Vibration-Attenuating Egg-Shaped Rail Fasteners Used by Washington Metropolitan Area Transit Authority

HOMER M. CHEN

The principal method for mitigating underground noise and vibrations in the Washington Metropolitan Area Transit Authority's (WMATA's) Metrorail system has been floating slabs. One type of polyurethane isolator pads supporting the floating slabs has been defective, however, and about 18,800 track-ft of floating slabs has settled unevenly, causing operation and maintenance problems. In seeking an alternative method for mitigating underground noise and vibrations, WMATA conducted an in-service testing program of vibration-attenuating rail fasteners in 1983 under FTA sponsorship. The fastener tested, which is manufactured by Clouth of Cologne, Germany, is known as Cologne egg. The testing results indicate that the Cologne egg fasteners can yield vibration attenuation up to 8 dB, a moderate reduction yet one that is adequate for certain locations. A set of specifications was then developed for vibration-attenuating rail fasteners by De Leuw, Cather & Co., WMATA's general engineering consultant. The testing program under the contract specifications was successful. Accordingly, about 11,000 units will be procured for new construction. With the egg-shaped rail fastener, WMATA not only has found an alternative method for mitigating underground vibrations, but also has saved $3.5 million in the new construction by replacing the floating slabs with the egg-shaped fasteners in the areas where moderate vibration mitigation is required.

Noise and vibration control has been a primary consideration in the design of the Washington (D.C.) Metropolitan Area Transit Authority's (WMATA's) Metrorail system since 1966. The goal has been to assure Metro patrons and neighbors of a quiet and comfortable environment.

Floating slabs have been the principal method for mitigating underground noise and vibrations. Figure 1 shows the typical configurations of WMATA's floating slabs. Because one type of polyurethane isolator pads supporting the floating slabs has proved to be defective, though, about 18,800 track-ft of floating slabs has settled, causing operation and maintenance problems. In seeking an alternative method for the mitigation of underground noise and vibrations, WMATA conducted an in-service testing program of vibration-attenuating rail fasteners in 1983 under the sponsorship of the Urban Mass Transportation Administration, now FTA. The type of tested was manufactured by Clouth of Cologne, Germany. It was an egg-shaped fastener used by Cologne Transit, thus named the Cologne egg. This testing program was assisted by WMATA's general engineering consultant, De Leuw, Cather & Company (DCCO), and the acoustical consultant, Wilson Ihrig & Associates, Inc. (WIA) of Oakland, California. The testing results indicate that the Cologne egg fasteners can yield vibration attenuation up to 8 dB, a moderate reduction yet one that is adequate for certain locations. On the basis of these results, DCCO developed a set of specifications for vibration-attenuating rail fasteners. The fasteners subsequently were procured from Advanced Track Products, Inc. (ATP) of Stanton, New Jersey (now Mattituck, New York). The following describes the essentials of the specifications.

Washington Metropolitan Area Transit Authority, 600 5th ST. N.W., Washington, D.C. 20001.

GENERAL DESCRIPTION OF FASTENERS

The metal components, consisting of a body ring or frame and a floating top or rib plate, were ductile iron. The elastomer component was natural rubber, although a neoprene or a blend of the two was also acceptable. The vibration-attenuating fastener must meet all operation requirements in the WMATA Metrorail system, so the new egg-shaped fastener went through several modifications in order to pass the qualification tests before production. The shape was the only portion of the design that was adopted from the original tested Cologne egg fasteners.

QUALIFICATION TESTS

The fastener qualification tests required four prototype fasteners complete with the modified rail section as shown in Figure 2. The test sequence was as follows:

1. Dynamic stiffness test,
2. Electrical resistance test,
3. Longitudinal restraint test,
4. Spring rate and deflection test (Cases 1 and 2),
5. Repeated-load test (1.5 million cycles),
6. Heat-aging procedure,
7. Push-pull test (1 million cycles),
8. Repeated-load test (1.5 million cycles),
9. Spring rate and deflection test (Cases 1 and 2),
10. Longitudinal restraint test,
11. Electrical resistance test, and
12. Dynamic stiffness test.

The elastomer tests and the fastener fabrication were performed by the Goodyear Tire & Rubber Company of St. Marys, Ohio, and the dynamic stiffness tests were performed by WIA. All other tests

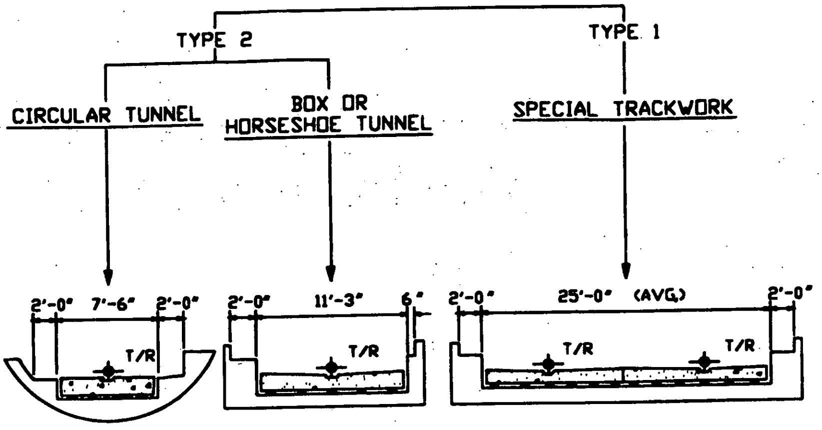

FIGURE 1 WMATA floating slab configurations.

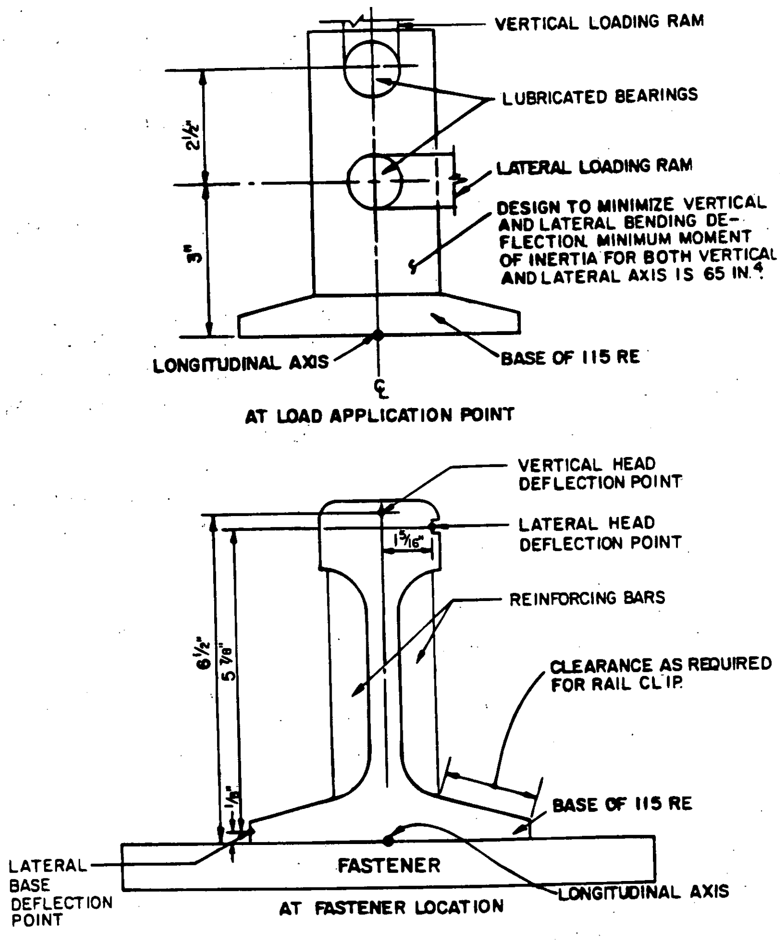

FIGURE 2 Modified rail section.

were conducted by Construction Technology Laboratories, Inc. of Skokie, Illinois. The WMATA project team consisted of George Skorupski and Art Lohrman of DCCO and Albert Maden and Homer Chen of WMATA.

After the seventh test (push-pull), the first set of prototype fasteners showed signs of cracks of the elastomer. The remaining tests were stopped. After the fasteners were modified, a new set of prototype fasteners was produced.

TEST RESULTS

Typical test results for dynamic stiffness are shown in Figure 3. The data fall within the acceptance limits.

Typical results from the electrical resistance and impedance tests are given in Tables 1 and 2. The acceptance criteria are 1.0 μamp maximum current for 100 volts DC and 10,000 ohms minimum impedance for any frequency with 50 volts RMS AC.

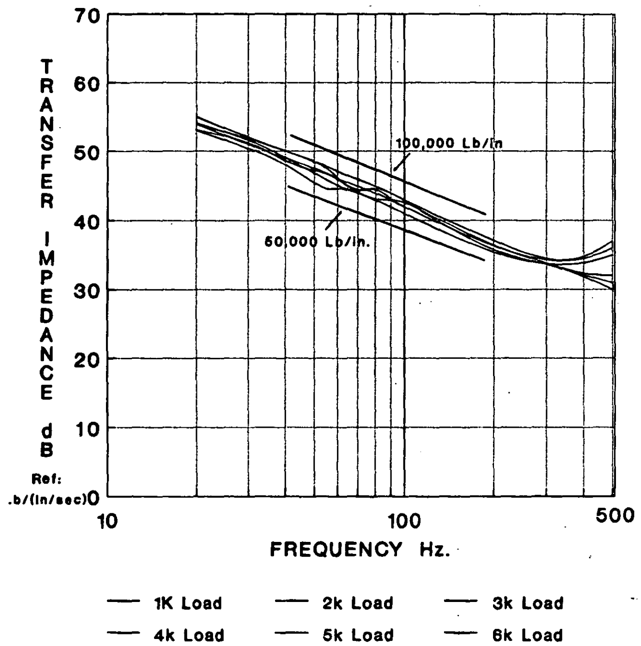

FIGURE 3 Dynamic stiffness test results, Fastener 3H10P20.

The results of the longitudinal restraint test, are shown in Figure 4, and the acceptance criteria are shown in Figure 5. For the spring rate and deflection test, the four prototype fasteners were loaded and had the deflections measured. Figures 6 and 7 show the vertical and lateral response loadings as a function of time. The vertical load points were loaded equally with a load that varies as shown by Curve V. The lateral load points were loaded equally with a load that varies as shown by Curve L.

The vertical and lateral loads were applied simultaneously in accordance with values shown in Figures 6 and 7. Typical test results for each vertical and lateral load are shown in Figures 8 and 9, respectively. The results of Case 1 and 2 tests can be seen in Tables 3 and 4.

The repeated-load test was for endurance. The four prototype fasteners went through the testing procedure for loading conditions under Cases 3, 4, and 5 as shown in Figure 7. The following are the acceptance criteria: at no time during the test shall any fastener component, including the anchorage to the test block, exhibit any sign of failure by slippage, yielding, or fracture, and more than a 10 percent increase in deflection or decrease in spring rate during the test is a sign of failure.

For the heat-aging test, each of the four fasteners with all components was aged in an air oven for 336 hr at 70°C using the aging methods specified by ASTM D573.

TABLE 1 Electrical Resistance Test Results

	Measured Current, microampere			
	Fastener L3H5P10	Fastener 3H10P20	Fastener 3H15P30	Fastener 3H20P40
Before 1KV Standoff	0.010	0.010	0.010	0.020
After 1KV Standoff V.	0.005	0.008	0.006	0.009

TABLE 2 Electrical Impedance Test Results

Frequency Hz.	Impedance, K ohms			
	Fastener L3H5P10	Fastener 3H10P20	Fastener 3H15P30	Fastener 3H20P40
20	12,499.0	12,499.0	16,665.2	16,665.7
40	7,141.9	7,141.9	7,141.4	7,141.9
60	4,544.5	4,544.5	4,998.6	4,999.0
80	3,570.4	3,570.4	3,570.0	3,845.2
100	2,776.8	2,776.8	2,939.7	2,940.2
200	1,387.9	1,427.6	1,427.1	1,469.6
400	693.4	703.2	712.8	745.3
600	462.0	470.7	474.7	494.0
800	346.2	351.1	358.3	369.4
1,000	278.5	283.2	287.6	296.6
2,000	141.6	143.2	145.2	150.9
4,000	81.2	82.3	83.3	86.6
6,000	62.7	63.6	64.2	67.0
8,000	55.0	55.9	56.4	58.7
10,000	50.3	50.9	51.4	53.6

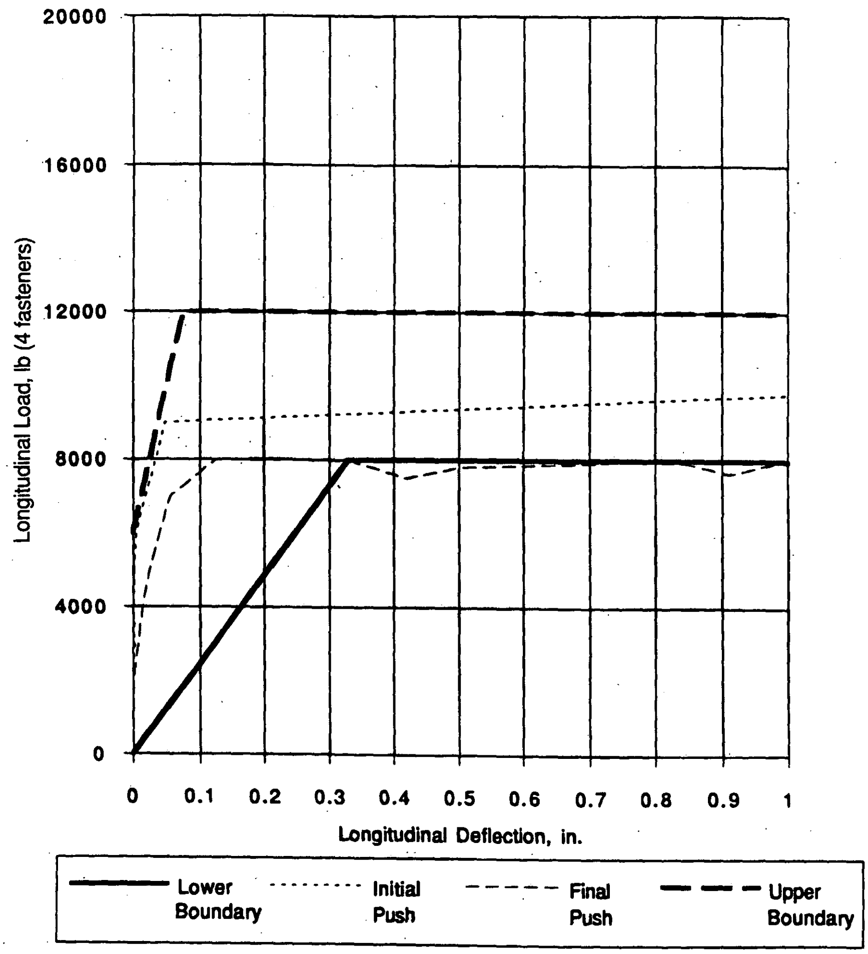

FIGURE 4 Longitudinal restraint test results, WMATA Fasteners 10, 20, 30, and 40.

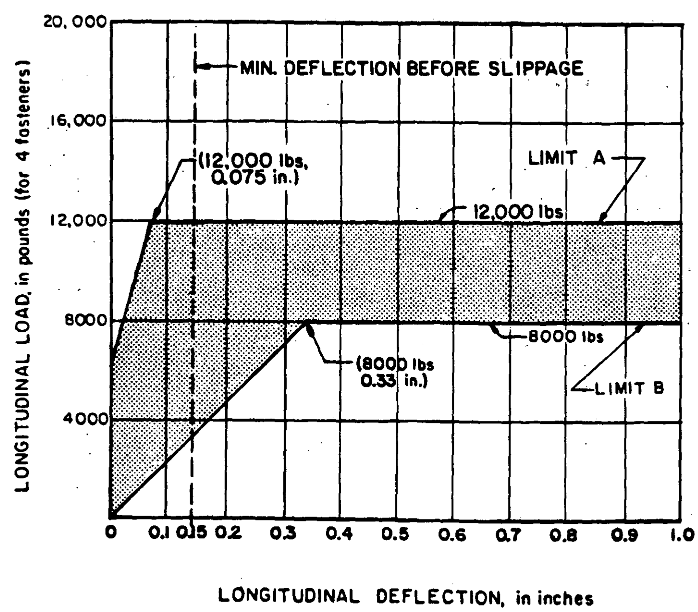

FIGURE 5 Longitudinal restraint test acceptance criteria.

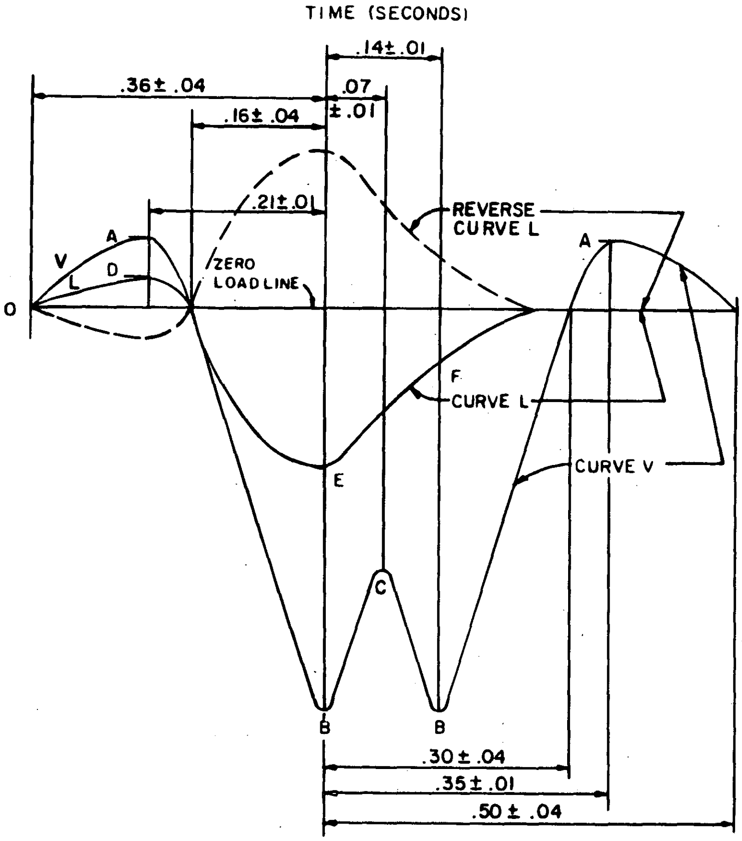

FIGURE 6 Spring rate, deflection, and repeated load tests.

SPRING RATE AND DEFECTION TEST — REPEATED LOAD TEST

CASE

		1	2		3	4	5		
VERTICAL CURVE V	A	-900	-540		-1060	-1343	-892	LBS	TOTAL RESPONSE LOAD
	B	+21	+12.6		+25.2	+31.5	+21	KIPS	
	C	+13.5	+8.1		+16.2	+20.25	+13.6	KIPS	
LATERAL CURVE L	D	_535	-800		_640	-1340	-1340	LBS	
	E	+12.6	+18.9		+15.1	+4.9	+4.9	KIPS	
	F	+4.9	+7.4		+5.8	+12.3	+12.3	KIPS	
					99	1	1		

NO. OF CYCLES OF EACH CASE PER 100 CYCLES OF REPEATED LOAD TEST.

FIGURE 7 Loading cases for spring rate, deflection, and repeated load tests.

In the push-pull test, a cyclic longitudinal load was applied at the rate of one cycle per second to the base of the rail at the rail centerline to deflect the rail ±⅛ in. about the initial position relative to the test block for 1 million cycles. The four fasteners were to withstand the 1 million cycles of loading with no evidence of failure. No component of the fastener was to exhibit any evidence of failure by yielding, slippage, or fracture.

The second repeated-load test was to determine the conditions of the four fasteners after undergoing the heat-aging and push-pull tests. After they passed these tests, the four fasteners went through, once more, the spring rate and deflection, longitudinal restraint, electrical resistance, and dynamic stiffness tests before they were considered acceptable.

During the fastener production run, four fasteners were selected randomly by the WMATA engineer from the initial 50 and from each subsequent 2,000 fasteners, or portion thereof, for quality-control tests in spring rate and deflection, longitudinal restraint, electrical resistance, and dynamic stiffness. The quality-control plan also included the assurance that the material used in the fasteners met the approved specifications.

Figure 10 shows the top, side, and end views of the egg-shaped fasteners produced by ATP.

APPLICATION

As of August 1994, 4,100 units had been delivered to WMATA. About 370 of them were installed 30 in. apart in the Green Line tunnel near the Waterfront Station so that their effectiveness in mitigating underground vibrations could be tested against the effectiveness of the floating slabs mounted with other existing direct-fixation fasteners; Table 5 presents the test results. On the basis of this information, about 8,700 units for the Mid-City Route and 2,200 units for the Outer F Route, both in the future Green Line extension, were

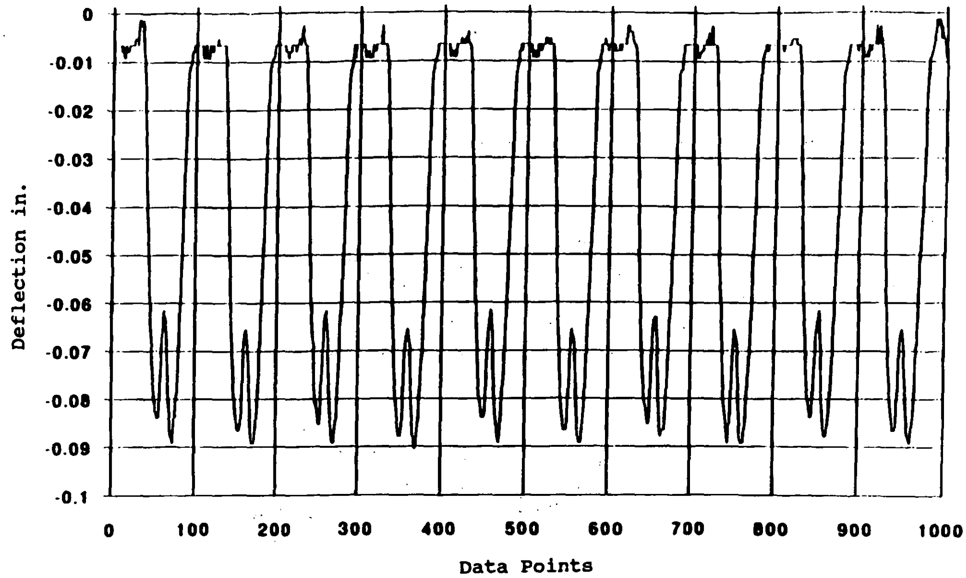

FIGURE 8 Average vertical deflections, Case 1, WMATA Pads 10, 20, 30, and 40.

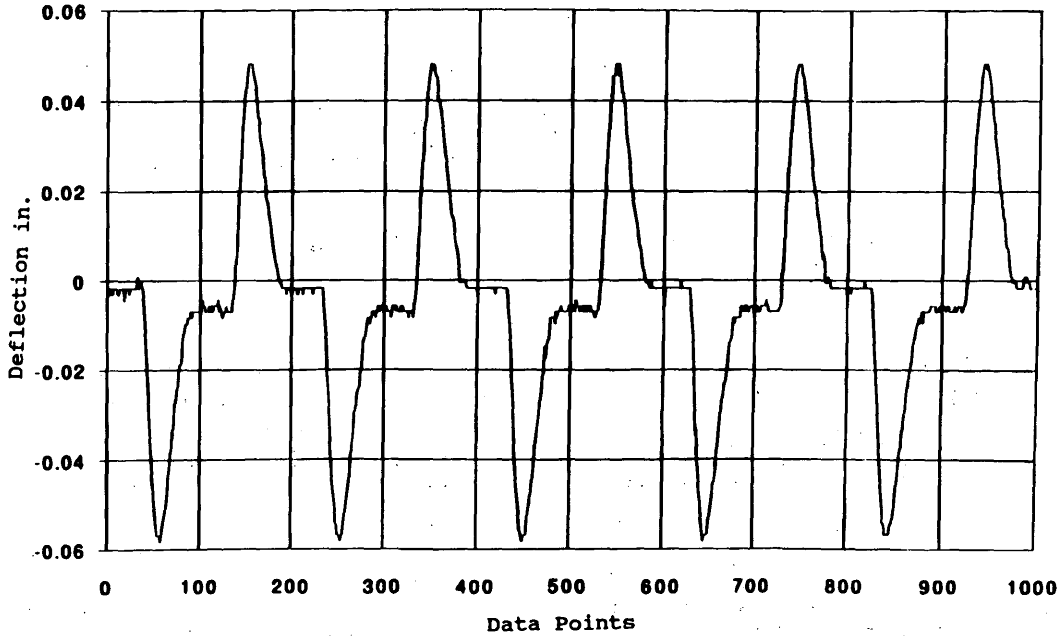

FIGURE 9 Average lateral base deflections, Case 1, WMATA Pads 10, 20, 30, and 40.

TABLE 3 Spring Rate and Deflection Test Results, Case 1

Avg. Incremental Spring Rates			Avg. Lateral Deflection. in.	
Increment	Vert. lb/in	Lat. lb/in	Rail Base	Rail Head
0 - Max. Load	67,745	58,893	0.054	0.105
0.20 - 0.25 sec.	61,580	53,030	-	-
0.25 - 0.30 sec.	70,890	58,110	-	-
0.30 - 0.36 sec.	76,630	56,890	-	-
Average	67,700	56,010	-	-
Ratio*	0.80	0.86	-	-
			Avg. Rotation	
			0.510	

TABLE 4 Spring Rate and Deflection Test Results, Case 2

Avg. Increment Spring Rates			Avg. Lateral Deflection, in.	
Increment	Vert. lb/in	Lat. lb/in	Rail Base	Rail Head
0 - Max Load	80,214	38,523	0.122	0.223
0.20 - 0.25 sec.	62,940	39,010	-	-
0.25 - 0.30 sec.	75,890	35,860	-	-
0.30 - 0.36 sec.	94,360	42,040	-	-
Average	77,730	38,970	-	-
Ratio*	0.69	0.82	-	-
			Avg. Rotation	
			0.997	

* Ratio of smallest incremental spring rate divided by largest incremental spring rate.

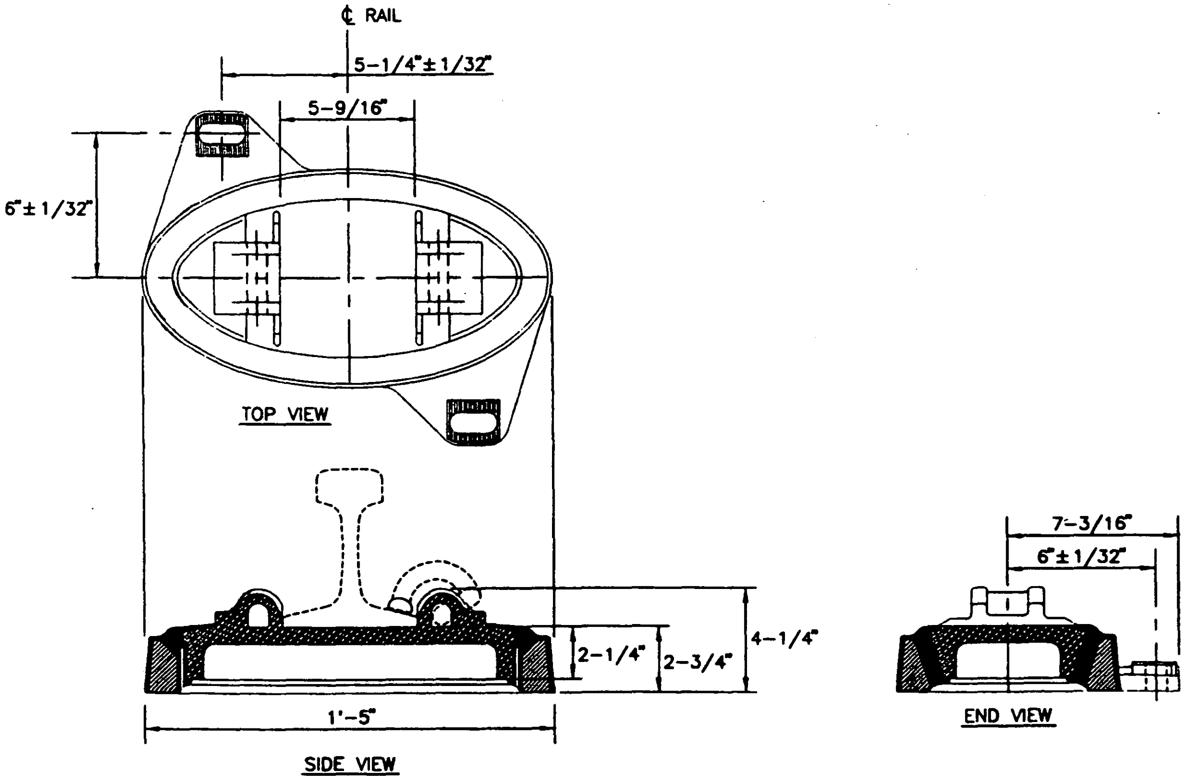

FIGURE 10 Egg-shaped direct-fixation rail fastener.

processed for contract award in late December 1994. Testing is expected for fall 1995. According to ATP, the Boston Transit Authority has also placed an order for 3,800 WMATA egg-shaped fasteners.

The WMATA egg-shaped fasteners, when the required vibration attenuation is less than 8 dB, are the alternative means for alleviating underground vibration. Substantial cost savings can be achieved when they are substituted for floating slabs ($48/ft versus $300/ft for floating slab). Floating slab construction is still necessary where vibration mitigation of 8 dB or more is required.

The general description of the WMATA egg-shaped fastener and specification can be obtained from ATP, the contractor.

TABLE 5 Performance of Ground borne Vibration Mitigation Devices

DEVICE	ATTENUATION dB	FREQUENCIES	COMMENT
FLOATING SLABS	2 TO 15 15 TO 20	31.5 TO 63 63 TO 250	FLOATING SLABS PERFORM BEST BETWEEN 31.5 TO 250 Hz RANGE AND MITIGATE UP TO 20 dB
COLOGNE EGGS	0 TO 2 2 TO 8 8 TO 10	< 20 Hz 31.5 TO 63 63 TO 250	UP TO 8 dB REDUCTION IS PROVIDED IN AUDIBLE RANGE OF GROUNDBORNE VIBRATION INDUCED NOISE

NOTE: THESE dB ATTENUATION ARE RELATIVE TO WMATA DFF HIXON AND LORD RAIL FASTENERS INSTALLED BETWEEN 1978 - 1986.

CONCLUSIONS

In conclusion, the testing program of the egg-shaped rail fasteners was considered successful. With these fasteners, WMATA not only has found an alternative method for mitigating underground vibrations, but also has saved $3.5 million in the new construction by replacing the floating slabs with the egg-shaped fasteners in the areas where moderate vibration mitigation is required.

REFERENCES

1. *Contract Specifications—Trackwork 12, Vibration Attenuating Underground d.f. Fastener Procurement.* Contract 2Z708R. Washington (D.C.) Metropolitan Area Transit Authority, Dec. 1988.
2. *Fastener Qualification Tests for WMATA Contract 2Z708R.* Vols. 1 and 2. Construction Technology Laboratories, Inc., Skokie, Ill., Feb. 1993.

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