Structural Analyses of Two Typical Medium-Duty Transit Buses

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Finite-element computer models were developed for two medium-duty transit buses: a 21-ft bus with 11 seats (22 passengers) and a 25-ft bus with 13 seats (26 passengers). Two models of each bus were derived: one with passenger seats fastened to the bus floor only and one with seats attached to both the bus sidewalls and the floor. The models were each analyzed under three cases of bus deceleration: with seat belts installed and used on all passenger seats, with seat belts installed on all seats but used by approximately half of the bus passengers, and with seat belts installed and used on the front seats only. Each load case was analyzed using seven bus floor angles from 0 to 30 degrees. The following conclusions were reached with respect to the structural responses of a typical medium-duty transit bus to bus deceleration: (a) maximum member stresses should generally be lower with full versus staggered seat belt use or versus front seat belt use only; (b) maximum member stresses should generally be higher with seats attached to both the sidewalls and the floor versus seats fastened to the floor only; (c) maximum member stresses could be relatively high in the seat anchorage members for wall- and floor-mounted seats and in the perimeter frame members for floor-mounted only seats; and (d) differences should be relatively small between the maximum member stresses for shorter versus longer medium-duty transit buses.

A study to assess the structural responses of medium-duty transit buses subjected to various levels of bus deceleration is currently under way at the Department of Civil Engineering, Wayne State University. The principal objective of this investigation is to perform parametric analyses with various combinations of seat belt use and seat mounting in order to measure any differential stresses that might be generated in the structural members of the buses under passenger inertial forces caused by bus deceleration.

A comprehensive literature review conducted as a part of the project showed very little research to assess the behavior of the structural components of a bus frame under bus deceleration. Reports dealing with front-end crash tests of school and transit buses have concentrated on "visible" damage, including passenger seat detachment from the floors (*1–4*), slippage of the frame-to-chassis connections (*1,5,6*), and buckling of the floor (*1,2,4*). The crash responses of the remaining structural components of the buses tested were not reported, however.

One previously reported use of finite-element computer modeling in the analysis of transit buses was a series of models developed by DAF Trucks, Eindhoven, the Netherlands (*7*). The goal was to measure the effects of bending stiffness and torsional stiffness on the dynamic responses and hence the ride comfort of passengers. No analyses under bus deceleration were performed, however.

The work presented here is a continuation of the research conducted by Dusseau et al. (*8,9*). That effort involved finite-element analysis of the structure of a 25-ft transit bus that included the frame, floor, and chassis. Assumptions were made about the loading conditions under bus deceleration. Parametric results for floor angles from 0 to 30 degrees at maximum deceleration were derived for floor-mounted seats using two loading patterns: with seat belts installed and used on all passenger seats and with seat belts installed and used on the front seats only. It was found that the structural members in the frame could experience moderate to substantial decreases in maximum stress if seat belts were installed and used on all seats, whereas the maximum stresses in the chassis members could be slightly higher to moderately higher if seat belts were installed and used on all seats.

In the present study, finite-element computer models were developed for two medium-duty transit buses: a 21-ft bus with 11 seats and a capacity of 22 passengers and a 25-ft bus with 13 seats and a capacity of 26 passengers. Two finite-element models were derived for each transit bus studied: one with passenger seats fastened to the floor only (model with floor-mounted seats) and one with seats attached to both the sidewalls and the floor (model with wall-mounted seats). The four bus models were each analyzed under three cases of bus deceleration: with seat belts installed and used on all seats (full seat belt use), with seat belts installed on all seats and used by about half of the passengers (staggered seat belt use), and with seat belts installed and used on the front seats only (front seat belt use only). Results using seven angles of tilt from 0 to 30 degrees for the bus floor at maximum deceleration were derived for each load case.

The major additions in the present study compared with the previous investigation are (a) the analysis of the 21-ft bus; (b) the inclusion of the sidewalls, backwall, and roof for each model; (c) the analysis of models with wall-mounted seats; and (d) the load case with staggered seat belt use.

MODELS AND ASSUMPTIONS

The 21-ft bus is a shorter version of the 25-ft bus with two fewer seats and about 4 ft less chassis, frame, floor, and body. The same chassis and axle spacing are used for both buses, however. All of the steel members in the frame, chassis, body, and seats are cold-formed steel sections with minimum yield stresses of 30,000 psi. The floor is composed of exterior grade plywood with an estimated yield stress of 2,500 psi. The floor

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has steel plate reinforcing along the lines where the interior legs of the seats are bolted to the floor and along the plywood seam that follows the centerline of the floor. Steel plate is also used in the tops of the rear wheel wells.

The floor is supported by lateral frame members fabricated from channel sections; these run between the sidewalls and support the body, floor, and frame. Angle sections are used for the skirting and other frame members around the perimeter of the floor. The lateral frame members are welded to longitudinal chassis caps fabricated from channel sections and are attached to the chassis with U-bolt connections. The chassis is composed of two longitudinal members fabricated from channel sections and are connected at intervals by lateral chassis members also fabricated from channel sections. The body is fabricated from square tubes and channel sections, and the seats are fabricated from square tubes and steel plates. The floor-mounted seats have two inverted T-legs with the interior legs fastened to the floor and the exterior legs fastened to the perimeter of the frame. The wall-mounted seats are similar to the floor-mounted seats but with the exterior legs deleted and the exterior edges of the seats fastened to seat anchorage members that run the length of the bus body.

The simplifications and assumptions made in developing the bus models were as follows:

1. Because the goal of the research was to assess the relative effects of seat mounting and seat belt use on the dynamic responses of the transit buses modeled, two key simplifications were made in modeling the buses: (a) only the inertial forces due to the passengers were considered in the analyses, and (b) the front portion of the body, the stairs, the battery tray, and other minor structural members that contribute little to the stiffness and strength of the bus structure were excluded from the models.

2. The plywood floor was modeled using plate finite elements as depicted in Figure 1 for the 21-ft bus. Because the plywood floor was modeled without seams, the steel plate reinforcing along the centerline of the floor was not included

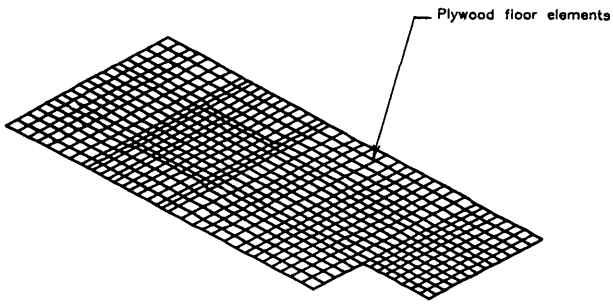

FIGURE 1 Plywood floor elements for 21-ft bus.

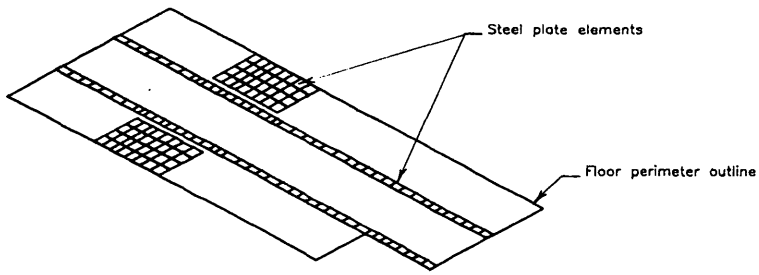

FIGURE 2 Steel plate elements for 21-ft bus.

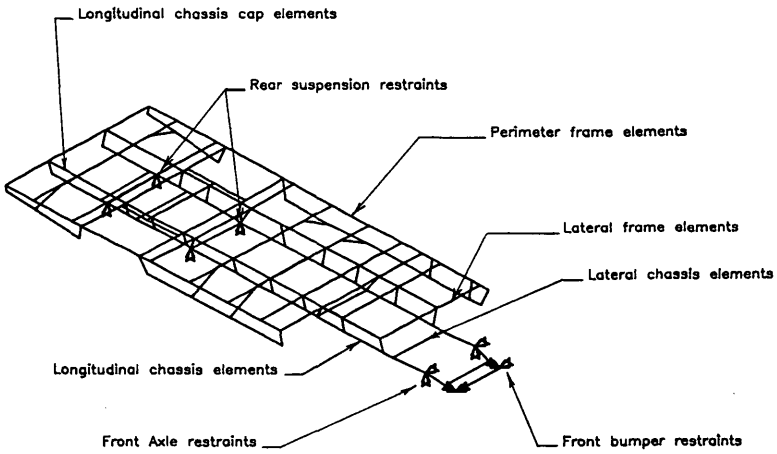

FIGURE 3 Bus frame elements, chassis elements, and boundary conditions for 21-ft bus.

in the model. The steel plate reinforcing along the bolt line of the interior seat legs and in the rear wheel wells was modeled using plate elements as shown in Figure 2 for the 21-ft bus.

3. The lateral frame members, perimeter frame members, and longitudinal chassis caps were all modeled using beam finite elements as illustrated in Figure 3 for the 21-ft bus. For simplicity, the centroids of these beam elements were all placed in the same horizontal plane as the plywood floor. The longitudinal chassis members, lateral chassis members, and skirting members were also modeled using beam elements as depicted in Figure 3. Also shown in Figure 3 are semirigid (high-stiffness) elements that were used to connect the centroids of the longitudinal chassis members with the lateral frame members at the points at which the lateral frame members are welded to the longitudinal chassis caps.

4. The sidewalls, backwall, and roof members were modeled using beam elements as depicted in Figure 4 for the 21-ft bus model.

5. The front axle is assumed to bottom out under bus deceleration. Therefore (as shown in Figure 3), the buses were modeled with vertical and lateral restraints at the points at which rubber stops are attached to the longitudinal chassis members to prevent damage due to bottoming out of the front axle. Longitudinal and lateral restraints were used at the front of the longitudinal chassis members where the front bumper is attached, and vertical restraints were used at the points at which the rear leaf springs are attached to the longitudinal chassis members.

6. Each floor-mounted and wall-mounted seat was represented by five semirigid members that were arranged like a swingset with one horizontal element connecting the nodal points representing the centers of gravity (CGs) of the two

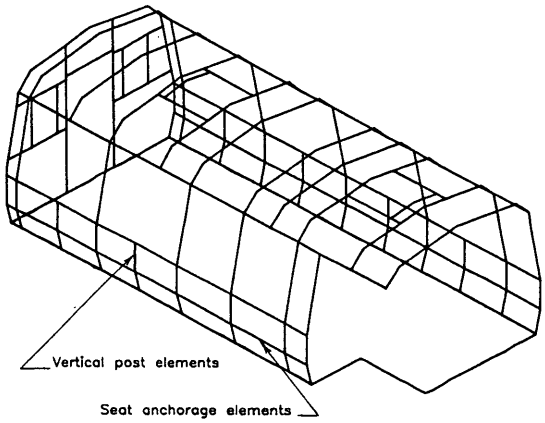

FIGURE 4 Bus body elements for 21-ft bus.

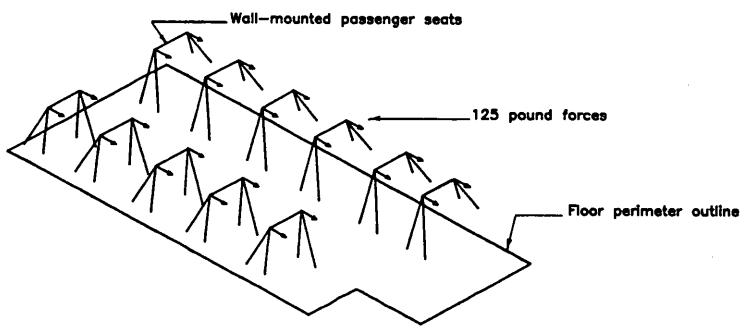

FIGURE 5 Passenger seats and load application for 21-ft bus with wall-mounted seats and full seat belt use.

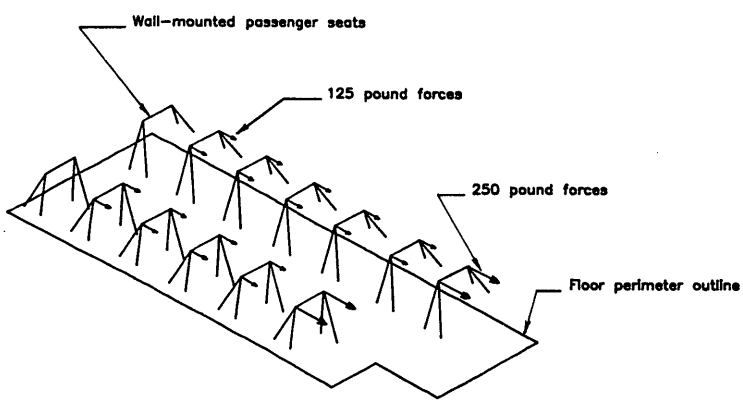

FIGURE 6 Passenger seats and load application for 25-ft bus with wall-mounted seats and front seat belt use only.

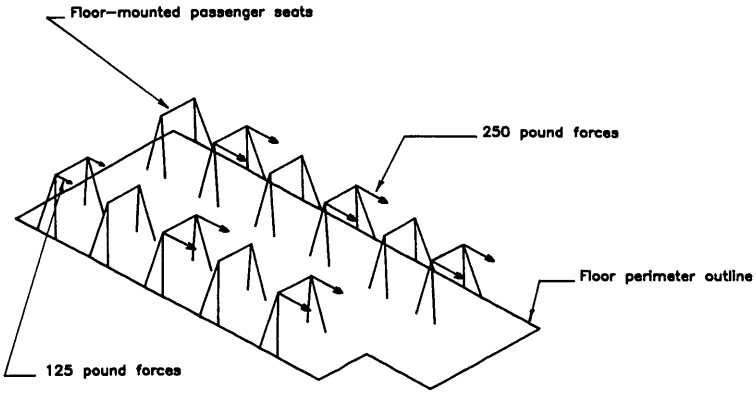

FIGURE 7 Passenger seats and load application for 21-ft bus with floor-mounted seats and staggered seat belt use.

passengers in the seat and two diagonal elements connecting each of these CG points to the floor or sidewalls at or near the points at which the actual seats are attached. Figures 5 and 6 depict the 21- and 25-ft buses, respectively, with wall-mounted seats, and Figure 7 shows the 21-ft bus with floor-mounted seats.

7. The finite-element program used for the investigation was the ANSYS program developed by Swanson Analysis Systems, Inc., Houston, Pennsylvania.

LOAD CASES

An average weight of 125 lbs was assumed for each bus passenger on the basis of a mix of adults and children. Thus, to simulate the loads generated by passenger inertia under a 1 *g* bus deceleration, a force of 125 lb/bus passenger was used. These forces were applied using seven angles of tilt from 0 to 30 degrees for the bus floor at maximum deceleration. These angles of tilt were simulated by "tilting" the forces as opposed to tilting the models.

The loading pattern used to represent bus deceleration with full seat belt use consisted of two 125-lb forces applied to each passenger seat (as shown in Figure 5 for the 21-ft bus with wall-mounted seats). For load cases with unbelted passengers, a 125-lb force was applied to the seat in front of each unbelted passenger. Thus, for bus deceleration with front seat belt use only (as depicted in Figure 6 for the 25-ft bus with wall-mounted seats) no forces were applied to the rear seats, two 125-lb forces were applied to each intermediate seat, and two 250-lb forces were applied to each front seat. For bus deceleration with staggered seat belt use, a checkerboard loading pattern (as depicted in Figure 7 for the 21-foot bus with floor-mounted seats) was used.

ANALYSIS RESULTS

Table 1 gives the 12 load cases analyzed; Table 2 gives the maximum element stresses of bus deceleration and the corresponding floor angles; and Table 3 gives the lateral and longitudinal locations of the maximum element stresses. The longitudinal locations in Table 3 are measured along the centerline of the bus beginning at the back and are normalized with respect to the bus length. Thus, the longitudinal location 0.00 refers to the point at which the rear bumper is attached, and the location 1.00 refers to the point at which the front bumper is attached. The lateral locations in Table 3 are measured from the centerline of the bus and are normalized with respect to the half-width of the floor. Thus, the lateral location −1.00 refers to the left edge of the floor and the lateral location +1.00 refers to the right edge.

Analysis Limitations

The analysis results in Table 2 have certain limitations based on the modeling assumptions used in the analyses. These limitations are centered on the maximum levels of bus deceleration for which the analysis results are valid. The assumptions that control these limiting values of bus deceleration involve the applied load, the linear elastic analysis procedure, and the boundary conditions.

As discussed, because the finite-element analyses were primarily aimed at determining the effects on maximum member stresses caused by seat belt use and seat mounting, the inertia of the bus members and the bus components and the gravitational forces generated by the bus and the bus passengers were not considered in the analyses. These forces could play a role in determining the level of bus deceleration at which member yielding first occurs and hence the level of deceleration at which the linear elastic analysis results are no longer valid, but the authors believe that the effects of these forces will not be a major factor in this determination. This is because nearly all of the members that yield first are those that are directly connected to the bus seats and hence are most affected by passenger inertia. On the basis of the effects of passenger inertia only, the levels of bus deceleration at which member yielding first occurs and hence the maximum level of deceleration for which the linear elastic analyses are valid are given in Table 1.

The boundary conditions for the front bumper and front axle locations appear to be valid under all levels of bus deceleration, but the vertical restraints at the rear spring locations may not be. As shown by crash test videos of school buses, large front-end collisions can cause the rear wheels to

TABLE 1 Bus Load Cases and Limiting Values of Bus Deceleration

LOAD CASE	BUS VERSION AND SEAT TYPE	SEAT BELT USAGE	BUS DECELERATION LIMITS, g		
			ELASTIC FINITE-ELEMENT MODELS	BOUNDARY CONDITIONS (BUS FLOOR ANGLE)	
				0 DEGREES	30 DEGREES
21F1	21-Foot Bus with Floor-Mounted Seats	Full Seat Belt Usage	10.6	27.2	6.9
21F2	21-Foot Bus with Floor-Mounted Seats	Staggered Seat Belt Usage	6.0	24.0	7.0
21F3	21-Foot Bus with Floor-Mounted Seats	Front Seat Belt Usage Only	6.6	21.9	6.9
21W1	21-Foot Bus with Wall-Mounted Seats	Full Seat Belt Usage	5.7	28.1	7.0
21W2	21-Foot Bus with Wall-Mounted Seats	Staggered Seat Belt Usage	3.1	26.3	7.1
21W3	21-Foot Bus with Wall-Mounted Seats	Front Seat Belt Usage Only	4.7	23.8	7.1
25F1	25-Foot Bus with Floor-Mounted Seats	Full Seat Belt Usage	12.8	27.2	5.9
25F2	25-Foot Bus with Floor-Mounted Seats	Staggered Seat Belt Usage	6.3	23.8	5.9
25F3	25-Foot Bus with Floor-Mounted Seats	Front Seat Belt Usage Only	6.5	21.8	5.9
25W1	25-Foot Bus with Wall-Mounted Seats	Full Seat Belt Usage	8.5	26.9	5.9
25W2	25-Foot Bus with Wall-Mounted Seats	Staggered Seat Belt Usage	4.4	24.7	5.9
25W3	25-Foot Bus with Wall-Mounted Seats	Front Seat Belt Usage Only	4.4	22.7	5.9

TABLE 2 Maximum Element Stresses and Corresponding Bus Floor Angles Versus Bus Load Cases

ELEMENT DESCRIPTIONS	MAXIMUM ELEMENT STRESSES PER G (ksi/g) / CORRESPONDING BUS FLOOR ANGLES (degrees)											
	LOAD CASE 21F1	LOAD CASE 21F2	LOAD CASE 21F3	LOAD CASE 21W1	LOAD CASE 21W2	LOAD CASE 21W3	LOAD CASE 25F1	LOAD CASE 25F2	LOAD CASE 25F3	LOAD CASE 25W1	LOAD CASE 25W2	LOAD CASE 25W3
Primary Structural Members												
Plywood Floor Elements	0.069 0	0.076 0	0.081 0	0.069 0	0.115 0	0.117 0	0.069 0	0.075 0	0.083 0	0.071 0	0.140 0	0.113 0
Lateral Frame Elements	1.43 0	2.35 0	2.26 0	1.36 10	2.28 0	1.60 0	1.47 0	2.12 0	2.16 0	1.41 0	1.48 0	1.61 0
Longitudinal Chassis Elements	1.09 0	1.30 0	1.35 0	1.44 30	1.59 30	1.91 30	1.71 25	1.66 20	1.26 0	1.56 25	1.29 15	1.66 30
Secondary Structural Members												
Body Elements	1.96 10	2.55 0	2.72 0	5.29 30	9.65 30	6.44 0	2.35 30	3.71 15	1.99 15	3.52 30	6.89 5	6.87 30
Steel Plate Elements	0.72 0	0.80 0	0.85 0	0.86 0	1.50 0	1.52 0	0.73 30	0.79 0	0.87 0	0.86 0	1.58 0	1.55 0
Perimeter Frame Elements	2.82 0	4.99 0	4.55 15	1.16 0	1.59 0	1.24 30	2.31 0	4.80 0	4.60 15	1.50 30	1.52 30	1.04 30
Longitudinal Chassis Cap Elements	1.11 30	1.13 0	0.77 0	1.15 0	1.61 0	0.98 30	1.13 30	0.87 30	0.85 30	1.23 30	1.20 30	1.08 30
Lateral Chassis Elements	0.66 30	0.87 30	0.77 30	0.43 30	0.40 30	0.49 30	0.38 30	0.58 30	0.51 30	0.34 30	0.52 30	0.34 30

TABLE 3 Longitudinal and Lateral Locations Corresponding to Maximum Element Stresses

ELEMENT DESCRIPTIONS	LONGITUDINAL LOCATIONS / LATERAL LOCATIONS											
	LOAD CASE 21F1	LOAD CASE 21F2	LOAD CASE 21F3	LOAD CASE 21W1	LOAD CASE 21W2	LOAD CASE 21W3	LOAD CASE 25F1	LOAD CASE 25F2	LOAD CASE 25F3	LOAD CASE 25W1	LOAD CASE 25W2	LOAD CASE 25W3
Primary Structural Members												
Plywood Floor Elements	0.82 -0.40	0.82 -0.40	0.82 -0.40	0.29 -0.46	0.69 -0.50	0.69 -0.50	0.84 -0.40	0.84 -0.40	0.84 -0.40	0.18 0.50	0.18 0.50	0.69 -0.31
Lateral Frame Elements	0.82 -0.45	0.82 -0.45	0.82 -0.45	0.33 -0.43	0.45 -0.45	0.55 -0.45	0.84 -0.35	0.84 -0.45	0.84 -0.45	0.84 -0.35	0.84 -0.35	0.84 -0.35
Longitudinal Chassis Elements	0.84 -0.35	0.84 -0.35	0.84 -0.35	0.53 -0.35	0.53 -0.35	0.53 -0.35	0.29 0.35	0.23 0.35	0.96 0.33	0.29 0.35	0.29 0.35	0.58 -0.35
Secondary Structural Members												
Body Elements	0.00 1.03	0.65 -1.03	0.65 -1.03	0.40 -1.06	0.40 -1.06	0.72 -1.06	0.18 -1.03	0.18 1.03	0.68 -1.00	0.68 -1.06	0.12 1.06	0.68 -1.06
Steel Plate Elements	0.82 -0.40	0.82 -0.40	0.82 -0.40	0.59 -0.40	0.59 -0.40	0.65 -0.40	0.84 -0.40	0.84 -0.40	0.84 -0.40	0.15 -0.40	0.15 0.40	0.69 -0.40
Perimeter Frame Elements	0.10 -1.00	0.47 -1.00	0.64 -1.00	0.20 -1.00	0.49 -1.00	0.64 -1.00	0.68 -1.00	0.19 1.00	0.68 -1.00	0.28 -1.00	0.28 1.00	0.66 -1.00
Longitudinal Chassis Cap Elements	0.03 -0.40	0.50 -0.40	0.18 0.40	0.18 -0.40	0.50 -0.40	0.34 -0.40	0.26 0.40	0.26 -0.40	0.40 -0.40	0.40 -0.40	0.40 0.40	0.40 -0.40
Lateral Chassis Elements	0.34 0.00	0.34 0.00	0.34 0.00	0.34 0.00	0.51 0.00	0.34 0.00	0.42 0.00	0.24 0.00	0.57 0.00	0.24 0.00	0.24 0.00	1.00 0.00

lift off the ground. Thus, at high levels of bus deceleration, the vertical restraints at the rear spring locations may no longer be valid for the models presented here. During the course of the analyses, the reactions at these locations were carefully monitored and recorded. Assuming that the rear of the bus will be held down by a gravitational force of 11,000 lb, which is the maximum capacity of the rear axle, the maximum bus decelerations required before the reactions at the rear spring locations exceed this 11,000-lb limit are given in Table 1 for bus floor angles of 0 and 30 degrees. Although the bus inertia could play a role in determining the level of bus deceleration beyond which the assumed boundary conditions are no longer valid, the authors believe that because much of the mass of the bus chassis is at or below the level of attachment of the rear springs, the bus inertia will not be a major factor in this determination.

Primary Structural Members

The floor-frame-chassis system is the primary structural system that provides strength and stiffness for the transit buses modeled. The plywood floor members, lateral frame members, and longitudinal chassis members were thus classified as primary structural members on the basis of their relative size, location, and importance as members of the floor-frame-chassis system.

Plywood Floor Elements

For the plywood floor elements, the most severe case was the 25-ft bus with wall-mounted seats and staggered seat belt use (25W2) at a floor angle of 0 degrees. The maximum stress of 0.140 ksi/*g* for this case was 97 percent higher than full seat belt use (25W1), 24 percent higher than front seat belt use only (25W3), 87 percent higher than floor-mounted seats (25F2), and 22 percent higher than the 21-ft bus (21W2). The maximum stresses for Case 25W2 and two other cases occurred near the rear wheel wells. The skirting members and other perimeter frame members are discontinuous at the rear wheel wells. The maximum stresses for six cases were near the left front passenger seat. The loads acting on the front seats are doubled for cases with staggered seat belt use and with front seat belt use only. The maximum stresses for the remaining three cases occurred between the left rear wheel well and the left front seat.

Lateral Frame Elements

The most severe case for the lateral frame elements was the 21-ft bus with floor-mounted seats and staggered seat belt use (21F2) at a floor angle of 0 degrees. For this case, the maximum stress of 2.35 ksi/*g* was 64 percent larger than full seat belt use (21F1), 4 percent larger than front seat belt use only

(21F3), 3 percent larger than wall-mounted seats (21W2), and 11 percent larger than the 25-ft bus (25F2). The maximum stresses occurred near the left front seat for Case 21F2 and eight others, and between the left rear wheel well and the left front seat for three cases.

Longitudinal Chassis Elements

For the longitudinal chassis elements, the worst case was the 21-ft bus with wall-mounted seats and front seat belt use only (21W3) at a floor angle of 30 degrees. The maximum stress of 1.91 ksi/*g* for this case was 33 percent higher than full seat belt use (21W1), 20 percent higher than staggered seat belt use (21W2), 41 percent higher than floor-mounted seats (21F3), and 15 percent higher than the 25-ft bus (25W3). The maximum stresses occurred between the left rear wheel well and the left front seat for Case 21W3 and three other cases, near the right rear wheel well for four cases, and near the front seats for four cases.

Secondary Structural Members

Because they contribute less to the strength and stiffness of the buses that were modeled and hence are of less overall importance to the structure of these buses, the following were classified as secondary structural members: the body members, steel plate members, perimeter frame members, longitudinal chassis caps, and lateral chassis members.

Body Elements

The worst case for the body elements was the 21-ft bus with wall-mounted seats and staggered seat belt use (21W2) at a floor angle of 30 degrees. For this case, the maximum stress of 9.65 ksi/*g* was 83 percent larger than full seat belt use (21W1), 50 percent larger than front seat belt use only (21W3), 278 percent larger than floor-mounted seats (21F2), and 40 percent larger than the 25-ft bus (25W2). For all six cases with wall-mounted seats, the maximum stresses occurred in the seat anchorage members. For the cases with floor-mounted seats, five cases had maximum stresses in the vertical posts below the windows and one case had maximum stress along the left edge of the frame.

Steel Plate Elements

For the steel plate elements, the most severe case was the 25-ft bus with wall-mounted seats and staggered seat belt use (25W2) at a floor angle of 0 degrees. The maximum stress of 1.58 ksi/*g* for this case was 84 percent higher than full seat belt use (25W1), 2 percent higher than front seat belt use only (25W3), 100 percent higher than floor-mounted seats (25F2), and 5 percent higher than the 21-ft bus (21W2). The maximum stresses occurred near the rear wheel wells for Case 25W2 and one other case, near the left front seat for six cases, and between the left rear wheel well and the left front seat for four cases.

Perimeter Frame Elements

The most severe case for the perimeter frame elements was the 21-ft bus with floor-mounted seats and staggered seat belt use (21F2) at a floor angle of 0 degrees. For this case, the maximum stress of 4.99 ksi/*g* was 77 percent larger than full seat belt use (21F1), 10 percent larger than front seat belt use only (21F3), 214 percent larger than wall-mounted seats (21W2), and 4 percent larger than the 25-ft bus (25F2). The maximum stress occurred between the left rear wheel well and the left front seat for Case 21F2 and six other cases, near the rear wheel wells for four cases, and near the left rear seat for one case.

Longitudinal Chassis Cap Elements

For the longitudinal chassis cap elements, the worst case was the 21-ft bus with wall-mounted seats and staggered seat belt use (21W2) at a floor angle of 0 degrees. The maximum stress of 1.61 ksi/*g* for this case was 40 percent higher than full seat belt use (21W1), 64 percent higher than front seat belt use only (21W3), 42 percent higher than floor-mounted seats (21F2), and 34 percent higher than the 25-ft bus (25W2). The maximum stresses occurred between the rear wheel wells and the front seats for Case 25W2 and six others, near the rear wheel wells for four cases, and near the left rear seat for one case.

Lateral Chassis Elements

The most severe case for the lateral chassis elements was the 21-ft bus with floor-mounted seats and staggered seat belt use (21F2) at a floor angle of 30 degrees. For this case, the maximum stress of 0.87 ksi/*g* was 32 percent larger than full seat belt use (21F1), 13 percent larger than front seat belt use only (21F3), 118 percent larger than wall-mounted seats (21W2), and 50 percent larger than the 25-ft bus (25F2). The maximum stresses occurred between the rear wheel wells and the front seats for Case 21F2 and seven others, at the rear wheel wells for three cases, and at the front of the bus for one case.

SUMMARY AND CONCLUSIONS

Four finite-element computer models were developed for the structure of two typical medium-duty transit buses using floor- and wall-mounted seats. Assumptions were made regarding the loading conditions in the event of bus deceleration. Parametric results for floor angles of 0 to 30 degrees at maximum deceleration were derived for loading patterns with full seat belt use, staggered seat belt use, and front seat belt use only.

The following conclusions pertain to the bus responses with staggered and front seat belt use only versus full seat belt use:

1. For the plywood floor elements and the lateral frame elements, the load cases with staggered seat belt use and front

seat belt use only had slightly higher (+5 percent) to substantially higher (+97 percent) maximum stresses than full seat belt use.

2. The longitudinal chassis elements in the 21-ft bus had a slightly higher (+10 percent) to moderately higher (+33 percent) maximum stresses with staggered seat belt use and front seat belt use only versus full seat belt use.

3. For the longitudinal chassis elements in the 25-ft bus models, the load cases with staggered seat belt use and front seat belt use only had moderately lower (−26 percent) to slightly higher (+6 percent) maximum stresses compared with full seat belt usage.

4. The secondary structural members had moderately lower (−31 percent) to substantially higher (+108 percent) maximum stresses with staggered seat belt use and front seat belt use only versus full seat belt use.

The following conclusions pertain to the bus responses with wall- versus floor-mounted seats:

1. The maximum plywood floor element stresses per *g* were slightly higher (+1 percent) to substantially higher (+87 percent) with wall-mounted seats than floor-mounted seats.

2. The lateral frame elements had slightly lower (−3 percent) to moderately lower (−30 percent) maximum stresses with wall-mounted seats than with floor-mounted seats.

3. In the 21-ft bus, the longitudinal chassis elements had maximum stresses that were moderately higher (+22 percent) to substantially higher (+41 percent) with wall-mounted seats than floor-mounted seats.

4. The longitudinal chassis elements in the 25-ft bus had maximum stresses that were moderately lower (−22 percent) to moderately higher (+32 percent) with wall-mounted seats than floor-mounted seats.

5. The body elements, steel plate elements, and longitudinal chassis cap elements had slightly higher (+4 percent) to very substantially higher (+278 percent) maximum stresses with wall-mounted than floor-mounted seats.

6. The maximum stresses in the perimeter frame elements and the lateral chassis elements were slightly lower (−9 percent) to substantially lower (−77 percent) with wall-mounted seats than floor-mounted seats.

The following general conclusions can be drawn about the responses of typical medium-duty transit buses to bus deceleration:

1. With full seat belt use, maximum member stresses should in general be lower than with staggered seat belt use or front seat belt use only. The more-uniform distribution of passenger inertial loads resulting from full seat belt use offers a clear advantage to the structure of the transit bus under bus deceleration.

2. Maximum member stresses should in general be lower with floor-mounted than wall-mounted seats. With their exterior legs attached directly to the perimeter of the frame, floor-mounted seats appear to offer a distinct benefit to the bus structure under bus deceleration.

3. The maximum stresses could be relatively high in the seat anchorage members with wall-mounted seats and in the perimeter frame members with floor-mounted seats. Thus, these members could yield at relatively low levels of deceleration and could continue to yield and deform as deceleration increases. In this way, the authors believe that these secondary structural members may act as "passenger shock absorbers" in that their deformation (and hence their absorption of energy) could cushion the passengers, thus reducing the level of deceleration felt by the passengers.

4. In general, the differences should be relatively small between the maximum member stresses for shorter medium-duty transit buses and the corresponding maximum stresses for longer buses. Although the shorter buses have fewer passengers and thus less passenger inertial load, the longer buses have more members and provide more avenues for stress redistribution, which results in lower member stresses per unit of load. It should again be noted, however, that the inertia of the bus members and the bus components was not included in the analyses. Therefore, the inertia of the additional 4 ft of bus in the 25-ft bus versus the 21-ft bus could cause more maximum member stresses to be higher in the 25-ft bus under actual bus decelerations.

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REFERENCES

1. D. M. Severy, H. M. Brink, and J. D. Baird, School Bus Passenger Protection. *Proc., Automotive Engineering Congress*, SAE, Detroit, Mich., Jan. 1967, pp. 290–379.
2. D. J. LaBelle. Barrier Collision and Related Impact Sled Tests on Buses in Intercity Service. *Proc., 7th Stapp Car Crash Conference*, Institute of Transportation and Traffic Engineering, 1965, pp. 46–53.
3. K. Rompe and H. J. Kruger. Possibilities of Development in Bus Safety. *International Journal of Vehicle Design—The Journal of Vehicle Engineering Components*, Vol. 7, Nos. 5/6, Sept. 1986, pp. 178–191.
4. C. R. Ursell. *A Study Relating to Seat Belts for Use in Buses.* Report HS-802 253. U.S. Department of Transportation, Jan. 1977.
5. G. N. Farr. *School Bus Safety Study, Volume 1.* Report TP 6222 E. Traffic Safety Standards and Research, Transport Canada, Ottawa, Ontario, Jan. 1985.
6. D. A. Alianello and W. E. Levan. *Crash Testing of Thomas Minotour Vehicle, 1986 Thomas Bus, Intermediate School Bus.* Calspan Report 7481-1. Calspan Corporation, Buffalo, N.Y., June 1986.
7. F. G. J. Van Asperen and H. J. M. Voets. Optimization of the Dynamic Behavior of a City Bus Structure. *Proc., International Conference on the Bus '86.* Institution of Mechanical Engineers,

Mechanical Engineering Publications, Ltd., London, England, Sept. 1986.
8. R. A. Dusseau, S. Khasnabis, and T. J. Dombrowski. Impact of Seat Belts on the Structure of a Typical Transit Bus. In *Transportation Research Record 1322*, TRB, National Research Council, Washington, D.C., 1991.
9. S. Khasnabis, R. A. Dusseau, and T. J. Dombrowski. Safety Implications of Seat Belts on Transit Buses. In *Transportation Research Record 1322*, TRB, National Research Council, Washington, D.C., 1991.

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