U.S. Department
of Transportation

**Federal Railroad
Administration**

Impact Performance of Draft Gears in 263,000 Pound Gross Rail Load and 286,000 Pound Gross Rail Load Tank Car Service

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Office of Research and
Development
Washington, DC 20590

DOT/FRA/ORD-06/16

June 2006

REPORT DOCUMENTATION PAGE

Form approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE**	**3. REPORT TYPE AND DATES COVERED**

4. TITLE AND SUBTITLE

Impact Performance of Draft Gears in 263,000 Pound Gross Rail Load and 286,000 Pound Gross Rail Load Tank Car Service

5. FUNDING NUMBERS

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBERS

9. SPONSORING/MONITORING AGENGY NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
1120 Vermont Avenue, NW, MS-20
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DOT/FRA/ORD-06/16

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/ABAILABILITY STATEMENT

This document is available through National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT

This project quantified the impact performance of draft gears on tank cars for both the 263,000 and 286,000 gross rail load (GRL) conditions and the corresponding effect on the structural integrity of stub sills. Full-scale physical impact testing with an instrumented tank car for the 263,000 GRL case using 6 different draft gear combinations of prime, average, and soft draft gear conditions were performed. Impact speeds of 2 to 9 mph were tested. Loss in draft gear performance with age/use along with performance comparisons of draft gears qualified under M-901G versus M-901E were obtained. Test results from the 263,000 GRL cars are presented and used to validate an finite element analysis model with scaled up car mass to predict draft gear performance for the 286,000 GRL case.

This study showed that draft gears in prime condition are the most effective at reducing car impact forces, especially at higher speeds where the most damage occurs. Draft gears in the soft condition provided the least protection. M-901G gears offered better performance at the higher speeds of interest than the M-901E gears. The average setup, a combination of soft and prime gears, performed better than soft gear setup.

14. SUBJECT TERMS

Draft gear, tank car safety, tank car impacts, stub sill stresses

15. NUMBER OF PAGES

41

16. PRICE CODE

17. SECURITY CLASSIFICATION	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rec. 2-89)
Prescribed by ANSI/NISO Std. 239.18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

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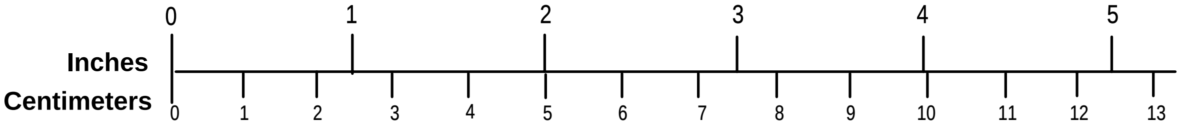

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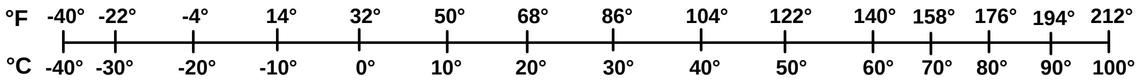

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Updated 6/17/98

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ACKNOWLEDGEMENTS

The authors wish to thank the Office of Research & Development of the Federal Railroad Administration, in particular Ms. Claire Orth and Mr. Jose S. Peńa, for funding this research effort. We also wish to thank Mr. Jim Rader of the Office of Safety of the Federal Railroad Administration for his valuable input into the program. Our sincere thanks are also due to GATX, especially Mr. William Garfield and Mr. Doug Mullins, for providing the test car.

EXECUTIVE SUMMARY

The stub sill on a tank car is one of the failure prone sections of the overall tank car, and failures can lead to stub sill separation, loss of lading, or even derailment. Such safety concerns are heightened in the case of hazardous material transport. With an increasing number of tank cars being introduced into 286,000 lb gross rail load (GRL) service, the stub sill tank car interface requires further scrutiny.

The stub sill is subjected to considerable stress levels because of loads that are induced under typical revenue service operations. Draft gear systems are designed to reduce the force levels seen by tank cars. Therefore, draft gear performance has a significant effect on the structural integrity of tank car stub sills. Draft gears with higher capacities can generally absorb more energy and offer better protection. Typically, draft gears reach their peak capacity after being broken-in. Towards the end of their operating lives, they tend to become softer and lose some of their capacity.

Under a 286,000 lb GRL load environment, longitudinal forces are expected to be much higher. The capacity of draft gears to protect tank cars in that severe environment will have a significant effect on the safety of hazmat transportation using tank cars in 286,000 lb GRL service. The safety of tank cars in 286,000 lb GRL service, therefore, cannot be adequately addressed without considering the performance of draft gears used on the tank cars. It has generally been believed in the tank car industry that draft gears qualified under M-901G specifications offer superior performance compared to draft gears specified under M-901E specifications. However, specific differences in draft gear performance between E gears and G gears have not been previously quantified even for 263,000 lb GRL tank cars. Apparent loss in draft gear performance with age/use has not been quantified either. Hence, a need to quantify these differences existed, so that their effect on the safety of 286,000 lb GRL cars could be addressed.

The primary objective of this project is to quantify the benefits of using M-901G specification draft gears as compared to M-901E specification draft gears on tank cars in 286,000 lb GRL service. An additional objective is to quantify the benefits of using draft gears in prime condition as compared to draft gears in soft condition.

As part of this project, a test tank car was instrumented, loaded to simulate 263,000 lb GRL service and tested on an impact ramp. Six different draft gear combinations were tested as part of this program. The scenarios included testing with soft gears on the anvil car (tank car) only and soft gears on the hammer car and the anvil car.

To better present the results from the six different cases tested, the results are condensed from the various cases into three different impact conditions:

1. Prime condition: This condition represents the cases where the impact involved draft gears in prime condition at struck and striking ends.

2. Average condition: This condition represents the cases where the impact involved a soft draft gear at the struck end and a prime condition draft gear at the striking end.

3. Soft condition: This condition represents the cases where the impact involved soft draft gears at the struck and striking ends.

In addition, finite element models that simulated the impact behavior of tank cars were developed. These models were validated using the test data and used to simulate draft gear behavior under 286,000 lb GRL loading. The following conclusions were reached from the testing and simulations:

1. Prime gears (M-901G gears and M-901E gears in prime condition) induced the lowest coupler forces, especially at higher impact speeds where the potential for damage is the highest. Impacts in the soft condition (draft gears at the struck and striking ends in used condition) produced the highest coupler forces at all speeds.

2. A comparison of the stresses developed at critical locations indicated that gears in prime condition offered the best protection. Soft gears produce the highest stress in the tank car at all speeds, with the differences increasing substantially at higher speeds. At speeds less than 6 mph, prime gears induce slightly higher stresses than the average gears. This small disadvantage at lower speeds, however, is not enough to offset the significant advantage offered by the prime gears at higher speeds. At these high impact speeds (where the likelihood of damage is the highest), prime gears induce considerably lower stresses.

3. Data from simulations of 286,000 lb GRL service impacts using validated models indicated that prime gears would continue to offer superior protection, especially at higher speeds. At lower speeds, no significant differences existed in performance between 286,000 lb GRL service and 263,000 lb GRL service. The speed at which coupler forces started to increase under 286,000 lb GRL service was higher for the prime gears, indicating additional reserve capacity in the friction packs of the draft gears.

4. Comparisons of E gears in prime condition and G gears indicated that the E gears offered marginally better performance at lower speeds, while the G gears offered better performance as speeds increased.

5. Overall, prime gears offer better protection under both 263,000 lb GRL service and 286,000 lb GRL service. However, in the prime conditions that were tested/simulated, draft gears at the struck and striking ends were in good condition. Generally, tank car owners have no control over placement of their cars in a train and subsequently over the draft gear conditions of adjacent cars. While a given tank car may be equipped with a prime gear, it may impact against a car with soft gears while over-the-road. The average setup that was tested represents this scenario. In such scenarios, the protection benefits offered by the prime gears may not be fully realized. Even in such scenarios, a prime gear will protect the car better, as evidenced by the performance of the average setup compared to the soft setup. In the 263,000 lb GRL and 286,000 lb

GRL service, the average gear setup performed better than the soft gear setup at almost all speeds.

6. An overview of the test and simulation data indicates that different gears are at their best at different speed ranges. Given the large number of variables involved, it is a difficult task to design draft gears to perform well at all speeds. However, it would be a worthwhile effort to try and tune draft gear performance in the design process to maximize the protection offered by draft gears.

1.0 Introduction

1.1 Background

Tank cars in revenue service are subject to occasional cracking and failures at the stub sill tank interface. The structural integrity of a tank car is highly dependent on the strength of its stub sill tank car interface. This interface is a very failure prone section of the overall tank car, and failures can lead to stub sill separation, loss of lading, or even derailment. Such safety concerns are heightened in the case of hazardous material transport. With the number of tank cars being introduced into 286,000 lb GRL service, the stub sill tank car interface requires further scrutiny.

The stub sill is subjected to considerable stress levels under typical revenue service operations. When cars are over-the-road (OTR), in-train forces are generated due to run-ins and run-outs, which induce stresses in the stub sill region. Run-in and run-out events typically result in impact speeds of about 1–2 mph between cars. Train makeup operations in railway yards generally involve higher impact speeds and high longitudinal forces, leading to higher stresses. Draft gear systems at the end of each car are designed to absorb some of the impacting energy and reduce the force levels seen by tank cars in impact yard and OTR conditions. The effectiveness of these draft gear systems governs how much energy is absorbed by the draft gears and consequently the level of impact protection offered. Draft gear performance, therefore, has a significant effect on the structural integrity of tank car stub sills.

Draft gears for freight cars are certified under either section M-901E or section M-901G of the Association of American Railroads (AAR) Manual. Most of the draft gears out in the market today are certified under M-901E, which requires drop hammer tests. M-901E gears must have a minimum official capacity of 36,000 ft-lb, when tested under the standard 27,000 lb drop hammer. They must also have a capacity of at least 6,000 ft-lb at 1-5/16 in. travel. While M-901G specifications were established in 1964, common usage of these gears is relatively recent. These gears are certified using impact tests and must have a minimum rating impact velocity of 5 mph. Rating impact velocity is the velocity that produces a reaction of 500,000 lb. The impacts are to be conducted using 70-ton cars. This report will refer to the M-901E draft gears as E gears and the M-901G draft gears as G gears.

Draft gears typically use friction wedges in series with springs (steel, rubber, or elastomer) to absorb impact energy. Draft gears with higher capacities can generally absorb more energy and therefore offer better protection. Typically, draft gears reach their peak capacity after being broken-in. Towards the end of their operating lives, they tend to become softer and lose some of their capacity.

Under a 286,000 lb GRL load environment, longitudinal forces during yard impact and OTR conditions will be much higher. The capacity of draft gears to protect tank cars in that severe environment will have a significant effect on the safety of hazmat transportation using tank cars in 286,000 lb GRL service. Therefore, the safety of tank cars in 286,000 lb GRL service cannot be adequately addressed without considering the performance of draft gears used on the tank cars. It has generally been believed in the tank car industry that G gears offer superior performance to E gears in revenue service. However, specific differences in draft gear performance between E gears and G gears has not been previously quantified. Apparent loss in draft gear performance with age/use has not been quantified either. Hence, a need to quantify these differences existed, so that their effect on the safety of 286,000 lb GRL cars could be addressed.

A previous project done by Sharma & Associates, Inc. (SA), for the Federal Railroad Administration (FRA) evaluated the effects of coupler height mismatch on tank car stub sill integrity of 263,000 lb GRL tank cars. Part of that project conducted full scale impact testing of a 263,000 lb GRL GATX tank car using E gears in prime condition and G gears in new condition. Since the majority of tank cars in service use regular (softer) E gears, additional testing is required to quantify gear performance. This will assist in quantifying the benefits of using premium gears in tank cars transporting hazardous material (HM) and 286,000 lb GRL service.

1.2 Objectives

The primary objective of this project was to quantify the benefits of using G spec draft gears as compared to E spec draft gears on tank cars under 286,000 lb GRL service. An additional objective was to quantify the benefits of using draft gears in prime condition as compared to draft gears in soft condition. As part of the project, full-scale impact testing was conducted on a test GATX tank car at various impact speeds with different gears on the tank car. The impact test series included testing with soft gears on the anvil car (tank car) only and soft gears on the hammer car and the anvil car. The results from the tests were combined with modeling of tank car impacts to quantify draft gear performance.

2.0 Impact Testing

The outline of the test plan was similar to the testing done as part of the earlier project [1]. A test tank car (Figure 1), generously donated by GATX, was instrumented for monitoring strains at critical locations. This was followed by a series of specifically designed impact tests to evaluate tank car response to different draft gear types and configurations.

Figure 1. Test tank car

2.1 Test Car Setup

The test tank car (GATX 15693) is a DOT 111A100W1 non-insulated car with a built date of January 1981. It has a capacity of 26,791 gallons, with a light weight of 70,200 lb and a load limit of 192,800 lb. The stub sill consists of two channels and a top plate. The sill connects to the tank through a head brace near the bolster (Figure 2). The head brace is connected to the tank shell through a reinforcement pad (head pad extension). The front draft lugs and the striker are a single casting that is welded onto the web of the sill. The rear draft lugs and the center bowl are a single casting that is bolted on to the web of the sill. The material of tank head, tank shell, and head pad extension is American Society for Testing and Materials (ASTM) A515, Gr. 70 LR (yield point (yp): 38,000 psi). The head brace material is ASTM A36 (yp: 36,000 psi), and the draft sill material is ASTM A572, Gr. 50 (yp: 50,000 psi).

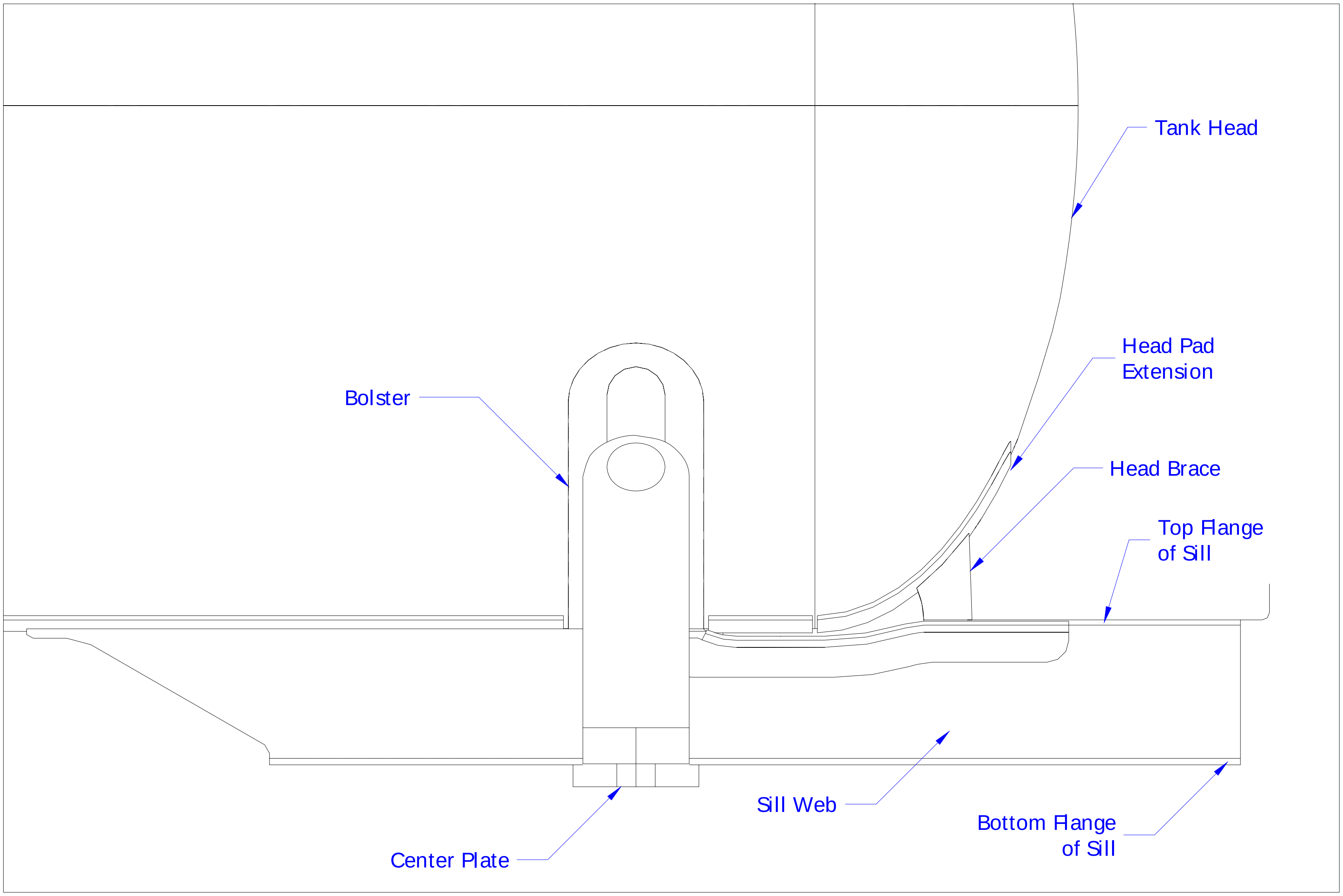


Figure 2. Schematic of test tank car

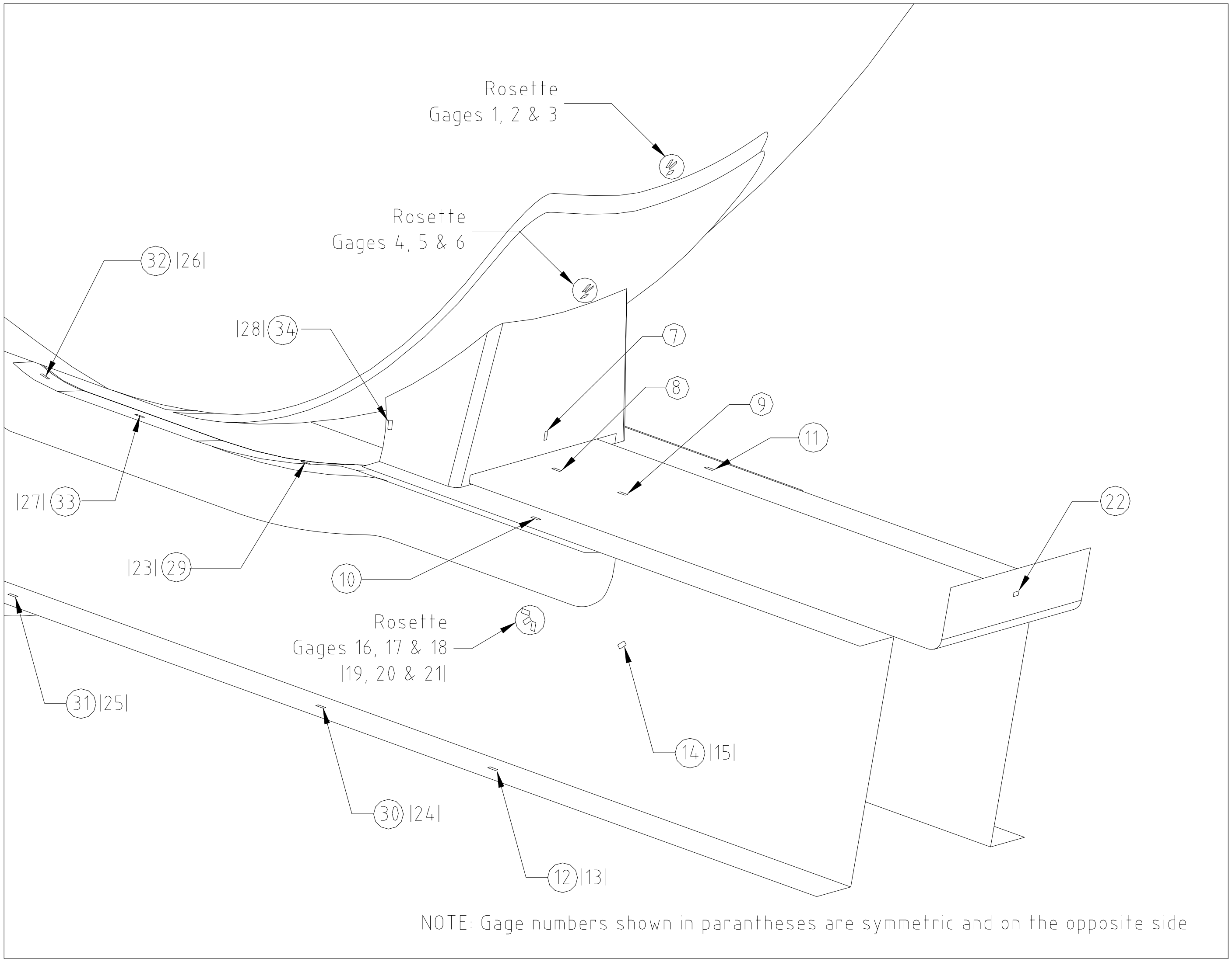
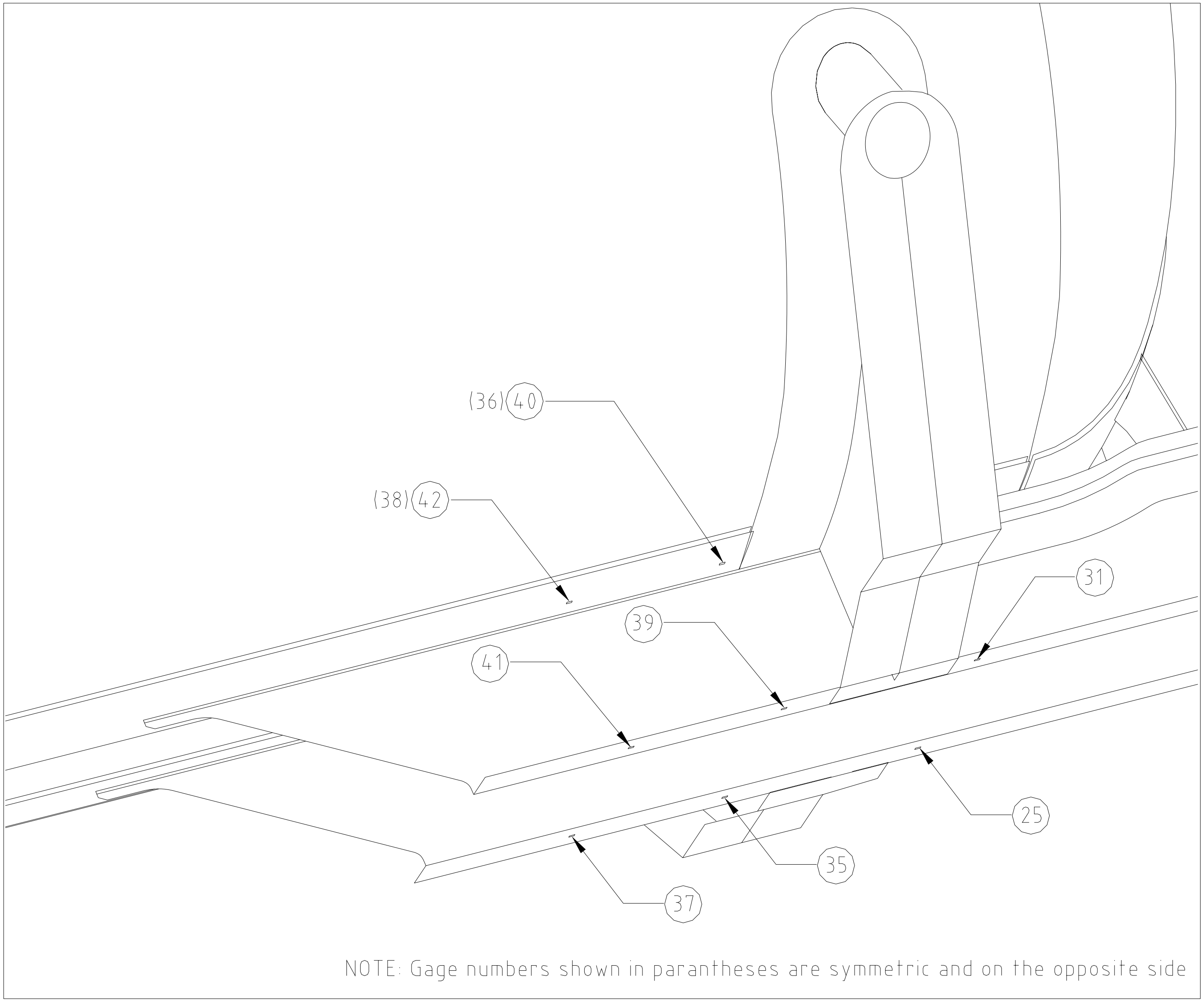


Figure 3. Gage locations on test car−View 1



NOTE: Gage numbers shown in parantheses are symmetric and on the opposite side

Figure 4. Gage locations on test car–View 2

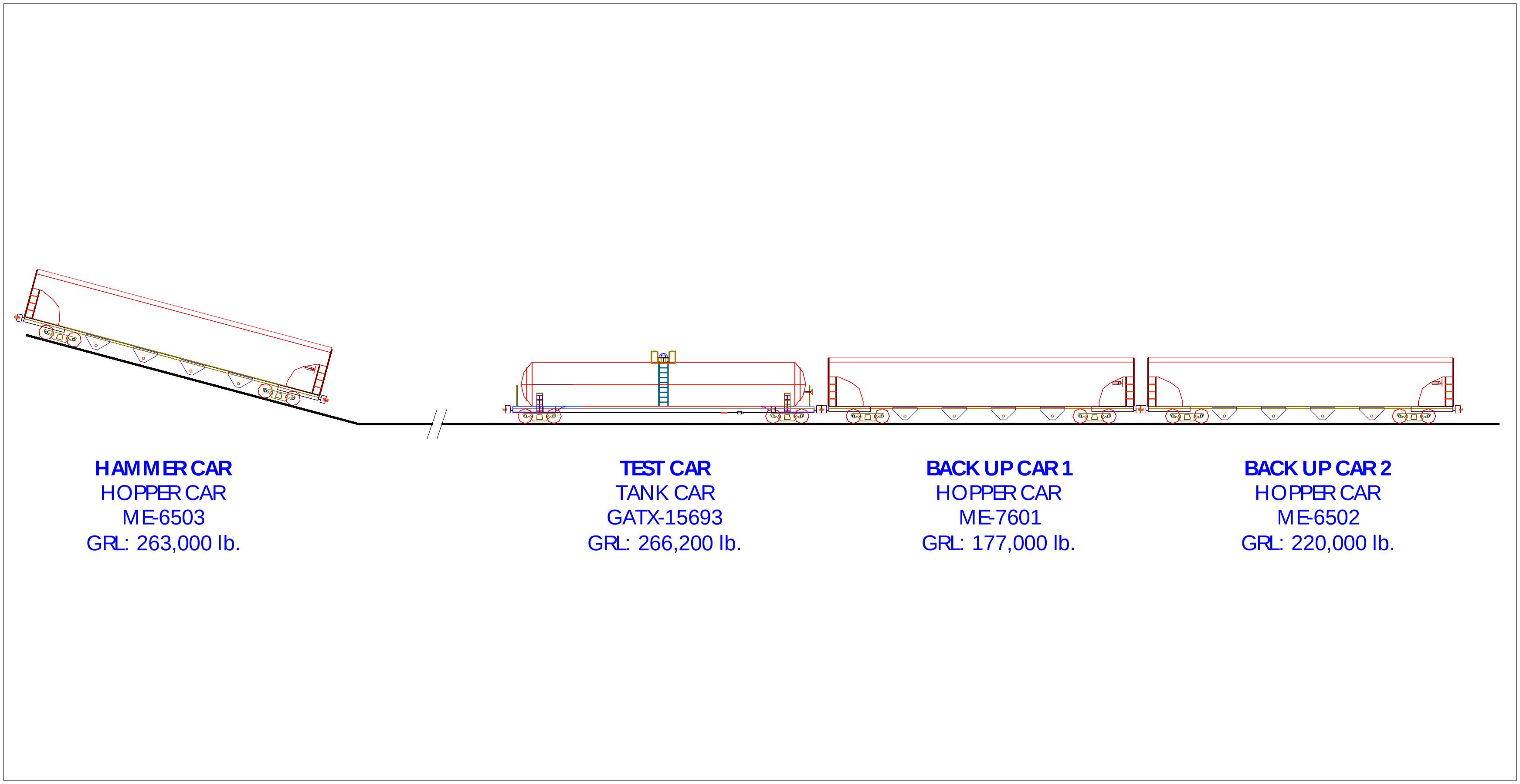


Figure 5. Schematic of impact test setup

The test car was loaded with water to weigh 266,200 lb GRL. The A end of the car was instrumented with strain gages at critical locations on the stub sill, tank head, reinforcement pad, and head brace. Gage locations were determined based on preliminary finite element analysis, consultations with industry experts, and an industry survey of fatigue crack locations on cars of similar design. Care was taken to place strain gages away from stress concentrations, so that the strains in the parent material would be measured. As a part of the instrumentation, 30 single element and 4 rectangular rosette strain gages, 42 channels total, were applied. Based on results from initial static tests, data from 28 channels was collected for the impact tests. Figures 3 and 4 represent the gage locations (listed in table 1). Miner Enterprises, Inc. (Geneva, IL) conducted the instrumentation and testing. Miner and SA completed the data acquisition during impact testing.

2.2 Impact Test Setup

The impact tests were conducted using an inclined test track (impact ramp). Desired impact speeds were obtained by releasing a hammer car from different heights on the impact ramp. A hopper car loaded to weigh 263,000 lb GRL served as the hammer car. Two backup cars were behind the tank car, weighing a total of 397,000 lb, with hand-brakes applied on the last car (Figures 5, 6, and 7). The tank car, hammer car, and backup cars were all equipped with E couplers. The A end of the tank car (instrumented end) was the struck end. The tank car and the backup cars were bunched together after each impact.

In addition to the strain channels, coupler force at the impacting end (using a dynamometer coupler in the hammer car), draft gear travel (struck end of the tank car) and impact velocity were also measured. For some of the impacts, coupler force at the B end of the tank car was measured.

2.3 Draft Gear Configurations

Part of SA’s earlier work included two series of impact tests. The first series used E gears in prime condition (model A) at either end (struck end and non-struck end) of the tank car (impact set #1). These gears were provided with the test car. The second series used G gears in new condition, at either end of the tank car (impact set #2). For these test series, the striking end of the hammer car was equipped with a draft gear in prime condition, which was supplied by Miner as part of the test setup. Reference [1] presents the results from these tests.

For this project, two 2 sets of draft gears (model B & model C) from two different manufacturers in used condition were selected. The selected gears were subjected to standard hammer tests to ascertain that their capacities satisfied AAR (M-901E) specifications (36,000 ft-lb). Four different impact series were conducted with these gears (impact sets 3 through 6).

Figure 6. Car on impact test track

Figure 7. Hammer car on impact ramp

The first series was conducted with draft gears of model B at either end of the tank car (impact set #3). The Miner-supplied E gear was maintained on the striking end of the hammer car from the previous tests.

The second series used draft gears of model C at either end of the tank car (impact set #4). The Miner-supplied E gear was maintained on the hammer car.

The third series used model B draft gears at the struck end of the tank car and the striking end of the hammer car (impact set #5). One of the model C draft gears was used at the non-struck end of the tank car.

The fourth series used model C draft gears at the struck end of the tank car and the striking end of the hammer car (impact set #6). One of the model B draft gears was used at the non-struck end of the tank car. Table 1 illustrates the various configurations. This table also shows the impact series names used and the impact conditions referred to in this report.

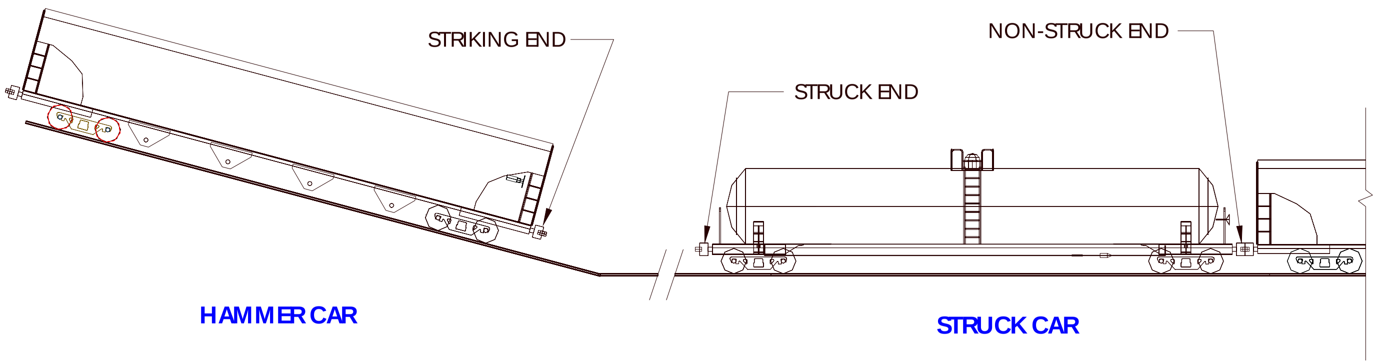
For each test series, the impact tests started with an impact velocity of about 2 mph. For impact sets 3 and 4, impacts were continued with increasing impact speed until the draft gears on the tank car bottomed out. For impact sets 5 and 6, impacts were continued until a coupler force of 950,000 lb was reached.

Table 1. Draft Gear Configurations

Impact Set No. and Name		Hammer Car Striking End	Tank Car Struck End	Tank Car Non-Struck End	Impact
1	Prime A	MS[1]	Model A[2]	Model A[2]	Prime Condition
2	G	MS[1]	New G	New G	
3	Average B	MS[1]	Model B[3]	Model B[3]	Average Condition
4	Average C	MS[1]	Model C[3]	Model C[3]	
5	Soft B	Model B[3]	Model B[3]	Model C[3]	Soft Condition
6	Soft C	Model C3	Model C[3]	Model B[3]	

Notes

1. MS–Miner supplied gears on hammer car, which were E gears in their prime.
2. Model A gears used in series 1 were supplied with the test car by GATX and were in prime condition.
3. Models B and C were used E gears from two different manufacturers. They were within M-901E specifications.



3.0 Test Results

The raw data collected during the impact tests was further processed using some data processing software routines that were developed in-house. These routines filter the data as needed and convert it into a useful and readable format, while also converting the measured strain data into stress data, including the calculation of principal stresses wherever rosettes were used. Zero balancing of the data is also done during this process.

To compare the relative performance of the draft gears tested, coupler force histories (at the impacting end) and stress histories at three critical locations on the car structure were studied. The locations studied were the tank head (shell), the head pad extension, and the head brace. The locations picked are also generic (i.e., the results at these locations would be applicable at corresponding locations on most tank car designs). Figures 8 and 9 marked the three locations as A, B, and C, respectively.

To better present the results from the six different cases tested, the results were condensed from the various cases into three different impact conditions:

1. Prime condition: The results from impact sets 1 and 2 (see Table 1) were combined into this condition. This condition represents the cases where the impact involved draft gears in prime condition at struck and striking ends. As reported in the previous work [1], the performances of the prime E gear was comparable to the performance of the G gears at most speeds. It was reasonable, therefore, to combine the results from the two test sets for this discussion. As noted in [1], the G gear had a slight advantage at higher (greater than 8 mph) speeds; the ramifications of which a subsequent section will discuss.

2. Average condition: The results from impact sets 3 and 4 (see Table 1) were combined into this condition. This condition represents the cases where the impact involved a soft draft gear at the struck end and a good draft gear at the striking end. A comparison of the specific performance differences between sets 3 and 4 is not very relevant to this project. However, the appendix presents these results.

3. Soft condition: The results from impact sets 5 and 6 (see Table 1) were combined into this condition. This condition represents the cases where the impact involved soft draft gears at the struck and striking ends. As in the previous case, comparison of the specific performance differences between these sets is not very relevant to this project. However, the appendix presents these results.

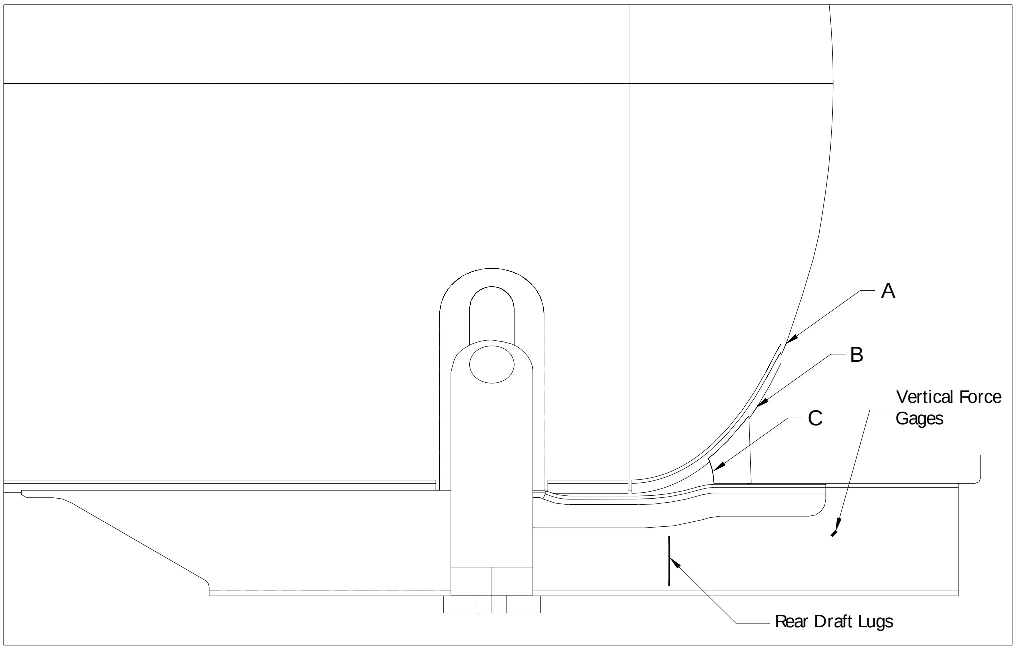


Figure 8. Critical locations–Elevation

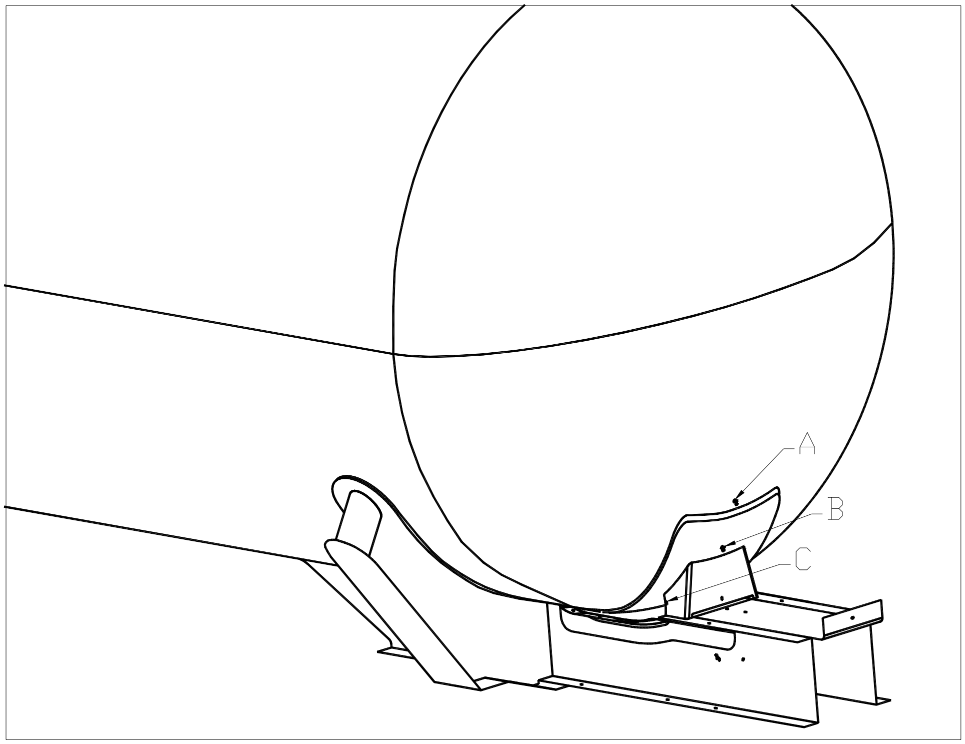


Figure 9. Critical locations–Isometric view

3.1 Coupler Force Comparisons

Figure 10 presents peak coupler force data from various impact runs. It is seen that the coupler forces using prime gears at impact speeds between 3 mph and 6 mph is slightly higher but significantly lower at higher speeds (where most chance for damage exists). For example, at an impact speed of 7 mph, the prime gears have a peak coupler force of 557,000 lb, whereas the average gears have a force of 705,000 lb (27 percent higher), and the soft gears have a peak coupler force of 959,000 lb (72 percent higher). It is also observed that, at speeds less than 3 mph (typical OTR run-in/run-out speeds), the prime gears are not any higher than the other gears. While tank cars must be switched at impact speeds lower than 4 mph, impact speeds of 8 mph or more are not uncommon. If such an impact were to occur at an average or soft condition, it is quite likely that the resulting coupler force would be over a million pounds or even over the 1.25 million pound design limit of tank cars, even under 263,000 lb GRL loading.

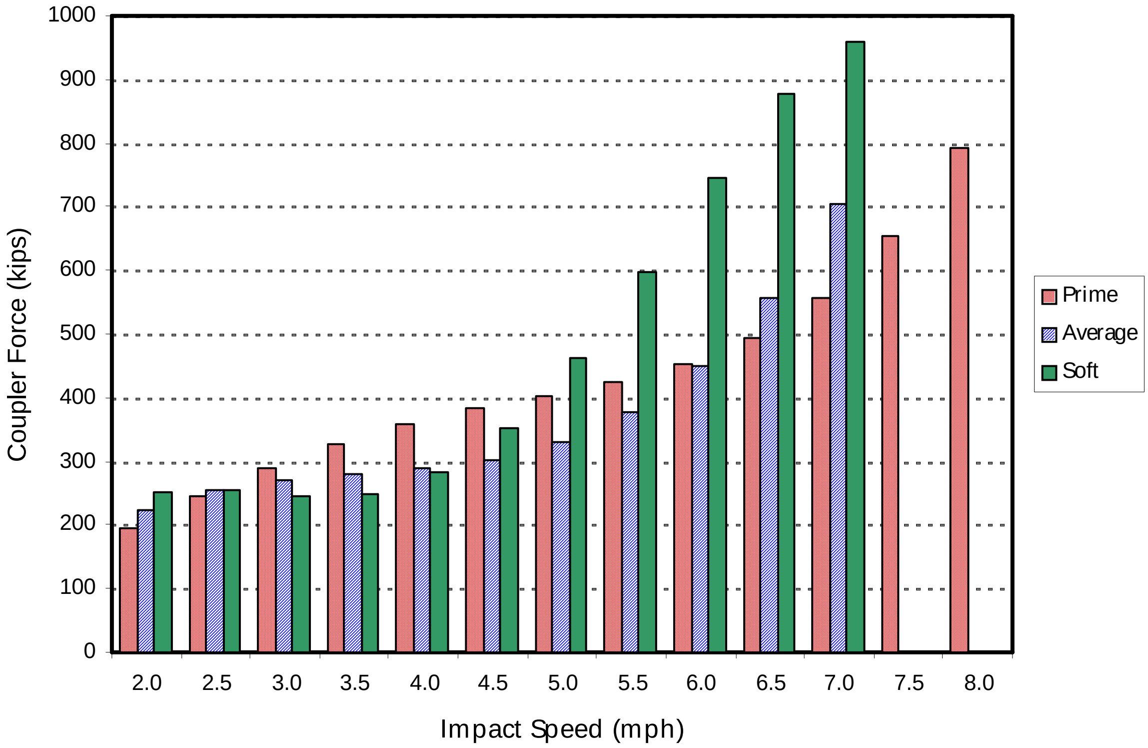


Figure 10. Peak coupler forces

3.2 Stresses at Critical Locations

An analysis of stresses at critical locations also emphasizes that high stresses result from using soft gears on tank cars, especially at higher speeds. Figure 11 displays the stresses on the tank shell (location A). It is seen that the soft gears produce the highest stress in the tank car at all speeds, with the differences increasing substantially at higher speeds. At speeds less than 6 mph, prime gears induce slightly higher stresses than the average gears. At higher impact speeds (where the likelihood of damage is the highest), however the prime gears induce considerably lower stresses.

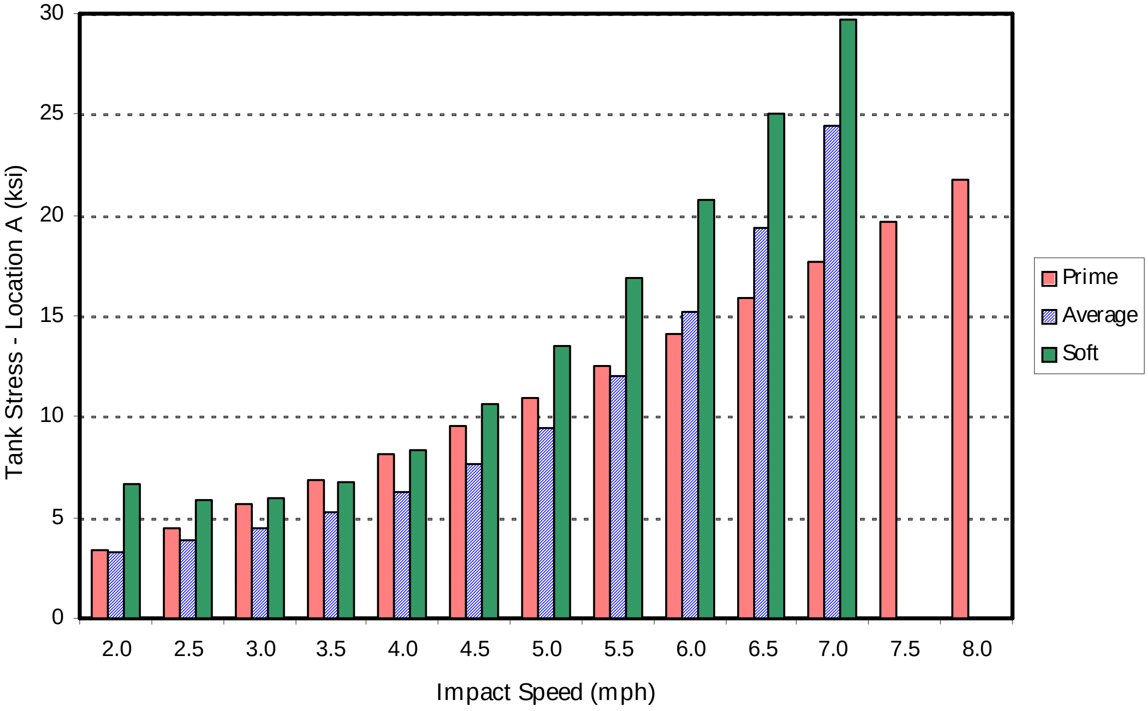


Figure 11. Principal stresses on the tank head (location A)

The stresses at the pad follow a similar trend (Figure 12). Soft gears provide the least protection at almost all speeds. Average gears provide good protection at low impact speeds, but the level of protection drops as impact speeds increase. The prime gears provide reasonable protection at low speeds and excellent protection as impact speeds increase.

Stresses in the head brace could only be compared between the average and soft gear sets (Figure 13) resulting from change in gage location and orientation after the first set of tests (with the prime gears). As seen, soft gears provide significantly less protection when compared to the average gears, just as observed at the other locations. Given these observations about coupler forces and stresses at the other locations, it would be reasonable to expect that the prime gears would have offered superior protection at this location also.

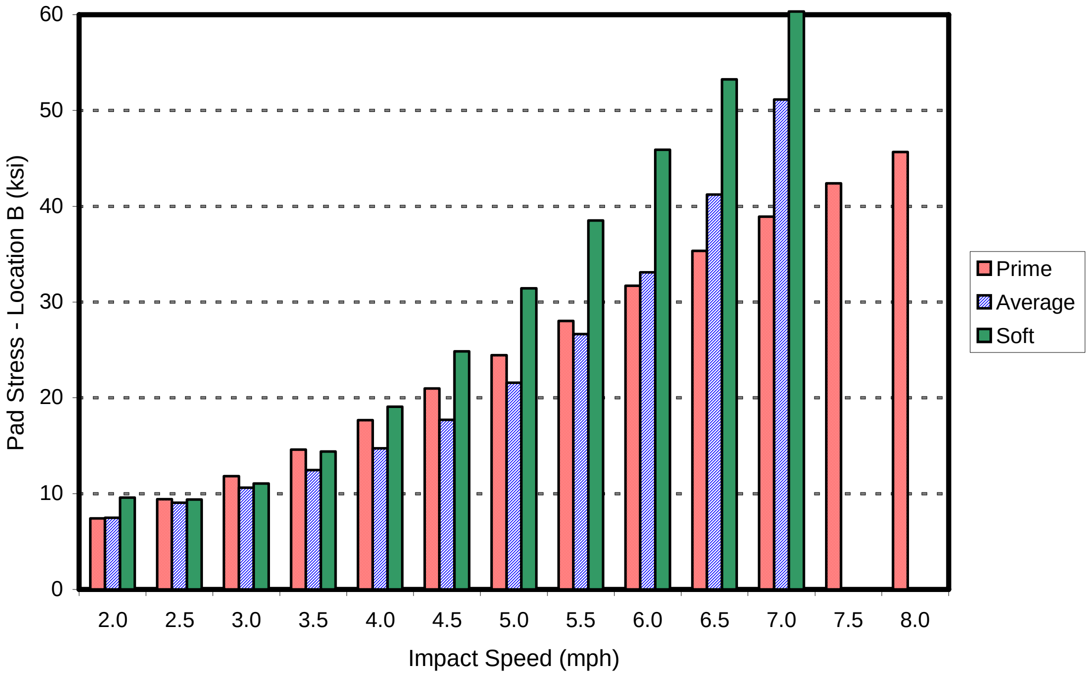


Figure 12. Principal stresses on the reinforcing pad (location B)

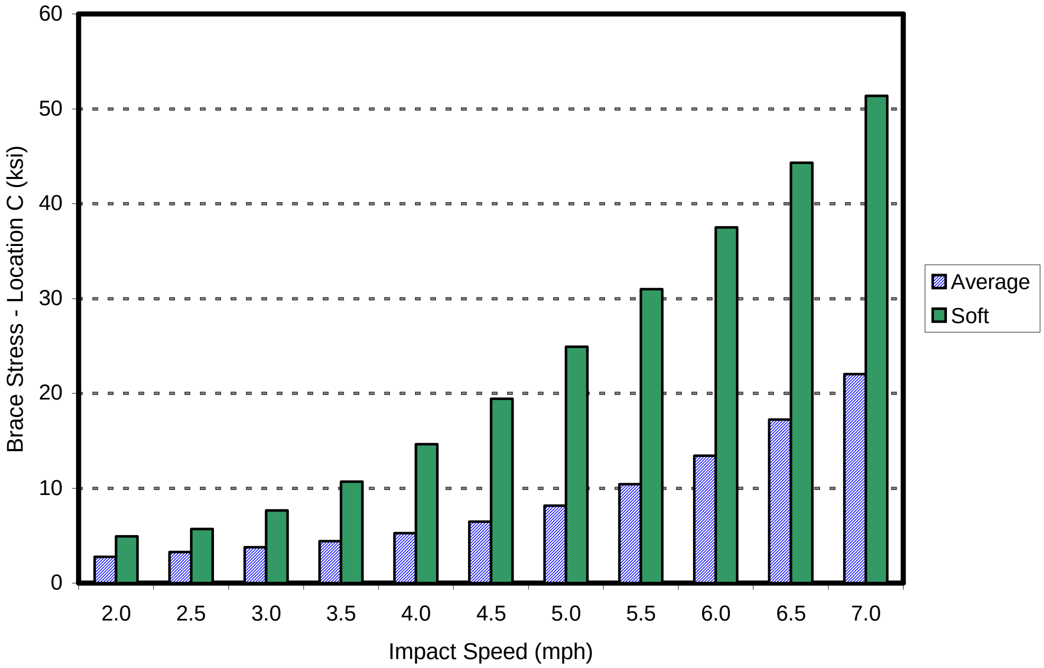


Figure 13. Principal stresses at the head brace (location C)

3.3 Summary

The impact test series evaluated the performance of different draft gear types and conditions as applied to tank cars with 263,000 lb GRL loading. In summary, from the test results, prime gears provide the best protection from overload impacts, with their advantage over the soft gears being significant at all impact speeds. Average gear setups provide reasonable protection at lower speeds, but their performance at higher speeds is lacking when compared to the prime gears. However, average gear setups do provide better protection than soft gear setups at all speeds.

Generally, tank car owners have no control over placement of their cars in a train and subsequently over the draft gear conditions of adjacent cars. While a given tank car may be equipped with a prime gear, it may impact against a car with soft gears while OTR. The average setup that was tested represents this scenario. In such scenarios, the protection benefits offered by the prime gears may not be fully realized. Even in such scenarios a prime gear will protect the car better, as evidenced by the performance of the average setup compared to the soft setup.

4.0 Impact Modeling for 286,000 lb GRL Loading

One of the main objectives of this project was to evaluate the effects of gear type and gear condition on the protection offered to tank cars in 286,000 lb GRL service. Such an evaluation for cars in 263,000 lb GRL service was done as part of the impact test series. Since a similar test program for 286,000 lb GRL cars was outside this project's scope, an alternate approach was chosen. A finite element model to simulate tank car impacts was developed for 263,000 lb GRL cars. This model was validated using data from the tests. Upon proper validation, the model was up rated to 286,000 lb GRL cars, and the resulting coupler forces were evaluated for various impact speeds.

4.1 Model Development

First, a detailed finite element model suitable for dynamic analysis was developed paying close attention to all the relevant details, including the complex shape of the stub sill tank car connection, the weldments between different components, the bolted draft lugs, and the center plate (Figure 14). The model also accounts for complete draft gear/coupler characteristics, coupler shank-to-striker contact parameters, detailed truck suspension characteristics (Figure 15), and the masses and stiffnesses of the hammer car and backup cars. The model uses LS-DYNA, an explicit finite element solver for modeling impact.

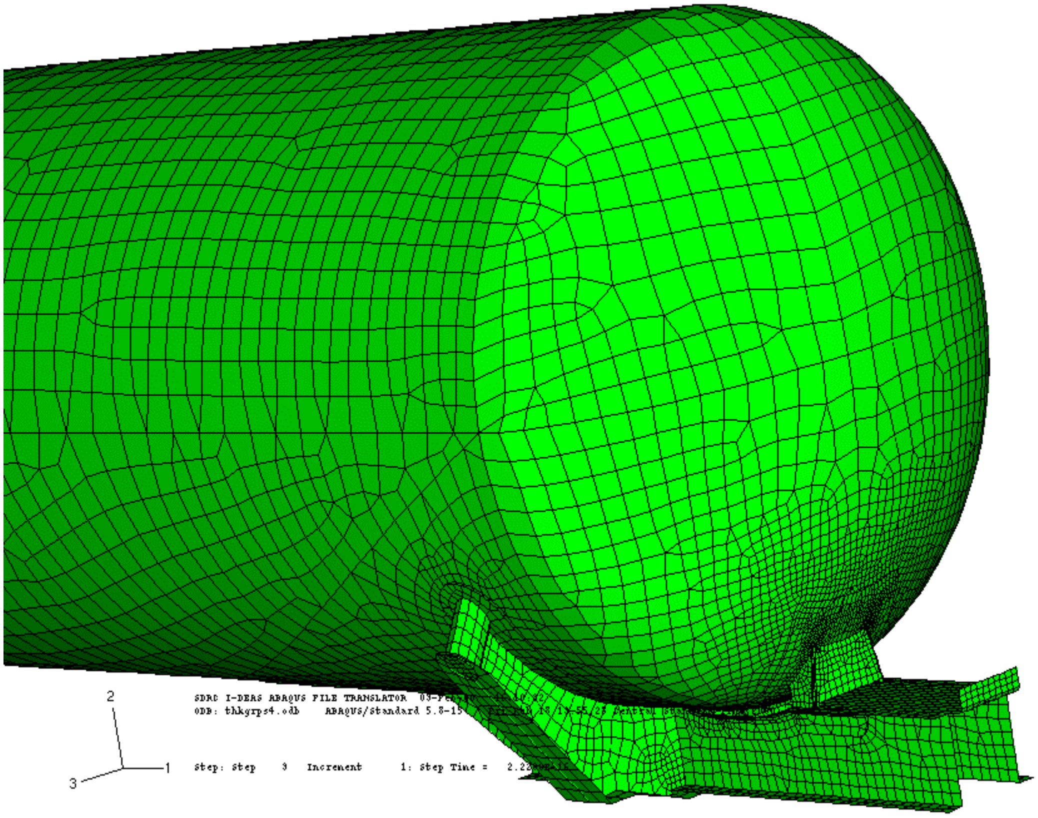


Figure 14. Finite element model of tank car structure

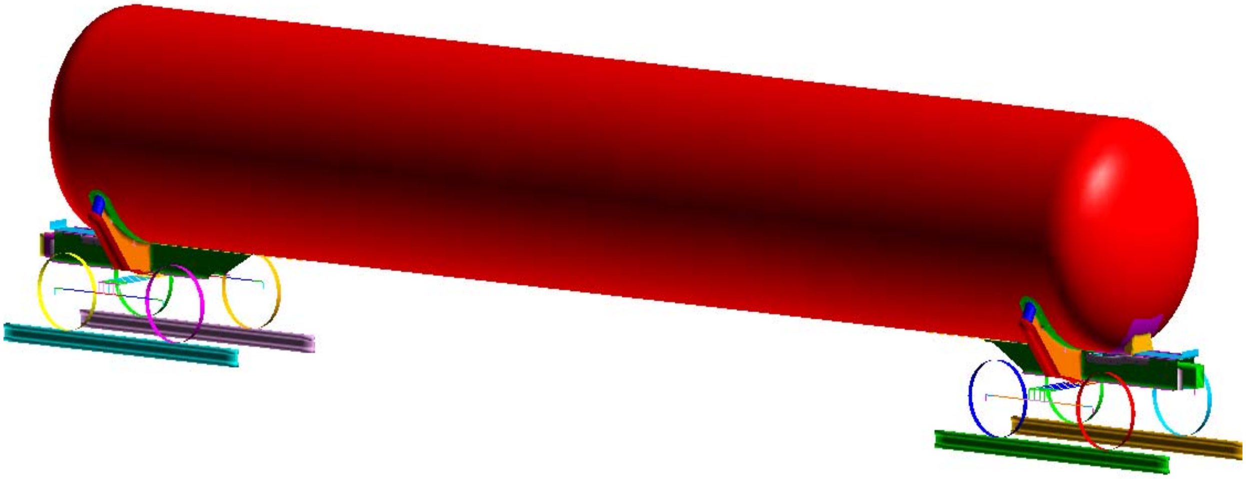


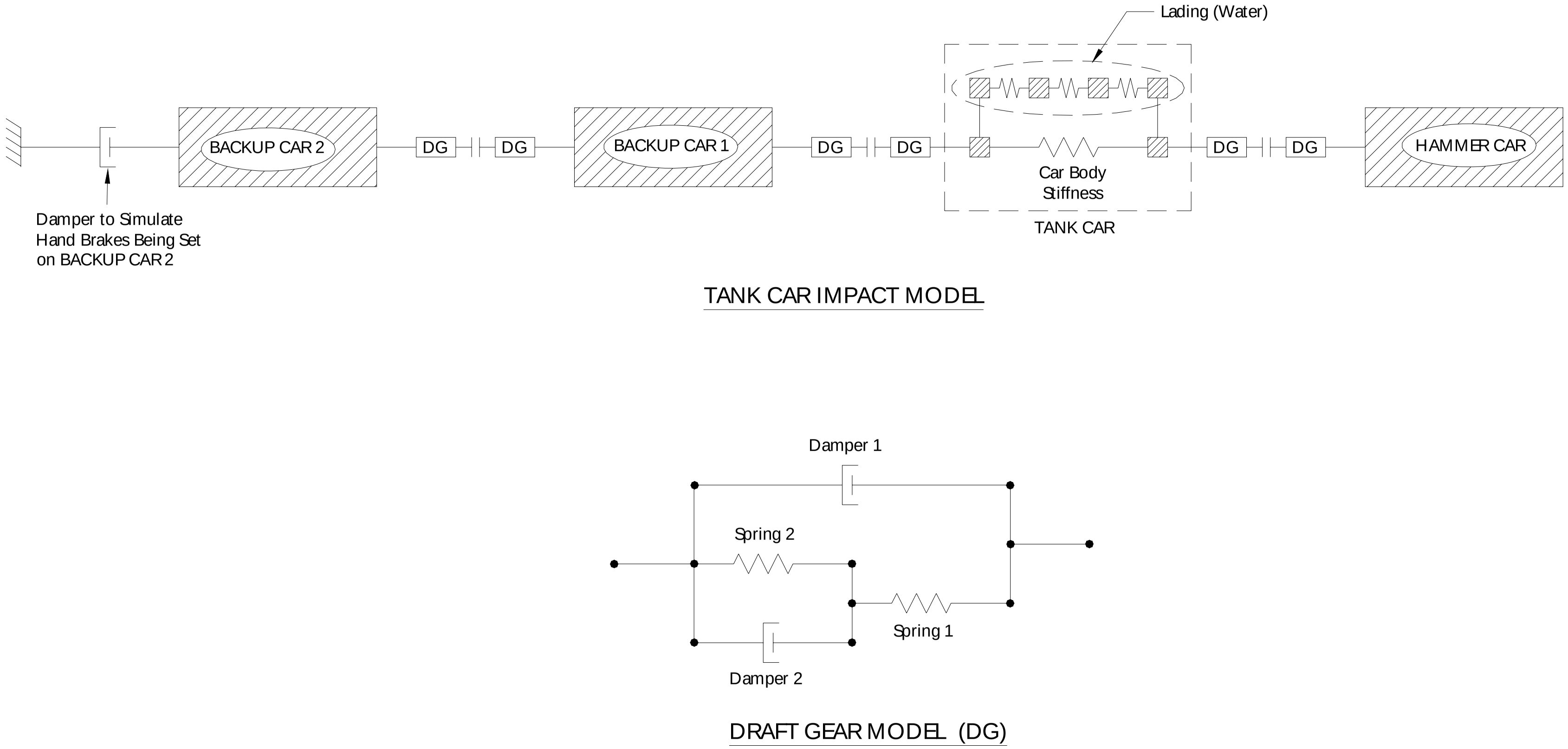
Figure 15. Finite element model of tank car including suspension

In addition, a coupler force model was developed which modeled the cars and their lading through a series of springs, dampers, and masses. The sloshing of water inside the tank car was modeled using a series of springs and masses. Draft gear characteristics at all the car interfaces was also modeled in detail (Figure 16). Non-linear characteristics for the various springs and dampers used (especially in the draft gear systems) was modeled to represent the behavior observed during the impact tests. This model was also created in LS-DYNA and used for most of the subsequent work.

4.2 Model Validation

The coupler force model was validated for the six different impact scenarios, as presented in Table 1. During the validation process, the characteristics of the model that pertained to car and lading (i.e., the car body stiffnesses and masses), were kept constant for all six scenarios. Draft gear characteristics, however, were tuned to best represent the performance observed during the tests. At the end of validation, six different models represented the six scenarios, with the models differing between each other only in draft gear characteristics. The draft gear characteristics for each scenario were kept constant for the range of impact speeds (2–8.5 mph) that the simulations were run.

Draft gear characteristics were modeled using appropriate springs and dampers. The main draft gear spring was modeled using appropriate loading and unloading curves that were derived from the coupler force versus draft gear travel plots from the impact tests. Figure 17 shows the derived loading/unloading curves for the M-901G gear. The characteristics of the dampers were picked to represent the observed behavior at all speeds.



TANK CAR IMPACT MODEL

DRAFT GEAR MODEL (DG)

Figure 16. Schematic of coupler force impact model

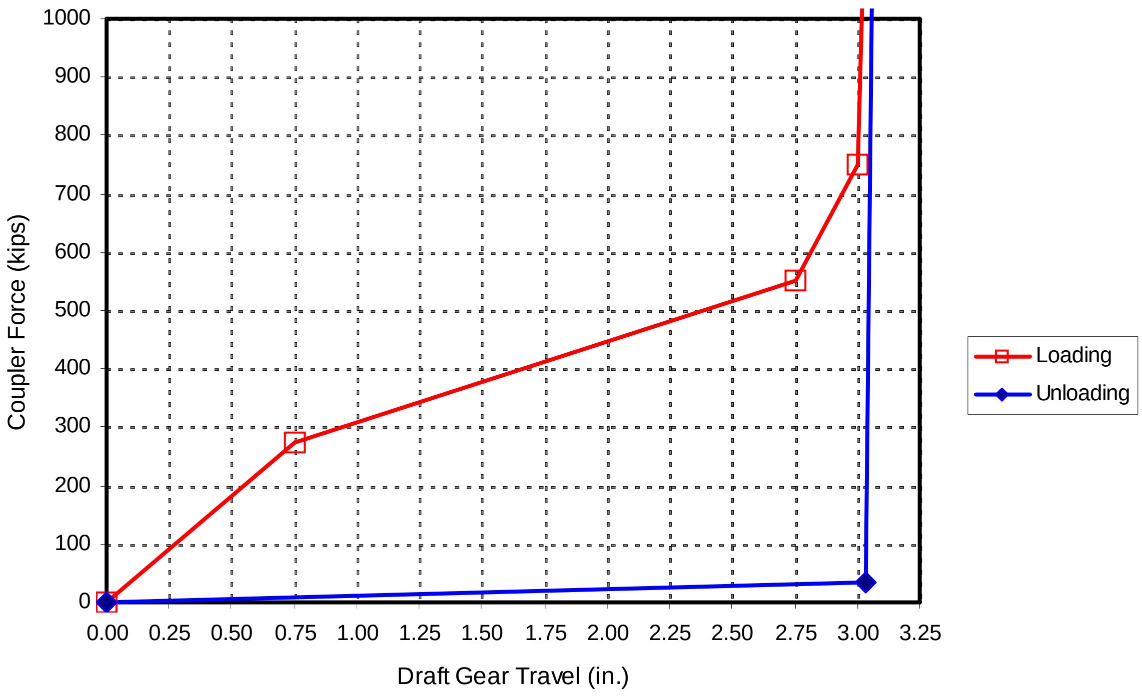


Figure 17. Loading and unloading characteristics for primary draft gear springs–G gear

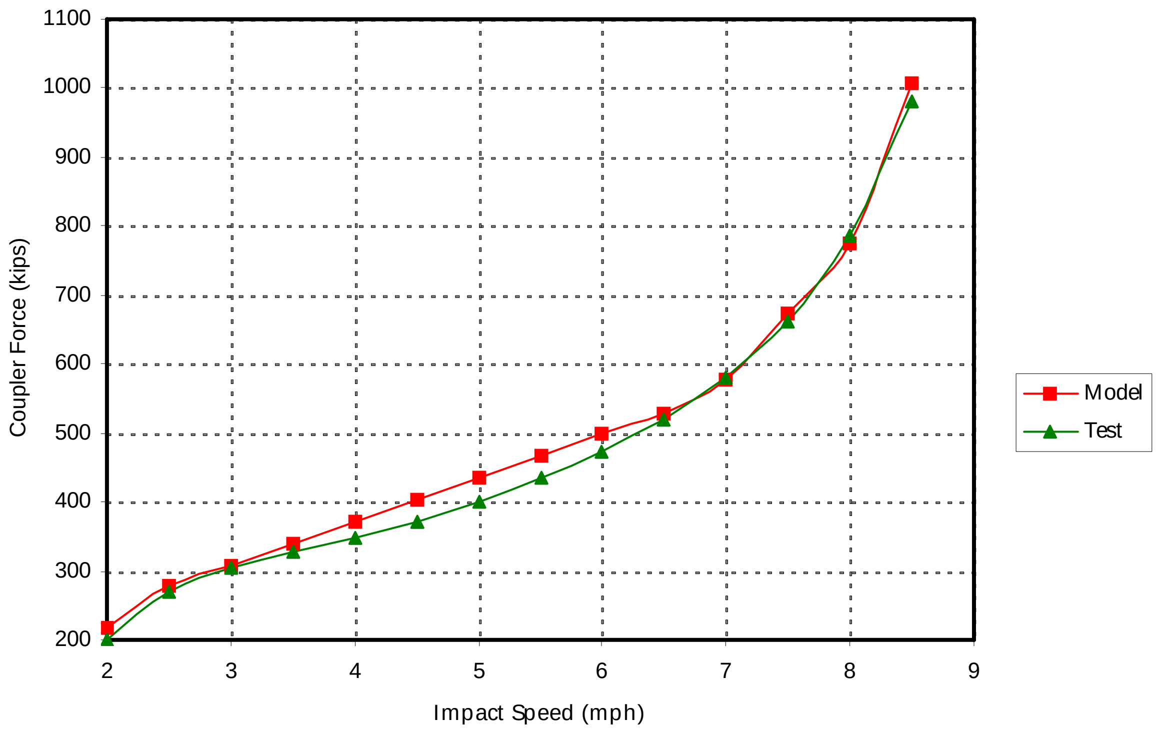


Figure 18. Comparison of model and test data–G gear

Figure 18 shows the measured data for scenario 2 (G gear–see Table 1) as compared to model data. As seen, the model tracks the measured data very well. Similar comparisons were seen for all five scenarios. The performance of draft gears is well represented by these models, especially at speeds greater than 4 mph. In some cases, however, the low speed performance was not duplicated exactly.

4.3 286,000 Lb GRL Tank Cars

The above-mentioned models that were validated using test data were then scaled to represent impact scenarios using 286,000 lb GRL cars. Essentially, all parameters were retained except the car masses which were scaled up. The simulations were then run for impact speeds between 2 and 9 mph for all six scenarios. Certain key observations may be made by studying the results:

1. Figure 19 shows the coupler forces resulting from various impact speeds for the three gear conditions. As seen in the previous chapter, prime gears continue to offer superior protection even in 286,000 lb GRL service, especially at speeds higher than 5 mph. Soft gears provide the least protection at most speeds. Average gears provide reasonable protection at lower speeds, but as speeds increase the levels of protection offered drop.

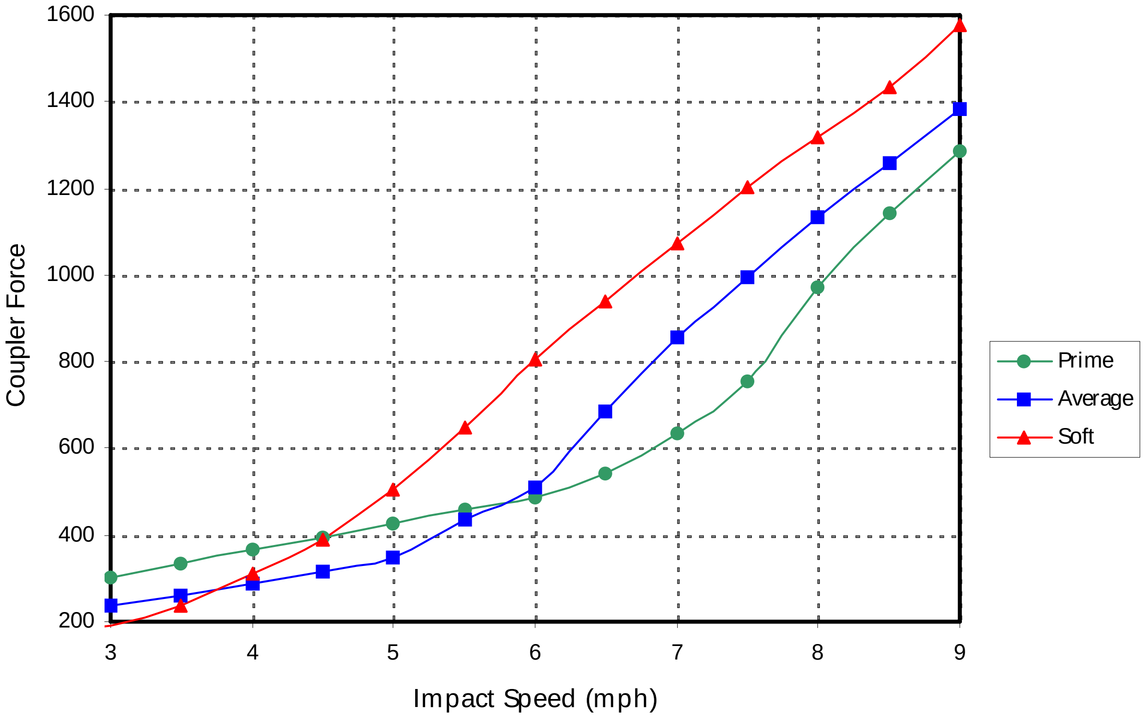


Figure 19. Coupler forces under 286,000 lb GRL loading

2. Figure 20 shows the performance of the two prime gears, the G gear and the E gear in prime condition (model A). It is seen that the G gears offer better performance at higher speeds (greater than 6.5 mph). At lower speeds, the E gear offers slightly better performance

3. Figures 21, 22 and 23 show the coupler forces for 263,000 lb GRL cars (model), 286,000 lb GRL cars (model) and the measured test data (for 263,000 lb GRL cars). It can be seen from these charts that, at lower speeds, no significant differences exist in coupler forces between 263,000 lb GRL cars and 286,000 lb GRL cars for a given set of draft gears. The lack of variation in coupler forces at these speeds indicates that the friction packs in the gears have sufficient capacity to absorb the additional impact energy arising from the increased mass. However, at a certain speed, 286,000 lb GRL cars start producing higher coupler forces. The impact speed at which this separation occurs varies from gear type to gear type and is one measure of the draft gears capacity to protect tank cars. The separation speed is highest for the prime gears (approximately 6.5 mph) and lower for the soft gears (about 4mph), once again underlining the superior protection offered by the prime gears. In other words, prime gears offer 286,000 lb GRL cars the same protection as 263,000 lb GRL cars over a larger range of speeds, as compared to the soft gears.

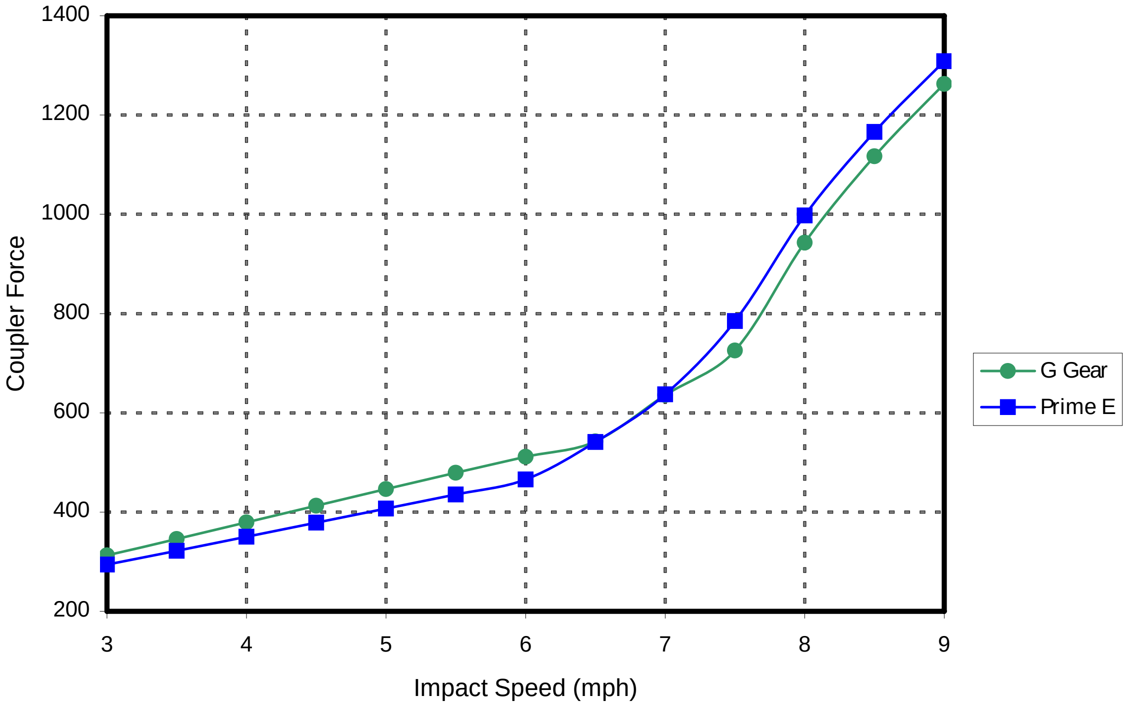


Figure 20. Comparison of coupler forces–Prime E gears versus G gears–286,000 lb GRL loading

4.4 Summary

As part of the modeling effort, validated finite element models that represent draft gear behavior in the six different scenarios were developed. The models were then scaled for simulating impact of 286,000 lb GRL cars. It was seen from these simulations that prime gears provided the best protection for tank cars, especially as speeds increased.

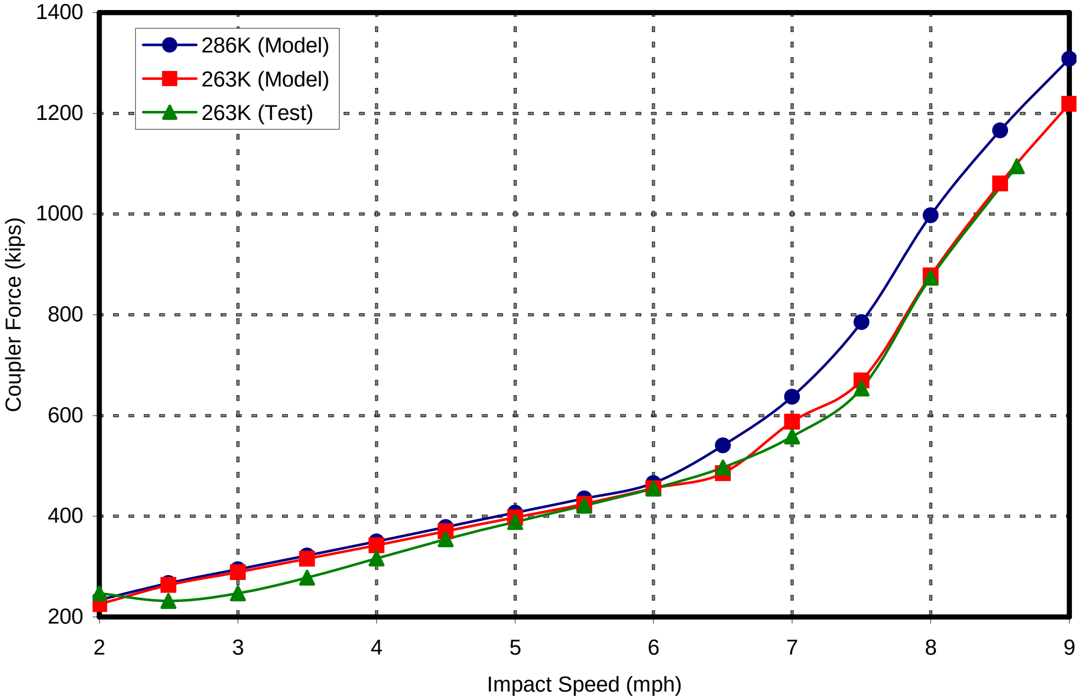


Figure 21a. Scenario 1–Prime A gear

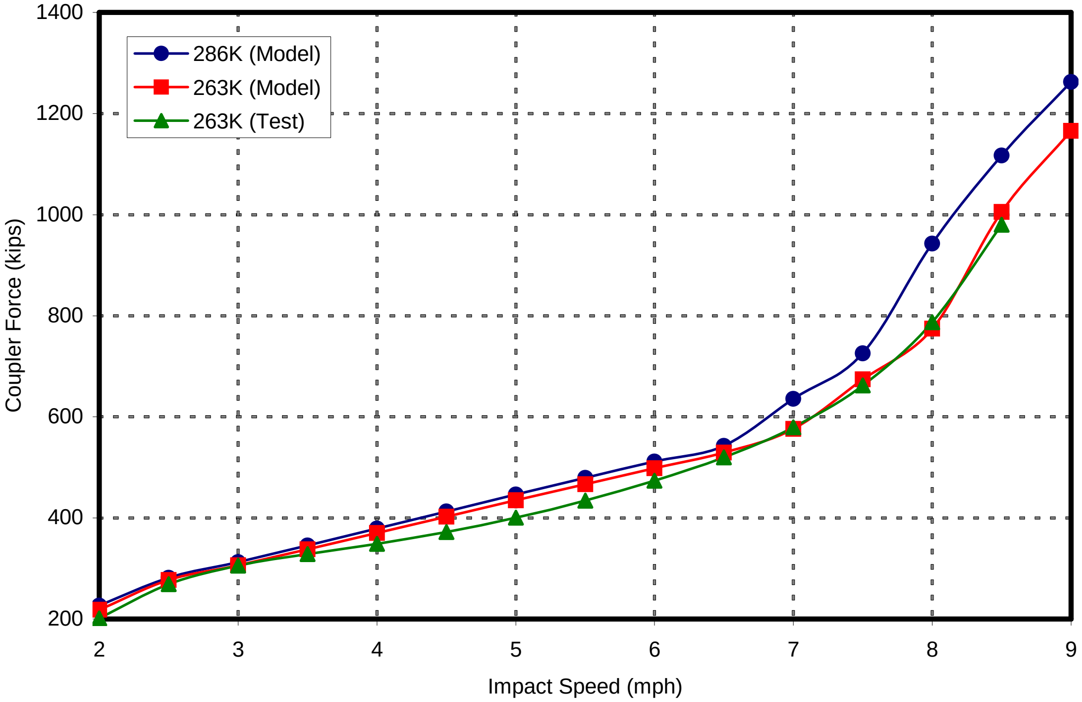


Figure 21b. Scenario 2–G gear

Figure 21. Coupler force comparisons–Prime gears

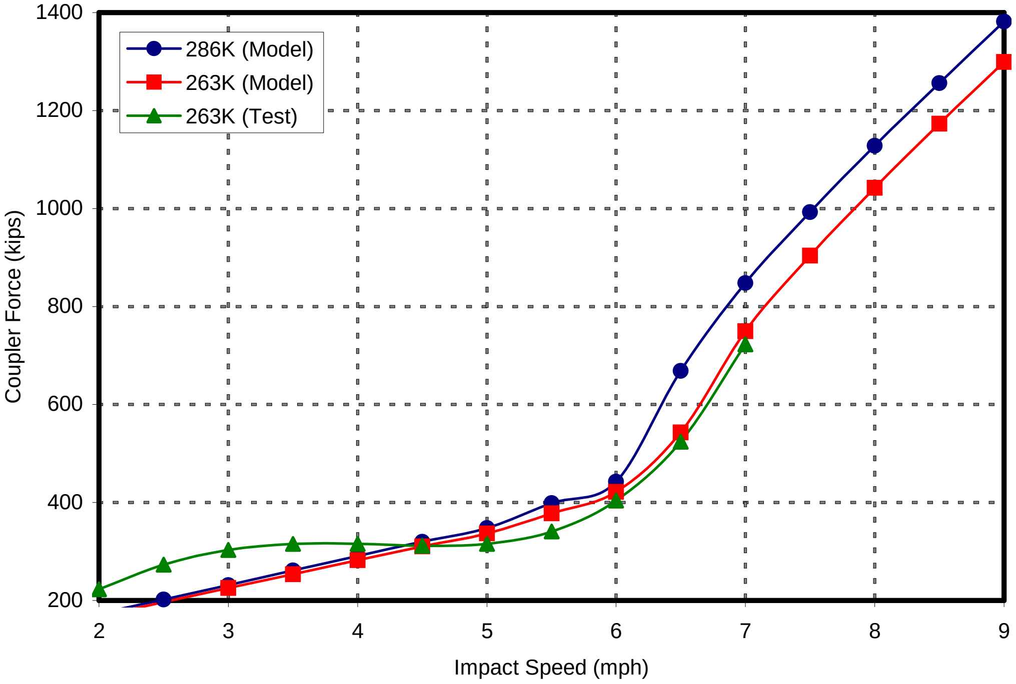


Figure 22a. Scenario 3–Average B gear

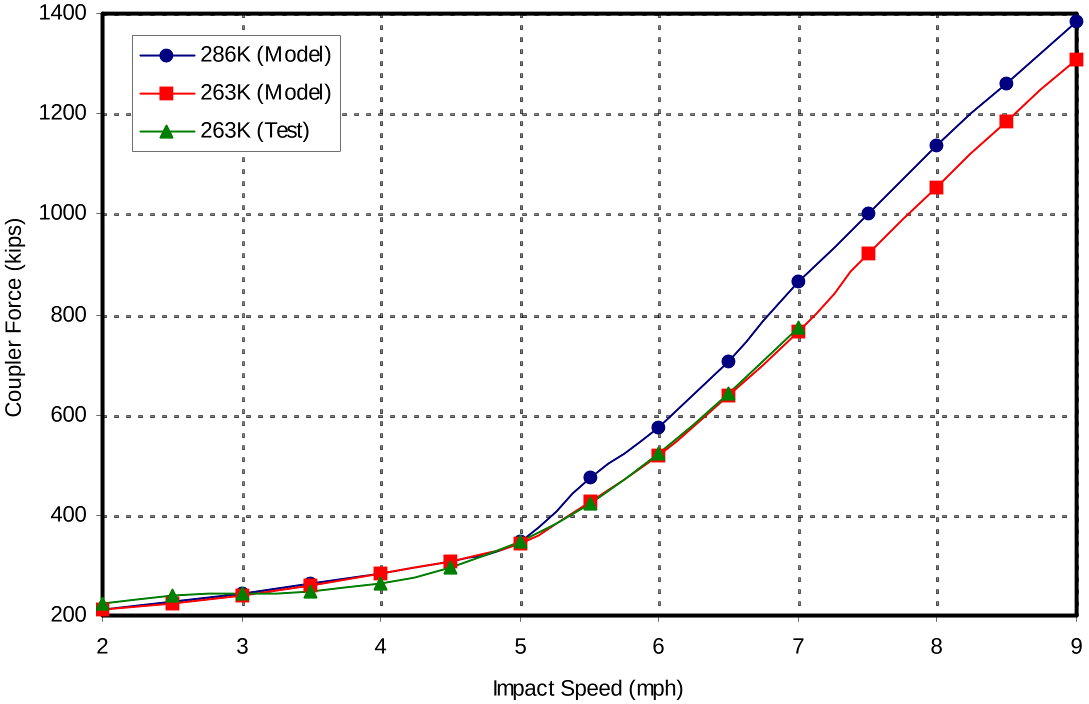


Figure 22b. Scenario 4–Average C gear

Figure 22. Coupler force comparisons–Average gears

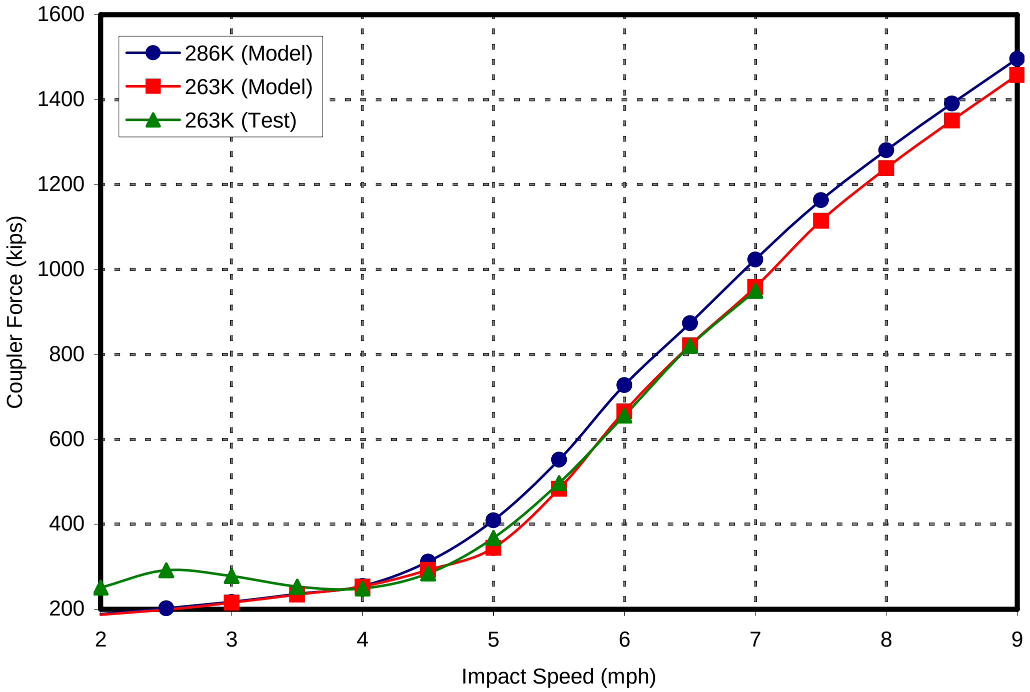


Figure 23a. Scenario 5–Soft B gear

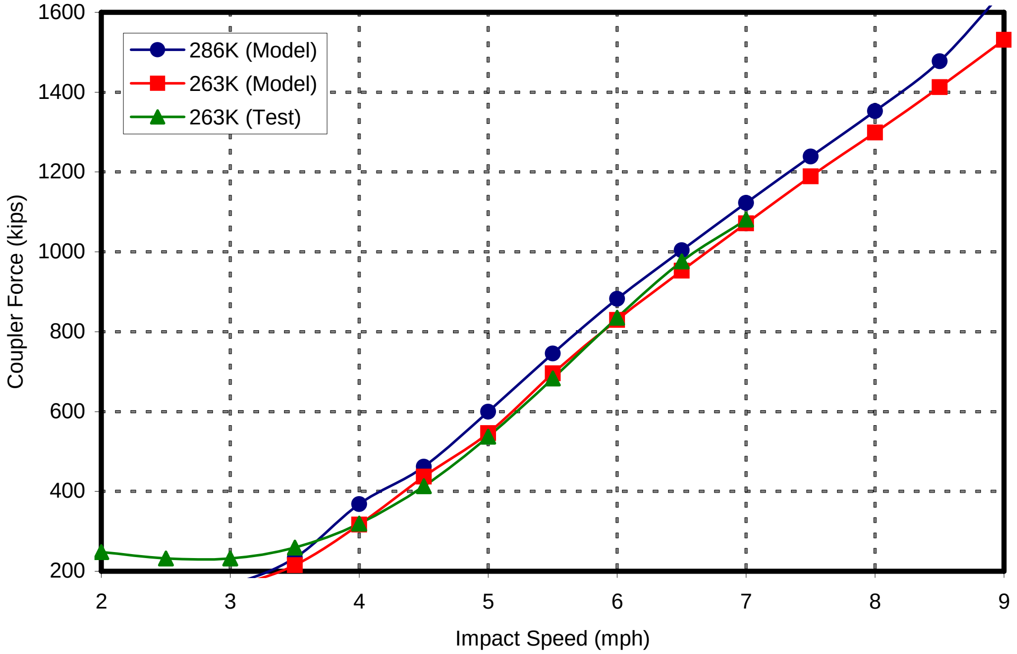


Figure 23b. Scenario 6–Soft C gear

Figure 23. Coupler force comparisons–Soft gears

5.0 Conclusions and Recommendations

As part of this project, a test tank car was instrumented, loaded to simulate 263,000 lb GRL service and tested on an impact ramp. Six different draft gear combinations were tested as part of this program. Subsequent to the testing, finite element models that simulated the impact behavior of tank cars was developed. These models were validated using the test data and used to simulate draft gear behavior under 286,000 lb GRL loading. The following conclusions were reached from the testing and simulations.

1. When coupler forces from the tests were compared, it was seen that the prime gears (M-901E gears in prime condition and M-901G gears) induced the lowest coupler forces, especially at higher impact speeds where the potential for damage is the highest. Impacts in the soft condition (draft gears at the struck and striking ends in used condition) produced the highest coupler forces at all relevant speeds.

2. A comparison of the stresses developed at locations A, B, and C indicated that the best protection was offered by the gears in prime condition. Soft gears produce the highest stress in the tank car at all speeds, with the differences increasing substantially at higher speeds. At speeds less than 6 mph, prime gears induce slightly higher stresses than the average gears. This small disadvantage at lower speeds, however, is not enough to offset the significant advantage offered by the prime gears at higher speeds. At these high impact speeds (where the likelihood of damage is the highest), the prime gears induce considerably lower stresses.

3. Simulations of 286,000 lb GRL service impacts using validated models indicated that prime gears would continue to offer superior protection, especially at higher speeds. At lower speeds, no significant differences existed in performance between 286,000 lb GRL service and 263,000 lb GRL service. The speed at which coupler forces started to increase under 286,000 lb GRL service was higher for the prime gears, indicating additional reserve capacity in the friction packs of the draft gears.

4. Comparisons of E gears in prime condition and G gears indicated that the E gears offered marginally better performance at lower speeds, while the G gears offered better performance as speeds increased.

5. It was seen that prime gears offer better protection under both 263,000 lb GRL service and 286,000 lb GRL service. In the prime conditions that were tested/simulated, however, draft gears at the struck and striking ends were in good condition. Generally, tank car owners have no control over placement of their cars in a train and subsequently over the draft gear conditions of adjacent cars. While a given tank car may be equipped with a prime gear, it may impact against a car with soft gears while OTR. The average setup that was tested represented this scenario. In such scenarios, the protection benefits offered by the prime gears may not be fully realized. However, even in such scenarios a prime gear will protect the car better, as evidenced by the performance of the average setup compared to the soft setup. In both 263,000 lb GRL and 286,000 lb GRL service, the average gear setup performed better than the soft gear setup at almost all speeds.

6. An overview of the test and simulation data indicates that different gears are at their best at different speed ranges. Given the large number of variables involved, it is a difficult task to design draft gears to perform well at all speeds. However, it would be a worthwhile effort to try and tune draft gear performance in the design process to maximize the protection offered by draft gears.

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ACRONYMS

AAR	Association of American Railroads
ASTM	American Society of Testing and Materials
FRA	Federal Railroad Administration
GRL	gross rail load
OTR	over-the-road
SA	Sharma & Associates, Inc.