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Investigation of Yard Impact Forces on 286,000 lb Tank Cars

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TP 13591E

Technical Report
March 2000

Rapport technique
CSTT-RVC-TR-039

UNLIMITED
UNCLASSIFIED

ILLIMITÉE
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Canada

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J. Coleman
General manager/
Gestionnaire principal

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13591E	2. Project No. 9579	3. Recipient's Catalogue No.
4. Title and Subtitle Investigation of Yard Impact Forces on 286,000 lb Tank Cars		5. Publication Date March 2000
		6. Performing Organization Document No.
7. Author(s) J.Z. Xu and J. Zhang		8. Transport Canada File No. ZCD2450-D-12-5
9. Performing Organization Name and Address National Research Council Canada Centre for Surface Transportation Technology Building U-89, Lester Road Ottawa, Ontario K1A 0R6		10. PWGSC File No.
		11. PWGSC or Transport Canada Contract No.
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final
		14. Project Officer Brian Marshall

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Cosponsored by Transport Dangerous Goods Directorate, Transport Canada

16. Abstract

This study examines the effect of 286,000 lb tank car gross weight on peak coupler impact force during coupling of strings of cars in a hump yard. The project was conducted using a proven Automatic Dynamic Analysis of Mechanical Systems (ADAMS) computer simulation model. The study considers various combinations of hammer and anvil cars, for four different draft gear types. It also compares the peak coupler impact forces to those for tank cars loaded to 263,000 lb.

The peak coupler impact force increases slightly less than the increase in gross weight. A draft gear with capability to absorb large amounts of energy has a significant effect in attenuating peak coupler impact force.

17. Key Words Tank car, ADAMS, railway impact, computer modeling	18. Distribution Statement Limited number of copies available from the Transportation Development Centre E-mail: *tdccdt@tc.gc.ca*

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages x, 32	23. Price Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13591E	2. N° de l'étude 9579	3. N° de catalogue du destinataire
4. Titre et sous-titre Investigation of Yard Impact Forces on 286,000 lb Tank Cars		5. Date de la publication Mars 2000
		6. N° de document de l'organisme exécutant
7. Auteur(s) J.Z. Xu et J. Zhang		8. N° de dossier - Transports Canada ZCD2450-D-12-5
9. Nom et adresse de l'organisme exécutant Conseil national de recherches du Canada Centre de technologie des transports de surface Édifice U-89, Lester Road Ottawa, Ontario K1A 0R6		10. N° de dossier - TPSGC
		11. N° de contrat - TPSGC ou Transports Canada
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final
		14. Agent de projet Brian Marshall

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Projet coparrainé par la Direction du transport des marchandises dangereuses, Transports Canada

16. Résumé

Cette étude examine la force d'impact maximale exercée sur un attelage par des wagons-citernes de 286 000 lb de masse brute lors du regroupement de wagons pour former des trains dans un triage à butte. L'étude, menée à l'aide du modèle de simulation par ordinateur ADAMS (pour *Automatic Dynamic Analysis of Mechanical Systems*), examine plusieurs combinaisons de «rames-béliers» et de «rames-enclumes», et quatre types d'appareils de traction. Elle compare en outre les forces d'impact maximales engendrées par les wagons-citernes de 286 000 lb avec celles produites par des wagons-citernes de 263 000 lb de masse brute.

Le taux d'accroissement de la force d'impact maximale exercée sur l'attelage demeure légèrement en deçà du taux d'accroissement de la masse brute des wagons-citernes. L'utilisation d'un appareil de traction doté d'une grande capacité d'amortissement atténue grandement la force d'impact sur l'attelage.

17. Mots clés Wagon-citerne, ADAMS, accostage de véhicules ferroviaires, modélisation par ordinateur	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires. Courriel : *tdccdt@tc.gc.ca*

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 32	Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

EXECUTIVE SUMMARY

This project was initiated in response to a request from Transport Canada to develop permit criteria with respect to tank cars weighing 286,000 lb. It builds on computer simulations of coupler impact forces on 263,000 lb tank cars conducted in 1998, in which an Automatic Dynamic Analysis of Mechanical Systems (ADAMS) model was developed and used to predict the impact forces of acid-filled tank cars.

The following draft gear were investigated:

- Crown SE2, which represents the upper bound of AAR Specification M901-E;
- TF-880, which represents the lower bound of AAR Specification M901-E;
- Crown TG, which represents AAR Specification M901-G; and
- Mark 50.

Transport Canada defined 68 simulation cases for this study. The work was conducted using the proven ADAMS simulation model for the impact at coupling, for moving (hammer) tank cars and stationary (anvil) cars. The work also examined the effects of four different types of draft gear on the coupler impact forces. The cases considered each used a particular combination of hammer and anvil cars, car gross weight, and draft gear. Simulation runs for each case were made at seven impact speeds, from 3.5 to 9.5 mph. Each car was loaded to 98 percent of its volumetric capacity with a fluid.

The performance characteristics of the draft gear were obtained from drop hammer tests.

This work shows that the same trends found in previous studies regarding the effects of numbers of hammer and anvil cars apply for all of the draft gear considered here.

The peak coupler impact force increases consistently with an increase in tank car gross weight when the same draft gear is used. The average increase in peak coupler impact force over all speeds and combinations of hammer and anvil cars is 3.9 percent. This is less than the 8.7 percent increase in tank car gross weight of 286,000 lb over 263,000 lb. The greatest increase in peak coupler impact force reached 8.8 percent for moderate impact speeds, in the range 5 to 7 mph. It tended to be below average at impact speeds below and above this range.

The Crown SE2, Crown TG, and Mark 50 draft gear provided essentially the same energy absorption capability over the range of impact speeds. The TF-880 draft gear provided similar capability for speeds up to about 5 mph, but at higher speeds it clearly provided much better capability to absorb energy. It reduced the coupler impact force at the highest impact speeds by about 20 percent from the values for the other three draft gear.

A draft gear having properties equivalent to or approaching those of the TF-880 used in this work more than compensates for the effect of an increase in gross weight from 263,000 lb to 286,000 lb on coupler impact forces. It should provide an additional margin of safety

against brittle fracture, which may occur when these cars experience a high-speed coupling.

The draft gear characteristics used in this study are idealized, and are biased toward those required for higher impact speeds. The same characteristic is used for all speeds. This assumption is likely to produce reasonable estimates for coupler impact forces at higher speeds, but may slightly underestimate them at lower speeds. The relationship between the draft gear characteristic obtained from a drop hammer test and the response of a draft gear during coupling is still not well understood. The drop hammer produces a nominal draft gear characteristic. Draft gear in service will have some range of characteristics. How that range of draft gear characteristics affects coupler impact force is also not well understood. These factors merit further investigation.

SOMMAIRE

Cette étude faisait suite à une demande de Transports Canada de mettre au point des critères pour l'homologation de wagons-citernes de 286 000 lb de masse brute. Elle s'appuyait sur une autre étude du même genre menée en 1998 sur des wagons-citernes de 263 000 lb. Cette dernière étude a mis au point un modèle d'analyse dynamique de systèmes mécaniques (ADAMS, pour *Automatic Dynamic Analysis of Mechanical Systems*), utilisé pour prédire les forces d'impact de wagons-citernes remplis de solution acide.

Les appareils de traction suivants ont été étudiés :

- Crown SE2, représentant la limite supérieure de la spécification M901-E de l'AAR;
- TF-880, représentant la limite inférieure de la spécification M901-E de l'AAR;
- Crown TG, représentant la spécification M901-G de l'AAR;
- Mark 50.

Transports Canada avait défini 68 configurations à soumettre à la simulation. Les travaux ont été réalisés à l'aide du modèle ADAMS, déjà éprouvé pour l'étude du comportement au choc de rames-béliers et de rames-enclumes lors de la formation de trains. Les chercheurs ont aussi examiné l'effet de quatre types d'appareils de traction sur les forces d'impact sollicitant l'attelage. À chaque simulation, on faisait varier la combinaison rame-bélier et rame-enclume, la masse des wagons et le type d'appareil de traction. Chaque combinaison a été soumise à des essais simulant sept vitesses d'accostage, variant de 3,5 à 9,5 mi/h. Chaque wagon était rempli de liquide à 98 p. cent de sa capacité volumétrique.

Les caractéristiques de performance des appareils de traction ont été déterminées par des essais de résistance au choc au mouton.

L'étude a confirmé les tendances révélées par les travaux antérieurs concernant l'effet du nombre de wagons constitutifs des rames-béliers et des rames-enclumes, pour tous les appareils de traction étudiés ici.

La force d'impact maximale exercée sur l'attelage augmente comme on peut s'y attendre avec l'accroissement de la masse brute des wagons-citernes, pour un même appareil de traction. L'accroissement moyen de cette force d'impact, pour toutes les vitesses d'accostage et toutes les combinaisons de rames-béliers et rames-enclumes, est de 3,9 p. cent. C'est moins que les 8,7 p. cent d'accroissement de la masse brute des wagons-citernes, de 263 000 lb à 286 000 lb. Le taux d'accroissement le plus notable de la force d'impact (8,8 p. cent) a été enregistré aux vitesses d'accostage modérées, de 5 à 7 mi/h. En deçà et au delà de cette plage de vitesses, l'accroissement de la force d'impact était généralement inférieur à la moyenne.

Les appareils de traction Crown SE2, Crown TG et Mark 50 présentent essentiellement la même capacité d'amortissement à toutes les vitesses d'accostage étudiées. L'appareil TF-880 ne se démarquait pas des autres jusqu'à environ 5 mi/h, mais aux vitesses plus

élevées, sa capacité d'amortissement était nettement supérieure. En effet, aux vitesses supérieures, les forces d'impact sur l'attelage enregistrées avec le TF-880 étaient d'environ 20 p. cent inférieures à celles obtenues avec les trois autres appareils de traction.

Un appareil de traction possédant des propriétés équivalentes ou quasi équivalentes à celles du TF-880 utilisé pour les présents essais ferait plus que compenser l'effet de l'accroissement de la masse brute des wagons-citernes, de 263 000 lb à 286 000 lb, sur les forces d'impact exercées sur l'attelage. Ce type d'appareil devrait offrir une marge de sécurité supplémentaire contre la rupture fragile susceptible de survenir lors d'accostages à grande vitesse.

Les caractéristiques de performance attribuées aux appareils de traction aux fins des simulations étaient idéalisées : elles correspondaient généralement aux caractéristiques nécessaires pour résister aux vitesses d'accostage les plus grandes. Mais les mêmes valeurs ont été utilisées pour toutes les vitesses d'accostage. Cette façon de faire permet d'estimer de façon assez réaliste la force d'impact aux vitesses élevées, mais sous-estime quelque peu cette force, à faible vitesse. Le rapport entre les caractéristiques de performance de l'appareil de traction à l'essai de résistance au choc au mouton et le comportement du même appareil lors d'un accostage n'a pas été clairement établi. L'essai au mouton donne une valeur nominale de résistance au choc. En service, l'appareil de traction affichera différentes valeurs à l'intérieur d'une plage. Quel est le rapport entre cette plage de valeurs et la force d'impact à l'accostage? Voilà des thèmes auxquels devraient être consacrées d'autres recherches.

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1. INTRODUCTION

Canada’s Transportation of Dangerous Goods Regulations currently limit the gross weight of rail tank cars carrying dangerous goods to 263,000 lb. However, Transport Canada has received requests to transport dangerous goods in tank cars with a gross weight up to 286,000 lb. Transport Canada's over-riding concern in addressing this issue is safety. A number of accidents and incidents involving spillage of dangerous goods in the past decade have been linked to the forces during the impact that follows humping or flat-switching while coupling tank cars in railway yards. The accidents and incidents of concern involve unexpected cracking of the tank car shell in the region of the stub-sill.

A typical tank car consists of a tank structure, with a stub sill at each end that connects to a truck. Each stub sill contains a pocket that accommodates a draft gear. This connects to a coupler, and cushions the car against impact forces. The draft gear provides longitudinal cushioning over a stroke of about 3 in, and theoretically limits the peak buff (compression) coupling force to about 500,000 lb. A typical friction-type draft gear can absorb 50,000 ft-lb of energy before it bottoms. When the kinetic energy to be absorbed exceeds the combined capacity of the draft gear at the point of impact, the draft gear bottoms and the buff force rises rapidly due to car inertial mass and longitudinal structural stiffness. This force is transmitted through the coupler yokes, draft gear and stub sills into each tank car structure, and causes stresses in these components.

Failures, and the discovery of cracks in the stub sill area of many tank cars, resulted in an intensive inspection and repair program throughout Canada and the United States [1]. The Transportation Safety Board of Canada has suggested that some tank car stub sill and tank fractures may have resulted from high impact forces that occurred when humping tank cars made of steel with poor low-temperature impact toughness [1]. Transport Canada initially contracted the Centre for Surface Transportation Technology of the National Research Council Canada (NRC/CSTT) to identify the service load environment that can lead to crack initiation and subsequent failure in the stub sill and tank connection. NRC/CSTT developed a finite element model of the tank car that emphasized the stub sill-to-tank connection, and identified critically stressed areas. Preliminary results from this stress analysis were then used to plan full-scale tests that consisted of applying various quasi-static coupler loads and twisting moments. Good correlation was found between finite element analysis and experimental strain measurements, and several critically stressed area were identified, together with two distinct load paths within the tank car structure [2]. A series of dynamic impact tests were conducted, and the impact force at coupling was measured. The project concluded that stresses should remain below the design criteria for single car impacts up to 10 mi/h.

Transport Canada extended this work in 1996 by asking NRC/CSTT to examine extreme twisting that might occur during a derailment. This included further finite element analysis, and full-scale tests, including an actual derailment. This work revealed that a derailment that occurs at speed during revenue service can involve much more twisting than a simple derailment at low speed in a rail yard. Significant vertical forces are transmitted through shelf-type couplers, that may induce stresses that can produce cracks [3]. These cracks may propagate immediately in an unstable manner, or later if the car is subject to an extreme impact during coupling.

In further work for Transport Canada, NRC/CSTT developed and validated a multi-body dynamic model in the ADAMS environment to predict the coupler impact force during coupling of tank cars in a railway hump yard. The ADAMS tank car model showed good correlation for a series of baseline impact tests, where a single moving (hammer) tank car impacted four stationary (anvil) tank cars. Additional work demonstrated the utility of the model for examining the effects of impact speed, tank fill level, payload weight and different numbers of hammer and anvil tank cars [4].

NRC/CSTT collected a much larger set of yard impact data in 1997, for different numbers of water-filled hammer and anvil tank cars weighing 169,000 lb fully loaded, for various impact speeds. An instrumented car at different positions in the impact sequence measured the coupler forces [5], which were correlated with predictions from the ADAMS dynamic model [6]. The ADAMS model was then used to predict impact forces for acid-filled tank cars weighing 263,000 lb.

The various tests and modeling studies have established a broad understanding of the impact forces that occur in multi-car impacts. They have shown that the most significant factors are the number, mass and speed of the hammer cars at the time of coupling; the number and mass of the anvil cars; and the characteristics of the draft gear. The results have helped Transport Canada develop a clear language regulation for the allowable speed for coupling tank cars, the number of cars that may be coupled at one time, and criteria for inspection after a high-speed coupling.

Railways have now requested that tank cars carrying dangerous goods be allowed to operate at a gross weight of 286,000 lb. Transport Canada contracted NRC/CSTT to conduct a simulation study using the NRC/CSTT ADAMS model with tank cars at the higher gross weight. Transport Canada provided data for three draft gear, which allowed an opportunity to assess draft gear capacity on the effect of the higher weight. Runs were also made using the same Mark 50 draft gear and 263,000 lb gross weight as previously used, to allow correlation with previous work. In addition, runs were made for some mixed conditions, with some tank cars at a gross weight of 286,000 lb, and others at a gross weight of 263,000 lb.

This report outlines the details and results of the simulation requirement identified above. It includes a brief description of the simulation model, the draft gear parameters provided by Transport Canada, a list of ADAMS model simulation cases, and the results.

2. SCOPE OF COMPUTER SIMULATION STUDY

2.1 The ADAMS Model

The ADAMS tank car model represents longitudinal and vertical motions of the tank, bolster and truck frames, and pitch of the tank. Lateral, roll and yaw motions are not included, as they are not significant in the impact that occurs when coupling in a yard. The model consists of various masses, linear and non-linear springs, dampers, and friction elements. It accounts for draft gear non-linear performance characteristics, rigid car body motions, friction between the truck side frame and bolster, possible separation of the truck center plate from the bolster, vertical friction between couplers, non-linearity in the truck suspension, and track elasticity. The model also represents fluid slosh in the tank, with a simple quasi-static model for liquid centre of gravity motion and damping, both of which depend on tank fill level. The ADAMS tank car model showed good correlation for a series of baseline impact tests, where a single moving (hammer) tank car impacted four stationary (anvil) tank cars. Additional work demonstrated the utility of the model for examining the effects of impact speed, tank fill level, payload weight and different numbers of hammer and anvil tank cars [4].

2.2 Draft Gear

The following four draft gear are used for this work:

- Crown SE2;
- TF-880;
- Crown TG; and
- Mark 50.

The Crown SE2 represents draft gear near the upper bound of Association of American Railroads (AAR) specification M901-E [7]. The TF-880 represents draft gear near the lower bound of AAR specification M901-E [7]. The Crown TG represents draft gear near the upper bound for AAR specification M901-G [8]. The Mark 50 draft gear has been used exclusively in previous studies conducted by NRC/CSTT, and it is used here to provide a link to those studies.

Transport Canada provided force-displacement measurements from a series of drop hammer tests for the first three of these draft gear, for this work. NRC/CSTT already had a force-displacement characteristic for the Mark 50 draft gear. NRC/CSTT used the force-displacement from the highest drop for each of the three new draft gear for this work. This represents the most severe condition. The force-displacement characteristic for each of the four draft gear are shown in Figures 1 through 4.

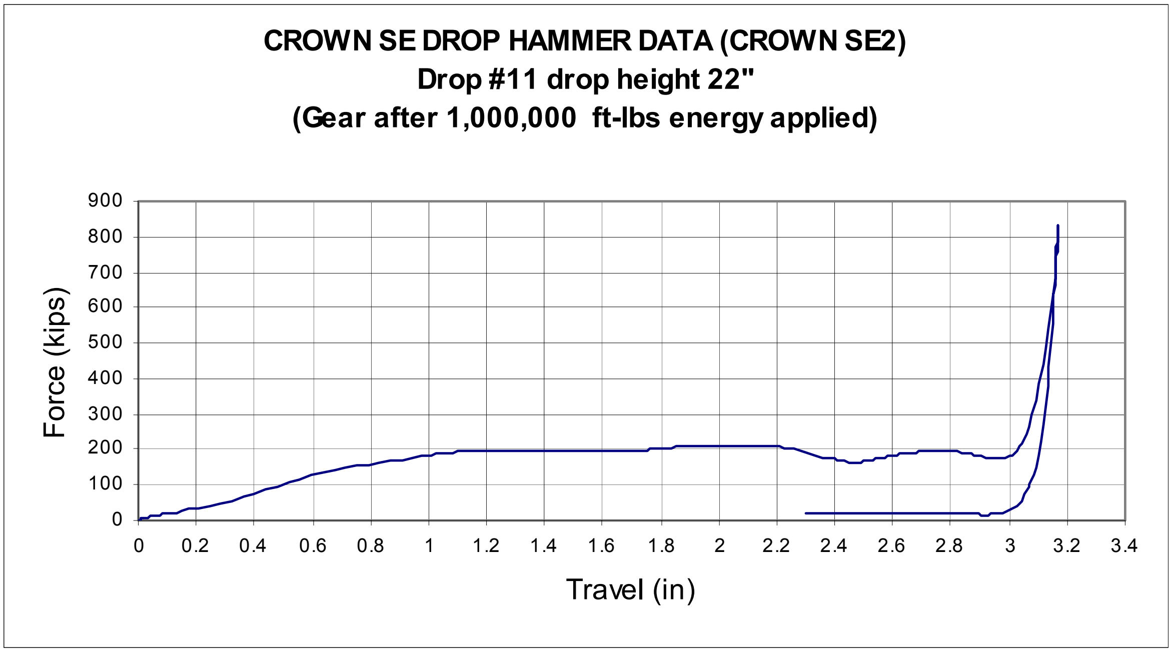


Figure 1. CROWN SE2 draft gear performance

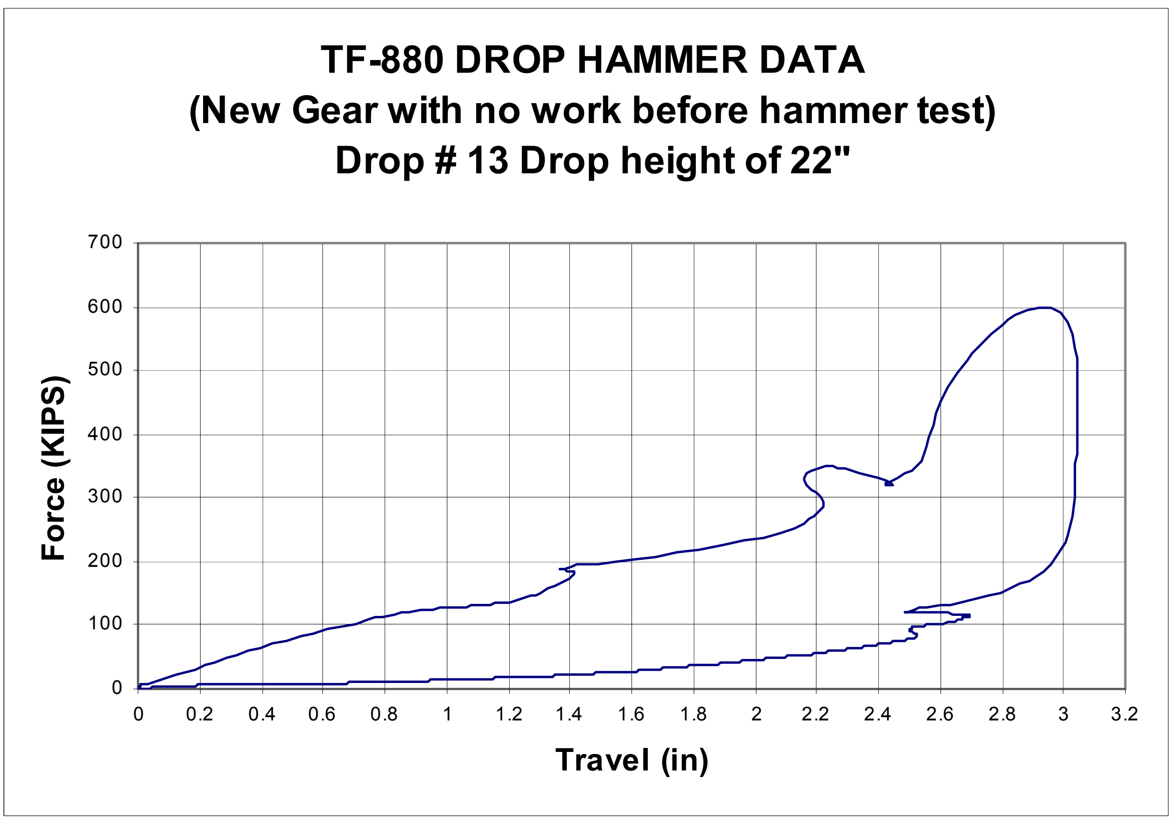


Figure 2. TF-880 draft gear performance

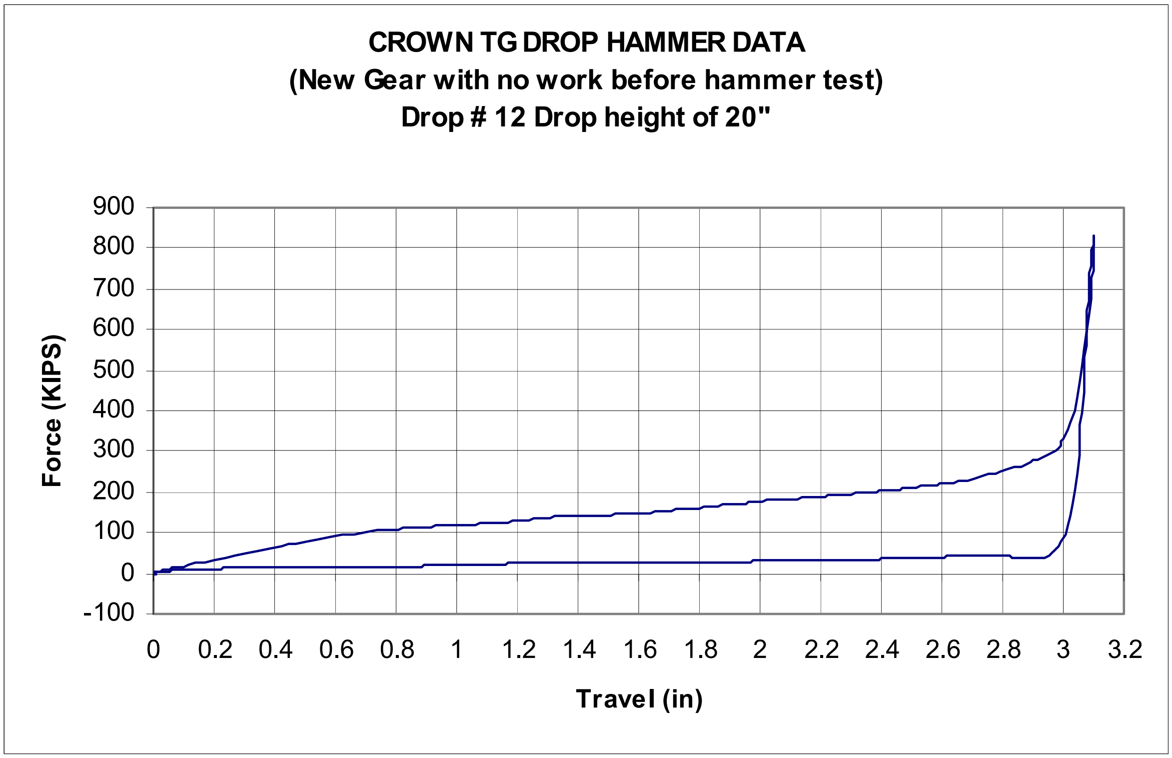


Figure 3. Crown TG draft gear performance

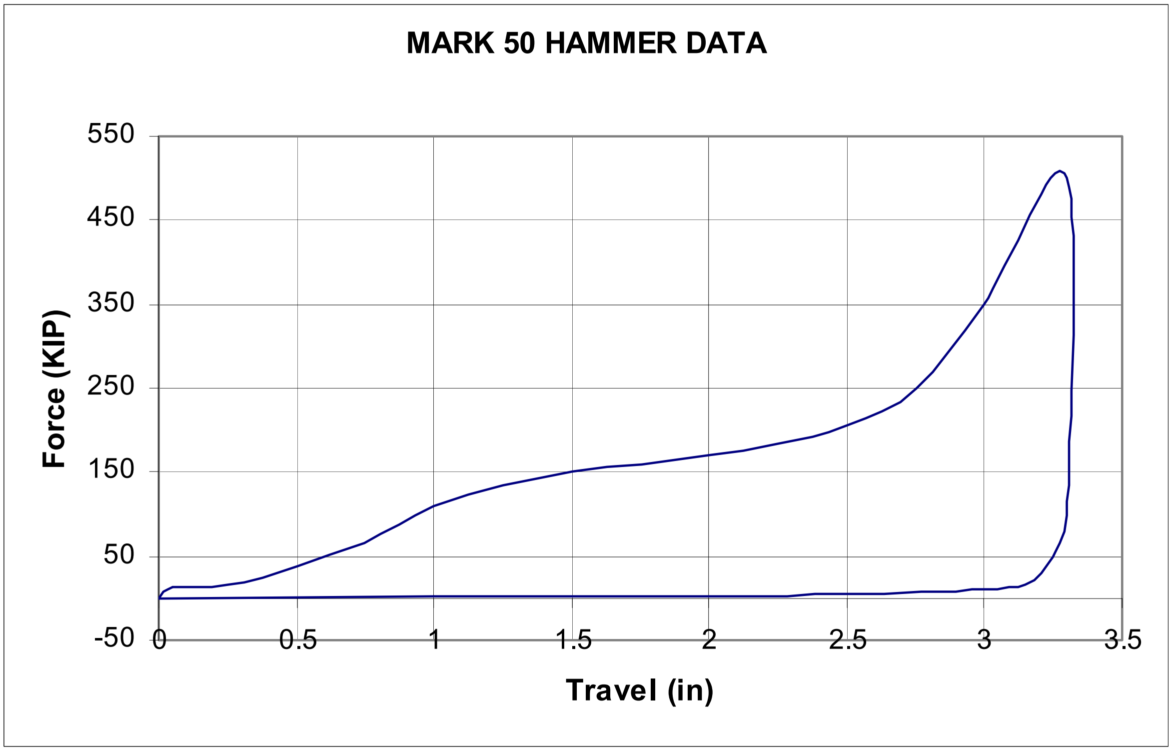


Figure 4. Mark 50 draft gear performance

2.3 Tank Car Gross Weight

The critical loading, which gives the highest coupler impact force, is with the tank car at its maximum allowable gross weight. The tank car is filled to 98% of capacity with fluid. The desired gross weight is achieved either by adjusting the fluid density for a tank with given volume, or adjusting the volume for a fluid of fixed density. Either way, runs were made at a gross weight of 286,000 lb, and at a gross weight of 263,000 lb.

2.4 Tank Car Impact Simulation Matrix

The simulation matrix starts with 1, 2 or 3 hammer cars impacting on 1, 2, 3 or 5 anvil cars, and all cars use the same draft gear. This gives the 12 cases shown in Table 1.

Table 1. Simulation Matrix

No. of Hammer Tank Cars	No. of Anvil Tank Cars
1	1
1	2
1	3
1	5
2	1
2	2
2	3
2	5
3	1
3	2
3	3
3	5

These 12 cases were run with all tank cars at a gross weight of 286,000 lb, for each of the four draft gear. This gives 48 cases, as listed in Table 2. In addition, the same 12 cases were run with all cars at a gross weight of 263,000 lb, with all cars using the Mark 50 draft gear, as listed in Table 3. These 12 cases serve as a baseline, to connect to previous work.

Finally, there are four cases where either one or two 286,000 lb hammer tank cars impact one or five 263,000 lb anvil tank cars. The hammer cars use either Crown TG or TF-880 draft gear. The anvil cars use TF-880 draft gear in all cases. This gives 8 additional cases, as listed in Table 4. The simulation matrix is thus composed of 68 cases, as shown in Tables 2, 3 and 4 below.

Each configuration shown in Tables 2, 3 and 4 is described by a configuration code that describes the number and weight of hammer and anvil cars. The code is of the form iH-jA, where i is the number of hammer cars, H indicates hammer car, j is the number of anvil cars, and A indicates anvil car. Thus, configuration code 1H-2A represents one hammer car coupling with two anvil cars, and configuration code 3H-5A represents three hammer cars coupling with five anvil cars.

Table 2. 286,000 lb Tank Car Impact Simulation Matrix

Case	Hammer cars			Anvil cars			Config Code	Group
	No Cars	Weight (lb)	Draft gear	No Cars	Weight (lb)	Draft gear		
1	1	286,000	Crown SE2	1	286,000	Crown SE2	1H-1A	1
2	1	286,000	TF-880	1	286,000	TF-880	1H-1A	1
3	1	286,000	Crown TG	1	286,000	Crown TG	1H-1A	1
4	1	286,000	Mark 50	1	286,000	Mark 50	1H-1A	1
5	1	286,000	Crown SE2	2	286,000	Crown SE2	1H-2A	2
6	1	286,000	TF-880	2	286,000	TF-880	1H-2A	2
7	1	286,000	Crown TG	2	286,000	Crown TG	1H-2A	2
8	1	286,000	Mark 50	2	286,000	Mark 50	1H-2A	2
9	1	286,000	Crown SE2	3	286,000	Crown SE2	1H-3A	3
10	1	286,000	TF-880	3	286,000	TF-880	1H-3A	3
11	1	286,000	Crown TG	3	286,000	Crown TG	1H-3A	3
12	1	286,000	Mark 50	3	286,000	Mark 50	1H-3A	3
13	1	286,000	Crown SE2	5	286,000	Crown SE2	1H-5A	4
14	1	286,000	TF-880	5	286,000	TF-880	1H-5A	4
15	1	286,000	Crown TG	5	286,000	Crown TG	1H-5A	4
16	1	286,000	Mark 50	5	286,000	Mark 50	1H-5A	4
17	2	286,000	Crown SE2	1	286,000	Crown SE2	2H-1A	5
18	2	286,000	TF-880	1	286,000	TF-880	2H-1A	5
19	2	286,000	Crown TG	1	286,000	Crown TG	2H-1A	5
20	2	286,000	Mark 50	1	286,000	Mark 50	2H-1A	5
21	2	286,000	Crown SE2	2	286,000	Crown SE2	2H-2A	6
22	2	286,000	TF-880	2	286,000	TF-880	2H-2A	6
23	2	286,000	Crown TG	2	286,000	Crown TG	2H-2A	6
24	2	286,000	Mark 50	2	286,000	Mark 50	2H-2A	6
25	2	286,000	Crown SE2	3	286,000	Crown SE2	2H-3A	7
26	2	286,000	TF-880	3	286,000	TF-880	2H-3A	7
27	2	286,000	Crown TG	3	286,000	Crown TG	2H-3A	7
28	2	286,000	Mark 50	3	286,000	Mark 50	2H-3A	7
29	2	286,000	Crown SE2	5	286,000	Crown SE2	2H-5A	8
30	2	286,000	TF-880	5	286,000	TF-880	2H-5A	8
31	2	286,000	Crown TG	5	286,000	Crown TG	2H-5A	8
32	2	286,000	Mark 50	5	286,000	Mark 50	2H-5A	8
33	3	286,000	Crown SE2	1	286,000	Crown SE2	3H-1A	9
34	3	286,000	TF-880	1	286,000	TF-880	3H-1A	9
35	3	286,000	Crown TG	1	286,000	Crown TG	3H-1A	9
36	3	286,000	Mark 50	1	286,000	Mark 50	3H-1A	9
37	3	286,000	Crown SE2	2	286,000	Crown SE2	3H-2A	10
38	3	286,000	TF-880	2	286,000	TF-880	3H-2A	10
39	3	286,000	Crown TG	2	286,000	Crown TG	3H-2A	10
40	3	286,000	Mark 50	2	286,000	Mark 50	3H-2A	10

Case	Hammer cars			Anvil cars			Config Code	Group
	No Cars	Weight (lb)	Draft gear	No Cars	Weight (lb)	Draft gear		
41	3	286,000	Crown SE2	3	286,000	Crown SE2	3H-3A	11
42	3	286,000	TF-880	3	286,000	TF-880	3H-3A	11
43	3	286,000	Crown TG	3	286,000	Crown TG	3H-3A	11
44	3	286,000	Mark 50	3	286,000	Mark 50	3H-3A	11
45	3	286,000	Crown SE2	5	286,000	Crown SE2	3H-5A	12
46	3	286,000	TF-880	5	286,000	TF-880	3H-5A	12
47	3	286,000	Crown TG	5	286,000	Crown TG	3H-5A	12
48	3	286,000	Mark 50	5	286,000	Mark 50	3H-5A	12

Table 3. 263,000 lb Tank Car Impact Simulation Matrix

Case	Hammer cars			Anvil cars			Config Code	Group
	No Cars	Weight (lb)	Draft gear	No Cars	Weight (lb)	Draft gear		
49	1	263,000	Mark 50	1	263,000	Mark 50	1H-1A	1
50	1	263,000	Mark 50	2	263,000	Mark 50	1H-2A	2
51	1	263,000	Mark 50	3	263,000	Mark 50	1H-3A	3
52	1	263,000	Mark 50	5	263,000	Mark 50	1H-5A	4
53	2	263,000	Mark 50	1	263,000	Mark 50	2H-1A	5
54	2	263,000	Mark 50	2	263,000	Mark 50	2H-2A	6
55	2	263,000	Mark 50	3	263,000	Mark 50	2H-3A	7
56	2	263,000	Mark 50	5	263,000	Mark 50	2H-5A	8
57	3	263,000	Mark 50	1	263,000	Mark 50	3H-1A	9
58	3	263,000	Mark 50	2	263,000	Mark 50	3H-2A	10
59	3	263,000	Mark 50	3	263,000	Mark 50	3H-3A	11
60	3	263,000	Mark 50	5	263,000	Mark 50	3H-5A	12

Table 4. Mixed Gross Weight Tank Car Impact Simulation Matrix

Case	Hammer cars			Anvil cars			Config Code	Group
	No Cars	Weight (lb)	Draft gear	No Cars	Weight (lb)	Draft gear		
61	1	286,000	TF-880	1	263,000	TF-880	1H-1A	13
62	1	286,000	TF-880	5	263,000	TF-880	1H-5A	13
63	2	286,000	TF-880	1	263,000	TF-880	2H-1A	14
64	2	286,000	TF-880	5	263,000	TF-880	2H-5A	14
65	1	286,000	Crown TG	1	263,000	TF-880	1H-1A	15
66	1	286,000	Crown TG	5	263,000	TF-880	1H-5A	15
67	2	286,000	Crown TG	1	263,000	TF-880	2H-1A	16
68	2	286,000	Crown TG	5	263,000	TF-880	2H-5A	16

2.5 Simulation Methodology

The peak coupler impact force was calculated for hammer cars moving at a speed of 3.5, 4.5, 5.5, 6.5, 7.5, 8.5 or 9.5 mi/h to couple with stationary un-braked anvil cars.

The Mark 50 has been the only draft gear used in previous NRC/CSTT studies, because it is believed to represent most closely on average the characteristics of tank cars available to NRC/CSTT for testing. The nominal force-displacement characteristic for the Mark 50 used in simulations was obtained from drop hammer tests of new draft gear. However, the NRC/CSTT tank cars have seen considerable service, and they sit idle in the yard for extended periods between tests. The draft gear are probably not consistent between cars. It is not surprising, therefore, that there was some lack of consistency between impact forces for various configurations of hammer and anvil cars. This was evident when simulations conducted with the nominal Mark 50 draft gear characteristics were compared with test data. However, it was possible to match the coupler impact force time history and peak value from simulation and test for each test configuration by suitable adjustment of the force-displacement characteristic of the draft gear. The adjustments were determined by trial-and-error, to achieve a reasonable match in both coupler impact force time history and peak impact force between the simulation and test over the range of test speeds.

No test data are available for the cases considered in this study, so it is not possible to match simulation results with tests for the various draft gear and configurations of hammer and anvil cars. This work therefore uses the nominal force-displacement characteristic of each draft gear, as shown in Figures 1 through 4, at the maximum energy absorption levels specified by the manufacturer. The results of a simulation may not necessarily match the results of a comparable test. However, prior work does provide confidence that trends of peak coupler impact force with speed, tank car gross weight and draft gear that would occur in tests with the same vehicles would also be represented by the simulation. Thus, while the simulation may not necessarily predict the absolute value of a coupler impact force, it would be expected to predict trends due to variation in the various parameters. So, if the simulations show little effect on coupler impact force for some parameter, then it is probably not a significant factor in yard impact, and may not need to be controlled from that point of view. However, if variation of another parameter does have a significant effect, then it may be a candidate for some controls.

3. Simulation Results

Tables 2, 3 and 4 list 68 simulation cases. Each case was run for hammer car speeds of 3.5, 4.5, 5.5, 6.5, 7.5, 8.5 and 9.5 mi/h. The anvil cars were stationary and un-braked. The peak coupler impact force was calculated for each run.

Figures 5 through 16 present the results for all cases listed in Tables 2 and 3. Each figure gives the results for one impact configuration, shown in the graphic. The table lists the peak coupler impact force for all four draft gear at a tank car gross weight of 286,000 lb, and for the Mark 50 draft gear at a tank car gross weight of 263,000 lb. The columns headed by **K** normalize the result for a draft gear at a tank car gross weight of 286,000 lb by the result for a Mark 50 draft gear at a tank car gross weight of 263,000 lb. **K** is a factor defined as:

$$\mathbf{K} = \mathbf{F} / \mathbf{F}_{263,M50}$$

where

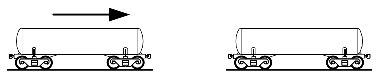
$\mathbf{F}$ = Peak coupler impact force for a particular tank car configuration at a gross weight of 286,000 lb, for a particular draft gear and impact speed; and

$\mathbf{F}_{263,M50}$ = Peak coupler impact force for the same tank car combination at a gross weight of 263,000 lb, with the Mark 50 draft gear, at the same impact speed.

The chart plots peak coupler impact force for the four draft gear at a tank car gross weight of 286,000 lb, and the Mark 50 draft gear at a tank car gross weight of 263,000 lb, against impact speed.

Figures 17 and 18 present the results for all cases listed in Table 4. The table lists the peak coupler impact force for all four tank car configurations shown, with the hammer cars at a gross weight of 286,000 lb, and the anvil cars at a gross weight of 263,000 lb. Th chart plots the results against impact speed.

Figure 5. Results for 1 Hammer Car and 1 Anvil Car, 1H-1A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.052	263	1.363	197	1.021	205	1.062	193
4.5	205	0.553	369	0.995	320	0.863	389	1.049	371
5.5	577	0.890	526	0.812	669	1.032	662	1.022	648
6.5	973	0.989	717	0.729	1,029	1.046	1,038	1.055	984
7.5	1,282	1.018	978	0.777	1,332	1.057	1,343	1.067	1,259
8.5	1,560	1.010	1,253	0.812	1,677	1.087	1,635	1.060	1,543
9.5	1,898	0.983	1,517	0.786	1,983	1.027	1,930	1.000	1,930

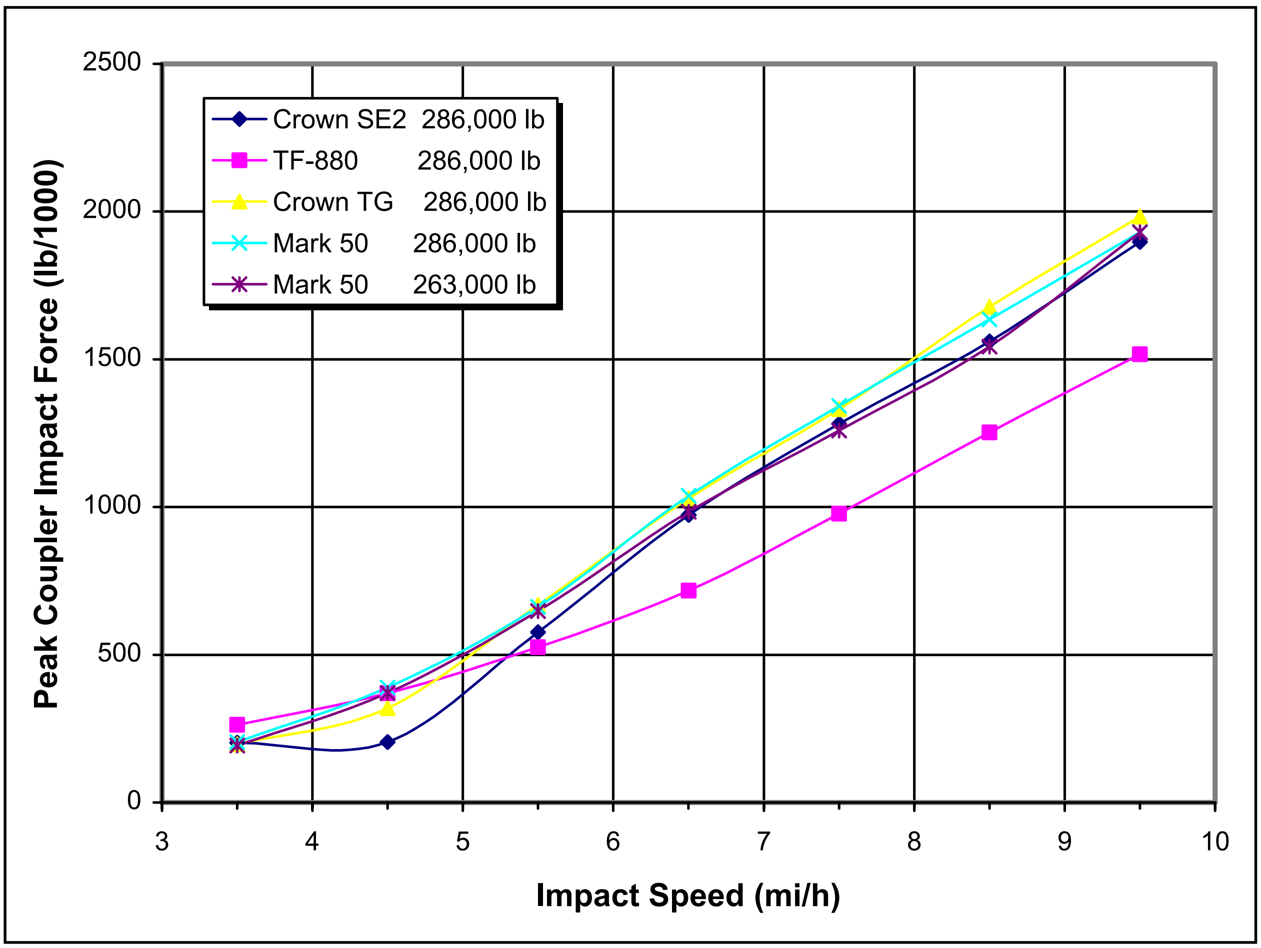
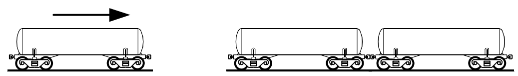


Figure 6. Results for 1 Hammer Car and 2 Anvil Cars, 1H-2A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.005	272	1.347	209	1.035	208	1.030	202
4.5	297	0.765	389	1.003	412	1.062	387	0.997	388
5.5	736	1.097	556	0.829	813	1.212	730	1.088	671
6.5	1,073	1.042	755	0.733	1,120	1.087	1,106	1.074	1,030
7.5	1,367	1.032	1,030	0.777	1,430	1.079	1,385	1.045	1,325
8.5	1,647	1.026	1,319	0.821	1,722	1.072	1,671	1.040	1,606
9.5	1,954	1.024	1,628	0.853	2,036	1.067	1,958	1.026	1,908

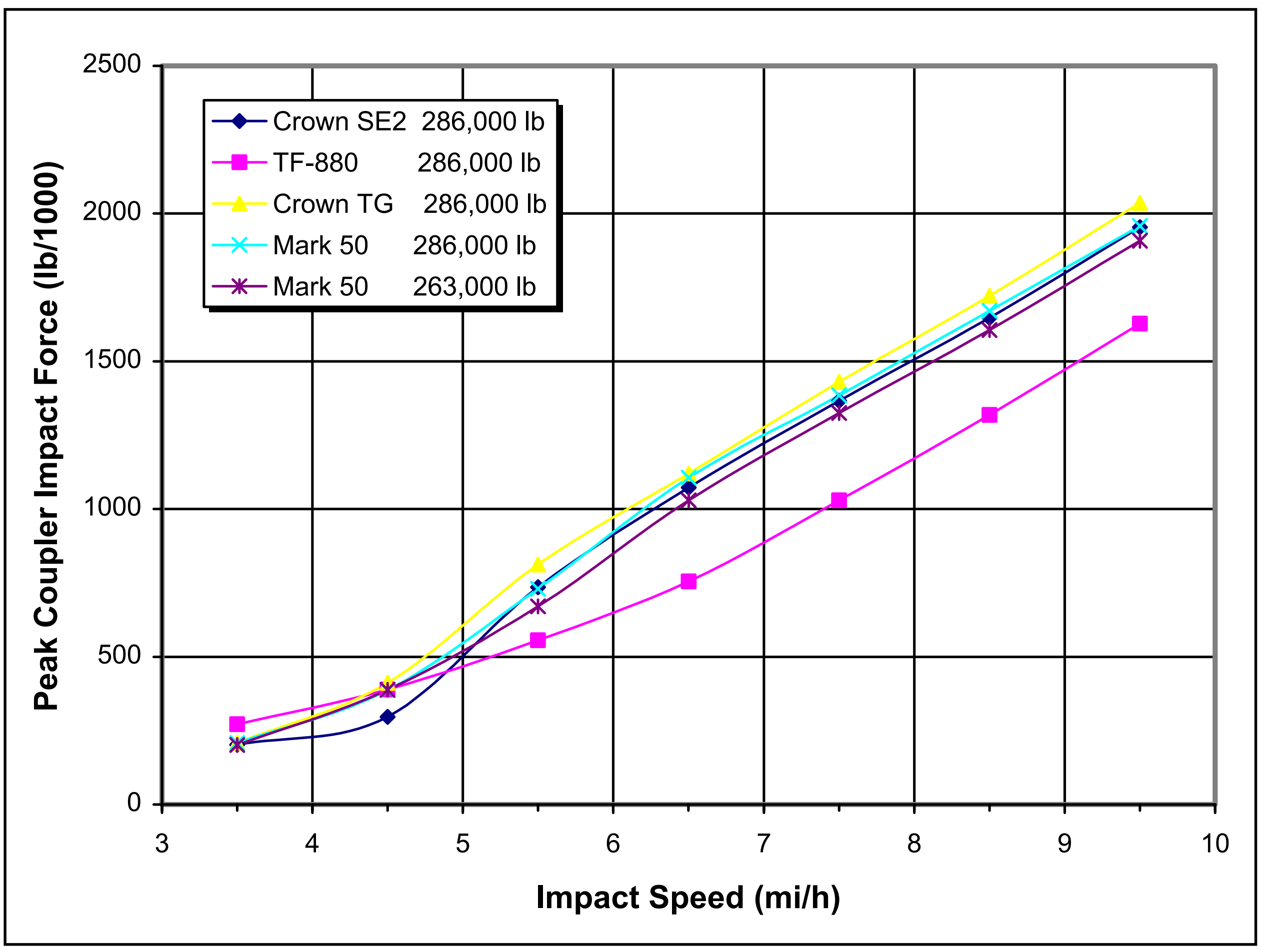
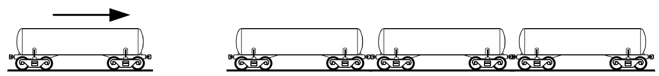


Figure 7. Results for 1 Hammer Car and 3 Anvil Cars, 1H-3A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.005	272	1.347	208	1.030	207	1.025	202
4.5	300	0.771	389	1.000	412	1.059	387	0.995	389
5.5	737	1.098	556	0.829	813	1.212	730	1.088	671
6.5	1,074	1.042	755	0.732	1,120	1.086	1,088	1.055	1,031
7.5	1,368	1.032	1,030	0.777	1,430	1.079	1,384	1.045	1,325
8.5	1,647	1.026	1,319	0.822	1,722	1.073	1,670	1.040	1,605
9.5	1,954	1.024	1,629	0.854	2,036	1.067	1,957	1.026	1,908

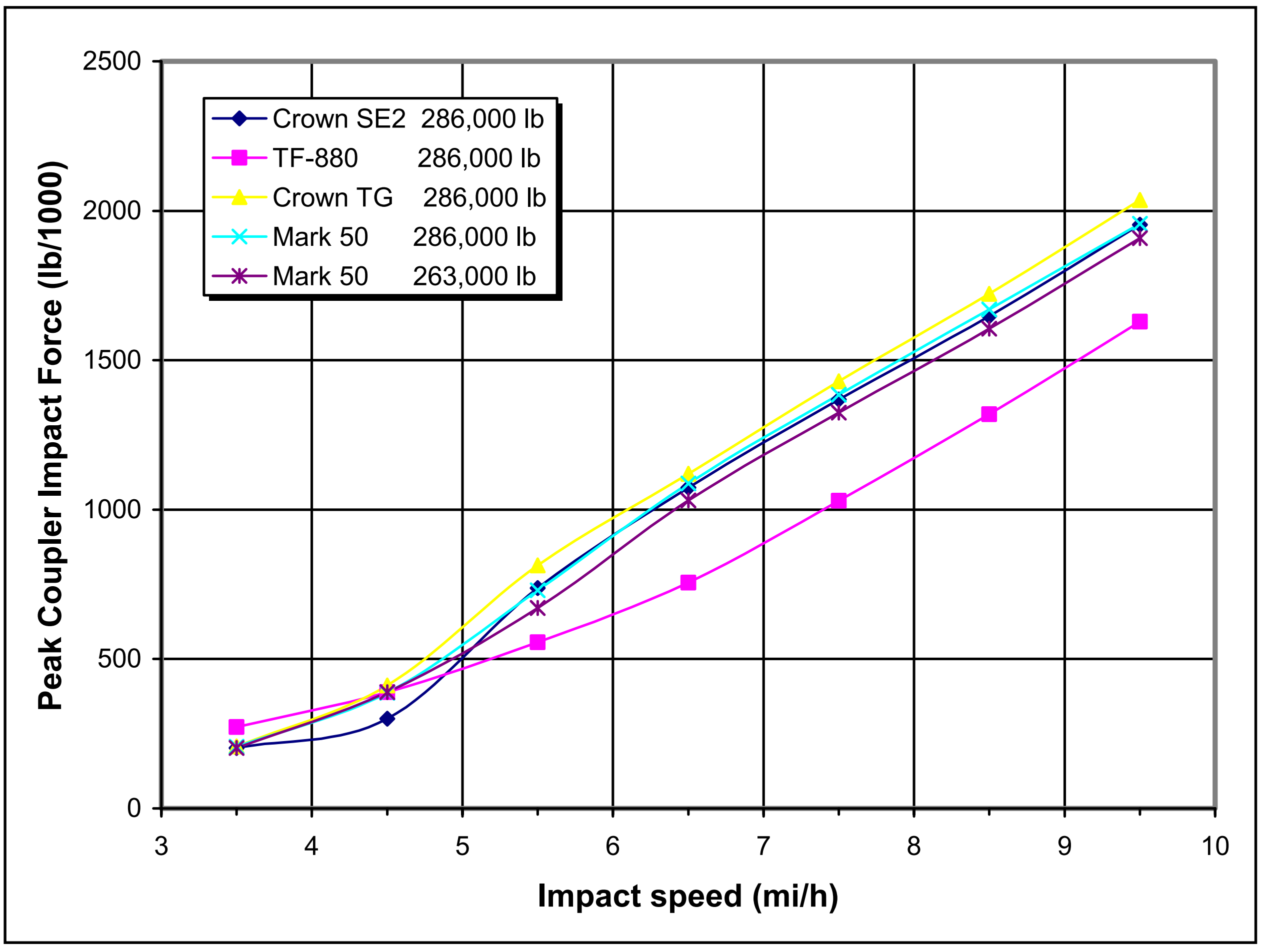
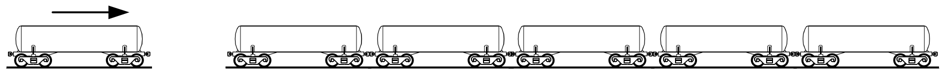


Figure 8. Results for 1 Hammer Car and 5 Anvil Cars, 1H-5A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.005	272	1.347	209	1.035	206	1.020	202
4.5	300	0.773	389	1.003	412	1.062	387	0.997	388
5.5	737	1.098	556	0.829	813	1.212	730	1.088	671
6.5	1,073	1.042	755	0.733	1,120	1.087	1,088	1.056	1,030
7.5	1,367	1.031	1,030	0.777	1,430	1.078	1,385	1.044	1,326
8.5	1,647	1.026	1,319	0.822	1,722	1.073	1,671	1.041	1,605
9.5	1,954	1.024	1,628	0.853	2,036	1.067	1,958	1.026	1,908

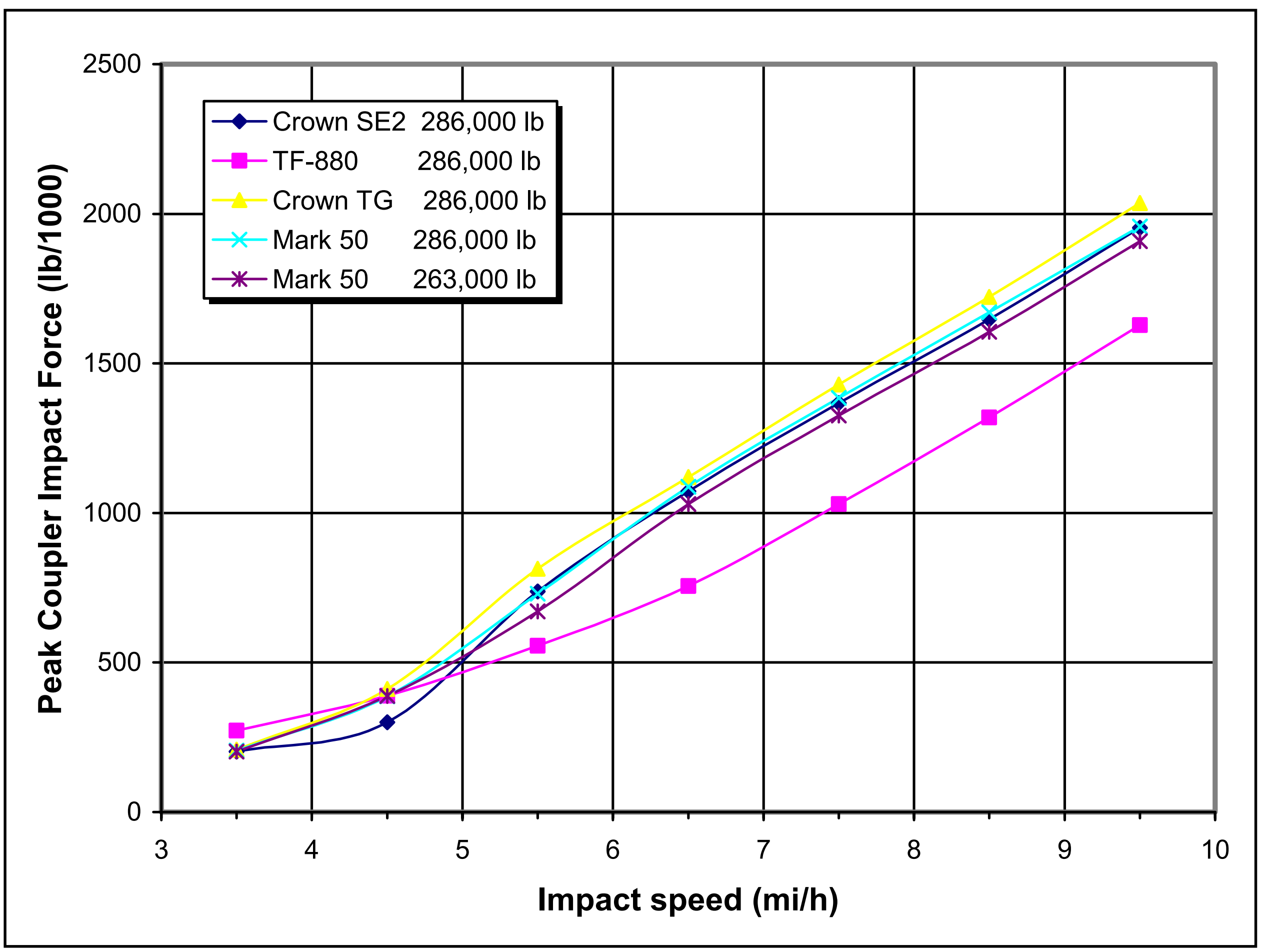
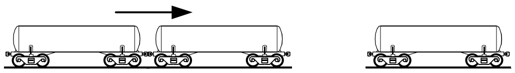


Figure 9. Results for 2 Hammer Cars and 1 Anvil Car, 2H-1A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.000	274	1.350	209	1.030	208	1.025	203
4.5	299	0.775	383	0.992	406	1.052			386
5.5	720	1.089	554	0.838	797	1.206	693	1.048	661
6.5	1,022	1.013	749	0.742	1,078	1.068	1,071	1.060	1,009
7.5	1,359	1.039	990	0.757	1,403	1.073	1,368	1.046	1,308
8.5	1,644	1.055	1,278	0.820	1,703	1.093	1,614	1.036	1,558
9.5	1,926	1.010	1,551	0.813	2,026	1.062	1,896	0.994	1,907

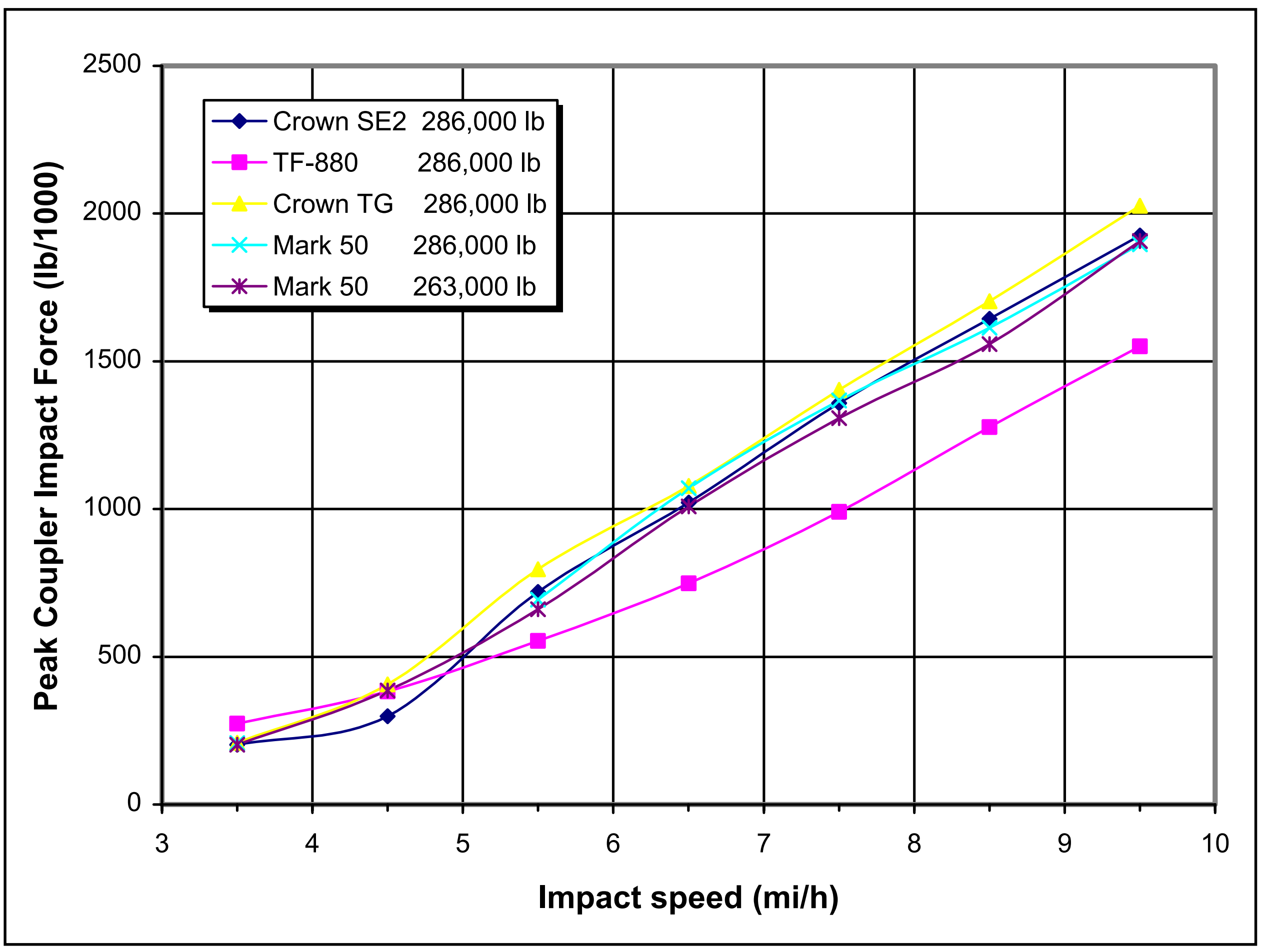
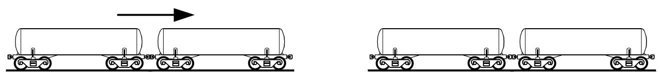


Figure 10. Results for 2 Hammer Cars and 2 Anvil Cars, 2H-2A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	0.981	288	1.391	238	1.150	212	1.024	207
4.5	521	1.339	414	1.064	523	1.344	391	1.005	389
5.5	833	1.165	579	0.810	871	1.218	769	1.076	715
6.5	1,136	1.071	800	0.754	1,159	1.092	1,117	1.053	1,061
7.5	1,420	1.051	1,064	0.788	1,461	1.081	1,410	1.044	1,351
8.5	1,696	1.041	1,351	0.829	1,748	1.073	1,695	1.041	1,629
9.5	1,985	1.030	1,662	0.862	2,062	1.070	1,976	1.025	1,927

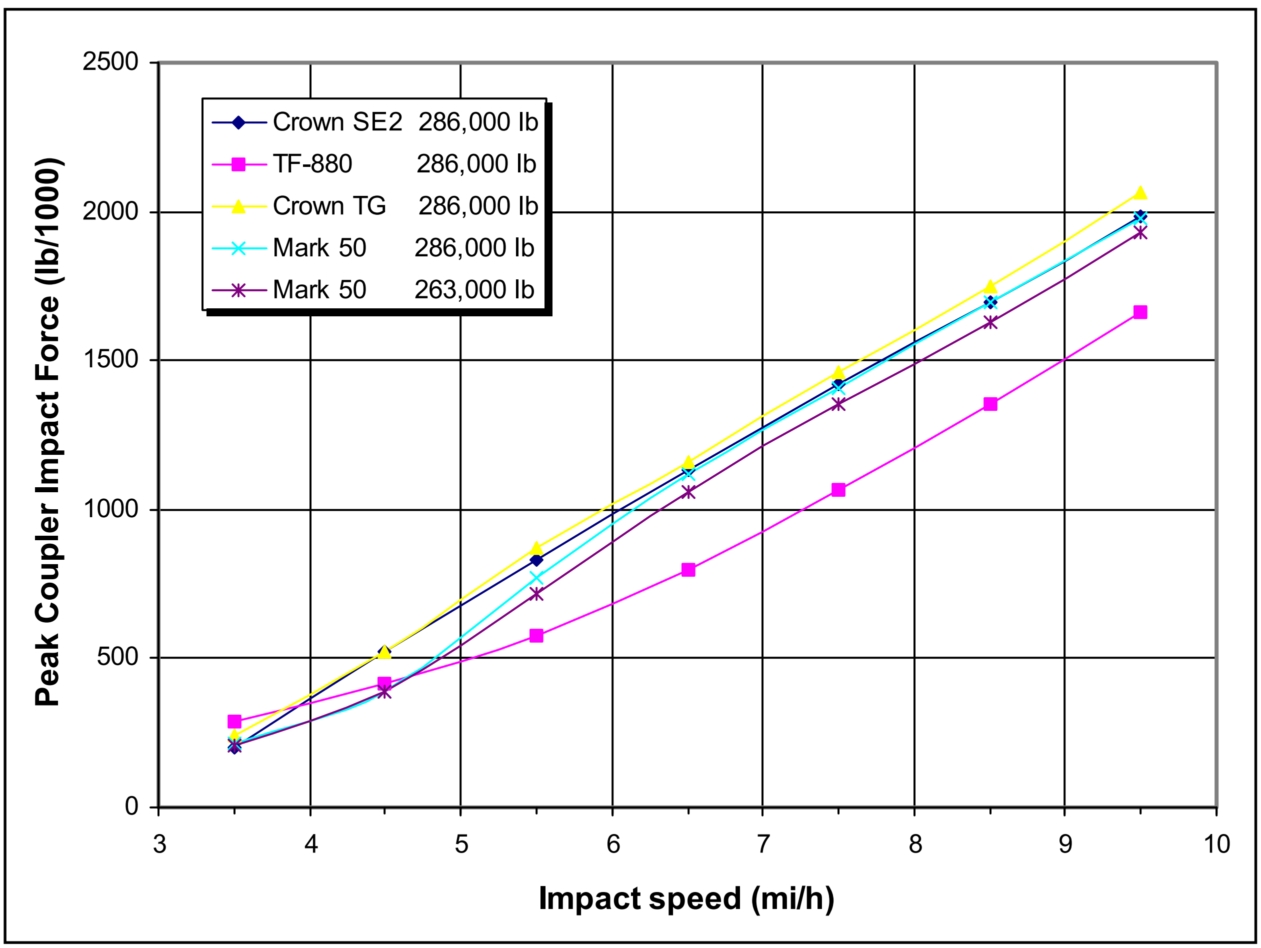
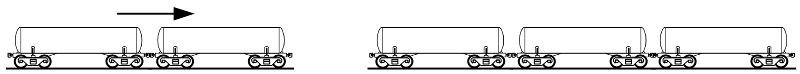


Figure 11. Results for 2 Hammer Cars and 3 Anvil Cars, 2H-3A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	234	1.130	288	1.391	238	1.150	212	1.024	207
4.5	522	1.342	414	1.064	523	1.344	391	1.005	389
5.5	833	1.165	579	0.810	871	1.218	769	1.076	715
6.5	1,137	1.072	800	0.754	1,160	1.093	1,117	1.053	1,061
7.5	1,421	1.052	1,064	0.788	1,461	1.081	1,410	1.044	1,351
8.5	1,696	1.041	1,351	0.829	1,749	1.074	1,695	1.041	1,629
9.5	1,985	1.030	1,662	0.862	2,063	1.071	1,976	1.025	1,927

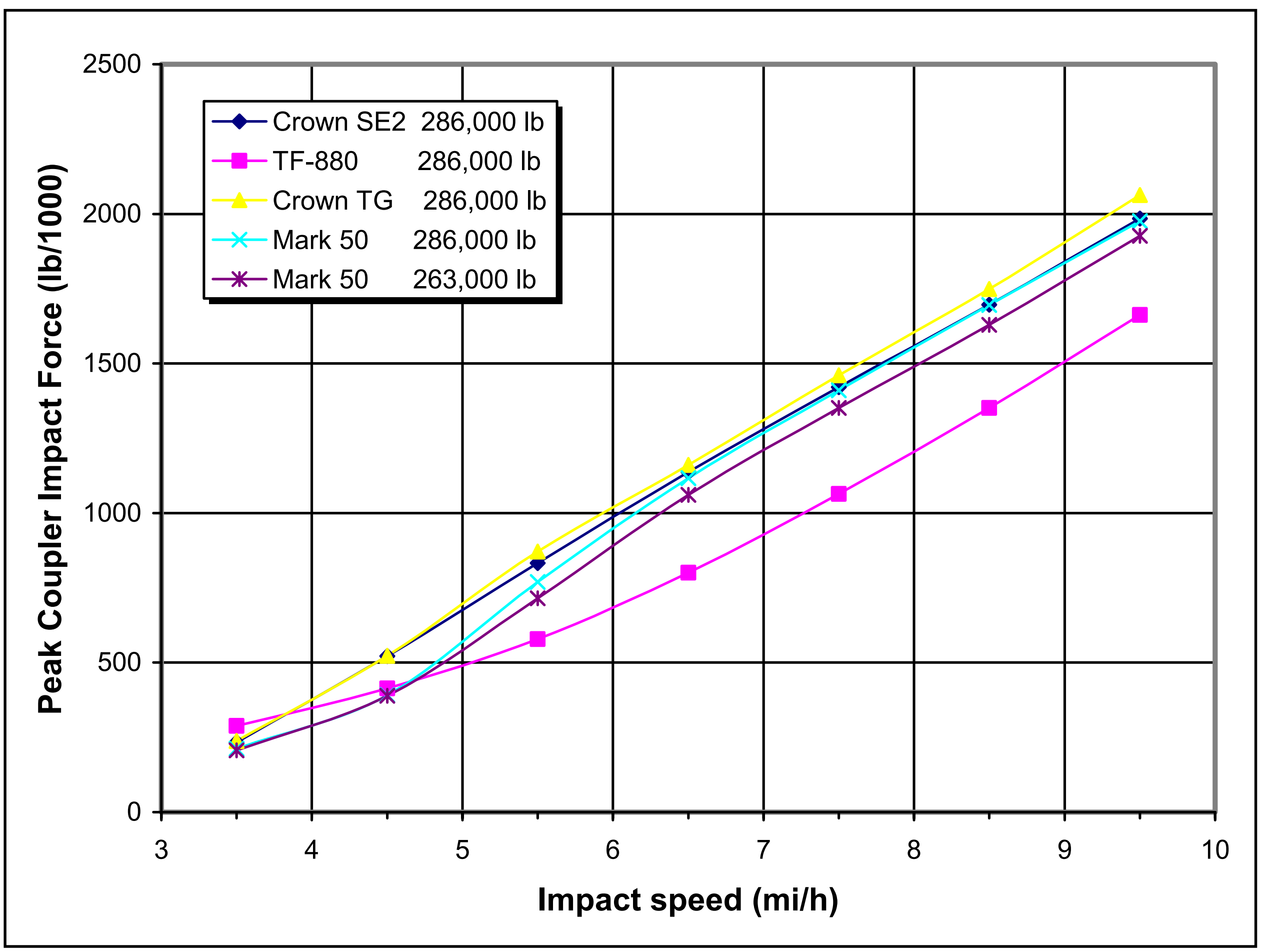
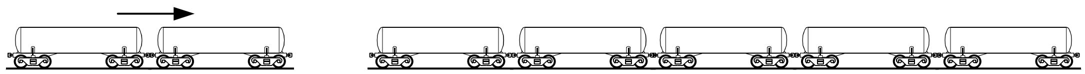


Figure 12. Results for 2 Hammer Cars and 5 Anvil Cars, 2H-5A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	0.981	288	1.391	239	1.155	213	1.029	207
4.5	523	1.344	414	1.064	524	1.347	391	1.005	389
5.5	833	1.165	579	0.810	871	1.218	757	1.059	715
6.5	1,137	1.072	800	0.754	1,160	1.093	1,118	1.054	1,061
7.5	1,420	1.051	1,065	0.788	1,461	1.081	1,410	1.044	1,351
8.5	1,646	1.010	1,351	0.829	1,749	1.073	1,695	1.040	1,630
9.5	1,985	1.030	1,662	0.862	2,062	1.070	1,976	1.025	1,927

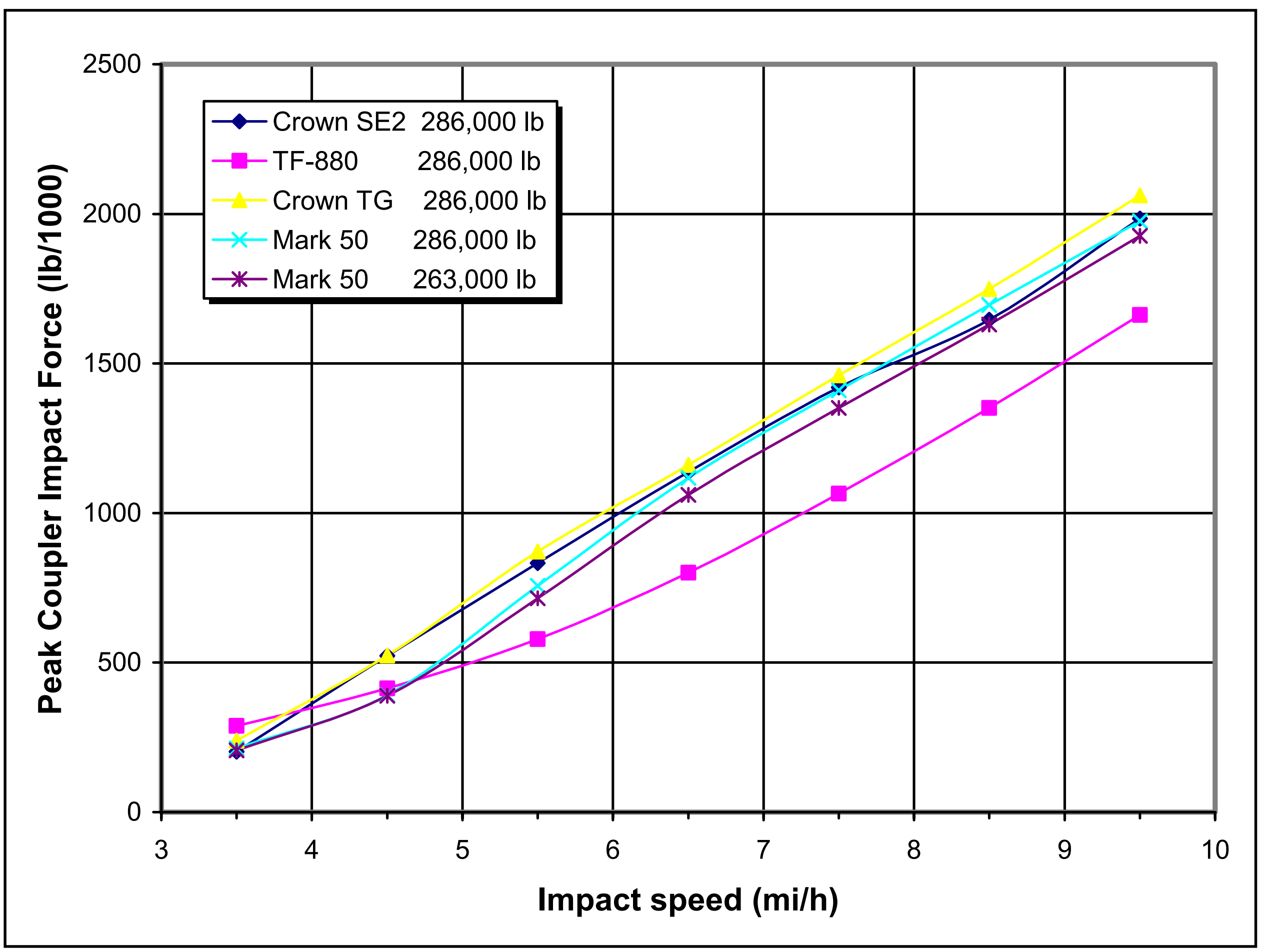
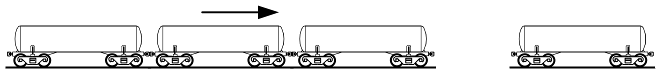


Figure 13. Results for 3 Hammer Cars and 1 Anvil Car, 3H-1A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	1.005	273	1.351	208	1.030	208	1.030	202
4.5	301	0.776	389	1.003	413	1.064	387	0.997	388
5.5	737	1.098	556	0.829	813	1.212	730	1.088	671
6.5	1,074	1.042	755	0.732	1,120	1.086	1,087	1.054	1,031
7.5	1,368	1.032	1,030	0.777	1,430	1.079	1,385	1.045	1,325
8.5	1,647	1.026	1,319	0.822	1,722	1.073	1,671	1.041	1,605
9.5	1,953	1.024	1,629	0.854	2,036	1.067	1,957	1.026	1,908

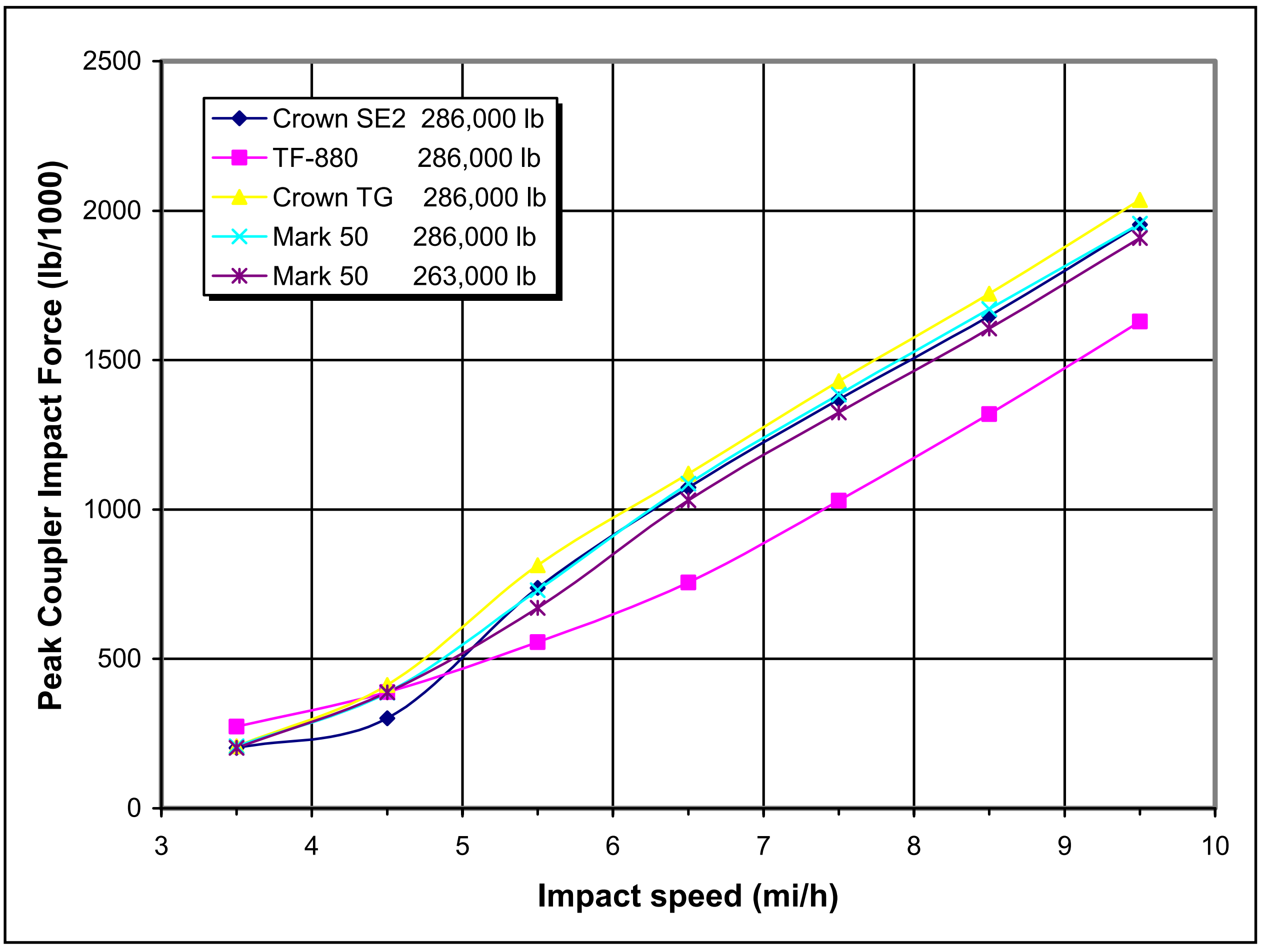
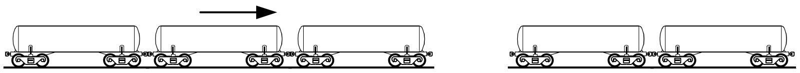


Figure 14. Results for 3 Hammer Cars and 2 Anvil Cars, 3H-2A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	0.981	288	1.391	239	1.155	209	1.010	207
4.5	523	1.344	414	1.064	524	1.347	391	1.005	389
5.5	833	1.165	579	0.810	871	1.218	769	1.076	715
6.5	1,136	1.072	800	0.755	1,160	1.093	1,117	1.054	1,060
7.5	1,421	1.052	1,061	0.785	1,461	1.081	1,410	1.044	1,351
8.5	1,696	1.040	1,351	0.829	1,748	1.072	1,694	1.039	1,630
9.5	1,985	1.030	1,662	0.862	2,062	1.070	1,976	1.025	1,927

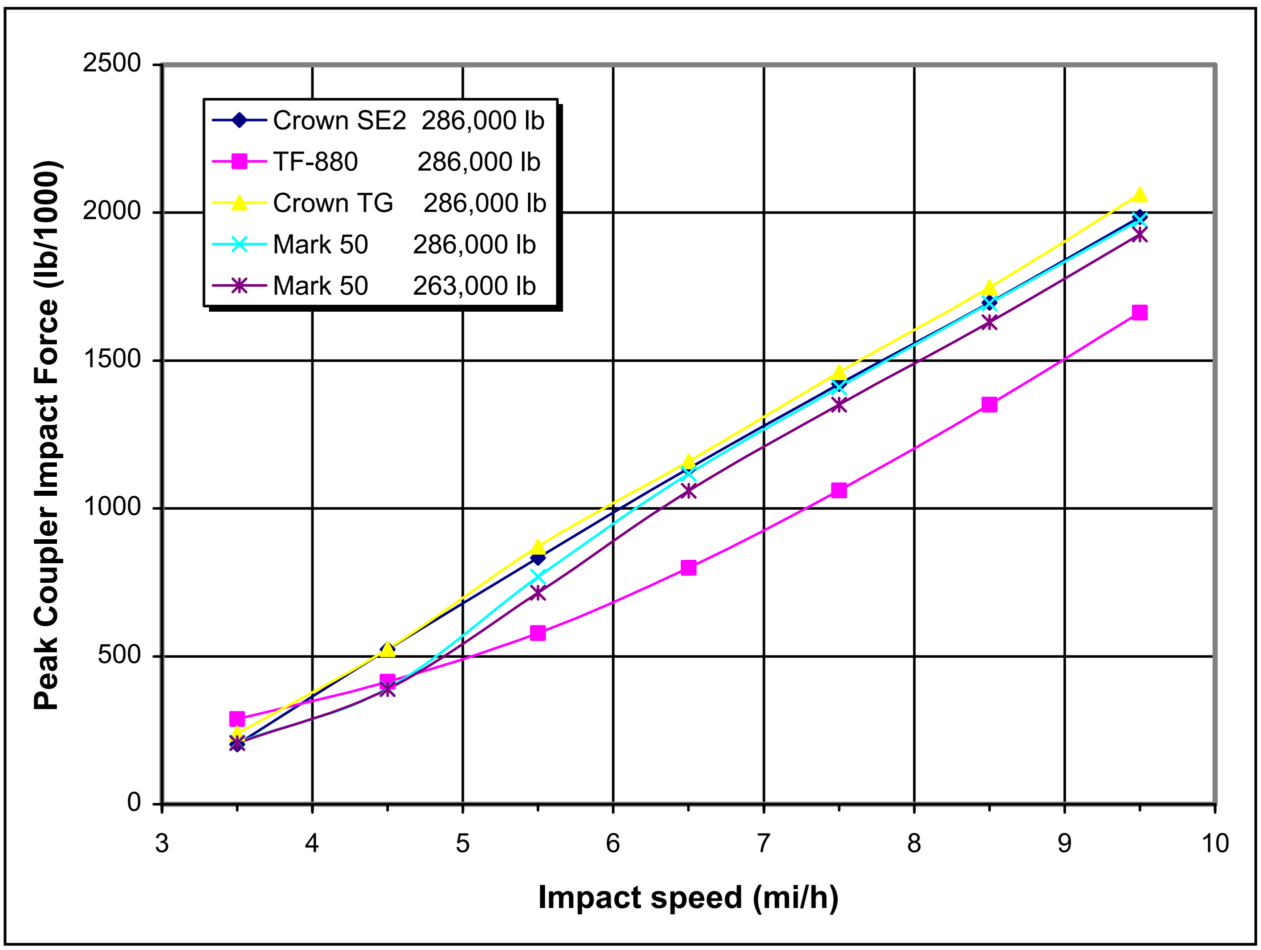
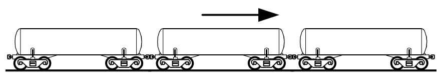


Figure 15. Results for 3 Hammer Cars and 3 Anvil Cars, 3H-3A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	0.981	288	1.391	239	1.155	214	1.034	207
4.5	525	1.350	414	1.064	524	1.347	391	1.005	389
5.5	834	1.165	579	0.809	871	1.216	770	1.075	716
6.5	1,136	1.071	800	0.754	1,160	1.093	1,117	1.053	1,061
7.5	1,419	1.050	1,062	0.786	1,461	1.081	1,410	1.044	1,351
8.5	1,696	1.040	1,351	0.829	1,749	1.073	1,695	1.040	1,630
9.5	1,985	1.030	1,662	0.862	2,062	1.070	1,976	1.025	1,927

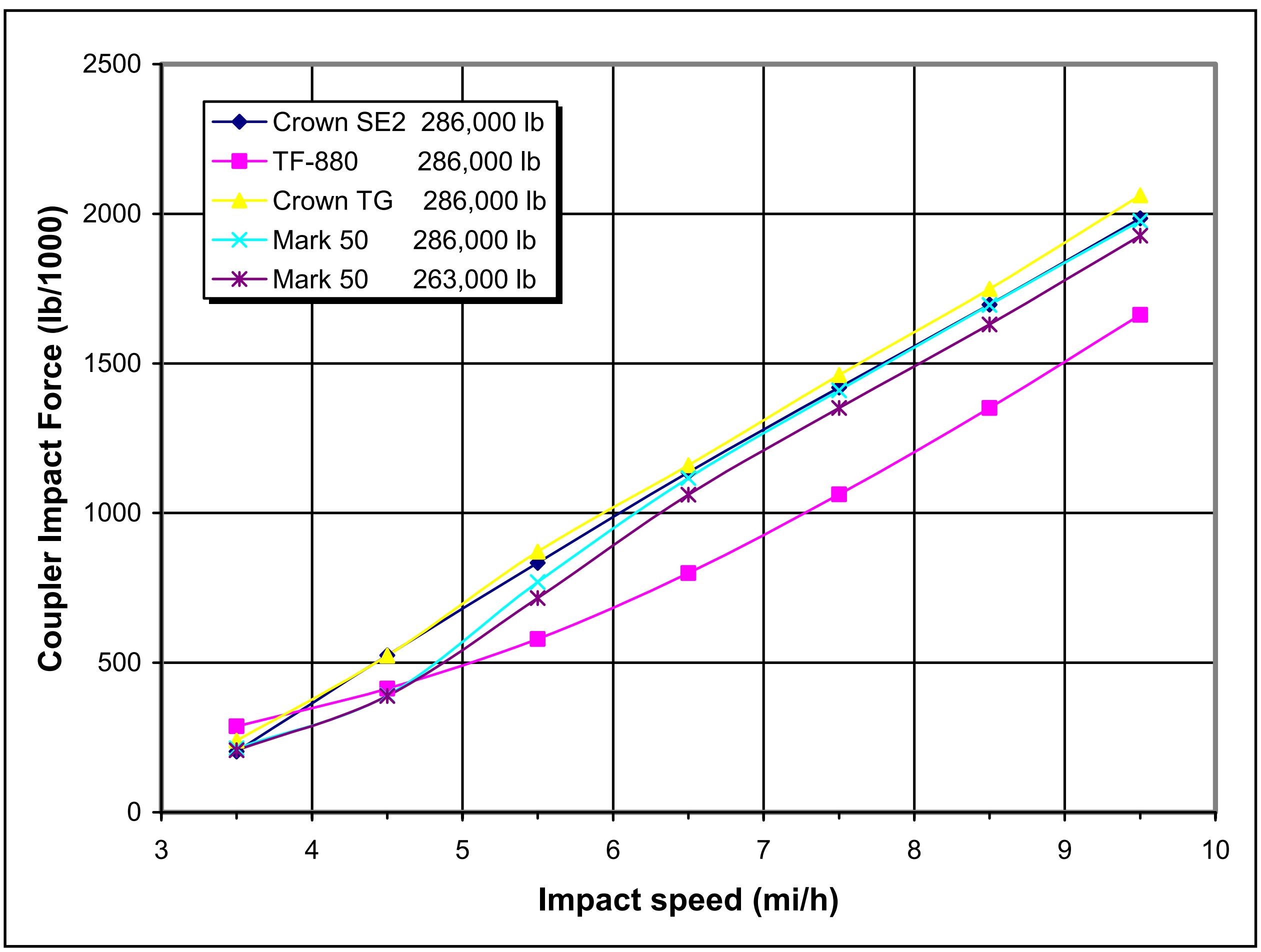
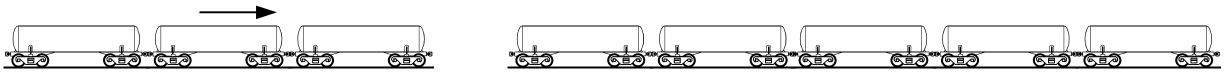


Figure 16. Results for 3 Hammer Cars and 5 Anvil Cars, 3H-5A



Peak Coupler Impact Force (lb/1000)
Various Impact Speeds, Draft Gear and Car Weights

Speed (mi/h)	Crown SE2 286,000 lb		TF-880 286,000 lb		Crown TG 286,000 lb		Mark 50 286,000 lb		Mark 50 263,000 lb
	Force	K	Force	K	Force	K	Force	K	Force
3.5	203	0.981	288	1.391	239	1.155	213	1.029	207
4.5	525	1.350	414	1.064	524	1.347	391	1.005	389
5.5	834	1.166	579	0.810	871	1.218	769	1.076	715
6.5	1,137	1.073	800	0.755	1,160	1.094	1,117	1.054	1,060
7.5	1,421	1.052	1,061	0.785	1,461	1.081	1,410	1.044	1,351
8.5	1,697	1.041	1,351	0.829	1,749	1.073	1,695	1.040	1,630
9.5	1,985	1.030	1,662	0.862	2,062	1.070	1,976	1.025	1,927

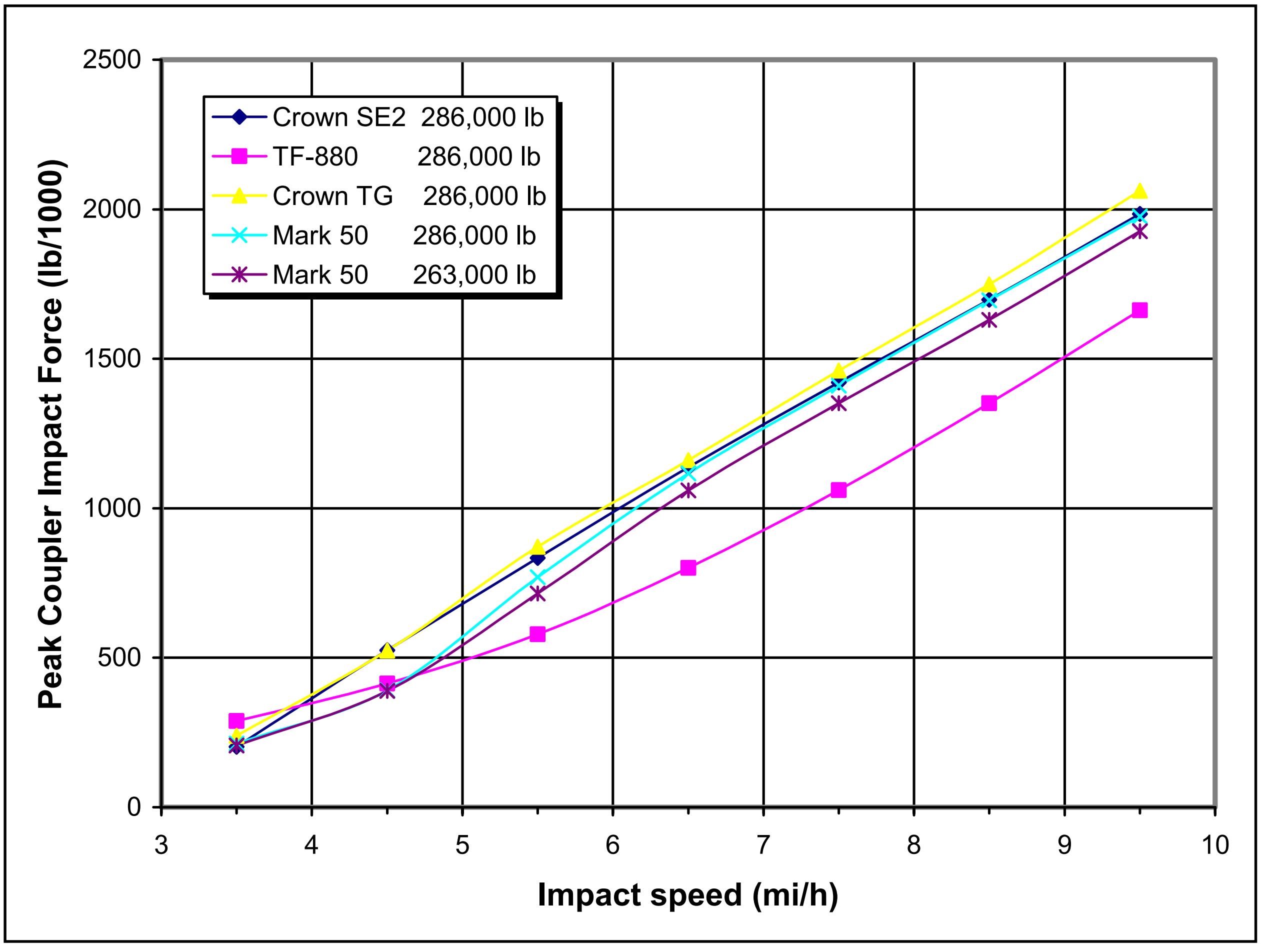


Figure 17. Results for Various Hammer and Anvil Car Configurations
Hammer Cars at 286,000 lb with TF-880 Draft Gear
Anvil Cars at 263,000 lb with TF-880 Draft Gear

Peak Coupler Impact Force (lb/1000)
Various Car Configurations

Speed (mi/h)	Car Configuration			
	1H-1A	1H-5A	2H-1A	2H-5A
3.5	257	267	267	281
4.5	360	380	377	403
5.5	506	543	536	559
6.5	695	733	722	771
7.5	923	1,003	961	1,037
8.5	1,217	1,290	1,244	1,322
9.5	1,501	1,596	1,519	1,629

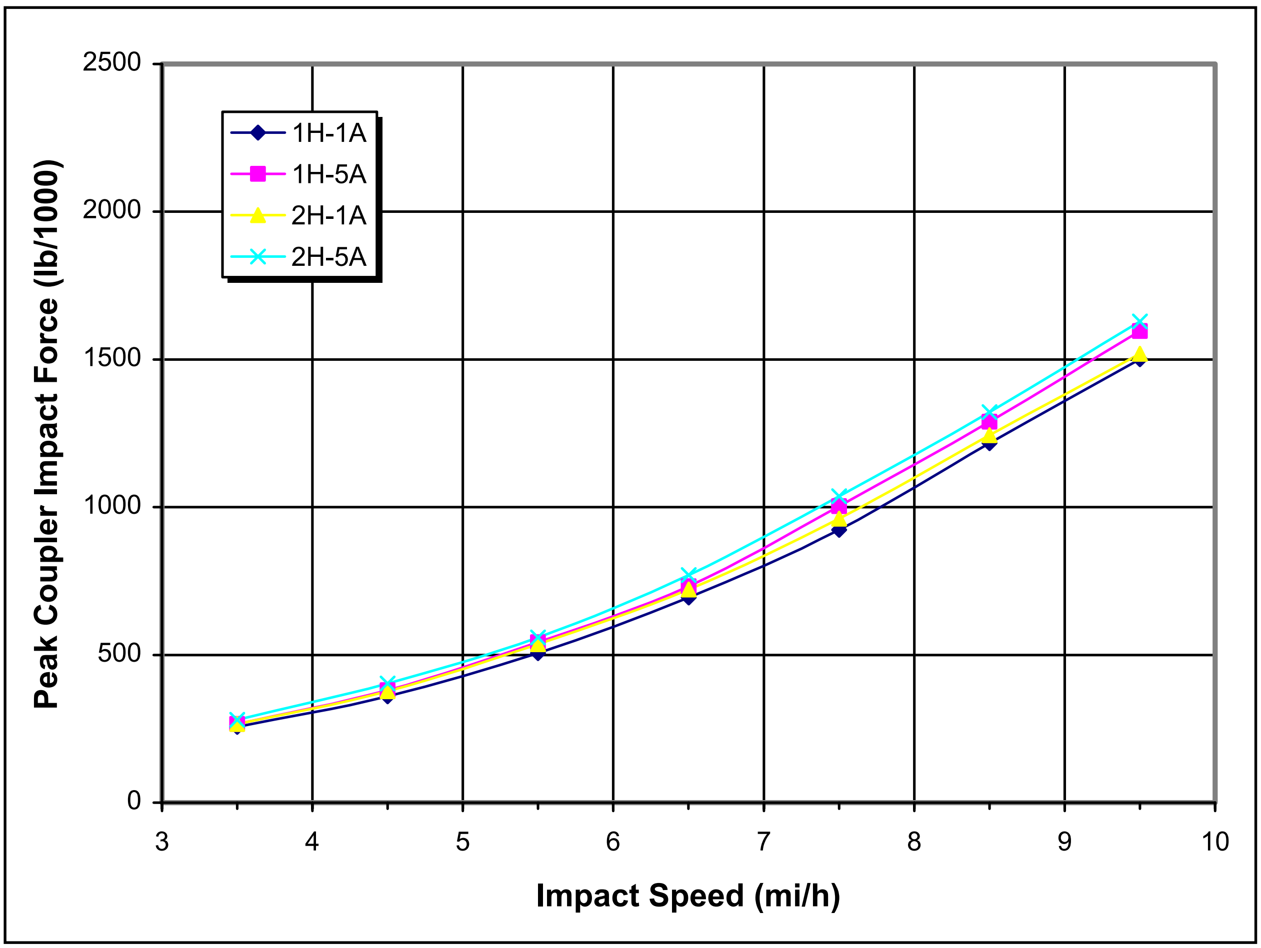
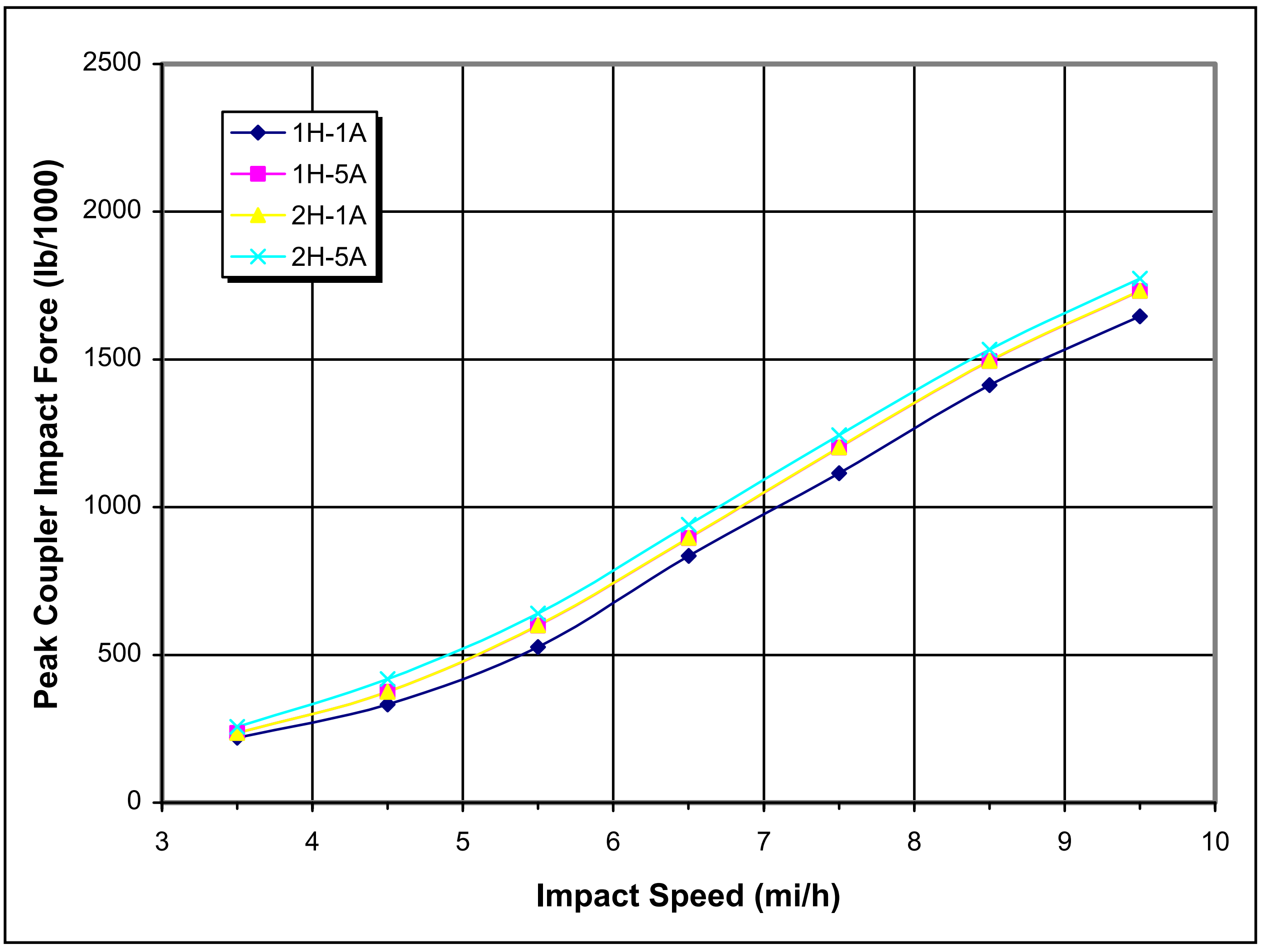


Figure 18. Results for Various Hammer and Anvil Car Configurations
Hammer Cars at 286,000 lb with Crown TG Draft Gear
Anvil Cars at 263,000 lb with TF-880 Draft Gear

Peak Coupler Impact Force (lb/1000)
Various Car Configurations

Speed (mi/h)	Car Configuration			
	1H-1A	1H-5A	2H-1A	2H-5A
3.5	220	236	236	257
4.5	333	375	375	418
5.5	527	599	600	640
6.5	836	895	896	941
7.5	1,115	1,202	1,203	1,244
8.5	1,413	1,494	1,495	1,533
9.5	1,646	1,732	1,733	1,774



4. Discussion

4.1 Effect of Tank Car Gross Weight

Two groups of simulation cases are compared to investigate the effect of tank car gross weight on peak coupler impact force.

The first group consists of those cases from Tables 2 and 3 that use only the Mark 50 draft gear. The tank car configurations with a gross weight of 286,000 lb in Table 2 are compared to the corresponding configurations from Table 3, where the tank car configurations have a gross weight of 263,000 lb. The comparison is best seen by comparing the tabulated values for the **K** factor for the Mark 50 draft gear in Figures 5 through 16. For convenience, these factors are summarized by impact configuration in Table 5, and are shown in Figure 19, below.

The increase in peak coupler impact force appears highest for moderate impact speeds, in the range 5 to 7 mi/h. It tends to be lower at low impact speeds, and at the highest impact speeds. The greatest increase was 8.8%, for three impact configurations at an impact speed of 5.5 mi/h. The average increase in peak coupler impact force, for all speeds and impact configurations, was 3.9%. This is less than half the increase in tank car gross weight of 286,000 lb over 263,000 lb, which is 8.7%.

The second group consists of those cases from Tables 2 and 4 that use only the TF-880 draft gear. Tank car configurations in Table 2 where all cars have a gross weight of 286,000 lb are compared to the corresponding configurations from Table 4, where the hammer cars have a gross weight of 286,000 lb and the anvil cars have a gross weight of 263,000 lb. The results are presented in Table 6, and are shown in Figure 20, below. The **K** factors in Table 6 are the ratio of the peak coupler impact force for all cars at a gross weight of 286,000 lb to the peak coupler impact force for hammer cars at a gross weight of 286,000 lb and anvil cars at 263,000 lb.

The increase in peak coupler impact force also appears highest for moderate impact speeds, in the range 5.5 to 7.5 mi/h. It tends to be lower at low impact speeds, and at the highest impact speeds. The greatest increase was 6.0%, for one impact configuration at an impact speed of 7.5 mi/h. The average increase in peak coupler impact force, for all speeds and impact configurations, was 2.8%.

Table 5. Ratio of Peak Impact Coupler Forces for Mark 50 Draft Gear
<u>Hammer and Anvil Cars at 286,000 lb</u>
Hammer Cars and Anvil Cars at 263,000 lb

Speed (mi/h)	Tank Car Impact Configuration											
	1H-1A	1H-2A	1H-3A	1H-5A	2H-1A	2H-2A	2H-3A	2H-5A	3H-1A	3H-2A	3H-3A	3H-5A
3.5	1.062	1.030	1.025	1.020	1.025	1.024	1.024	1.029	1.030	1.010	1.034	1.029
4.5	1.049	0.997	0.995	0.997		1.005	1.005	1.005	0.997	1.005	1.005	1.005
5.5	1.022	1.088	1.088	1.088	1.048	1.076	1.076	1.059	1.088	1.076	1.075	1.076
6.5	1.055	1.074	1.055	1.056	1.060	1.053	1.053	1.054	1.054	1.054	1.053	1.054
7.5	1.067	1.045	1.045	1.044	1.046	1.044	1.044	1.044	1.045	1.044	1.044	1.044
8.5	1.060	1.040	1.040	1.041	1.036	1.041	1.041	1.040	1.041	1.039	1.040	1.040
9.5	1.000	1.026	1.026	1.026	0.994	1.025	1.025	1.025	1.026	1.025	1.025	1.025

Figure 19. Ratio of Peak Impact Coupler Forces for Mark 50 Draft Gear
<u>Hammer and Anvil Cars at 286,000 lb</u>
Hammer Cars and Anvil Cars at 263,000 lb

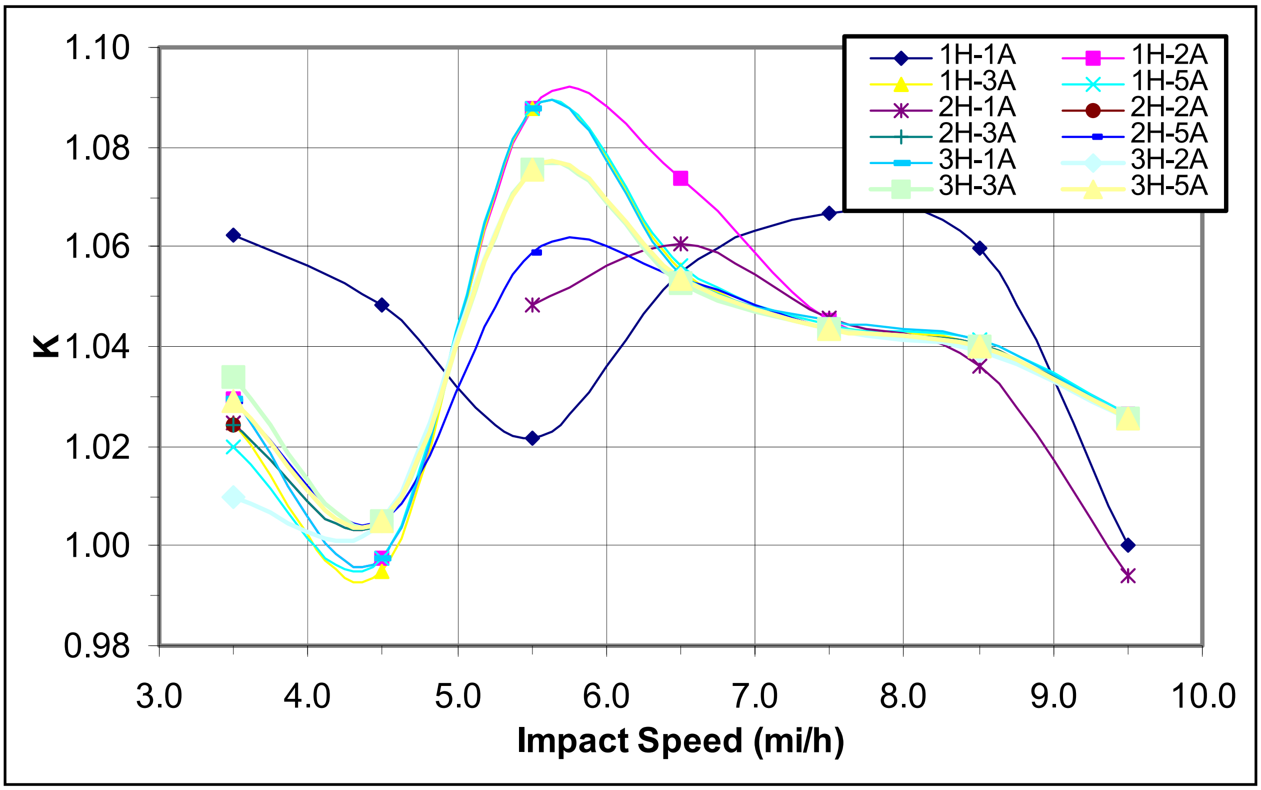
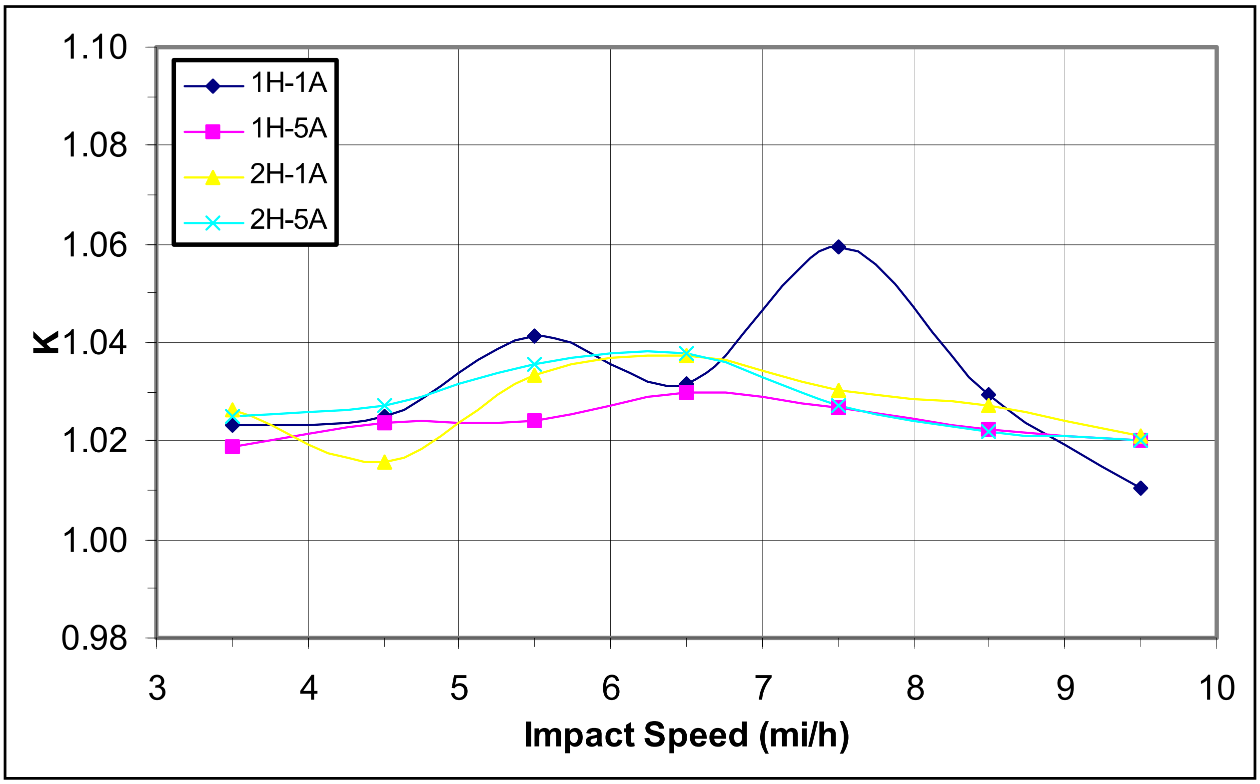


Table 6. Ratio of Peak Impact Coupler Forces for TF-880 Draft Gear
<u>Hammer and Anvil Cars at 286,000 lb</u>
Hammer Cars at 286,000 lb and Anvil Cars at 263,000 lb

Speed	Tank Car Impact Configuration			
(mi/h)	1H-1A	1H-5A	2H-1A	2H-5A
3.5	1.023	1.019	1.026	1.025
4.5	1.025	1.024	1.016	1.027
5.5	1.040	1.024	1.034	1.036
6.5	1.032	1.030	1.037	1.038
7.5	1.060	1.027	1.030	1.027
8.5	1.030	1.022	1.027	1.022
9.5	1.011	1.020	1.021	1.020

Figure 20. Ratio of Peak Impact Coupler Forces for TF-880 Draft Gear
<u>Hammer and Anvil Cars at 286,000 lb</u>
Hammer Cars at 286,000 lb and Anvil Cars at 263,000 lb



4.2 Effect of Draft Gear

Four draft gear have been investigated in this project:

- Crown SE2;
- TF-880;
- Crown TG; and
- Mark 50.

The effects of draft gear are revealed by considering the 12 hammer-anvil tank car configurations where all cars had a gross weight of 286,000 lb, and all cars in each configuration used the same draft gear. These results are found in Figures 5 through 16. The curve for the Mark 50 draft at a tank car gross weight of 263,000 lb should be ignored in the graphs.

The graphs in Figures 5 through 16 show a consistent trend for all combinations of hammer and anvil cars. The Crown SE2, Crown TG and Mark 50 draft gear have quite similar capability to absorb energy over the entire range of impact speeds. The TF-880 has similar capability to the other three draft gear at impact speeds up to about 5 mi/h. However, at higher impact speeds, the TF-880 clearly has much better capability to absorb energy than the other draft gear. The TF-880 appears to reduce the peak coupler impact force by about 20% from the values observed for the other three draft gear.

The effect of draft gear was identified quantitatively using **K** factors similar to those given in Figures 5 through 16. Table 7 presents **K** factors for the peak coupler impact force for the given draft gear divided by the peak coupler impact force for the Mark 50 draft gear, averaged over speeds of 6.5 mi/h and higher. This speed range was chosen because there was greater consistency in K factor for this range, compared to lower speeds. This may be because the draft gear force-displacement characteristic emphasizes a high-speed coupling. It is also appropriate to select this speed range, because a high-speed coupling is more likely to damage a tank car. The table presents results for all 12 car configuration cases. The results are quite consistent for all car configurations, except that 1H-1A is a bit lower. The row labeled “Overall” shows the overall average across all cases, and the row labeled “CoV” shows the coefficient of variation across all cases, which is the standard deviation divided by the average. Thus, despite the lower values for the case 1H-1A, the magnitude of the coefficients of variation shows there is considerable overall consistency.

So, from Table 7, for any car configuration where each car has the same draft gear, and any impact speed of 6.5 mi/h or more:

- the Crown SE2 draft gear results in an average coupler impact force about 0.5% lower than the Mark 50;
- the TF-880 draft gear results in an average coupler impact force about 23.2% lower than the Mark 50; and
- the Crown TG draft gear results in an average coupler impact force about 3.3% higher than the Mark 50.

Table 7. Average K Factors for all Car Configurations at 286,000 lb Impact Speeds of 6.5 mi/h and Higher

Case	Draft Gear		
	Crown SE2	**TF-880**	**Crown TG**
1H-1A	0.957	0.743	1.009
1H-2A	0.985	0.762	1.029
1H-3A	0.990	0.765	1.034
1H-5A	0.989	0.765	1.033
2H-1A	0.996	0.758	1.039
2H-2A	1.007	0.777	1.037
2H-3A	1.008	0.777	1.038
2H-5A	1.000	0.777	1.037
3H-1A	0.990	0.765	1.033
3H-2A	1.008	0.777	1.037
3H-3A	1.007	0.777	1.038
3H-5A	1.008	0.777	1.038
Overall	0.995	0.768	1.033
CoV	1.5%	1.4%	0.8%

These results were obtained with all tank cars at a gross weight of 286,000 lb. However, since the impacts speeds were high, it is likely that similar results would apply for other similar gross weights. These results quantify the visual effect of Figures 5 to 16. There is no practical difference between Crown SE2 and Mark 50 draft gear. The difference between Crown TG and Mark 50 would quite possibly be masked in any test by sample differences between individual draft gear in the cars tested, so it might be difficult to demonstrate the difference in practice. A draft gear with performance comparable to the TF-880 clearly offers a significant reduction in peak coupler impact force over the other three draft gear. This arises from two features of its force-displacement characteristic, shown in Figure 2, compared with the force-displacement characteristics of the other three draft gear, shown in Figures 1, 3 and 4. First, the TF-880 characteristic lacks the sharp, high spike at the end of the stroke that happens with the other three draft gear. Its stop is apparently cushioned. Second, the body of the characteristic shows it is absorbing perhaps twice as much energy as the other three draft gear. It is hardly surprising that these important differences show up strongly in the overall results.

5. CONCLUSIONS

The objective of the work reported here is to assess the effect of a change in gross weight from 263,000 lb to 286,000 lb on the peak coupler impact force when tank cars are coupled in a yard. The work was conducted using a proven ADAMS simulation model for the impact at coupling, for various numbers of moving (hammer) tank cars and various numbers of stationary (anvil) cars. The work also examined the effect of four different types of draft gear on the coupler impact forces. Sixty-eight cases were considered, each with a particular combination of hammer and anvil cars, car gross weight, and draft gear. Simulation runs were made at seven impact speeds, from 3.5 to 9.5 mi/h, for each case. Each car was loaded to 98% of its volumetric capacity with a fluid.

This work shows that the same trends found in previous studies regarding the effect of numbers of hammer and anvil cars apply for all the draft gear considered here.

The peak coupler impact force increases consistently with an increase in tank car gross weight when the same draft gear is used. The average increase in peak coupler impact force over all speeds and combinations of hammer and anvil cars is 3.9%. This is less than the 8.7% increase in tank car gross weight of 286,000 b over 263,000 lb. The greatest increase in peak coupler impact force reached 8.8% for moderate impact speeds, in the range 5 to 7 mi/h. It tended to be below average at impact speeds below and above this range.

The Crown SE2, Crown TG and Mark 50 draft gear provided essentially the same energy absorption capability over the range of impact speeds. The TF-880 draft gear provided similar capability for speeds up to about 5 mi/h, but at higher speeds it clearly provided much better capability to absorb energy. It reduced the coupler impact force at the highest impact speeds by about 20% from the values for the other three draft gear.

A draft gear having properties equivalent to or approaching those of the TF-880 used in this work more than compensates for the effect of an increase in gross weight from 263,000 lb to 286,000 lb on coupler impact forces. It should provide an additional margin of safety against brittle fracture that may occur when these cars experience a high-speed coupling.

The draft gear characteristics used in this study are idealized, and are biased towards those required for higher impact speeds. The same characteristic is used for all speeds. This assumption is likely to produce reasonable estimates for coupler impact forces at higher speeds, but may slightly under-estimate them at lower speeds. The relationship between the draft gear characteristic obtained from a drop hammer test, and the response of a draft gear during coupling, is still not well understood. The drop hammer produces a nominal draft gear characteristic. Draft gear in service will have some range of characteristics. How that range of draft gear characteristics affects coupler impact force is also not well understood. These factors merit further investigation.

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