AN EVALUATION OF HAZMAT DOUBLE STACK COFC CONFIGURATIONS

by

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performed for

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14 - Hazmat

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1.0 INTRODUCTION

The Federal Railroad Administration (FRA) is responsible for ensuring the safe transport of hazardous material by rail. The Office of Safety requested the Office of Research and Development to conduct a study on the use of double stack containers carrying hazardous materials. Previous research was conducted on container on flatcar (COFC) service for tank containers and portable tanks in single stack. Double stack service was prohibited due to the flat cars not having end-of-car cushioning. A shipper has recently conducted tests with double stack containers and claim they are safe in normal rail transit. Data from these tests were presented to the FRA to substantiate the claim.

As a part of the studies being conducted, the Office of Research and Development issued a Purchase Order Contract to George Kachadourian Engineering Services to perform an analytic study of the feasibility of allowing tank containers and portable tank containers to be in double stack COFC service for the transportation of hazardous material by rail. This analytical study purchase order consisted of the following four tasks:

Task 1. Review technical information submitted by the Union Pacific Railroad Company (UPRR) in support of their claim that the proposed double stack configurations for hazardous material shipment in tank containers are as safe as the current use of COFC shipments.

Task 2. Conduct engineering studies to analyze the test data submitted by the UPRR. Areas to be addressed included rock and roll, stability, slack action, and impacts.

Task 3. Use the computer program FRATE in support of the analysis, including modifications to the model to simulate double stack configurations.

Task 4. Prepare draft and final reports on analyses conducted.

Tasks 1 and 2 have been completed and the results presented in the letter report in Reference 1. [1]

The freight car configuration under question is typically a five-unit articulated car using 70-ton three piece trucks at each end and 125-ton three piece trucks at the four points of articulation. The cars are referred to as well cars because the car floors are typically 10 in. above the top of rail and are designed this way to enable double stacking of containers.

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[1] References are listed on page 36.

The transport of hazardous liquid materials in tank containers are the specific concern of this effort. The typical weights of these loaded liquid tanks are such that maximum gross weight of the well car is reached with single stack. They can, however, be double stacked if the specific gravity (SpG) of the liquid is less than 0.70 or if loaded and empty tanks are mixed. Double stacked containers were also included in the study since they can be mixed in a consist with tank containers.

This report begins with a summarization of the results of Tasks 1 and 2, and then presents the results of the Tasks 3 and 4 efforts.

2.0 SUMMARY OF TASKS 1 AND 2

Tasks 1 and 2 of the Purchase Order Contract,DTFR53-89-P-00591, "Evaluation of Hazmat Double Stack COFC Configurations", required the contractor to perform a review and engineering studies on data submitted by the Union Pacific Railroad Company intended to justify the claim that the double stack configuration for hazmat shipment in tank containers is as safe as the current use of COFC shipments. Data were presented for Rock and Roll, High Speed Stability, Train Slack, and Impacts, these being four areas previously specified by the FRA as needing definition.

The general conclusion reached by the review and analysis is that the data presented by the UPRR are not sufficient to justify permission for the use of double stack tank containers in well cars.

In the case of lateral stability, improvement is needed in the performance of the 70-ton trucks.

For Train Slack and End-of-Car Impacts, one would expect significant change in performance because of the large change in end-of-car cushioning: 89 ft flatcars have 13.5 times the cushioning travel than well cars have. No data was presented on Train Action. Very limited data was presented on End-of-Car Impacts. Justifying data is needed in both of these areas.

Rock and Roll performance was evaluated only for cross level wave lengths of 39 ft. With the high CG's of double stack configurations, critically large Rock and Roll response can be expected with cross level wave lengths that are close to truck spacing distances. Further, there is very little data available on track geometry variations in the wave length range of 50 to 58 ft. Additional data is consequently needed both on well car performance and geometry of service track.

2.1 Rock and Roll

The UPRR letter presents data on rail tests that show the well car to perform better then the 89 foot (ft) flatcar, in Rock and Roll. Also, it was reported that there were a number of configuration changes tested which had little effect on the roll resonance response. These changes included different trucks, different friction shoes, different side bearing configurations, and the testing of a single platform unit. However, all testing was performed with 39 ft staggered rail and, with its 50 ft truck spacing, the well car was not at all sensitive to the 39 ft wave length. The results must be restricted to 50 ft truck spacing on 39 ft rail. Although 39 ft wave lengths are predominant in track geometry variations, especially for the staggered rail cross level variation that drives rock and roll, there are a wide range of wave lengths actually present in service track. A complete evaluation of Rock and Roll performance should include information in the following two areas:

1. Track geometry data for service rail that includes the 50 to 58 ft truck spacing of well cars. A related concern that must be addressed is that the 62 ft midchord measurement systems used in the past were blind to track geometry variations at and near 62 ft.

2. Response of the well car to amplitudes and wave lengths of rail geometry variations that are representative of service rail and that include well car truck spacing.

There are two configurational parameters that have the greatest influence on the Rock and Roll performance of a freight car: the height of the center of gravity (CG) and the truck spacing. Table 1 lists typical CG heights and truck spacings for 89 ft flatcars, covered hopper cars and well cars.

The 89 ft flatcar has been found to be a relatively good performer in the 39 ft rail rock and roll test because of its relatively low center of gravity but more significantly, because of its 66 ft truck spacing and relatively flexible body which cause it to be insensitive to 39 ft staggered rail.

Conversely, the covered hopper car has been found to be a poor performer because of its relatively high CG and also because its truck spacing is close to the 39 ft rail length.

Although 39 ft is the wave length of cross level perturbations that occurs most frequently in service track (because of the predominance of 39 ft rail), there are other wave lengths present. With the high CG's of covered hopper and double-stack well cars, the existence of these other wave lengths should not be ignored.

TABLE 1
COMPARISON OF THE CG HEIGHT AND TRUCK SPACING
OF SEVERAL TYPE OF FREIGHT CARS

Vehicle	CG Height (in)	Truck Spacing (ft)
89'Flatcar	80-85	66
Covered Hopper	95-100	40-45
Well Car (a)	102-120	50-58
Well Car (b)	87-105	50-58
Well Car (c)	48-51	50-58

Notes: CG Height measured from top of rail for the gross weight of the car.

Well Car (a): Double-stacked 9.5 ft containers, includes case with loaded top and empty bottom containers: total height of car = 20 ft.

Well Car (b): Double-stacked 8 ft containers, includes case with loaded top and empty bottom containers: total height of car = 17 ft.

Well Car (c): Single-stack 8.5 ft tank containers, tank dia. 7.5 ft, filled to 5700 gal. (90% capacity), with 9.30 lb./gal. (1.12 kg/l), at max allowable gross wt. of well car.

The Well Car (a), of Table 1, with double-stacked, 9.5 ft containers is seen to have extremely high CG's but despite this can be expected to perform well in 39 ft staggered rail, rock and roll tests because of the 50-58 ft truck spacing. The performance of well cars can be further improved through a lowered CG if the container height is limited to eight feet, as in the example Well Car (b) of Table 1.

The typical tank container used in rail service is 20x8.5x8 ft in length, height, and width with volume capacities ranging from 4300 to 6600 gal. Any of these tanks in double stack, filled to capacity with a liquid having specific gravity of one, would exceed the max gross weight allowable of the well car. The 6600 gal tank in single-stack, filled to 96% of volume capacity with water would equal the max gross weight allowable for the well car. Limiting liquid tank containers carrying hazardous materials to single-stack use would eliminate concern over the rock and roll problem and would not adversely affect the efficient use of the well car.

In summary, although the safe rock and roll performance of well cars with 39 ft staggered rail is assured, performance with rail geometry variations of 50-58 ft wave lengths is not known. A determination needs to be made of well car performance with these wave lengths and their frequency of occurrence and amplitudes in service track. Both cross level and alignment variations should be considered. A preliminary performance evaluation has been made analytically using the FRATE computer program as part of the effort of this report and is presented in Section 3 below. Track geometry data for the 50-58 ft wave length range probably exists in the files of RR companies, the FRA, and FRA contractors.

Also, resonance response in both the first and second roll modes should be determined. The second roll mode can be characterized as a roll-sway mode.

There are two additional potential problem areas that should be addressed. The first is that rail geometry definitions made with 62 ft chord offset measurements are insensitive to wave lengths near 62 ft, and consequently, existing rail geometry data may be inadequate for the assessment of the performance of cars with 58 ft truck spacing.

The second potential problem area has to do with the high CG's of double stack cars and their tendency to roll-over when in a curve, under draft conditions, at low speeds, and including cross level and curve perturbations. For the case of tank containers carrying liquid lading, the lateral shift of the center of gravity due to liquid slosh should also be included in the assessment of roll over margins. This could be done either as a statics problem or with FRATE to include the dynamics of liquid slosh.

2.2 High Speed Stability

Attachment B to the subject UP letter presents results from high speed stability tests of the two configurations of an 89 ft flatcar with containers and a five unit APLX double stack container car.

The 89 ft flat was reported to hunt at speeds of 50 mph or faster when equipped with Stucki constant contact side bearings and standard roller bearing adapters. After Miner side bearings and/or modified roller bearing adapters were installed, the car was reported to be stable at all speeds. Thus, the well cars should also be stable if they are equipped with Miner side bearings and/or modified roller bearings the well cars.

The APLX well car test results indicated that the inner (125 ton) trucks were stable at all speeds tested (70 mph max). However, the end trucks (70-ton) did occasionally hunt at speeds between 65 and 70 mph. This would indicate that the 70-ton truck hunts at lower speeds in the well car application than in 89 ft flatcars. This difference in stability performance of 70-ton trucks can be attributed to the difference in gross weight. That is, the load carried by the 70-ton truck in the well car is 25 to 30 percent less than the flatcar truck.

Thus, the hunting threshold of the 70-ton truck can be expected to be at lower speeds as used in well cars than as used in 89 ft flatcars. From experience in the industry, Reference 2 for example, the hunting threshold will be further lowered with lightly loaded and empty vehicles and with wear of wheels and truck parts. There is, consequently, a high probability that the well car 70-ton trucks will be unstable within the operating speed range.

2.3 Train Slack

According to the data presented by UPRR, a unit train of well cars, using M-901-G draft gear, would have about 2 ft of slack for each 1000 ft of train where a unit train with 89 ft flatcars, using 15 inch end-of-car cushioning, would have about 27 ft of slack per 1000 ft of train. With no further justification, UP concluded the well car to be trouble free with respect to train slack. There should be data presented or reports referenced that would substantiate this conclusion.

2.4 Impacts

Attachment D of the subject Union Pacific letter presents data from impact tests of a six-platform Budd Lo-Pac car and four flatcars to substantiate the hypothesis that "-container accelerations on well cars without end-of-car cushioning are comparable to those experienced on flatcars with end-of-car cushioning --- attributed to the increased mass of the well car." That is, the test well car of 671,000 lb gross rail load (GRL) impacting into an anvil group of three 70-ton covered hopper cars (estimated 600,000 lb GRL) can be expected to experience lower "g" forces than a single flatcar of 200,000 lb GRL (assumed) impacting into a similar anvil group (also assumed).

The hypothesis is reasonable but its significance is moot. Because of the large GRL the coupler forces will be proportionally larger despite the lower "g" forces on the containers. Further, if the anvil group for the well car test were increased in mass to be proportionally the same as in the flatcar test, the coupler forces would be further increased and the container g's would be about the same as or greater than in the flatcar depending on the length of cushioning in the couplers. Also the use of trailers on five of the six platforms adds uncertainties to the test results because the fore-and-aft dynamics of trailers and containers are very different.

One observation to be made from the test data presented in Attachment D of the UP letter is that the M-901-G draft gear reaches the end of its 3.5 in. travel with impact speeds above 4.5 mph. The data shows coupler forces and container g's increasing at increased rates for impact speeds beyond 4.5 mph.

2.5 Summary

The data presented in the UPRR letter is not sufficient to verify the safety of transport of hazardous materials in double-stack well cars. In comparisons with 89 ft flatcar performance, the effects of higher CG's are not accounted for and the "as safe as" assessment is not complete. The following areas need further investigation.

a. Rock and Roll. The response of well cars to cross level variations with wave lengths of 50-58 ft. needs to be determined, as well as the frequency of occurrence and amplitudes of these cross levels in service track.

b. Sway and Roll. The response of well cars to alignment variations with wave lengths of 50-58 ft. needs to be determined, as well as the frequency of occurrence and amplitudes of these variations in service track.

c. High Speed Stability. The high speed stability of the 70-ton trucks, used at the end positions of the five car units, needs to be improved.

d. Train Slack. Direct data or references should be obtained which show that a well car train using M-901-G draft gear will have satisfactory and controllable train action with acceptable buff and draft transient forces.

e. Impact Loads. The use of the M-901-G draft gear rather than end-of-car cushioning, all other things being the same, would result in increased forces on the couplers and container attachments. The prohibition of hump-yard impacts eliminates the worst of these loads. It is presumed that the well cars in question have met the AAR design demonstration requirements for buff and draft and impact load conditions (excluding hump-yard impacts). Evidence of this demonstration needs to be presented. The data presented comparing well car and flatcar impact test results is not sufficient.

f. Curving. A determination should be made of the roll-over margins with the conditions of draft in a curve, at low speeds, with cross level and curve perturbations, and the lateral shift of the CG due to liquid cargo movement.

3.0 ROCK AND ROLL ANALYSIS

Five-unit double-stack well car configurations with truck spacings between 50 and 58 ft appear to perform well on 39-ft staggered rail, rock and roll test track. However, the CG's of double-stacked containers are probably higher than for any other class of car in service. Because of the high CG's there is concern as to well car performance over rail with cross level and alignment variations having wave lengths close to truck spacing.

The concern leads to two questions: (1), what is the performance of the well car for all wave lengths of cross level and alignment variation; and (2), what amplitudes of these variations are of probable occurrence in service track?

The rock and roll analyses performed in this task were intended to provide a qualified answer to the first question. The results are qualified in that the models used are approximations and the results obtained are consequently also approximate. The value of the analyses is that trends can be reliably shown and problem areas can be identified.

3.1 Description of Analysis

The analyses performed used a mathematical simulation of a single unit of the well car. Motions were imposed at the wheel-rail interface representing cross level and alignment variations using four wave lengths: 39, 46, 52, and 58 ft. Track speed was varied from 10 to 70 mph. Results were presented as variation of response with track speed, and variation of response at critical speed with rail wave length.

The analyses were performed using FRATE, Reference 3, a digital computer program for analysis of dynamic response of railcars developed under FRA sponsorship. Because it was necessary that certain nonlinear properties of freight cars be included, FRATE uses lumped mass modeling and a numerical integration method of solution. The program is written in FORTRAN and has been adapted for use on personal computers. The analyses of this report were performed on a NEC PowerMate 386/20 using the Lahey F77L version 4.00 to compile and link the program.

There are two unusual features in FRATE: (1) the truck model used; and (2) the lading model used. The truck model includes the following features:

- o The primary and secondary suspensions are modeled separately, where the primary includes track stiffness and can be used to simulate changes of lateral stiffness with and without flange contact.
- o Separation occurs when vertical forces reach zero at the

wheel-rail interfaces, at the side bearings, and at the center plates.

- Friction snubber forces are included as coulomb damping.
- Hydraulic snubbers are included as viscous damping active only in the compression stroke of the damper.
- The roll spring rate changes with roll condition, i.e., when: (1) the friction snubber force reaches the value at which the snubber shoe starts to slide; (2) the center plate transitions from seated to rocking; (3) side bearing contact is made; and (4) the center plate lifts off the center bowl.

The lading model enables independent modeling of four lading masses that includes vertical, lateral, and roll dynamics of each lading mass. In the case of liquid lading the first lateral slosh mode can be simulated.

The wave form used for the profile and alignment rail perturbations are shown in Figures 1 and 2. The profile variation of each rail was generated with a (cos - 1) function which results in a sinusoidal shape that dips below the uniform profile line. Five wave lengths were used with the amplitude varied by a second (1 - cos) function, so that with a designated cross level of 0.75 inches, the first and last waves were approximately 0.08 inches in cross level, the second and fourth waves 0.50 inches, while only the middle wave was at 0.75 inches.

The same wave form was used for the alignment variation. The phasing between alignment and profile was tried with both down-rail-out and down-rail-in. The basic analysis was performed with cross level only. Then check runs were performed to shown the effects of alignment and cross level together.

This wave form, with variations on wave length and height, was used for the following reasons. Profile variations in service track tend to dip below the uniform profile and also tend to occur in series. The roll response of one unit of the five unit well car will tend to force a roll response in each of the other units. Thus, if the well car traverses a single cross level perturbation, each unit will receive five roll impulses; one from its traverse of the perturbation and one from each of the other four units as they each traverse the perturbation.

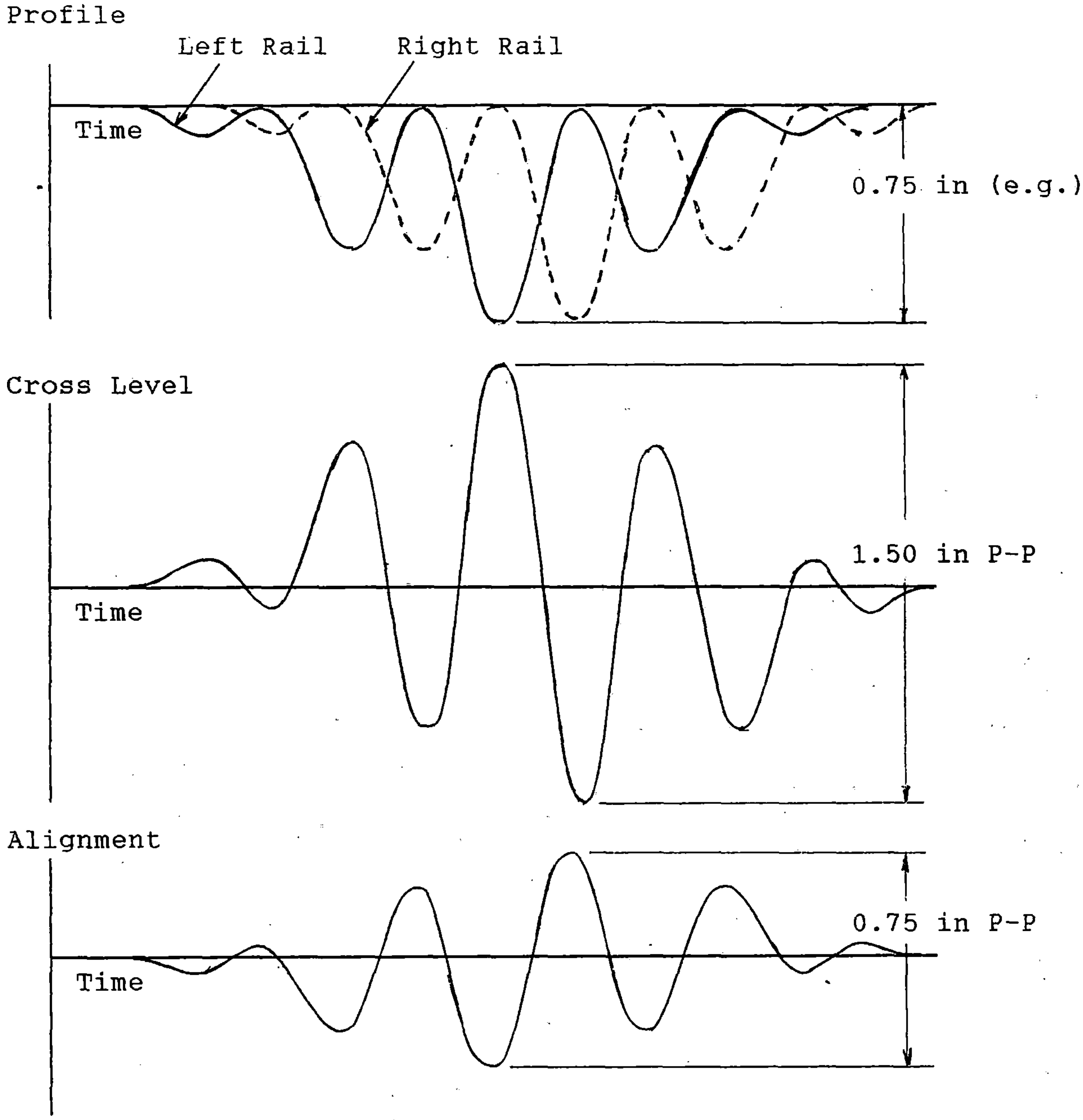

FIGURE 1

TRACK GEOMETRY WAVE FORMS USED IN ANALYSIS AT TRUCK A

Profile, Cross Level, and Alignment

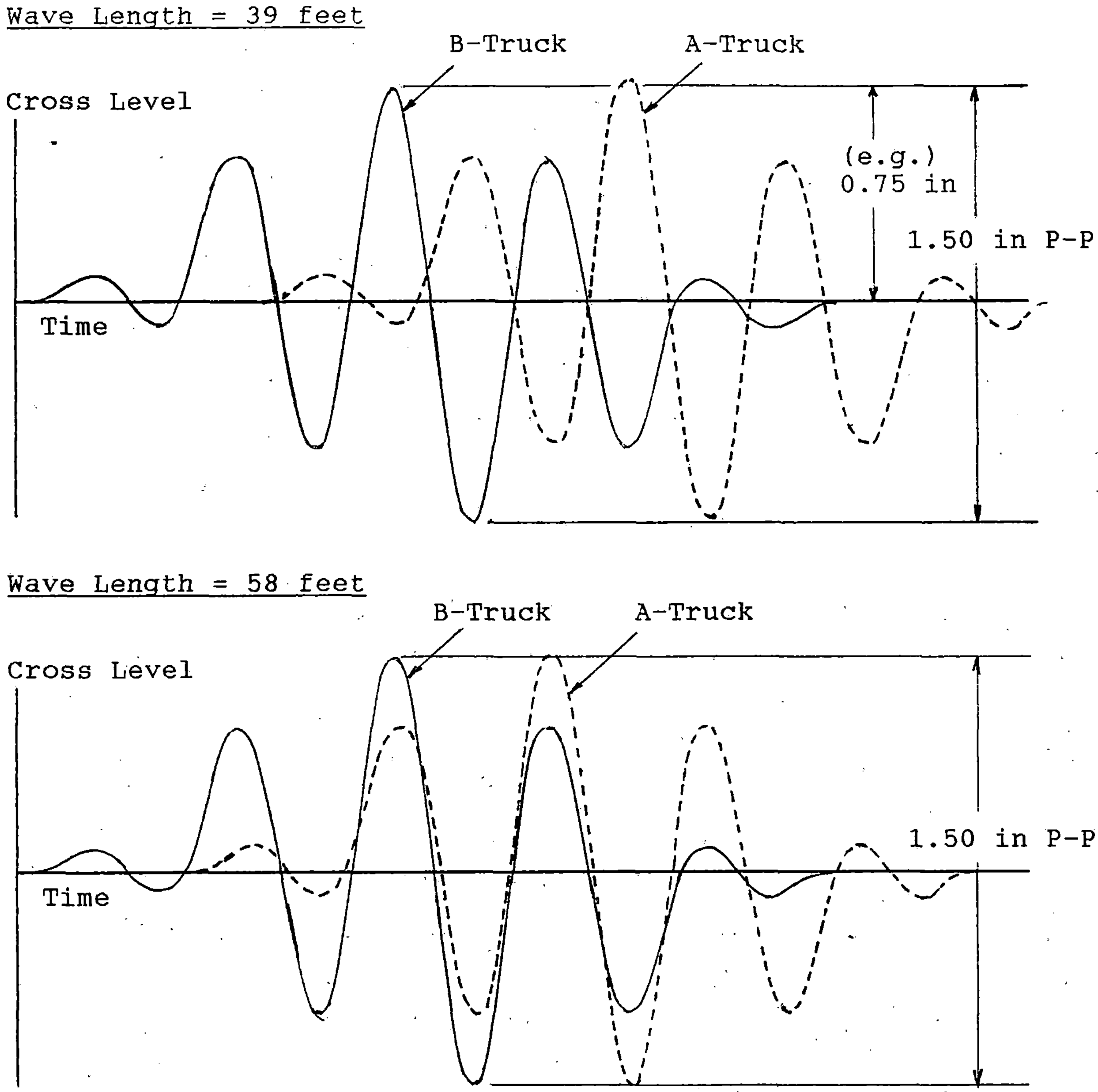

FIGURE 2

COMPARISON OF TRACK GEOMETRY WAVE FORMS
FOR 39 AND 58 FOOT WAVE LENGTHS

Cross Level Variations at Trucks A and B

3.2 Description of the Well Car Models

The well car models developed for the Rock and Roll analysis were based on configuration data from three manufacturers of five-unit well cars:

- Thrall Car Manufacturing Company, Chicago Heights, Illinois
- Trinity Industries Inc., Hammond, Indiana and
- Gunderson Inc., Portland, Oregon.

A summary of pertinent data for each of these configurations is listed in Table 2. The three configurations are seen to be similar: light weight is between 36,400 and 38,000 lb; capacity is between 121,500 and 122,400 lbs; Gross Rail Load (GRL) is between 794,000 and 797,500 lbs; truck center distances are between 50.15 and 58.83 ft; and the container platform for the light weight vehicle is between 10.375 and 11.0625 in. In addition, three piece trucks are used throughout: 70-ton for the end trucks and 125-ton for the inner units and all trucks are equipped with 16 in. center plates and constant contact side bearings.

TABLE 2
WELL CAR CONFIGURATION DATA

Item	Weight, (lbs)		
	Thrall	Trinity	Gunderson
Units A & B: Lt Weight	38,000	36,400	36,800
Capacity	121,500	122,400	122,000
Units C, D & E: Lt Weight	38,000	36,400	36,000
Capacity	121,500	122,400	122,000
Total Capacity (lb)	607,500	612,000	610,000
Truck Weight: 70-Ton	(included in light weight)		
125-Ton			
Gross Rail Load	797,500	794,000	794,000
Truck Centers: End Units	50.65 ft	50.49 ft	50.15 ft
Center Units	58.83 ft	50.86 ft	50.23 ft
Height of Platform (Lt.Wt.)	11.0625 in	10.375 in	10.875 in

Using the data in Table 2, a "generic" configuration was devised, shown in Table 3, that was representative of all three. The truck weights are estimates.

TABLE 3
GENERIC WELL CAR WEIGHT DATA

Item	Weight (lb)
Platform Body, per unit	26,000
Capacity per unit	122,000
Total Capacity	610,000
Truck: 70-ton	8,000
125-ton	12,000
Max Gross Rail Load	804,000
Truck Center Distance	58 ft
Height of Platform	10 in

Using this generic configuration, five computer models were developed which included variations of: solid and liquid cargo; double and single stack; and nominal and high CG. The models, identified as Well1 - Well5, are described below and in Table 4.

Well1 - A nominal, double stack configuration with 9.5 ft containers, cubed with 17.8 lb/cu ft solid cargo.

Well2 - A high CG configuration for double stacked 9.5 ft containers, top containers cubed with 17.8 lb/cu ft cargo, and bottom containers empty.

Well3 - Hazardous liquid tank containers in single stack. Container height = 8.5 ft, tank ID = 7.5 ft. Liquid SpG = 1.12.

Well4 - A nominal configuration for double stack liquid tank containers. Container height = 8.5 ft, tank ID = 7.5 ft. Liquid SpG = 0.66.

Well5 - A high CG configuration for double stacked hazardous liquid tank containers. Liquid SpG = 1.00 in top tanks. (Bottom tanks empty)

TABLE 4
MODEL CONFIGURATION DESCRIPTION

Config	Cargo	Stack	Container Ht. (ft)	GRL (1) (ton)	CG (2) (in)
Well1	Solid	Double	9.5	80	101.99
Well2	Solid	Double	9.5	57	115.75
Well3	Liquid	Single	8.5	80	48.54
Well4	Liquid	Double	8.5	80	84.82
Well5	Liquid	Double	8.5	69	108.83

Notes: (1) Gross Rail Load per unit well car, where 80 ton = maximum allowable GRL.
(2) CG height is from top of rail

The program FRATE is written for a single unit, two truck freight car and so it was consequently necessary to make some simplifying assumptions. The dimensions used were representative of an inner unit and truck properties were for an inner (125-ton) truck. Because the analysis model included only one unit it was necessary to adjust the truck properties to account for the condition that each inner truck supports two car units. Accordingly, truck weight, stiffness, and damping properties were halved. The inherent assumption is that the two unit bodies on the shared truck have the same motions.

All of the detailed data for each of the five models as used in FRATE are contained in Appendix A. The same truck and car body model was used for all five models with the same stiffness and damping properties. The weights, inertias, and CG heights were adjusted for each model.

3.3 Rock and Roll Analysis Results

Rock and roll analyses were performed for the five configurations described above and detailed in the Appendix. The analyses consisted of inputting track geometry variations and outputting responses of the well car model. The model responses of interest were car body roll angles, liquid lading slosh motions, and forces at the wheel rail interface.

The results of the analyses with Well1 are presented in Figure 3, which shows car body roll response for rail speeds from 10 to 70 mph with the four rail geometry wave lengths of 39, 46, 52, and 58 ft. Maximum roll angles obtained were 1.5 deg Peak-to-Peak (P-P) with 39 ft rail and 5.0 deg P-P with 58 ft waves. The wheel-to-rail vertical load was at 2 percent of static load when the body roll was at its maximum point of 5.0 degrees. This is close enough to be called a borderline wheel lift condition.

The results of the Well2 analyses are presented in Figures 4 and 5 showing car body roll angles for track speeds from 10 to 70 mph: Figure 4 for the four rail geometry wave lengths of 39, 46, 52 and 58 ft with the cross level amplitude of 0.75 in; and Figure 5 for the three cross level amplitudes of 0.75, 0.65, and 0.60 in with the 58 ft wave length. With 39 ft rail, the maximum roll angle was 2.0 deg P-P at 22 mph. However wheel lift occurred at the cross level amplitude of 0.75 in with rail wave length of 52 and 58 ft, and at 0.65 in cross level with 58 ft wave length.

The results of analyses with Well3 are presented in: Figure 6, which shows car body roll variation with speed for rail lengths of 39 and 58 ft; Figure 7, which shows the effects of alignment variation; and Figures 8 and 9 which show the amplitudes of liquid slosh motions. As expected, because of the low CG of Well3, the roll responses are small: 0.9 deg P-P with 39 ft rail, and less than 1.5 deg P-P with 58 ft rail.

When alignment rail geometry variations are imposed on the Well3 model in combination with cross level, the result is a 10 percent variation of car body roll response, increased or decreased depending on the phasing between cross level and alignment and the speed range. This effect can be seen in Figure 7. The effect on liquid slosh is much greater with the slosh amplitudes being changed between 60 and 100 percent as shown in Figures 8 and 9.

The liquid slosh motions are the lateral motions of the center of gravity of the sloshing liquid (assumed to be 35 percent of total liquid). Slosh motions reach a maximum of 10 in P-P with 39 ft rail and 18 in P-P with 58 ft rail. This is not seen to be a problem since in the worst case minimum vertical wheel loads were 70 percent of static load. However, this conclusion must be associated with the single stack, Well3 configuration which has a very low CG and is not responsive to rock and roll.

Results of analyses performed on Well4 and Well5 are presented in Figures 10 and 11 which show car body roll response over the speed range from 10 to 70 mph for the cross level wave lengths of 39, 46, 52, and 58 ft. The responses for these two configurations are very similar, the significant difference being that Well5, with the higher CG, has the larger roll response: maxima of 4.1 deg for Well5 and 3.7 deg for Well4. Both configurations have increasing response for increasing wave length of cross level and critical speeds ranging from 12 to 19 mph.

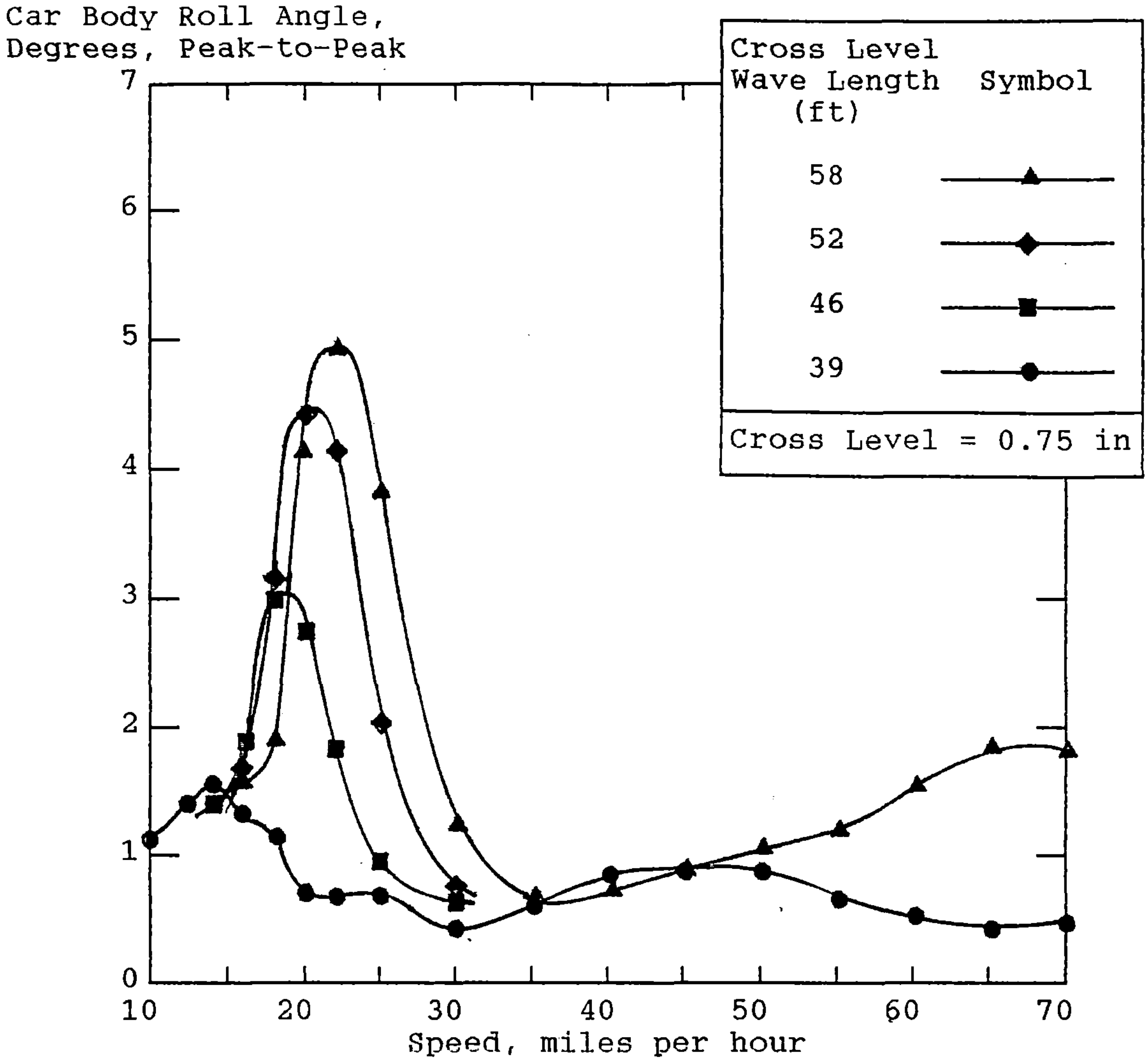

FIGURE 3

WELL1 ROCK AND ROLL RESPONSE
WITH VARIATION OF TRACK SPEED AND CROSS LEVEL WAVE LENGTH

Double stacked containers, CG at 101.99 in.

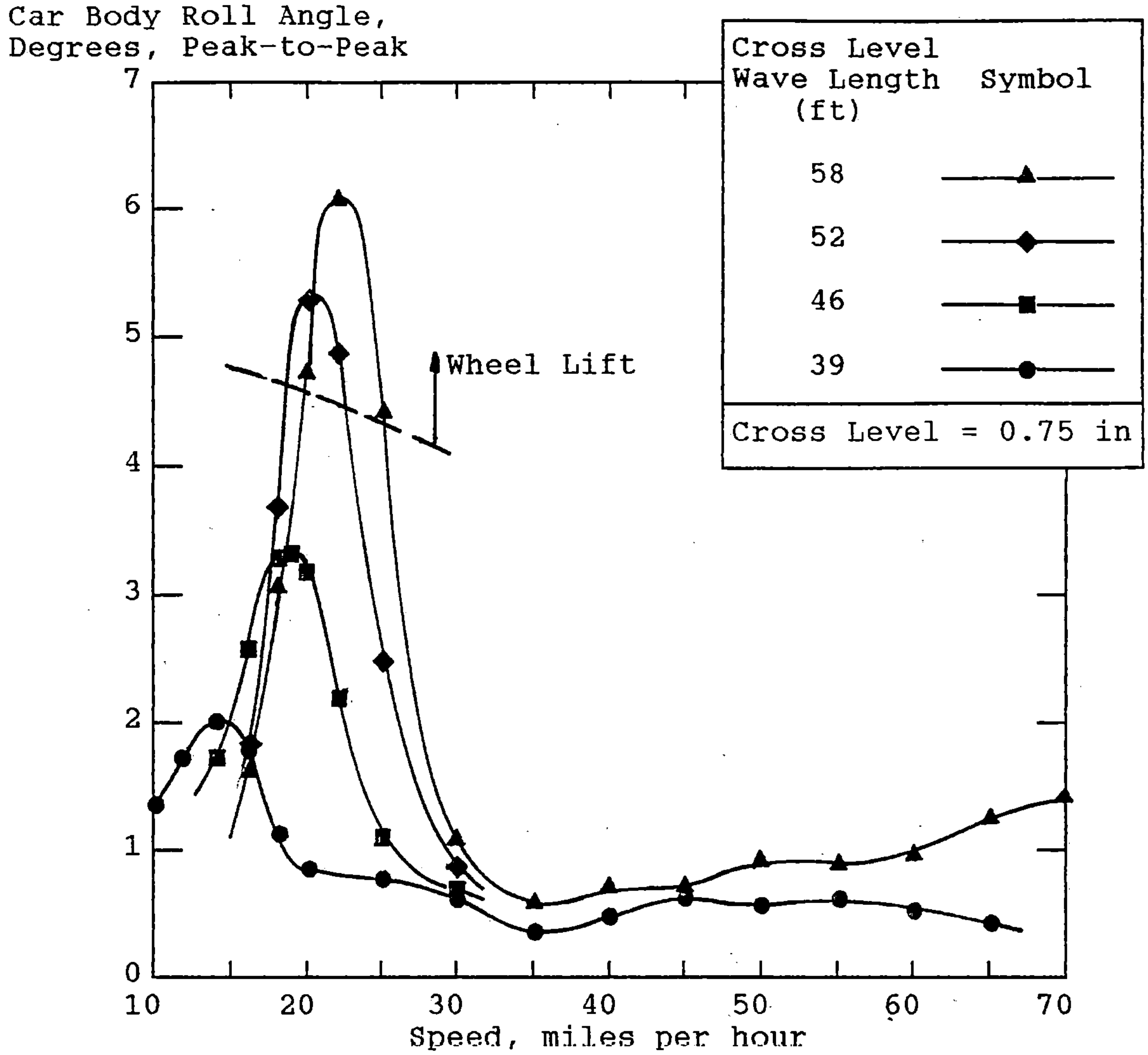

FIGURE 4

WELL2 ROCK AND ROLL RESPONSE
WITH VARIATION OF TRACK SPEED AND CROSS LEVEL WAVE LENGTH

Double stacked containers, CG at 115.75 in.

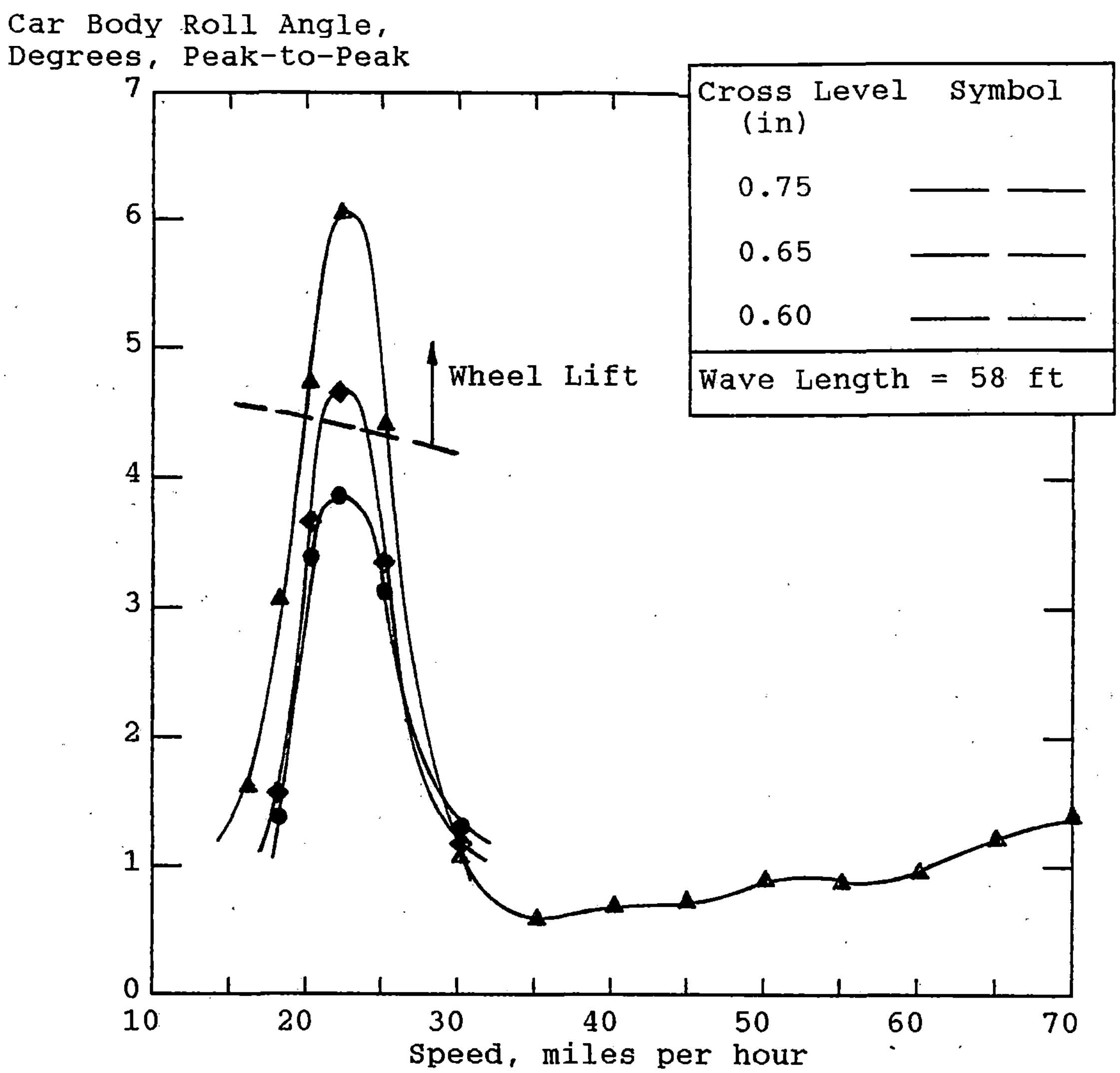

FIGURE 5

WELL2 ROCK AND ROLL RESPONSE
WITH VARIATION OF TRACK SPEED AND CROSS LEVEL AMPLITUDE

Double stacked containers, CG at 115.75 in.

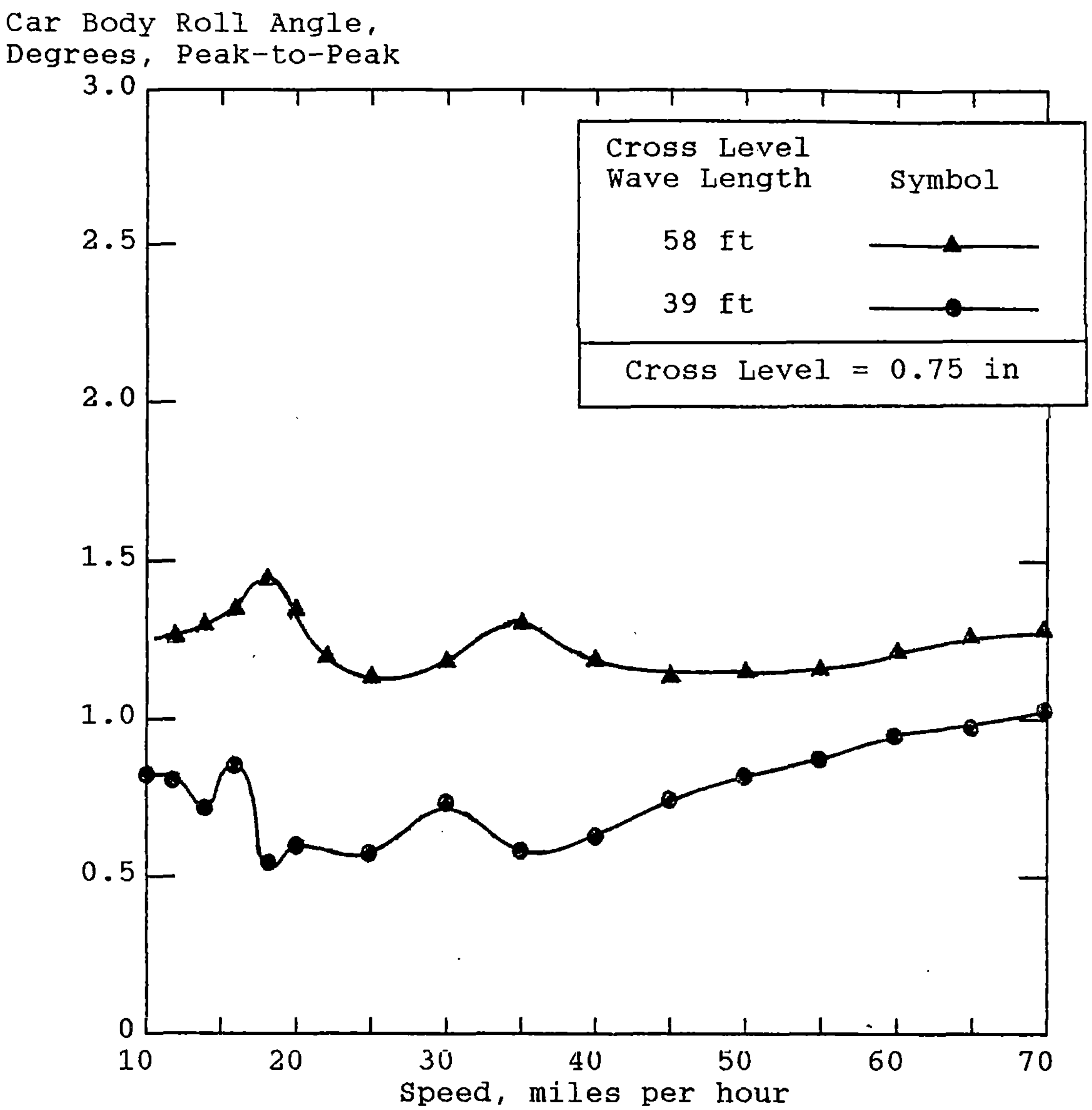

FIGURE 6

WELL3 ROCK AND ROLL RESPONSE FOR CROSS LEVEL WAVE LENGTHS OF 39 AND 58 FEET

Single stacked tank containers, CG at 48.54 in.

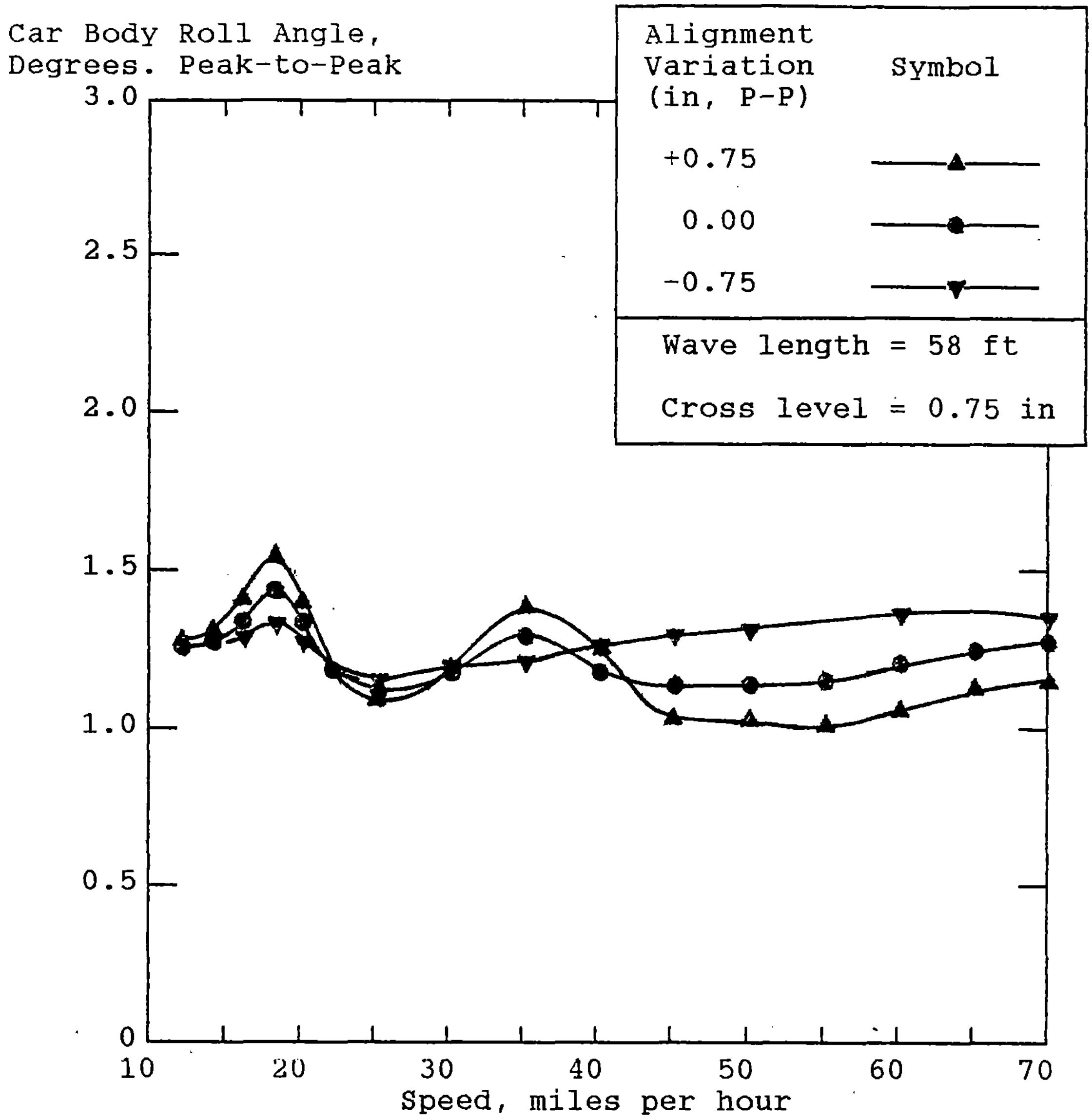

FIGURE 7

WELL3 ROCK AND ROLL RESPONSE,
EFFECTS OF COMBINED CROSS LEVEL AND ALIGNMENT VARIATION

Single stacked tank containers, CG at 48.54 in.

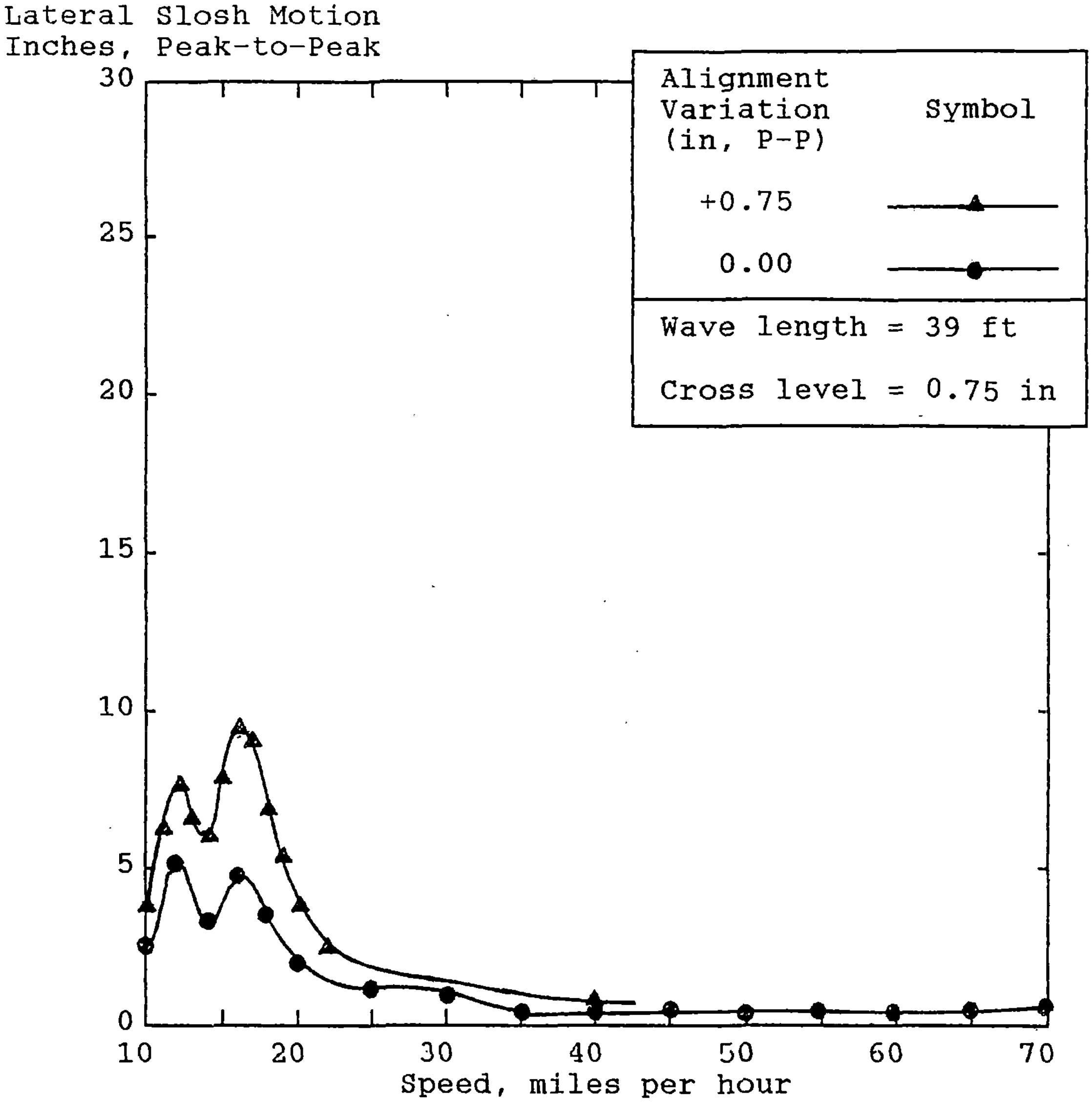

FIGURE 8

WELL3 LIQUID SLOSH RESPONSE IN ROCK AND ROLL, EFFECTS OF COMBINED CROSS LEVEL AND ALIGNMENT WITH 39 FOOT WAVE LENGTH

Single stacked tank containers, CG at 48.54 in.

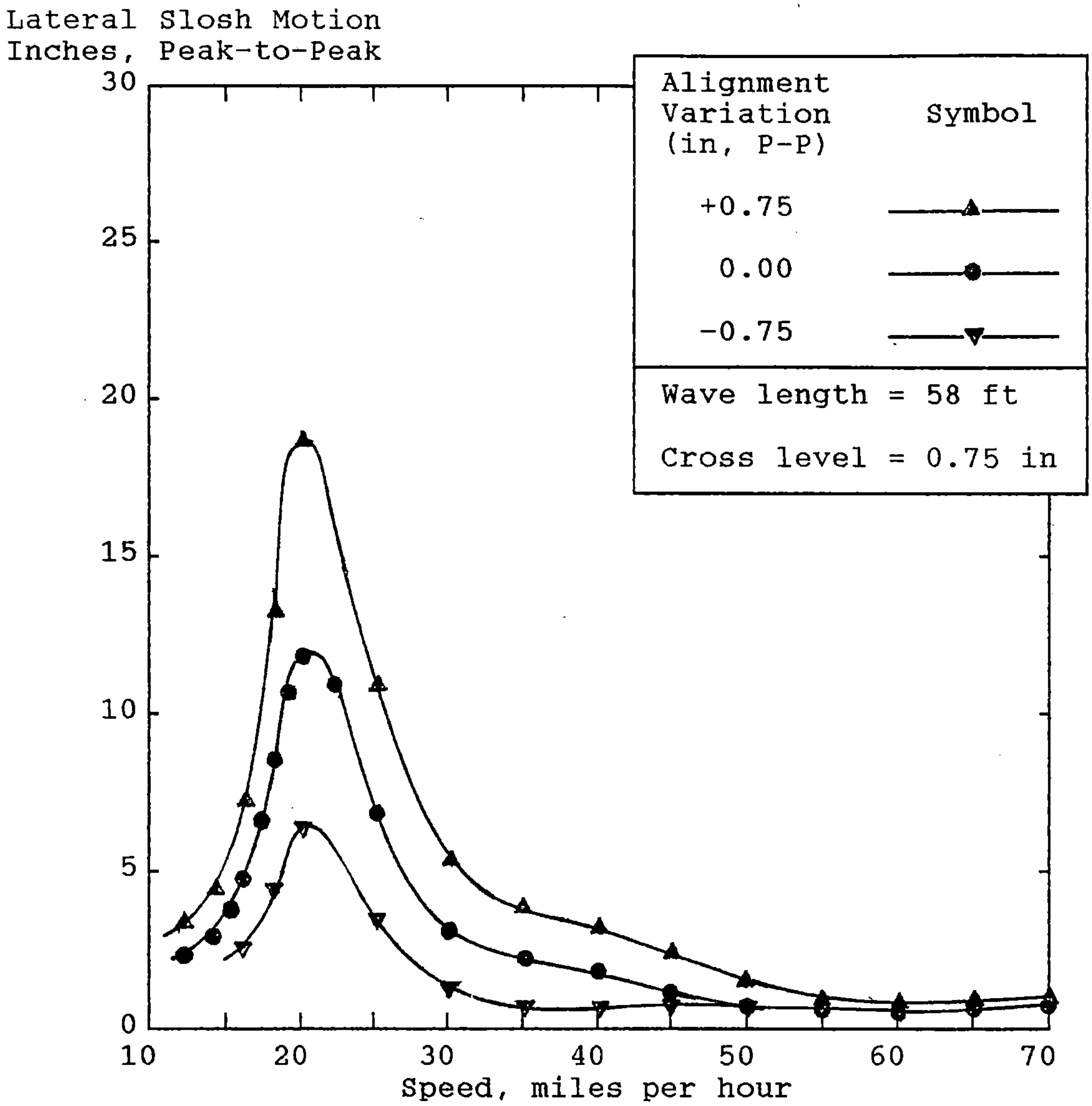

FIGURE 9

WELL3 LIQUID SLOSH RESPONSE IN ROCK AND ROLL, EFFECTS OF COMBINED CROSS LEVEL AND ALIGNMENT WITH 58 FOOT WAVE LENGTH

Single stacked tank containers, CG at 48.54 in.

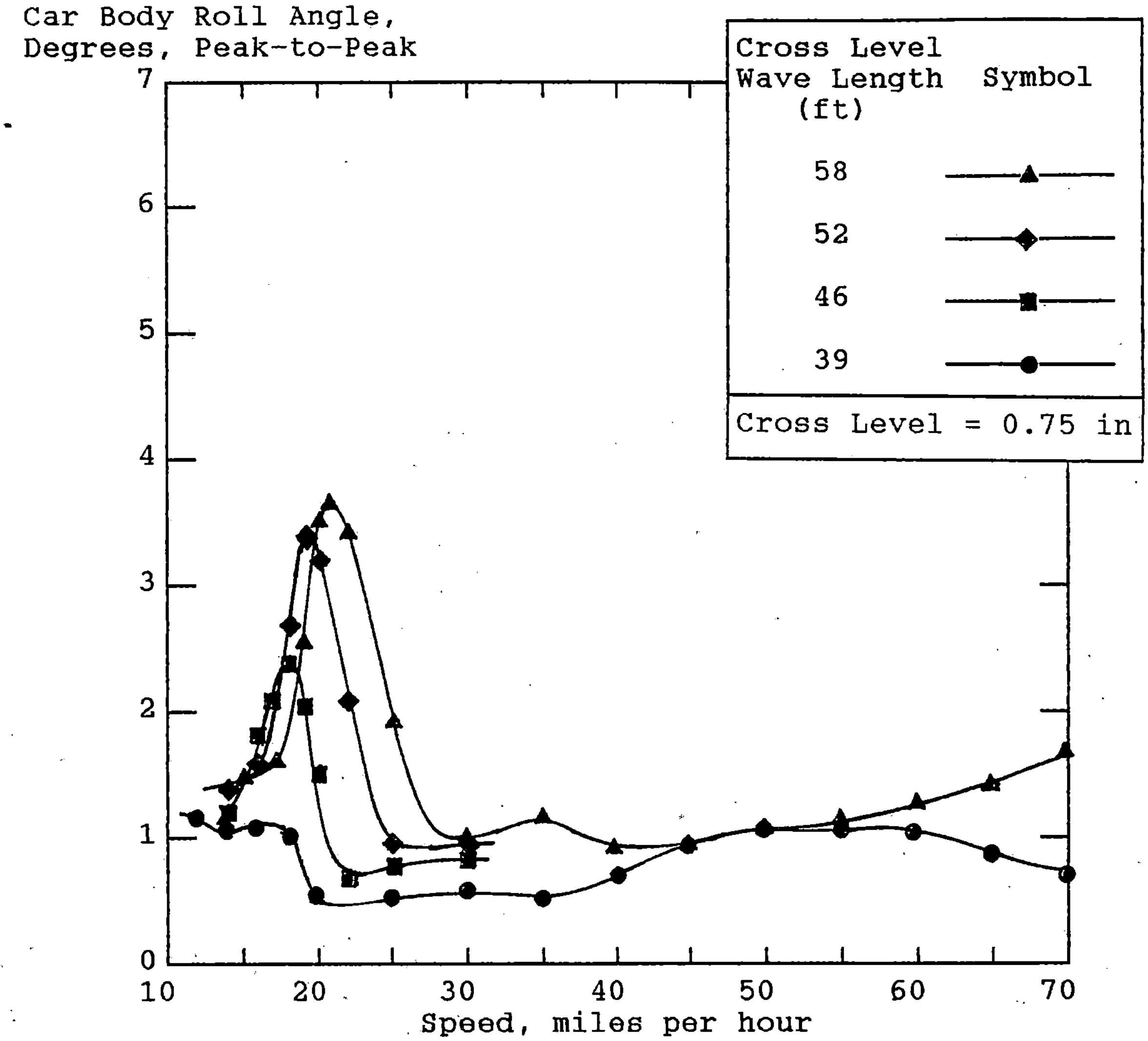

FIGURE 10

**WELL4 ROCK AND ROLL RESPONSE
WITH VARIATION OF TRACK SPEED AND CROSS LEVEL WAVE LENGTH**

Double stacked tank containers, CG at 84.82 in,

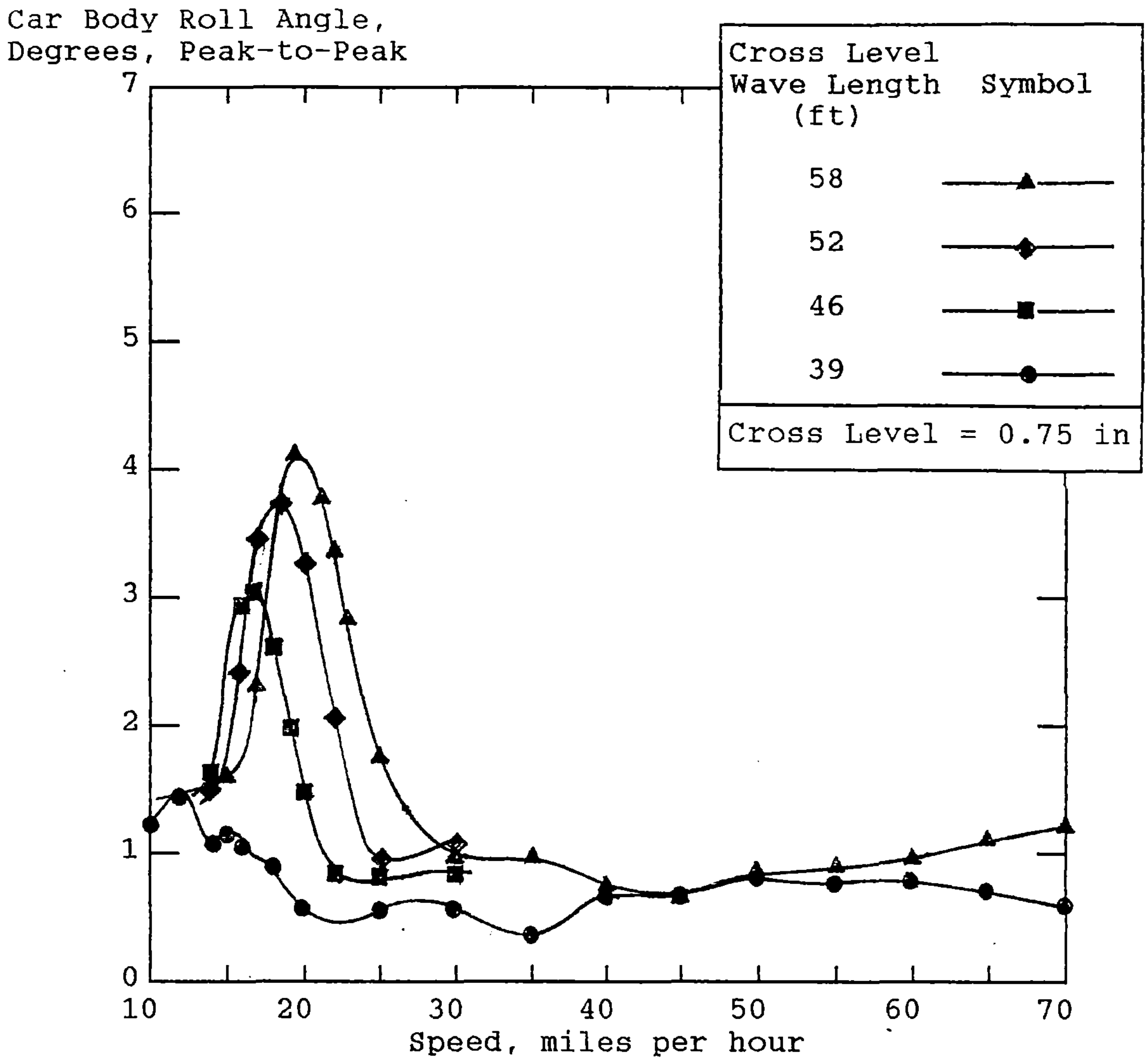

FIGURE 11

WELL5 ROCK AND ROLL RESPONSE
WITH VARIATION OF TRACK SPEED AND CROSS LEVEL WAVE LENGTH

Double stacked tank containers, CG at 108.83 in,

3.4 Rock and Roll Summary

Results of the rock and roll analyses performed on the five well car configurations are summarized in Table 5 and Figures 12 through 14. Table 5 lists the critical speeds, maximum car body roll angles, and minimum wheel loads for each model and each of the four cross level wave lengths analyzed. The data are also plotted against wave length in Figures 12 and 13, and against cross level amplitude in Figure 14.

All five configurations behaved well for the 39 ft staggered rail condition. The largest car body roll angle, Figure 12, was 2.0 deg P-P for Well2, the model with the highest CG. However, there was more wheel unloading than the small roll angles would indicate, the worst case again being Well2 with a minimum wheel load of 33% of static.

Model Well3 (single stack tank) is seen to be unresponsive to any wave length of cross level.

For the four configurations other than Well3, the roll response and wheel unloading increased as the cross level wave length was increased, reaching maximum values as the wave length approached the truck spacing of 58 ft.

As expected, the response of each configuration was strongly related to the height of its CG: Well2, with the highest CG, had the largest responses and Well3, with the lowest CG, had the smallest. The one exception was with Well5, CG = 108.83 in, which had smaller responses than Well1, CG = 101.99 in. This was probably due to differences in roll moments of inertia: Well5 is the lighter in weight of the two and, despite its higher CG, has smaller roll inertias. It should also be noted that the liquid lading tends not to roll with the rest of the vehicle, a factor which also tends to lower the roll inertia in comparison to a vehicle with solid lading.

Well2, the configuration with the highest CG, had the largest responses. Wheel lift was experienced at 0.65 in cross level with wave length of 58 ft, Figure 14, and at 0.75 in cross level with wave lengths of 58 and 52 ft, Figure 12. Car body roll angles were near 5 deg P-P in each case.

One significant observation to be made from this analysis is found in Figures 12 and 13. That is that wheel lift occurs before car body roll angles reach 6 deg P-P, the generally accepted safe limit for roll amplitude. It stands to reason that high bodied vehicles with high CG's cannot safely roll to as large angles as other cars that are not as tall.

Analysis runs were made for Well3, Well4, and Well5 with both cross level and alignment track geometry variations with the 58 ft wave length. That is, as each rail was perturbed down 0.75 in, it was given an alignment variation of 0.375 outward. The results are presented in Table 5. Well3 again shows small effects. However, Well4 and Well5 show significant wheel unloading when alignment variations are added: Well4 dropping from 34% of static vertical load to 13%, while Well5 goes from 8% to wheel lift.

TABLE 5
SUMMARY OF ROCK AND ROLL ANALYSIS RESULTS
Cross Level Input = 0.75 in

Model	Wave Length (ft.)	Critical Speed (mph)	Car Body Roll (deg P-P)	Wheel Load (% static)
Well1	39	14	1.6	53
	46	18	3.0	33
	52	20	4.5	8
	58	22	5.0	2
Well2	39	14	2.0	33
	46	18	3.4	6
	52	20	5.3	0
	58	22	6.0	0
Well3	39	16	0.9	74
	58	18	1.5	75
	58 (1)	18	1.6	70
Well4	39	12	1.2	67
	46	18	2.4	55
	52	19	3.4	42
	58	20	3.7	34
	58 (1)	20	4.5	13
Well5	39	12	1.5	56
	46	17	3.0	34
	52	18	3.7	14
	58	19	4.1	8
	58 (1)	20	5.1	0

(1) Combined 0.75 in cross level and 0.75 in P-P alignment.

Configuration Description

Config	CG (in)	Cargo	Stack
Well1	101.99	Solid	Double
Well2	115.75	Solid	Double
Well3	48.54	Liquid	Single
Well4	84.82	Liquid	Double
Well5	108.83	Liquid	Double

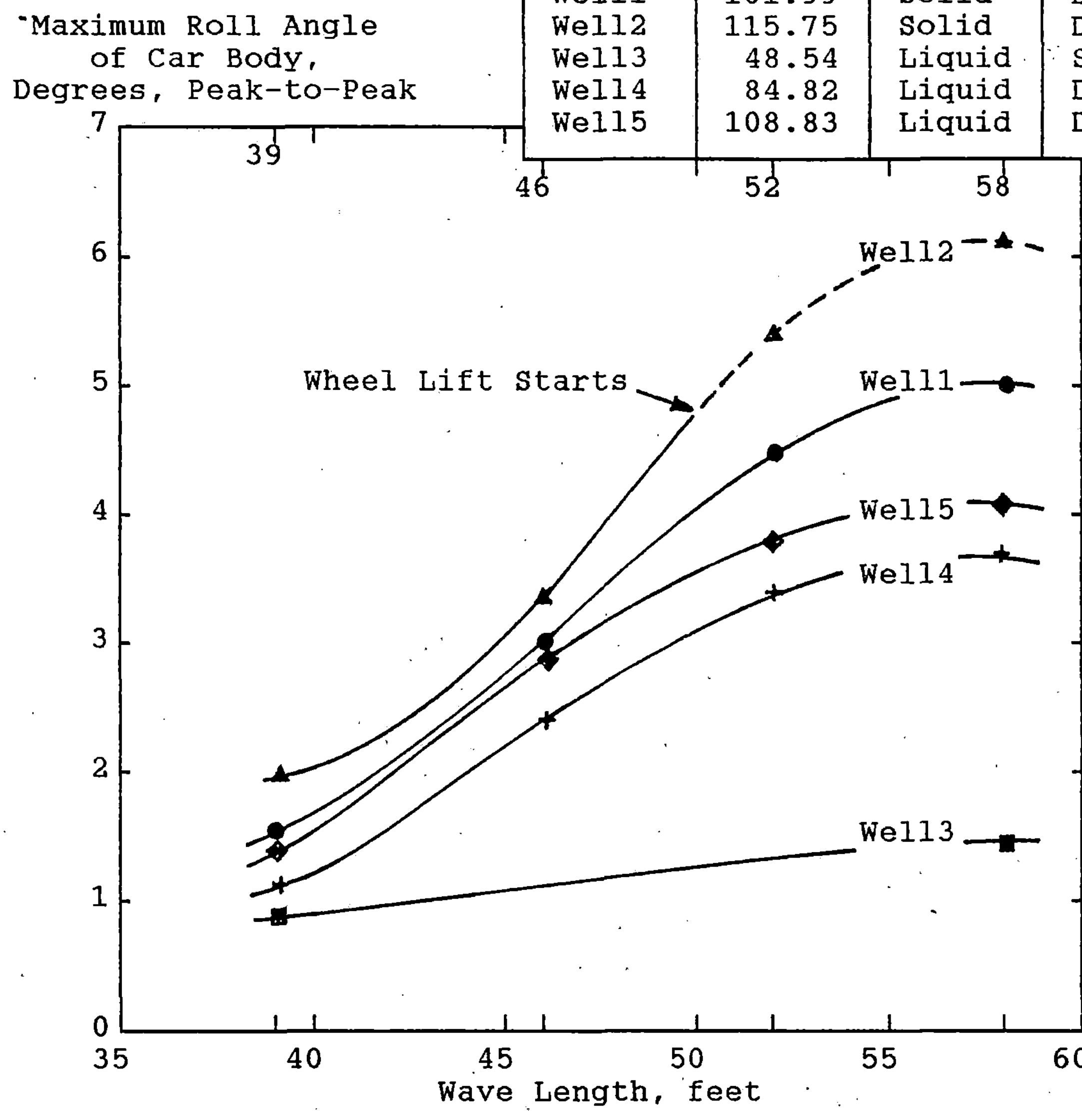

FIGURE 12

COMPARISON OF MAXIMUM CAR BODY ROLL FOR FIVE CONFIGURATIONS, SHOWING EFFECTS OF CROSS LEVEL WAVE LENGTH

Cross Level = 0.75 in

Configuration Description

Config	CG (in)	Cargo	Stack
Well1	101.99	Solid	Double
Well2	115.75	Solid	Double
Well3	48.54	Liquid	Single
Well4	84.82	Liquid	Double
Well5	108.83	Liquid	Double

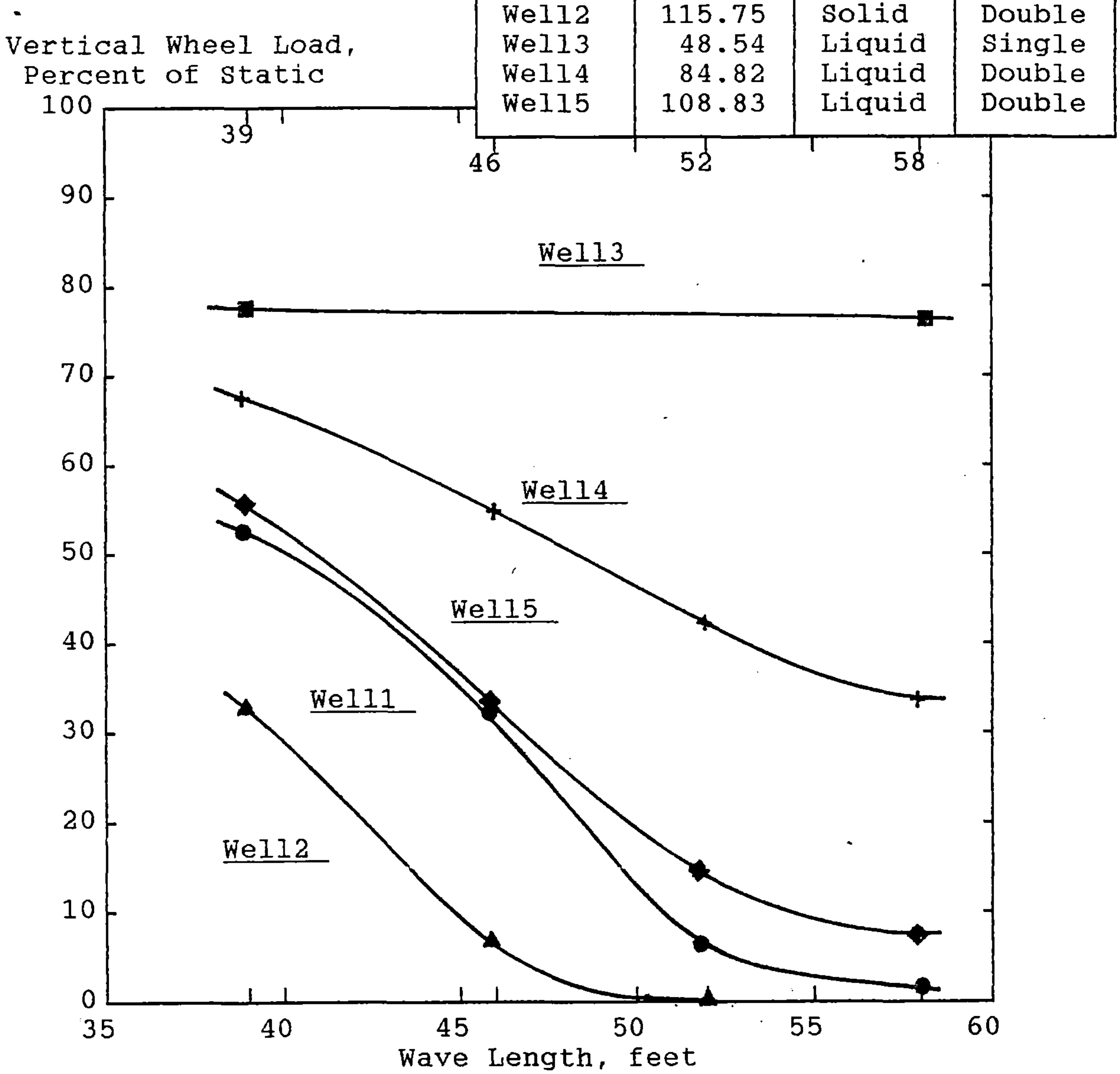

FIGURE 13

COMPARISON OF MINIMUM WHEEL LOADS FOR FIVE CONFIGURATIONS, SHOWING EFFECTS OF CROSS LEVEL WAVE LENGTH

Cross Level = 0.75 in

Configuration Description

Config	CG (in)	Cargo	Stack
Well1	101.99	Solid	Double
Well2	115.75	Solid	Double
Well3	48.54	Liquid	Single
Well4	84.82	Liquid	Double
Well5	108.83	Liquid	Double

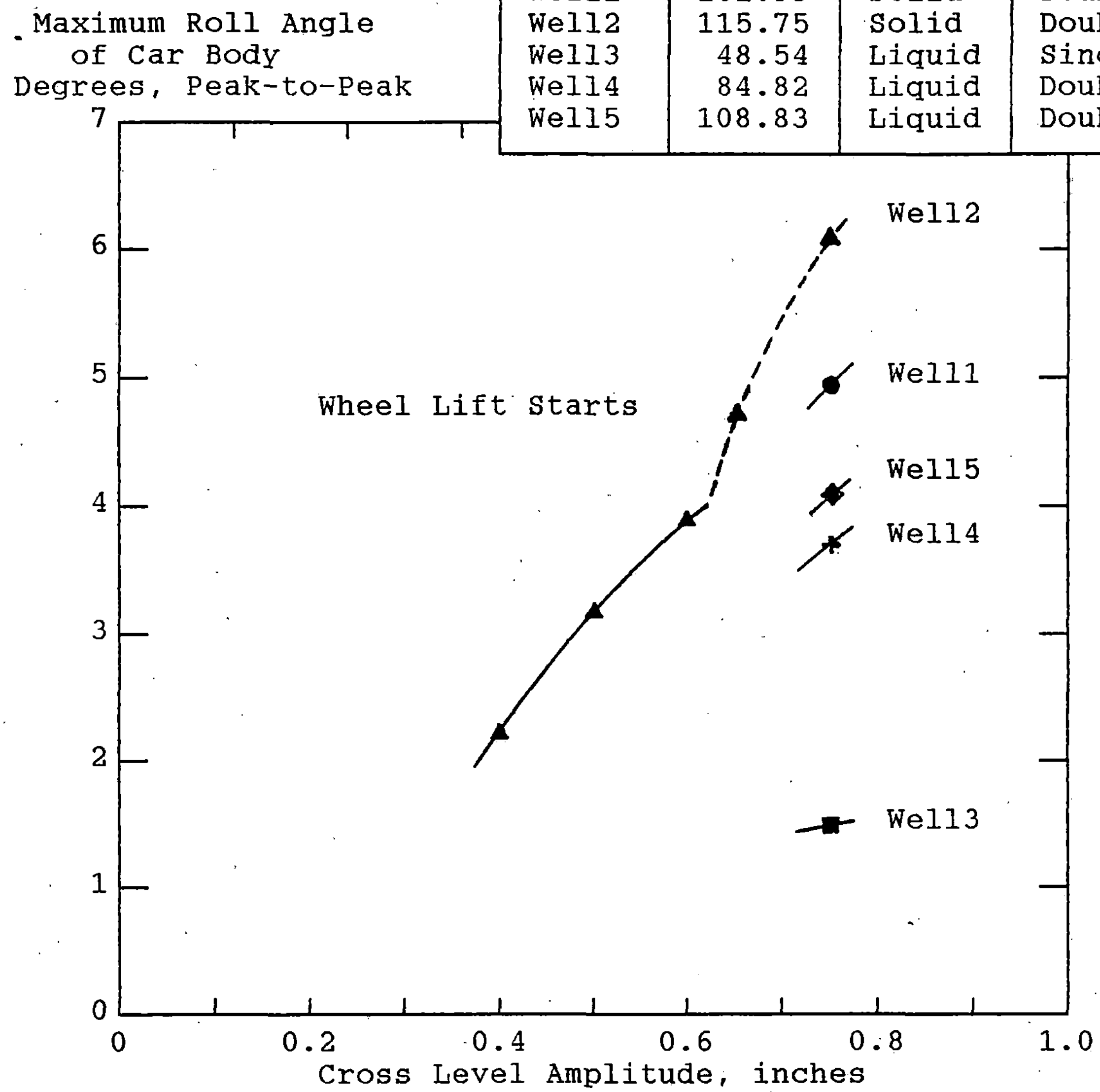

FIGURE 14

COMPARISON OF MAXIMUM CAR BODY ROLL FOR FIVE CONFIGURATIONS, EFFECTS OF CROSS LEVEL AMPLITUDE, WITH WAVE LENGTH = 58 FT.

4.0 THE EFFECTS OF LOW SPEED AND DRAFT CONDITIONS IN CURVES

When a freight car goes through a curve under draft conditions and at slow speeds, there are two force conditions that are changed. One is that the gravity force of the car weight shifts towards the inner rail, the amount of the shift depending on the super elevation of the track and the height of the CG. Further, there is a lateral component of the gravity force acting on the inner rail that is a function of the super elevation.

The second force change is that the draft force has a component that is radial to the curve. This lateral force, acting at the coupler, has a resulting roll moment acting on the car and a lateral force acting on the inner rail.

These force changes result in the loss of margin for three conditions:

lift-off of the outer wheel,

roll-over of the car, and

roll-over of the inner rail.

Calculations were made to determine the changes in these wheel-rail forces for a range of CG heights, track curvature angles, and super elevations. The draft force was assumed to be 400,000 lb. The results are presented in Figures 15 and 16, which show vertical loads on the inner and outer wheels and lateral loads on the inner wheels for a range of CG heights and track curvature.

These results show that there is a significant reduction of margins in the three conditions mentioned. For example, vertical loads on the outer wheel can range from 90 to 40 percent of static depending on curvature and CG height.

The effects of a 0.75 in rail perturbation in the curve can be approximated by combining the wheel unloadings shown in Figures 13 and 15. This would show that for a vehicle with a CG in the 100 to 110 in range, curvature in the 6 to 10 deg range, and rail perturbation wave lengths in the 39 to 45 ft range wheel lift will occur.

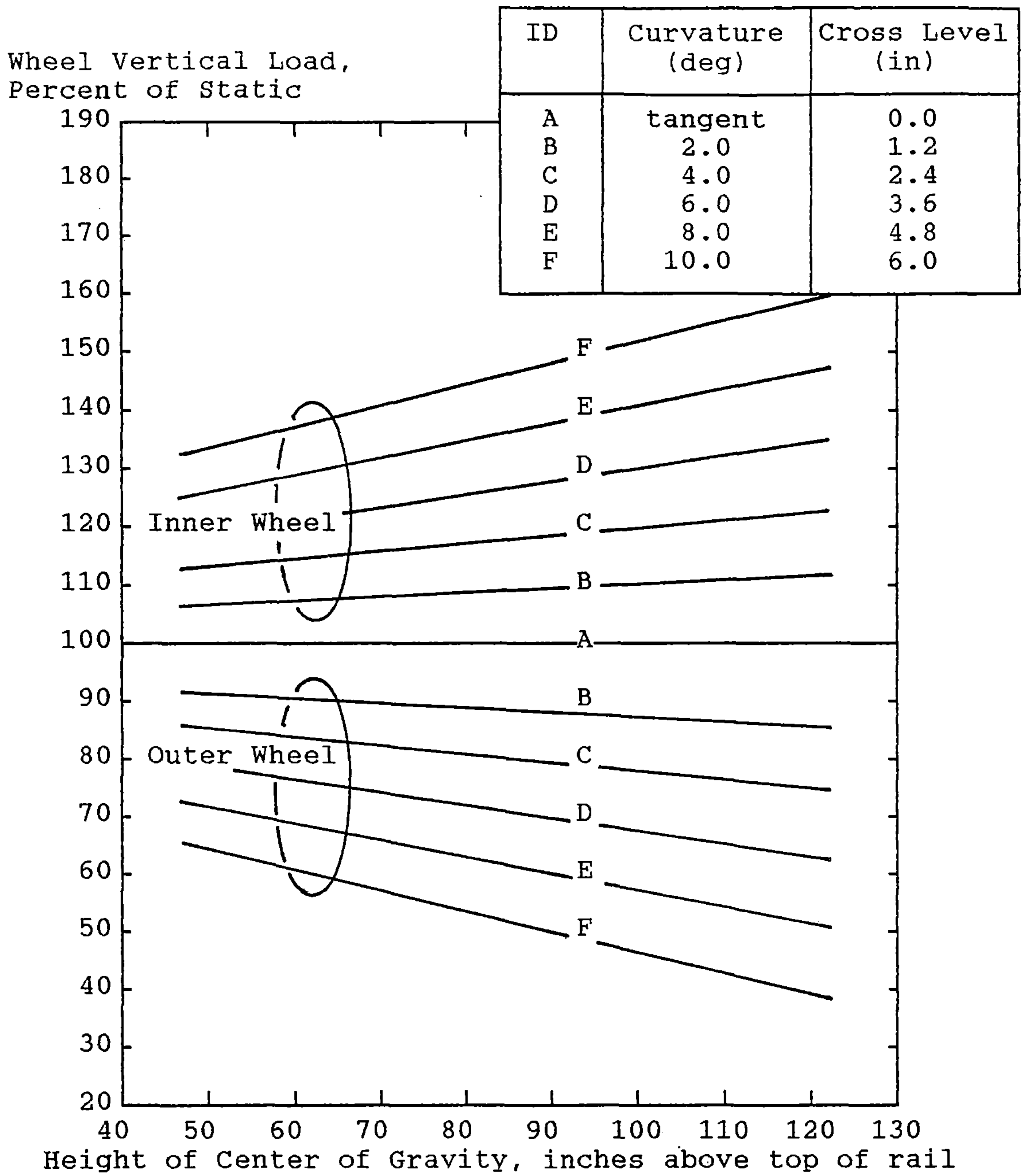

FIGURE 15

VERTICAL WHEEL LOADS ON CURVED TRACK, AT LOW SPEEDS, WITH 400,000 POUNDS DRAFT

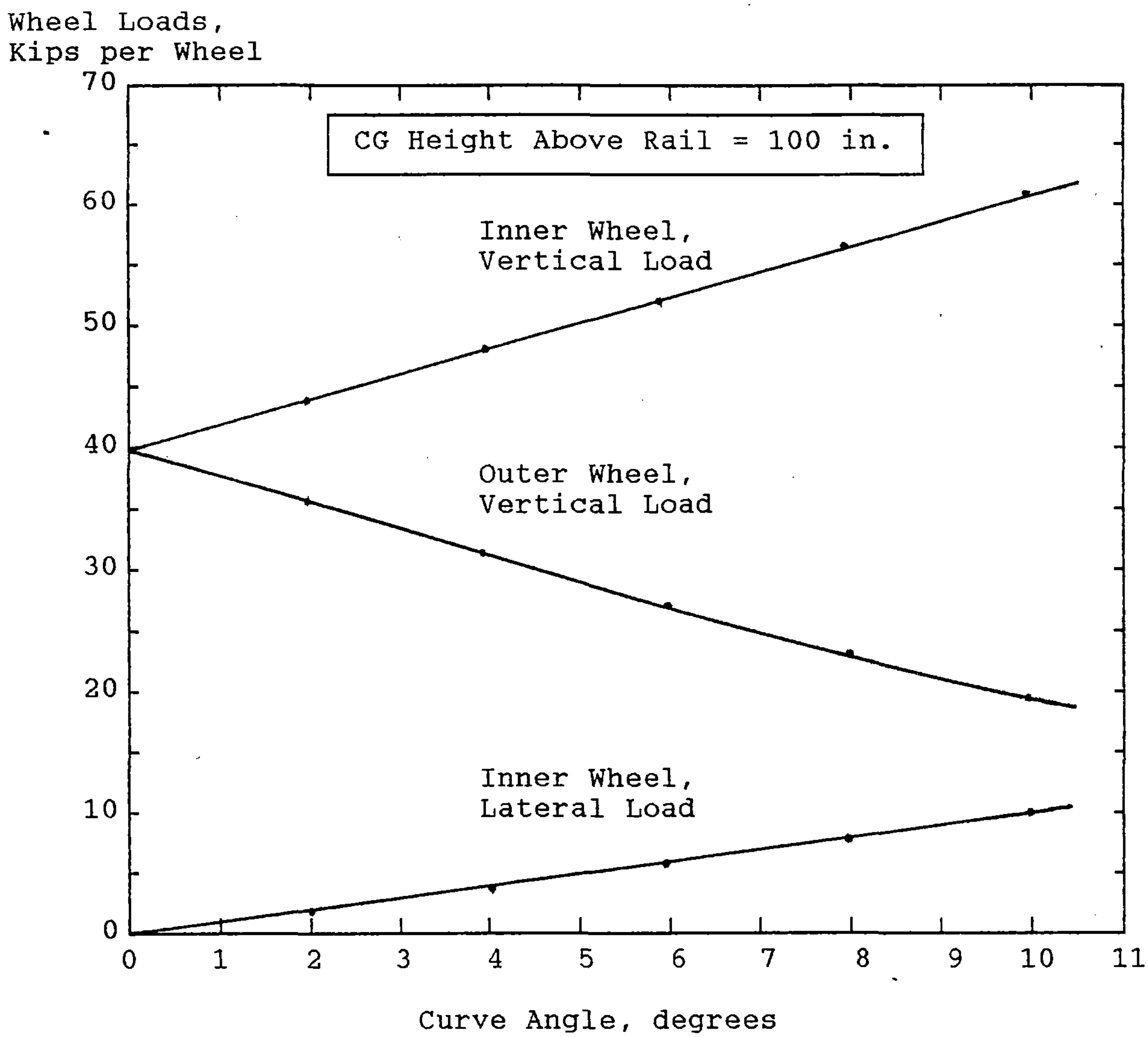

FIGURE 16

VERTICAL AND LATERAL WHEEL LOADS ON CURVED TRACK,
AT LOW SPEEDS, UNDER DRAFT

5.0 CONCLUSIONS AND RECOMMENDATIONS

In response to the UPRR request to transport hazardous liquid in tank containers, double stacked in well cars, the FRA requested data to assure safe operation relative to four areas of concern:

- Rock and Roll;
- High Speed Stability;
- Train Slack; and
- Impacts.

Upon review for this report, the data presented by the UPRR in response to the FRA request were found to be incomplete. The data were from a limited number of tests and the test results in some cases left reason for doubt as to the safe performance of these configurations. Conclusions reached and recommendations are presented below for each of these four areas of concern.

A fifth concern on the derailment potential in curves at low speeds was added.

<u>Rock and Roll: Conclusions</u>

The UPRR request referred to movement of portable tanks and IM portable tanks in double-stack well cars, which was interpreted to mean the double stacking of tank containers. However, the capacity of the tanks defined by UP will equal the full load capability of the well car when single stacked and with liquid of specific gravity equal to one. If double stacked the liquid cargo specific gravity must be less than 0.66 in order to stay within GRL limits.

With respect to rock and roll, all concern would be removed if transport of hazardous liquid were limited to unit trains of well cars with single stack tank containers.

However, for the purposes of this report, tank containers in single and double stack and solid cargo containers in double stack were studied. It was also considered that a well car could have a mix of loaded and empty containers with the loaded containers on top and the empty on the bottom in order to include maximum possible CG heights.

It was concluded that well cars with truck spacing in the 50 to 58 ft. range will perform well over 39 ft. staggered rail test track.

It was also concluded that the well car with single stack tank containers was safe at any cross level wave length.

It was shown, by FRATE analysis of double stack well cars, that performance degrades as the wave length of the perturbed track is increased from 39 to 58 ft, and as the CG height is increased. Performance of double stack tank containers with all tanks loaded was marginal. Performance of double stack tanks with the bottom tanks empty and the two double stack configurations with solid cargo were all unacceptable in that wheel lift was predicted.

Because of the extensive use of 39 ft rail and the resulting predominance of 39 ft wave lengths in track geometry variations, the standard practice has been to test rock and roll performance of freight cars with 39 ft staggered rail. However, FRA Track Safety Standards do not specify wave length, other than the 62 ft limit, and consequently cross level perturbations of 0.75 in and greater, can occur in class 3 track at any wave length up to 62 ft and be within FRA Track Safety Standards.

Rock and Roll: Recommendations

1. It is recommended that the restriction be placed on all double stacked well cars that a loaded container never be in a top position when there is an empty container in a bottom position.

2. It is recommended that cross level and alignment track geometry data be assembled or acquired that include wave lengths up to 62 ft. Be aware that there are track geometry measurement systems which are blind to wave lengths near 62 ft.

3. It is recommended that, until the data requested in Recommendation 2 are available, transport of liquid hazardous liquids be limited to single stack configurations.

High Speed Stability: Conclusions

The 70-ton trucks, used in the end positions of the well cars, will occasionally hunt in the 65 to 70 mph speed range. The hunting threshold can be expected to be lower with lightly loaded and empty cars and lowered further with wear of wheels and other truck parts.

High Speed Stability: Recommendations

1. It is recommended that the 70-ton trucks used in well cars be modified to preclude hunting below 70 mph.

2. It is recommended that inspection and maintenance

schedules and procedures for hazardous liquid tank container configurations be revised in order to maintain the hunting threshold to above 70 mph.

<u>Train Slack: Conclusions</u>

The UPRR data show that there is much less slack in train consists of well cars than in consists of 89 ft flat cars and uses this datum point to justify the conclusion that the well car consist will be trouble free with respect to train slack. Although the conclusion is probably correct, corroborating data are needed.

<u>Train Slack: Recommendation</u>

1. It is recommended that request be made to the UPRR that data or report references be provided that would substantiate the hypothesis that well car consists have no problems with respect to train slack.

<u>Impacts: Conclusions</u>

Comparison of flat cars and 5-unit well cars under equivalent impact conditions will show container G forces to be higher in the well car and coupler forces to be much higher in the well car. These results are so because of the short stroke of the M901-G draft gear, compared to end-of-car cushioning on flat cars, and because of the large GRL of the 5-unit well car.

<u>Impacts: Recommendations</u>

1. It is recommended that the UPRR provide the results of AAR Specification M-1001, Chapter XI tests on the subject well cars.

<u>Low Speed Curving: Conclusions</u>

An evaluation was made of the wheel rail forces for a double stacked well car on curved track at low speeds. The four variables of track curvature, super elevation, CG height of the car, and draft force on the car were considered. Reduced margins were shown but no unsafe conditions were predicted. However, with the inclusion of roll transients due to cross level perturbations, wheel lift conditions were predicted.

<u>Low Speed Curving: Recommendations</u>

1. It is recommended that this analysis be extended to include a range of possible draft loads, to include a more rigorous treatment of the dynamic effects of rail perturbations, and to evaluate inner rail overturning loads.

LIST OF REFERENCES

1. G. Kachadourian, Results of Review Performed in Compliance with Tasks 1 and 2 in the Statement of Work for DTFR53-89-P-00591. Letter No. GK-1003, G. Kachadourian, Purcellville, VA, November 22, 1989.

2. V. T. Hawthorne, Truck Hunting in the Three-Piece Freight Car Truck. ASME Publication No. 79-WA/RT-14, December 1979.

3. G. Kachadourian, User's Manual for FRATX1 and FRATF1 Freight Car Dynamics Analysis Computer Program, FRA/ORD-81-54, the MITRE corporation, McLean VA, July 1981.

APPENDIX A

WELL CAR MODEL DATA USED IN FRATE ANALYSES

The model data used in the FRATE analyses presented in this report are tabulated this appendix. The dimensional, spring, and damping data used in the trucks and car body are contained in Tables A1 and A2 and are common to all five models. The mass, inertia, and CG data are given in Tables A3a through A7b. Mass, inertia, spring, and damping data for the sprung lading are contained in the "b" Tables.

LIST OF TABLES

TABLE A1
DIMENSIONAL DATA USED IN THE WELL CAR MODELS IN FRATE

Inner Unit: 125-ton Trucks, 58 ft Truck Spacing

Variable	Value	Description
R(1), R(3)	58.00 in	lateral distance between wheels
R(2), R(4)	79.00 in	distance between spring nest centers
R(9)	108.00 in	width of car body
R(10)	50.00 in	distance between side bearings
R(11)	79.00 in	distance between hydraulic snubbers
R(12)	79.00 in	distance between friction snubbers
R(13)	13.00 in	effective B center plate diameter (1)
R(14)	13.00 in	effective A center plate diameter (1)
L	696.00 in	truck spacing (58.0 ft.)
HCG	(2) in	height of total unit CG, from rail
HTRK	6.00 in	height of center bowl above axle
HAXL	19.00 in	height of axle above rail
H	(2) in	(HCG-HTRK-HAXL)*2.0
OR(1)	348.00 in	dist from cntr to B-end of end unit
OR(2)	-348.00 in	dist from cntr to A-end of end unit
GAPA	0.006 rad	side bearing gap, A-end
GAPB	0.006 rad	side bearing gap, B-end

Notes:

1. The beveled edges of the 16 inch center plates reduce the effective diameters to 13 in, with respect to center plate rocking.

2. Load configuration dependent - see weight and CG tables.

TABLE A2
SPRING AND DAMPING DATA FOR WELL CAR MODELS

Spring and Damper Numbers	Spring Constant	Damping (C/Cc)	Units
K(1), (3), (7), (9)	0.10E6		lb/in
C(1), (3), (7), (9)		0.50E3 (0.01)	lb/in/sec
K(2), (8)	0.10E5		lb/in
C(2), (8)		0.12E3 (0.024)	lb/in/sec
KFCB, KFCA	0.69E5		lb/in
K(4), (10)	0.336E5		lb/in
C(4), (10)		0.50E3 (0.03)	lb/in/sec
K(5), (11)	0.10E5		lb/in
C(5), (11)		0.09E3 (0.018)	lb/in/sec
K(6), (12)	0.80E8		in lb/rad
C(6), (12)		0.57E6 (0.014)	in lb/rad/sec
KLSB, KLSA	0.20E6		lb/in
CLSB, CLSA		0.18E4 (0.018)	lb/in/sec
KCP6, KCP12	0,80E8		in lb/rad
CCP6, CCP12		0.38E6 (0.01)	in lb/rad/sec
FFSB, FFSA		0.30E4	lb
GAPB, GAPA	0.006		rad

Notes:

1. For damping ratio calculation assume Cc = .5 x K. (From Cc = 2 x K / (6.28 x f), and f = 1.274 Hz)

2. The values in this table were used for all configurations. The spring and damping values used for the lading changed for each model and are presented in Tables A3b, A4b, A5b, A6b, and A7b.

TABLE A3a
WEIGHT AND CG DATA, MODEL WELL1
Double-Stacked Containers, Cubed at Max Gross Weight

Item	Weight (lb)	CG (in)	WT x CG (kip in)
Top Container: Body	15,000	183.0	2,745.0
Cargo less MLAD	36,800	184.0	6,771.2
MLAD(2)	4,600	184.0	846.4
MLAD(4)	4,600	184.0	846.4
Bottom Container: Body	15,000	67.5	1,012.5
Cargo less MLAD	36,800	68.5	2,520.8
MLAD(1)	4,600	68.5	315.1
MLAD(3)	4,600	68.5	315.1
(Total Load)	(122,000)	(126.0)	(15,372.5)
Carbody (empty)	26,000	20.85	542.1
(Carbody loaded)	(148,000)	(107.53)	(15,914.6)
Trucks	12,000	33.65	403.8
Gross Rail Load	160,000	101.99	16,318.4

HCG = 101.99 in

H = (HCG - HTRK - HAXL)*2.0 = 153.98 in

Configuration description. All values for one inner well car unit with:

- 125-ton trucks
- Two, 9.5 ft high, 40-ft containers
- Capacity each container, 2590 cu ft
- Cargo density to cube, 17.8 lb/cu ft

TABLE A3b

FRATE READY MASS AND INERTIA DATA, MODEL WELL1

Double-Stacked Containers, Cubed at Max Gross Weight

FRATE Symbol	Description	Value (a)
M(1), M(2)	B-Truck, A-Truck Mass	15.54
M(3)	Carbody Mass (b)	335.70
MLAD(1-4)	Lading Mass (each)	11.92
I(1), I(2)	B-, A-Truck Roll Inertia	1.286E4
I(3)	Carbody Roll Inertia, Y-Y	1.425E6
I(4)	Carbody Pitch Inertia, X-X	9.070E6
I(5)	Carbody Yaw Inertia, Z-Z	7.450E6
ILAD(1-4)	Lading Roll Inertia (each)	4.970E3

Notes: (a) Units are - lb sec sq/in for mass
- lb in sec sq for inertia

(b) Carbody, in FRATE usage, includes unsprung lading.

Lading Spring and Damper Calculations

Assume: f(z) = 12 Hz, f(x) = 10 Hz, f(roll) = 8 Hz

Using: K = M*(6.2832*f)sq

KLAD(1,4,7,10) = 11.92*39.48*144 = 6.78E4 lb/in

KLAD(2,5,8,11) = 11.92*39.48*100 = 4.71E4 lb/in

KLAD(3,6,9,12) = 4.97E3*39.48*64 = 1.26E7 lb in/rad

Using: Cc = K/(3.1416*f) and C/Cc = 0.02

CLAD(1,4,7,10) = 36.0 lb/in/sec

CLAD(2,5,8,11) = 30.0 lb/in/sec

CLAD(3,6,9,12) = 1.0E4 in lb/rad/sec

TABLE A4a
WEIGHT AND CG DATA, MODEL WELL2
Double-Stacked Containers, Top Cubed, Bottom Empty

Item	Weight (lb)	CG (in)	WT x CG (kip in)
Top Container: Body	15,000	183.0	2,745.0
Cargo less MLAD	36,800	184.0	6,771.2
MLAD(1)	2,300	184.0	423.2
MLAD(2)	2,300	184.0	423.2
MLAD(3)	2,300	184.0	423.2
MLAD(4)	2,300	184.0	423.2
Bottom Container: Body	15,000	67.5	1,012.5
(Total Load)	(76,000)	(160.81)	(12,221.5)
Carbody (empty)	26,000	20.85	542.1
(Carbody loaded)	(102,000)	(125.13)	(12,763.6)
Trucks	12,000	36.0	432.0
Gross Rail Load	114,000	115.75	13,195.5

HCG = 115.75 in

H = (HCG - HTRK - HAXL)*2.0 = 181.50 in

Configuration description - all values are for one inner, well car unit with:
125-ton trucks
Two, 9.6 ft high, 40-ft containers, top cubed, bottom empty
Capacity each container, 2590 cu ft
Cargo density to cube, 17.8 lb/cu ft

TABLE A4b

FRATE READY MASS AND INERTIA DATA, MODEL WELL2

Double-Stacked Containers, Top Cubed, Bottom Empty

FRATE Symbol	Description	Value (a)
M(1), M(2)	B-Truck, A-Truck Mass	15.54
M(3)	Carbody Mass (b)	264.25
MLAD(1-4)	Lading Mass (each)	5.96
I(1), I(2)	B-, A-Truck Roll Inertia	1.286E4
I(3)	Carbody Roll Inertia, Y-Y	1.403E6
I(4)	Carbody Pitch Inertia, X-X	7.421E6
I(5)	Carbody Yaw Inertia, Z-Z	6.034E6
ILAD(1-4)	Lading Roll Inertia (each)	2.485E3

Notes: (a) Units are - lb sec sq/in for mass
- lb in sec sq for inertia

(b) Carbody, in FRATE usage, includes unsprung lading.

Lading Spring and Damper Calculations

Assume: f(z) = 12 Hz, f(x) = 10 Hz, f(roll) = 8 Hz

Using: K = M*(6.2832*f)sq

KLAD(1,4,7,10) = 5.96*39.48*144 = 3.39E4 lb/in

KLAD(2,5,8,11) = 5.96*39.48*100 = 2.36E4 lb/in

KLAD(3,6,9,12) = 2.49E3*39.48*64 = 6.30E6 lb in/rad

Using: Cc = K/(3.1416*f) and C/Cc = 0.10

CLAD(1,4,7,10) = 90.0 lb/in/sec

CLAD(2,5,8,11) = 75.0 lb/in/sec

CLAD(3,6,9,12) = 2.5E4 in lb/rad/sec

DLAD(I) = 261.0, 87.0, -87.0, -261.0 in

HL(I) = 4 x 76.5 in RLAD(I) = 4 x 0.0 in

TABLE A5a
WEIGHT AND CG DATA, MODEL WELL3
Single Stack Tank Containers, 90% Fill with 1.12 SpG Liquid

Item	Weight (lb)	CG (in)	Wt. x CG (kip in)
Container Bodies (two)	16,000	61.0	976.0
Non-sloshing Liquid	68,900	41.44	2,855.2
Sloshing Liquid	37,100	85.0	3,153.5
(Total Load)	(122,000)	(57.25)	(6,984.7)
Carbody - empty	26,000	20.85	542.1
(Carbody - loaded)	(148,000)	(50.86)	(7,526.8)
Trucks	12,000	20.0	240.0
Gross Rail Load	160,000	48.54	7,766.8

HCG = 48.54 in

H = (HCG - HTRK - HAXL)*2.0 = 47.09 in

Configuration description. All values are for one inner well car unit with:
- 125-ton trucks
- Two, 8.5 ft high, 20-ft tank containers with 7.5 ft ID
- Capacity each container, 6340 US gal
- Filled to 5700 gal (90%) each container
- Liquid density, 9.30 lb/gal, (1.12 kg/l)

M(3) = (148000 - 37100)/386 = 287.31 lb sec sq/in

MLAD = 37100/(4 x 386) = 24.03 lb sec sq/in

TABLE A5b

FRATE READY MASS AND INERTIA DATA, MODEL WELL3

Single Stack Tank Containers, 90% Fill with 1.12 SpG Liquid

FRATE Symbol	Description	Value (a)
M(1), M(2)	B-Truck, A-Truck Mass	15.54
M(3)	Carbody Mass (b)	287.31
MLAD(1-4)	Lading Mass (each)	24.03
I(1), I(2)	B & A-Truck Roll Inertia	1.286E4
I(3)	Carbody Roll Inertia, Y-Y	1.617E5
I(4)	Carbody Pitch Inertia, X-X	8.984E6
I(5)	Carbody Yaw Inertia, Z-Z	8.950E6
INLAD(1-4)	Lading Roll Inertia (each)	1.334E4

Notes: (a) Units are - (lb sec sq)/in for mass
- lb in sec sq for inertia

(b) Carbody, in FRATE usage, includes unsprung lading.

Lading Spring and Damper Calculations

Assume: f(z) = 8 Hz, f(x) = 0.6 Hz, f(roll) = 0.2 Hz

Using: K = M*(6.2832*f)sq

KLAD(1,4,7,10) = 24.03*39.48*64 = 6.07E4 lb/in

KLAD(2,5,8,11) = 24.03*39.48*0.36 = 3.42E2 lb/in

KLAD(3,6,9,12) = 1.33E4*39.48*0.04 = 2.11E4 lb in/rad

Using: Cc = K/(3.1416*f) and C/Cc = 0.05, 0.02, 0.10

CLAD(1,4,7,10) = 121.0 lb/in/sec

CLAD(2,5,8,11) = 3.6 lb/in/sec

CLAD(3,6,9,12) = 3350.0 in lb/rad/sec

DLAD(I) = 180.0, 60.0, -60.0, -180.0 in

HL(I) = 4 x 34.14 in RLAD(I) = 4 x 0.0 in

TABLE A6a
WEIGHT AND CG DATA, MODEL WELL4
Double-Stacked Tank Containers, 95% Fill with 0.66 SpG Liquid

Item	Weight (lb)	CG (in)	WT x CG (kip in)
Top Container Bodies (two)	16,000	164.0	2,624.0
Non-sloshing Liquid	36,000	145.0	5,220.0
Sloshing Liquid	9,000	188.0	1,692.0
Bottom Container Bodies	16,000	61.0	976.0
Non-sloshing Liquid	36,000	42.0	1,512.0
Sloshing Liquid	9,000	85.0	765.0
(Total Load)	(122,000)	(104.83)	(12,789.0)
Carbody (empty)	26,000	20.85	542.1
(Carbody loaded)	(148,000)	(90.08)	(13,331.1)
(" - less slosh liquid)	(130,000)	(83.65)	(10,874.1)
Trucks	12,000	20.00	240.0
Gross Rail Load	160,000	84.82	13,571.1

HCG = 84.82 in

H = (HCG - HTRK - HAXL)*2.0 = 119.64 in

Configuration description - all values are for one inner well car unit with:
- 125-ton trucks
- Four, 8.5 ft high, 20-ft containers
- Capacity each tank, 4300 gal
- Filled to 95% volume with 5.51 lb/gal liquid

M(3) = (148,000 - 18,000)/386 = 336.79 lb sec sq/in

MLAD(1-4) = 18,000/(4 x 386) = 11.66 lb sec sq/in

TABLE A6b

FRATE READY MASS AND INERTIA DATA, MODEL WELL4

Double-Stacked Tank Containers, 95% Fill with 0.66 SpG Liquid

FRATE Symbol	Description	Value (a)
M(1), M(2)	B-Truck, A-Truck Mass	15.54
M(3)	Carbody Mass (b)	336.79
MLAD(1-4)	Lading Mass (each)	11.66
I(1), I(2)	B-, A-Truck Roll Inertia	1.286E4
I(3)	Carbody Roll Inertia, Y-Y	0.8426E6
I(4)	Carbody Pitch Inertia, X-X	8.039E6
I(5)	Carbody Yaw Inertia, Z-Z	7.504E6
ILAD(1-4)	Lading Roll Inertia (each)	5.000E3

Notes: (a) Units are - lb sec sq/in for mass
- lb in sec sq for inertia

(b) Carbody, in FRATE usage, includes unsprung lading.

Lading Spring and Damper Calculations

Assume: f(z) = 12 Hz, f(x) = 0.7 Hz, f(roll) = 0.2 Hz

Using: K = M*(6.2832*f)sq

KLAD(1,4,7,10) = 11.66*39.48*144 = 6.63E4 lb/in

KLAD(2,5,8,11) = 11.66*39.48*0.49 = 225.6 lb/in

KLAD(3,6,9,12) = 5.00E3*39.48*0.04 = 7.89E3 lb in/rad

Using: Cc = K/(3.1416*f) and C/Cc = 0.02, 0.02, 0.20

CLAD(1,4,7,10) = 35.2 lb/in/sec

CLAD(2,5,8,11) = 2.05 lb/in/sec

CLAD(3,6,9,12) = 2.5E3 in lb/rad/sec

DLAD(I) = 121.0, -121.0, 121.0, -121.0 in

HL(I) = 104.35, 104.35, 1.35, 1.35 in RLAD(I) = 4 x 0.0 in

TABLE A7a
WEIGHT AND CG DATA, MODEL WELL5
Double-Stacked Tank Containers,
Top Tanks at 95% Fill with 1.00 SpG Liquid, Bottom Tanks Empty

Item	Weight (lb)	CG (in)	WT x CG (kip in)
Top Container Bodies (2)	16,000	164.0	2,624.0
Sloshing Liquid Lading	13,600	188.0	2,556.8
Non-sloshing Lading	54,400	145.0	7,888.0
Bottom Container Bodies	16,000	61.0	976.0
(Total Load)	(100,000)	(140.45)	(14,044.8)
Carbody (empty)	26,000	20.85	542.1
(Carbody loaded)	(126,000)	(115.77)	(14,586.9)
(" - less slosh lading)	(112,400)	(107.03)	(12,030.1)
Trucks	12,000	36.0	432.0
Gross Rail Load	138,000	108.83	15,018.9

HCG = 108.83 in

H = (HCG - HTRK - HAXL)*2.0 = 167.66 in

Configuration description - all values are for one inner, well car uinit with:

- 125-ton trucks
- Four, 8.5 ft high, 20-ft tank containers
- Capacity each tank, 4300 gal, top tanks at 95%, bottom empty
- Cargo density 8.34 lb/gal (SpG = 1.00)

M(3) = 112,400 / 386 = 291.19 lb sec sq / in

MLAD(1-4) = 13,600/(4 x 386) = 8.81 lb sec sq / in

TABLE A7b

FRATE READY MASS AND INERTIA DATA, MODEL WELL5

Double-Stacked Tank Containers,
Top Tanks at 95% Fill with 1.00 SpG Liquid, Bottom Tanks Empty

FRATE Symbol	Description	Value (a)
M(1), M(2)	B-Truck, A-Truck Mass	15.54
M(3)	Carbody Mass (b)	291.19
MLAD(1-4)	Lading Mass (each)	8.81
I(1), I(2)	B-, A-Truck Roll Inertia	1.286E4
I(3)	Carbody Roll Inertia, Y-Y	0.970E6
I(4)	Carbody Pitch Inertia, X-X	7.331E6
I(5)	Carbody Yaw Inertia, Z-Z	6.629E6
ILAD(1-4)	Lading Roll Inertia (each)	3.788E3

Notes: (a) Units are - lb sec sq/in for mass
- lb in sec sq for inertia

(b) Carbody, in FRATE usage, includes unsprung lading.

Lading Spring and Damper Calculations

Assume: f(z) = 12 Hz, f(x) = 0.7 Hz, f(roll) = 0.2 Hz

Using: K = M*(6.2832*f)sq

KLAD(1,4,7,10) = 8.81*39.48*144 = 5.01E4 lb/in

KLAD(2,5,8,11) = 8.81*39.48*0.49 = 1.704E2 lb/in

KLAD(3,6,9,12) = 3.788E3*39.48*0.04 = 5.982E3 lb in/rad

Using: Cc = K/(3.1416*f) and C/Cc = 0.02, 0.02, 0.20

CLAD(1,4,7,10) = 26.6 lb/in/sec

CLAD(2,5,8,11) = 1.55 lb/in/sec

CLAD(3,6,9,12) = 1.90E3 in lb/rad/sec

DLAD(I) = 182.0, 61.0, -61.0, -182.0 in

HL(I) = 4 x 80.97 in RLAD(I) = 4 x 0.0 in

An Evaluation of Hazmat Double Stack COFC Configurations, George Kachadourian, 1990 -14-
HazMat