Compression Loads for Light Rail Vehicles in the United States

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The requirements of the Americans with Disabilities Act for (LRVs), resulting in the emergence of lower floors and cut-outs in the underframe for wheelchair lifts, will create new challenges for structural engineers. These challenges will make it necessary to reexamine the specified LRV design compression loads and to compare them with design compression loads on other types of vehicles. When a comparison takes into consideration the size of the trains and their operating speeds, a case can be made for lowering the compression load of 2 *g* at AWO (empty) vehicle weight currently prevailing in U.S. specifications. A crash index is introduced that indicates how much compression resistance is assigned to absorb and disperse a unit of a train's energy. It is concluded that the LRV crash index is approximately four times higher than that for mainline or rapid transit cars. Accordingly, LRV compression loads should be lowered to provide greater safety, lower weight, lower energy consumption, and more attractive general arrangements.

T he compression load is a design load that engineers apply to the ends of a railcar to squeeze it longitudinally for either strength calculations or testing. The car must not change its shape permanently under the action of the specified compression load.

SPECIFIED COMPRESSION LOADS FOR LIGHT RAIL VEHICLES

Although federally mandated or unequivocally accepted compression load standards do not exist, the 2-*g* practice (i.e., specifying a compression load equal to two weights of the empty car) until recently appeared to be taking hold in the United States.

Some simple calculations indicated that these values for the compression load were high. The weights and operational speeds of various trains—mainline commuter, rapid transit, and light rail vehicle (LRV)—were compared, and it was found that in terms of the forces and dissipated energy that can occur in collisions, American LRVs are relatively much stronger than other types of rail vehicles.

The objectives of this paper are as follows:

- Identify the problem,
- Bring it to the attention of the professional community,
- Indicate some possible ways of handling it, and
- Generate the interest of the broader segments of the industry in attacking the issue.

The facts in hand are the two widely accepted design buff loads: 800,000 lb for mainline commuter passenger coaches and 200,000 lb for self-propelled mass transit vehicles. Many years of experience with such vehicles, and a statistically sufficient number of investigated collisions and passenger injuries, indicate that 800,000 lb for commuter cars and 200,000 lb for transit cars provide a good measure to be applied in the design and evaluation of passenger rail vehicles. The practice of operating railcars built to such a specification appears to be well recognized by the mass transit community as

providing an acceptable compromise between the two main requirements for protecting passengers against injury: a car body structure that is sufficiently impact-resistant and, at the same time, sufficiently shock-absorbing (collapsible).

What is wrong with the fact that American LRVs are much stronger than other types of rail vehicles? What is wrong is that such LRVs might be too rigid, which may hurt people when, during a collision where there is no adequate cushioning effect provided by the collapsing structure, they are thrown violently against the elements of the vehicle interior.

It is true that more severe types of injuries (called primary injuries) occur when the car body shell opens or collapses under the forces of collision. However, statistics for heavy rail passenger operations show that although primary injuries are frequently fatal, the number of secondary injuries due to passenger impact against the car interior is much larger (1). For instance, within the statistical period of 1966 to 1973, there were 50 passenger fatalities in the United States due to primary injuries, and one fatality and 1,661 injuries due to the impact of passengers against the car interior. These statistics become even more telling when one realizes that out of 50 primary-injury fatalities, 45 occurred in a single accident. In addition, in this infamous collision (in Chicago) the problem was not the insufficient resistance to compression load, but the fact that one car overrode the other and penetrated the passenger compartment. Such collisions are unlikely on LRVs because of their lower masses and velocities.

Thus, a vehicle of optimal safety will be neither too weak nor too strong. A proper amount of structural vulnerability is beneficial in the sense that the collapsing structure provides cushioning between a passenger and the obstruction causing the collapse. A car structure should resist impact but also absorb the impact energy.

Finally, if LRV cars are made too strong they will be unnecessarily heavy, thus more expensive, and their design will impose limitations on such attractive arrange-

ments as large windows and low floors. Heavier cars will also consume more energy and therefore cost more to operate.

COMPRESSION LOADS FOR OTHER RAILCARS

One reason for the apparently excessive LRV car body stiffness is the fact that for LRVs, and only for LRVs, the compression load is not specified as an absolute force but as a fraction of car body weight. In American practice LRV specifications do not indicate that the compression load should be so many pounds. Instead, it should be twice (or some other multiple) its empty weight. And this creates a problem.

Begin the comparison with mainline and commuter cars. The specified compression load for these cars is 3356 kN (equal to 800,000 lb of force). This requirement remains constant irrespective of the number of cars in a train consist (Figure 1). Thus, whether there will be two cars, five, or ten in the train consist, a single car must resist the same 3356 kN (800,000 lb).

The same logic applies to rapid transit cars with their 889-kN (200,000-lb) compression load requirement (Figure 2). Whether for a single car, or a consist of two, four, or more cars, the strength requirement remains the same.

The predecessors to contemporary LRVs, the original President's Conference Committee (PCC) cars, had various weights, depending on their type and application. The weights of the early PCC cars are as follows (2, p. 190):

- Brooklyn 1001: 15 112 kg (33,360 lb),
- Chicago 4002: 16 489 kg (36,400 lb), and
- St. Louis 1500: 15 230 kg (33,620 lb).

MYSTERY OF ORIGINAL PCC CARS

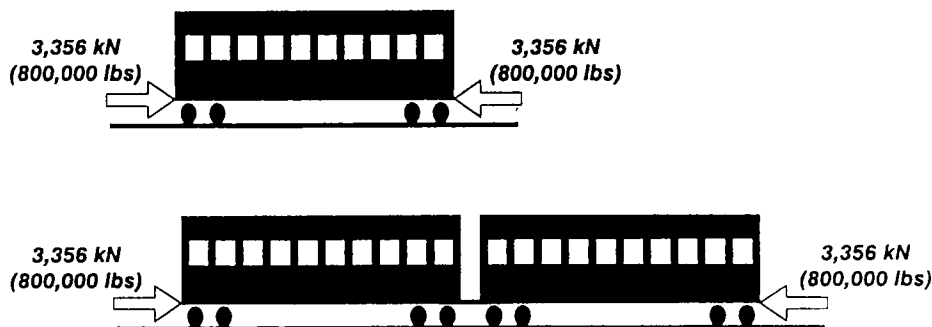Unfortunately, the compression load of the PCC cars has not been established. Nevertheless, for the sake

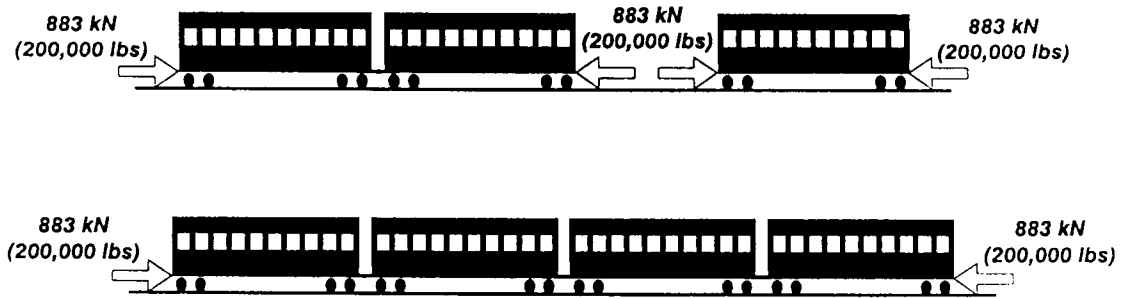**FIGURE 1** Compression load for mainline railcars.

FIGURE 2   Compression load for rapid transit railcars.

of argument, assume that the PCC compression load indeed was equal to twice the weight of an empty car (2 g). Thus, the compression loads for the cars listed earlier presumably were as follows:

- Brooklyn: 279 kN (66,720 lb),
- Chicago: 324 kN (72,800 lb), and
- St. Louis: 299 kN (67,240 lb).

Therefore, assume that the compression load of the PCC cars averaged approximately 311 kN (70,000 lb). On occasion, these cars were coupled in pairs or in multiple-unit trains, as seen in the pictures in *The PCC Car: An American Original* (2, pp. 82, 105, 108, 110). There is no evidence that on these occasions transit authorities made massive structural modifications to multiply the compression load of these cars by the number of cars in a train consist. This was the same policy as described earlier in respect to mainline and mass transit cars (Figure 3).

This policy prevailed until the concept of articulation became popular for reasons of reduced operational cost. Then, suddenly, a unit that should have been considered as consisting of two car bodies was treated as a single car with the resulting extreme increase of design compression load (Figure 4).

TIME FOR A CHANGE

What is being challenged here is not any particular value for the compression load but the doubling of this value when a coupler joint between cars is replaced by an articulation joint. Adding more articulations in future designs for the U.S. market—two, three, or more —may lead to a further increase of compression load requirements.

It appears reasonable to abandon the convention of defining compression loads as a function of LRV weight. The author recommends that the LRV car body
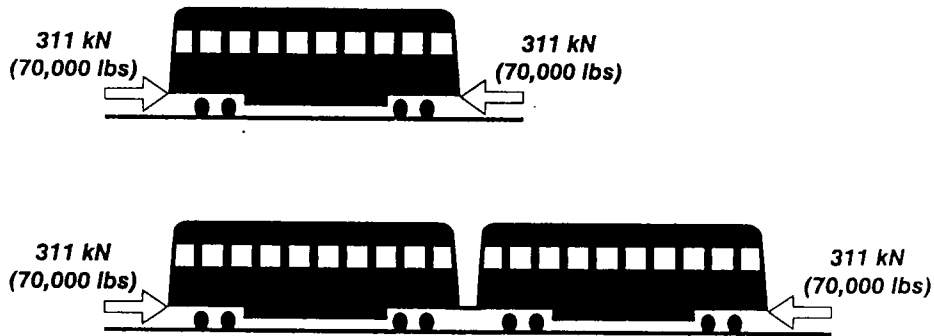

FIGURE 3   Presumed compression load on PCC cars.

FIGURE 4   Compression load for present-day American LRVs.

TABLE 1 Compression Load for Present-Day American LRVs (kN) (1 kN = 224.94 lb)

Column (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Unit Weight							Compression	
	Car	Locomotive	Train Weight	Maximum Speed		Speed Square	Kinetic Energy	Load	Crash Index
	(kg)	(kg)	(kg)	(km/h)	(m/sec)	(m/sec)square	(kJoules)	(kNewtons)	
					(5) x 0.28	(6)x(6)	(4)x(7)/2000		(9)/(8)
4 LRVs	40,770	NA	163,080	80	22.22	493.73	4.03E+04	711	1.77E-02
10 Rapid Transit Cars	38,505	NA	385,050	120	33.33	1,110.89	2.14E+05	889	4.16E-03
10 Commuter Cars + 2 Locos	54,360	181,200	906,000	152	42.22	1,782.53	8.07E+05	3,356	4.16E-03

design squeeze force be specified in terms of an absolute load, similar to the requirements for rapid transit and commuter rail cars in the United States and for LRVs elsewhere in the world.

SUGGESTED SPECIFIED COMPRESSION LOAD

To determine the best specified compression load, compare the kinetic energies of three of the heaviest train sets for each of the main rail vehicles—namely, LRV, rapid transit, and commuter cars—each train set running at the highest operational speed (Table 1). For each type of car these would be the most disastrous conditions in case of a collision. The specified compression loads will be divided by the calculated train energies [(Table 1, Column 8; kinetic energy = mass × velocity^2/2g, and g = 9.81 m/sec^2 (32.2 ft/sec^2)]. The resulting values (Table 1, Column 10) will tell how much compression resistance is assigned to handle (i.e., to absorb and disperse) a unit of the train's energy.

The analysis shows (Figure 5) that the car bodies of LRVs in the United States are overbuilt when compared with mass transit and commuter cars. Dissipating one unit of energy uses 17.7 units of compression resistance in LRVs but only 4.16 units in mass transit and commuter cars.

Such a comparison will always be based on matters of judgment, and with different assumptions the results will differ somewhat in each case. For instance, the maximum speed of the commuter car can be assumed to be 160 rather than 152 km/hr (100 rather than 95 mph), the number of cars in the rapid transit train 12 rather than the 10 used here, or the cars loaded rather than empty. However, with a little attention to detail, and while maintaining some level of reasonableness, it will be seen that the differences identified among the types of cars investigated remain in roughly the same relation: the expected collision performance of rapid transit and commuter cars will be comparable; that of LRVs, quite different.

What would the LRV compression load be if the car were required to have the same crash index as rapid transit and commuter cars? This can be calculated as follows:

Since

Crash index = (compression load)/(kinetic energy)

then

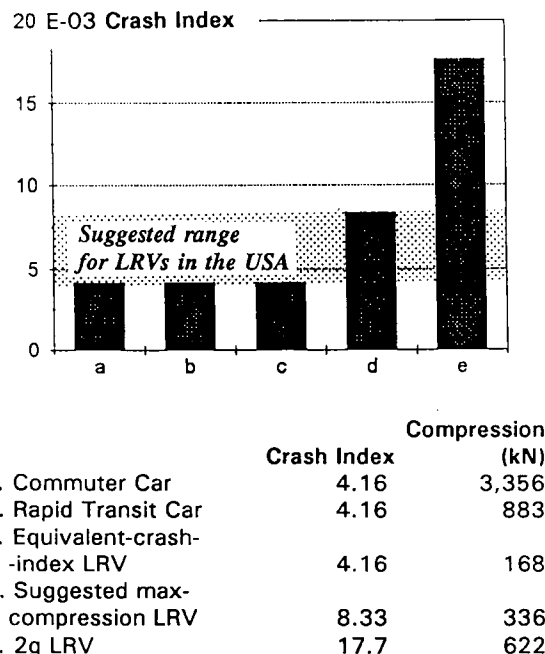Compression load = (crash index) × (kinetic energy)

Thus, if the desired crash index for LRVs is to resemble those for mass transit and commuter cars (i.e., to be approximately 4.16 × 10^{-3}), the equivalent compression load for LRVs would be

Compression load$_{LRV}$ = (4.16 × 10^{-3}) × (4.03 × 10^4) (kJ)

= 168 kN (37,800 lb)

(For energy value, see Table 1.)

	Crash Index	Compression (kN)
a. Commuter Car	4.16	3,356
b. Rapid Transit Car	4.16	883
c. Equivalent-crash--index LRV	4.16	168
d. Suggested max-compression LRV	8.33	336
e. 2g LRV	17.7	622

FIGURE 5 Suggested range for LRV crash indexes.

TABLE 2   Crash Indexes for Various Railcars

Baltimore	886
Boston, Kinki Sharyo	333
Boston, Low-Floor Spec	640
Buffalo	632
Chicago Low-Floor Spec	489
Calgary	591
Cleveland	333
Denver	720
Edmonton	591
Los Angeles Blue Line	836
Philadelphia City Transit	441
Philadelphia Red Arrow	441
Pittsburgh	782
Portland, Bombardier	756
Portland, Siemens/Duewag	756
Sacramento	711
San Diego SD 100	720
San Francisco, Boeing LRV	551
San Francisco, Breda LRV	445
Santa Clara	862
St. Louis	800
Toronto CLRV	445
Toronto ALRV	445
European Standard	200
Suggested for the USA	266-355

Similarly, the crash index for a car with the maximum suggested compression load of 336 kN (80,000 lb) (Table 2) would be

$$\text{Crash index}_{\text{LRV max}} = 336 \ (\text{kN})/4.03 \times 10^4 \ (\text{kJ})$$

$$= 8.33 \times 10^{-3}$$

CONCLUSIONS

The design compression load will most likely be decided every time a new car is ordered, in negotiations among the purchasing transit authority, the vehicle procurement consultant, and the car builder. More than the crash index will have to be considered. The most important will be the results of an examination of the injury statistics of past LRV collisions. However, even with a bias for having LRVs built relatively stronger than rapid transit and commuter cars, it would be difficult, in the author's opinion, to justify compression loads higher than half of what is specified today, or 267 to 336 kN (60,000 to 80,000 lb) (Table 2). This is certainly true for the LRV train set investigated here, consisting of four 38 000 to 41 000-kg (83,885- to 90,500-lb) cars and capable of speeds up to 88 km/hr (55 mph).

Those indicating that Europe can afford lower compression loads because their LRV consists are shorter and slower [with maximum speeds of 64 to 72 km/hr (40 to 45 mph)] might notice that the new compression loads suggested here for the United States would still be 1.3 to 1.8 times higher than those in Europe, currently specified at 200 kN (45,000 lb) (Table 2).

It should come as no surprise if LRVs ordered in the United States in the future are allowed to be built to load requirements lower than those used today.

REFERENCES

1. Report MA-06-0025-79-9. Urban Mass Transit Administration, U.S. Department of Transportation, 1979.
2. Kashin, S., and D. H. Demoro. *The PCC Car: An American Original.* Interurban Press, Glendale, Calif., 1986.