Guidelines for Designing Bridge Piers and Abutments for Vehicle Collisions – Phase I

TPF-5(106)
Project 9-4973
Simulation Analysis
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Outline

- Background & Objective
- Modeling & Simulation Methodologies
- Simulation Matrices
  - Pier Size (24", 36", 48")
  - Heavy truck (SUT, Tractor Trailer)
    - Ballast (Soft, Rigid)
  - Vehicle Velocity (40, 50, 60 MPH)
- Results and Conclusion

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Background

- Full scale crash tests of bridge piers are rarely conducted. The lack of test data makes it hard to quantify the magnitude of force imparted on a bridge pier upon impact by a heavy truck. However, recent advances in finite element methodologies and computer hardware allow researchers to investigate impact phenomenon of such events with great details and fidelity.

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Background, Cont'd

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Objective

- The objective for this portion of the research is to conduct finite element analyses to understand the vehicle-pier interaction with particular considerations to pier diameter, vehicle velocity, vehicle type and vehicle ballast types.

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Modeling Methodology

1. Rigid pier – fixed boundary conditions, thus max possible force is incurred.
2. Heavy truck.
   - Dump Truck (65,000 lbs.) with
     - Rigid Cargo
     - Soft Cargo
   - Tractor Trailer (80,000 lbs.) with
     - Rigid Cargo
     - Soft Cargo

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Modeling Methodology

- Tractor-trailer model is being developed by Battelle for the FHWA (beta version just released). Also, there is known dump truck model available in the public domain for team to use. Therefore, due to the time constraint of the project, TTI research team had to perform the following.
  1. Refine the mesh of the tractor model (based on earlier alpha release) to enhanced its ability to capture frontal impact phenomenon
  2. Extend the tractor model to represent a dump truck model
  3. Built a trailer model based on measurement from an actual trailer unit

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Modeling Methodology

1. Material characterization was based on exiting material cards in the original model and on known specification for a given material (steel , wood, rubber).
2. Failure in certain connections was also introduced to account for drive axle failure and king-pin release as we as articulation for the dump truck model.

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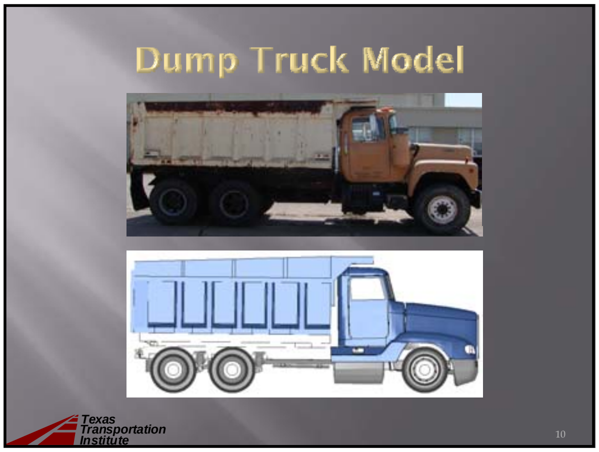
Dump Truck Model
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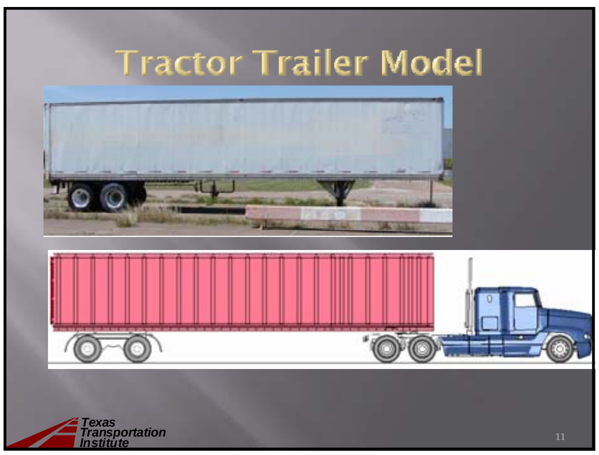
Tractor Trailer Model
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Tractor Trailer Model:
Pin Release
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Simulation Methodology

- Quantify sensitivity to pier diameter.
  - 24", 36", 48" Diameter piers were compared.
- Identify key components affecting pier impact force curve.
  - Engine Block
  - Ballast
- Quantify the effects of velocity on pier impact force curve.
  - 40, 50, 60 MPH
- Quantify the effects of the stiffness of the ballast.

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DUMP TRUCK (S.U.T.)

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Dump Truck Simulation Matrix Overview

	Pier Diameter	Vehicle (Weight)	Cargo/Ballast	Impact Speed
Matrix I	24"	Dump Truck (65 K-lb)	Rigid	50
	36"	Dump Truck (65 K-lb)	Rigid	50
	48"	Dump Truck (65 K-lb)	Rigid	50
Ballast Test Matrix	36"	Dump Truck (65 K-lb)	Rigid	40
	36"	Dump Truck (65 K-lb)	Rigid	50
	36"	Dump Truck (19 K-lb)	Rigid	50
Matrix II	36"	Dump Truck (65 K-lb)	Rigid	40
	36"	Dump Truck (65 K-lb)	Rigid	50
	36"	Dump Truck (65 K-lb)	Deformable	60
Matrix III	36"	Dump Truck (65 K-lb)	Deformable	40
	36"	Dump Truck (65 K-lb)	Deformable	50
	36"	Dump Truck (65 K-lb)	Deformable	60

Note: Matrix II 60 MPH unstable with rigid ballast

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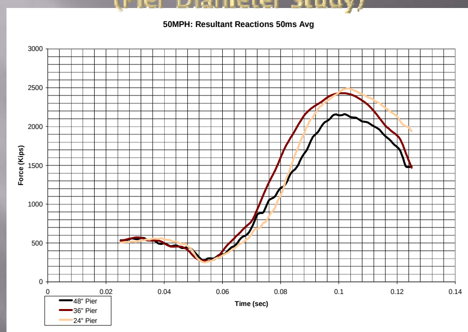
Matrix I Results
(Pier Diameter Study)



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Matrix I Summary

- It was determined that pier impact force was independent of pier diameter.
  - A constant pier diameter of 36″ was selected for all further analysis.

Note: Similar observation was made by Consolazio and Cowan in "Nonlinear analysis of barge crush behavior and its relationship to impact resistant bridge design". Computer and Structures, Vol. 81, (2003) pages 547-557.

However, they noticed that crush force is different for square impactor (pier).

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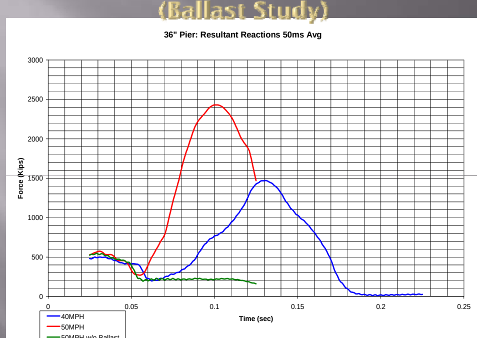
Ballast Test Matrix Results
(Ballast Study)



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Ballast Test Matrix Summary

- Better understand the pier-vehicle interaction with regards to various ballasts and the lack of.
- As suspected, impact force is directly related to these key factors:
  - Ballast mass
  - Ballast stiffness
  - Vehicle Velocity

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Peak Force Analysis

- Determine factors influencing and/or causing peaks in the impact force plots.
- Main components:
  - Engine Block
  - Ballast

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Sequential of Impact

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Sequential of Impact
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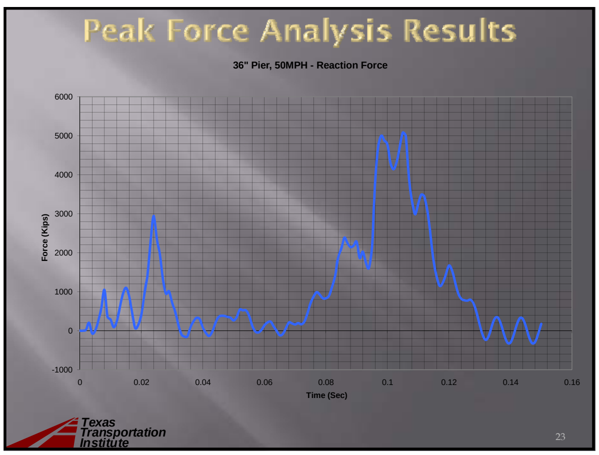
Peak Force Analysis Results
36" Pier, 50MPH - Reaction Force
Force (Kips)
6000
5000
4000
3000
2000
1000
0
-1000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Time (Sec)
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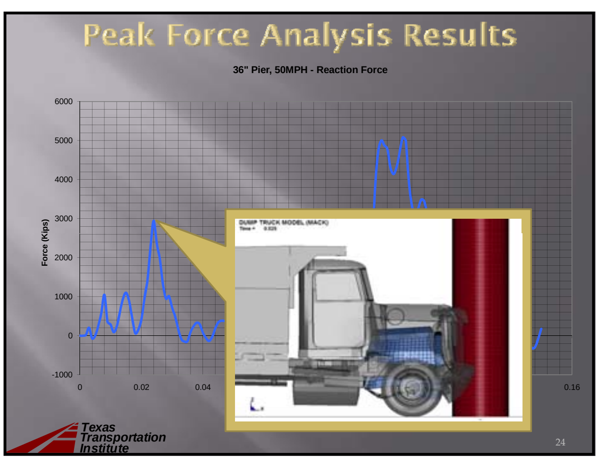
Peak Force Analysis Results
36" Pier, 50MPH - Reaction Force
Force (Kips)
6000
5000
4000
3000
2000
1000
0
-1000
0
0.02
0.04
0.16
DUMP TRUCK MODEL (MACK)
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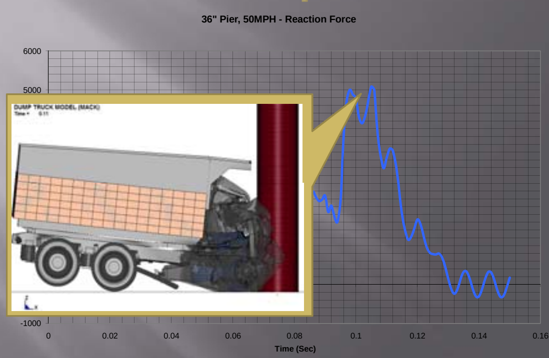
Peak Force Analysis Results



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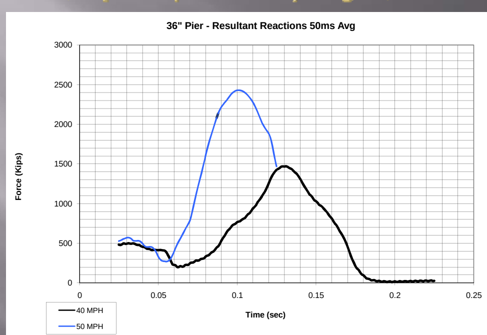
Matrix II Results
(Impact Speed Study: Rigid)



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Matrix II Summary

- Determine the effects of velocity and the corresponding pier force imposed.
  - 36″ Pier
  - 40, 50, 60 MPH
  - Rigid Ballast
  - 60 MPH case was unstable with rigid ballast
- Increases in vehicle velocity lead to higher pier impact force.

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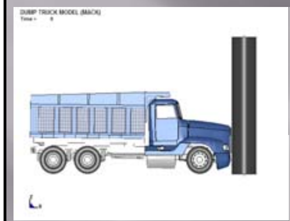
Matrix III Results (Impact Speed Study: Deformable)



Matrix III Summary

- Determine the effects of velocity and its corresponding imposed pier force.
  - 36″ Pier
  - 40, 50, 60 MPH
  - Deformable Ballast
- As stated previously, increases in vehicle velocity lead to higher pier impact force.
- However, the forces for the deformable case were considerably lower than that of the rigid case (Matrix II).

TRACTOR TRAILER

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Tractor Trailer Simulation Matrix Overview

	Pier Diameter	Vehicle (Weight)	Cargo/Ballast	Impact Speed
Matrix IV	36"	Tractor-Trailer (80 k-lb)	Deformable	40
	36"	Tractor-Trailer (80 k-lb)	Deformable	50
	36"	Tractor-Trailer (80 k-lb)	Deformable	60
Matrix V	36"	Tractor-Trailer (80 k-lb)	Rigid	40
	36"	Tractor-Trailer (80 k-lb)	Rigid	50
	36"	Tractor-Trailer (80 k-lb)	Rigid	60

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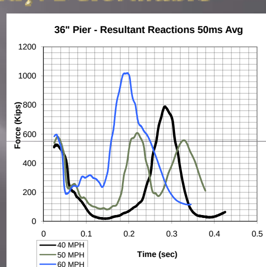
Matrix IV Results
Impact Speed Study: Deformable



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Matrix IV Summary

- Determine the effects of velocity and its corresponding pier impact force.
  - 36″ Pier
  - 40, 50, 60 MPH
  - Deformable Ballast

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50 MPH Discrepancy Explanation

- It was initially thought the 50 mph force curve would lie directly between the 40 mph and 60 mph cases
- This curve was found to be highly dependent on the interaction between the pier, engine, and trailer structure

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50 MPH Discrepancy Explanation

- In the case of 60 mph and 40 mph impact the trailer structure remains interlocked with the engine block
  - Force is directly induced to the pier
  - Results in a consistent force curve
- For the 50 mph case the trailer structure slips above the engine block
  - Force is not induced through the engine block
  - Results in a valley during slip on the force curve

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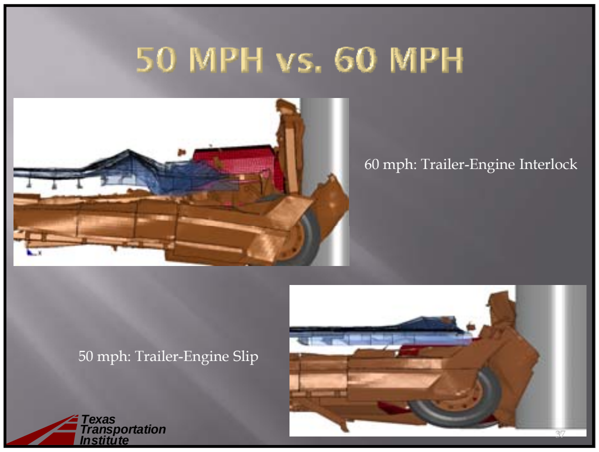
50 MPH vs. 60 MPH
60 mph: Trailer-Engine Interlock
50 mph: Trailer-Engine Slip
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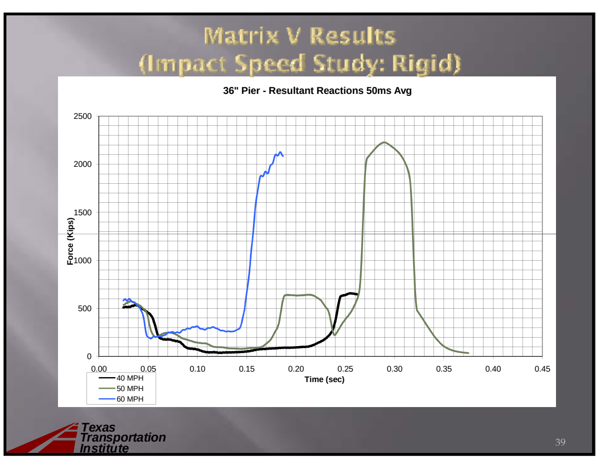
Matrix V Results
(Impact Speed Study: Rigid)
36" Pier - Resultant Reactions 50ms Avg
Force (Kips)
2500
2000
1500
1000
500
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Time (sec)
40 MPH
50 MPH
60 MPH
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Matrix V Summary

- Determine the effects of velocity and its corresponding pier impact force.
  - 36″ Pier
  - 40, 50, 60 MPH
  - Rigid Ballast
- Each case yielded unstable numerical results.
  - Spikes in the data were expected with the impact of two rigid components (i.e. ballast & pier).

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Force Distribution

- Determine distribution of the force with respect to the height of the Pier
- The pier was divided into several components to count as force transducers

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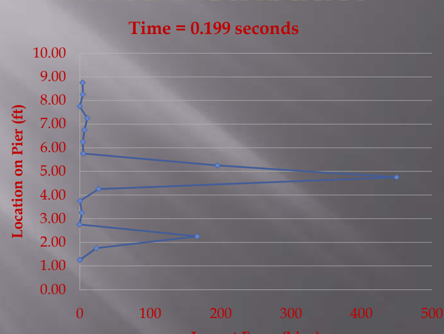
Force Distribution



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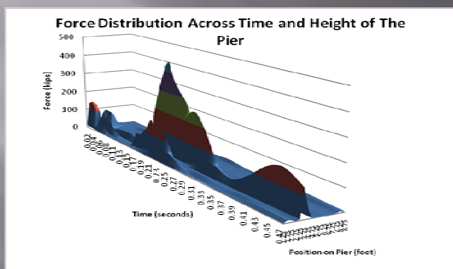
Force Distribution



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Conclusions

- Pier Diameter has insignificant effect on impact magnitude
- Impact force has a direct correlation with vehicle velocity, mass and ballast stiffness
- Vehicular cab crush was similar in all simulation matrices

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Conclusions

- The maximum impact force due to articulation of the engine block with the pier is around 600 kips
- The maximum impact force due to articulation of the ballast with the pier can go up to 2300 kips.
- The force seems to concentrate around 5-ft from the ground.

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