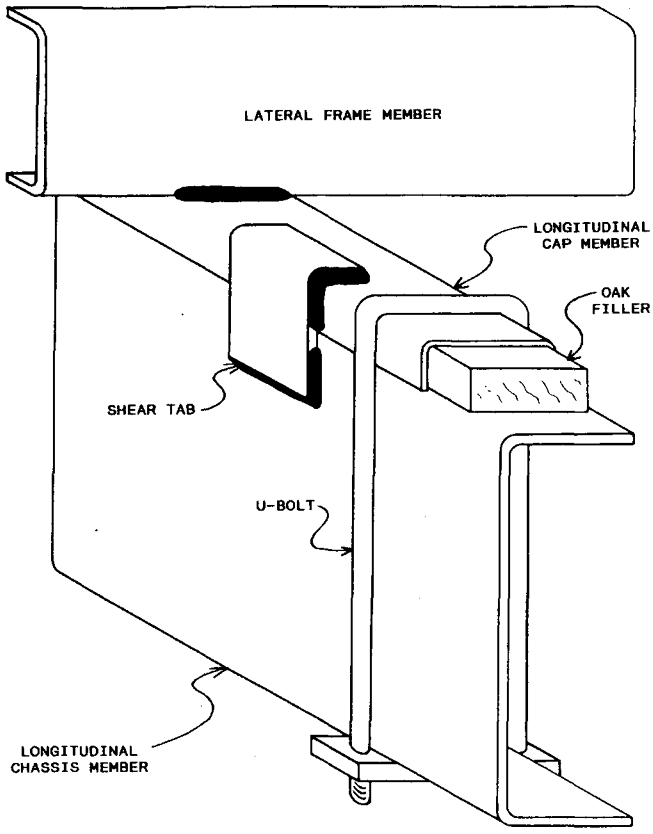

FIGURE 3 Structural components of frame-to-chassis connection.

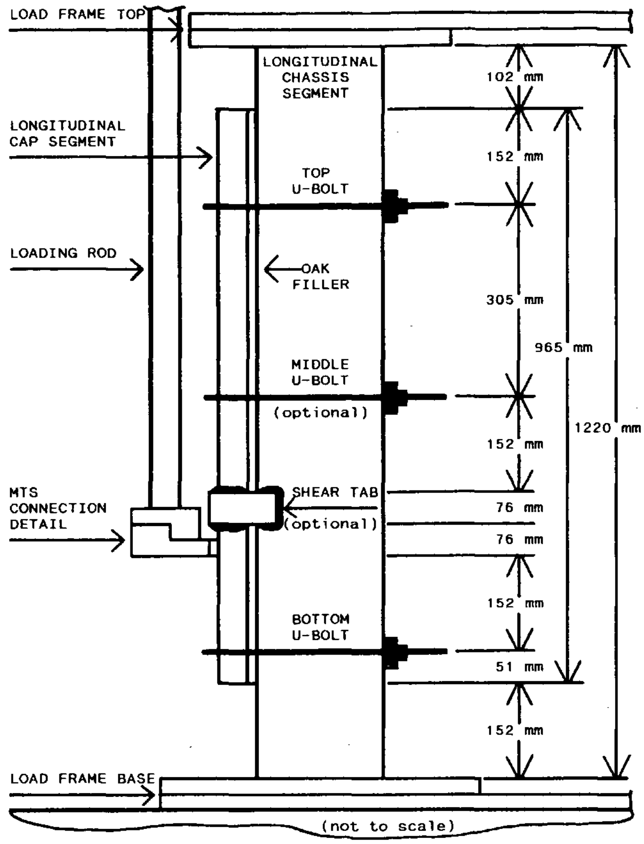

FIGURE 4 Schematic diagram of load platform and specimen.

of the following components:

1. A 1220-mm segment of the longitudinal chassis members that was fabricated from cold-formed steel channel sections with flange widths of 76 mm,
2. A 965-mm segment of the longitudinal cap members that was fabricated from cold-formed steel channel sections with widths of 76 mm and depths of 25 mm,
3. A 965-mm segment of the 64- × 25-mm oak filler that was sandwiched between the longitudinal chassis segment and the longitudinal cap segment,
4. Two or three U-bolts with diameters of 13.3 mm, and
5. An optional steel shear tab with a width of 76 mm.

An MTS connection detail was welded to the longitudinal cap segment and served to connect the test specimen with a 2.5-in. steel loading rod that was fastened to the loading head of the MTS machine. The U-bolts, shear tabs, longitudinal chassis segments, and longitudinal cap segments were all ordered from the same vendors used by the bus manufacturer using the same specifications as the manufacturer.

The principal difference between the test specimens for the 1989 and 1992 buses was the depth of the longitudinal chassis members. These members had minimum depths of 152 mm for the 1989 buses and 229 mm for the 1992 buses. The resulting U-bolts had overall lengths of 203 and 279 mm, respectively.

Shearing forces representing the inertia of the bus body, frame, and passengers that could be generated in an emergency situation were applied to each test specimen through the loading rod and the MTS connection detail and were increased until failure occurred. For each test specimen, the shear forces applied and the relative displacements between the longitudinal cap segment (which represents the bus frame) and the longitudinal chassis segment were recorded. A total of 24 specimens representing the 1989 bus design were tested along with 8 specimens of the 1992 bus design.

1989 BUS DESIGN TESTS

Specimen Configurations

Three parameters were considered in deriving the primary test specimens for the 1989 bus design: U-bolt torque, number of U-bolts, and use of shear tabs. The U-bolt torque used by the bus manufacturer for tightening the nuts on all U-bolts is 74.6 N-m. Because it was initially believed that U-bolt torque could play a role in the shear capacity of the U-bolt connections, six bolt torques were used for the 1989 bus specimens: 61.0, 67.8, 74.6, 81.3, 88.1, and 94.9 N-m. These six U-bolt torques correspond to percentages of 82, 91, 100, 109, 118, 127, and 136, respectively, relative to the manufacturer's U-bolt torque of 74.6 N-m.

Four specimens were tested at each of the six U-bolt torques: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. Thus, 24 primary specimens of the 1989 bus design were tested. For the specimens with two U-bolts, the U-bolt spacing was 761 mm, which is approximately the same as the maximum U-bolt spacing in the 1989 and 1992 bus designs. For the specimens with three U-bolts, the minimum U-bolt spacing of 305 mm is approximately the same as the minimum U-bolt spacing used in the 1989 and 1992 bus designs.

For each test specimen, shear forces were applied using a displacement controls procedure in which the relative displacement of the longitudinal cap segment versus the longitudinal chassis segment was increased at a uniform rate. For the 12 specimens without shear tabs, the rate of relative motion was 25.4 mm/min for the entire 152.4 mm of motion allowed. Although this rate of relative motion is much slower than what might be experienced under emergency conditions, it was initially thought that a faster rate would make it much more difficult to record adequately all of the test results (both measured and videotaped) for the 1989 bus specimens.

For the 12 specimens with shear tabs, the rate of relative motion was 6.4 mm/min for the first 25.4 mm of motion and then 25.4 mm/min for the remaining 127.0 mm of motion. The very slow initial rate was chosen to record adequately the failure mechanism for the shear tabs, which were expected to fail within the first 25.4 mm of relative motion. The rate for the remaining 127.0 mm of relative motion, which was expected to occur after failure of the shear tabs, was the same as the rate used for the 12 specimens without shear tabs.

Test Results

Plots of shear force versus relative displacement were derived for the 24 primary test specimens representing the 1989 bus design. As depicted in Figure 5 for the specimen with a torque of 61 N-m, three U-bolts, and no shear tab, the plots of shear force versus relative displacement for the specimens without shear tabs were all characterized by a gradual buildup of force to a maximum value. This gradual buildup of force began almost immediately as the oak filler started to slip along the top of the longitudinal chassis segment and ended at a relative displacement of 28 to 41 mm when one or more U-bolts slipped (as noted in Figure 5). The U-bolt slippage occurred at the bottom of the U-bolt where the base plate of the U-bolt slid along the bottom flange of the longitudinal chassis segment. For most of these 12 specimens, further cycles of force buildup and slippage occurred, but in none of the specimens did the subsequent shear forces exceed the maximum value derived before slippage of the first U-bolt. The results for all 12 test specimens indicated no apparent correlation between U-bolt torque and shear capacity. This lack of correlation is illustrated in Figure 6, which contains plots of shear force at first U-bolt slippage versus initial U-bolt torque for the four types of specimens that were tested at each U-bolt torque.

As shown in Figure 7 for the specimen with a torque of 61 N-m, three U-bolts, and one shear tab, the plots of shear force versus relative displacement for the specimens with shear tabs were all

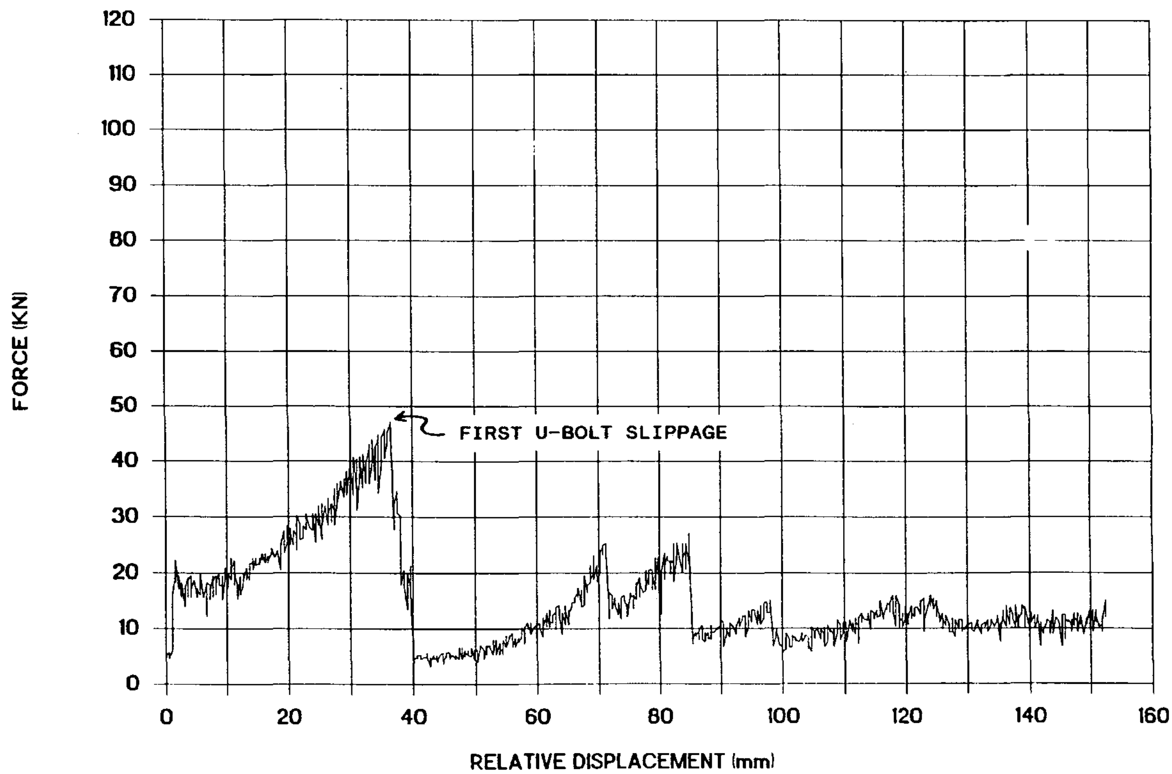

FIGURE 5 Shear force versus relative displacement for 1989 specimen with initial U-bolt torque of 61 kN, three U-bolts, and no shear tab.

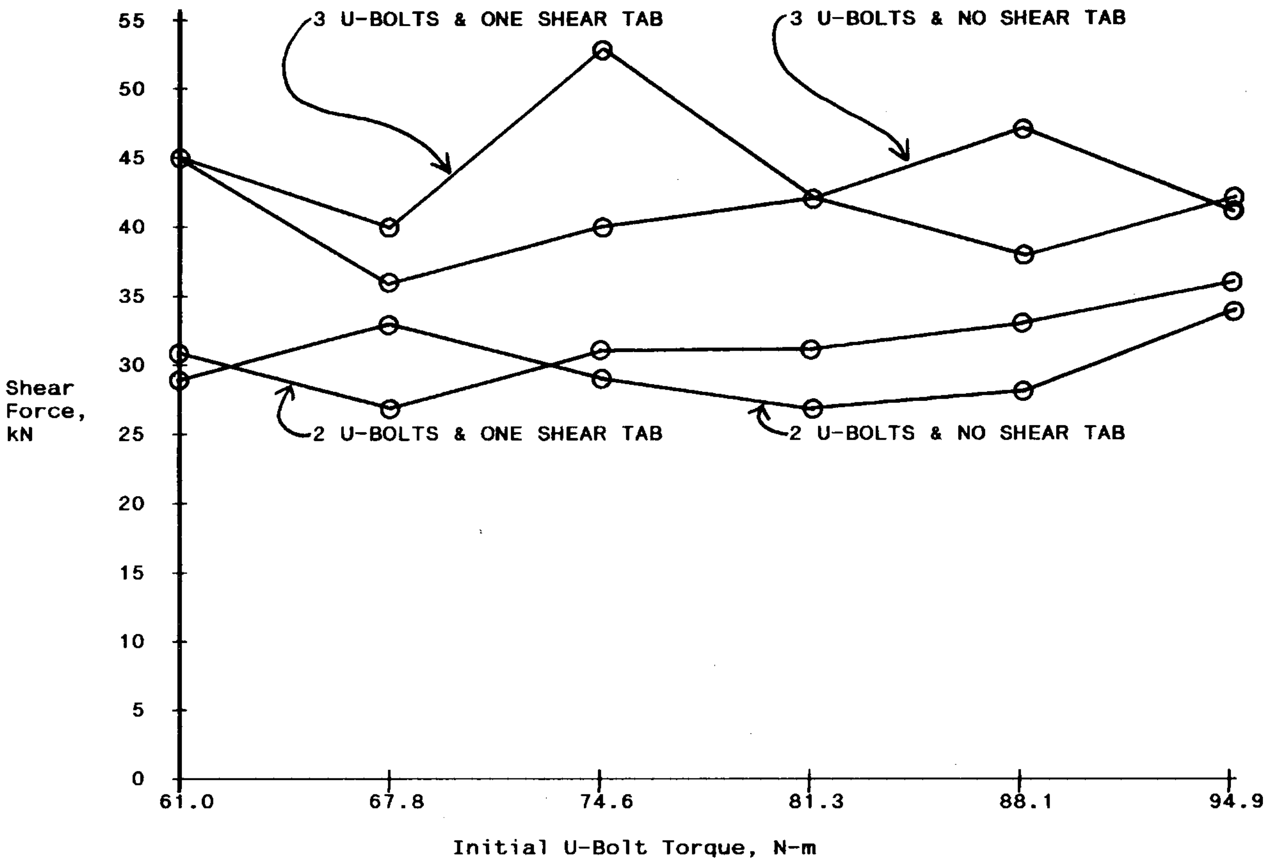

FIGURE 6 Plots of shear force at first U-bolt slippage versus initial U-bolt torque.

characterized by a rapid buildup of force to a maximum value. This rapid buildup of force ended when the shear tabs failed (as noted in Figure 7), which occurred within a relative displacement of 15 mm. The primary mechanism that was observed for shear tab failure was tearing of the shear tab welds. The failure of the shear tabs was followed by a gradual buildup of force similar to the specimens without shear tabs, which ended with slippage of the first U-bolt. The rest of the curves were very similar to curves for the specimens without shear tabs. Because the shear capacity of these specimens was reached when the shear tabs failed, the results for all 12 specimens indicated no correlation between U-bolt torque and shear capacity.

Table 1 presents a summary of the results for the 1989 bus specimens with averages for the four types of specimens tested at each U-bolt torque. The results in Table 1 for each test include the shear force at first U-bolt slippage, the relative motion at first U-bolt slippage, the U-bolt angle of tilt at first U-bolt slippage, and the capacity of the shear tabs for the specimens with shear tabs. Also included in Table 1 are the shear force capacities of the U-bolts and the shear tabs taken as a percentage of the mean values. All but one of the U-bolt shear capacities were within 16 percent of the mean value, and all but one of the shear tab capacities were within 12 percent of the average value.

The average shear capacities for the U-bolts were 15.4 and 14.2 kN/U-bolt for the specimens with two and three U-bolts, respectively. At first U-bolt slippage, the average relative motion was 36.2 mm, and the average U-bolt angle of tilt was 0.176 rad. The first specimen tested with shear tabs (U-bolt torque of 61 N-m and two U-bolts) had a premature weld failure due to the poor quality of this initial weld. Excluding this first specimen, the average capacity of the remaining 11 specimens with shear tabs was about 93.4 kN/tab.

1992 BUS DESIGN TESTS

Specimen Configurations

After testing the 1989 bus specimens and after careful evaluation of the test results, more information was desired on the effects of the rate of relative motion on the maximum shear capacity of the U-bolts and the shear tabs. Thus, the three parameters that were considered for the 1992 bus specimens were rate of relative motion, number of U-bolts, and use of shear tabs. On the basis of the results for the 1989 bus specimens, which indicated that U-bolt torque has no bearing on the maximum shear capacity of the U-bolt connections, the U-bolt torque used for the 1992 bus specimens was the same 74.6 N-m used by the bus manufacturer.

Four specimens of the 1992 bus were tested at the same rates of relative motion as the 1989 bus specimens: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. For the two specimens without shear tabs, a rate of 25.4 mm/min was used for the entire 152.4 mm of motion allowed. For the two specimens

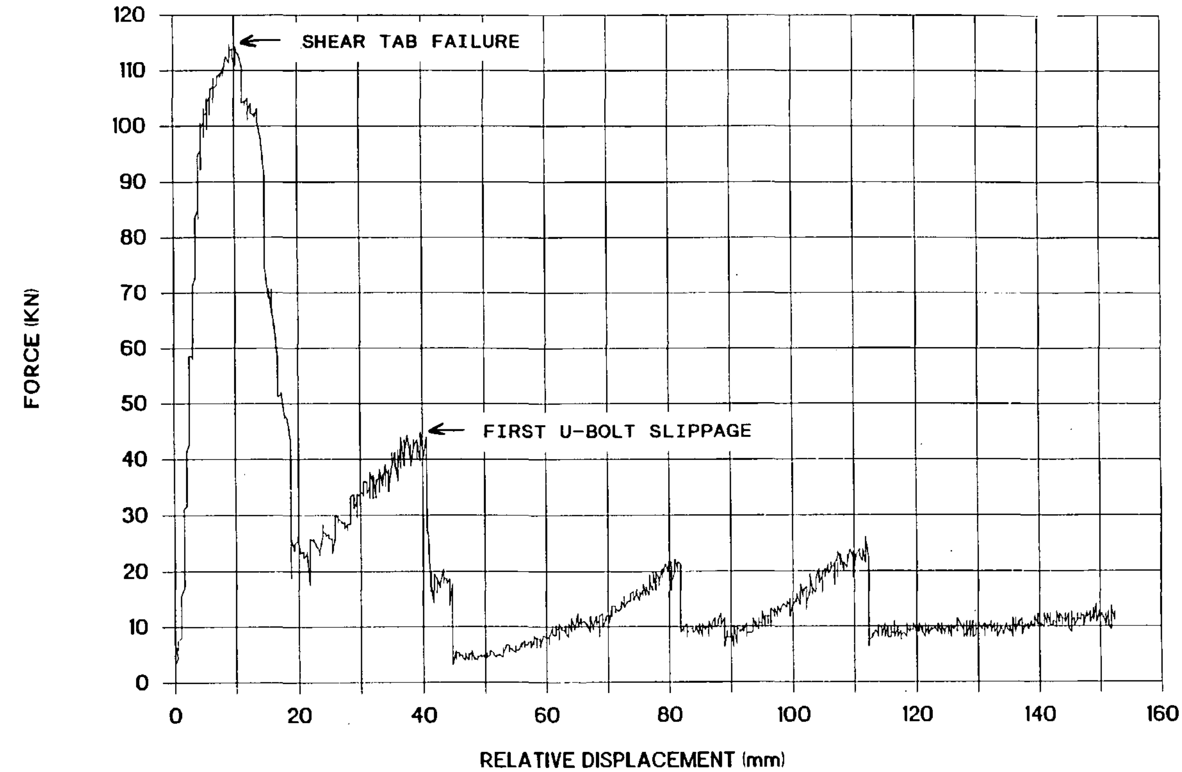

FIGURE 7 Shear force versus relative displacement for 1989 specimen with initial U-bolt torque of 61 kN, three U-bolts, and one shear tab.

with shear tabs, a rate of 6.4 mm/min was used for the first 25.4 mm of motion and a rate of 25.4 mm/min was used for the remaining 127.0 mm of motion.

Four specimens of the 1992 bus were tested at rates of relative motion that were 15 times higher than the rates used for the 1989 bus specimens: two U-bolts with no shear tab, two U-bolts with one shear tab, three U-bolts with no shear tab, and three U-bolts with one shear tab. For the two specimens without shear tabs, a rate of 6.4 mm/sec was used for the entire 152.4 mm of motion allowed. For the two specimens with shear tabs, a rate of 1.6 mm/sec was used for the first 25.4 mm of motion and then a rate of 6.4 mm/sec was used for the remaining 127.0 mm of motion.

Test Results

Plots of shear force versus relative displacement were derived for the eight primary test specimens representing the 1992 bus design. Because of a lack of adequate clearance for certain components of the test specimens, three of the eight primary specimens were stopped short of the 152.4 mm of relative motion originally planned. Despite this limitation, all eight specimens reached at least 105 mm of relative motion, the four test specimens with shear tabs reached shear tab failure, and all eight specimens reached first U-bolt slippage.

As illustrated in Figure 8 for the specimen with the slower rate of relative motion, three U-bolts, and no shear tab, the plots of shear force versus relative displacement for the four specimens without shear tabs were similar to the plots derived for the 1989 bus specimens (Figure 5). As in the 1989 bus results, there was a gradual buildup of force that ended when one or more U-bolts slipped. Unlike the 1989 bus results, however, three of the four 1992 bus specimens reached higher levels of shear force after the first U-bolt slipped. As depicted in Figure 9 for the specimen with the slower rate of relative motion, three U-bolts, and one shear tab, the plots of shear force versus relative displacement for the four specimens with shear tabs were also similar to the plots derived for the 1989 bus specimens (Figure 7). As in the 1989 bus results, there was a rapid buildup of force that ended when the shear tabs failed. This was followed by a gradual buildup of force similar to the specimens without shear tabs, which ended with slippage of the first U-bolt. Unlike the 1989 bus results, however, all four specimens reached higher levels of shear force (due to U-bolt strength) after the shear tabs failed.

Table 2 presents a summary of the results for each 1992 bus specimen with averages for the four types of specimens tested at each rate of relative motion. The results given in Table 2 for each test include the shear force at first U-bolt slippage, the relative motion at first U-bolt slippage, the U-bolt angle of tilt at first U-bolt slippage, and the capacity of the shear tabs for the specimens with shear tabs. Also included in Table 2 are the shear force capacities of the U-bolts and the shear tabs taken as a percentage of the mean values. All of the U-bolt shear capacities were within 18 percent of the mean value, and all of the shear tab capacities were within 11 percent of the average value.

The average shear forces at first U-bolt slippage were 38.3 and 37.1 kN/U-bolt for the specimens with two and three U-bolts, respectively. These much higher U-bolt shear capacities for the 1992 bus specimens versus the 1989 bus specimens were partly the result of steel-to-steel coefficients of friction that were esti-

TABLE 1 Laboratory Test Results: 1989 Bus Specimens

U-bolt Torque, N-m	Number of U-bolts	Shear Tabs? yes or no	Test Results at First U-bolt Slippage				Shear Tab Results	
			Shear Force, kN	Per-cent of Mean	Relative Motion, mm	Angle of Tilt, radians	Force, kN	Per-cent of Mean
61.0	2	no	29	97%	39.8	0.193	NA	NA
		yes	31	100%	36.4	0.177	36*	NA*
	3	no	45	107%	36.9	0.180	NA	NA
		yes	45	105%	41.0	0.199	115	120%
67.8	2	no	33	110%	36.9	0.180	NA	NA
		yes	27	87%	38.4	0.187	98	105%
	3	no	36	86%	36.9	0.180	NA	NA
		yes	40	93%	34.9	0.170	98	102%
74.6	2	no	29	97%	34.9	0.170	NA	NA
		yes	31	100%	38.7	0.188	97	104%
	3	no	40	95%	32.9	0.161	NA	NA
		yes	53	123%	28.6	0.140	95	99%
81.3	2	no	27	90%	37.5	0.182	NA	NA
		yes	31	100%	37.5	0.182	93	100%
	3	no	42	100%	36.4	0.177	NA	NA
		yes	42	98%	36.4	0.177	90	94%
88.1	2	no	28	93%	33.5	0.163	NA	NA
		yes	33	106%	40.4	0.196	82	88%
	3	no	47	112%	38.7	0.188	NA	NA
		yes	38	88%	31.8	0.155	96	100%
94.9	2	no	34	113%	32.3	0.158	NA	NA
		yes	36	116%	39.3	0.191	96	103%
	3	no	41	98%	32.3	0.158	NA	NA
		yes	42	98%	36.4	0.177	85	89%
average test results	2	no	30	100%	35.8	0.174	NA	NA
		yes	31	100%	38.4	0.187	93	100%
	3	no	42	100%	35.7	0.174	NA	NA
		yes	43	100%	34.9	0.170	96	100%

* premature failure, value not included in average test results.

mated to be 55 percent higher for the 1992 bus specimens versus the 1989 bus specimens.

The average relative motion at first U-bolt slippage was 78.2 mm, and the average U-bolt angle of tilt at first U-bolt slippage was 0.273 rad. For the specimens with shear tabs, the average capacity of the shear tabs was 92.0 kN/shear tab.

A comparison of the shear forces at first U-bolt slippage under the fast versus slow rates of relative motion reveals decreases of 5 to 31 percent with an average decrease of approximately 18 percent. Similarly, a comparison of the capacities of the shear tabs under the fast versus slow rates of relative motion reveals decreases of 10 to 19 percent with an average decrease of about 15 percent. Thus, the results for the 1992 bus specimens indicate that a rate of relative motion 15 times faster, which approximates a more severe emergency situation, would result in small to moderate decreases in the shear capacities of the U-bolts and the shear tabs.

CRITICAL BUS DECELERATIONS

The average results from Tables 1 and 2 indicate that the capacity per shear tab should be approximately 93 kN, while the shear capacity per U-bolt should be about 14.8 kN for the 1989 bus design and 37.7 kN for the 1992 bus design. For the 26-passenger (7.5-m) versions of these buses, the number of shear tabs per bus was 2, whereas the number of U-bolts per bus was 14 for the 1989 bus and 12 for the 1992 bus. Thus, the bus shear capacities (F_v) should be approximately 186 kN (2 shear tabs at 93 kN/tab) for the shear tabs in the 1989 and 1992 buses, 207 kN (14 U-bolts at 14.8 kN each) for the U-bolts in the 1989 bus, and 452 kN (12 U-bolts at 37.7 kN each) for the U-bolts in the 1992 bus. Assuming an average passenger weight of about 0.6 kN and assuming the total weight of the bus body, frame, seats, and so forth in the bus passenger compartment to be approximately 10 kN, then the crit-

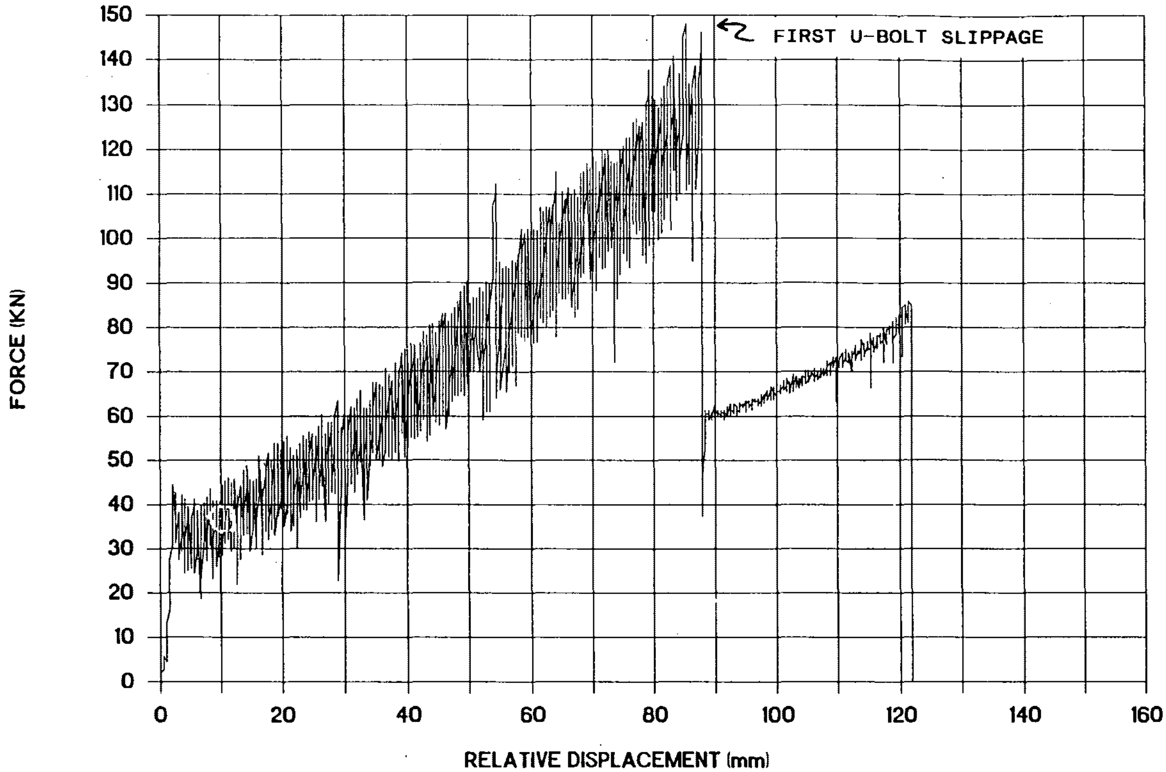

FIGURE 8 Shear force versus relative displacement for 1992 specimen with slow rate of relative motion, three U-Bolts, and no shear tab.

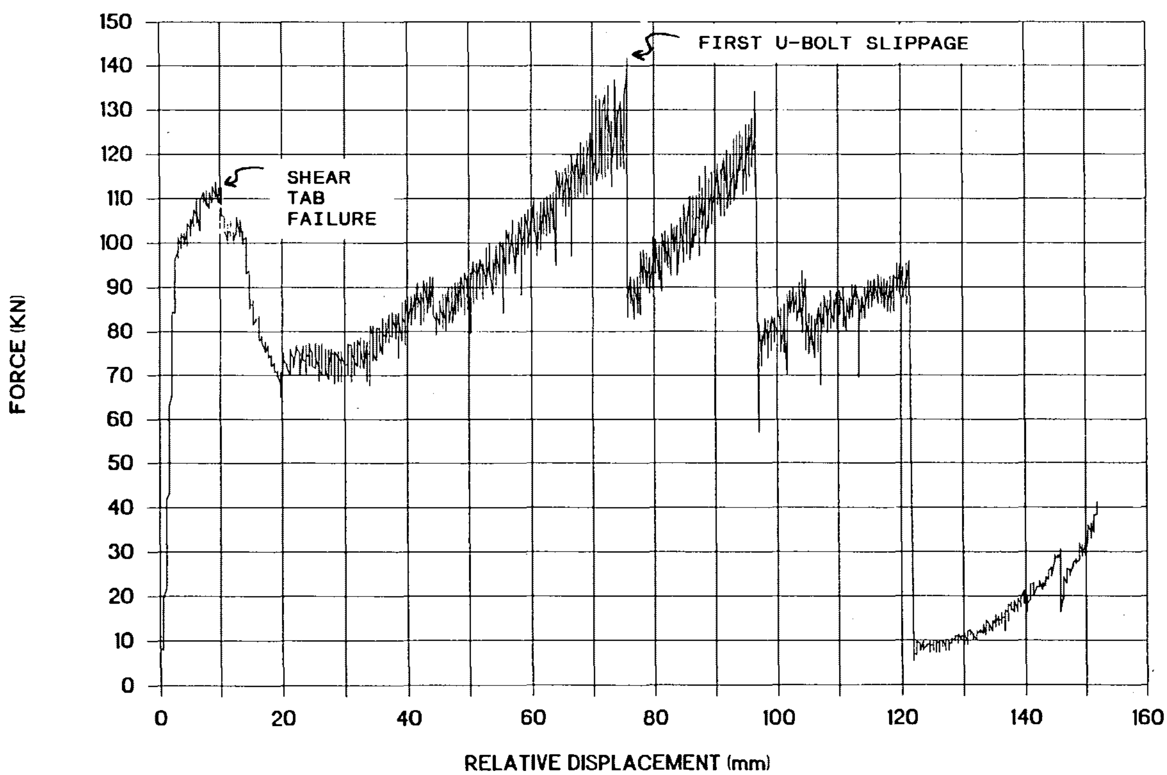

FIGURE 9 Shear force versus relative displacement for 1992 specimen with slow rate of relative motion, three U-bolts, and one shear tab.

TABLE 2 Laboratory Test Results: 1992 Bus Specimens

Rate of Relative Motion	Number of U-bolts	Shear Tabs? yes or no	Test Results at First U-bolt Slippage				Shear Tab Results	
			Shear Force, kN	Percent of Mean	Relative Motion, mm	Angle of Tilt, radians	Force, kN	Percent of Mean
slow	2	no	75	106%	72.1	0.253	NA	NA
		yes	84	102%	84.7	0.294	89	106%
	3	no	129	114%	87.8	0.304	NA	NA
		yes	129	118%	75.6	0.264	111	111%
fast	2	no	67	94%	68.7	0.241	NA	NA
		yes	80	98%	76.2	0.266	80	95%
	3	no	98	87%	88.1	0.305	NA	NA
		yes	89	82%	72.6	0.254	90	90%
average test results	2	no	71	100%	70.4	0.247	NA	NA
		yes	82	100%	80.4	0.280	84	100%
	3	no	113	100%	88.0	0.305	NA	NA
		yes	109	100%	74.1	0.259	100	100%

ical bus decelerations (D_{cr}) required to cause failure of the shear tabs and the U-bolts can be calculated using

$$D_{cr} = \frac{F_v}{[(26) \cdot (0.6) + 10]} = \frac{F_v}{26} \qquad (1)$$

where F_v equals the maximum shear capacities of the shear tabs or the U-bolts, in kilonewtons. The resulting critical bus decelerations would be approximately 7 *g* for the shear tabs in both the 1989 and 1992 buses, 8 *g* for the U-bolts in the 1989 bus, and 17 *g* for the U-bolts in the 1992 bus, where *g* is the gravitational acceleration constant (9.81 m/sec^2). Assuming a bus velocity (V) of 25 m/sec, these levels of bus deceleration would translate into stopping distances (L_{st}) calculated as follows:

$$L_{st} = \frac{V^2}{(2 \cdot g \cdot D_{cr})} = \frac{(25)^2}{[2 \cdot (9.8) \cdot D_{cr}]} = \frac{32}{D_{cr}} \qquad (2)$$

The resulting stopping distances would be 4.6 m for shear tab failure in the 1989 and 1992 buses, 4.0 m for U-bolt failure in the 1989 bus, and 1.9 m for U-bolt failure in the 1992 bus. These very short stopping distances would most likely require a serious collision involving either a massive stationary object, a vehicle of comparable weight moving at a comparable speed in the opposite direction, or a vehicle of lesser weight moving at a greater speed in the opposite direction. As a comparison, assuming an emergency braking distance without collision of 100 m at a speed of 25 m/sec, the level of bus deceleration required would only be about 0.3 *g*.

CONCLUSIONS

The authors' conclusions relative to the test parameters are as follows:

1. Comparing the 1989 bus specimen results as a function of the initial U-bolt torque, no correlation was found between the U-bolt torque and the shear capacity of the shear tabs or the U-bolts, most likely because the U-bolts yielded before the shear tabs failed and before the first U-bolt slipped.
2. Comparing the 1992 bus specimen results as a function of the rate of relative motion, very substantial increases (+1,400 percent) in the rate of relative motion resulted in slight to moderate decreases (−5 to −31 percent) in the shear capacity of the U-bolts and the shear tabs.
3. Comparing the test results for the 1992 and 1989 bus specimens (with adjustments made for the differences in the estimated steel-to-steel coefficients of friction for each specimen), substantial increases in the depth of the longitudinal channel members (+50 percent) resulted in substantial increases (+65 percent) in the U-bolt shear capacity.
4. Comparing the test results for all specimens, the shear capacities of the U-bolts are somewhat less than 50 percent greater with three versus two U-bolts, which most likely reflects the greater probability of having at least one U-bolt slip if more U-bolts are present. This in turn implies that in the real buses, which have 12 or more U-bolts, the maximum shear capacity before first U-bolt slippage may be somewhat lower than the values derived in the present study.

Conclusions relative to the performance of the typical 1989 and 1992 bus designs are as follows:

1. With two shear tabs each, the typical 1989 and 1992 bus designs would appear to have virtually the same maximum shear tab capacity.
2. After accounting for the differences in the steel-to-steel coefficient of friction for each specimen, the typical 1992 bus design with only 12 U-bolts would appear to have a moderately higher (+41 percent) total U-bolt shear capacity versus the typical 1989 bus design, which has 14 U-bolts.

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