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Comparison of Coupler Forces — Cushion Units versus Standard Draft Gear Using the TOES™ Model

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Summary

The performance of 15-inch travel end-of-car cushion units was compared with that of standard steel spring/wedge draft gear using Train Operations and Energy Simulator (TOES™) software. This work was completed as part of the Association of American Railroads' Strategic Research Initiative on Dynamic Load Environment of Train Equipment. A key objective of this research project is to help develop improved cushion unit designs that would significantly reduce longitudinal coupler forces within trains made up of a large number of cushion unit cars and allow the use of more of these types of cars in a single train consist. Performance comparisons were based on coupler force response and knuckle fatigue damage. Several basic operation scenarios were used to generate the dynamic coupler force values. Results indicate that for all operation situations tested, the calculated peak forces and fatigue damage were significantly higher. Peak forces were at least 1.5 times higher and estimated fatigue damage was at least 3 times higher for the train equipped with cushion units.

It has been known for several years that end-of-car cushion units can improve ride quality for sensitive lading by reducing the frequency and magnitude of high level buff or compressive coupler forces due to yard impacts. Recently, however, concern has grown that use of long travel cushion units could also result in larger peak draft forces during standard train operations. The draft force levels could be especially high when several cushion unit cars are coupled together within a train.

Some basic train handling scenarios were simulated using TOES™ analysis. Analysis experiments were conducted using trains with only cushion unit cars and then with trains of similar size, but with all cars utilizing standard draft gear only. A TOES™ simulation was also completed with a mixture of cushion unit and standard draft gear cars. These simulations demonstrated the following:

- Peak buff and draft coupler loads were significantly higher for the cars with the cushion units than those with standard draft gear. The increase in peak force was by a factor of 1.5 to 2.0 depending on train length.
- Calculated fatigue damage for the knuckle was also significantly higher for a car in a cushion unit train when compared with a car in a train with standard draft gear. The increase in fatigue damage was by a factor of 3 to 6, depending on train length.



INTRODUCTION

Railroads continue to experience coupler related failures in standard revenue service. Particularly noteworthy have been recent failures on cars fitted with cushioned draft gear. There is significant concern that high dynamic coupler loads could be one of the most significant operation problems resulting from the use of longer trains containing a significant number of cars with cushioned units.

Car repair billing data processed for 2008-2011 shows coupler failure rates (i.e., reported failures divided by the number of couplers in service during the same time) on autorack cars with 10-inch travel cushion units were about 17.3 percent. From the same data, coupler failure rates for box cars with 10-inch travel cushion units were about 11.9 percent. Failure rates for the same types of cars with standard draft gear were 8.8 percent for box cars and 0.85 percent for autorack cars.

The availability of revenue service dynamic load data is limited, however, especially for coupler force data associated with cushion units. As a result, there is a need for a program designed to aid in the understanding of the magnitude of the full spectrum of the revenue service load environment for cars equipped with cushion units.

The objective of this research was to evaluate the basic differences in longitudinal coupler force environment that could exist between trains with cushion units and those with standard draft gear. This was done using TOES™ software to calculate the coupler forces created by several basic train handling scenarios.

PROCEDURE

This study employed analysis of the following five different trains:

- Two locomotives followed by 30 freight cars, all with 15-inch deflection cushion units and all with a gross rail load (GRL) of 286,000 pounds.
- Two locomotives followed by 30 freight cars, all with standard draft gear and all with a GRL of 286,000 pounds.
- Two locomotives followed by 50 freight cars, all with 15-inch deflection cushion units and all with a GRL of 286,000 pounds.
- Two locomotives followed by 50 freight cars, all with standard draft gear and all with a GRL of 286,000 pounds.
- Two locomotives followed by 30 freight cars, the first 10 cars had 15-inch deflection cushion units and the remainder had standard draft gears. All cars had a GRL of 286,000 pounds.

Each train model was subjected to four basic train handling scenarios as described below. These scenarios were designed to “bunch” the train and then to stretch or extend the train.

1. With the train traveling at 50 mph on level track, the service brakes were applied fully until the train slowed to approximately 25 mph. The brakes were then released and the throttle was applied until the train reached approximately 50 mph. Throttle application occurred within two seconds of full brake release. The throttle was applied in steps: Notch 1 after 100 feet, Notch 2 after an accumulated 200 feet, Notch 3 after 300 feet, Notch 6 after an additional 1,000 feet, and Notch 8 after 2,300 feet. The total distance traveled for the scenario was approximately 25,000 feet.
2. With the train traveling at 50 mph on level track, the dynamic brake system was applied fully until the train slowed to approximately 30 mph. The dynamic brake system was then released and the throttle was applied (as in Scenario 1) until the train reached approximately 50 mph. The total distance traveled for the scenario was approximately 35,000 feet.
3. The train ascended a 1 percent grade traveling at 30 mph and then slowing to about 17 mph near the top of the grade. The 1 percent upward grade was followed by a short level section and then a 1 percent downgrade. On the descending grade, the train was held to a maximum speed of about 62 mph using dynamic braking. The descending grade was followed by level track. When the train reached the final level section, dynamic braking was deactivated and the throttle was applied in steps to maintain a train speed of about 55 mph. The total distance traveled for the scenario was approximately 72,000 feet.
4. The train began ascending a 1 percent grade traveling at 30 mph and then decelerated to a constant speed of approximately 17 mph near the top of the grade. The 1 percent upward grade was followed by a short level section and then a 1 percent downgrade. On the descending grade, the train was held to a maximum speed of about 62 mph using dynamic braking. The descending grade was followed by a short section of level track and then another ascending grade of 1 percent. When the train reached the second ascending grade, dynamic braking was deactivated and the throttle was applied in steps until the train was again traveling at constant speed. The total distance traveled for the scenario was approximately 72,000 feet.

Primary analysis output values observed were the longitudinal coupler forces at each end of each car. Also used for the comparison of performance was fatigue damage accumulated for the knuckle pulling face. A relationship between draft force and stress in the knuckle pulling face had been determined from significant finite element modeling during previous research projects.^{1,2} Fatigue damage was then estimated using a component stress-life curve with a fatigue

strength of approximately 15,000 psi at a life of two million cycles.

Some basic characteristics for the TOES™ model are as follows. The standard draft gear model has a piecewise linear force-displacement characteristic obtained by averaging the overlays of force-displacement curves obtained from testing at various impact speeds. The force-displacement characteristics are basically bilinear and are “hard coded” in the TOES™ software. The end-of-car cushion unit in TOES™ is modeled as a nonlinear hydraulic shock absorber or damper. The force required to compress the unit increases parabolically with an increase in compressive velocity of the rod and piston head. When load is released, the rod and piston will return to the unloaded or neutral length due to a travel dependent return force (gas pressure or return spring). During buff or compression travel, a draft load of 100,000 pounds must be attained before the orifices that pass fluid begin to open. As buff travel continues, the orifice opening progresses linearly until a buff load of 200,000 pounds is reached. These characteristics are also hard coded in the TOES™ software. The standard TOES™ cushion unit model has no load versus deflection characteristics for extension past the neutral condition (no active draft).^{3,4}

RESULTS

Observations of the results indicated that longitudinal coupler forces were consistently highest at the first to fifth cars behind the locomotive. As a result, the following comparisons use the coupler force data for the fifth car.

For almost every simulated scenario, the calculated peak longitudinal coupler forces were significantly higher for the train with cushion units than for the train with standard draft gear. Figures 1 and 2 and Tables 1 and 2 show these observations. Data in these tables show that the peak coupler forces on the cushion unit car were often 1.5 to 2 times greater than those calculated for the car with standard draft gear.

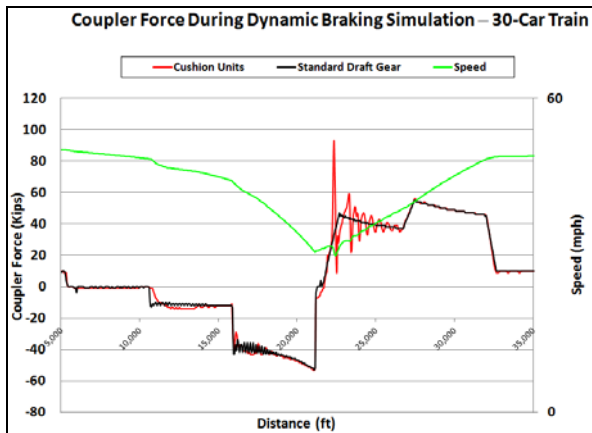


Figure 1. Coupler Force, Scenario 2, 30 Cars

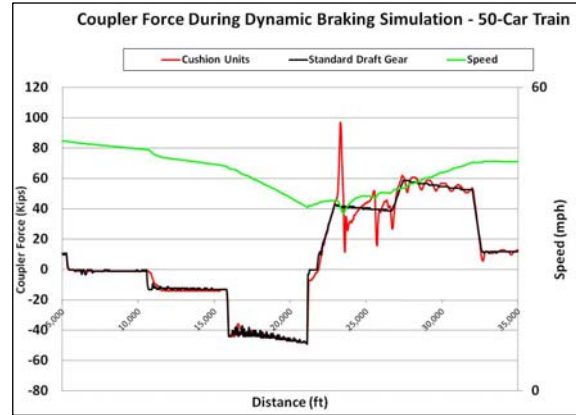


Figure 2. Coupler Force, Scenario 2, 50 Cars

Table 1. Peak Longitudinal Coupler Force in Pounds, 30 Cars

Scenario No.	Standard Draft Gear Cars		Cushion Unit Cars	
	Peak Draft	Peak Buff	Peak Draft	Peak Buff
1	75,000	6,000	79,000	1,000
2	55,000	53,000	93,000	53,000
3	20,000	79,000	78,000	119,000
4	57,000	79,000	83,000	119,000

Table 2. Peak Longitudinal Coupler Force in Pounds, 50 Cars

Scenario No.	Standard Draft Gear Cars		Cushion Unit Cars	
	Peak Draft	Peak Buff	Peak Draft	Peak Buff
1	68,000	8,000	99,000	1,000
2	69,000	49,000	97,000	49,000
3	29,000	126,000	50,000	162,000
4	57,000	126,000	87,000	162,000

It was also observed that the peak buff and draft forces calculated for the 50-car train were generally higher than those calculated for the 30-car train. This was not universal, however, as illustrated in Tables 1 and 2. Perhaps more important than peak forces, however, is the fatigue damage accumulated by the knuckle, coupler pulling lugs, and coupler pin supports resulting from the larger number of high range force cycles that occurred among the cars of the 50-car train when compared with the maximum damage calculated within the 30-car train. This is illustrated by comparing the coupler force plots in Figures 1 and 2. The damage calculated resulting from the force ranges at the most severe location of the 50-car train with standard draft gear was about 2.8 times more than that calculated for the 30-car train. For the cars with cushion units, the damage was about 1.3 times more severe for the 50-car train.

When the accumulated fatigue damage on the knuckle face was calculated for all four train handling scenarios of a 30-car train, the estimated damage for the cushion unit train was about 6.6 times greater than that for a train with standard draft gear. For a 50-car train, the calculated damage for the cushion unit train was approximately 3.2 times greater than that calculated for a train with standard draft gear.

As Figure 3 and Table 3 show, when a 30-car train was created using 10 cars with cushion units and 20 cars with standard draft gear, the peak buff and draft forces were significantly lower than that of a 30-car train assembled with all cushion unit cars. The comparison of peak forces calculated for a 30-car train with all standard draft gear cars and the 30-car train with 10 cushion unit cars and 20 standard draft gear cars was not as definitive. Using knuckle fatigue damage to compare performance, however, provides a different perspective. The draft load induced knuckle fatigue damage calculated for the train with 10 cushion unit cars and 20 standard draft gear cars was only about 50 percent of the damage calculated for a 30-cushion unit car train, but 3.5 times greater than the damage calculated for a train with 30 standard draft gear cars.

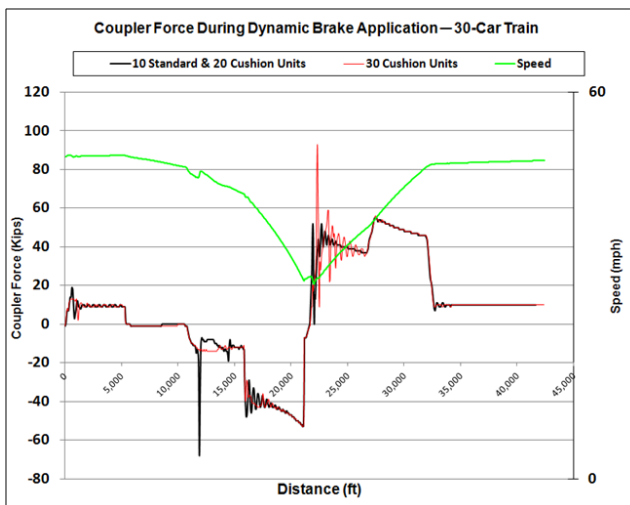


Figure 3. Coupler Force, Scenario 2, 10 Cushion Unit Cars and 20 Standard Draft Gear Cars

Table 3. Peak Longitudinal Coupler Force in Pounds, 30 Mixed Cars

Scenario No.	10 Cushion Unit Cars and 20 Standard Draft Gear Cars		30 Cushion Unit Cars	
	Peak Draft	Peak Buff	Peak Draft	Peak Buff
1	66,000	1,000	79,000	1,000
2	52,000	68,000	93,000	53,000
3	50,000	213,000	78,000	119,000
4	60,000	213,000	83,000	119,000

CONCLUSIONS

TOEST™ simulation results demonstrate how the presence of a large number of cars with cushion units can result in larger and more damaging coupler forces. These basic simulations were designed to understand the types of forces that might be created within trains that contain a large number of cushion unit cars and how the forces might compare with those created within trains with standard draft gear cars. The experiments were also designed to study the effects of a variable, such as number of cushion unit cars, on peak forces and knuckle fatigue damage.

FUTURE WORK

Work is currently underway to collect actual revenue service coupler force data for a 286,000-pound cushion unit car with 15-inch travel cushion units. It is anticipated that the revenue service load data will contribute significantly to the understanding of the types of train operations that occur with regularity. It is also anticipated that the results of these and subsequent simulations can aid in understanding how cushion unit cars may contribute to the magnitude and frequency of large in-train coupler forces.

After this field data is used to validate the cushion unit option in the TOEST™ software, plans are to complete additional simulations in an effort to optimize train operations and the characteristics of the cushion units in such a way that in-train coupler forces can be somewhat minimized.

REFERENCES

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