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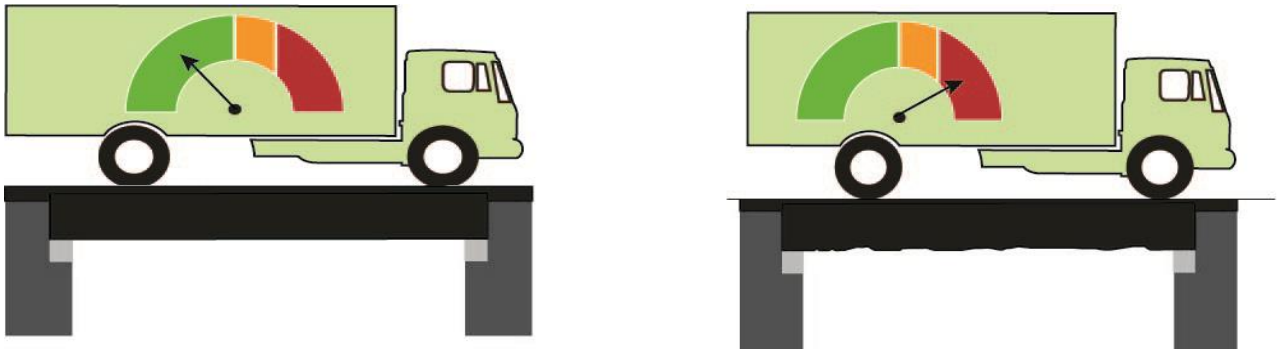
Drive-by Bridge Damage Evaluation Using Relative Displacement History



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Nassim Uddin

NCTSPM

National Center For Transportation System Productivity And Management

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Research Introduction

- Most of the 40s' or 50s' bridges in North America and Europe has deteriorated significantly.

- Heavy truck weight in combination with deterioration problems have led to plenty of U.S. bridges being classified as structurally deficient or functionally obsolete.

Research Introduction (Cont…)

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Bridge Visual Inspection

I-35W Mississippi River bridge

Research Introduction (Cont…)

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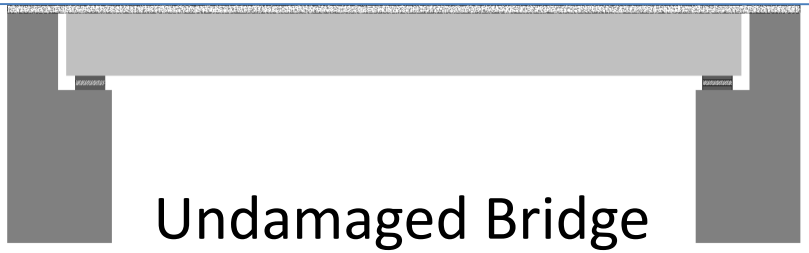
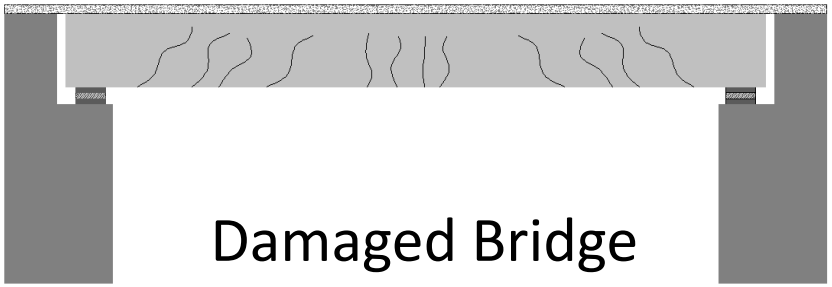
- An Efficient Method is needed to inspect the bridges to evaluate the damage.
- Previously, bridge used to be instrumented in order to inspect the bridge.
- Recently many scientists transfer to instrument a vehicle Pass over the bridge which known as "**Drive-By Bridge Inspection**"

Research Introduction (Cont…)

- What is Drive-By Bridge Inspection



Undamaged Bridge



Damaged Bridge

Research Objective

- 1) Develop Innovative and Novel “Apparent profile (AP)” Concept As a Damage Indicator
- 2) Demonstrate “AP” for practical application of bridge problems

1)AP Concept: What is AP?

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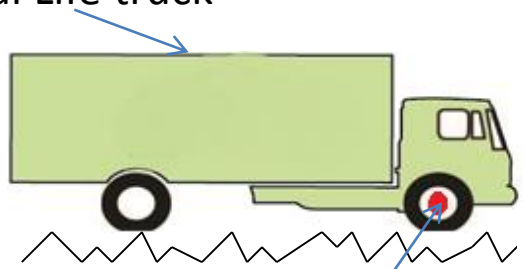
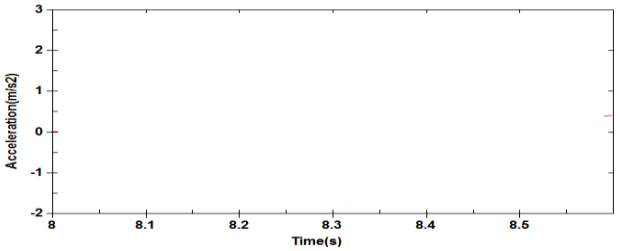
In Field

Real Life truck



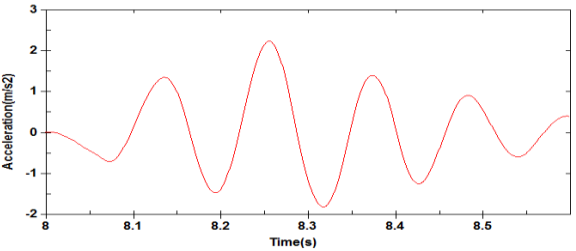
Measured acceleration



Unknown Road Profile

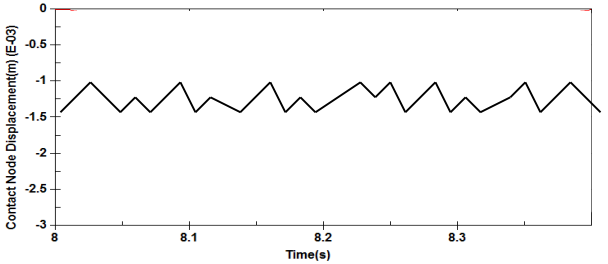
Accelerometer

Computer Algorithm



Input : Axle Acceleration

LS-Dyna Model



Output : The Road Profile

1)AP Concept: What is AP? (Cont…)

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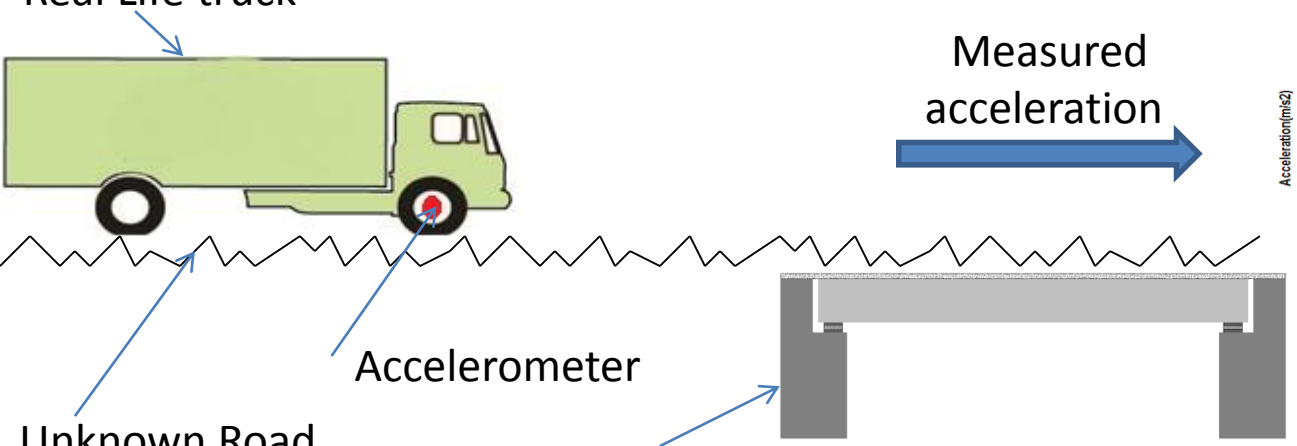
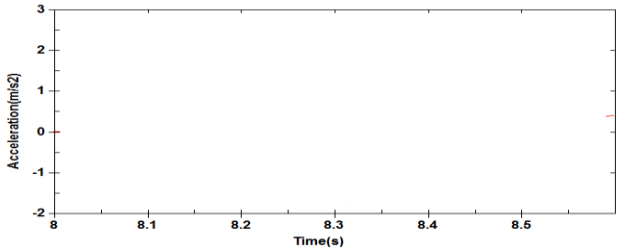
In Field

Real Life truck



Measured acceleration



Accelerometer

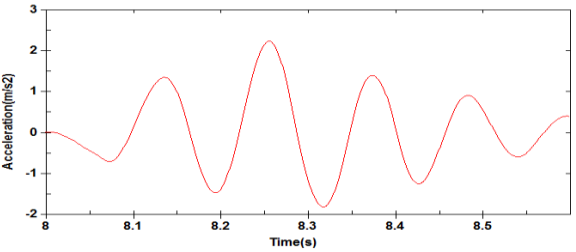
Unknown Road Profile

Bridge on the Road

Contaminated Road Profile or "Apparent Profile"

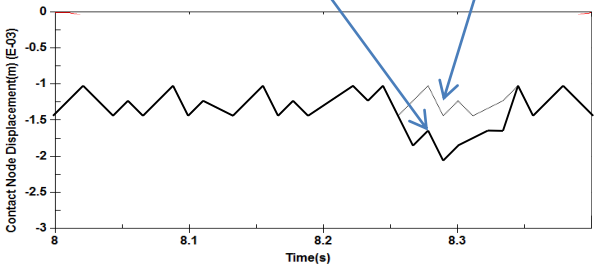
Original Road Profile

Computer Algorithm



Input : Axle Acceleration

LS-Dyna Model



Output : A Road Profile **Contaminated by bridge Displacement Which is the "Apparent Profile"**

1)AP Concept: How to use “AP “ in Bridge Inspection

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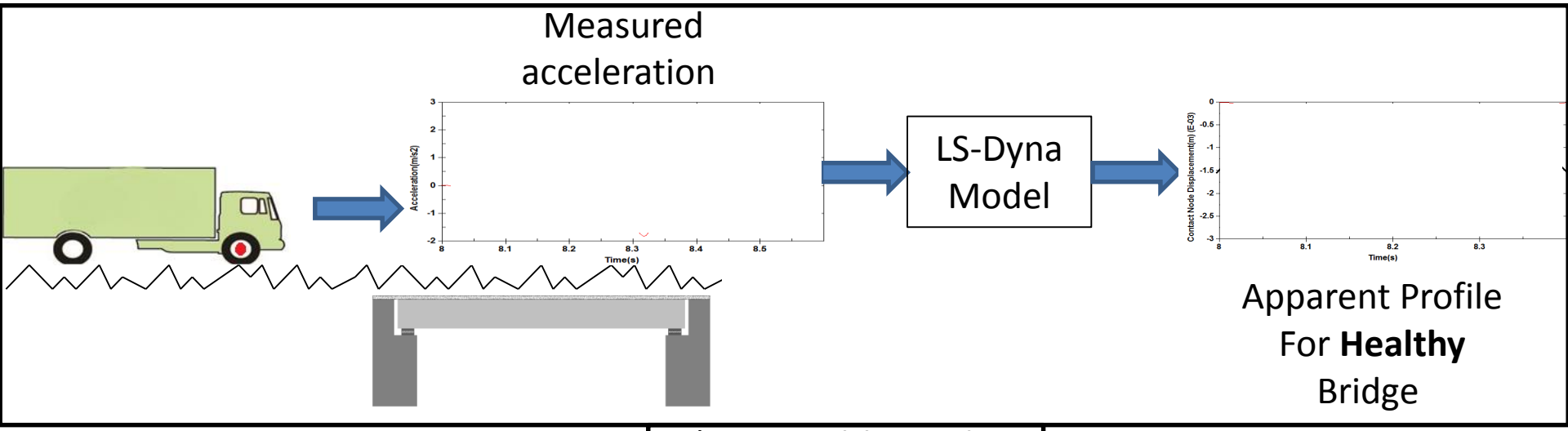
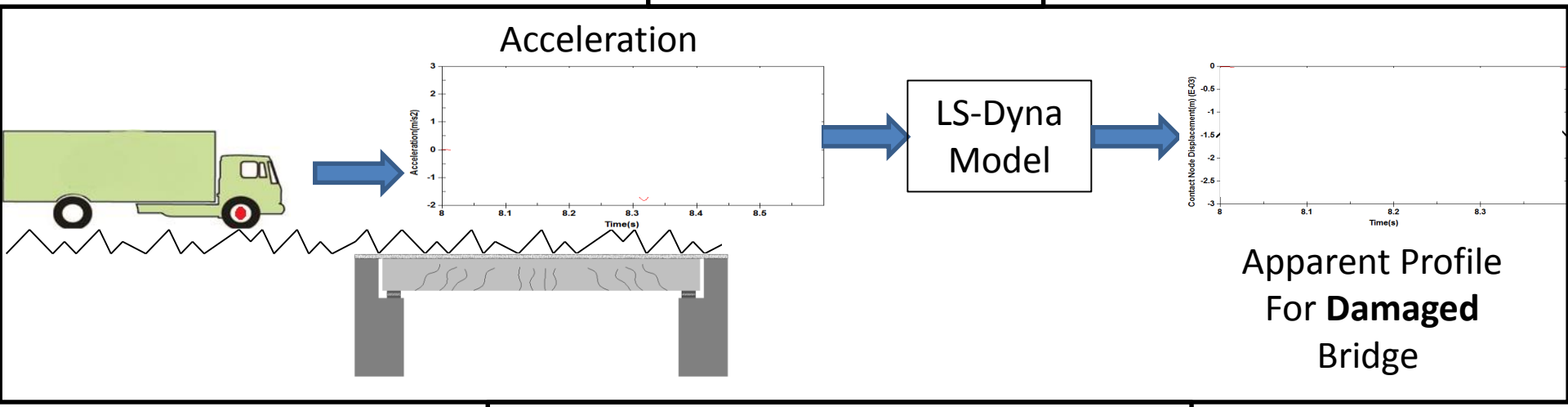


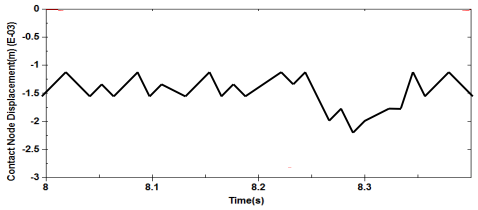
1) For Healthy Bridge



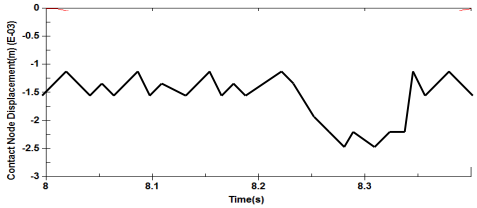
2) For Damaged Bridge (ex: 10% damage)

1)AP Concept: How to use AP in Bridge Inspection(Cont…)

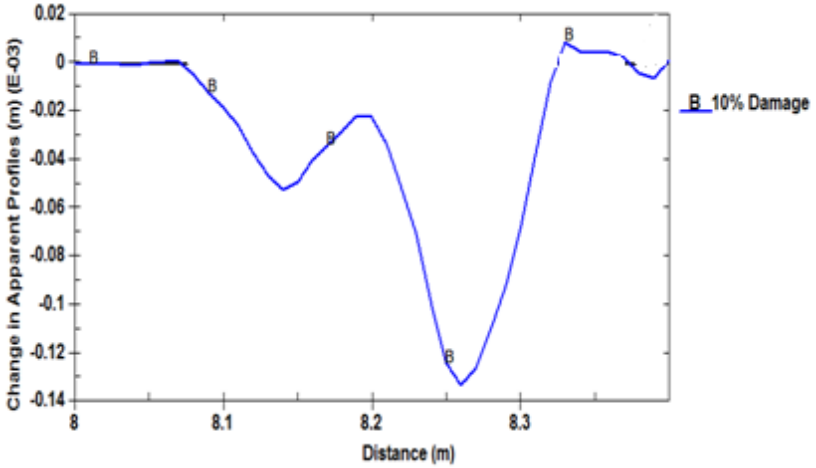
Subtracting the Healthy Apparent Profile From Damaged Apparent Profile to get the "**Difference In Apparent Profile**" Which shows to be a good damage indicator



Apparent Profile For Healthy Bridge



Apparent Profile For Damaged Bridge



Difference in Apparent Profile for 10% Damage or Relative Displacement History

1)AP Concept: Test "AP" as a damage indicator

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1) Bridge Model

Three different bridges are studied in this study and their properties as shown in the table

Bridge	First Natural Frequency(Hz)	Moment of inertia around horizontal axe (m^4)	Section Area (m^2)
10m	8.75	0.0434	2.04
20m	3.77	0.1518	2.40
30m	2.39	0.3534	2.76

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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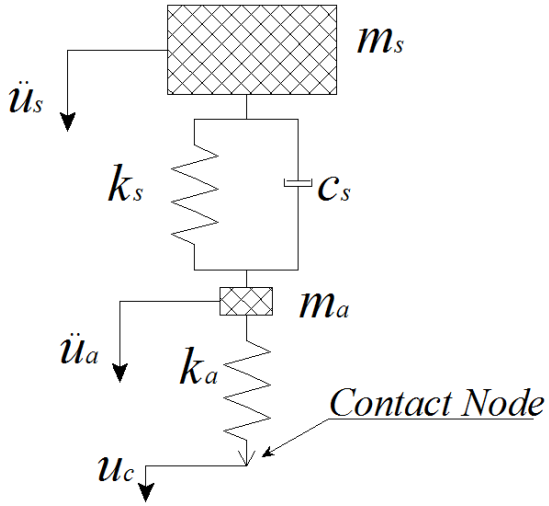
2) Vehicle Model

- A quarter Car model with 2DOF which allows for mass bouncing is used in the study.
- The quarter car properties is as shown in the following table

Property	Unit	Symbol	Quarter Car Model
Body Mass	kg	m_s	17300
Axel Mass	kg	m_a	700
Suspension Stiffness	N/m	k_s	4×10^5
Suspension Damping	N.s/m	c_s	10×10^3
Tire Stiffness	N/m	k_a	1.75×10^6
Body mass frequency of vibration	Hz	f_{bounce}	0.69
Axel mass frequency of vibration	Hz	f_{axle}	8.8



1)AP Concept: Test "AP" as a damage indicator (Cont…)

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3) Vehicle Bridge Interaction Modelling

- LS-Dyna Finite Element Analysis program is used to model the Vehicle Bridge Interaction

1)AP Concept: Test “AP” as a damage indicator (Cont…)

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4) **Modelling Stages:**
   1. **STAGE “1”:** is to make an LS-Dyna quarter Car model equivalent to the real life truck to get an acceleration data (to represent real life acceleration data)

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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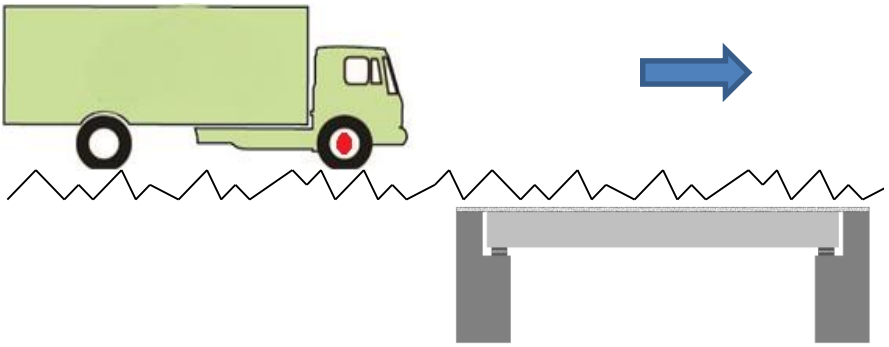
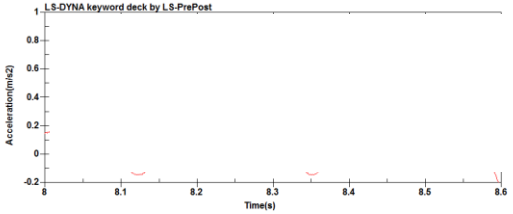
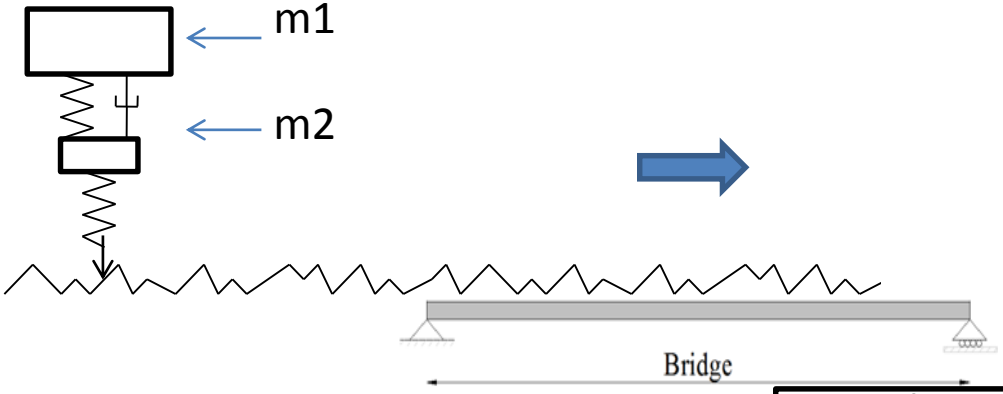


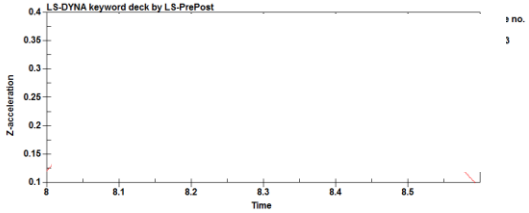
Real Life



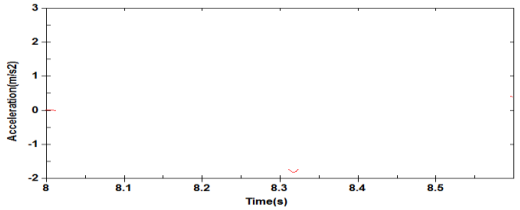
Measured acceleration



Equivalent LS-dyna Model



m1 acceleration



m2 acceleration

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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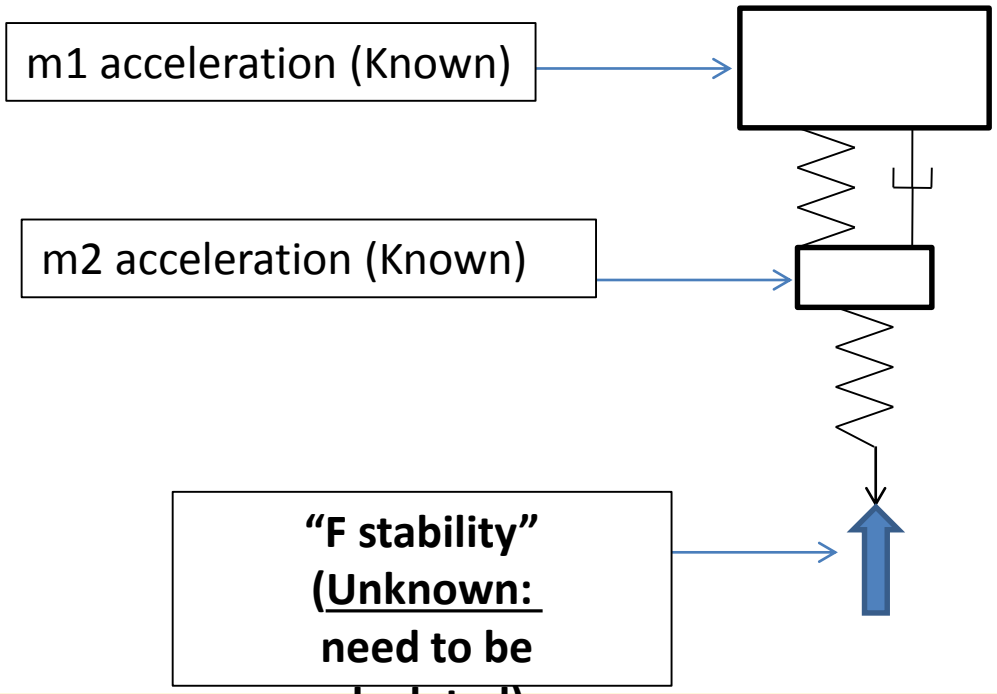
4) **Modelling Stages:**

2. **STAGE "2":**

- To recalculate the **"Apparent Profile"** , the force applied by the truck on the road need to be calculated. It will indicate what known as **"F stability"**



1)AP Concept: Test "AP" as a damage indicator (Cont…)

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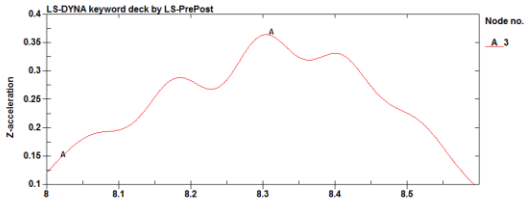
4) **Modelling Stages:**

2. **STAGE "2":**

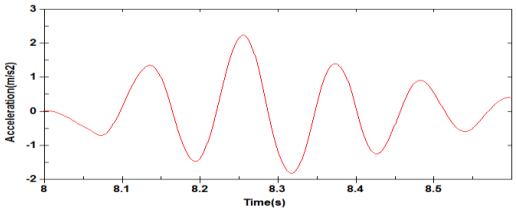
- Get **"F stability"** by applying Newton's Second Law

$$\textbf{F stability} = m_1 \times a_1 + m_2 \times a_2$$



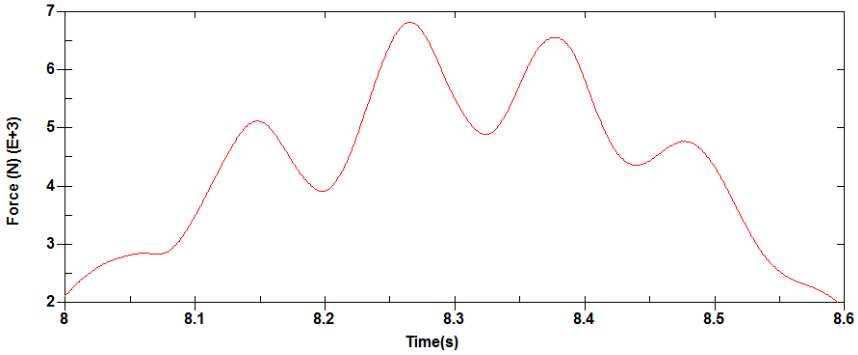
m1 acceleration

m1



m2 acceleration

m2



F stability

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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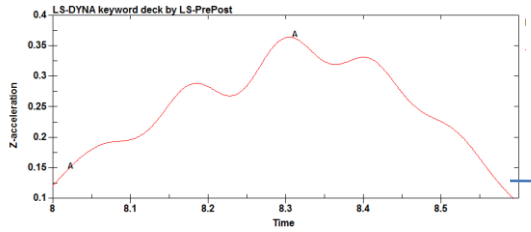
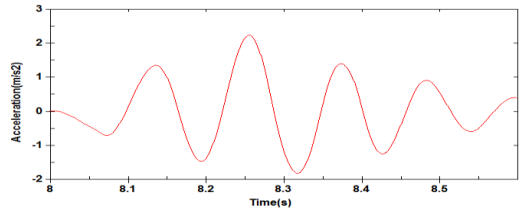
4) Modelling Stages:

2. STAGE "2"

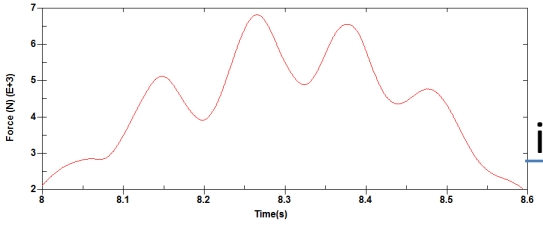
- Apply the F stability, m_1 acceleration and m_2 acceleration as an input to get the **"Apparent Profile"**



m1 acceleration



m2 acceleration



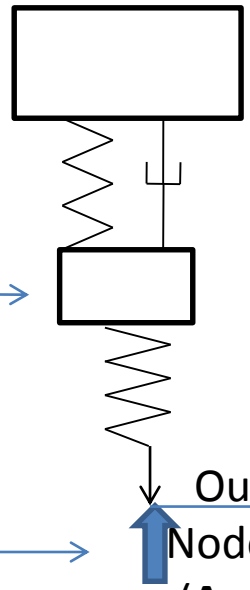
F stability

LS-Dyna
Quarter Car Model

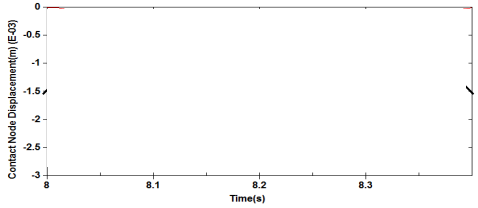
input

input

input



Output : Contact Node Displacement **(Apparent Profile)**



Apparent Profile

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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1) Study "AP" for Different "Road Roughness"

- Two different roughness are tested
  A. Smooth road profile
  B. Rough Road Profile (Class "A" & "B")

1) Study "AP" for Different "Damage Representation"

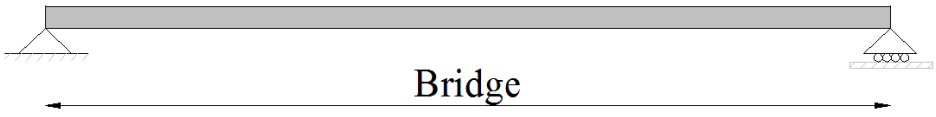
- Two different Damage Representation are used :
  A. Increase in Structural Damping
  B. Loss in Structural Stiffness

1)AP Concept: Test "AP" as a damage indicator (Cont…)

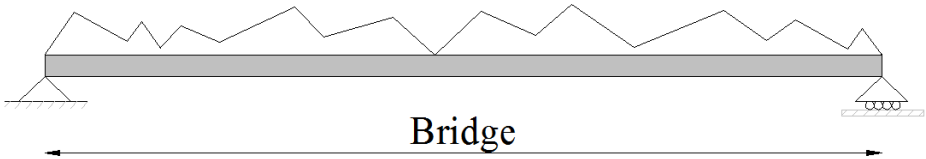
School Of Engineering

1) Study "AP" for Different "Road Roughness"

- two methods two cases are studied :
  A. Smooth road profile
  B. Rough Road Profile (Class "A" & "B")



a. Smooth Profile



b. Rough Profile

- For the two cases, Damage is presented as increase in Damping Ratio
- The 10m,20m & 30m bridge were tested and show the same results, so the **20m** bridge is discussed here only.

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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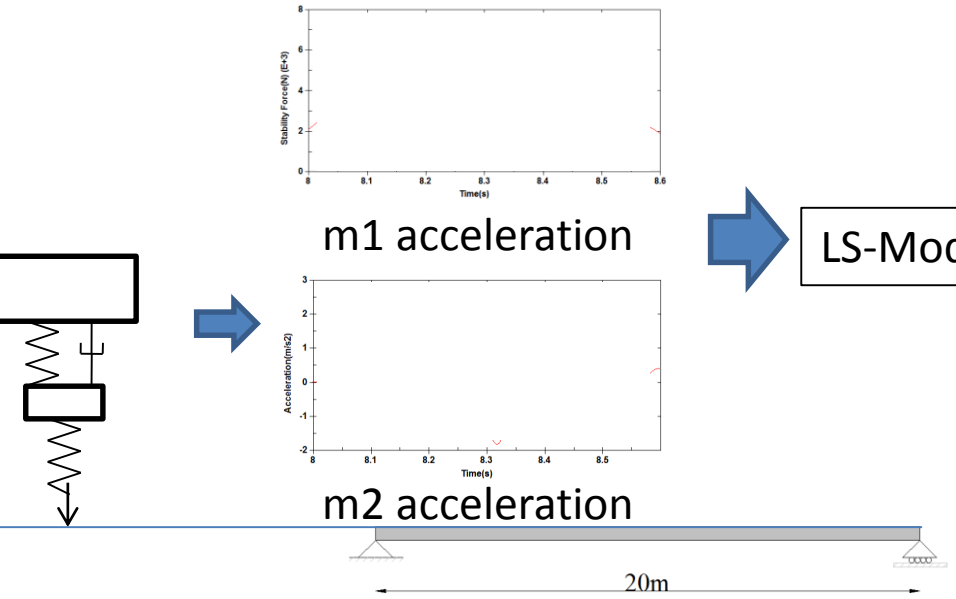
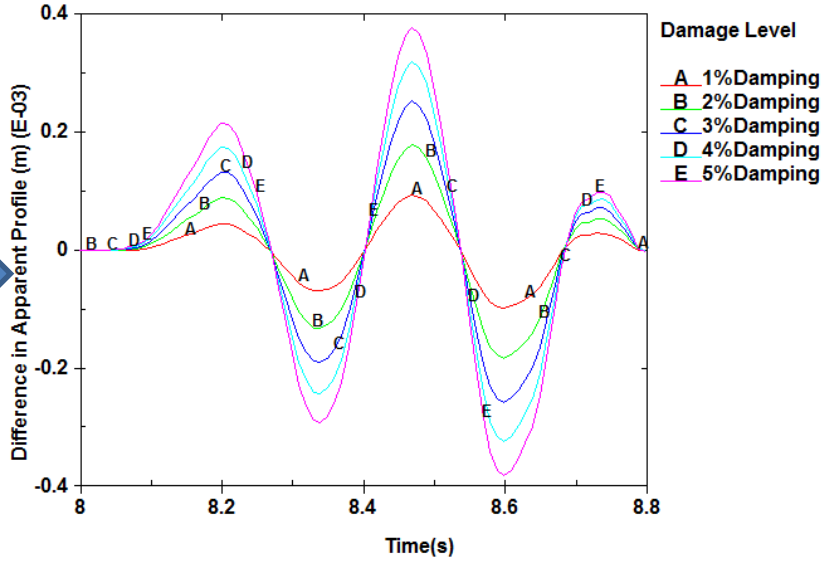
A. Smooth Roughness :



LS-Model



1) For Damping ratio "ζ" =1%
2) For Damping ratio "ζ" =2%
3) For Damping ratio "ζ" =3%
4) For Damping ratio "ζ" =4%
5) For Damping ratio "ζ" =5%

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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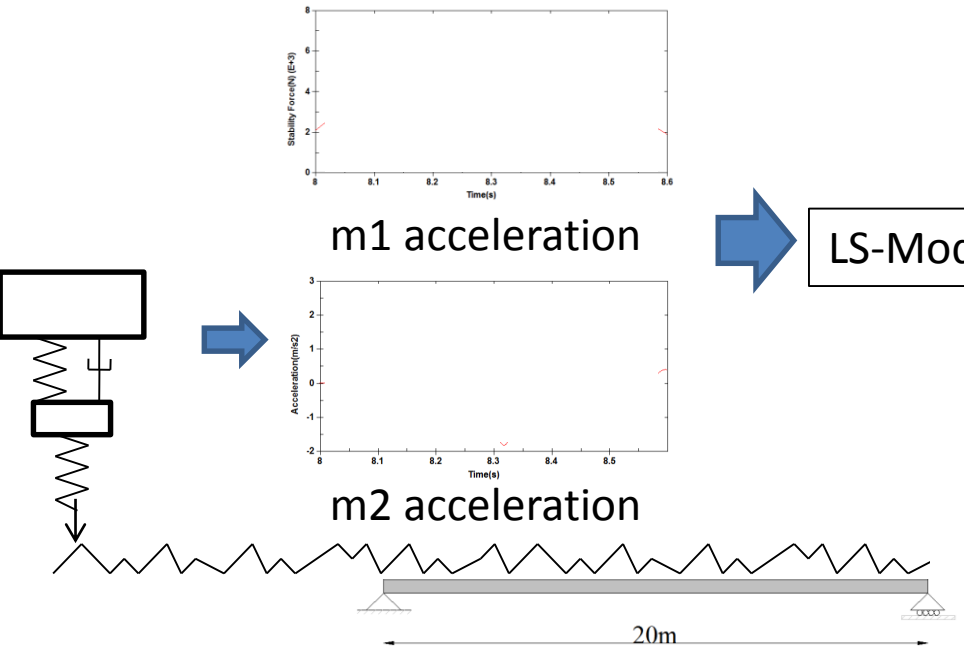
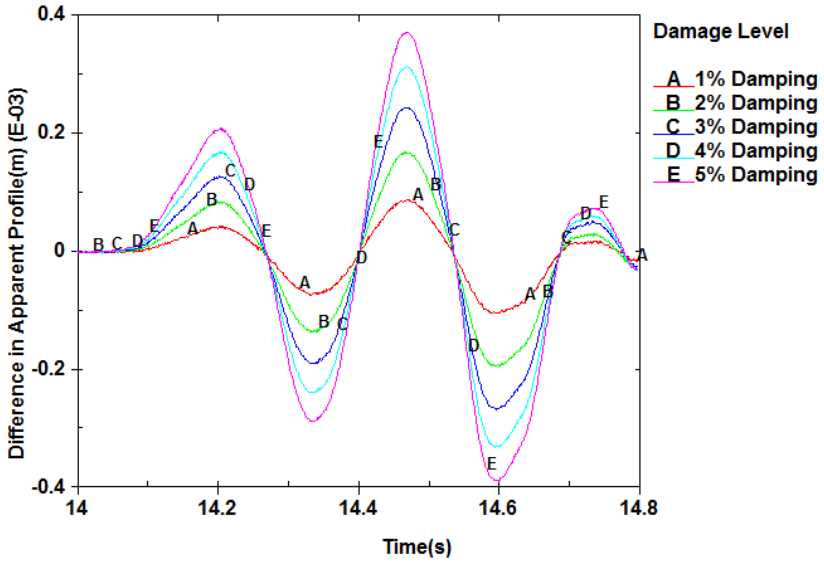
B. For Roughness Class "A":



LS-Model



1) For Damping ratio "ζ" =1%
2) For Damping ratio "ζ" =2%
3) For Damping ratio "ζ" =3%
4) For Damping ratio "ζ" =4%
5) For Damping ratio "ζ" =5%

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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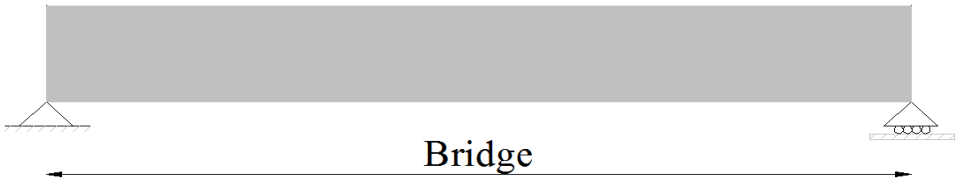
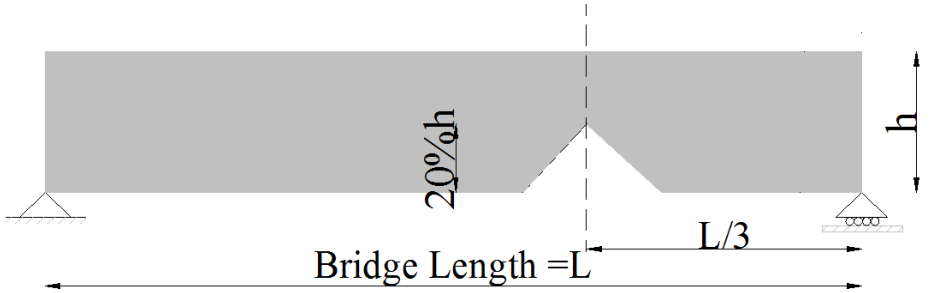
1) Study "AP" for Different "Damage Representation"

A. As increase in damping ratio
B. As reduction in Structural Stiffness
(At 1/3 of Bridge Span)



a. Increase in Damping Ratio
(Example)
ζ original =1%
ζ damaged =5%



b. Loss in Structural Stiffness
(Example)
20%h crack = 20% Damage

- A smooth Profile is used for the simulation

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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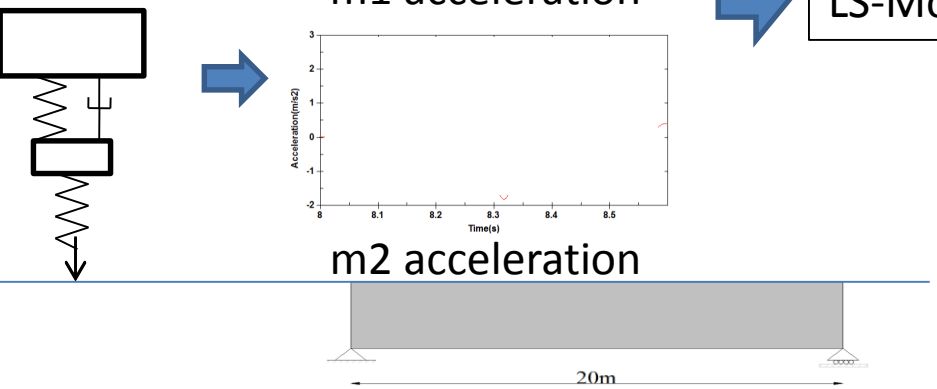
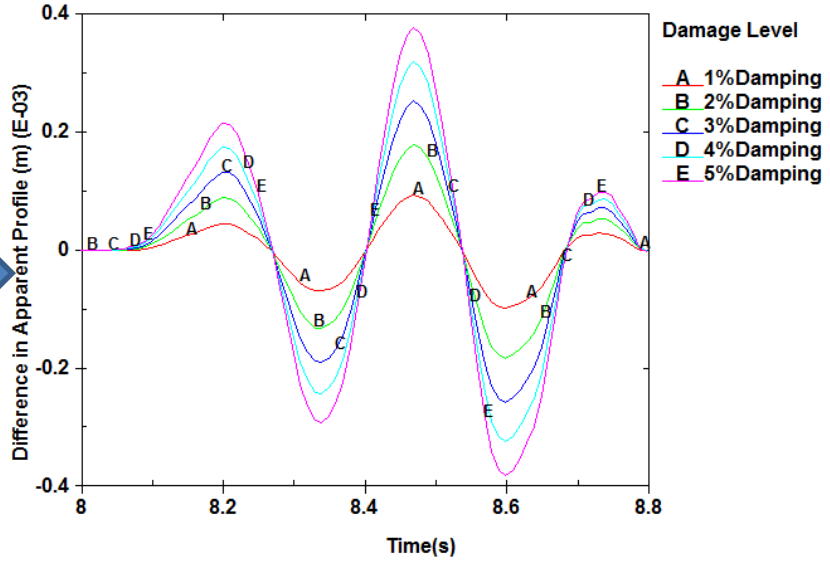
A. Change in Damping



LS-Model



1) For Damping ratio "ζ" =1%
2) For Damping ratio "ζ" =2%
3) For Damping ratio "ζ" =3%
4) For Damping ratio "ζ" =4%
5) For Damping ratio "ζ" =5%

1)AP Concept: Test "AP" as a damage indicator (Cont…)

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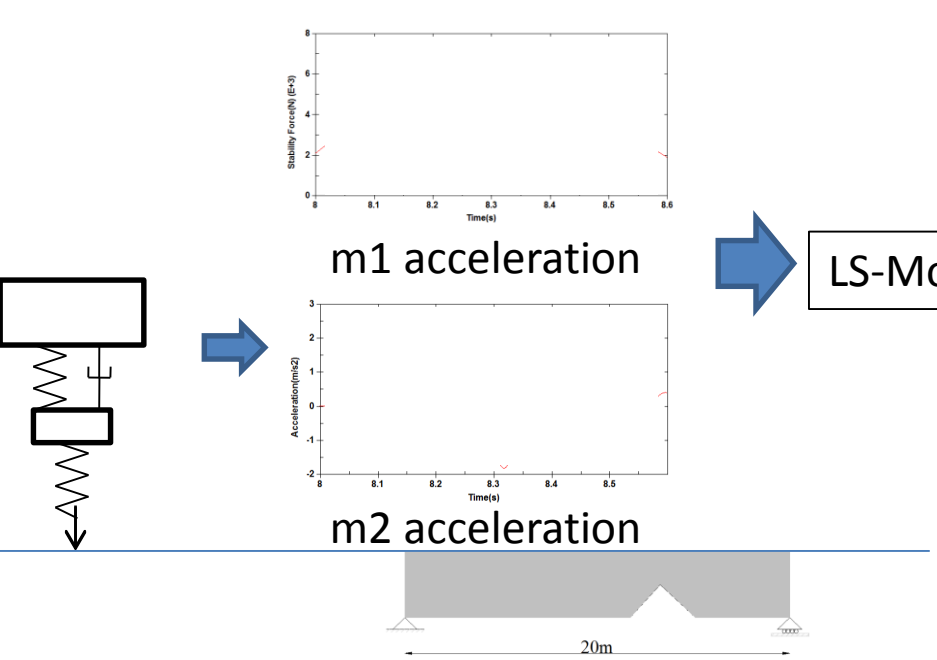
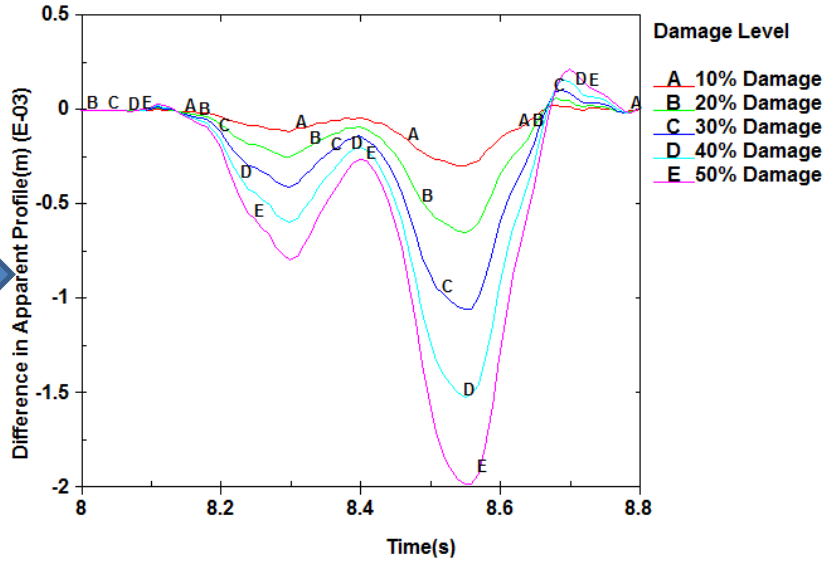
B. Change in Structure Stiffness



LS-Model



1) For 10% Damage
2) For 20% Damage
3) For 30% Damage
4) For 40% Damage
5) For 50% Damage

2)"AP" Application in Bridge Damage Evaluation

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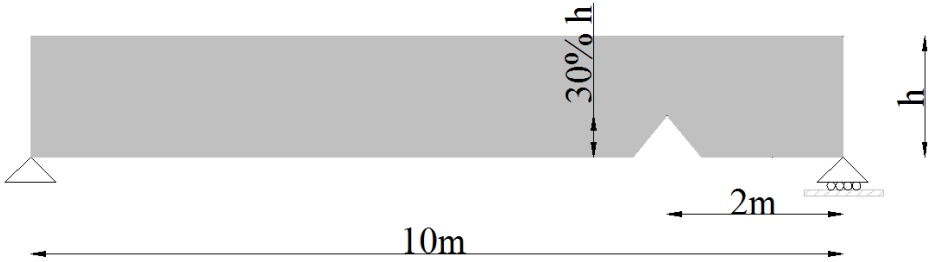
Use Apparent Profile to Evaluate Bridge Damage

- The goal here is to evaluate the damage of an existing bridge using the **Apparent Profile**

1) Bridge under Study

- The **Damaged location** is **20%L** of the Span Length
- The **Damage Level** is **30%**



Bridge(m)	**First Natural Frequency** (Hz)	**Moment of inertia around horizontal axe** (m^4)
10	8.75	0.0434

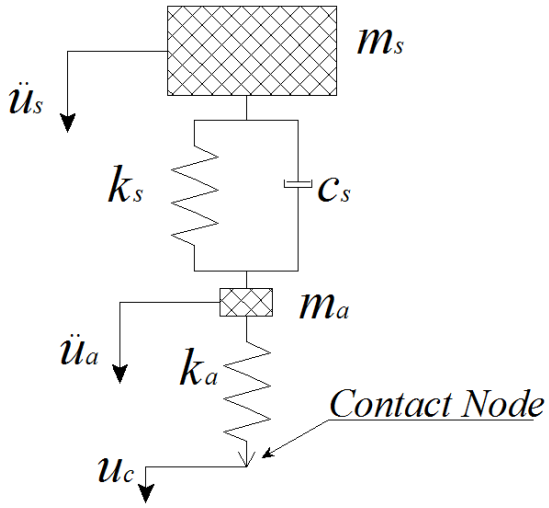
2)"AP" Application in Bridge Damage Evaluation (Cont…)

School Of Engineering

2) Vehicle Model

- A quarter Car model with 2DOF which allows for mass bouncing is used in the study.
- The quarter car properties is as shown in the following table

Property	Unit	Symbol	Quarter Car Model
Body Mass	kg	m_s	17300
Axel Mass	kg	m_a	700
Suspension Stiffness	N/m	k_s	4×10^5
Suspension Damping	N.s/m	c_s	10×10^3
Tire Stiffness	N/m	k_a	1.75×10^6
Body mass frequency of vibration	Hz	f_{bounce}	0.69
Axel mass frequency of vibration	Hz	f_{axle}	8.8



2)"AP" Application in Bridge Damage Evaluation (Cont…)

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3) Vehicle Bridge Interaction Modelling

- LS-Dyna Finite Element Analysis program is used to model the Vehicle Bridge Interaction

2)"AP" Application in Bridge Damage Evaluation (Cont…)

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4) Modelling Stages:

The process will be divide into two main stages

A. **STAGE 1: Create A "Damage Mapping"**

B. **STAGE 2: Extract the Damaged Bridge Apparent Profile**

C. **STAGE 3: Compare the Extracted Apparent Profile with the Damage Mapping**

2)"AP" Application in Bridge Damage Evaluation: STAGE 1 (Evaluate the Damage Mapping)

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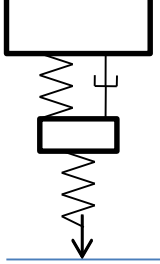
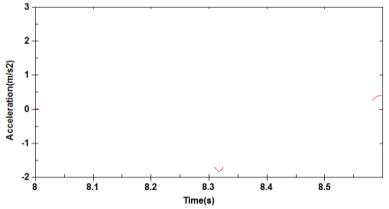
What is Damage Mapping?

- **Damage Mapping** is a set of "Apparent Profiles" for different **Damage Values** at different **Damage Locations**
- The process of creating the **Damage Mapping** is as follows

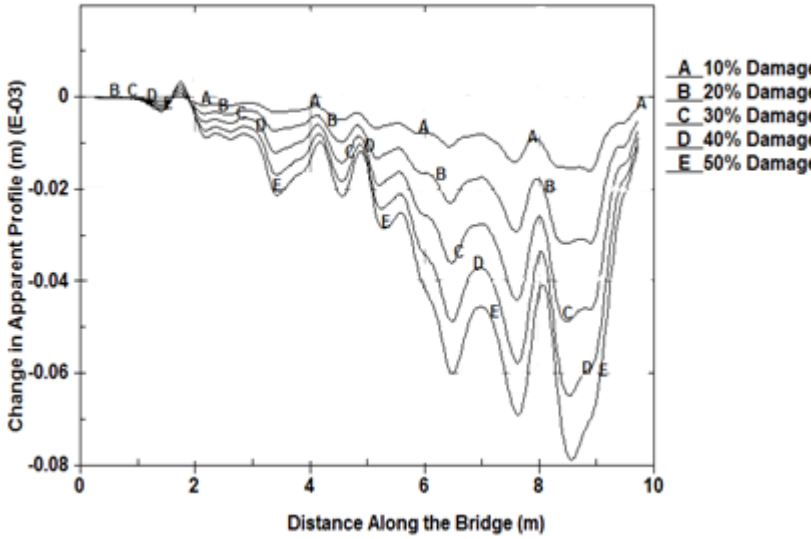
m1 acceleration

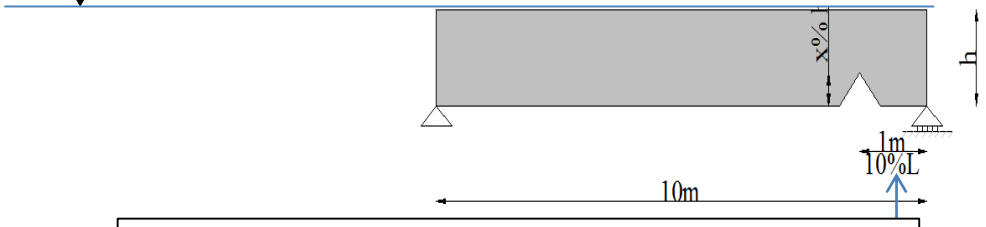




m2 acceleration

LS-Model





1)Crack Located at 10% of bridge span

2) x=10% of h

1) For Crack = 10%h (10% Damage)
2) For Crack = 20%h (20% Damage)
3) For Crack = 30%h (30% Damage)
4) For Crack = 40%h (40% Damage)
5) For Crack = 50%h (50% Damage)

2)"AP" Application in Bridge Damage Evaluation: STAGE 1 (Evaluate the Damage Mapping) (Cont…)

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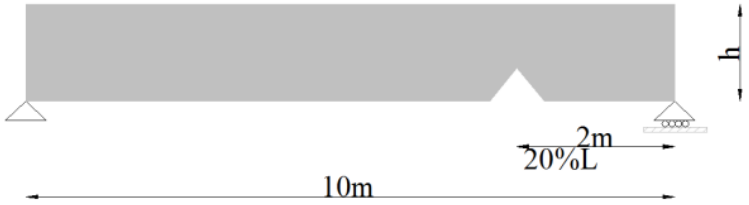
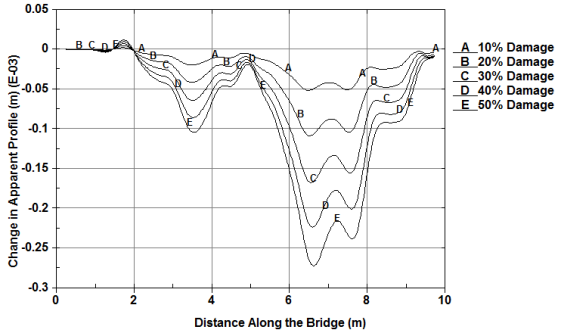
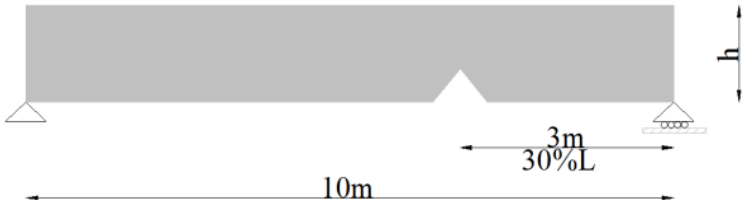
What is Damage Mapping?

- The processes repeated for different damage location

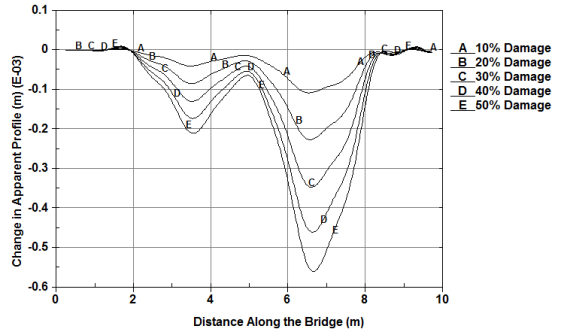


Crack Located at 20% of bridge span





Crack Located at 30% of bridge span



…… And So on then

2)"AP" Application in Bridge Damage Evaluation: STAGE 1 (Evaluate the Damage Mapping) (Cont…)

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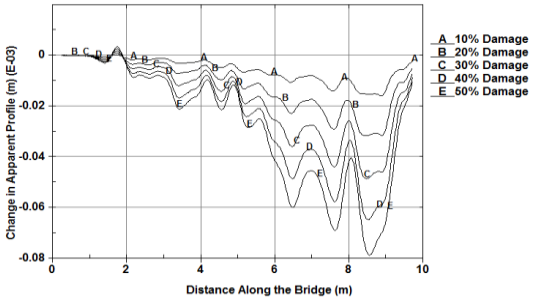
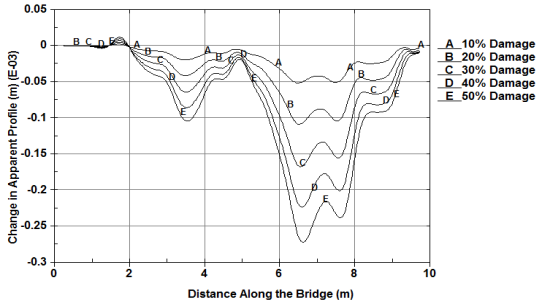
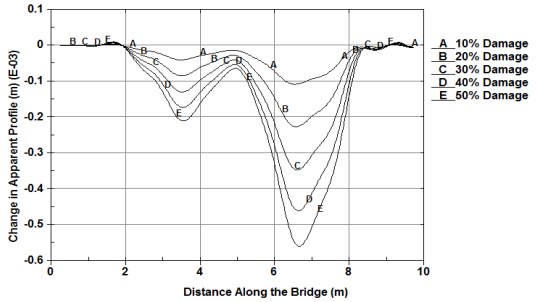
Damage Mapping



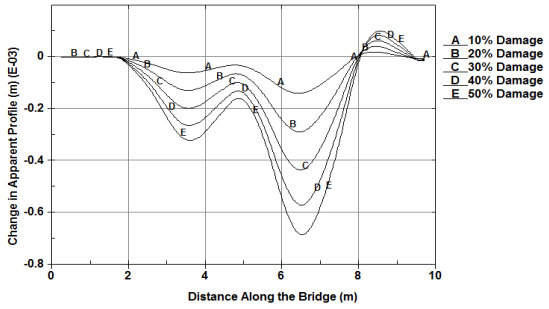
1) For crack at 10%L



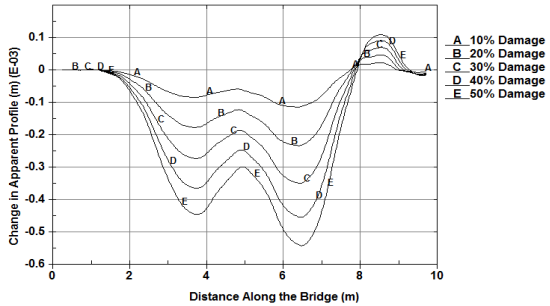
2) For crack at 20%L



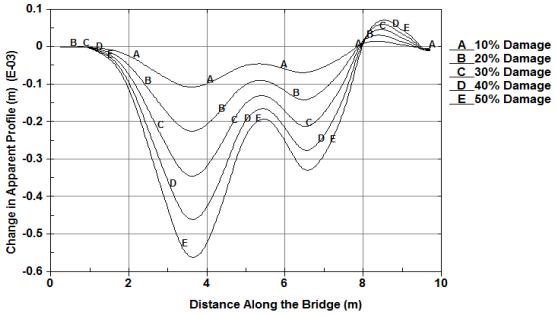
3)For crack at 30%L



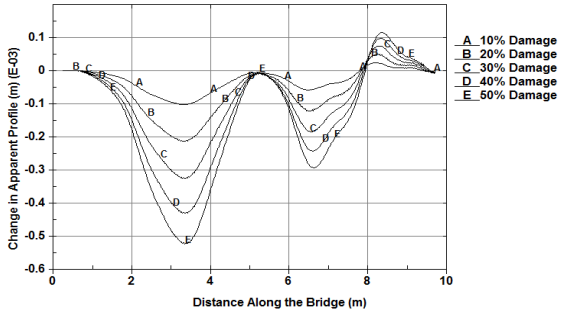
4) For crack at 40%L



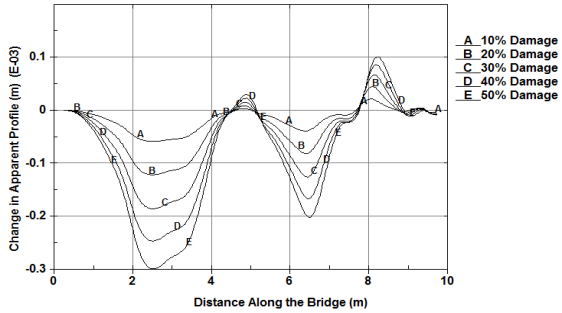
5) For crack at 50%L



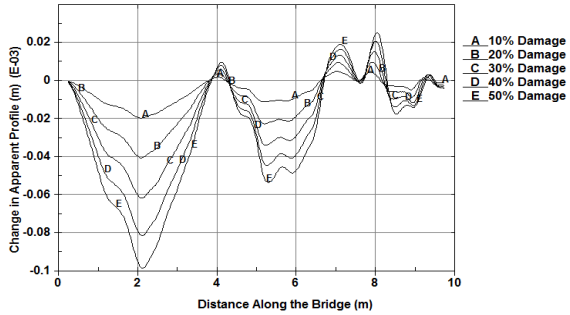
6)For crack at 60%L



7) For crack at 70%L



8) For crack at 80%L



9)For crack at 90%L

2)"AP" Application in Bridge Damage Evaluation: STAGE 2 (Extract "AP" for Damaged Bridge)

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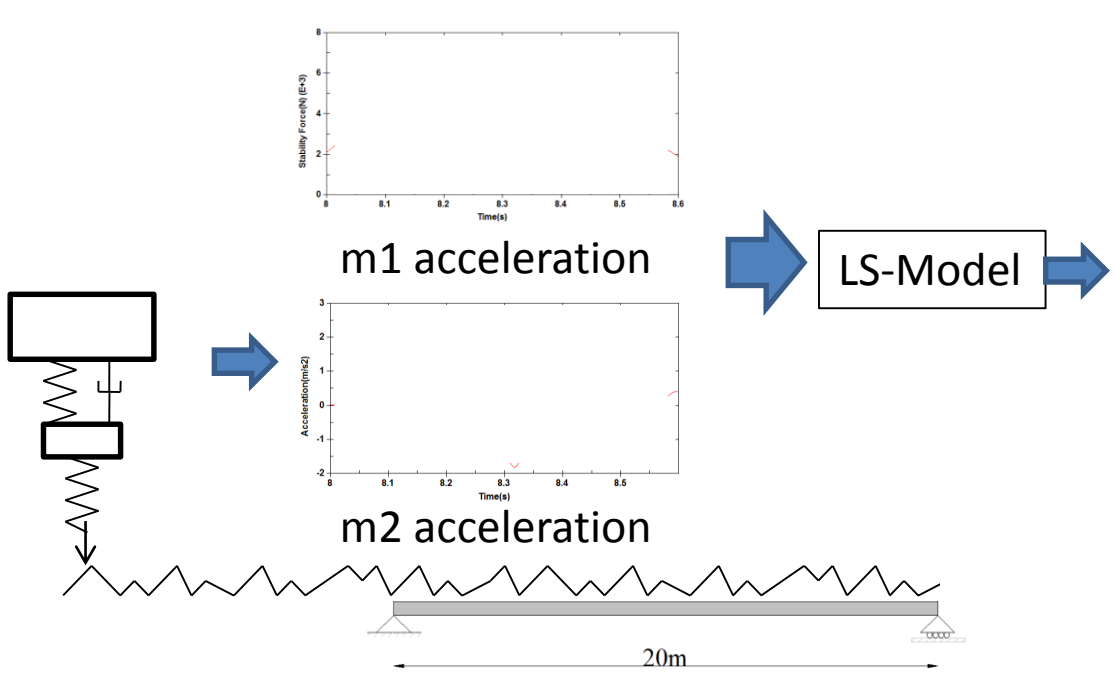
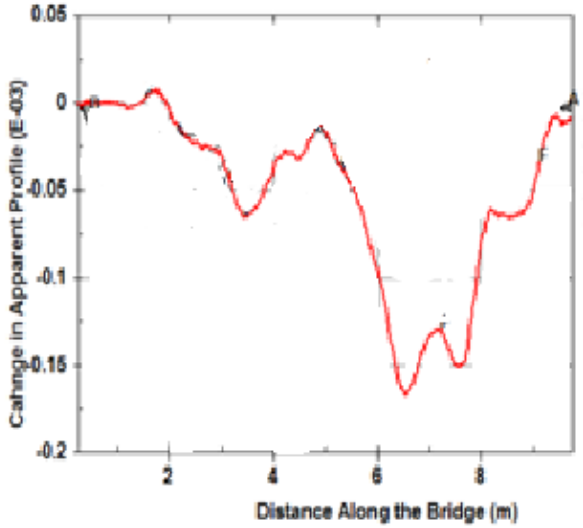
B) Extract Bridge Apparent Profile :

- As Described in the previous slides :





Apparent Profile For Damaged Bridge

2)"AP" Application in Bridge Damage Evaluation: STAGE 3 (Compare Bridge "AP" with Damage Mapping)

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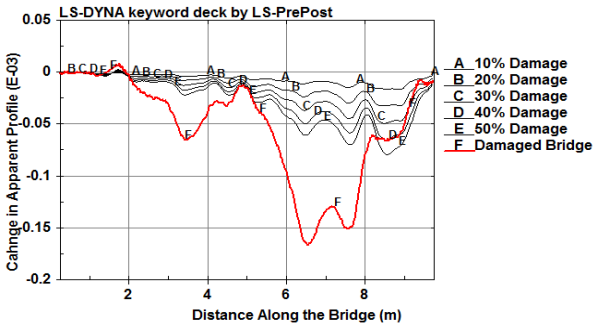
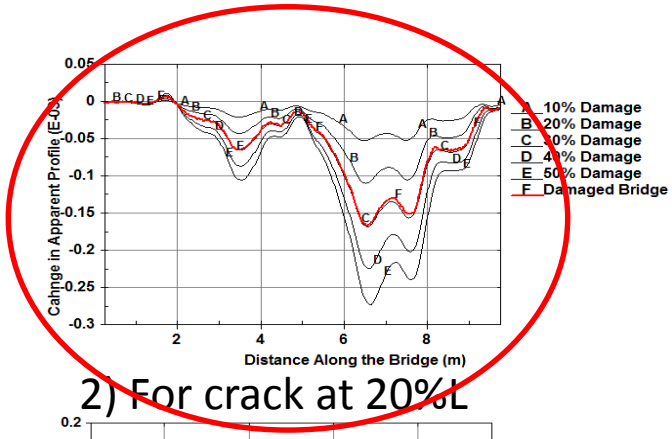
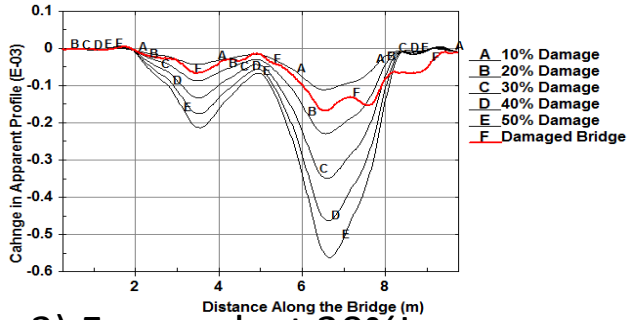


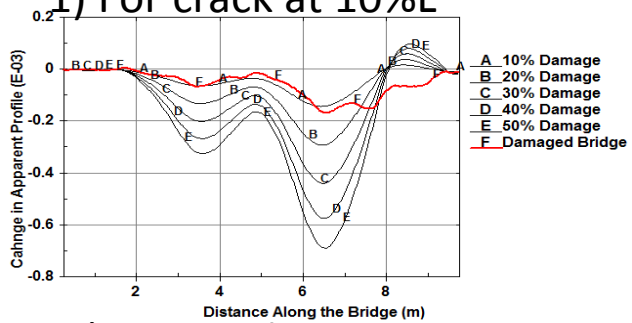
1) For crack at 10%L



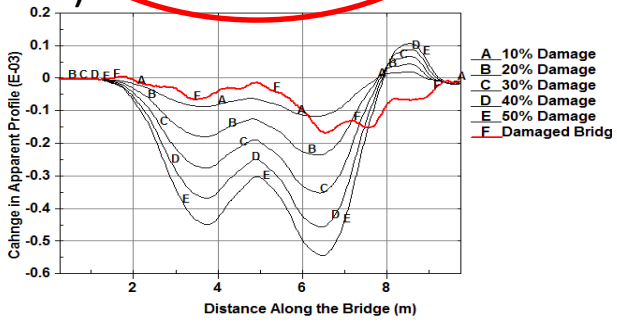
2) For crack at 20%L



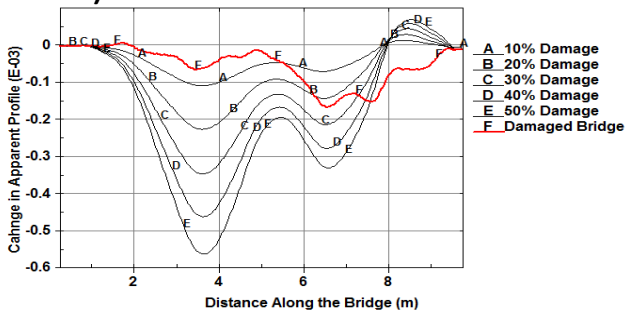
3) For crack at 30%L



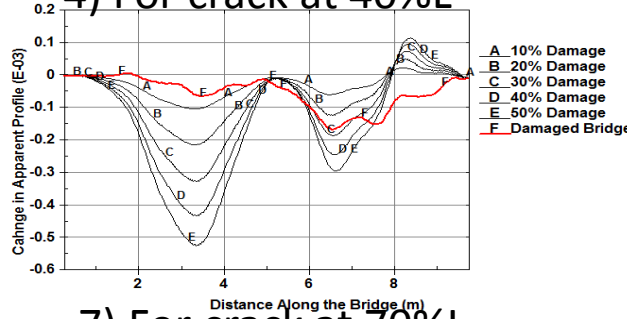
4) For crack at 40%L



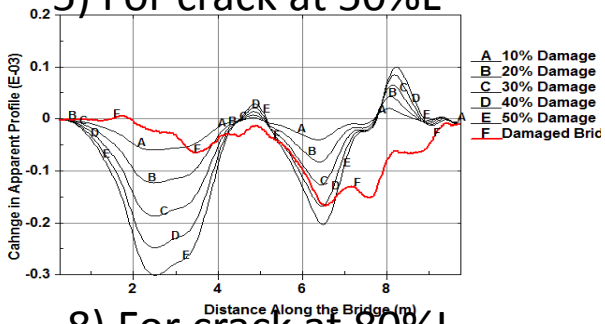
5) For crack at 50%L



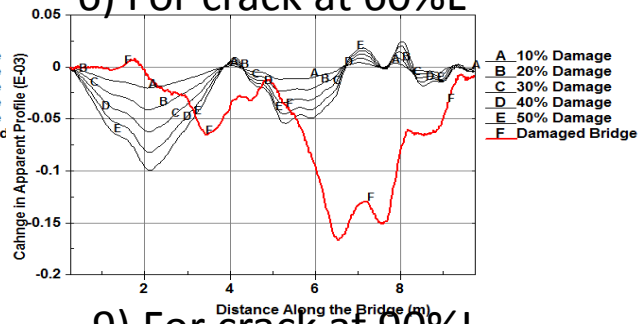
6) For crack at 60%L



7) For crack at 70%L

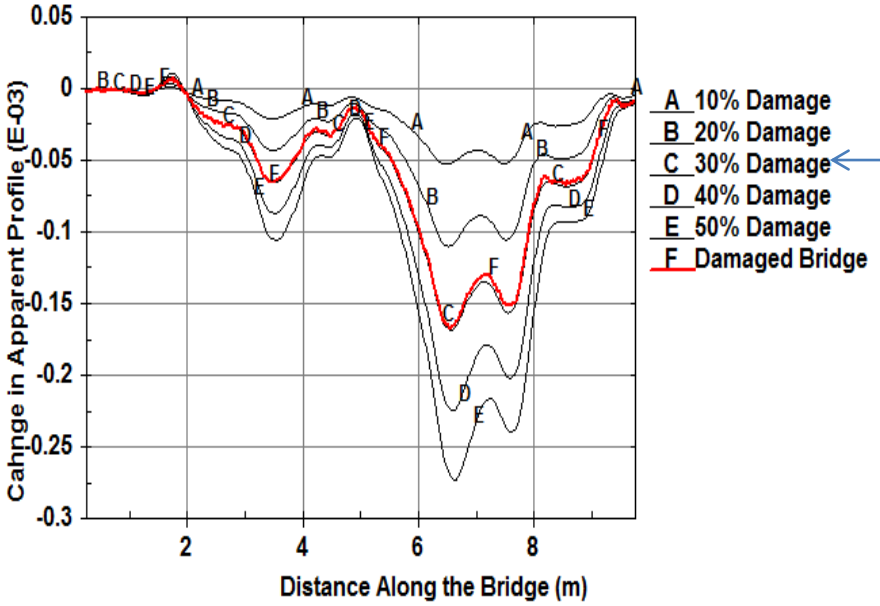


8) For crack at 80%L



9) For crack at 90%L

2)"AP" Application in Bridge Damage Evaluation: STAGE 3 (Compare Bridge "AP" with Damage Mapping) (Cont…)

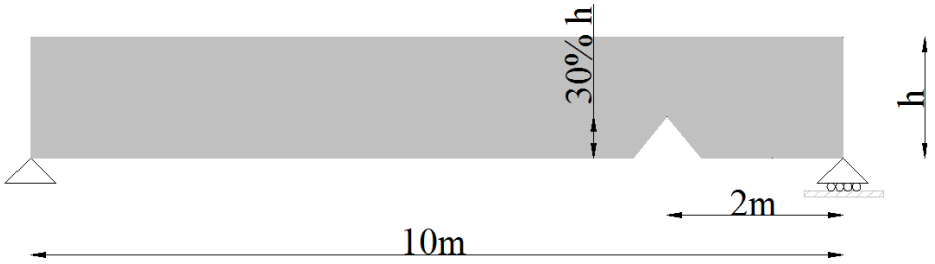


30% Damage

2) For crack at 20%L

At 20% of bridge span

Result From Comparing "AP" with the Damage Mapping



Bridge under Study

Conclusion

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1. The Apparent Profile shows to be good for smooth and rough profiles

2. The Apparent Profile shows to detect damage for both adopted damage criteria

3. The Apparent Profile can be used to evaluate the Damage value and location for bridges.

Questions

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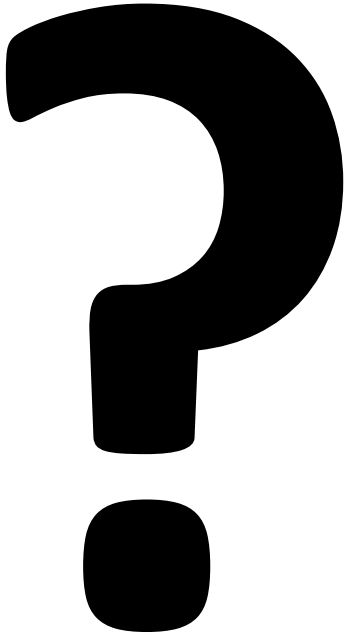
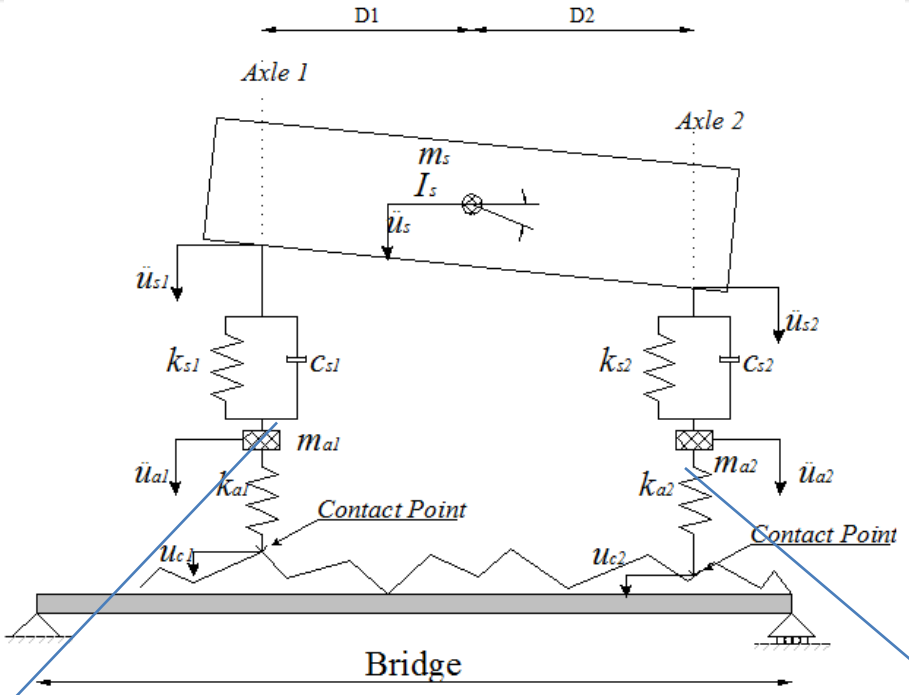
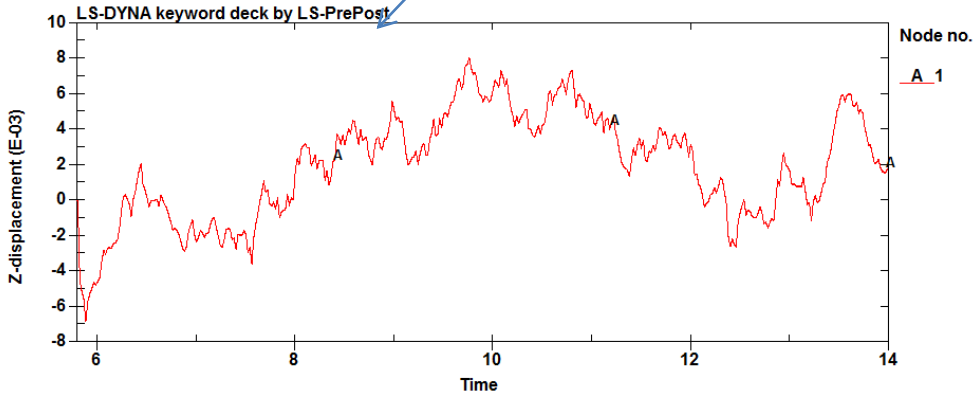
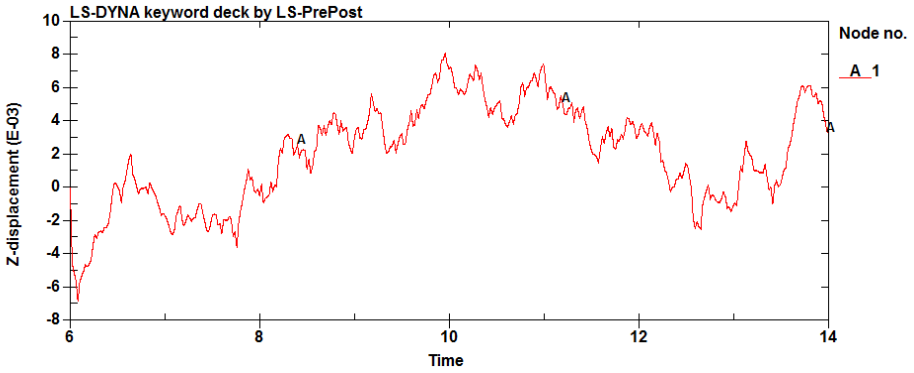



D1
D2
Axle 1
Axle 2
m_s
I_s
$\ddot{u}_s$
$\ddot{u}_{s1}$
$\ddot{u}_{s2}$
k_{s1}
c_{s1}
k_{s2}
c_{s2}
m_{a1}
m_{a2}
$\ddot{u}_{a1}$
$\ddot{u}_{a2}$
k_{a1}
k_{a2}
Contact Point
Contact Point
u_{c1}
u_{c2}
Bridge

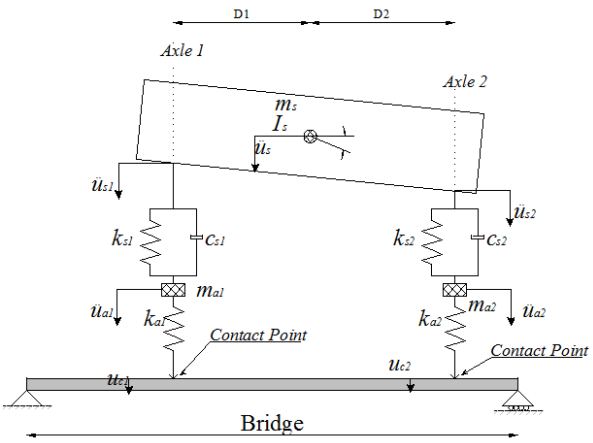

LS-DYNA keyword deck by LS-PrePost
Node no.
A 1
Z-displacement (E-03)
Time
10
8
6
4
2
0
-2
-4
-6
-8
6
8
10
12
14

AP1

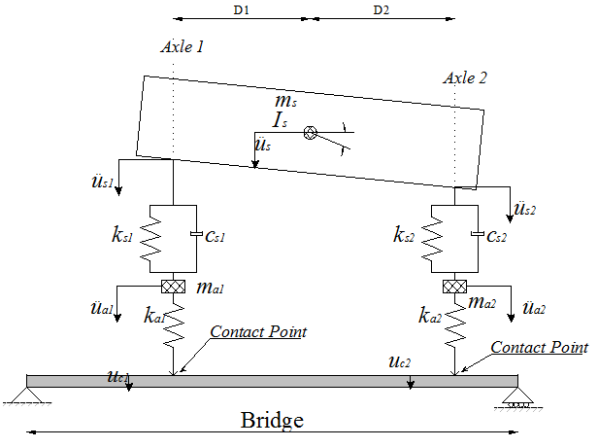

LS-DYNA keyword deck by LS-PrePost
Node no.
A 1
Z-displacement (E-03)
Time
10
8
6
4
2
0
-2
-4
-6
-8
6
8
10
12
14

AP2

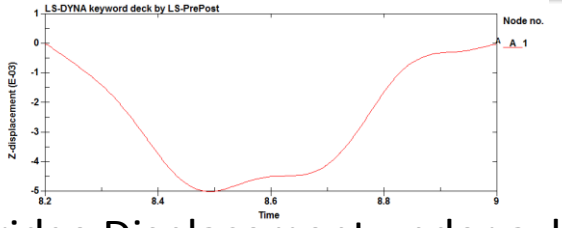
For NO Roughness



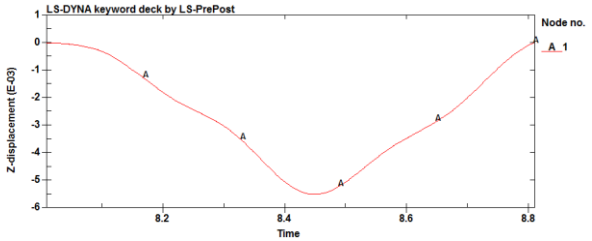
For 1% Damping



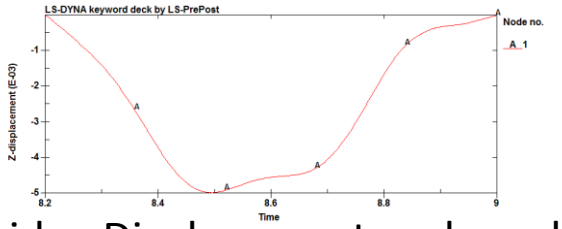
For 2% Damping



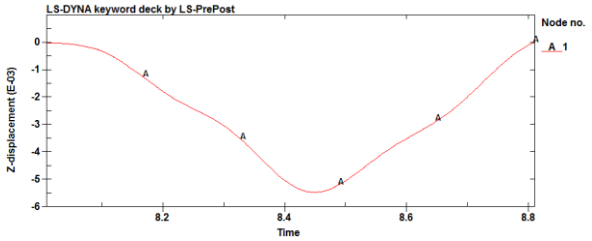
Bridge Displacement under axle 1



Bridge Displacement under axle 2



Bridge Displacement under axle 1



Bridge Displacement under axle 2

For NO Roughness

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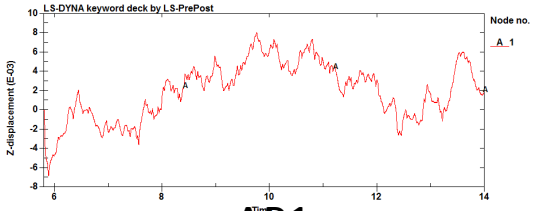
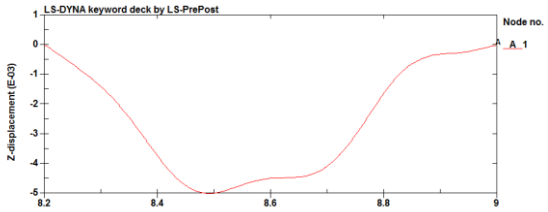
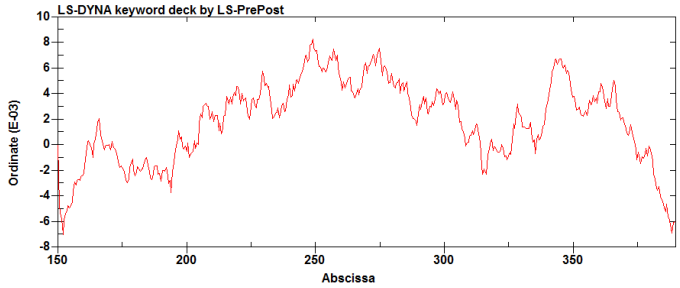
For 1% Damping



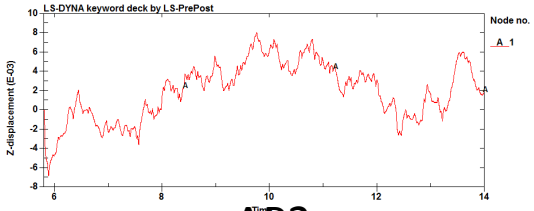
AP1



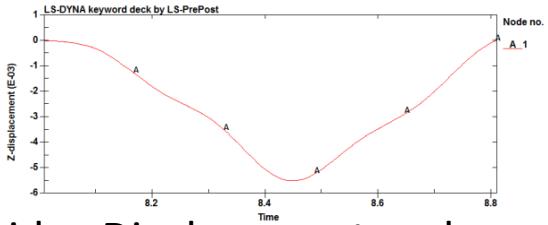
Bridge Displacement under axle 1



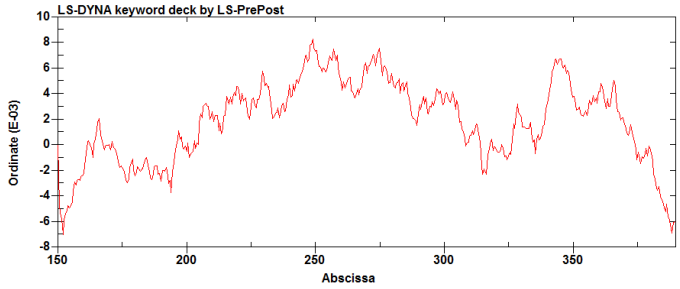
Road Roughness Under Axle 1



AP2



Bridge Displacement under axle 2



Road Roughness Under Axle 2