Modeling and Simulation of Bogie Impacts on Concrete Bridge Rails using LS-DYNA®

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Abstract

Bridge rails are constructed to contain and redirect an errant vehicle. They are constructed to withstand the impact severity of such vehicular impact based on the desired containment level. To evaluate the structural integrity of a given bridge rail design, bogie tests were conducted using a 5000 lb bogie as an impactor. In this paper, LS-DYNA was used to model the concrete barrier to simulate the bogie impact. Three material models in LS-DYNA (type 72R3, 84 and 159) were used to simulate the impact event. The rebars to concrete coupling was modeling via the ****CONSTRAINED_LAGRANGE_IN_SOLID*** *feature in LS-DYNA. Time history and deformation profile comparisons between tests and LS-DYNA simulations are presented in this paper. Figure 1 below shows a damage profile for the barrier as tested and as simulated in LS-DYNA.*

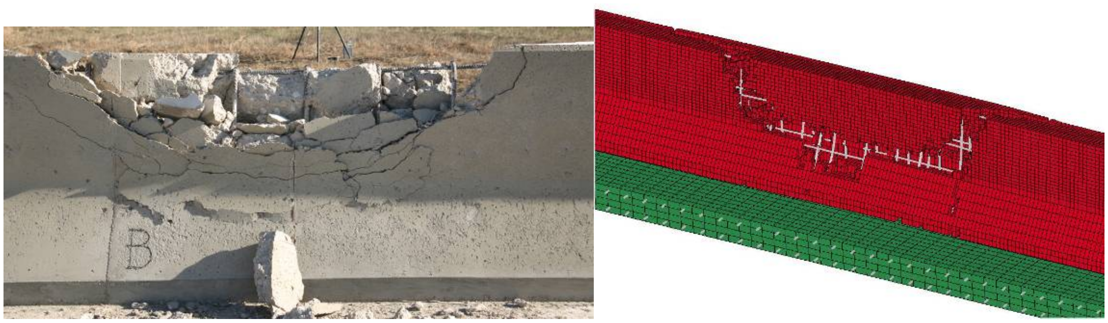


Figure 1 Damage profile of a concrete barrier after an impact test (left) and an impact simulation (right).

Introduction

Concrete barriers have been extensively used in roadside safety applications. In the past, finite element analysts modeled these barriers using rigid or elastic material characterization for two main reasons. First reason has to do with computer hardware speed and thus analysts would save time by assuming rigid or elastic material behavior for the concrete barriers. The other reason was the lack of suitable constitute model that captures the behavior of concrete while not being overwhelmingly difficult to use. Although, there are several material models in LS-DYNA that can be utilized to model concrete material, the required input parameters may not be readily available to the user. In this paper, three material models with simple or default parameter generation are presented without performing calibration exercise. The idea for this approach is to help the analyst perform preliminary evaluation of the structural integrity with minimum information (e.g., unconfined compressive strength, aggregate size). As an example, the evaluation of a barrier design that has not been built yet.

The material models used are ***MAT_072R3** (***MAT_CONCRETE_DAMAGE_REL3**), ***MAT_084** (***MAT_WINFRITH_CONCRETE**) and ***MAT_159** (***MAT_CSCM**). The structure presented in this paper is a safety bridge railing that was impacted by a 2268 kg (5000 lb) bogie fitted with a three-cylinder steel crushable nose. Two tests (each with different nominal speed, 15 mph and 20 mph) were conducted (1). Tests results summary along with their simulations are presented herein.

The safety shape barrier tested is the TxDOT Type T501 bridge rail system shown in figure 2 below. The shape and the reinforcement details of this barrier were intended as retrofit for the original T501 design. This retrofit incorporates one starter bar between the deck and the barrier. This is a 19 mm (#6) bar shown as detail 1 in figure 2. The average unconfined compressive strength of the concrete of the barrier was 27.15 MPa (3937 psi) and of the concrete of the deck was 36.58 MPa (5305 psi). The maximum aggregate size was 25.4 millimeter (1 inch).

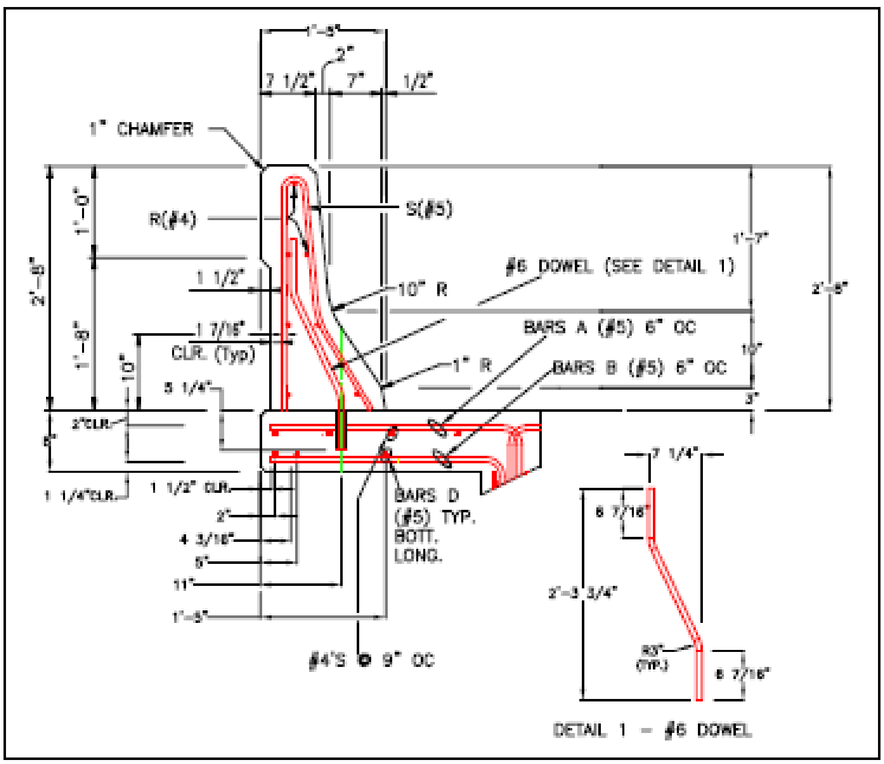
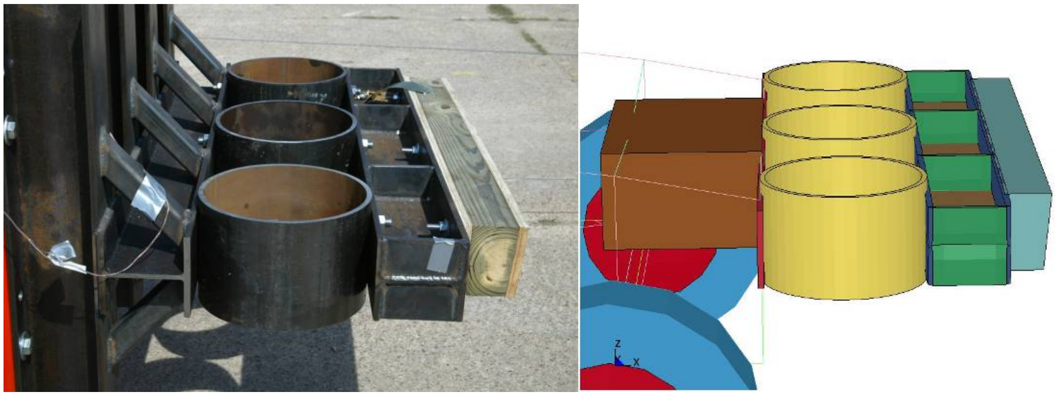


Figure 2 TxDOT T501 barrier drawing (from Williams *et al.*)

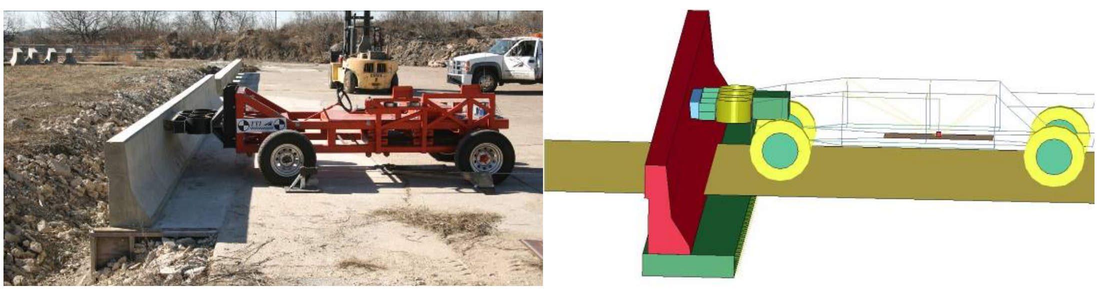
Overview of the Model

The National Crash Analysis Center's (NCAC) bogie model was ballasted to 2268 kg (5000 lb) and modified to incorporate the three crushable cylinders with the spreader attachment as a nose which is shown in figure 3 and 4 below.



(a) (b)

Figure 3 Crushable steel pipes nose (a) test, (b) model.



(a) (b)

Figure 4 Bogie impact setup for the T501 safety shape rail (a) test, (b) model.

The T501 model incorporated explicit rebar models as beam elements as shown in figure 5b and figure 5d. The beam elements were constrained to the concrete continuum by using the **`*CONSTRAINED_LAGRANE_IN_SOLID`** feature in LS-DYNA.

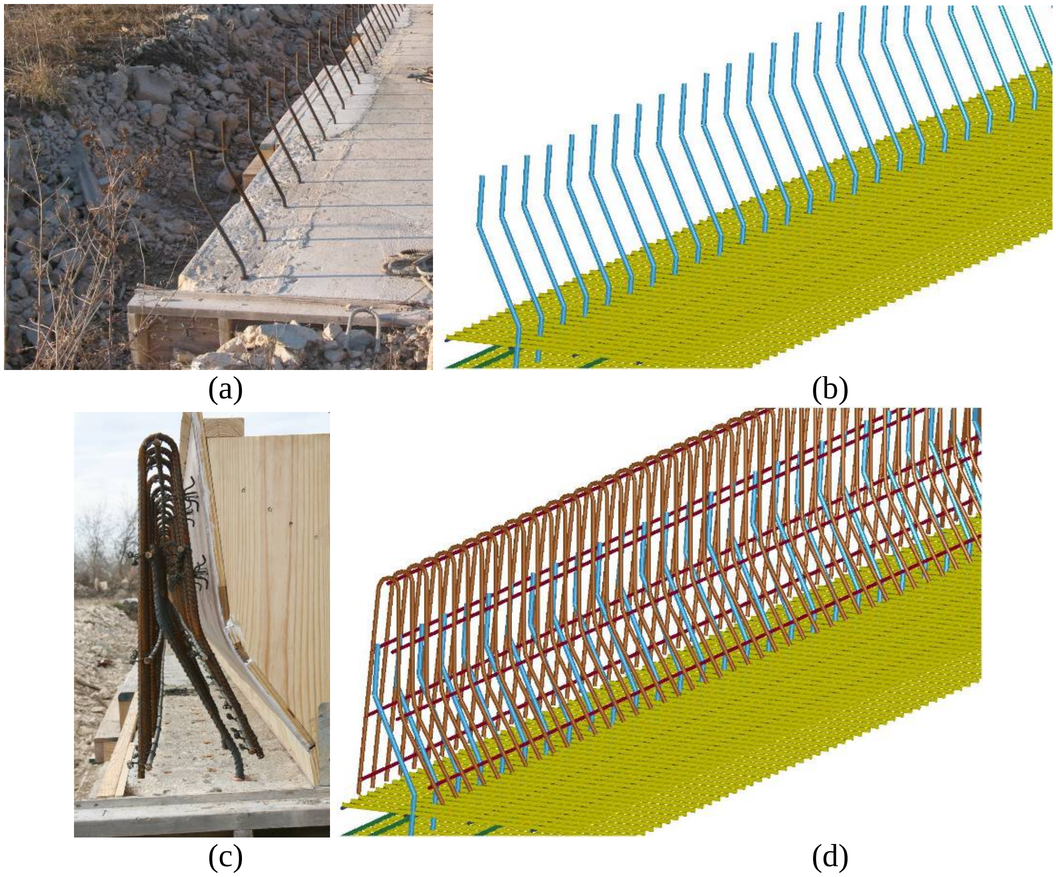


Figure 5 TheT501 bridge rail rebar configuration. (a) and (c) test, (b) and (d) model.

Concrete Material Models Used

First the short input for ***MAT_CONCRETE_DAMAGE_REL3** was used to generate to full detailed input using the unconfined strength of 27.144 MPa (units are metric ton for mass, millimeter for length and seconds for time). This simplified input (generator) is shown in Table 1 below.

Table 1 Simplified input for MAT72R3

***MAT_CONCRETE_DAMAGE_REL3_TITLE**
f'c 3937 psi
72R3

$#	mid	ro	pr					
	1	2.32E-09						
$#	ft	a0	a1	a2				
	0	-27.144						
$#	slambda	nout	edrop	rsize	ucf	lcrate	locwidth	npts
	0	0	0	0.03937	145			
$#	lambda1	lambda2	lambda3	lambda4	lambda5	lambda6	lambda7	
	0	0	0	0	0	0	0	
$#	lambda09	lambda10	lambda11	lambda12	lambda13	b3	a0y	a1y
	0	0	0	0	0	0	0	0
$#	eta1	eta2	eta3	eta4	eta5			

	0	0	0	0	0			
$#	eta09	eta10	eta11	eta12	eta13	b2	a2f	a2y
	0	0	0	0	0	0	0	0

Once the detailed input is generated along with and equation of state in the "messag" The user needs to check and change if needed certain parameters per the note given with the detailed input in the "messag" file.

$-------------------------- MATERIAL CARDS -----------------------------------
$ LS-DYNA Keyword Generated Input for Release III
$ [Default values = K&C generic f'c=6580 psi concrete]
$ >>> Users need to change/check: MatID & RO & Rsize & LocWidth for units <<<

The note alerts the user to check the material identification number of the material model, to check the density value of the material, to check the unit conversion for length factor and to input three times the maximum aggregate diameter. More information about the use of this model is given by Schwer and Malvar (2). The second concrete model with simplified input is the ***MAT_WINFRITH_CONCRETE.** This material model requires a little bit more input than just the unconfined compressive strength of concrete to be quantified as simple input. However, the other inputs can be provided via empirical formulae. For example the initial tangent modulus (TM) can be approximated as $57{,}000\sqrt{f'c}$ where $f'c$ is the unconfined compressive of concrete in psi and the modulus will be in psi as well but it should be converted to the unit of choice. The other term is the uniaxial tensile strength (UTS), this can be approximated from the formula $7\sqrt{f'c}$ (psi). Finally, the fracture energy (FE for RATE equal 0 to include strain rate effects) was taken from the Gft term (fracture energy) generate by ***MAT_CSCM_CONCRETE**. The input used is shown in table 2 below.

Table 2 Simple input for MAT 84

***MAT_WINFRITH_CONCRETE_TITLE**
winfrith f'c=3937 psi

$#	mid	ro	Tm	pr	ucs	Uts	fe	asize
	102	2.32E-09	24665.48	0.19	27.143	3.028	0.07043	12.7
$#	e	ys	Eh	uelong	rate	conm	conl	cont
	0	0	0	0	0	-4		
$#	eps1	eps2	eps3	eps4	eps5	eps6	eps7	eps8
	0	0	0	0	0	0	0	0
$#	p1	p2	P3	p4	p5	p6	p7	p8
	0	0	0	0	0	0	0	0

The Winfrith concrete model allows the user to overlay the calculated crack pattern over the deformed shape by writing a crack information file. To write the crack information file, the user needs to add the control command ***DATABASE_BINARY_D3CRACK** to the input file and excute LS-DYNA with the additional argument of **q=dyncrack.** Here **dyncrack** is the file with the crack information. The third model used is ***MAT_CSCM_CONCRETE** which requires $f'c$ and maximum aggregate size to model concrete material. The input used is shown in table 3 below.

Table 3 Simplified input for MAT 159

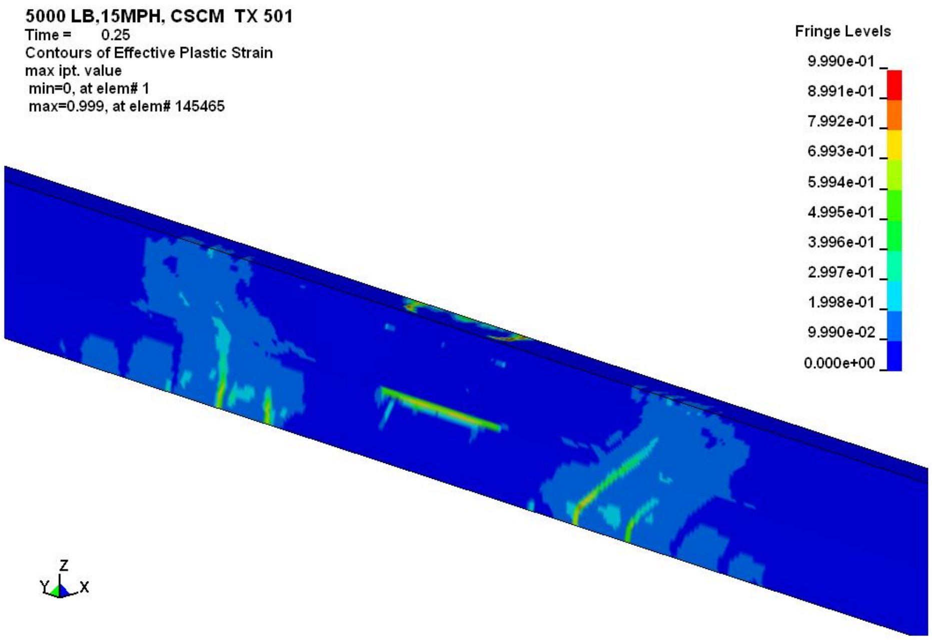
***MAT_CSCM_CONCRETE_TITLE**
f'c 3937 psi concrete

$# mid	ro	nplot	incre	irate	erode	recov	itretrc
1	2.32E-09	1					
$# pred							
0							
$# fpc	dagg	units					
27.144	25.4	2					

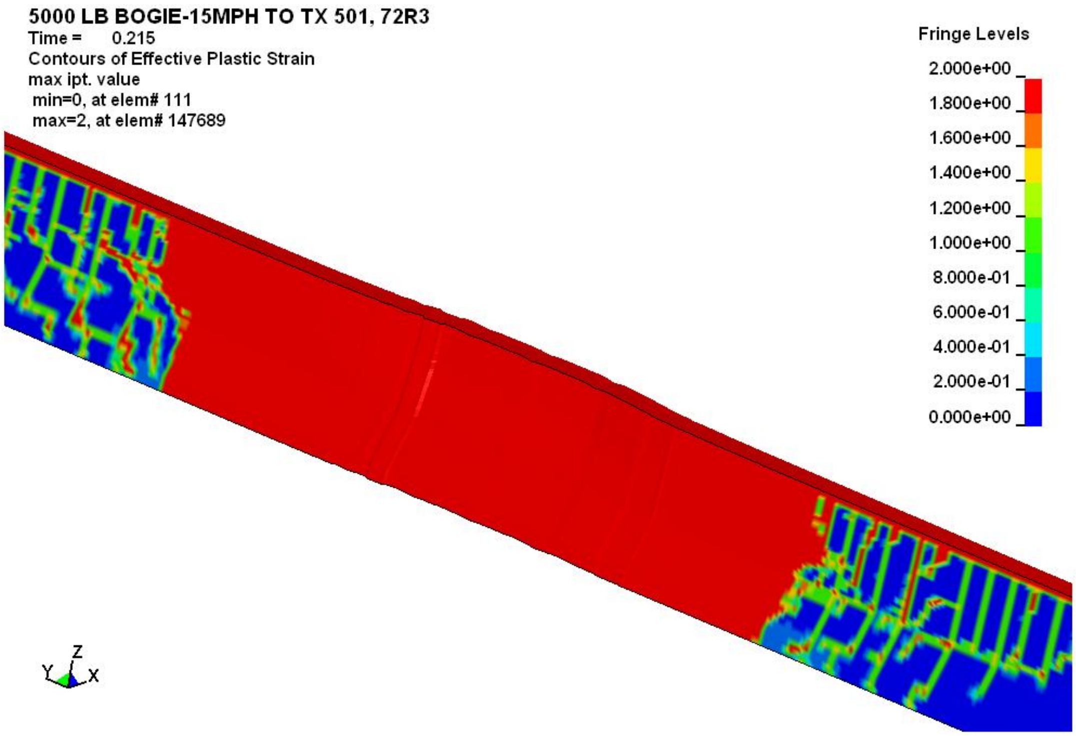
Tests and Simulations Results

The first test was the bogie impact at 24 km/hr (15 mph) speed. The barrier was able to absorb the energy of impact with no fracture but developed crack profile as shown in figure 6(a).

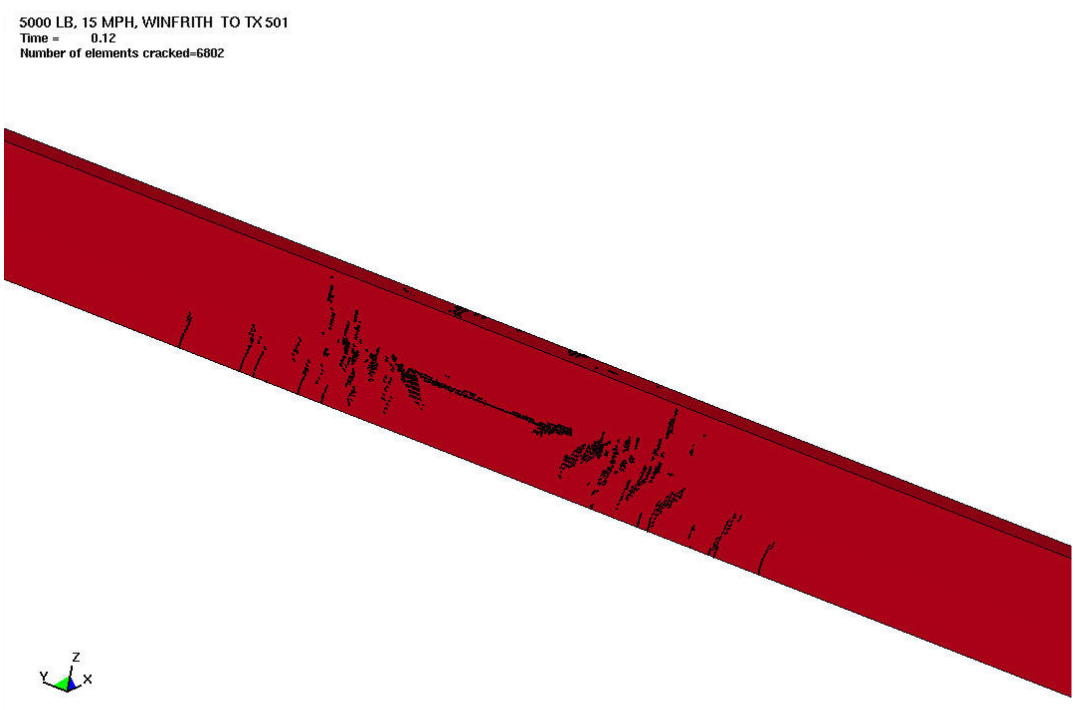
(a)



(b)



(c)



(d)

Figure 6 Damage profile for the 24 km/hr (15 mph) test.

(a) test and (b) CSCM model, (c) 72R3 model and (d) Winfrith model.

As for the simulation cases, they are shown in figure 6 (b, c and d) for material models 159, 72R3 and 84 respectively. Material models 159 and 84 showed lesser deflection than that of material model 72R3 and damage/crack patterns that resemble the crack patterns observed in the test. However, they were not necessarily all-encompassing of the test crack patterns. On the other hand, material 72R3 model showed a rather larger damaged area and more pronounced deformed profile. As for bogie's acceleration histories, test and simulation cases showed an overall comparable characteristics. Material model 84 and 159 captured the peak impact acceleration (force) but material 72R3 showed a rather softer response. All material models exhibited earlier stiff response than the test prior to the peak deceleration point as shown in figure 7.

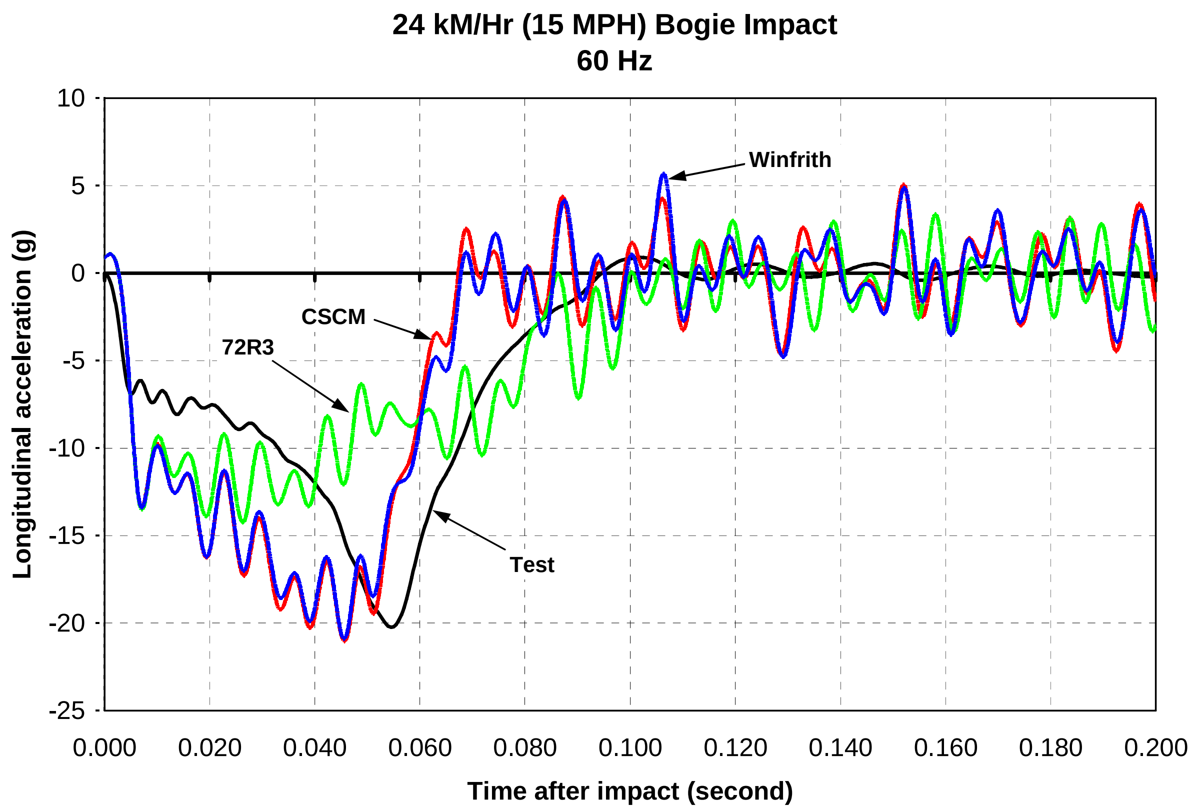
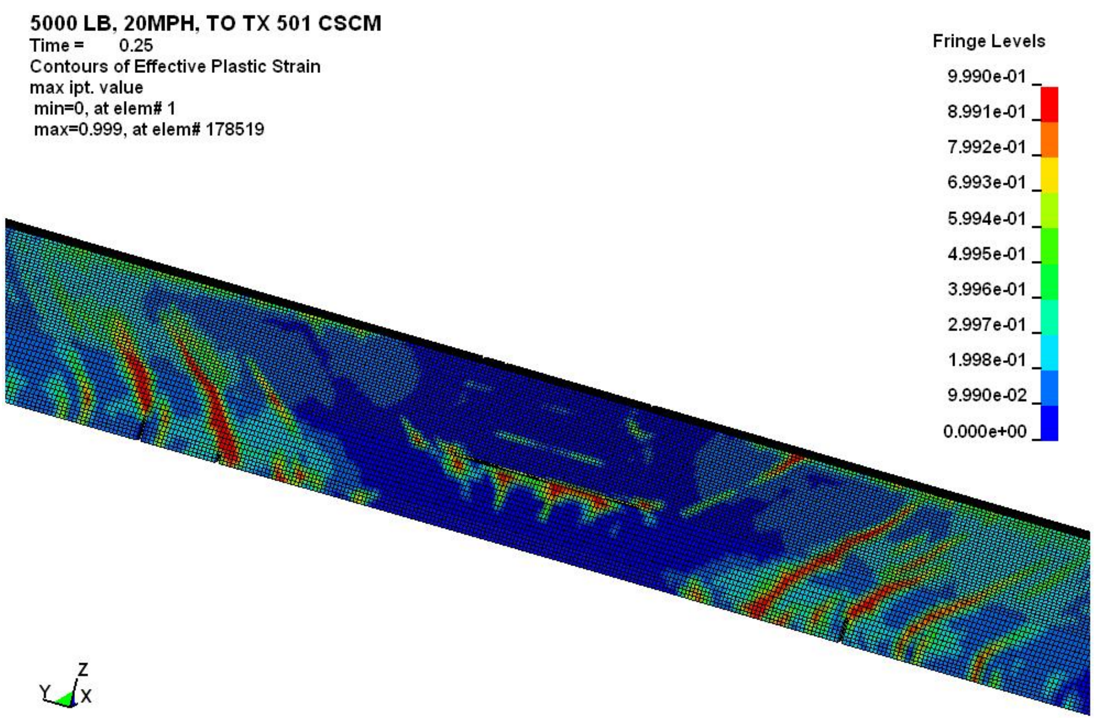


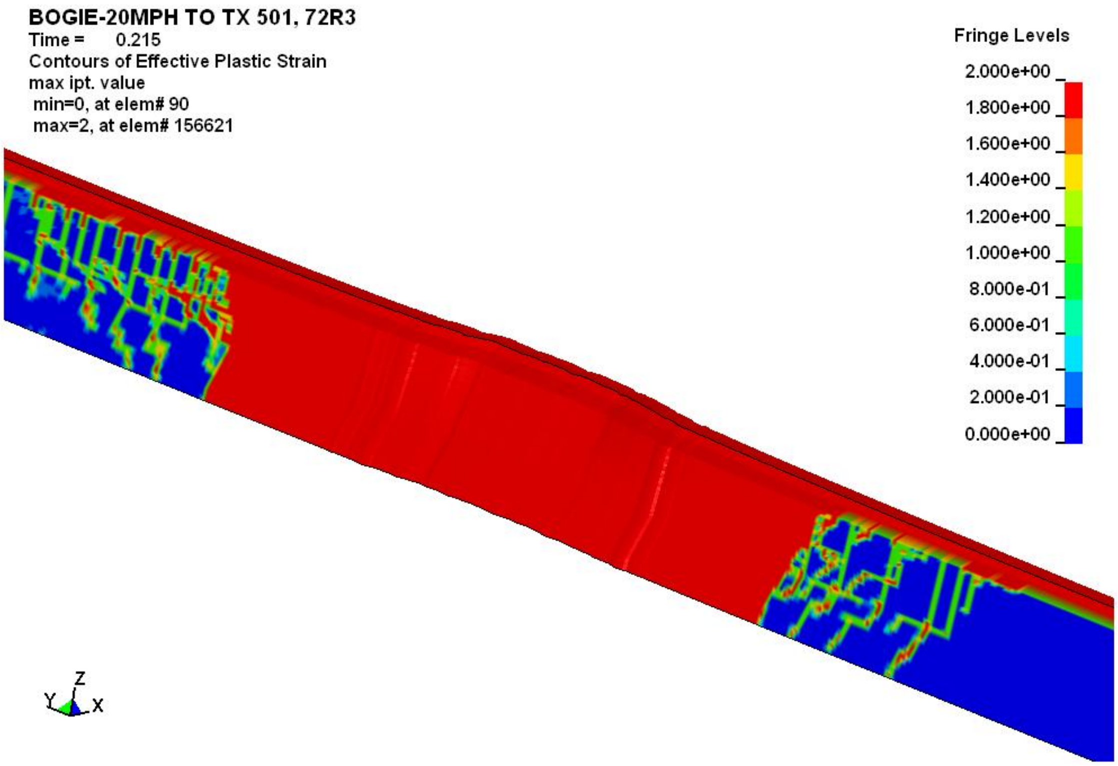
Figure 7 Acceleration history for the 24 kM/Hr (15 MPH) impact.

As for the second test, the bogie speed was 32 km/hr (20 mph) at impact. The barrier was not able to absorb the energy of impact without fracturing. The top of the barrier fractured around the impact in a pattern shown in figure 8a. As for the simulation cases, material 159 model showed a comparable damage profile to the over all test pattern but element erosion was minimal as shown in figure 8b. Same observation can be made for material 84 model which is shown in figure 8d. As for material 72R3 model, figure 8c shows more deformation and larger damaged area of the barrier than observed in the test.

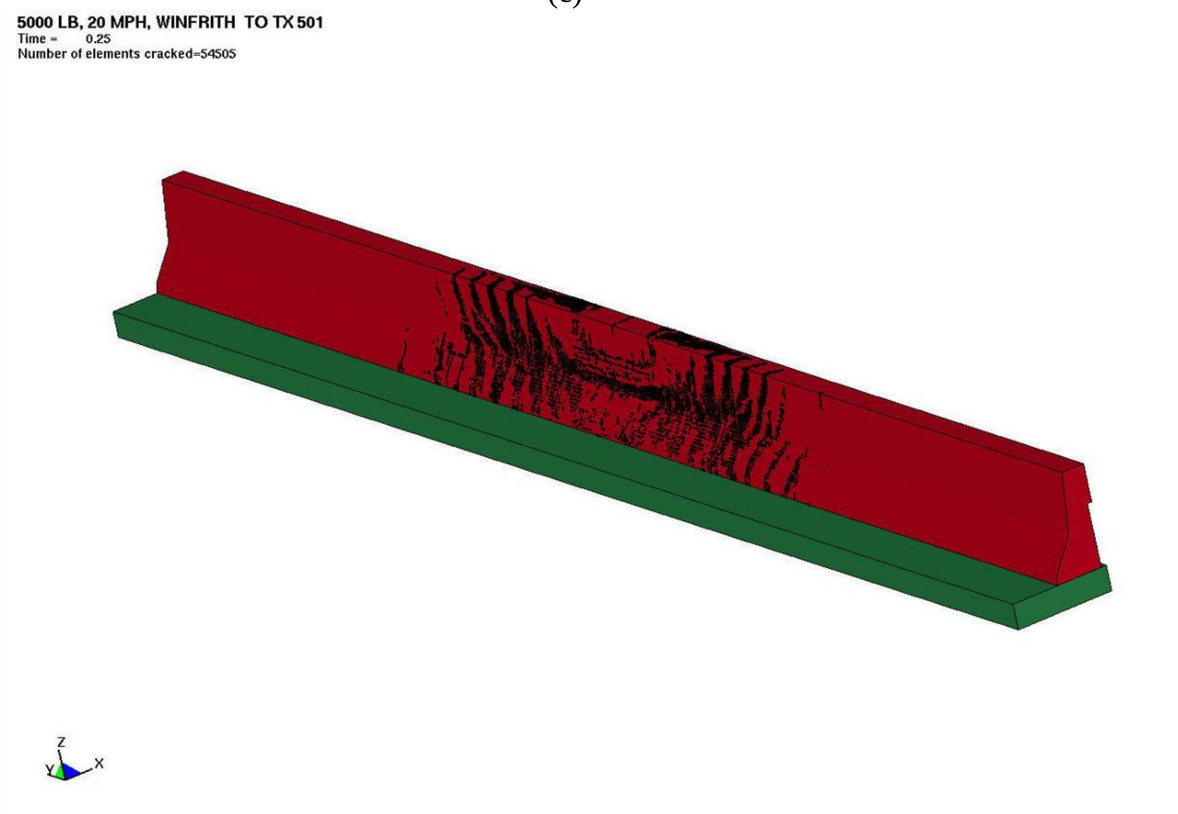
(a)


5000 LB, 20MPH, TO TX 501 CSCM
Time = 0.25
Contours of Effective Plastic Strain
max ipt. value
min=0, at elem# 1
max=0.999, at elem# 178519
Fringe Levels
9.990e-01
8.991e-01
7.992e-01
6.993e-01
5.994e-01
4.995e-01
3.996e-01
2.997e-01
1.998e-01
9.990e-02
0.000e+00
Z
Y
X

(b)



(c)



(d)

Figure 8 Damage profile for the 32 km/hr (20 mph) test.

(a) test and(b) CSCM model, (c) 72R3 model and (d) Winfrith model.

Bogie's acceleration histories form both test and simulation cases showed an overall comparable characteristics for material model 84 and 159 in terms of the peak impact acceleration (force) but material 72R3 showed a rather softer response similar to that observed in the low speed simulation. Similar to the 32 kmh test, the three material models exhibited earlier stiff response than the test prior to the peak deceleration point as shown in figure 9.

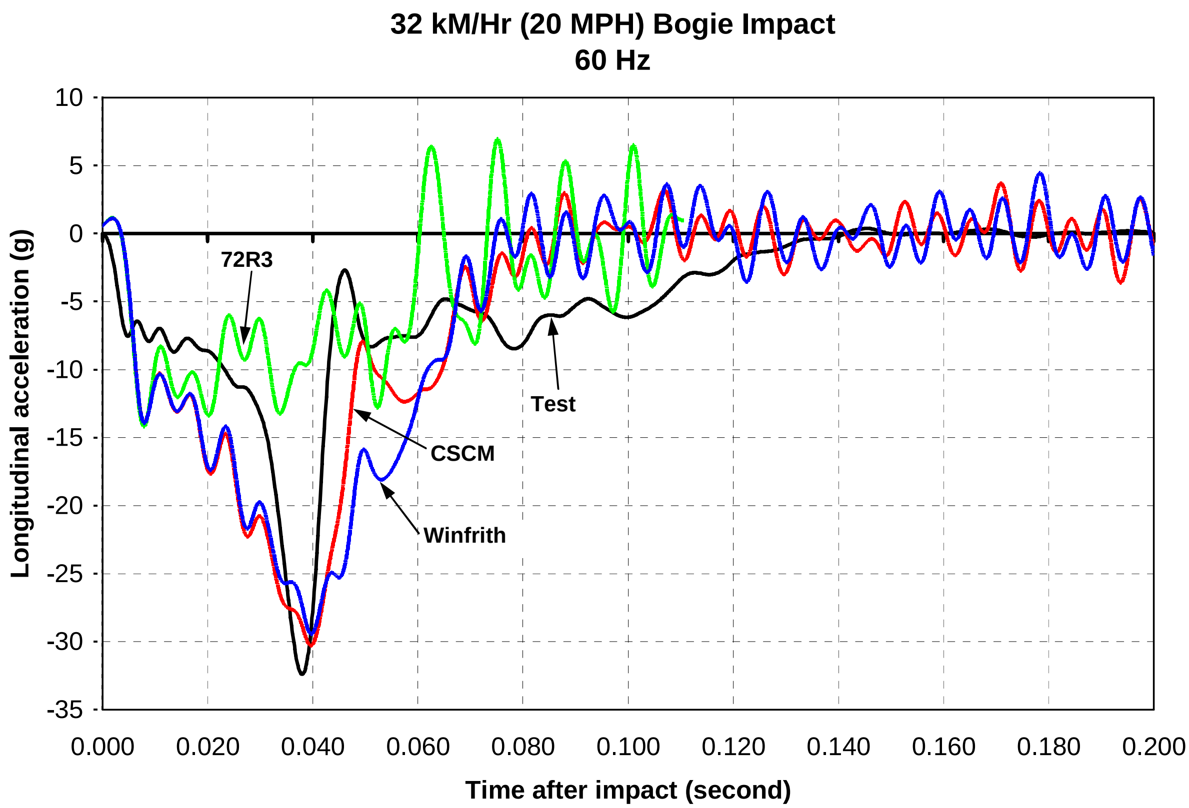


Figure 9 Acceleration history for the 32 kM/Hr (20 MPH) impact.

Summary and Conclusions

Numerical analyses were conducted using LS-DYNA material model type 72R3, 84, and 159 based on simple or default parameter generation within the three models. Other needed parameters were obtained using either literature or from other material models within LS-DYNA . This simulation exercise was meant as a "non-calibration" simulation exercise to help the analyst understand the overall behavior of a given bridge rail barrier. However, the analyses showed good potential for using the models in analyses of steel-reinforced concrete roadside safety barriers. The T501 bridge rails study is a good example of the use of these models in roadside safety applications. The different impact speed for the T501 test provided a good benchmark for evaluating the usability of the three concrete material models. Performing calibration exercise with small scale experiment and/or material tests such as triaxial test would definitely improve the accuracy of these models in terms of predictability.

References

1- Williams, William, Alberson, Dean, Buth, Eugene and Wanda Menges. "*Repair/Retrofit Anchorage Designs for Bridge Rails*". Report 0-4823-T1-1. Texas Transportation Institute, College Station, TX. March 2007.
2- Schwer, Leonard, and Malvar, Javier. "Simplified Concrete Modeling with *MAT_CONCRETE_DAMAGE_REL3", JRI LS-DYNA USER Week, 2005
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4- Murray, Y. D., Abu-Odeh, A., and Bligh, R. "*Evaluation of LS-DYNA Concrete Material Model 159*". Report FHWA-HRT-05-063, Federal Highway Administration, May 2007.
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